Management of Clay Soils for Rainfed Lowland Rice-based Cropping Systems

Proceedings of ACIAR International Workshop held at the Bureau of Soil and Water Management, Quezon City, Manila 20–24 November 1995

Editors: G. Kirchhof and H.B. So

Australian Centre for International Agricultural Research
Canberra, 1996

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. Its mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australian and other country researchers in fields where Australia has special research competence.

Where trade names are used this does not constitute endorsement of nor discrimination against any product by the Centre.

ACIAR PROCEEDINGS

This series of publications includes the full proceedings of research workshops or symposia organised or supported by ACIAR. Numbers in this series are distributed internationally to selected individuals and scientific institutions.

Kirchhof, G. and So, H.B. 1996. Management of clay soils for rainfed lowland rice-based cropping systems. Proceedings of a workshop held at the Bureau of Soil and Water Management, Quezon City, Manila, 20–24 November 1995. ACIAR Proceedings No. 70, 259 p.

ISBN 1 86320 176 9

Editorial management: P.W. Lynch

Technical editor: P.J. Knight

Typeset and page layout: Sun Photoset Pty Ltd, Brisbane, Australia

Printed by: Brown Prior Anderson, Melbourne, Australia

Contents

DRY SEASON CROPS

INTERNATIONAL RESEARCH ON LOWLAND RICE-BASED CROPPING SYSTEMS

CONCLUSION

Foreword

Productive land in tropical lowland rice areas is now almost fully utilised, and increased production must come from intensification of agriculture rather than expansion of land area. In non-irrigated regions with distinct dry seasons it is often possible to grow upland crops such as maize, mungbeans or soybeans immediately after the harvest of the wet-season rice. Even without rainfall during the dry season, there should be sufficient water stored in the soil profile to meet the needs of the dry season crop. However, yields of post-rice dry season crops have usually been low, and risks associated with establishment of the crops have discouraged inputs such as cultivation, fertilizers and other amendments to raise the yields.

ACIAR supported a research project entitled 'Management of clay soils under lowland rice-based cropping systems' from 1992 to the end of 1995. The aim of the project was to develop soil management practices that could overcome the adverse soil physical conditions that limit the germination and establishment of post-rice dry season crops. Research included consideration of the effects of wet cultivation for the rice crop on subsequent dry season crop yields, as well as soil management between the rice and subsequent dry season crop. Experimental work was conducted in Indonesia, the Philippines and Australia.

These Proceedings contain the papers presented at a workshop held in Quezon City, Philippines, in November 1995. The results of the ACIAR project and related work in South and Southeast Asia were presented and discussed. ACIAR wishes to record its appreciation to those who organised the workshop, particularly the project participants from the Bureau of Soils and Water Management, Quezon City, and The University of Queensland. We also acknowledge financial support from AusAID, and strong representation at the workshop from the International Rice Research Institute.

R.J. Clements
Director, ACIAR

Preface

Rice is the most important staple food in Asian countries. The 1994 UN Food and Agriculture Organisation (FAO) yearbook stated that the total global area under rice was 147 million hectares, 130 million hectares of that in Asia. IRRI records in 1995 showed that the vast majority of rice is grown as paddy or lowland rice, either under irrigated (81 million hectares globally, 93% in Asia) or dryland conditions (40 million hectares). The most common soil management strategy for paddy rice is to puddle the soil before rice seedlings are manually transplanted. Puddling is the most important soil management practice for rice production. It serves primarily to reduce the soil's hydraulic conductivity and to ensure that inundated conditions are maintained during the cropping cycle so that weeds are easily controlled and water stress avoided. It creates soft soil and makes transplanting of seedlings easy and allows rapid establishment of the transplanted rice seedlings.

Where irrigation is not available, rice is generally grown under rainfed conditions during the rainy season. Upland crops can be planted after lowland rice in rainfed areas depending on soil type, climatic conditions during the dry season and economic considerations. However, the previously puddled soil layer poses considerable restrictions on cropping after rice. Although beneficial for rice, soil puddling has adverse effects on the soil physical properties. Anaerobic conditions are unfavourable for upland crop establishment while the puddled layer is wet. Upon drying it becomes hard very quickly.

Following several months of inundation during the rice phase the subsoil water contents are generally high and sufficient to grow a moderate upland crop, for example, legumes. However, yields of these dry season crops under rainfed conditions are very low and unreliable with mungbean yields of less than 0.5 t/ha and maize yields of only 1 t/ha. These low yields do not provide adequate incentives and the farmer tends to leave the land fallow until the next rice crop. The land after lowland rice represents an underutilised resource. There are more than 40 million hectares in Asia and potentially 100 million hectares in Africa where suitable soil management techniques would allow exploitation of unused subsoil water stores. The potential benefit in bringing these soils into production during the dry season is not only in increased food production but also in diversification. Mungbean, for example, is called 'the poor man's meat'. An increase in production in rainfed lowland areas would greatly benefit the rural economy of developing nations and farmers' well-being.

The objective of ACIAR Project 8938, 'Management of Lowland Rice-based Cropping Systems', was to develop suitable management practices to grow food legumes after the rice crop on these puddled soils. The project was a collaborative effort between the Department of Agriculture (The University of Queensland, Brisbane, Australia), CSIRO Division of Soils (Canberra, Australia), The University of Brawijaya and the Research Institute for Legume and Tuber Crops (both in Malang, Indonesia), the Research Institute for Maize and Other Cereals (Maros, Indonesia) and the Bureau of Soil and Water Management (Quezon City, the Philippines). The project was conducted from January 1992 to December 1995. Findings were presented during an international workshop 20–22 November 1995 at the Bureau of Soil and Water Management in Quezon City. Other scientists with similar interests were invited and contributed to the workshop. These Proceedings describe the results of the work conducted by the project team as well as papers on related research carried out and presented by scientists from the international community.

I. Willett, H. Bing So and G. Kirchhof

ACIAR PROJECT 8938

Management of Clay Soils for Lowland Rice-based Cropping Systems: An Overview of ACIAR Project 8938

H.B. So[1] and A.J. Ringrose-Voase[2]

Abstract

In this project the authors address the problem that yields of legume crops grown in the dry season (DS) after lowland rice are generally low. This is despite adequate water commonly being available in the soil profile to grow a reasonably good yielding DS crop without irrigation. Maize yields are as low as 1 t/ha or less, soybean and cowpea 0.3 to 0.8 t/ha in Indonesia, and mungbeans around 0.5 t/ha in the Philippines. These are all very much below the yield potential of the soils. For example, mungbean yields of 2.2 t/ha have been achieved in the Philippines by the International Rice Research Institute (IRRI) on similar soils without irrigation or additional fertilizers.

The causes of low yields of DS crops after rice are mainly poor crop establishment and poor root growth due to physical constraints resulting from the breakdown of soil structure during wet cultivation (puddling) for rice. Yields are also limited by biological and chemical constraints.

As a result of these low yields, farmers are reluctant to invest in post-rice crops. Therefore, land available after the harvest of lowland rice (at least 51 million hectares in Asia according to Huke 1982) represents an under-utilised resource that can be used to meet the food requirement of the ever increasing population of the developing world. To increase the utilisation of these soils, improved management practices are required to enable dry season crops to use the stored water in the soil profile after the rice crop.

The general objective of this project was to develop soundly based soil management technologies that can overcome soil physical limitations to DS crop production after lowland rice.

The specific objectives of the program for partners in the developing countries were:

1. To test a range of practices that have the potential to overcome adverse soil physical conditions for DS crops after rice.
2. To evaluate these practices by:
   (a) measuring the changes in soil physical and chemical conditions throughout the complete cropping cycle from rice to DS crops;
   (b) determining the performance of the crop (establishment and growth) and its ability to extract soil water.

The Australian program provided strategic support for the research programs conducted by the developing country partners. Its specific objective was to determine the mechanisms involved in both dispersion due to puddling and in flocculation and structural reformation as the soil dries after draining surface water from rice fields.

To keep pace with rapidly expanding populations, the production of food legumes and other dry season (DS) crops must be increased within the lowland rice growing areas in Indonesia and the Philippines as well as in other countries of Southeast Asia. There are 8.2 and 3.5 million hectares of lowland rice in Indonesia and the Philippines alone, with

[1] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia
[2] CSIRO Division of Soils, GPO Box 639, Canberra, 2601, Australia

3 and 2 million hectares of rainfed lowland rice respectively (Huke 1982). A common feature of lowland rice is that the amount of soil water remaining in the dry season after the rice crop is adequate for a DS crop. Despite the potentially high productivity of DS crops grown in these soils, yields are generally low. Yields are as low as 1 t/ha or less for maize, 0.3 to 0.8 t/ha for soybeans and cowpeas in Indonesia (Hoque 1984) and 0.5 t/ha for mungbeans in the Philippines (M.R. Recel, pers. comm.). These yields do not provide adequate returns to the farmer so that lowland rice soils, in particular rainfed lowland rice soils, represent an underutilised resource during the DS. The potential yield for mungbean in the Philippines is approximately 2.2 t/ha (So and Woodhead 1987). Therefore, increasing yields of DS crops would increase the utilisation of land and residual soil water during the period between rice crops.

Despite the lower yields of DS crops compared to rice, the lower costs and higher prices of some DS crops, in particular mungbean, can result in greater net returns from these crops than from the rice if moderate yields can be obtained (Maranan 1986, 1987). Considerable benefits could be expected from growing DS crops, including increased farmer income and nutrition and a reduction in imports of food legumes. In 1987, imports of maize and soybeans into Indonesia were about $25 million and $63 million respectively and about $7 million and $2.5 million to the Philippines. Peanut imports were $22 million and $7.5 million respectively. In addition, the introduction of food legumes into the rice rotation could result in substantial savings in nitrogenous fertilizers. These benefits would also be applicable to lowland rice areas in other Southeast Asian countries.

Both the Indonesian and Philippine governments place high priority on raising yields of DS crops, particularly legume crops, as a means of increasing farmers' income, as well as general nutrition levels. The Indonesian government expressed this through its five-year plans (PELITAs), of which the fourth plan is current. The Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) has a Mungbean Development Action Plan to co-ordinate efforts to increase production of mungbeans.

The causes of low yields of DS crops after rice are often poor crop establishment and inferior root growth due to adverse physical conditions of the soil which, in turn, are caused by the wet cultivation (puddling) undertaken for paddy rice (Adisarwanto et al. 1989; Pasaribu and McIntosh 1985; So and Woodhead 1987). Yields are also limited by nutritional and biological constraints. The biological constraints, particularly the dynamics of rhizobium, as well as chemical (soil acidity) and nutritional aspects have been addressed in other ACIAR projects. This project proposed to complement previous and existing projects by addressing the soil physical constraints and, to a lesser extent, the nutritional limitations of the soil after lowland rice.

Background to the Project

Rice in Southeast Asian countries is mostly grown under lowland conditions with 1 to 3 crops a year depending on the availability of irrigation water and the use of modern, short season varieties. A common feature of lowland areas is that after long-term submergence for rice, there is sufficient water stored in the soil after rice harvest to grow a dry season (DS) crop with reasonable yield potential (Pasaribu and McIntosh 1985). However, the mean yields given above under current management practices are generally very low and well below the yield potential when grown after rice due to poor and uneven establishment caused by the adverse physical conditions of previously puddled soils (Adisarwanto et al. 1989; Pasaribu and McIntosh 1985). The area of rainfed lowland rice is approximately 51 millon hectares in Asia (Huke 1982). In the DS, this area represents a large, underutilised resource. Furthermore, in Africa there are 100 million hectares of underutilised wetlands that could potentially be adapted to rainfed lowland rice with appropriate soil physical management (Woodhead 1990).

Since the late 1960s the realisation that multiple cropping programs are essential in attempts to raise production from rice-based systems culminated in the formation of the Asian Cropping Systems Network. This allows IRRI and the national programs from the various countries to develop jointly appropriate rice-based cropping systems in major rice growing environments in Asia (Hoque 1984). If soil management is to be an integral part of improved cropping systems, the dynamics of the soil under such paddy soils must be better understood.

The importance of legumes in rice-based cropping systems

Indonesia has been self-sufficient in rice since 1985 through the success of the government coordinated BIMAS (mass guidance) and INMAS (mass intensification) programs during past five-year plans or PELITAs. From 1984, PELITA IV gave special attention to the first palawija crop (first secondary crop within a lowland rice–palawija 1–palawija 2 cropping system), with particular emphasis on legumes (Nanseki et al. 1989). These crops were targeted for increased production with the aim of improving farmers' income and nutritional status (Vademecum BIMAS 1987). The target, in irrigated lowland areas, is to replace the third rice crop with palawija and, in rainfed lowland areas, to grow palawija before or after the rice crop. Based on the rate of consumption and imports, the major DS crops in Indonesia are, in decreasing order, maize, soybeans, peanuts and mungbeans (FAO 1984).

The success of the BIMAS and INMAS programs is partly due to the setting of realistic production targets, which are negotiated for each province, county and village which elects to join the program. These production targets, when agreed to by the parties concerned, become contracts that must be adhered to (Agricultural Intensification Program 1988/89) and involve a minimum mandatory set of technology packages (recipes) that must be carried out. If the recipe is adhered to, a minimum and achievable improved yield level is guaranteed. However, these technology packages do not include soil physical management recommendations due to a lack of knowledge in this area. Where adequate irrigation water is available, improved technology for soybean has recently been launched through the government extension program 'Supra-insus' (special program for intensification) with the aim of raising soybean yield from 1–1.5 t/ha (Sumarno 1990). As yet, satisfactory packages have not been developed for DS crops after rice.

In the Philippines, the major DS crops are, in decreasing order, maize, mungbean and soybean (Philippine Yearbook 1988). PCARRD has a Mungbean Development Action Plan aimed at introducing and studying the impact of new technologies for mungbeans, in particular new varieties which are shorter, faster maturing and higher yielding (Cabahug 1990). Faster growing varieties are particularly suitable for growing after rice, when the legume is largely dependent on stored soil water. Mungbean is the major legume crop in the Philippines partly because, with a protein content of 20%–25%, it provides a cheap source of protein, often being referred to as 'the poor man's meat' (Cabahug 1990). Its price is relatively stable and farmer consumption tends to compensate for any over-production, because unlike soybean, it does not require processing. In addition, it is more profitable than other legumes and rice, if moderate yields can be obtained as shown in Table 1.

Modest increases in mungbean yield in a rice–legume rotation can result in net returns from mungbean being greater than that from the rice component (Lavapiez et al. 1977; Maranan 1986, 1987). The profitability of mungbean in Indonesia is also cited as a major incentive towards its use after rice. However, under current management practices, yields of DS crops are poor and result in a reluctance by farmers to invest management and resources in DS crops, so that much land is underutilised after lowland rice (Varade 1990). In addition, there is a social preference for rice. Therefore, the introduction of management systems that can stabilise yields of DS crops, particularly legumes, after rice will have considerable socioeconomic benefits.

Table 1. National average yield, actual price (Philippine Pesos/kg), relative profitability and the ratio of returns/costs for several crops in the Philippines, 1985 (Adriano and Cabezon, 1987).

Crops	Yield t/ha	Price Pesos/kg	Total returns Pesos/ha	Cost of production Pesos/ha	Net returns Pesos/ha	Net returns/ costs %
Rice	2.4	3.24	7776	5370	2406	44.8
Maize	1.04	2.80	2912	2078	834	40.1
Soybean	0.99	7.30	7227	3697	3530	95.5
Mungbean	0.69	15.40	10626	3780	6846	181.1
Peanut	0.85	10.10	8585	6959	1626	23.4

Physical limitations of puddled soil

The physical limitations imposed by puddled soil have been recognised as the major cause of poor establishment and yield of post-rice crops in Asia, including soybeans in East Java (Adisarwanto et al. 1989) and mungbeans in the Philippines and other Asian countries (IRRI 1984; Mahata et al. 1990; So and Woodhead 1987; Varade 1990; Woodhead 1990). Puddling is associated with the breakdown of soil aggregates during wet cultivation (Adachi 1990; Sharma and De Datta 1985) and results in a massive soil structure after rice. After drainage of the surface water prior to rice harvest, the water content of the surface soil decreases, which is accompanied by a relatively rapid increase in redox potential (IRRI 1987; Maghari 1990) and a slower increase in soil strength (IRRI 1985, 1986, 1987, 1988). Puddling also creates a compacted layer below the puddled layer, whose strength increases rapidly during drying, (IRRI 1986). The effect of seasonal conditions and soil type on the germination, establishment and root growth of DS crops after rice is determined by the interactions between the rates of change of redox potential, soil strength and available water as the soil dries. To devise ways of overcoming these limitations, it is important to quantify the nature of these interactions through a program of detailed monitoring of soil physical conditions.

Effect of delay between field drainage and sowing on germination and establishment of post-rice DS crops

Successful crop establishment is essential for high yields to be obtained because yield of DS legumes is linearly related to plant population density up to 0.55–0.6 million plants/ha for mungbean (IRRI 1988; So and Woodhead 1987). In turn, rapid germination, which is dependent largely on soil water content and seed–soil contact, is essential to avoid other biotic factors preventing its completion (So and Woodhead 1987).

In this context, the length of the delay between field drainage and sowing the DS crop has a major influence on establishment because of its affect on soil water content. Although mungbeans under controlled conditions can still germinate at soil water potentials as low as –2.2 MPa (below wilting point), poor seed–soil contact reduces germination rates at low potentials and radicle elongation is reduced at potentials below 0.2 MPa (Fyfield 1987; IRRI 1988). In addition, emergence tends to fall below 50% when potential is reduced below 0.1 MPa (IRRI 1986).

Reports on the appropriate period of delay vary and probably reflect differences in climatic conditions during experiments and in soil type. Under conditions of little rain after drainage of surface water, it appears that emergence on silty clay loams is highest when mungbeans are sown before 6–10 days after drainage (DAD) (Cook 1989; Cook et al. 1995; Fyfield 1987; IRRI 1987, 1988). Later sowing tends to reduce emergence, growth and yield of mungbeans because of low water potentials and increased seedbed and subsoil strength. The latter prevents roots from exploiting water stored deeper in the profile. On the other hand, growth and yield can also be reduced after sowing at very short delays of 0–3 DAD due to low redox potentials and poor aeration (IRRI 1987). It is not clear how these periods would vary with soil types.

Since rice is generally harvested 7–10 DAD, it is therefore important that sowing of DS crops be carried out as soon as possible after harvest. However, in regions where the probability of rainfall after rice harvest is high, farmers tend to avoid waterlogging by either postponing sowing or by providing surface drainage (e.g. on the Vertisols around Ngale, East Java, T. Adisarwanto, pers. comm.).

Relay cropping, where legumes are sown soon after draining and before rice is harvested, has been tried as a means of reducing the sowing delay. However, this method tends to reduce establishment and yield, as well as to increase problems of weeds and ratooning of rice (IRRI 1987, 1989).

Soil amendments

Surface mulch

The use of surface organic mulch reduces the rate of water loss from the soil. Mulching with rice straw at 8 t/ha over the mungbean rows has been shown to improve emergence by 17% when sown 17 days after draining (IRRI 1988). In the drier regions of the Philippines, a mulch rate of 1.6 t/ha increased yield by 26% (IRRI 1989). Similarly, in East Java, a surface mulch of 5 t/ha rice straw increased yield by 30% (Adisarwanto 1985).

Incorporation of organic matter may improve soil in the long term, but four years of organic matter incorporation caused only marginal improvement in topsoil porosity and infiltration rate and had no significant effect on the crop (T. Woodhead, pers. comm.). This, however, might help to offset the deterioration in soil structure under intensive rice-based cropping systems (Cass et al. 1994).

Chemical amendments

Calcium ameliorants, such as gypsum and lime, have been used successfully to overcome soil physical problems associated with dispersion of Vertisols (McKenzie and So 1989a, b; So and McKenzie 1984) and possibly wet cultivation of clay soils. They have also been used in rice bays of the New South Wales (NSW) Riverina to prevent cloudy water by suppressing dispersion (Bacon 1979). Because puddling can cause dispersion of soil aggregates, it is possible that calcium ameliorants may improve structural development and water relations in puddled soils and assist the germination and establishment of DS legumes. Gypsum applied to a silty clay loam rice soil 10 days before draining (20 days before harvest) resulted in higher seed zone water content over the 30 days after harvest and increased wheat seedling emergence when moisture conditions were sub-optimal (Zhang 1990). The response to calcium should be dependent on the soil's clay content.

The uncertainties surrounding the use of surface organic mulch and gypsum or lime as part of soil management practices and its effect on the DS crops after rice warrants further investigation.

Tillage

The structure of the puddled layer becomes massive as the soil dries. Puddling also results in the formation of compacted soil layers below the puddled zone, whose strength increases very rapidly as the soil dries, limiting the depth of root exploitation

(IRRI 1986). The rate of drying is a function of time after drainage and hence a function of time of delay in sowing. The significance of the strength of this layer is that the depth of exploitable soil determines the yield of the crop. For example, mungbean yield is generally correlated with the depth at which the penetrometer resistance increases sharply (IRRI 1985, 1986). The growth of peanuts can also be adversely affected by the compacted layer and can be significantly improved by breaking that layer (G. Wright, ACIAR Peanut Project No. 8834, pers. comm.).

Attempts have been made to overcome these physical constraints using tillage. However, to date the effects of tillage on yield are unclear. In some experiments, tillage caused insignificant or no increases in yield (IRRI 1986, 1987, 1988, 1989). In other experiments, deep tillage produced significant yield increases (IRRI 1988). This uncertainty may be related to the interaction between tillage and the length of time tillage was carried out after draining of the surface water. Tillage during 0–7 DAD may not be beneficial because the soil is too wet and would result in cloddy seedbeds with poor seed–soil contact (Cook 1989; Cook et al. 1995; Zhang 1990). However, when the delay between field drainage and sowing is increased to improve conditions for tillage, the yield advantage can become a yield penalty because water becomes more limiting and can be lost faster from tilled soil (Cook 1989; Cook et al. 1995; IRRI 1987, 1989).

The disappointing responses to tillage found in many experiments may also be because tillage is not adequately loosening the soil. Results show that manual loosening of the soil to 1 m using a spade consistently improved mungbean yield more than tillage (IRRI 1987, 1988). The probable residual effects of DS tillage on increased percolation from the subsequent rice crop have not been widely investigated, but appear insignificant (IRRI 1984) because deep cracks developed irrespective of whether tillage was used or not.

Deep strip tillage, a new technology developed at IRRI which breaks the compacted layer directly below the crop rows, can significantly improve soil physical conditions and root growth of mungbeans (IRRI 1984, 1985, 1986, 1987; So and Woodhead 1987; Woodhead 1990). However, deep tillage has a high draft requirement which can be met only by four-wheel drive tractors or cable winch systems which are generally not available in Southeast Asia (IRRI 1985, 1986). In addition, four-wheel drive tractors can result in greater compaction. Therefore, this solution does not seem to be a practical option for the near future (T. Woodhead, pers. comm.).

Seeding techniques

The most commonly used seeding technique for DS legumes after rice is manual dibbling. However, Cook et al. (1995) found that dibbling gives variable results, especially when the soil is wet in the few days after rice harvest. An inexpensive alternative was manual furrow seeding, which also gave variable results, but was better in wet soils. Neither method was reliable at lower water contents. They also found that an inverted-T seeder (Choudhary 1985) pulled by a hand-tractor gave better performance in tilled soils except when very wet or dry.

Effects of puddling intensity on subsequent DS crops

Wet cultivation or puddling is synonymous with rice culture in Asia and is used to assist in transplanting rice seedlings, to reduce water and nutrient losses, and to control weeds (Sharma and De Datta 1985). Puddling breaks down and disperses soil aggregates into individual component particles. The degree of dispersion for a given puddling effort is dependent on the structural stability of the soil and is likely to affect the regeneration of soil structure after rice harvest, which, in turn, will affect the DS crop. The effects of degree of puddling prior to the rice phase on structure regeneration and growth of a DS crop after rice depends on soil type. For example, increasing intensity of puddling resulted in increased maize yields on a Vertisol but decreased yields in hardsetting, lighter textured Regosols (Tranggono and Willatt 1988). Similarly, intensive puddling increased DS mungbean yield on a clay loam but decreased it on a sandy loam (IRRI 1988). These differences were attributed to clay content and mineralogy. The concept of partially controlling soil structure regeneration after rice through the puddling treatment prior to the rice phase should be investigated further by determining which soil types are responsive.

Crop/cultivar selection for improved root performance

A factor which could assist the penetration of compacted subsoils is the pressure that the root system itself can exert. Differences exist between root systems in their ability to penetrate compacted layers. For example, bahia-grass penetrates compacted subsoils better than cotton, which has a taproot, with the result that cotton grown after bahia-grass yields better and extracts more water than cotton after cotton (Elkin et al. 1977). Similarly, maize after pigeonpea grows better and yields more than maize after maize, partly because of the superior penetration by pigeonpea roots (Hulugalle and Lal 1986). Similar cases have been reported in Australia. To date, there is no information on the ability of tropical species and cultivars to grow through hard soils. Such information would assist in the selection of crops suitable as DS crops after lowland rice and could possibly be used to breed suitable cultivars for that purpose. At The University of Queensland, techniques to investigate this characteristic on a routine basis have been developed.

Roots with the ability to penetrate hard subsoils would proliferate provided they are able to extract available water, which is determined by soil hydraulic characteristics. Work at The University of Queensland with 12 cultivars of sorghum showed great differences between cultivars in their ability to extract water from the subsoil even when adequate roots were present at depth for all cultivars (So and Jayasekara 1991). Productivity is strongly associated with this characteristic and with the amount of extractable soil water. Similar observations were made of peanut cultivars used in the ACIAR Peanut Improvement Program (G. Wright, pers. comm.) and these root characteristics should be further investigated.

Soil chemical and biological limitations

Crops grown in lowland soils after rice harvest may suffer from deficiencies of plant nutrients and from a lack of suitable microorganisms, such as rhizobia or VA mycorrhiza, which may not survive prolonged waterlogged conditions. The availability of residual nutrients from the rice phase is dependent on soil type. In 1984, IRRI achieved mungbean yields of 2.1 t/ha after rice without fertilizer, inoculum or irrigation and with only 35 mm of DS rain (IRRI 1985). However, during an earlier visit to East and Central Java, the authors saw significant responses of mungbean and peanuts after rice to various combinations of fertilisers and inoculum. The interaction of phosphorus and zinc has been observed in student projects with Vertisols in Indonesia (S. Setijono, pers. comm.). Zinc, copper and boron deficiencies have been reported for IR64 rice in some areas of East Java and zinc and copper applications have increased lowland rice yields (Suyono 1990). Therefore, it is possible that these elements could be deficient for DS crops as well and should be evaluated.

Summary

It is clear that the limitations to dry season crop growth and yield after lowland rice soils are complex and still not clearly understood. The need for solutions to the problems associated with clay soils after lowland rice has received strong endorsement from the Asian Rice Farming Systems Network workshop in Bogor on 2–5 October, 1989 which recommended that work in this area should be initiated simultaneously in a number of Asian countries.

Objectives of the Project

General objectives

Overall objective of the project was to develop soundly-based soil management technologies that can overcome soil physical limitations to DS crop production after lowland rice harvest.

Specific objectives of the program in partner countries

1. To test a range of practices that have the potential to overcome adverse soil physical conditions for DS crops after rice, including amendments (calcium or organic matter mulch), specific tillage technologies and a range of delay periods in sowing of the DS crop after rice harvest.
2. To evaluate these practices by:
   (a) measuring the changes in soil physical and chemical conditions throughout the complete cropping cycle from rice to DS crops;
   (b) determining the performance of the crop (establishment and growth) and its ability to extract soil water.

Specific objectives of the Australian research program

The Australian program aimed to provide strategic support for the research programs conducted in the partner countries. Its specific objective was to determine the mechanisms involved in soil dispersion due to puddling and in flocculation and structural reformation as the soil dries after draining surface water from rice fields.

Possible effects from the ameliorative treatments of the soil for the DS crop may have detrimental as well as beneficial effects on the following rice crop. For example, paddy fields may become more permeable and leaky but residual N from legumes may be beneficial for rice. Therefore, it was important to monitor the changes in physical properties throughout the complete cropping cycle. The potential practices investigated included some promising tillage technologies, as well as chemical and organic amendments and seeding technologies.

Selection of Appropriate Sites

It is important that the technology developed in this project can be transferred readily across a range of soils and climates. Therefore, the project was designed with a series of benchmark sites with common treatments, a common DS crop species (mungbean) and common methodologies covering a range of sites with different soils and climates. Treatments and species specific to particular areas or soils were included at relevant sites. The sites in Indonesia were Ngale (deep Vertisol) and Jambegede (silty clay loam) in East Java, where soybean and peanuts were included alongside mungbean, and a site near Maros in South Sulawesi (silty clay). The sites in the Philippines were the research station at San Ildefonso, Bulacan (Vertisol) and a farmer's field near Manaoag, Pangasinan (silty clay). The sites covered a wide range of clay contents and clay mineralogies and shrink/swell properties (Ringrose-Voase et al. 1995, 1996). The Ngale site has the greatest clay content with 74% total clay and 54% (on whole soil basis) swelling clay (smectite), giving it the greatest shrink/swell potential (0.19 linear shrinkage). The site at San Ildefonso has 41% total clay and 26% swelling clay and intermediate shrink/swell potential (0.07 linear shrinkage). It also has a significant sand content of 31%. The Maros and Manaoag sites have similar particle size distributions with 46% and 52% total clay, respectively. However, they have very different mineralogies with 9% and 32% swelling clays, respectively, which gives them different shrink/swell potentials (0.05 and 0.10 linear shrinkage, respectively). Jambegede has 45% total clay with 15% swelling clays.

Collaborating Institutions for the Project

The project was a collaborative effort of six institutions:

The University of Queensland as the commissioned organisation with:
Assoc. Prof. Hwat Bing So (Project Leader, soil physics and management),
Dr Gunnar Kirchhof (Project Coordinator, soil physics and management).

CSIRO, Division of Soils, Canberra with:
Dr A.J. Ringrose-Voase (soil structure),
Dr J.M. Kirby (soil mechanics).

University of Brawijaya, Malang, Indonesia with:
Dr Wani Hadi Utomo (soil physics and management),
Dr R. Tranggono (soil tillage and mechanisation).

Research Institute for Legume and Tuber Crops (RILET[1]) Malang with:
Dr Titis Adisarwanto (legume agronomist).

Research Institute for Maise and other Cereals[2], Maros with:
Dr B. Prastowo (agricultural engineer).

Bureau of Soil and Water Management, Quezon City, Philippines with:
Dr Godofredo Alcasid (soil scientist),
Mrs Esperanza Dacanay (soil physics and management).

Benefits Expected from the Project

Technical and training benefits

At the time the project was initiated, it was expected that the project would suggest some soil management practices which could be selected for further development. Such practices would be acceptable to farmers and allow inclusion of a DS crop in rice-based cropping systems, or improve the performance of existing DS crops. In addition, gaining a better understanding of the physical conditions, in particular the hydrology, of drying rice soils of various types and in various climatic regimes, can lead to recommendations of which soil type/climate combinations are suitable for growing DS legumes with a reasonable chance of success. Understanding the interaction between the hydrology of a soil type and the local climate can help in designing optimum sowing windows when the probability of success is greatest.

The project provided research training in soil physical management to staff in the partner countries.

The program at The University of Queensland and the CSIRO Division of Soils provided basic data on the mechanisms of soil improvement by various management practices and assisted the collaborators in the interpretation of field results. Information gained from this project will also be useful in the rice-growing regions of Australia such as the Murray irrigation areas and northern Queensland, where lowland rice is part or becoming part of the existing crop rotation. The project provided further training to an Australian scientist in tropical agriculture. From the technological point of view, dispersion is a major fundamental process involved in the degradation of Australian clay soils as a result of cultivation practices. Therefore, a better understanding of this process and the subsequent reformation of soil structure will assist in the development of improved management practices for irrigated and dryland agricultural systems in Australia.

[1] Formerly called: Malang Research Institute for Food Crops (MARIF)
[2] Formerly called: Maros Research Institute for Food Crops (MORIF)

Economic benefits

The inclusion or improved performance of DS crops is expected to improve farmer income within a sustainable cropping system. It will create new opportunities for increasing farm income or food production for home consumption. Suitable management practices have the potential to increase farm income by increasing both the utilisation of farm resources in the DS and their productivity, particularly where DS irrigation is not available.

The impact of the results from this project will vary from site to site and will depend on a number of factors. Table 1 provides a comparison of the ratio of net returns/costs of the various DS crops in the Philippines to that for rice. The higher profitability of mungbeans and soybeans compared to rice indicates that modest yields or yield increases for these crops can provide higher returns to the farmer than the rice component. A similar situation could be expected in Indonesia.

The national impact of increasing productivity of soils which are currently underutilised in the dry season could be significant. Only modest increases in productivity would be required to overcome shortages in domestic food production in Indonesia and Philippines and to reduce the necessity for imports of grain legumes. For example, a small increase of soybean yield of about 0.5 t/ha over 20% of the lowland rice area in Indonesia (1 million hectares) would be adequate to overcome the current import requirement of the last few years of around 300 000 to 500 000 t/year. Similar calculations can be made for other commodities.

References

Adachi, K. 1990. Effects of rice-soil puddling on water percolation. In: Trans. 14th International Congress of Soil Science, Kyoto. Vol. 1, 146–151.

Adisarwanto, T. 1985. The influence of planting methods and mulching on soybean seed yield. In: Shanmugasundaram, S. and Sulzberger, E.W., ed., Soybean in Tropical and Subtropical Cropping Systems. Taiwan, Asian Vegetable Research and Development Centre, 215–217.

Adisarwanto, T., Santoso, B., Manshuri, G. and Floyd, C. 1989. Agronomic Survey of MK1 Soybean on Sawah in East Java (Jember to Madiun), 21–24 June 1989. Malang Research Institute for Food Crops, E. Java, Indonesia.

Adriano, M.S. and Cabezon, V.E. 1987. Economic policies affecting crop diversification in the Philippines. In: Irrigation Management for Diversified Cropping. Sri Lanka: International Irrigation Management Institute.

Agricultural Intensification Program. 1988/89. Special province of Yogyakarta (translated from: Keputusan Gubernur Kepala Daerah Istimewa Yokyakarta No. 165/KPTS/1988 tentang Program Intensifikasi Pertanian Tahun 1988/1989, Propinsi DIY, BIMAS Propinsi DIY).

Bacon, P.E. 1979. Efficiency of different calcium application methods in controlling muddy water. In: Proc. Australian Society of Soil Science Inc. Conference, Yanco, NSW 116–121.

Cabahug, L.V. 1990. In praise of the marvellous mungbean. Food Legumes — Coarse Grains Newsletter, 12, 13–14.

Cass, A., Gusli, S. and MacLeod, D.A. 1994. Sustainability of soil structure quality in rice paddy-soyabean cropping systems in South Sulawesi, Indonesia. Soil Tillage Res., 31, 339–352.

Choudhary, M.A., 1985. Seeding techniques and machinery. In: Soil Physics and Rice. Los Baños, Philippines, International Rice Research Institute, 411–412.

Cook, S.M.F. 1989. Influence of Soil Physical Properties on Mungbean Emergence in Rice Soils. MSc thesis. University of Minnesota, USA.

Cook, S.M.F., Gupta, S., Woodhead, T. and Larson, W.E. 1995. Soil physical constraints to establishment of mungbeans (*Vigna radiata* L. Wilczek) in paddy rice (*Oryza sativa* L.) soils. Soil Tillage Res., 33, 47–64.

Elkin, C.B., Haaland, R.L. and Hoveland, C.S. 1977. Grass roots as a tool for penetrating soil hardpans and increasing crop yields. In: Proc. 34th Southern Pasture and Forage Crop Improvement Conference, Auburn University, Alabama, USA, 21–26.

FAO Yearbook. 1984. Vol. 38. Food and Agricultural Organisation Statistics Series No. 63.

Fyfield, T.P. 1987. Effects of Temperature, Water and Cultivation on the Establishment of a Mungbean Crop Following Paddy Rice. PhD thesis. University of Reading, U.K.

Hoque, M.Z. 1984. Cropping Systems in Asia: On-Farm Research and Management. Los Baños, Philippines, International Rice Research Institute.

Huke, R.E. 1982. Rice Area by Type of Culture: South, Southeast, and East Asia. Los Baños, Philippines, International Rice Research Institute, 32 p.

Hulugalle, N.R. and Lal, R. 1986. Root growth of maize in a compacted gravelly tropical Alfisols as affected by rotation with a woody perennial. Field Crops Research, 13, 33–44.

IRRI. 1984. Annual Report for 1983. Los Baños, Philippines, International Rice Research Institute.

— 1985. Annual Report for 1984. Los Baños, Philippines, International Rice Research Institute.

— 1986. Annual Report for 1985. Los Baños, Philippines, International Rice Research Institute.

— 1987. Annual Report for 1986. Los Baños, Philippines, International Rice Research Institute.

— 1988. Annual Report for 1987. Los Baños, Philippines, International Rice Research Institute.

— 1989. Annual Report for 1988. Los Baños, Philippines, International Rice Research Institute.

Lavapiez, L.M., Duran, B., Nicolas, J. and Price, E.C. 1977. Rice-mung cropping patterns in Manaoag, Pangasinan: A costs and returns study. Internal report. Agricultural Economics Department, International Rice Research Institute, Los Baños, Philippines.

Maghari, S. de G. 1990. Mungbean emergence and growth as influenced by soil submergence in previous rice crop. MSc thesis, University of Minnesota.

Mahata, K.R., Sen, H.S., Pradhan, S.K. and Mandal, L.N. 1990. No-till and dry ploughing compared with puddling for wet season rice on alluvial sandy clay loam in eastern India. J. Agric. Sci., 114, 79–86.

Maranan, C.G. 1986. Agricultural economic research at Guimba cropping systems site, Nueva Ecija, Philippines. Internal report. Agricultural Economics Department, International Rice Research Institute, Los Baños, Philippines.

— 1987. Economic performance of cropping patterns at Bantug, Guimba, Nueva Ecija CSR site, 1986–87. Internal report. Agricultural Economics Department, International Rice Research Institute, Los Baños, Philippines.

McKenzie, D.C. and So, H.B. 1989a. The effect of gypsum on Vertisols of the Gwydir Valley, NSW. I. Soil properties and wheat growth. Aust. J. Exp. Agric., 29, 51–62.

— 1989b. The effect of gypsum on Vertisols of the Gwydir Valley, NSW. II. Ease of tillage. Aust. J. Exp. Agric., 29, 63–67.

Nanseki, T., Morooka, Y. and Zakaria, A.K. 1989. Comparative advantage analysis of soybean in an upland area of West Java: A case study of mathematical programming approach. Palawija News 6,(2). CGPRT Newsletter.

Pasaribu, D. and McIntosh, J.L. 1985. Increasing tropical soybean production with improved cropping systems and management. In: Shanmugasundaram, S. and Sulzberger, E.W., ed., Soybean in Tropical and Subtropical Cropping Systems. Taiwan, Asian Vegetable Research and Development Centre, 1–11.

Philippine Yearbook. 1988.

Ringrose-Voase, A.J., Hutka, J., Beatty, J., Raven, M.D. and Rath, H. 1995. Analysis of some Indonesian and Philippine soils for ACIAR Project 8938 on 'Management of clay soils for lowland rice-based cropping systems'. CSIRO (Australia) Division of Soils Technical Report 11/1995.

Ringrose-Voase, A.J., Hutka, J., Clarke, M., Raven, M.D. and Schafer, B.M. 1996. Analyses of soil profiles at the experimental sites in Indonesia and the Philippines for ACIAR Project 8938 on 'Management of Clay Soils for Lowland, Rice-based Cropping Systems'. CSIRO (Australia) Division of Soils Technical Report 2/1996.

Sharma, P.K. and De Datta, S.K. 1985. Effects of puddling on soil physical properties and processes. In: Soil Physics and Rice. Los Baños, Philippines, International Rice Research Institute, 217–234.

So, H.B. and McKenzie, D.C. 1984. The use of gypsum in the management of the grey and brown clays of the Lower Gwydir Valley, NSW. In: McGarity, J.W., Hoult, E.H. and So, H.B., ed., The Properties and Utilisation of Cracking Clay Soils. Reviews in Rural Science 5, University of New England, NSW, Australia, 329–334.

So, H.B. and Jayasekara, K.S. 1991. The effect of shoot/root ratios on the water relations of sorghum. In: McMichael, B.L. and Persson, H., ed., Plant Roots and Their Environment. Developments in Agricultural and Managed Forest Ecology 24. Elsevier, Amsterdam, 557–565.

So, H.B. and Woodhead, T. 1987. Alleviation of soil physical limits to productivity of legumes in Asia. In: Wallis, E.S. and Blyth, D.E., ed., Food Legume Improvement for Asian Farming Systems. Canberra, ACIAR Proceedings Series No. 18, 112–120.

Sumarno. 1990. Soybean culture in Indonesia. Food Legumes — Coarse Grain Newsletter, 12, 9–10.
Suyono. 1990. Kajian Kebutuhan Unsur Mikro Pada Psaments Yang Disawahkan Dengan Paket Supra Insus (Evaluation of the Micro-nutrient Requirements of Lowland Soil under the Supra-insus Program). MAgrSc thesis, University of Gajah Mada, Yokyakarta, Indonesia.
Tranggono, R. and Willatt, S.T. 1988. The growth of maize after wetland rice in East Java. In: Proc. 11th Conference of the International Soil Tillage Research Organisation, Edinburgh, U.K. 10–15 July, 1988. 903–908.
Vademecum BIMAS. 1987. Vol. IV. Sekretariat Badan Pengendali BIMAS, Jakarta. (BIMAS Guidelines. Vol. IV. Secretariat of the BIMAS Executive Committee, Jakarta).
Varade, S.B. 1990. Establishment of non-rice crops in previously puddled soils. In: Trans. 14th International Congress of Soil Science, Kyoto, 1, 170–174.
Woodhead, T. 1990. Problems and opportunities in soil physical management in rice-based cropping systems. In: Trans. 14th International Congress of Soil Science, Kyoto, 1, 140–145.
Zhang Jiabao. 1990. Rice Soil Structural Management for Prompt and Effective Wheat Emergence and Yield in Irrigated Rice-Wheat Cropping Sequences in the Tropics. PhD thesis. University of the Philippines, Los Baños.

Management of Clay Soils for Lowland Rice-based Cropping Systems: Experiments and Methodology

H.B. So[1], G. Kirchhof[1], W.H. Utomo[2], T. Adisarwanto[3], B. Prastowo[4], E.V. Dacanay[5], G.N. Alcasid Jr[5] and A.J. Ringrose-Voase[6]

THE objectives of this project have been expressed in detail in another paper (So and Ringrose-Voase, these Proceedings). In planning and designing the experiments for this project, the authors were conscious of the future need for extrapolation of results to other soil types and climates. Therefore, sites were selected to cover a range of soil types and climates in Indonesia and the Philippines. It was also essential that some of the methodology used should be comparable and at least one crop be common to all sites. This allows general features to be extracted from the results. With these criteria in mind, the experiments represent a series of benchmark sites. The different field experiments were linked into a single project, complemented and strategically supported by the more basic research program in Australia at The University of Queensland and CSIRO Division of Soils, Canberra.

This project dealt with components of a cropping system that have vastly different requirements. The rice phase requires a puddled soil with the structure largely broken down, whereas the dry season (DS) crop requires a soil with good structure to express reasonable productivity. The authors recognised that the ameliorative treatments of the soil for the DS crop may have detrimental as well as beneficial effects on the subsequent rice crop, e.g. paddy fields may become more permeable and leaky; residual N from legumes may be beneficial for rice. Therefore, it was important that, where possible, the changes in physical properties be monitored throughout the complete cropping cycle.

[1] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia
[2] Department of Soil Science, University of Brawijaya Fakultas Pertanian, Jl. Mayjen Harjono 18, Malang 65145, Indonesia
[3] Research Institute for Legume and Tuber Crops (RILET), Kendalpayak, PO Box 66, Malang 65101, Indonesia
[4] Research Institute for Maize and other Cereals, Jl. Dr Ratulangi, Maros 90514, Indonesia
[5] Bureau of Soil and Water Management, Cnr Elliptical Rd and Visayas Av, Quezon City 1100, the Philippines
[6] CSIRO Division of Soils, GPO Box 639, Canberra, 2601, Australia

Objectives of the Project

General objectives

The overall longer-term objective of this project was to develop soundly-based soil management technologies that can overcome soil physical limitations to DS crop production after lowland rice harvest.

Specific objectives of the program in partner countries

Specific objectives of the overseas program were:

1. To test a range of practices that have the potential to overcome adverse soil physical conditions for DS crops after rice, including amendments (calcium or organic matter mulch), specific tillage technologies and a range of delay periods between rice harvest and sowing the DS crop.
2. To evaluate these practices by:
   (a) measuring the changes in soil physical and chemical conditions throughout the complete cropping cycle from rice to DS crops;
   (b) determining the performance of the crop (establishment and growth) and its ability to extract soil water.

Specific objectives of the Australian research program

The Australian program provided strategic support for the research programs conducted in the partner countries. The specific objective was to determine the mechanism of soil dispersion due to puddling and that of flocculation and structural reformation as the soil dries after draining surface water from the rice fields.

Research Program in Partner Countries

At each site in Indonesia and the Philippines, three field experiments were conducted to investigate the effect of potentially useful management practices on soil conditions and the resulting growth of DS crops.

The first two experiments were designed to reduce the need for large numbers of treatment combinations by separating treatments applied during the rice phase (E1) and treatments applied during the legume phase (E2).

A third experiment (E3) measured the dynamics of changes in soil properties in the period immediately following field drainage for rice harvest. The information gained from the latter will help extrapolate the results from the first two experiments to other soils and climates.

Experiment 1 (E1)

The objective of the first experiment was to investigate the effects of degree of puddling on soil physical conditions for the subsequent DS crop. Previous work indicated that increased puddling may increase yields of the following DS crop on heavy clay soils but decrease yield on lighter textured soils (Tranggono and Willatt 1988). If this is correct, puddling intensity can be used as an inexpensive and readily adoptable practice on suitable soils.

The treatments adopted consisted of 4 degrees of puddling imposed during soil preparation for the rice crop:

1. Dry cultivation prior to submergence.
2. One wet ploughing and harrowing using draught animals.
3. Two wet ploughings and harrowings using draught animals.
4. Two wet cultivations with rototiller or hydrotiller.

These treatments were combined with two post-rice tillage/sowing treatments (zero-till/dibbled vs ploughing, broadcasting and harrowing — PBH) for the DS crops in the Philippines. In Indosesia, the treatments were combined with two post-rice drainage treatments (without and with surface drains) with the DS crop being sown by dibbling. PBH is the common farmer practice in the Philippines and surface drains are common on heavy clay soils in Indonesia. Zero-till/dibble without surface drains was the treatment common to the two countries.

In both countries, the most common farmer practice of soil preparation for rice is two ploughings and harrowings using draught animals. Treatments were replicated four times at each site in each year.

Experiment 2 (E2)

The second experiment investigated the effects of DS crop management practices on soil properties and crop performance. To facilitate comparison with Experiment 1, soil was prepared for the rice phase by ploughing and harrowing twice.

Treatments included combinations of amendments (none — A0, gypsum — AG and organic matter mulch — AOM); cultivation (zero-till — C0 and rotovator — C1) and sowing delay (no delay — D0, 1 week delay — D1 and 2 weeks delay — D2) as follows:

T1:	C0	A0	D1	no fertilizer (farmers' practice in Indonesia)
T2:	C0	A0	D1	adequate fertilizers
T3:	C0	AG	D1	adequate fertilizers
T4:	C0	AOM	D1	adequate fertilizers
T5:	C0	A0	D0	adequate fertilizers
T6:	C0	A0	D2	adequate fertilizers
T7:	C1	A0	D1	adequate fertilizers
T8:	C1	A0	D2	adequate fertilizers
T9:	PBH	A0	D1	no fertilizer (farmers' practice in the Philippines)

The DS crop was sown by dibbling for all treatments except T9. Treatments were replicated four times at each site in each year. Note that:

- Treatments T1 to T8 were used on all sites and treatment T9 only in the Philippines.
- Treatments T1 and T2 provide a measure of the nutritional limitations of the various soil types.
- Treatments T2 to T4 provide a measure of the effects of gypsum and organic matter mulch.
- Treatments T2 and T5 to T8 provide a measure of the combined effects of cultivation and length of delay between rice harvest and sowing.

It should be pointed out that all the treatments had already been shown to be potentially useful for DS crops after rice in previous trials on specific soils and under a limited range of climatic conditions. Relevant information from these trials is limited and extrapolation to different conditions is difficult.

This project compared these potentially useful treatments on a range of soils and climatic conditions and attempted to quantify the agronomically relevant changes in the soil conditions resulting from these to enable extrapolation to other sets of environments in the future.

Experiment 3 (E3)

A third short-term field experiment was conducted by project staff from CSIRO Division of Soils at one or two sites each season. This experiment monitored changes in soil mechanical properties and soil structure with time as the soil dried after draining surface water prior to rice harvest.

The information obtained for each soil provides functional relationships required to interpret the conditions encountered at planting and during early seedling growth in the first two experiments which involve only three sowing delays. These experiments lasted 4 to 6 weeks each.

This experiment was carried out on soils with standard puddling treatments (two ploughings and harrowings). The following properties were measured at regular intervals (daily in the early stages): water content, soil strength (shear and penetrometer resistance), macropore structure development (using crack measurements and resin impregnated samples).

Dry season crop species

In experiments E1 and E2, mungbean was the DS crop common to all sites. Mungbean is the major DS legume crop in the Philippines and the third major legume in Indonesia. It is a robust and uncomplicated crop.

A second crop was included in East Java with soybean on the Vertisol (Ngale) and peanuts on the lighter textured soil (Jambegede).

Possible advantages and disadvantages to the rice crop from improvements to the dry season crop

The use of chemical amelioration and tillage for the DS crop may increase the percolation rate during the subsequent rice phase or possibly increase the energy required for puddling. In either case, the treatments may reduce the ability of the soil to pond water and shorten periods of inundation under rainfed conditions. This could lower productivity of the rice in areas of marginal rainfall. Therefore, it was important to monitor soil characteristics under both rice and DS crop components of the experiments to quantify this problem if it occurred.

On the other hand, the use of legumes in the rotation may be beneficial and increase the nitrogen available to the rice crop and reduce the requirement for expensive nitrogenous fertilizers.

Experimental sites

Indonesia

1. **Ngale:** A RILET (Research Institute for Legume and Tuber Crops)[1] experimental station. 175 km North-west of Malang, E. Java. Soil type: Deep Vertisol (heavy clay). Experimental crops: Mungbean and soybean.
2. **Jambegede:** A RILET[1] experimental station. 20 km South of Malang, E. Java. Soil Type: Silty clay loam. Experimental crops: Mungbean and peanut.
3. **Maros:** A demonstration site of the Research Institute for Maize and other Cereals[2] at Alleporea, 10 km from Maros, S. Sulawesi. Soil type: Medium clay alluvial soil. Experimental crop: Mungbean.

Philippines

4. **San Ildefonso:** BSWM (Bureau of Soils and Water Management) Research Station, Bulacan Province. 50 km North of Manila. Soil type: Vertisol (medium clay). Experimental crop: Mungbean.
5. **Manaoag:** Farmer's field, Pangasinan Province. 100 km North-north-west of Manila. (BSWM has a long history of collaboration with the farmer). Soil type: Silty clay alluvial soil. Experimental crop: Mungbean.

Measurements

Initial characterisation of the site

The uniformity of the sites were investigated using a 20–25 m grid system. Morphological descriptions were made to determine any gradation in soil characteristics and to help avoid any unrepresentative areas. Composite samples from sections of the field at different depths were analysed as follows to provide a baseline data-set prior to imposition of treatments:

- Soil texture, particle size analysis;
- CEC, cations, pH, EC , organic C;
- Soil water characteristics, available water capacity;
- Bulk density, macroporosity;
- Plastic and liquid limits;

[1] Formerly called: Malang Research Institute for Food Crops (MARIF)

[2] Formerly called: Maros Research Institute for Food Crops (MORIF)

- Soil structural stability (wet sieving and dispersibility).

  Field measurements were also be made for:
- Soil strength (shear vane or penetrometer);
- Infiltration rate.

Measurements during the rice phase

The following were measured at the start, middle and end of the rice phase:
- Infiltration rate;
- Dispersibilty of the soil;
- Yield of rice.

Measurements during the dry season crop phase

Soil measurements were made at the same time as plant measurements at the appropriate phenological phases of the crop e.g. emergence, vegetative, flowering, pod formation and maturity. Measurements included:

Soil Physical measurements:
- Infiltration rate (vegetative stage only);
- Structural stability (wet sieving/dispersibility) (vegetative stage only);
- Bulk density profile;
- Strength profile using penetrometers;
- Water content profile and crop water use;
- Root distribution/root length densities (at flowering only).

Plant measurements:
- Leaf water potentials (pressure bomb apparatus);
- Leaf area index;
- Plant height;
- Plant biomass and its components;
- Yield and yield components.

Climatic measurements (local weather station data):
- Rainfall;
- Evaporation (E pan);
- Temperature;
- Radiation.

Methodology training workshop

The success of the project in evaluating soil management practices for DS cropping over a range of different soils and climates was expected to be dependent on the adoption of a uniform methodology for all sites. To achieve this, a manual of standard procedures for the project was developed and a five-day workshop was conducted at the commencement of the project.

Australian Research Program

This part of the research program was based at The University of Queensland and was intended to provide strategic support to the field program through investigations into mechanisms of dispersion as a result of puddling and factors affecting the development of soil structure during drying.

Simulation of soil puddling and drying in the laboratory

(a) Laboratory experiments were conducted to measure the degree of dispersion of soils imported from the experimental sites together with a range of Australian soils, after the soil had been subjected to a range of puddling treatments. Degree of dispersion was adopted as a measure of the degree of puddling and the decrease in structural stability. Since one major objective of puddling is to reduce percolation rate, soil hydraulic conductivities were measured for each puddling treatment and related to the degree of dispersion.

(b) The effects of a single and repeated wetting and drying cycles on soil structural development were investigated.

Simulation of the rice-dry season crop sequence

Soil changes occurring during the rice-DS crop sequence were observed and quantified in large lysimeters (approximately 1.2 m × 1.5 m × 1 m in which rice was grown under puddled conditions and followed by a DS crop. Soils used covered a similar range of textures to those used in the field experiments.

Reference

Tranggono, R. and Willatt, S.T. 1988. The growth of maize after wetland rice in East Java. In: Proc. 11th Conference of the International Soil Tillage Research Organisation, Edinburgh, U.K., 10–15 July, 1988. 903–908.

Soil and Climate Description of Benchmark Sites for Lowland Rice-based Cropping Systems Research in the Philippines and Indonesia

B.M. Schafer[1] and G. Kirchhof[2]

Abstract

Morphological, physical, chemical and mineralogical properties of soils located at five major rice-growing areas of the Philippines (two sites) and in Indonesia (three sites) which were selected for lowland rice-based cropping systems research were used to classify the soils into the local soil series, Soil Taxonomy and The Australian Soil Classification systems. The descriptions were also used to select comparable Australian soils for detailed studies at The University of Queensland. These data were further intended to facilitate transfer of knowledge of improved farming systems technology to other lowland rice growing areas in the regions. The soils were classified as Vertisols, Andisols or Inceptisols and were characterised by clay contents ranging from 37% to 87% and cation exchange values ranging between 17 and 68 cmol (p+)/kg. pH values were neutral to mildly alkaline. Land surface and root zone attributes were qualitatively evaluated for plant growth limitations for potential post-rice production by description and interpretation of modified surface and subsoil properties associated with rice production. Climatic data are presented for each of the five sites and the characteristics for potential rainfall incidence are given.

THIS paper provides detailed descriptions of the soils and climates of experimental sites used for research into management of soil physical constraints for successful cropping of legumes in the dry season following lowland, flooded rice. The sites selected were located in five major rice growing areas which depended on seasonal rains for production.

Detailed soil descriptions using standard terminology were not available for the sites used for experimentation and available analytical data required to characterise the soil properties were inconsistent across the five sites. This was due to the use of different techniques employed by laboratories located in the regions. To overcome this problem, samples from the soil sites were analysed in the CSIRO Laboratories in Canberra and Adelaide (Ringrose-Voase et al. 1996). Furthermore, to facilitate transfer of soils information to other rice-growing regions, standard terminology was required to classify the soils according to Soil Taxonomy.

In the Philippines, the soils of the Bulacan Province have been described, mapped and classified in detail (Soil Survey Division 1987). A soil description and analytical characteristics were provided for soil near the site at Manaoag in the Pangasinin Province. However, the data were not correlated with soils in the region and terminology used was insufficient for classification.

The soils of East Java have been variously described and classified at the regional level but limited data were available for the selected experimental sites. In South Sulawesi, the soils of the Maros Agricultural Research Station have been described (Ali and Sawijo 1982) although the experimental site was outside of the area.

The climate in the Philippines is governed by north east and south west monsoon air streams. The north west monsoon originates in the cold Asiatic winter anticyclone and produces a distinct dry season from around October to May. The south west monsoon originates as an Indian ocean anticyclone

[1] Department of Plant Production, [2] Department Agriculture, The University of Queensland, Brisbane 4072, Australia

during the southern hemisphere winter. It usually commences in early May, reaches its maximum influence in August and abates in October. Monsoonal rains can occur as early as April and may persist to November.

The Philippines are located in a region which is recognised as having the greatest frequency of tropical cyclones (typhoons) in the world (Flores and Balagot 1969). They produce rainfall between May to December with a mean monthly frequency of greater than 0.5 throughout the year, but generally less than 1.0 between January and May.

The climate in Indonesia is dominated by monsoonal air streams which are at opposite times of the year to those in the Philippines. Rainfall on Java is largely affected by the position of the intertropical convergence zone which passes through twice annually. It is influenced by the mountainous areas of Borneo and Sumatra (Sukanto 1969). Although the wet and dry seasons are distinct, a lesser rainy season occurs during the dry season which results in rainfall throughout the year. In south east Sulawesi, a distinct dry season occurs but wet season rainfall is considerably higher than that of Java due to the influence of the land masses and mountains of Borneo. Compared to the Philippines, Indonesia has a very low incidence of tropical cyclones.

Methods

Soil pits were hand dug to a minimum depth of 1.5 m to expose a vertical face of soil within a rice paddy and also to expose a vertical face of the associated bund. The profiles were described using terminology proposed by McDonald et al. (1984) with minor modification by the use of consistence terms proposed by Anon. (1951). This modification was made to facilitate communication with the professional workers in the two countries. The sites and profile exposures were photographed to provide a visual record.

Soils were sampled for laboratory analysis by taking bulk samples from the designated horizons. These samples were analysed by the laboratories at the Bureau of Soil and Water Management (Quezon City, Metro Manila), Brawijaya University (Malang), Maros Research Institute for Food Crops (MORIF) in Ujung Pandang and CSIRO Laboratories in Canberra and Adelaide, Australia. Subsamples were retained for analysis in Australia to cross reference the reproducibility of standard techniques common to all laboratories.

Methods for soil chemical, physical and mineralogical determinations are documented by Ringrose-Voase et al. (1996). Chemical methods follow the Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson 1992). Particle size analysis was determined by the sedigraph method (Hutka and Ashton 1995) and mineralogy of the clay fraction was analysed semi-quantitatively by X-ray diffraction (Raven 1995).

The soils were classified according to Soil Taxonomy (Anon. 1994) and The Australian Soil Classification (Isbell 1995). Soil survey reports and local information gained from professional workers associated with the program were used to identify soils classified at the series level and to assist in the other classification systems. Correlation with The Australian Soil Classification has provided a basis for selecting comparable soils for the Australian component of the program.

Soil and Climate Descriptions

BENCHMARK SITE 1, San Ildefonso.
(See Plate 1)

Location: The Philippines, Luzon Island, Bulacan Province, **San Ildefonso,** Barangay Buenovista, CSWRRS Research Station.

Classification: Soil Series: Mahipon series.
Soil Taxonomy: Ustic Epiaquert.
Australian Classification: Endocalcareous, Mottled, Epipedal, Aquic Vertisol.

Topography: Gently sloping (3°) to undulating relief; site component, slightly dissected lower piedmont footslope fringing a closed depression.

Parent Material: Colluvium derived from sandstone, shale and limestone.

Drainage: Surface — well drained.
Internal — impeded, slowly permeable.

Land Use: Rice-based cropping.

Climate:
Average annual rainfall is 1986 mm. Long-term daily average rainfall and probability is given in Figure 1. The wet season lasts from around mid-May to November with highly variable daily rainfall events. Post-rice crops are usually sown between early December and late February which is at the end of the wet season. In contrast to the abrupt change from the dry to the wet season, the change from wet to dry is relatively gradual which is important for dry season crop establishment. Although the probability for rainfall remains above 10% throughout the dry season, the chances of crop damage from high

intensity storms are minimal. Occasional typhoon activity during this otherwise dry period may occur in some years.

Profile Morphology

Ap1 (mixed, puddled) 0–13 cm

Dark yellowish brown (10 YR 4/4) dark greyish brown (10 YR 4/2 moist), very dark grey (10 YR 4/1) dark brown (7.5 YR 4/4) (dominant) mixed, gravelly, fine sandy clay; moderate medium, 5–10 mm, angular blocky; rough ped fabric; dry extremely hard, moist firm, wet sticky and plastic. Common fine roots with rusty mottling on walls of very fine macropores (root channels). 25%–30%, 1–4 mm, subrounded, cemented ferromanganiferous nodules. Occasional, 7 cm diameter subrounded pebbles of dolerite. Field pH 6.0.

Clear discontinuous wavy with tongued pockets of gravelly fine sandy clay to:

A12 13–27 cm

Light brownish grey (10 YR 6/2 moist) with dark grey (10 YR 3/1), dark greyish brown (10 YR 4/2) many medium distinct mottles; gravelly fine sandy clay; moderate, 5–10 mm, angular blocky; rough ped fabric; dry extremely hard, moist firm, wet sticky and plastic. Few very fine macropores. 5%–10% soft to hard ferro-manganiferous nodules. Occasional subangular quartz and feldspar crystals. Field pH 6.0.

Discontinuous wavy to:

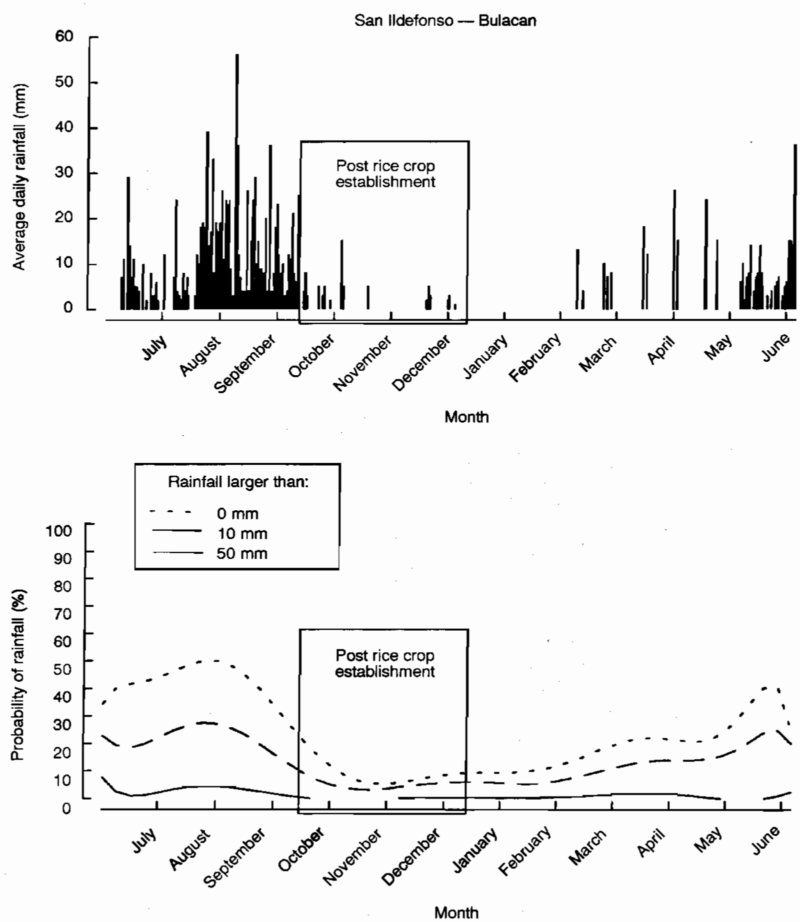
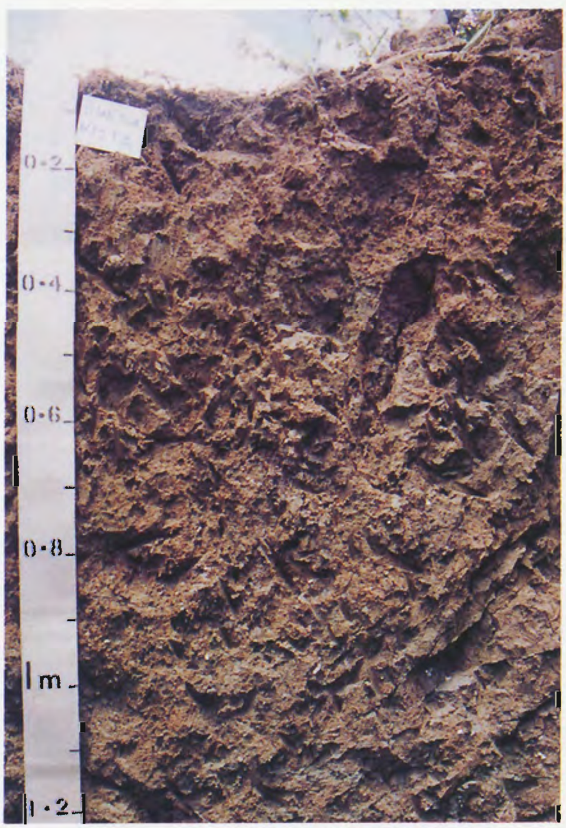


Figure 1. Medium-term average daily rainfall and probability for rainfall (1988–1995) at San Ildefonso, Bulacan.

Benchmark Site 1, San Ildefonso. Plate 1.



Ustic Epiaquert

B21Mn 27–67 cm

Light olive grey (5 YR 6/2 moist) with many, medium distinct brownish yellow (10 YR 6/6 moist) mottles; gravelly medium clay; strong, 20–50 mm, lenticular with intersecting slickensides parting to 10–50 mm, angular blocky and 2–5 mm lenticular; smooth ped fabric; dry hard, moist firm, wet sticky and plastic. Occasional, 2–5 mm diameter quartz gravels with translucent iron coatings. Common very fine pores and roots. Field pH 6.5.

Gradual wavy to:

B22Ca 67–97 cm

Light olive grey (5 YR 6/2 moist) with many, medium distinct brownish yellow (10 YR 6/6 moist) mottles; medium clay; strong, 20–50 mm lenticular with intersecting (30–60°) slickensides parting to 10–50 mm angular blocky and 2–5 mm lenticular; smooth ped fabric; dry hard, moist firm, wet very sticky and plastic. Field pH 8.0. 5%, subrounded, soft $CaCO_3$ nodules. Occasional black manganese nodules.

Gradual wavy to:

B23 97–140 cm

Light olive grey (5 YR 6/2 moist) medium clay; strong, 2–5 mm lenticular with slickensides on compound ped surfaces; smooth ped fabric; moist friable, wet sticky and very plastic. Occasional black sub-rounded manganese nodules. Field pH 8.0.

Clear to:

C 140–150 cm (continuing)

Weathered shale.

Notes:

1. Surface cracks up to 2 cm wide arranged in a pattern according to plant row and spacing configuration.
2. Concentrations of ferromanganiferous nodules in surface horizons are probably due to wetting and drying cycles of the surface soil which inundates during wet seasons. Current cropping practices have probably accelerated the process of nodule formation.
3. Layering evident in Ap horizon is due to puddling.
4. Tongues of Ap horizon soil material in A12 horizon are probably infill wash of surface material into vertical cracks following saturation and dispersion of soil material with low liquid limits.
5. Churning of material in the upper part of the profile is evident as pockets of soil material up to 50 cm diameter. The boundary of the pocket is coincidental with major slickensided surfaces.
6. Vertical cracking evident to 150 cm depth. Cracks are up to 1 cm wide and at intervals of 50 cm apart.
7. Soil properties of the bund are similar to Ap horizon. The position of the bunds is not permanently located and apparently they are reformed on a seasonal basis. This is probably due to the high shrink-swell clay which would cause bund failure with decreasing water content and concomitant soil shrinkage.

BENCHMARK SITE 2, Manaoag. (See Plate 2)

Location: The Philippines, Luzon Island, Pangansinan Province, **Manaoag**, Barangay Calmy, farmer's field.

Classification: Soil Series — San Manuel silty clay loam.
Soil Taxonomy — Typic Ustropept.
Australian Classification — Haplic, Eutrophic, Grey, Dermosol.

Topography: Backslope (<1°), recent levee.

Parent Material: Recent alluvium.

Drainage: Surface, subject to seasonal flooding; internal, moderately to well drained, moderately permeable.

Land Use: Cropping.

Climate:

Average annual rainfall recorded near to the experimental site is 1486 mm. The dry season extends from about mid-October to May (Figure 2). Compared to the San Ildefonso site, the transition from wet to dry season is more abrupt which can be explained by the lower probability of rainfall throughout the year. The wet season tends to commence with relatively large erratic rainfall events commencing in March which become more regular in occurrence by May with the incidence of moderate rain (10–50 mm per day). These rainfall events make the Manaoag area more suitable for post-rice cropping.

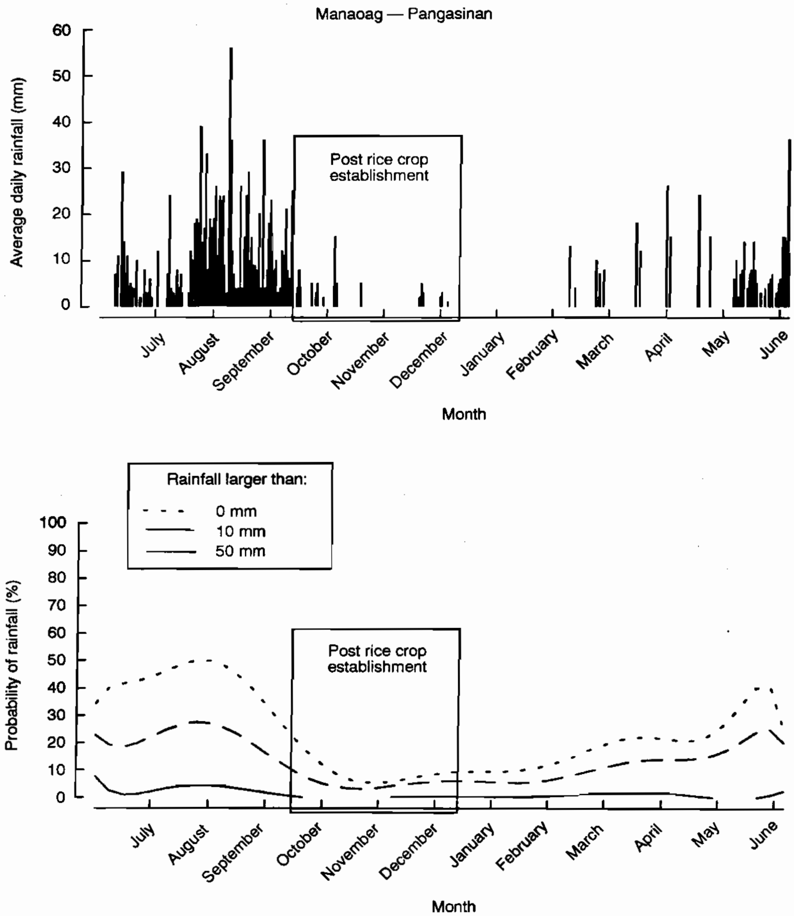


Figure 2. Recent average daily rainfall (1992–1994) at Manaoag, Pangasinan and probability for rainfall combined from three sites near Manaoag over nine years.

Profile Morphology

Ap1 0–11 cm

Very dark greyish brown (10 YR 3/2 moist) silty clay; coarse polyhedral with conchoidal faces (primary), breaking to compound prismatic (secondary), breaking to strong, 2–5 cm polyhedral (tertiary); rough ped fabric; dry extremely hard, moist very firm, wet sticky and plastic. Common fine roots. Field pH 6.5.

Abrupt smooth to:

Ap2 11–38 cm

Dark greyish brown (10 YR 4/2 moist) silty clay; coarse polyhedral with conchoidal faces breaking to compound prismatic, further breaking to strong, 2–5 cm polyhedral; rough ped fabric; dry extremely hard, moist very firm, wet stick and plastic. Common fine roots. Field pH 6.5.

Arbitrary clear smooth to:

A13 38–69 cm

Dark greyish brown (10 YR 4/2) silty medium clay; compound prismatic breaking to moderate fine 2–5 mm polyhedral with well developed organans, rough ped fabric; dry hard, moist friable, wet sticky and plastic. Occasional roots. Field pH 7.0.

Arbitrary clear smooth to:

Benchmark Site 2, Manaoag. Plate 2.

Typic Ustropept

A14 69–104 cm

Dark greyish brown (10 YR 4/2 moist) medium clay, compound prismatic 2–5 cm breaking to medium 3–7 mm polyhedral with well developed organans; rough ped fabric; dry extremely hard, moist friable, wet sticky and plastic. Occasional roots. Field pH 7.5.

Arbitrary clear to:

AC1 104–117 cm

Very dark greyish brown (10 YR 3/2) common medium distinct dark yellowish brown (10 YR 4/6) mottles; silty loam; compound prismatic breaking to medium, 3–7 mm polyhedral; rough ped fabric; dry hard, moist friable, wet sticky and plastic. Occasional roots. Field pH 7.5.

Arbitrary to:

AC2 117–160 cm (continuing)

Dark yellowish brown (10 YR 4/6) many medium distinct, very dark greyish brown mottles (organic); silty clay loam; compound prismatic breaking to medium 3–7 mm polyhedral; rough ped fabric; dry extremely hard, moist firm, wet sticky and plastic. Field pH 7.5.

Notes:

1. Macropores are well developed throughout the profile and appear to be old root channels.
2. Few large vertical cracks 1 cm wide to 1 m depth and 1 m spacing may be due to wetting and drying following compaction.
3. Compaction is evident in Ap horizons by the presence of domed conchoidal faces on upper surface of compound peds.
4. Well developed organans on surfaces of peds indicates organic matter redistribution and hence fertility to 1 m depth in the profile.

BENCHMARK SITE 3, Ngale. (See Plate 3)

Location: Indonesia, East Java, Ngawi, Ngale Experiment Station from the Research Institute for Legume and Tuber Crops RILET, Malang (formerly MARIF).

Classification: Soil series — unnamed.
Soil taxonomy — Chromic Epiaquert.
Australian Classification — Haplic, Epipedal, Aquic Vertisol.

Topography: Almost flat (<1°) floodplain.

Parent Material: Recent alluvium derived from limestone and intermediate to basic volcanic ash.

Drainage: Surface — subject to seasonal flooding.
Internal — poorly drained, slowly permeable.

Land Use: Lowland rice.

Climate:

Average annual rainfall at Ngale is 2179 mm. The wet season occurs during the period between October and April and is followed by a moderately wet dry season (Fig. 3). The transition from wet to dry season is gradual with a high probability of effective rainfall for post rice plant establishment and growth. Compared to the sites in the Philippines, post-rice crops are established earlier and at the end of the wet season. This is made possible due to the lower frequency of tropical cyclones and more reliable rainfall events.

Profile Morphology

AP1 (puddled) 0–20 cm

Dark grey (2.5 Y 4/0 moist) many fine distinct rusty mottles; medium clay; massive breaking to coarse angular blocky further breaking to fine, 2–3 mm angular blocky; rough ped fabric; wet very sticky, very plastic. Many fine roots. Field pH 8.5.

Abrupt smooth to:

AP2 (puddled) 20–33 cm

Dark grey (2.5 Y 4/0) many fine rusty mottles; medium clay; strong medium (5–7 mm) angular blocky; wet very sticky, very plastic. Common fine roots. Field pH 8.5.

Clear smooth to:

B21 33–72 cm

Dark grey (2.5 Y 4/0 moist) common medium distinct rusty mottles in top 10–15 cm; heavy clay (superplastic) strong coarse (7–14 cm) lenticular with strong intersecting slickensides breaking to strong fine 2–5 mm lenticular, smooth ped fabric (few macropores); wet very sticky, very plastic. Common fine roots. Field pH 8.5.

Gradual smooth to:

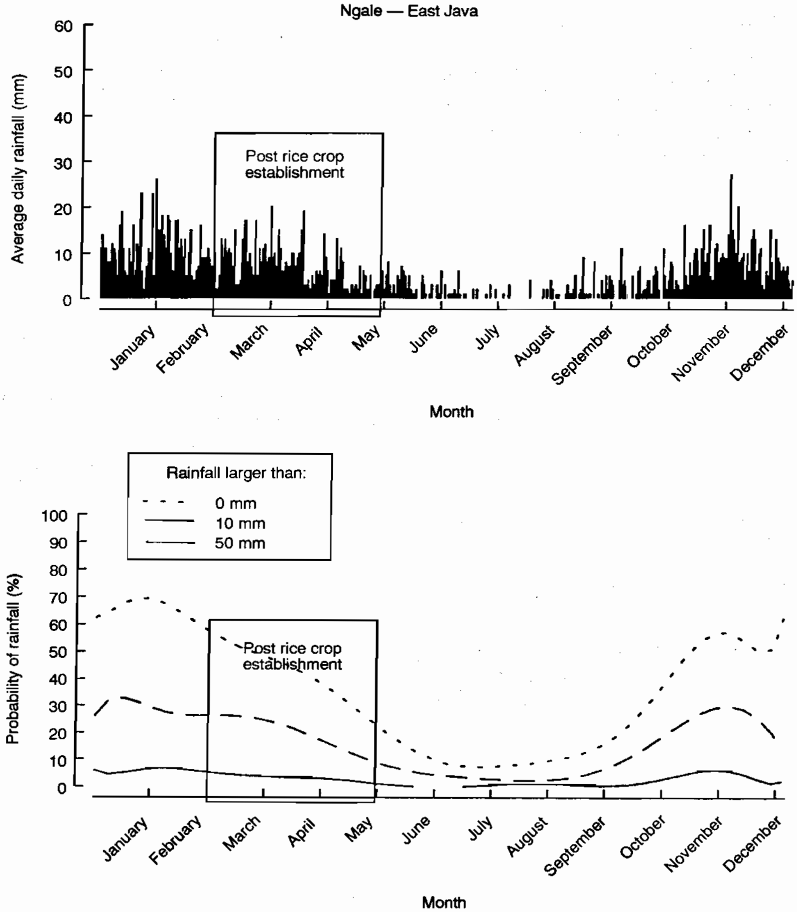


Figure 3. Long-term average daily rainfall and probability for rainfall (1981–1995) at Ngale.

B22 72–160 cm

Dark grey (2.5 Y 4/0 moist) heavy clay (superplastic) strong coarse (10–15 cm) lenticular breaking to fine 3–5 mm lenticular, well developed intersecting slickensides; smooth ped fabric with few macropores; wet very sticky, very plastic. Common fine roots. Field pH 8.5.

Gradual smooth to:

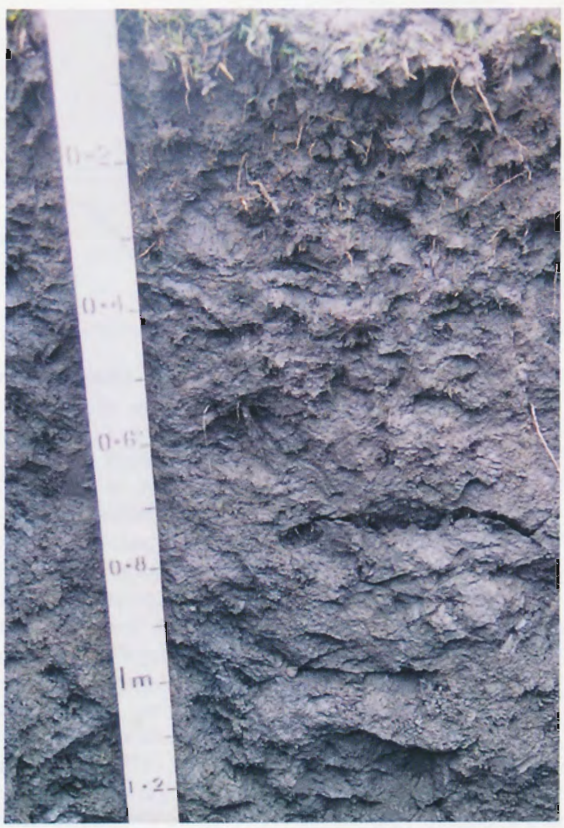
B23 160–170 cm

Dark grey (2.5 Y 4/0 moist) medium clay as above. Occasional subrounded $CaCO_3$ nodules. Field pH 8.5.

Notes:

1. **Bund 0–20 cm**
   Soil material description as for Ap1 except for fabric which is earthy due to the presence of well formed macropores which appear to be old root channels. Macropores have rusty coatings.
2. **B22 72–160 cm below bund**
   Presence of channels 1–1.5 cm diameter which appear to form preferred drainage channels and are infilled with dark grey (5 Y 4/1 moist) clay. Appears to be anaerobic. Channels could be due to macrofauna burrows (crabs).
3. Watertable apparent at 160 cm which coincides with accumulation of calcium carbonate below.
4. Grey colours suggest anaerobic conditions persist at least seasonally. Roots evident to 1.5 m are probably rice plant roots.
5. Moisture content throughout does not seem to be uniform. Where structure is more evident, soil appears better drained.
6. Patches of rusty brown mottles in top 10–15 cm of B21 appear to be concentrations of roots in more strongly structured soil (see 4 above). This is probably evidence of soil cloddiness.

Benchmark Site 3, Ngale. Plate 3.



Chromic Epiaquert

BENCHMARK SITE 4, Jambegede. (See Plate 4)

Location: Indonesia, East Java, **Jambegede,** 20 km south of Malang, Research Institute for Legume and Tuber Crops RILET, Malang (formerly MARIF) experimental station.

Classification: Soil series — unnamed.

Soil taxonomy — Anthraquic Hapludand.

Australian Classification — Mottled, Eutrophic, Black, Dermosol.

Topography: Levee backslope (1.5°).

Parent Material: Weathered andesitic tuff and ash.

Drainage: Surface — Seasonal flooding. Internal — Moderately well drained, moderately permeable.

Land Use: Rice-based cropping systems.

Climate:

Average annual rainfall at Jambegede is 2202 mm. The characteristics of rainfall distribution (Fig. 4) are regarded as being comparable to those at Ngale.

Profile Morphology

Ap (puddled) 0–18 cm

Very dark grey (10 Y 3/1 moist) admixed with partly humified crop residue: dark yellowish brown (10 YR 4/6) mottling at admixture face; light clay; blocks 10–15 cm cracking coincidentally with plant row distribution. Blocks

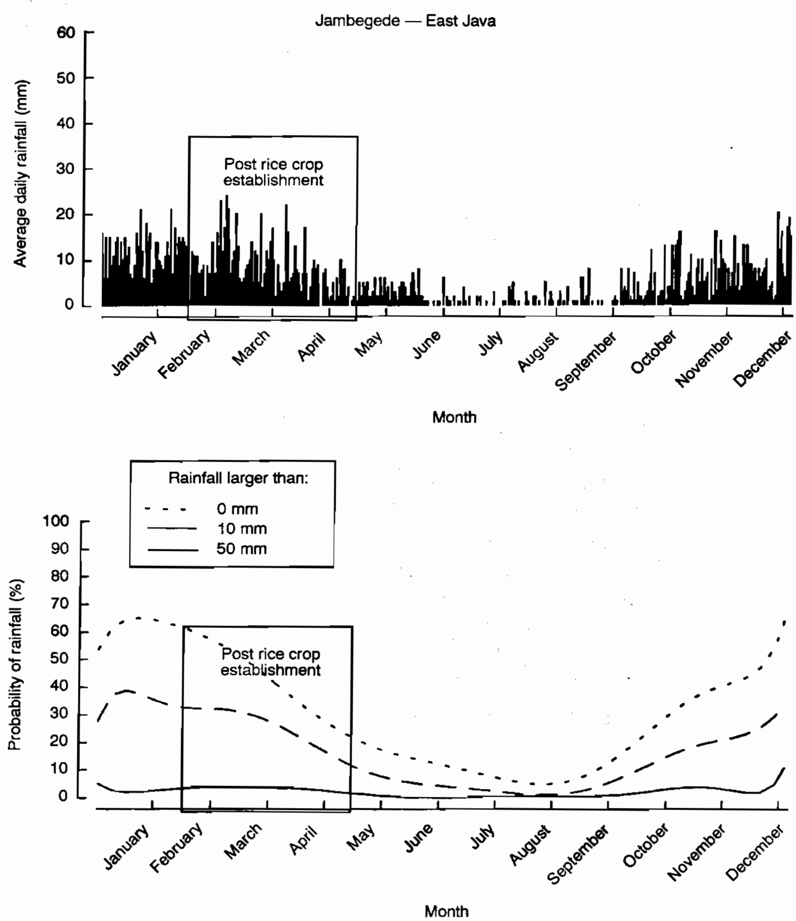
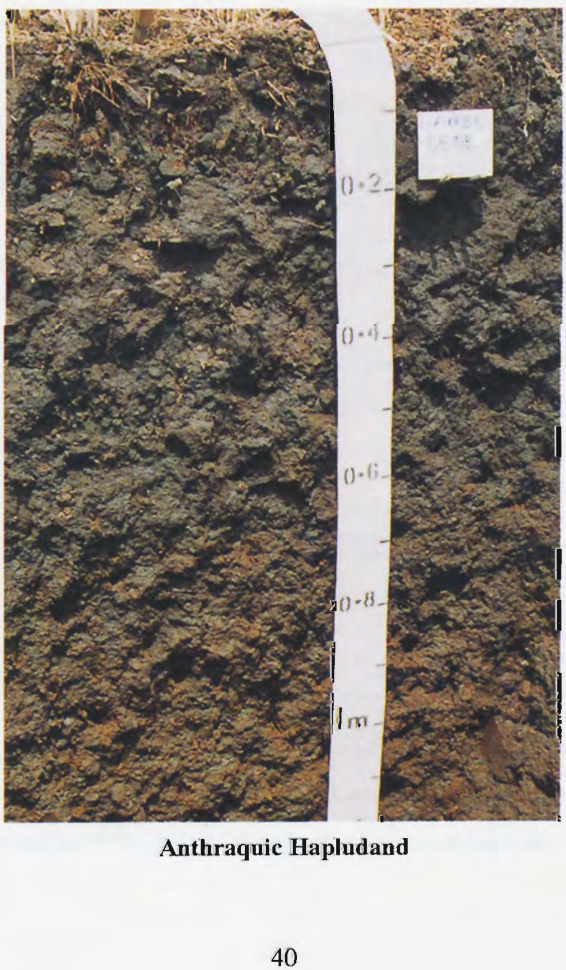


Figure 4. Long-term average daily rainfall and probability for rainfall (1983–1995) at Jambegede.

Benchmark Site 4, Jambegede. Plate 4.



Anthraquic Hapludand

break into 5–7 mm sub-angular with rusty brown cutans. Some evidence of platiness 2–5 cm width at base of puddling depth. Earthy fabric; moist friable, wet sticky and plastic. Common roots. Field pH 7–7.5.

Clear smooth to:

A12 18–45 cm

Very dark grey (10 YR 3/1 moist) common medium faint yellowish brown (10 YR 5/8) mottles; light to medium clay; strong coarse, 20–40 mm sub-angular blocky with incipient conchoidal faces on upper surfaces; rough ped fabric and macropores; moist friable to firm. Few reddish brown (2.5 YR 4/6) earthy scoria to 4 cm diameter. Field pH 8–8.5

Diffuse smooth to:

A13 45–62 cm

Very dark grey (10 YR 3/2 moist) common coarse distinct yellowish red mottle, medium clay; coarse angular blocky to strong polyhedral (5–7 mm), rough ped fabric and common macropores; moist friable to firm. Field pH 7–7.5. Few roots. Occasional (<5%) lumps 2–5 cm diameter soft reddish brown scoria.

Gradual smooth to:

AB 62–80 cm

Dark brown (7.5 YR 3/2 moist) with many coarse distinct grey (5 Y 4/1) mottles on ped surfaces and dark brown (7.5 YR 3/4) coatings in root channels; light medium clay; strong, fine 2–5 mm angular blocky; rough to smooth ped fabric; moist firm. Field pH 7–7.5. Occasional roots.

Gradual smooth to:

B2 80–160 cm

Dark brown (7.5 YR 3/2 moist) with common medium distinct mottles; light clay; strong angular blocky (2–5 mm), smooth ped fabric; wet sticky and plastic. Field pH 7.5. Occasional roots.

Notes:

1. Worm castes 3 mm in diameter are common and occupy up to 20% by volume at depth.
2. Surfaces of vughs (2–5 mm diameter) are convoluted suggesting preferred drainage channels are developed in some root channels.
3. pH increase in A12 together with conchoidal face development may indicate restricted drainage in compacted zone.
4. **Bund 0–23 cm**
   Very dark greyish brown (10 YR 3/2) clay loam, rat burrows evident and are infilled with plant and soil material. Below bund, soil material is compacted and similar to Ap horizon.
5. Macroporosity well developed throughout profile due to root and earthworm channels.

BENCHMARK SITE 5, Maros. (See Plate 5)

Location: Indonesia, South Sulawesi, **Maros** Baru, Buloe, farmers field 10 km from the Research Institute for Maize and non-rice Grain crops at Maros (Formerly called MORIF).

Classification: Soil Series — Bentomanaik (tentative).
Soil Taxonomy — Aeric Tropaquept.
Australian Classification — Ferric, Dermosolic, Redoxic, Hydrosol.

Topography: Alluvial flood plain (<1°).

Parent Material: Mixed alluvium derived from weathered basalt and karst.

Drainage: Seasonal inundation, water table to 5 cm surface. Rapid permeability.

Climate:

Average annual rainfall at the site is 3085 mm. Compared to East Java, the wet season is more intense with probabilities for daily rainfall events approaching 90% (Fig. 5). The transition from wet to dry season is abrupt although rainfall peaks in January and declines to a minimum in July. The transition from wet to dry season occurs during the period from April to May and is comparable to the sites in east Java.

Profile Morphology

AP1 (puddled) 0–12 cm

Dark grey (5 Y 4/1 moist) (gleyed) with rusty oxidation around root mass; clay loam; puddled; rough ped fabric; wet sticky, plastic. Field pH 6.0.

Abrupt smooth to:

AP2 (gleyed) 12–14 cm

Dark grey (5 Y 4/1 moist) organic clay loam; platey, rough ped fabric; wet sticky and plastic. Rapid oxidation on exposure to many coarse distinct yellowish red mottles. Field pH 6.5.

Abrupt smooth to:

AP3 (compacted) 14–22 cm

Greyish brown (10 YR 5/2 moist) clay loam; coarse sub-angular blocky breaking to medium (5 mm) angular blocky with some development of conchoidal faces on compound peds; rough to smooth ped fabric; wet sticky and plastic. Field pH 6.5.

Abrupt smooth to:

A14 22–41 cm

Greyish brown (10 YR 5/2) moist common distinct reddish brown mottle; clay loam medium sub-angular blocky breaking to fine (2–5 mm) sub-angular and angular blocky; rough ped fabric; wet sticky and plastic. Field pH 6.5.

Clear smooth to:

B2 FeMn (plinthic) 41–71 cm

Greyish brown (2.5 Y 5/2 moist) many coarse distinct dark brown (6.5 4/4) mottles; light clay and silty clay lining the walls of 3–7 cm diameter root channels; medium (5–7 mm) moderate sub-angular blocky; wet sticky and plastic. Field pH 7.0. 20%–30% soft ferromanganiferous nodules.

Gradual smooth to:

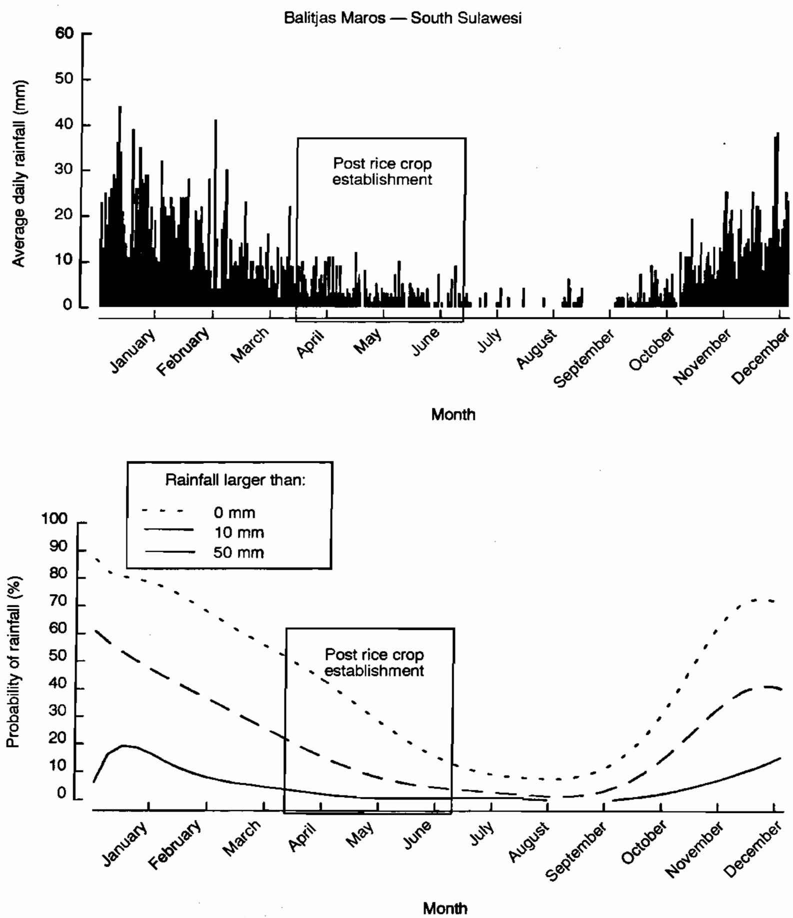
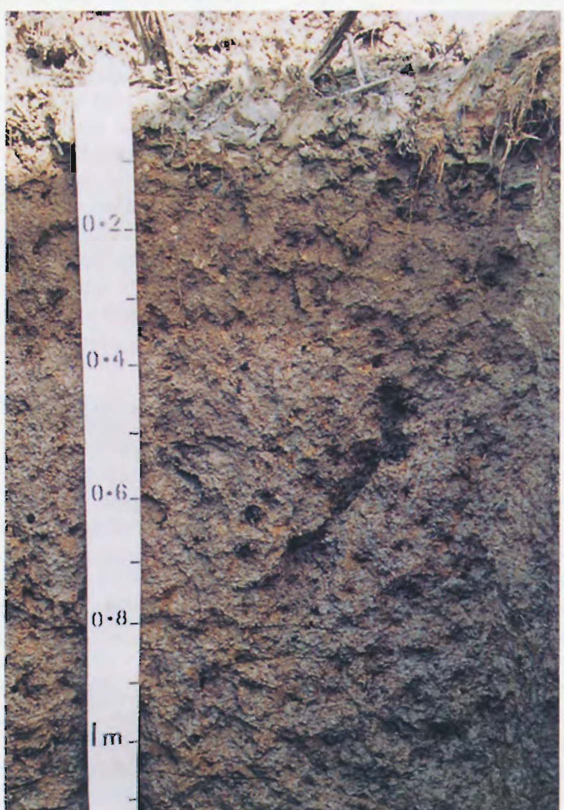


Figure 5. Long-term average daily rainfall and probability for rainfall (1976–1993) at Balitjas Maros.

Benchmark Site 5, Maros. Plate 5.



Aeric Tropaquept

B2 Fe 71–111 cm

Greyish brown (2.5 Y 5/2 moist) common medium distinct yellowish brown (10 YR 5/6) and few medium distinct yellowish brown (10 YR 4/6) mottles and black segregations (10 YR 3/1); light-medium clay; smooth ped fabric; wet sticky and plastic. Field pH 7.0.

Gradual smooth to:

B22 Fe 111–150 cm

Light brownish grey (2.5 Y 6/2) with common coarse distinct yellowish brown (10 YR 6/2) mottles and black (10 YR 2/1) manganese segregations; light clay; medium 5–7 mm moderate sub-angular blocky; smooth ped fabric with large macropores occupying 10%–40% of the surface area; wet sticky and plastic. Field pH 7.0.

Notes:

1. Walls of vughs coated with grey oriented silt are mammilated.
2. Macroporosity well developed throughout B2 horizons. Vughs range in size from less than 1 mm to 7 mm diameter.
3. Ap3 (compacted) — cutans on compound peds have a smooth ped fabric. Rough ped fabric is evident on primary units.
4. Ap1 (puddled) — brownish black manganese patina on compound ped surfaces indicates poor drainage.
5. Rapid oxidation on exposure may indicate acid-sulphate soil properties.

Soil Analytical Properties

The soils used for experimentation have more than 40% clay (<2 μm) throughout the profile which confirms the initial site selection of clay soils (Table 1). The Ustic Epiaquert (San Ildefonso) and Anthraquic Hapludand (Jambegede) profiles have significant sand in the surface horizons which is probably due to colluvial transport or surface soil material. The soil at San Ildefonso has the greatest change in particle size distribution over depth with clay content increasing from 40% at the surface to 75% at depth. The clay content of the soil at Jambegede increases with depth from 45% near the surface to 60% at depth, with a corresponding decrease in sand content. The Chromic Epiaquert (Ngale) is a heavy clay soil with clay content increasing from 74% in the surface to 88% at depth. The Typic Ustropept (Manaoag) and Aeric Tropaquept (Maros) have similar particle size distributions with 45% to 50% clay throughout. Sand content increases with depth from 3% near the surface to 10% at Manaoag and 20% at Maros. This characteristic of these two profiles suggests that the soil material is of alluvial origin.

Chemical and mineralogical analyses (Tables 2 and 3) show that the soils are neutral pH with the profiles at San Ildefonso and Maros being mildly acid in their surface horizons. Cation exchange capacities vary from 20 cmol (p+)/kg in the soil at Maros to nearly 70 cmol (+)/kg in the soil at Ngale. The exchange complexes are dominated by calcium and magnesium and show no imbalance of cations which would limit plant growth. These values are supported by the clay species identification which show a predominance of kaolinite and smectite. The soils at Manaoag and Maros also contain significant proportions of vermiculite and illite respectively.

The profile at Ngale was predominantly smectite which is reflected in the high cation exchange capacity values throughout. In contrast, the clay fraction of the profile at Manaoag contained 63% smectite in the surface which decreased with depth and is replaced by kaolinite. This suggests that the profile is layered with more recent alluvial depositions having higher smectite clay contents.

The smectite content of the soil profile at San Ildefonso is similar to that at Manaoag near the surface but remains constant with depth. However, the increase in clay per cent with depth results in the swelling clay component increasing from 26% to 46% with depth. In contrast, the clay fraction in the surface soil at Jambegede contained 33% smectite which decreased to 12% at depth.

The clay fraction in the soil at Maros contained 20% smectite near the surface which increased to 30% at depth. The relatively constant clay content in the soil results in the smectite content of the clay fraction only changing marginally from 9% to 15%.

Soil Limitations for Potential Plant Growth

Soil properties limiting plant growth were interpreted from the qualitative descriptions obtained for each site and profile (Table 4). Diagnostic pedological features given in the notes following each benchmark site were used to assess the potential of the soils for dry season crops which require soil depths greater than that provided by the puddled surface soil layers. The interpretations were based on the general edaphic conditions and do not account for the specific crop requirements. The term 'hardsetting' is used to define the soil surface condition created by puddling and drying.

At all sites, the bunds were found to have biological activity in the form of plants and animals (see notes following profile morphology) which may account for the reported 'leakiness'.

Table 1. Particle size distributions using USDA clay, silt and sand fractions.

Site Depth cm	Clay <2 µm	Silt Fine 2–20 µm	Silt Coarse 20–50 µm	Silt Total 2–50 µm	Sand Very fine 50–100 µm	Sand Fine 100–250 µm	Sand Medium 250–500 µm	Sand Coarse 500–1000 µm	Sand Very coarse 1000–2000 µm	Sand Total 50–2000 µm
San Ildefonso										
0–11	40.7	20.3	8.0	28.3	7.4	11.3	5.7	2.9	3.7	31.0
11–30	48.9	12.2	5.6	17.8	4.5	7.8	10.7	5.6	4.8	33.3
30–Ap T*	36.9	16.4	6.2	22.6	6.4	11.0	8.3	5.6	9.2	40.5
30–70	53.9	14.9	2.4	17.3	4.6	5.9	6.5	5.2	6.6	28.8
70–110	76.5	20.3	0.5	20.8	0.9	0.4	0.9	0.5	0.1	2.7
Manaoag										
0–11	52.3	36.4	5.7	42.1	2.3	1.9	0.6	0.6	0.2	5.6
11–38	53.4	37.8	5.2	43.0	2.3	1.1	0.1	0.0	0.0	3.6
38–69	47.6	44.0	4.9	48.9	2.1	1.2	0.1	0.0	0.0	3.5
69–104	49.7	36.2	6.8	43.0	4.2	2.7	0.1	0.1	0.2	7.3
104–117	49.9	32.3	8.8	41.1	5.8	2.8	0.2	0.1	0.0	9.0
117–160	47.0	31.8	11.3	43.1	6.5	3.3	0.1	0.0	0.0	9.9
Jambegede										
0–18	45.3	26.8	9.4	36.2	7.9	8.6	1.8	0.3	0.0	18.5
20–40	55.6	23.3	7.6	30.9	6.0	6.3	1.1	0.1	0.0	13.5
40–60	59.4	23.8	7.9	31.7	4.1	4.1	0.6	0.1	0.0	8.9
60–80	63.0	21.4	7.5	28.9	3.8	3.8	0.5	0.0	0.0	8.1
80–160	61.3	22.7	7.5	30.2	4.5	3.5	0.5	0.0	0.0	8.5
Ngale										
0–14	73.9	20.3	2.7	23.0	1.7	1.1	0.2	0.1	0.0	3.1
14–34	82.4	11.3	3.9	15.2	1.3	1.0	0.1	0.1	0.0	2.4
34–54	87.8	9.3	1.4	10.7	0.8	0.5	0.2	0.0	0.0	1.5
54–78	88.5	8.1	1.2	9.3	1.3	0.6	0.2	0.1	0.0	2.2
78–110	86.1	10.2	1.3	11.5	1.5	0.6	0.2	0.1	0.0	2.4
Maros										
0–12	45.9	44.4	6.7	51.1	2.2	0.8	0.1	0.0	0.0	3.0
12–14	46.7	43.9	6.1	50.0	2.3	0.7	0.1	0.2	0.0	3.3
14–22	52.5	37.9	5.6	43.5	2.4	1.3	0.1	0.1	0.1	4.0
22–41	49.4	38.4	7.0	45.4	3.4	1.4	0.2	0.1	0.1	5.2
41–71	52.7	29.7	7.2	36.9	5.0	4.1	0.5	0.4	0.4	10.4
71–110	45.7	27.7	7.4	35.1	5.2	5.0	0.4	0.4	8.3	19.2
110–150	49.8	28.7	6.9	35.6	7.4	6.4	0.3	0.2	0.3	14.6

*Tongues of Ap material at 30 cm depth

Table 2. Chemical properties.

Site	Depth cm	Organic carbon %	pH	EC	Exchangeable cations				CEC
			1:5 extract dS/m		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	
					cmol (p+)/kg				
San Ildefonso									
	0–11	1.165	6.54	0.090	11.5	7.7	0.58	0.22	21.4
	11–30	0.414	7.35	0.062	12.7	9.5	0.87	0.11	23.4
	30–Ap T*	0.429	7.42	0.059	9.1	7.3	0.76	0.00	17.4
	30–70	0.256	7.99	0.069	15.2	12.6	1.05	0.00	28.2
	70–110	0.128	7.80	0.140	27.3	22.3	1.29	0.00	49.1
Manaoag									
	0–11	1.130	7.71	0.112	36.0	10.6	0.42	1.02	43.6
	11–38	0.983	7.61	0.104	41.3	9.7	0.40	1.16	52.8
	38–69	0.829	7.55	0.120	42.1	7.5	0.34	0.70	49.2
	69–104	0.638	7.64	0.101	33.5	4.4	0.31	1.85	40.7
	104–117	0.477	7.76	0.094	31.5	4.5	0.25	1.26	42.3
	117–160	0.484	7.77	0.092	26.7	5.0	0.35	0.38	33.3
Jambegede									
	0–18	1.167	7.60	0.097	9.6	6.7	0.27	1.74	18.6
	20–40	0.784	7.23	0.178	9.1	6.9	0.52	1.48	17.2
	40–60	0.467	7.40	0.079	8.1	5.7	0.80	2.71	17.6
	60–80	0.423	7.56	0.073	7.4	5.0	0.76	2.94	16.6
	80–160	0.404	6.98	0.070	7.1	5.0	0.77	4.00	16.5
Ngale									
	0–14	1.432	7.05	0.103	52.4	14.5	0.32	0.89	69.5
	14–34	1.147	7.20	0.111	51.5	14.6	0.35	0.55	68.7
	34–54	0.748	7.21	0.108	51.3	13.8	0.39	0.31	62.6
	54–78	0.646	7.01	0.064	57.4	16.1	0.44	0.19	74.2
	78–110	0.564	7.64	0.060	52.4	15.3	0.42	0.31	68.0
Maros									
	0–12	1.632	4.88	0.106	5.7	4.8	0.20	1.56	15.6
	12–14	1.506	5.06	0.068	6.0	5.1	0.27	0.86	14.9
	14–22	0.688	6.25	0.059	9.7	7.9	0.25	0.79	17.6
	22–41	0.615	6.63	0.054	10.3	8.4	0.33	0.54	19.9
	41–71	0.267	6.75	0.066	11.9	9.3	0.49	1.01	22.2
	71–110	0.230	6.90	0.062	11.5	9.2	0.47	1.20	22.9
	110–150	0.197	6.97	0.057	12.1	10.1	0.43	1.67	24.9

*Tongues of Ap material at 30 cm depth

Table 3. Mineralogy of the clay fraction.

Site Depth cm	Illite	Kaolinite	Smectite	Vermiculite	Quartz	Goethite	Anatase	Feldspar	Cristobalite	Swelling clay*, % whole soil
	Mineralogical composition, % of <2 μm fraction									
San Ildefonso										
0–11	—	35 ± 5	63 ± 19	—	1 ± 1	—	<1	<1	—	26 ± 8
11–30	—	29 ± 4	70 ± 21	—	1 ± 1	—	<1	—	—	34 ± 10
30–70	—	34 ± 7	61 ± 15	<5	<1	—	—	—	—	33 ± 8
70–110	—	29 ± 6	60 ± 15	10 ± 3	<1	—	—	—	—	46 ± 11
Manaoag										
0–11	—	19 ± 4	63 ± 16	16 ± 5	<1	—	—	<1	—	33 ± 8
38–69	—	29 ± 6	51 ± 12	18 ± 6	<1	—	—	<1	—	24 ± 6
104–117	—	36 ± 7	48 ± 10	14 ± 4	<1	—	—	<1	—	24 ± 5
117–160	—	38 ± 8	46 ± 9	14 ± 4	<1	—	—	<1	—	22 ± 4
Jambegede										
0–18	—	65 ± 13	33 ± 8	—	<1	—	—	<1	—	15 ± 4
40–60	—	86 ± 17	13 ± 3	—	—	—	—	<1	—	8 ± 2
80–160	—	87 ± 17	12 ± 3	—	—	—	—	<1	—	7 ± 2
Ngale										
0–14	—	26 ± 5	73 ± 18	—	<1	—	Trace	—	Trace	54 ± 13
34–54	—	9 ± 2	90 ± 24	—	<1	—	Trace	—	Trace	79 ± 21
78–110	—	<5	>95	—	<1	—	Trace	—	Trace	84
Maros										
0–12	16 ± 3	55 ± 11	20 ± 5	<5	<1	5 ± 1	—	<1	—	9 ± 2
22–41	14 ± 3	47 ± 9	26 ± 7	<5	<1	8 ± 1	—	<1	—	13 ± 3
71–110	18 ± 4	41 ± 8	30 ± 8	—	<1	8 ± 1	—	<1	—	14 ± 4
110—150	15 ± 3	46 ± 9	30 ± 7	—	<1	8 ± 1	—	<1	—	15 ± 3

*Proportion of swelling clay on a whole soil basis is the proportion of smectite in the clay fraction multiplied by the proportion of clay (Ringrose-Voase et al. 1996).

Table 4. Qualitative descriptions of each site and profile.

Soils	Land surface limitations			Limitations in root zone					
	Seasonal flooding	Slope	Surface condition	Internal drainage	Permeability	Effective depth cm	Depth cm DSWT*	AWC estimate	Drainage class
Philippines									
Ustic Epiaquert	None	1–2°	Hard-setting	Poor, strongly mottled; Fe, Mn concentrations	Slow to very slow	100–150	>50	Moderate	Poorly drained
Typic Ustropept	None	<1°	Hard-setting	Moderately well drained, weak mottling	Moderate	100–150	>100	Moderate	Well drained
Indonesia									
Chromic Epiaquert	Seasonal	<1°	Self-mulching	Poorly drained (gleyed)	Slow to very slow	100–150	<50	High	Poorly drained
Anthraquic Hapludand	None	1.5°	Hard-setting	Moderately well drained, weak mottling	Moderate	100–150	>100	Moderate	Well drained
Aeric Tropaquept	Seasonal	<1°	Hard-setting	Rapidly drained; Fe, Mn concentrations	Moderate	100–150	>20	Low-moderate	Poor in wet season, well drained in dry season

*DSWT = Dry season watertable.

References

Ali, M.A. and Sawijo (1982). Detailed Soil Survey of the Maros Agricultural Research Station, South Sulawesi. Centre for Soil Research, Ujung Pandangan, Ministry of Agriculture, Govt. Indonesia, UNDP and FAO.

Anon. (1951). Soil Survey Manual, USDA Agric. Handbk. No. 18 (Govt. Printer, Washington DC).

Anon. (1994). Keys to Soil Taxonomy, USDA Agric. Handbk. No. 436 (Govt. Printer, Washington DC).

Flores, J.J. and Balagot, V.F. (1969). Climate of the Philippines. Ed. H. Arakawa. Climates of Northern and Eastern Asia. Elsevier, Amsterdam-London-New York, 59–204.

Hutka, J. and Ashton, L. (1995). Sedigraph particle size analysis of soil samples from the Griggward study area of the Wagga Wagga project. CSIRO (Australia) Division of Soils Technical Report 3/1995.

Isbell, R.F. (1995). The Australian Soil Classification, CSIRO Publications, Melbourne. In press.

McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1984). Australian Soil and Land Survey Handbook. Inkata Press, Melbourne.

Raven, M.D. (1995). Mineralogy of clay fractions from Indonesia and the Philippines. CSIRO (Australia) Division of Soils Mineralogical and Geochemical Services Report 187.

Rayment, G.E. and Higginson, F.R. (1992). Australian Laboratory Handbook of Soil and Water Chemical Methods. Australian Soil and Land Survey Handbooks, Vol. 3, Inkata Press, Melbourne, 330 p.

Ringrose-Voase, A.J., Hutka, J., Clarke, M., Raven, M.D. and Schafer, B.M. (1996). Analyses of soil profiles at the experimental sites in Indonesia and the Philippines for ACIAR Project 8938 'Management of clay soils for lowland, rice-based cropping systems', CSIRO (Australia) Division of Soils Technical Report 2/1996.

Soil Survey Division (1987). Soil Survey and Classification of the Bulacan Province, Bureau of Soils and Water Management, Department of Agriculture and Food (Manila), 384 p.

Sukanto, M. (1969). Climate of Indonesia. H. Arakawa, ed., Climates of Northern and Eastern Asia. Elsevier, Amsterdam-London-New York, 215–229.

EFFECTS OF SOIL PUDDLING

The Effect of Puddling Intensity and Compaction on Soil Properties, Rice and Mungbean Growth: A Mini-ricebed Study

G. Kirchhof[1] and H.B. So[1]

Abstract

The effect of soil puddling and soil compaction on soil physical properties, growth of wetland rice and post-rice mungbean was investigated using mini-ricebeds under controlled glasshouse conditions. Each mini-ricebed was approximately one cubic metre in size. Three different soil types were used, a well drained, permeable loam, a hardsetting, structurally unstable silty loam, and a medium clay. Soil puddling increased dispersion but dispersion decreased with time of inundation resulting in decreased K_{sat} with time of inundated conditions. Results showed that puddling can be reduced without affecting rice yields, except on sandy soils. Compaction decreases percolation rates except on clay soils and tended to reduce rice yields, but had no effect on mungbean yield. This study indicated that compaction may be beneficial for rice on coarse textured soils, but may have adverse effects on clay soils. Establishment percentage of mungbean was reduced on highly puddled, structurally unstable soils. Mungbean yield was reduced on structurally unstable soils puddled with high intensity. Puddling should be reduced on structurally unstable soils because it reduces crop establishment and yield. Mungbean yields of above 1 t/ha were achieved under conditions of non-limiting crop establishment on a soil depth of 65 cm and where 100 mm of water was available.

THE total global area of rainfed lowland rice was 40.5 million ha in 1992 (IRRI 1993). It accounts for 18% of the global rice supply. Most of these areas are located in Asia: 36% in South Asia, 43% in Southeast Asia and 27% in East Asia (IRRI 1993). In these areas rice is grown during the wet season on bunded fields. Soil preparation for rice traditionally requires soil puddling. It assists in weed control, facilitates transplanting and reduces water loss through reduction in water percolation rates, and therefore flooded conditions can be maintained for at least part of the rice cropping season. Irrigation is limited and generally not available during and after the rice crop. Rice fields are often left fallow due to the lack of water for an upland crop in the dry season following rice. However, soil water contents are generally high after rice harvest following several months of inundated conditions. Usage of soil water stored in the profile should be sufficient to grow a moderate upland crop, provided crop establishment is adequate and roots can access the subsoil water store. Potential crops in rice rotations are pulses, wheat and maize. The latter is generally grown at the end of the dry season and harvested prior to rice planting. In the Philippines, mungbean contributed 35% of the net return in a rice–mungbean–fallow system, although mungbean yields were as low as 0.33 t/ha following a rice crop of 4.1 t/ha (IRRI 1994). Under experimental conditions, mungbean yields of over 2 t/ha were achieved without irrigation (IRRI 1985). Yields were mainly affected by root depth. Yield increases for mungbean of 100 kg/ha were observed for additional exploitable soil depth ranging from 7 to 13 cm (IRRI 1985, 1986, 1988).

Poor soil physical conditions are the major limiting factors for successful upland cropping following rice. Soil puddling degrades soil structure and leads to reduced infiltration rates. Although macropores as elongated transmission pores are reduced,

[1] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia

the total porosity of puddled soils is generally increased due to an increase in small pores (Pagliai and Painuli 1988, Sharma and Bhagat 1993). The strength of puddled soil increases rapidly during drying (Cook et al. 1995). This is important for seed germination and crop establishment. If seeds are sown too late after rice harvest, soil strength may be too high resulting in poor crop establishment and shallow root systems with subsequent early onset of water stress leading to poor yields or crop losses. If seeds are sown too early after rice harvest, anaerobic conditions may reduce crop establishment and decrease yield potential (IRRI 1987).

A potential strategy to minimise soil structural degradation in rice-based cropping systems is a reduction in soil puddling (So and Woodhead 1987). Although beneficial effects from reduced puddling may increase post-rice legume yields, it may also increase water use, increase weed infestation and reduce yields of the primary rice crop. Nutrient uptake of rice may become limiting because roots only proliferate to a depth of 15–20 cm (Wopereis 1993) and do not penetrate soil layers where soil strength is above 0.4 MPa (IRRI 1986, Pagliai and Painuli 1988).

A rice–mungbean crop rotation was simulated under controlled conditions to evaluate the impact of different puddling intensities (experiment 1) and soil compaction (experiment 2) on the growth and yield of rice and mungbean on three different textured soils.

Materials and Methods

Design of the mini-ricebeds

Twelve mini-ricebeds were constructed of steel reinforced concrete boxes. Each weighed about 1000 kg. The mini-ricebeds had a wall thickness of 7.5 cm. Internal dimensions were 120 cm long, 92 cm wide and 78 cm deep. A drainage hole was located in the centre of the front wall. The base had a slope towards the drainage hole. It was 1 cm higher than the drainage hole (5 cm diameter) in the centre at the back of the base and at the front left and right, and 20 cm higher than the drainage hole in the back left and right corners. Inner walls were coated with cement glue to waterproof them. To ensure that walls were completely waterproof, two coats of bitumen emulsion were applied. Prior to packing the mini-ricebeds with soil, a 3 cm thick layer of coarse sand was spread in the base of each mini-ricebed to facilitate drainage. The drainage hole was blocked with gravel and the gravel covered with a small sheet of PVC (20 × 20 cm). The PVC sheet was attached to the wall. It served to prevent mixing of soil, sand and gravel that could result in erosion near the drainage outlet.

Instrumentation of the mini-ricebeds

Several access holes were located in the sides the walls of the mini-ricebeds, installed by placing PVC tubes inside the reinforcing steel mesh before the concrete was poured into the mould.

The mini-ricebeds were packed with three different soil types, a grey clay from rice-growing areas in Griffith NSW (GC_G), an alluvial silty clay loam from Moggill near the Brisbane River (AL_B) and a loam from the Lockyer Valley (LO_G). Using the Soil Taxonomy, they represented *Haploxererts*, *Argiustolls* and a *Fluventic Haplustoll*, respectively.

The soil was air-dried and crushed to pass a 2 cm mesh sieve. To avoid soil layering and to ensure uniform bulk density, the following method was used: A layer of about 10 cm of air-dry soil was filled into the mini-ricebeds. Water was added through the drainage hole until the soil was saturated. An additional 10 cm layer of air-dry soil was added. The mini-ricebeds were then left to drain and equilibrate over night before further packing. An axial compression force of about 20 kPa was applied for about 10 seconds. This was achieved by placing a board (10 × 40 cm) on the soil surface and applying a weight of 80 kg. This procedure was repeated until the entire soil surface had been loaded. The soil surface was loosened, water applied through the drainage hole and so on until the entire mini-ricebed was filled with soil. Instruments were installed while the mini-ricebeds were filled with soil.

Access holes, 5 cm in diameter, for the insertion of filter papers for matric potential measurements were located at the centre of the rear concrete wall. Measured from the top of the mini-ricebed, they were at depth increments of ~5 cm between approximately 5 and 30 cm depth and ~10 cm increments between approximately 30 and 70 cm depth. A piston made of PVC was inserted through the hole to a lateral depth of 10 cm. An O-ring was used to waterproof the gap between piston and concrete wall. For matric potential measurement, three filter papers (Whatman 42, treated with $HgCl_2$) were placed at the head of the piston and pushed against the soil surface inside the mini-ricebed. The outer filter papers were slightly smaller in diameter than the piston, and slightly larger than the centre filter paper. This was necessary to ensure that the centre filter paper did not become contaminated with soil. Filter papers were left for four days to equilibrate with the soil. After this period, the filter papers were removed and the wet weight of the centre filter paper determined immediately. Gravimetric water content was calculated after oven-drying the filter paper. Matric potential was estimated using the relationship between filter paper gravimetric water content and matric suction described by Fawcett and Collis-George (1967).

Access tubes in the front wall of the mini-ricebed were provided for tensiometers and root observation tubes. Punch tensiometers 50 cm long were used to determine matric potential. They were installed through the access hole sloping downwards at an angle of approximately 13°. Holes were located about 40 cm from the right wall. Measured from the top of the mini-ricebed, they were at approximate depths of 15, 25, 35, 55 and 75 cm depth. The tips of the tensiometers were approximately 30 cm from the aluminium access tube for soil water measurements (see below). If necessary, tensiometers were topped up with de-aired water at least 24 hours prior to measurement.

Access holes for root observations tubes were located 40 cm from the left wall. They were 9 cm in diameter and located 15, 25, 35, 55 and 75 cm from the top of the mini-ricebed. Acrylic glass root observation tubes were used. They were 65 cm long, had an outer diameter of 3.9 cm and a wall thickness of 0.5 cm. A horizontal line was cut along the left and right side of the tube for intercept count measurements. This line was marked every 100 cm to determine different locations on the intercept line. The root observation tubes were installed at an angle sloping upwards. For the top three access holes (at 10 cm intervals), an angle of 11° was used; for the bottom two root observations tubes (20 cm interval), an angle of 22° was used. This allowed an assessment of root growth in continuous depths. A bore scope was used to count intercepts of root with the intercept lines of the root observation tubes.

After the mini-ricebeds were packed, a uniformity crop was sown. Oats were sown after the mini-ricebeds were left to drain for about 2 weeks. The rice beds were flooded again after the oats had dried the soil to permanent wilting point. At harvest of the uniformity crop, each mini-ricebed had undergone two drying and wetting cycles.

Soil water contents were measured using a neutron moisture meter. Aluminium access tubes were installed during the growing cycle of the uniformity crop. They were located in the right rear corner, at 30 cm distance from the concrete wall. Soil samples were collected during tube installation for calibration of volumetric water content against count ratios.

Treatment application

Following harvest of the uniformity crop, two experiments were conducted. Each experiment comprised pre-rice treatments, (i) different puddling intensity and (ii) different compaction levels combined with soil type in a crop rotation of rice followed by mungbean. The soil was saturated for two weeks before puddling or compaction treatments were applied.

Puddling treatments

In the first (*puddling*) experiment, puddling treatments were applied using a laboratory puddling apparatus comprising a high torque DC motor rotating two steel rods that were inserted into the soil to a depth of 10 cm. The angular velocity used was 110 r/min. Steel rods had a diameter of 0.95 cm and were rotating in a radius of 5.8 cm. Two levels of puddling intensity were used. Puddling the soil for five minutes gave a low puddling intensity, and puddling the soil for 25 minutes gave a high pudding intensity. The times were chosen to correspond to puddling ratios of 5 and 25, where puddling ratio was defined as the volume of the soil directly exposed to the puddling implement compared to the total soil volume (Kirchhof and So 1995). The puddling ratio ranges from 0 for unpuddled soil and increases with increasing puddling intensity (e.g. a puddling ratio of 10 means a soil that was exposed to the puddling implement ten times).

Compaction treatments

In the second (*compaction*) experiment, compaction treatments were applied after each mini-ricebed was puddled with a puddling ratio of 10. Previously highly puddled mini-ricebeds were compacted by a 80 kg person walking barefoot in the mini-ricebed for five minutes. It was decided that this approach was the most suitable to simulate the compaction that occurs when animals are used to draw puddling implements.

Agronomic practices

The two experiments were conducted from 1993 to 1995 in a controlled temperature glasshouse (25 °C) at The University of Queensland, Brisbane. The rice variety *Blue Belle* and the mungbean variety *Walet* were used as indicator crops. Plant spacing for rice was 20 x 20 cm and three seedlings were planted per hill. Fertilizers were applied before transplanting of rice at a rate of 40 kg N/ha (as Nitram and KNO_3), 40 kg P/ha (as single superphosphate) and 30 kg K/ha (as KNO_3). Additional 40 kg N/ha (as Nitram) was applied one month after transplanting. Fertilizer for mungbean was applied to the water of the paddy shortly before rice harvest to ensure that fertilizer dissolved and became available in the root zone. Rates of 23 kg N/ha (as urea), 52 kg K/ha (as KCl) and 19 kg P/ha (as triple superphosphate) were used. Five mungbean seeds were sown into dibbling holes that were 4 cm deep with a hill spacing of 20 × 30 cm. To ensure that crop establishment was not a limiting factor, dibbling holes were created using a knife without compacting the walls of the hole. Where possible, dibbling holes were located near a crack to provide easy access for roots into the subsoil. Dibbling holes were covered with soil. Each hill received 10 mL of a water rhizobium suspension. Mungbean was thinned to two plants per hill after crop establishment, i.e., after the first pair of true leaves had appeared.

Rice was sown on 15 July 1993 for the first experiment. Puddling treatments were applied on 9 and 10 August 1993 and rice transplanted one week later (16 August 1993). Harvest was 115 days later on 9 December 1993. The vegetation period was longer than under field conditions because rice started to grow during the winter months. Surface water of the paddy was drained on 16 December 1993 and mungbean was sown one week later on 23 December 1993. Harvest was 71 days later on 4 March 1994. No irrigation was applied during mungbean growth.

In the second experiment, rice was sown on 8 April 1994. Rice beds were puddled on 14 and 15 April and compaction treatments applied immediately after. Seedlings were transplanted on 22 April 1994. Rice harvest was 165 days after transplanting on 4 October. The vegetation period was very long because rice grew during the winter months. The paddy was drained on 11 October and mungbean sown one week later on 18 October 1994. Harvest was 77 days later on 3 January 1995.

Measurements during plant growth

Suspended soil mass

The mass of suspended soil particles was measured one hour after puddling treatments were applied. One hundred mL of suspension was sampled at 1 cm depth from the puddled soil water suspension using a pipette. Soil mass in the suspension was measured after oven drying. This measurement was only carried out in the *puddling experiment.*

Wet sieving

Soil structural stability of the puddled layer was measured once, one week after puddling in the *puddling experiment.* Soil samples of about 150 g of saturated soil were taken one week after puddling treatments were applied. These were transferred to a tension table and left to drain overnight at –300 Pa suction. Half of each sample was used to determine soil water contents; the other half was used in the wet sieving procedure and dispersion measurements, respectively. Samples were wet sieved for 15 minutes in a nest of six sieves (mesh size 9.5, 5.1, 2.0, 1.0, 0.5, 0.25 mm). Sieving amplitude was 1.2 cm with an angular velocity of 20 r/min.

Dispersion

Samples for the determination of dispersible silt and clay were taken during the rice phase one week, two and four months after puddling for each experiment. Sampling and sample preparation procedure was the same as that used for wet sieving except that samples were transferred into a sedimentation cylinder instead of sieves. The cylinder was partly filled with water, samples were added and additional water was added to make up 1000 mL. Shaking was reduced to a minimum, but was adequate to produce a homogeneous systems suitable for sedimentation. The pipette method was used to measure dispersible silt and clay.

Percolation and evaporation

Evaporation was monitored regularly by weighing a water-filled black PVC evaporation box. The box was 31 × 61 cm and 11 cm high, filled with water 5–8 cm deep. It was placed on top of two adjacent mini-ricebeds. Flooded conditions were maintained during rice growth by blocking the drainage hole. A ruler was pushed into the puddled layer to a depth of about 15 cm to monitor water levels in each mini-ricebed.

For percolation measurements, the drainage hole was opened and drop of the water level monitored at 1 to 3 day intervals, depending on magnitude of percolation rate. Percolation rates were calculated as the difference between change in water levels in the mini-ricebeds and evaporation. Percolation measurements were carried out 1 week, 2 and 4 months after puddling in the puddling experiment; and only once on 22 April 1995, one week after puddling during transplanting, in the compaction experiment.

Matric potential and soil water contents

Volumetric soil water contents were measured in 10 cm intervals from depths 20 to 60 cm, using a neutron moisture meter. Soil samples for the determination of gravimetric water contents were taken from 0–2, 2–5 and 5–10 cm depths during the mungbean phase. Sample size was kept as small as possible to minimise disturbance of the soil surface.

Each sample had a diameter of approximately 2 cm. Matric potential was measured using punch tensiometers. During the first week after drainage, these measurements were taken every second day, time intervals were then steadily increased to two measurements per week at mungbean harvest.

Bulk density

Bulk densities were monitored during the mungbean phase of the compaction experiment. A transmission gauge type gamma probe (Ronley SDG 39) was used to determine bulk densities. PVC access tubes to accommodate the spikes of the gamma probe were installed during the rice phase of the experiment. These access tubes allowed the location of measurements to be fixed, thus enabling monitoring of bulk density changes over time. Depth of measurements was in 5 cm increments from 5 to 40 cm depth. The instrument was calibrated using standard glass techniques. The soil water content measurements from the neutron probe and gravimetric water contents were used to calculate bulk density from wet density obtained from the gamma probe. Due to different depth increments used for soil water and bulk density measurements, soil water contents were interpolated to correspond to the depths the gamma probe was used.

Soil strength

A RIMIK constant speed penetrometer was used in the *compaction* experiment to measure cone index to a depth of 45 cm in 2.5 cm intervals before and after compaction treatments were applied. The cone had a diameter of 1.2 cm and angle of 28°.

pH and Rh

Redox potential and pH of the paddy (water and puddled layer) was measured once in the *puddling* experiment on 1 November 1993, 77 days after transplanting. A battery-powered portable instrument was used to avoid errors due to earth loops.

Texture change due to puddling

The potential redistribution of soil particles due to puddling in the puddled layer was evaluated. Samples were taking after mungbean harvest in the *puddling* experiment at depths 0–1, 1–2, 2–4, 4–7 and 7–10 cm. The pipette and sieving method was used to obtain the particle size distribution at the different depths within the puddled layer.

Agronomic measurements on rice

Number of tillers and plant height were measured three times during the rice phase. Destructive sampling was limited to final harvest. Final grain yields and total biomass were determined. Root growth was measured once during the *puddling* experiment at the flowering stage.

Agronomic measurements on mungbean

Establishment of mungbean was estimated by comparing the number of seeds sown to the number of seedlings that established. During thinning, seedlings were collected for the determination of seedling weight. No further destructive sampling was carried out until harvest for seed yield and total biomass. Comparative measures for crop performance included the measurement of canopy cover and relative interception of photosynthetic active light. Canopy cover was determined using image analysis of black-and-white photos of the leaf canopy. These photos were obtained by placing black velvet on the soil surface and taking a photo of the canopy from a camera attached to a frame located 2 m above the mini-ricebed. Photos were overexposed to ensure that leaves would be shown as white against the black background. This measurement was carried at flowering in each experiment. A PAR light interception rod was used to determine light interception. This measurement was done twice during the *puddling* experiment. Relative leaf water content was measured once during grainfill in each experiment. The procedure described by Ludlow (1982) was followed. Five youngest, fully expanded leaves were collected from each mini-ricebed. Gravimetric water content was immediately measured on one half of the leaves, while the other half was cut into strips about 5 cm long and 2 cm wide. These strips were transferred into a water-filled container and exposed to direct sunlight in the glasshouse. Gravimetric water content was determined when the light compensation point was assumed to have been reached after 30 minutes. Before weighing for fresh weight determination, water on the leaf surface was dried using absorbant tissues. Relative water content was expressed as the ratio of water content for fresh and turgid leaves. Measurements of leaf water potential were made using the pressure bomb. These measurements were attempted once, but failed. Root growth was measured at flowering and at maturity in the *puddling* experiment.

Results and Discussion

Soil properties

The properties of the soils used are given in Table 1. The pH values were neutral to slightly acid with low electrical conductivities indicating no soil chemical restriction except the need to apply fertilizer to ensure non-limiting plant nutrition. The pH values changed slightly during the rice phase. The lowest pH and redox potential under submerged conditions was observed for the clay soils (GC_G) but pH and redox potential were not limiting to the growth of rice for all soils (Table 1).

Soil water content at pF 0 (–0.1 kPa) was similar for all soils. The volume of pores that drain until field capacity is reached was largest for the loam and similar for the silty loam and clay. Plant-available water was lowest for the loam due to its coarse texture compared to higher water-holding capacities for the heavier silty loam and clay soils. Lower plastic limits were similar for the three soils despite large textural differences. The liquid limit, and concomitantly, the plasticity index, followed the texture grades and increased with increasing clay content.

The clay soil (GC_G) and the silty loam soil (AL_B) were representative of lowland paddy soils and comparable to the soils used in the field experiments for ACIAR Project 8938. The loamy soil (LO_G) was included to allow comparison with a well structured soil type in which soil physical restrictions were minimal.

Assessment of soil puddling

The effects of low and high puddling intensity, or puddling ratios of 5 and 25, respectively, were evident in the amount of dispersed soil that remained in suspension after puddling (Fig. 1). Differences between low and high puddling intensity were large for the fine textured soil but not significantly different for the loamy soil. In terms of dispersion, this showed a fairly high structural stability of the loamy soil LO_G. Results from wet sieving were similar (Fig. 1) to those of suspended soil mass, but differences between soil types and puddling intensities were not significant. Several days after puddling, suspended soil had settled and measurement of suspended soil was no longer possible. Wet sieving was not repeated at later stages because of insufficient sensitivity for the detection of differences in puddling intensity. Another factor was excessive time for the analysis.

Dispersed clay was measured three times during the rice phase (Fig. 2). Dispersed clay was higher under high puddling intensity. Between soil types it followed the clay content of the soil and was therefore lowest in the loamy soil (LO_G) and highest in the clay soil (GC_G). The interesting observation was that the amount of dispersed clay decreased with increasing length of inundated conditions for the three different soils, although the decrease was only significant for the finer textured soils. For a comparison with clay soils, lower values of clay dispersion results in greater hydraulic conductivities (So and Cook 1993). This is associated with lower amounts of clay particles that can block pores for waterflow. In this case, however, the progressive reduction in dispersible clay resulted in a reduction in saturated hydraulic conductivity (Fig. 2). This

Table 1. Soil properties of the soils used in the mini-ricebeds.

Soil property		Grey clay Griffith GC_G	Lockyer Valley Gatton LO_G	Alluvial Brisbane AL_B
Standard measurement of pH (H_2O)		7.0	7.1	6.6
pH of submerged soil		6.8	6.4	7.0
Redox potential of submerged soil (mV)		189	74	173
Electrical conductivity (dS/m)		0.048	0.059	0.348
Soil water:	θ_g–1.5 MPa (g/g)	0.127	0.087	0.117
	θ_g–10 kPa (g/g)	0.334	0.220	0.320
	θ_g–0.1 kPa (g/g)	0.478	0.485	0.490
Texture:	% coarse sand (0.2–2 mm)	9.9	29.1	8.3
	% fine sand (20–200 µm)	34.0	41.6	45.9
	% silt (2–20 µm)	14.1	14.3	23.4
	% clay (<2 µm)	40.6	14.3	23.5
	texture grade	CLAY	LOAM	SILTY LOAM
Organic carbon		1.30%	1.11%	0.68
Consistency:	lower plastic limit (g/g)	0.22	0.19	0.20
	liquid limit (g/g)	0.40	0.27	0.357

may be due to a progressive consolidation process under submerged conditions in combination with precipitating clay particles which block pores and bond to particles. Dispersion induced by soil puddling is a mechanical process. Mechanical energy is needed to disperse clay particles which would normally flocculate spontaneously. Therefore, without further energy application some of the clay settles. This is in contrast to dispersion induced by high levels of exchangeable sodium where high sodium content per se is responsible for clay dispersion and clay remains dispersed without input of mechanical energy.

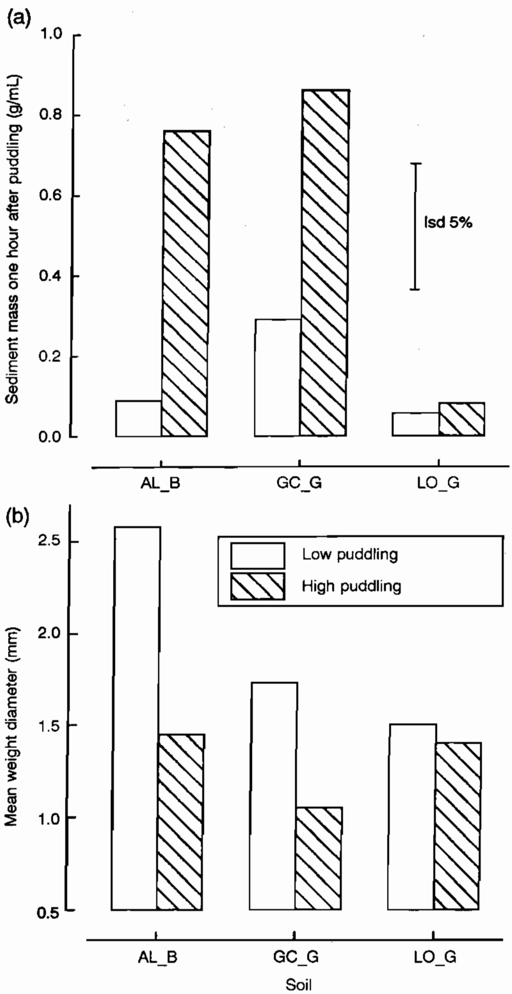


Figure 1. The effect of low and high puddling intensity on suspended soil mass (a) and mean weight diameter (b).

A major objective of puddling is a reduction in hydraulic conductivity, which is of major importance for weed control in paddy fields. An increase in soil puddling achieves this objective of decreasing percolation rates. However, of equal importance is the maintenance of submerged conditions to maintain the low hydraulic conductivity achieved. Lack of irrigation, drought or mid-season drainage may increase hydraulic conductivity due to crack formation, even if the soil remains close to saturation (Ringrose-Voase et al., these Proceedings). However, in some lowland rainfed rice production areas, water tables are close to or even above the soil surface. In such cases pudding, as a means to control weeds, would be of little importance. During these experiments submerged conditions were maintained through establishing high water tables, i.e. the drainage holes of the rice beds were blocked and only opened when percolation rates were measured.

Soil puddling changed the particle size distribution across the puddled layer. The soil surface tended to have an increased clay content and decreased coarse sand content (Fig. 3). However, no effect of soil puddling intensity on the redistribution in particle size could be detected.

The increased clay content at the soil surface supported the thought that clay particles precipitate over time and create a thin, reasonably impermeable surface seal that reduces percolation rates (Fig. 2). The formation of such a layer also has implications for water movement following the rice phase, in particular during the period before the seal is likely to rupture due to crack formation. Initial soil drying may be reduced. This would result in decreased water loss until the post-rice crop can be sown; it may, however, also increase the turnaround time if soil remains too wet for sowing.

Soil compaction

The effect of soil compaction was evaluated by measuring soil strength, bulk density and percolation rates. Soil strength profiles were recorded after the soil was submerged for about one week, 2 days before and 5 days after compaction treatments were applied (Fig. 4). Maximum soil strength recorded was about 800 kPa due to the very wet soil conditions. Despite these low soil strengths, root growth of rice may have been limiting because the threshold value of 400 kPa for rice, as reported by IRRI (1986) and Pagliai and Painuli (1988), was exceeded at depths greater than approximately 20 cm for the clay soil (GC_G) and at depths greater than 20–30 cm for the lighter textured soils. However, since rice roots do not tend to proliferate significantly below 20 cm depth under field conditions, the induced compaction was unlikely to affect rice growth. Soil strengths tended to decrease between the two different times of measurements. This decrease is probably due to an increase in soil water content and concomitant increased matric potential and indicated that water intake by soil clods (soaking, see Tuong and Cabangon, these Proceedings) was still occurring even after one week of flooding. The exception to this observation was the clay soil (GC_G) at depths greater than 20 cm. Soil strengths were much higher during the second measurement. However, this may be an experimental artefact associated with the high friction along the penetrometer shaft during insertion in very wet and sticky soil conditions. Compaction tended to increase soil strength, but differences were very small and statistically not significant. The penetrometer was unable to distinguish differences in compaction under these conditions.

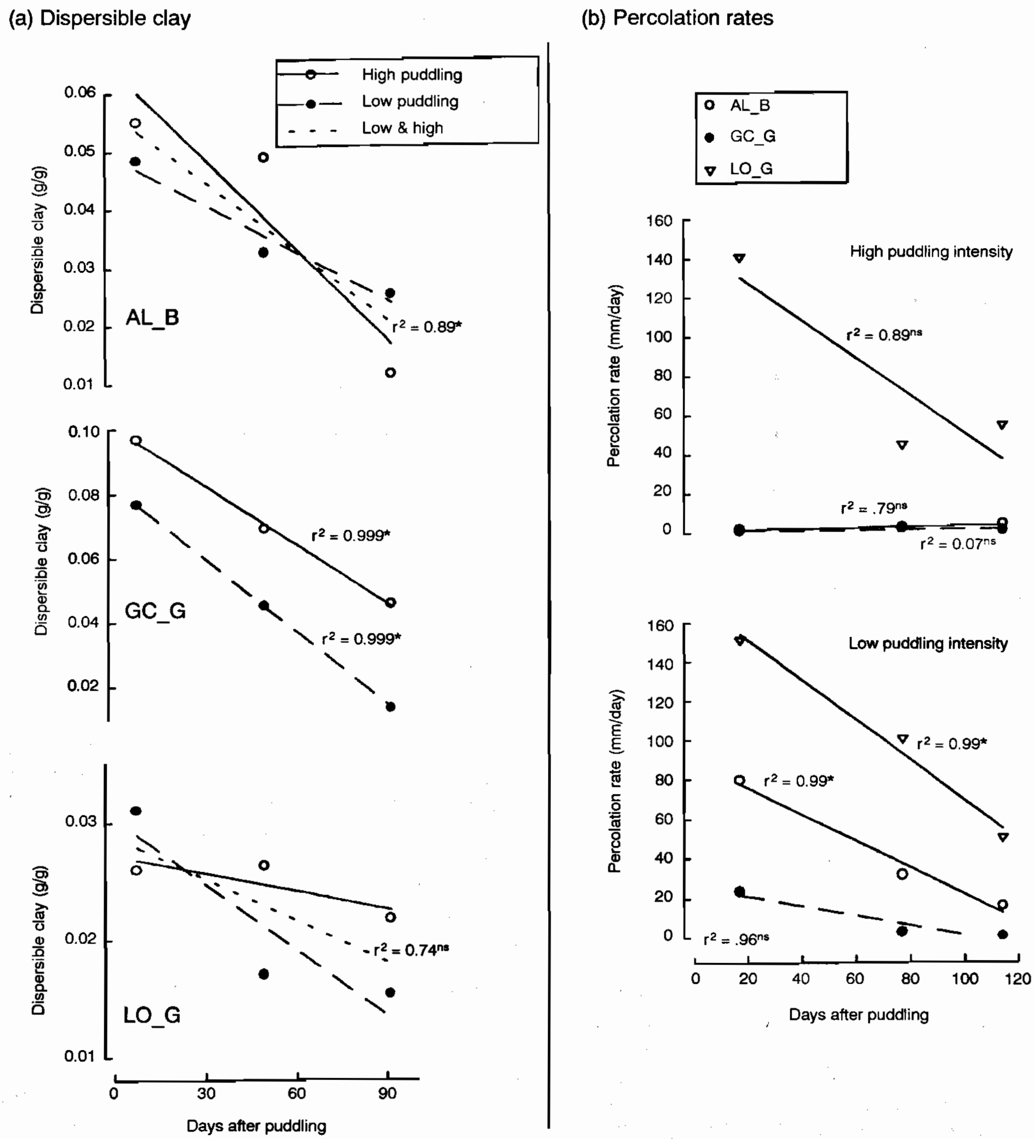


Figure 2. The change of dispersible clay (a) and percolation rates (b) during prolonged periods of flooding.

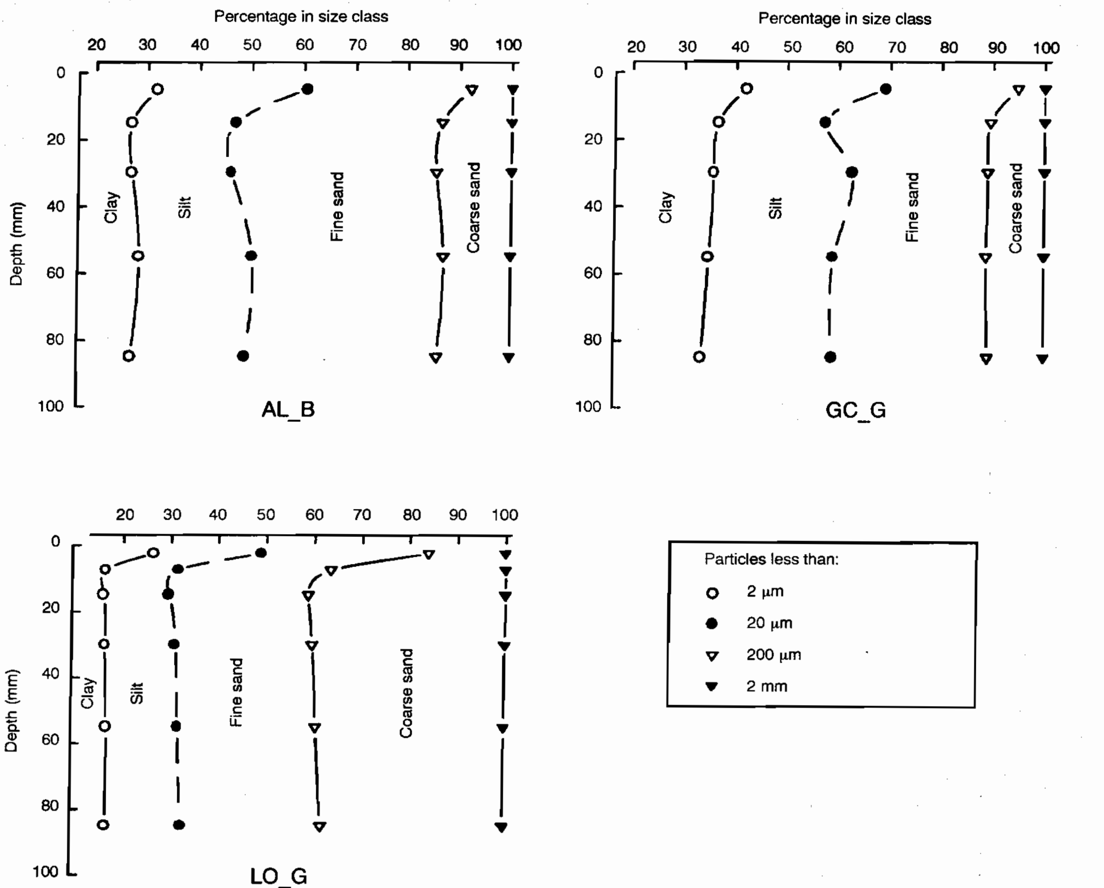


Figure 3. Texture profiles of the puddled layer in the puddling experiment.

Bulk densities tended to be increased by compaction to at least 40 cm depth of the soil profile for the coarser textured soils (AL_B and LO_G), and was not affected in the clay soil, GC_G (Fig. 5). Compaction treatments were applied about one week after flooding. It was thought that water intake had not been completed during that time. This means that air was still present in the coarse textured soils and increases in bulk densities due to compactive forces were possible. For the clay soil, however, water uptake would result in swelling and, assuming that very little air was present in the wet soil, compaction could not result in bulk density increase but would result mainly in soil deformation. If the soil is deformed or remoulded, it is also likely that its ability to swell is increased. Bulk density changes were monitored during the mungbean phase and compared to soil water content changes (Table 2). The loamy soil (LO_G) did not show changes in bulk density during the drying cycle except for one depth of non-compacted soil which was probably due to experimental errors. On the two other soils (GC_G and AL_B), soil compaction clearly resulted in increased shrinkage. Considering that shrinkage and swelling are major factors for soil structure reformation, the effect of soil compaction may not last long as soil compaction itself may promote self-amelioration.

Compaction decreased percolation rates significantly except on the clay soil, GC_G (Fig. 6). This was consistent with the effect of compaction on bulk density (Fig. 5) and suggested that bulk density was a good indicator to assess soil compaction. Compared to the soil puddling intensity (Fig. 2), percolation rates appeared to be more efficiently reduced by compaction on coarser textured soil

(LO_G), and through puddling on finer textured soils (GC_G). Similar reductions in percolation rates were observed for puddling or compaction in the silty loam (AL_B). Percolation rates were substantially higher for the clay soil (GC_G) in the compaction experiment compared to the puddling experiment. Cracks may not have closed after the three weeks of soaking. Although no measurements were carried out later during the season, it was observed that percolation rates of the clay dropped below those of the coarser-textured soils. This indicated further that sufficient time must be allowed on clay soils to take up water following a dry period before inundated conditions can be maintained, irrespective of soil puddling and soil compaction.

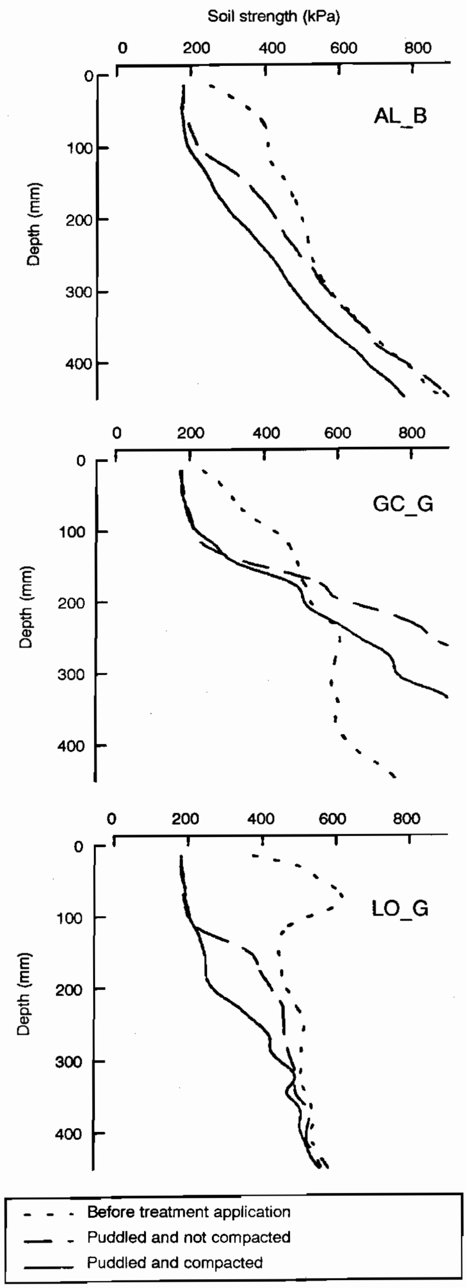


Figure 4. Soil strength before and after compaction application in the compaction experiment.

Rice growth

The effect of puddling on the growth of rice was evaluated by monitoring the height of rice plants at four different times during the growing cycle (Fig. 7). Puddling increased rice height slightly during the first 2½ months of growth but had no effect on the plant at maturity. There was also no effect on the number of tillers. Its average value was 11 tillers per hill.

Root growth was measured 70 days after transplanting (Table 3). No differences due to soil type and puddling where observed. In contrast to reports by Wopereis (1993), rice root penetrated well below 20 cm depth; in this case 12% of the roots were found below 22 cm depth. However, the majority of roots, 56%, was found within the puddled layer to 12 cm depth.

Rice yield was significantly affected by soil type and soil puddling intensity (Fig. 8). The clay soil (GC_G) had the highest yield and the silty loam soil (AL_B), the lowest yield. Soil puddling was only beneficial on the loamy soil (LO_G). It is possible that increased puddling is needed on permeable well-structured or coarse textured soils, such as the loam in this case, to create inundated conditions suitable for easy root proliferation within the puddled layer.

In the compaction experiment, soil compaction and soil type had no significant effect on rice yield, but there was a strong trend for decreased yield due to the presence of compacted layers below the puddled zone (Fig. 8). However, under conditions where water tables are low and a decrease in hydraulic conductivity is required, soil compaction may be beneficial (see Wade, these Proceedings). Yield reductions due to compaction are likely to be increased under drought conditions where roots may need to access subsurface water. At the same time however, compaction reduces water loss (Fig. 6). In this case compaction tended to have the largest yield reduction on the clay soil; at the same time, percolation was little affected by compaction. Compaction should therefore be reduced on clay soils to minimise yield losses. Because of the large

Table 2. Soil shrinkage* as affected by soil type and compaction level.

Depth (cm)	AL_B		GC_G		LO_G		lsd 5%
	Not compacted	Compacted	Not compacted	Compacted	Not compacted	Compacted	
5	none	0.21	none	none			ns
10		0.21	0.33	0.51	none		
15	0.19	0.17	none	0.23			0.09
20	none	0.14		0.45	0.13	none	
25	0.13	0.16	0.18	0.42			ns
30	none	none	0.18	none	none		
35			none				

*Shrinkage = volume change per soil water content change.

Table 3. Root distribution and depth for rice and mungbean in the puddling experiment.

Depth interval (cm)	Percentage of roots at different depths		
	Rice (70 days after transplanting) flowering stage	Mungbean	
		27 days after sowing	49 days after sowing
5–12	56	56	41
12–22	32	37	33
22–35	10	7	17
35–55	2	0	9

differences in percolation rates, and relatively small yield differences, compaction may be beneficial on coarser textured soils.

Yields in the puddling experiment were higher than those in the compaction experiment. This is due to the difference in season during which the experiments were conducted. Rice in the puddling experiment was grown from winter to summer, compared to a growing season of spring to autumn in the compaction experiment. Shorter days and reduced light intensity were responsible for reduced growth in the second year. Temperature may be an additional effect because temperature control in the glasshouse may not have been adequate to cope with cool winter nights in subtropical climates.

The mungbean phase

Crop establishment

Crop establishment percentage and seedling weight were not significantly affected by soil type or soil puddling intensity (Table 4). Average crop establishment was 90% under continuous drying condition in the glass house. Differences between low and high puddling intensities were very small (≤2.5%) for the clay and loamy soil, but crop establishment was decreased by 9% for the silty soil (AL_B) if puddled with high intensity. Silty soils tend to be hardsetting and structurally unstable (Isbell 1995). Such soils develop high soil strength rapidly upon drying. Intense puddling may have deteriorated soil structure further, hindering seedling emergence and subsequent crop establishment. These unstable silty soils are therefore more sensitive to high puddling intensity compared to structurally more stable soils.

Table 4. Mungbean establishment and seedling weight seven days after sowing in the puddling experiment.

Soil	Puddling	Seedling weight (mg)	Establishment (%)
AL_B	high	30	84
	low	30	93
GC_G	high	32	87.5
	low	24	85
LO_G	high	33	93.5
	low	33	94.5
P value for soil		0.088	0.18
P value for puddling		0.32	1
P value for soil × puddling		0.21	1

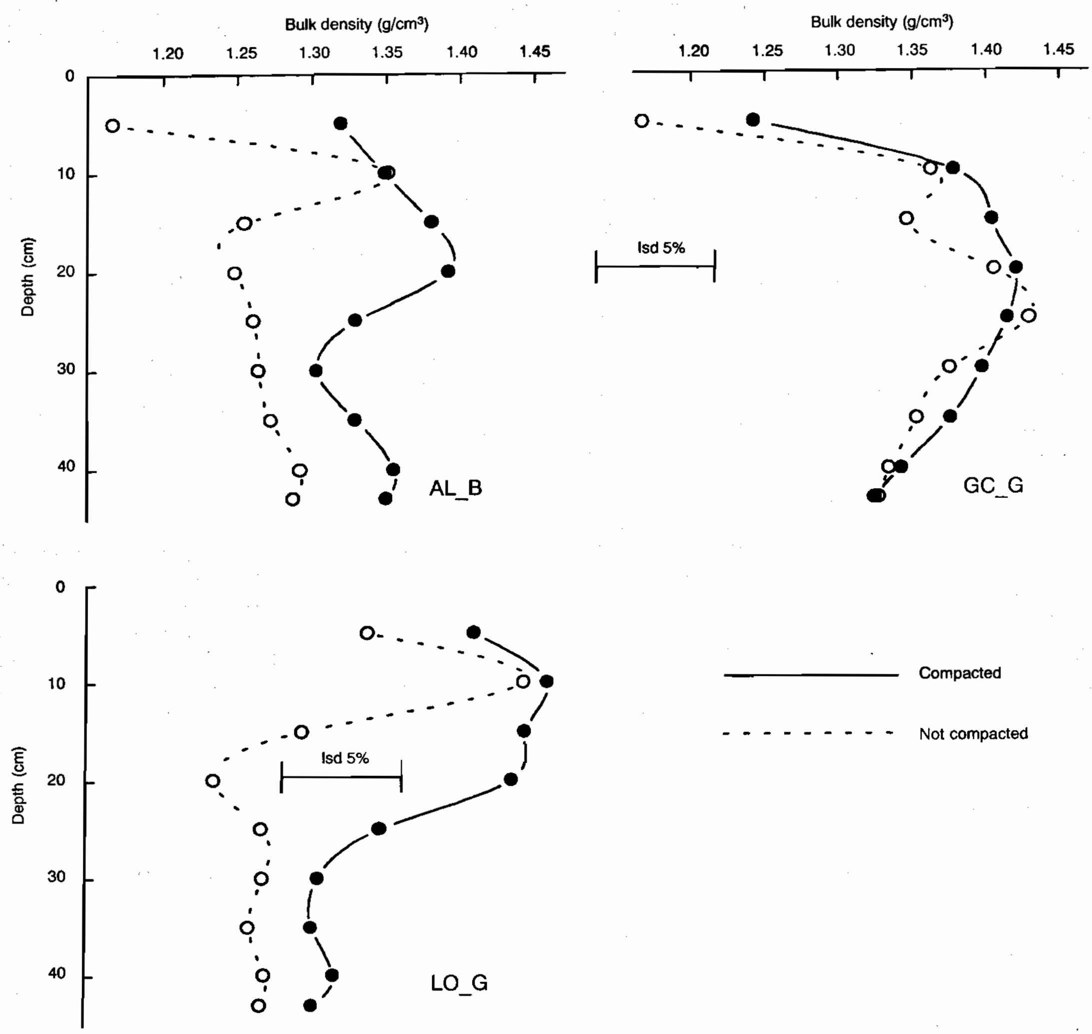


Figure 5. Bulk density profiles in the compaction experiment.

Seedling weight seven days after sowing was statistically not significantly affected by soil type or puddling intensity (Table 4). There were no differences between low and high puddling intensity for the silty soil (AL_B) and the loamy soils (LO_G). On the clay soil (GC_G) however, although statistically not significant, seedling weight when puddled with high intensity was about one third higher compared to low puddling intensity. This relatively large difference was probably due to lower soil water contents in the topsoil at seeding depth. Despite relatively small differences in gravimetric water content, matric potential was considerably lower for low, compared to high, puddling intensity (Table 5). Reduced drying in highly puddled clay soil may be due to the formation of a surface seal and the reduction in hydraulic conductivity (Fig. 2). The lower soil strength could therefore result in more vigorous seedling growth on the highly puddled clay soils.

The pattern of soil drying of uniform soil following saturated conditions shows that the surface has the lowest soil water content immediately after drying conditions are imposed. The thin layer of fine soil particles had a clear influence on soil drying. At the end of the paddy conditions when surface water had disappeared, the water content in the puddled layer was highest at the soil surface (Fig. 9). This was clearly due to the accumulation of clay at the soil surface. As the thin seal dried, its hydraulic conductivity decreased and resulted in reduced water loss from the soil below 20 cm depth. Further investigations are needed to clarify the effect of puddling intensity on surface seal formation and how it affects soil water movement, as well as the effect of soil puddling on the interaction of soil water, matric potential and soil strength.

Soil compaction had no effect on crop establishment or seedling weight (Table 6). The loamy soil had the highest establishment percentage and largest seedling while the clay soil the lowest establishment and smallest seedling. These differences were most likely associated with differences in soil strength

Table 5. Gravimetric water content and matric potential of the clay soil (GC_G) at 8 cm depth at three different times after drainage in the puddling experiment.

Stage/date	θ_g (g/g)		ψ_m (cm)	
	High puddling	Low puddling	High puddling	Low puddling
End of paddy (16 Dec 1992)	0.473	0.331	−13	−10
Sowing (23 Dec 1992)	0.277	0.254	−148	−248
Establishment (30 Dec 1992)	0.210	0.179	−226	−1260

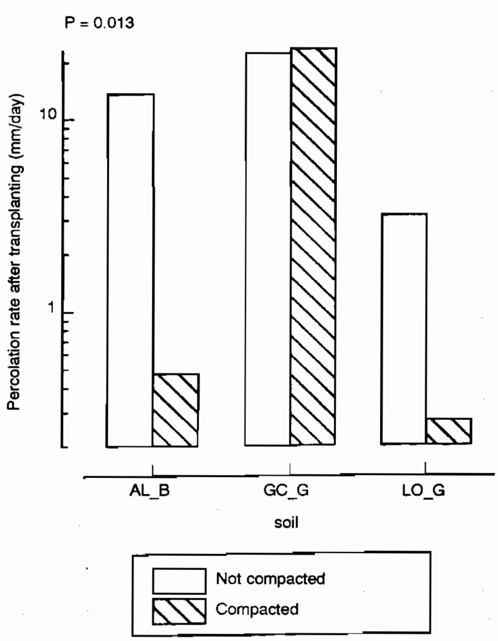


Figure 6. Percolation rates at transplanting in the compaction experiment.

between the different soils. The clay soil (GC_G) had the lowest matric potential but highest gravimetric water content between sowing and establishment, for the loamy soil (LO_G) it was the reverse, i.e. highest matric potential and lowest gravimetric water content. The silty soil AL_B showed intermediate values (Table 7). The low matric potential was probably the cause for the high soil strength that resulted in poorer crop establishment and reduced seedling vigour. Water loss between sowing and establishment in the topsoil was also greatest for the clay soil. Crack formation upon drying probably increased evaporation. This agreed with previous observations which showed that reduced evaporation, possibly through the formation of a clay seal due to puddling, resulted in improved seedling growth because matric potential and thus soil strength remained high.

Growth and yield

Following the establishment phase no further differences in growth were observed in the compaction experiment and yields averaged 1.2 t/ha. However, yields tended to be marginally smaller for the clay soils GC_G and silty soil AL_B if compacted (Table 6). In the puddling experiment however, differences in growth due to soil type increased during the early vegetative stage, but decreased towards maturity. Since the crop was thinned to uniform population density following establishment, observed differences were due to the differences in plant size or vigour that should be related to the ability of the crop to utilise water stored in the subsoil. However,

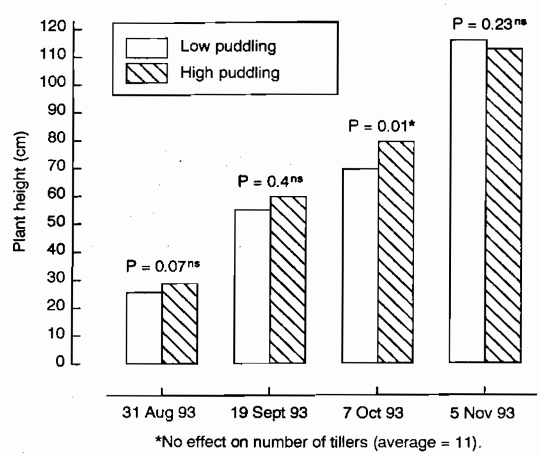


Figure 7. Rice height at different periods after transplanting as affected by low and high puddling intensity (P-value above bars indicate probability for significance).

despite differences in growth, differences in root growth could not be quantified. Irrespective of soil type and soil puddling intensity, roots penetrated to the bottom of the rice beds at a depth of 55 cm (Table 3).

At 23 days after sowing, pronounced differences in growth were observed between soil types. Analysis of the crop canopy (Fig. 10) showed that the clay soil GC_G had by far the smallest plants. Soil puddling, however, had no effect, except a trend to decreased canopy size in the sandy soils LO_G due to high puddling intensity. Growth rates on the sandy and silty soils was therefore much higher compared to the clay soil, possibly due to higher soil strength or persistence of anaerobic conditions in the subsoil of the clay that may have restricted root growth. However, higher growth rates coincide with faster soil water use and soil water depletion. If the soil water store is limited, water stress will set in earlier. The relative leaf water content was negatively related to canopy cover. Plants growing on the clay soil GC_G had much higher leaf water content, indicating less water stress, compared to the plants growing on the silty and sandy soils (Fig. 10). The effect of soil type and puddling intensity on light interception was similar to that on canopy cover. However, growth between 29 and 46 days after sowing was greater on the clay soil GC_G than on the sandy and silty soil (Fig. 11) and the initial large differences were considerably reduced. Plants growing on the clay soil obviously had more soil water available during that period compared to the sandy and silty soils.

Seed yields and biomass production was largest for the silty soil AL_B and smallest for the sandy soil LO_G (Fig. 12). Puddling intensity increased yields on the sandy soil but decreased yields on the silty soil. The low harvest index on the loamy soil indicated that plants were extremely water stressed during the generative growth phase. The higher yield

Table 6. Crop establishment and yield of mungbean in the compaction experiment.

Soil	Compaction	Seedling weight (mg)	Establishment (%)	Seed yield (t/ha)
AL_B	yes	47	89	1.16
	no	50	93	1.24
GC_G	yes	42	84	1.15
	no	42	80	1.24
LO_G	yes	57	91	1.14
	no	50	94	1.17
P value for soil		0.035	0.012	0.862
P value for compaction		0.673	0.702	0.375
P value for soil × compaction		0.379	0.389	0.941

Table 7. Gravimetric water content and matric potential at 8 cm depth at different times after drainage for the three different soils in the compaction experiment.

Soil	Soil water status	End of paddy 12 Oct 1994	Sowing 18 Oct 1994	Establishment 28 Oct 1994
AL_B	θ_g (g/g)	0.393	0.327	0.287
	ψ_m (cm)	–40	–118	–332
GC_G	θ_g (g/g)	0.396	0.342	0.240
	ψ_m (cm)	–17	–170	–361
LO_G	θ_g (g/g)	0.320	0.302	0.283
	ψ_m (cm)	–69	–85	–128
P values	θ_g	0.104	0.029	0.05
	ψ_m	<0.001	0.008	0.05

on highly puddled soil was probably due to reduced growth earlier in the season that left relatively more water available during the generative phase. Coupled with reduced crop establishment on the silty soil AL_B, soil puddling can be expected to have the largest detrimental effect on structurally unstable soils.

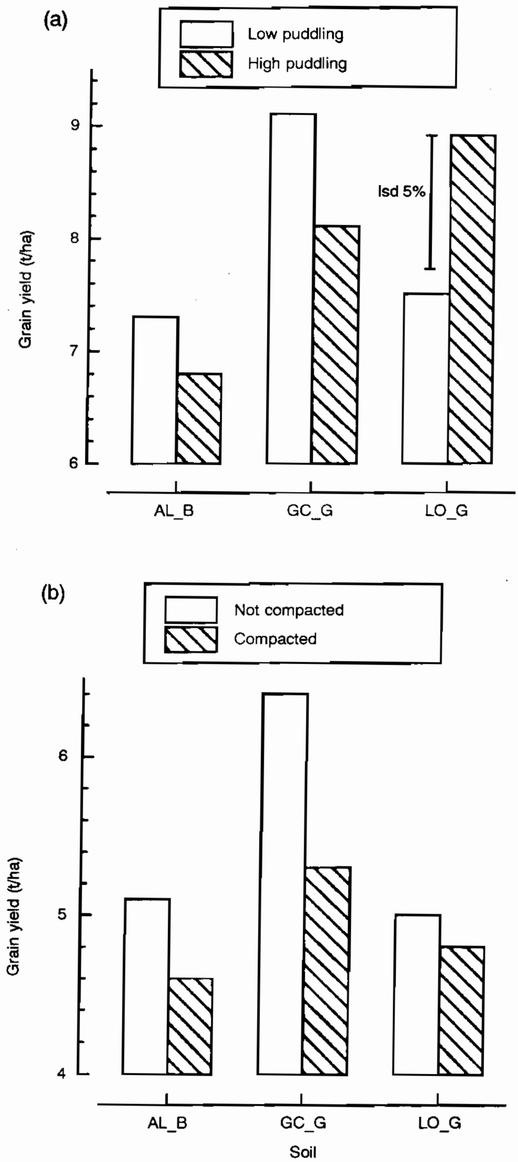


Figure 8. The effect of puddling (a) and compaction (b) on rice yield.

Water use

Water use during mungbean growth under continuous drying conditions following paddy drainage could be separated into four different stages. During the first stage, shortly after drainage, loss of water was approximately equal to potential evaporation. The initially very wet soil surface dried and its hydraulic conductivity decreased resulting in soil water loss rates lower than potential evaporation. This stage lasted for about one to two weeks during which the crop was sown. The second phase can be called *established phase*, because seedlings had emerged and the crop was established. These stages are equal to first and second stage of evaporation in the absence of crop growth (Hillel 1980). Water use by the crop was very small and rates of water loss remained low until plants had developed sufficient leaves for high transpiration rates coinciding with the period of maximum growth. This third phase could therefore be called *maximum uptake*. In these experiments, maximum uptake lasted until soil water was depleted and water stress started. This fourth and final stage could be called the *stress phase*.

Although these four stages are continuous, they could be separated by plotting cumulative water loss against time and optimising up to four linear regressions to describe the data. The program BREAKS written by Jones and Molitoris (1984) was used to obtain parameters for the different stages of water uptake. It shows the results of the regression procedures for the three different soils in the pudding experiment. It is important to note that the onset of stress determined by the statistical procedure coincided with visual observations of plants at the onset of wilting. The influence of soil type and puddling on water use parameters such as water loss during initial drying, duration of initial drying, rate of maximum uptake, onset of water stress and water usage was evaluated and showed that initial drying rate was larger in soils puddled with high intensity. This appeared to contradict earlier conjectures that high puddling intensity tends of conserve water due to the formation of surface seals. However, while drying rate indeed was faster closer to the soil surface than 5 cm depth under high puddling, the drying rate at depths between 5 cm and 10 cm, where roots of the emerging seedling would penetrate, was not affected. The higher soil water content at that depth due to high soil puddling could be maintained for longer periods, resulting in potentially more favourable conditions for the young seedling. This was of particular importance for the clay soil where the duration of initial drying was much shorter compared with the coarser-textured soils (Table 8).

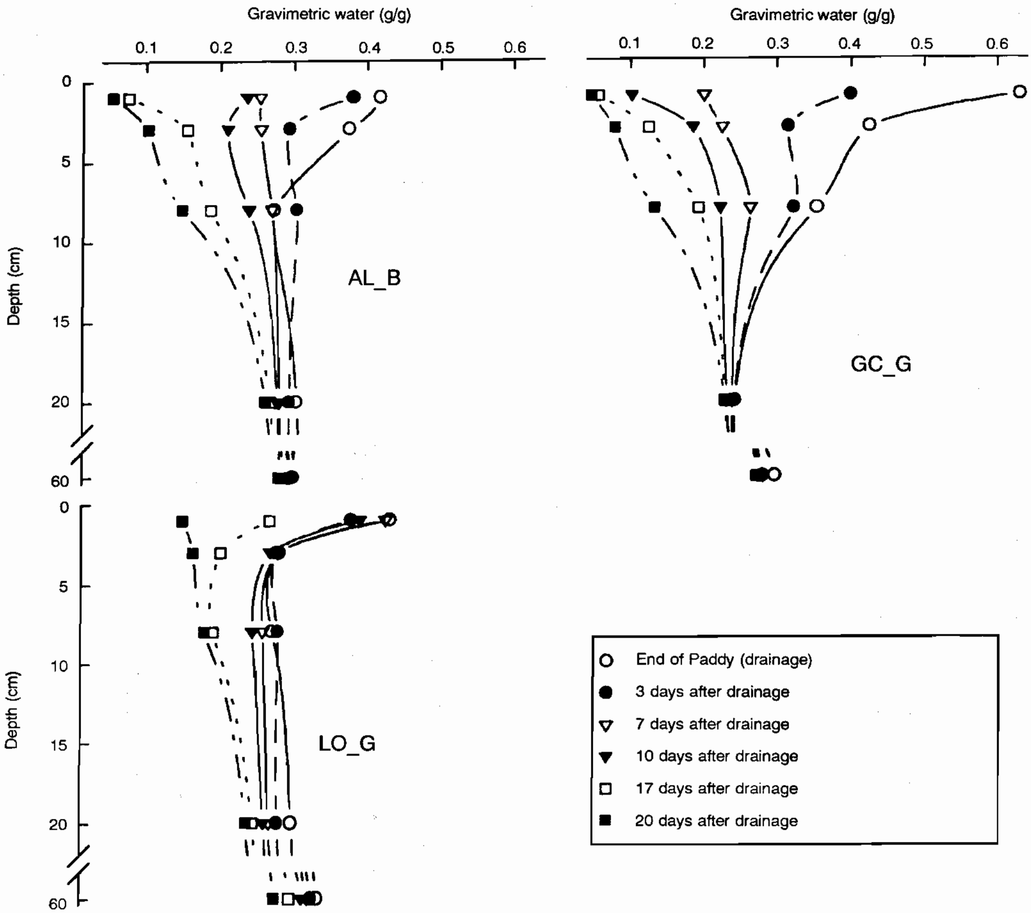


Figure 9. Soil water profiles of three different soils (average of high and low soil puddling) in the puddling experiment after drainage.

Rates of maximum uptake followed plant growth very closely (Fig. 10). Of particular interest was the difference in water uptake rate on the sandy soil LO_G puddled with high and low intensity (Table 9). High puddling strongly reduced water uptake and thus plant growth. These differences were most likely due to differences in root growth. However, the mini-rhizotrons used were not able to demonstrate differences in root growth.

Onset of water stress occurred earlier on the coarse textured soil compared to the clay soil due to faster water use during the phase of maximum water uptake. However, total water use remained lowest for the clay soil which also had the lowest biomass production and yield. Grain yield was closely related to water use for the clay and silty soil (Fig. 14). For each mm of soil water used an additional 5 kg of seeds was produced. Reports by IRRI (1985, 1986, 1988) showed yield increases for mungbean of 100 kg/ha if exploitable soil depth was increased from 7 to 13 cm. Assuming 20% plant available water, the exploitable soil depths would correspond to 14–26 mm of soil water. This equals 4–7 kg of grains per mm of soil water used and corresponds well with results from this study, despite the dissimilarity of glasshouse and field conditions.

Despite similar water use until the onset of water stress on the silty soil and the sand, yields were much different. This was due to the low harvest index of the crop grown on the sandy soil LO_G and also the cause of the lack of relationship between water use and yield (Fig. 14). The close relationship between total biomass and water use clearly showed that soil water was primarily used for vegetative growth: thus the low harvest index.

Table 8. Water use parameters for the puddling experiment.

Water uptake stage	Soil						LSD 5%
	AL_B		GC_G		LO_G		
	Puddling 1993						
	Low	High	Low	High	Low	High	
Initial drying rate (mm/d)	2.8	2.7	2.9	4.6	2.6	3.3	0.9
Duration of initial drying (d)	15.7		11.3		19.3		4.8
Rate of maximum water uptake (mm/d)	4.0	4.1	1.7	1.8	5.0	3.4	0.9 (lsd 10%)
Onset of water stress (d)	58.9		>77		60.3		4.6
Water used until stressed (mm)	154		118		159		15

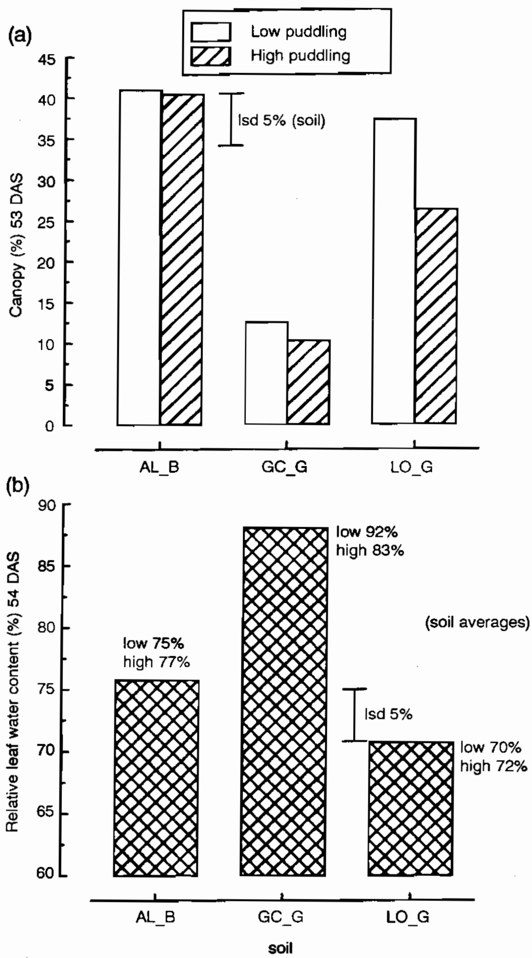


Figure 10. The effect of puddling on mungbean leaf canopy (a) and relative leaf water content (b) 23 days after sowing (DAS).

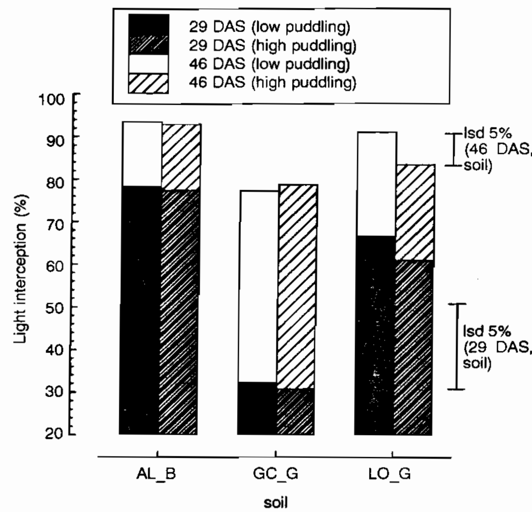


Figure 11. Mungbean light interception in the puddling experiment 29 and 46 days after sowing (DAS).

The different stages of water uptake were less defined in the compaction experiment (Table 9). Initial drying could not be differentiated from the phase of water uptake of established plants. This was probably due to earlier sowing compared to the previous year, mid-summer for the puddling experiment and mid-spring in the compaction experiment, where potential evaporation rates were similar to water uptake of established plants. Since plants grew into summer with increasingly hot temperatures, rates of maximum water uptake were higher and water stress occurred earlier on the silty soils AL_B and the clay soil GC_G, but approximately at the same time for the sandy soil LO_G. The high evapotranspiration rates resulted in higher water use but lower yields in the compaction experiment compared to the puddling experiment. The average harvest index was 28% and was not affected by soil type and compaction. It suggested that most water was used for vegetative growth and no more water was available for grainfill, resulting in relatively lower yields (Table 10). This was also the reason why no significant relationships were observed between water use between sowing and harvest, grain yield and total biomass production. It is interesting to note that yield on the clay soils GC_G was fairly closely predicted using the equation derived from the puddling experiment (Fig. 14). Increased water use on the coarser-textured soils was not reflected in higher yields due to reduced water use efficiency.

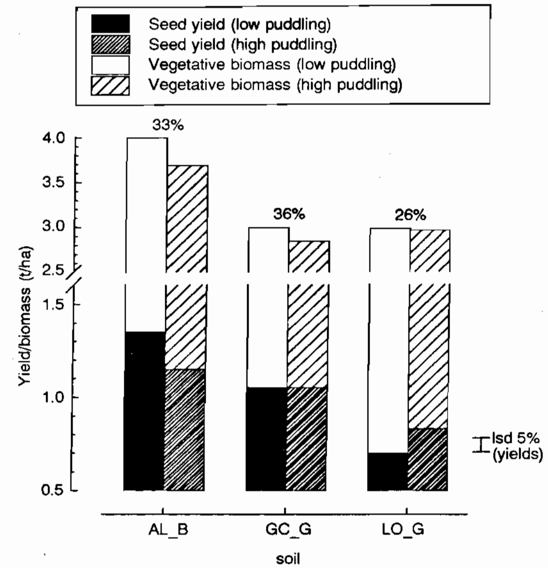


Figure 12. Mungbean biomass and seed yield in the puddling experiment (% values above bars are harvest indices).

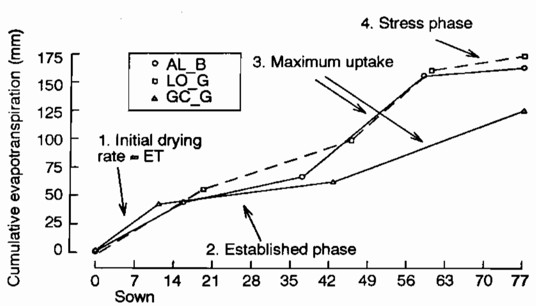


Figure 13. The different stages of water uptake during mungbean growth in the puddling experiment.

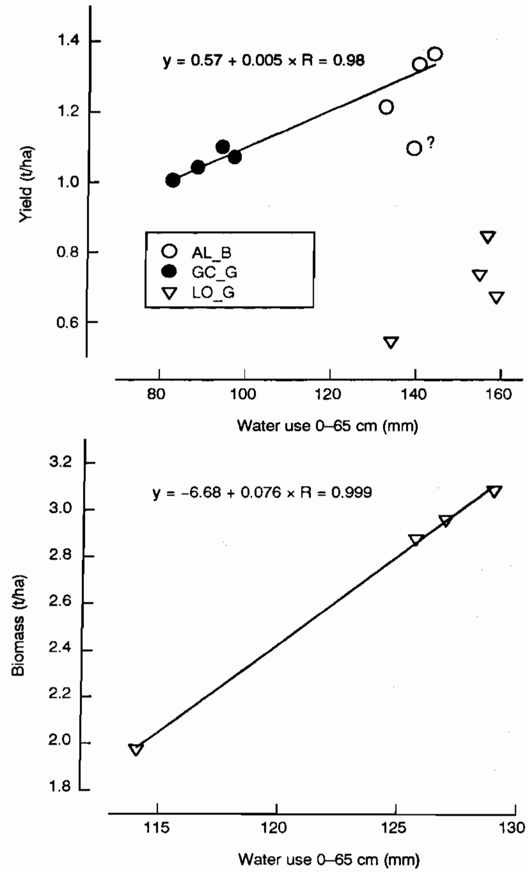


Figure 14. Soil water use and its relation to seed yield and total biomass for mungbean in the puddling experiment.

Table 9. Water-use parameters in 1994.

Water uptake stage	Soil			LSD 5%
	AL_B	GC_G	LO_G	
Rate of maximum water uptake (mm/d)	4.5	2.0	4.3	1.0
Onset of water stress (d)	53.4	63.7	60.0	7.0
Water use until stressed (mm)	171	132	182	20 (lsd 10%)

Table 10. Water use and mungbean yields for the three different soils in the compaction experiment.

Soil	Water use (mm)	Seed yield (t/ha)
AL_B	158	
GC_G	117	1.2 ± 0.1
LO_G	176	
lsd 5%	24	ns

It is important to note that soil water was limited by the depth of the mini-ricebeds. In both experiments water uptake clearly went to the bottom of the mini-ricebeds. This limitation is unlikely to exist under field conditions where roots could explore depths well below 1 m. Provided crop establishment and agronomic factors are not limiting and excessive rainfall does not occur during the growing season, yields in the field could be superior to those obtained under glasshouse conditions, even in the absence of rainfall.

Summary and Conclusion

- Soil puddling increased dispersion but dispersion decreased with time of inundation resulting in decreased K_{sat} with time of inundated conditions.
- Puddling can be reduced without affecting rice yields, except on sandy soils.
- Compaction decreases percolation rates except on clay soils and tends to reduce rice yields.
- Compaction is likely to be beneficial for rice on coarse-textured soils, but should be avoided on clay soils.
- Establishment percentage of mungbean was reduced on highly puddled structurally unstable (i.e. silty) soils.
- Mungbean yield was reduced on structurally unstable soils puddled with high intensity.
- Puddling should be reduced on structurally unstable soils because it reduces crop establishment and yield.
- Mungbean yields of above 1 t/ha are possible under conditions of non-limiting crop establishment on a soil depth of 65 cm and where 100 mm of water is available.

References

Cook, S.M.F., Gupta, S.C., Woodhead, T. and Larson, W.E. 1995. Soil physical constraints to establishment of mungbean (*Vigna radiata* L. Wilczek) in paddy rice (*Oryaza sativa* L.) soils. Soil and Tillage Research, 33, 47–64.

Fawcett, R.G. and Collis-George, N. 1967. A filter paper method for determining the moisture characteristics of soil. Australian Journal of Experimental Agricultural and Animal Husbandry, 162–167.

Hillel, D. 1980. Fundamentals of soil physics. Academic Press, New York, London, Toronto, Sydney, San Francisco.

IRRI 1985. Tillage and management of soil physical conditions. International Rice Research Institute Annual Report for 1984, International Rice Research Institute, Los Baños Laguna, Philippines PO Box 933, 1099 Manila, Philippines, 320–330.

IRRI 1986. Tillage and management of soil physical conditions. International Rice Research Institute Annual Report for 1985, International Rice Research Institute, Los Baños Laguna, Philippines PO Box 933, 1099 Manila, Philippines, 280–304.

IRRI 1987. Cultivation of puddled soils for rainfed legumes. Annual Report for 1986, International Rice Research Institute, PO Box 933, 1099 Manila, Philippines, 46–60.

IRRI 1988. Tillage and management of soil physical conditions. Annual Report for 1987, International Rice Research Institute, Los Baños Laguna, Philippines PO Box 933, 1099 Manila, Philippines, 398–414.

IRRI 1993. IRRI Rice Almanac 1993–1995. International Rice Research Institute, PO Box 933, 1099 Manila, Philippines.

IRRI 1994. Rainfed lowland rice ecosystems, Program report for 1993, International Rice Research Institute, PO Box 933, 1099 Manila, Philippines, 46–60.

Isbell, R.F. 1995. Sealing, crusting and hardsetting conditions in Australian soils. Proceedings, International Symposium on sealing, crusting and hardsetting soils: productivity and conservation, Brisbane, The University of Queensland, 7–11 February 1994, 15–30.

Jones, R.H. and Molitoris, B.A. 1984. A statistical method for determining the break point of two lines. Analytical Biochemistry, 141, 287–290.

Kirchhof, G. and So, H.B. 1995. Soil puddling for rice production and its effect on soil structure and water percolation. Proceedings, International Symposium on sealing, crusting and hardsetting soils: productivity and conservation, Brisbane, The University of Queensland, 7–11 February 1994, 413–420.

Ludlow, M.M. 1982. Measurement of stomatal conductance and plant water status. In: Coombs, J. and Hall, D.O., ed., Techniques in Bioproductivity and Photosynthesis, 44–57.

Pagliai, M. and Painuli, D.K. 1988. The physical properties of paddy soils and their effect on postrice cultivation for upland crops. In: Soil Management for Sustainable Rice Production in the Tropics. Selected papers from the first International Symposium on Paddy Soil Fertility, Chiang Mai, Thailand 6–13 December 1988. Ibsram Monograph No. 2, 391–415.

Sharma, P. K. and Bhagat, R.M. 1993. Puddling and compaction effects on water permeability of texturally different soils. Journal of the Indian Society of Soil Science, 41, 1–6.

So, H.B. and Cook, G.D. 1993. The effect of slaking and dispersion on the hydraulic conductivity of clay soils. Catena Supplement 24, 55–64.

So, H.B. and Woodhead, T. 1987. Alleviation of Soil Physical Limits to Productivity of Legumes in Asia. In: Wallis, E.S. and Byth, D.E. ed., Food Legume Improvement for Asian Farming Systems, Proceedings on an international workshop held in Khon Kaen, Thailand, 1–5 September 1986, 112–120.

Wopereis, M.C.S. 1993. Quantifying the impact of soil and climate variability on rainfed rice production. PhD thesis, Wageningen, Netherlands.

Changes to the Physical Properties of Soils Puddled for Rice during Drying

A.J. Ringrose-Voase[1], J.M. Kirby[1], Gunomo Djoyowasito[2], W.B. Sanidad[3], C. Serrano[3] and Tabran M. Lando[4]

Abstract

An experiment was carried out at the San Ildefonso, Manaoag, Maros and Ngale sites of ACIAR Project 8938. The experiment measured physical parameters as they changed in the period after draining flood water for rice harvest. The experiments were run for 4 to 6 weeks, during which they were kept free from weeds. Apart from Maros, where there were heavy rain showers, the sites received no effective rainfall during the experiment.

Soil moisture content and hydraulic potential in the upper 40 cm were measured regularly in five replicate plots. Evaporation from the soil was measured using mini-lysimeters. Strength properties were measured using a penetrometer and sheargraph. Cracks were measured using an intercept technique. Hydraulic conductivity was calculated using a modification of the instantaneous profile technique.

The sites behaved in a similar fashion, with initial loss of water by drainage, followed by loss by evaporation from the surface. However, the low conductivities limited the upwards supply of water for evaporation so that evaporation from the soil surface decreased. This resulted in strong drying of the upper 5–10 cm, but much smaller decreases in moisture content lower down. The strength of the upper layers increased as they dried.

The soil water profile was successfully modelled for one of the sites using SWIM (Ross 1990). This shows the potential for modelling soil physical conditions in the rice soils after drainage during the period when dry season legume crops might be established. Such models would aim to show soil–climate combinations where dry season legumes can be established after rice with a reasonable probability of success.

In addition to the E1 and E2 experiments carried out for ACIAR Project 8938 at each of the five sites for three years (So et al., these Proceedings), a third experiment, E3, was carried out once at four of the five sites. The aim of the E3 experiments was to provide basic data about the changing physical, mechanical and structural conditions in a rice soil during the period following drainage of flood water in preparation for rice harvest. Physical conditions in the upper part of the soil profile have a profound influence on the establishment of dry season (DS) crops sown during this period. These data are necessary to allow development of a dynamic model of the soil water profile which also controls changes in structural and strength properties. A crucial part of such a model is calculation of the hydraulic conductivity-matric potential relationship for the various soil layers. The model is intended to predict changes in the soil water profile and the structural and mechanical properties dependent on soil moisture after field drainage for various climatic conditions. This will allow investigation of how frequently a post-rice crop is likely to fail for particular soil–climate combinations. Failure could be caused by

[1]CSIRO Division of Soils, GPO Box 639, Canberra, ACT 2601 Australia
[2]Department of Agricultural Technology, Brawijaya University, Malang, East Java, Indonesia
[3]Bureau of Soils and Water Management, Elliptical Road cnr. Visayas Avenue, Quezon City, the Philippines
[4]Research Institute for Maize and Other Non-rice Cereal Crops, PO Box 173, Ujung Pandang, South Sulawesi, Indonesia

excess water during crop establishment. Alternatively, in climates where there is insufficient rainfall for the crop to survive with its roots solely in the surface layer, a crop might fail because its roots are unable to penetrate the subsoil to extract water.

Soils

E3 experiments were conducted at four sites: an experimental station at Barangay Buenavista, San Ildefonso, Bulacan Province, Philippines; a farmer's field in Barangay Calmay, Manaoag, Pangasinan Province, Philippines; a farmer's field at Allepolea near Maros, S Sulawesi, Indonesia; and an experimental station at Ngale, near Ngawi, E. Java, Indonesia. These sites have been described in detail by Schafer and Kirchhof (these Proceedings).

Ringrose-Voase et al. (1995) present some analyses of the soil (Table 1). The Ngale soil is a heavy clay with 80% < 2 μm. Maros and Manaoag have very similar particle size distributions with 50–55% < 2 μm and are both silty clays. San Ildefonso has the least clay (35–40% < 2 μm) and is a clay loam to clay. Unlike the other soils it has a significant sand fraction (35% > 50 μm). The clay fractions show a range of mineralogical compositions. San Ildefonso is dominated by smectite (63%) and kaolinite (35%); Manaoag by smectite (70%), vermiculite (15%) and kaolinite (10%); Maros by kaolinite (50%), smectite (25%) and illite (15%); and Ngale by smectite (95%). The range of clay minerals and clay contents gives a wide range in the contents of shrink/swell clays (Table 1). This is also reflected in the range of modified linear shrinkage (LS_{mod}) values from 5% to 19% measured using the method of McKenzie et al. (1994). In particular, the Maros and Manaoag soils have similar particle size distributions but have quite different clay minerals and shrink/swell potentials.

Ringrose-Voase et al. (1995) found that the soils are mainly neutral with those of Maros and San Ildefonso showing some acidity in the surface. ECs indicate that none of the soils are saline. The CECs vary from about 20 cmol (p+)/kg at Maros to nearly 70 cmol (p+)/kg at Ngale. The differences are due to mineralogy and clay content. However, the exchange complexes of all the soils are dominated by divalent cations (Ca and Mg) and none are sodic.

Methods

The experiment was conducted at San Ildefonso and Manaoag in January 1994 over periods of 26 and 28 days respectively. At Maros it was conducted in April–May 1993 for a duration of 34 days and at Ngale in May–June 1994 for 40 days.

The first experiment at Maros was carried out at the beginning of the dry season during the period when rice would be harvested and dry season crops planted. However, this period proved prone to occasional heavy rain, which considerably slowed drying of the soil. The other experiments were carried out in the middle of the dry season to ensure

Table 1. Particle size distributions, proportions (on whole soil basis) of swelling clay minerals (smectite and vermiculite) and modified linear shrinkages for the E3 sites (from Ringrose-Voase et al. 1995).

Site	Sand 50–2000 μm	Silt 2–50 μm	Clay <2 μm	Smectite + vermiculite	LS_{mod}
Depth, cm	% (whole soil)				
San Ildefonso (Ustic Epiaquert)					
0–11 cm	33	25	42	26±8	0.071
11–30 cm	34	17	49	34±10	
Manaoag (Typic Ustropept)					
0–7 cm	1	43	56	48±14	0.096
15–22 cm	2	43	55	47±14	
30–37 cm	2	44	54	46±14	
Maros (Aeric Tropaquept)					
0–12 cm	2	49	49	15±7	0.050
12–18 cm	3	44	53	16±7	
18–37 cm	4	43	53	16±7	
Ngale (Chromic Epiaquert)					
0–15 cm	6	16	78	74±22	0.192
15–25 cm	2	16	82	78±23	
25–40 cm	3	15	82	78±23	

the maximum possible drying and none received any substantial rain. The Ngale site was covered by a temporary rain shelter as a precaution, but this proved unnecessary.

All sites except Manaoag were prepared by puddling involving two animal-drawn ploughings and harrowings and were transplanted with rice, which was nearly ready for harvesting at the start of the experiment. During the rice crop, the flood water had receded on several occasions resulting in some consolidation of the puddled layer. The rice was harvested and the soil reflooded briefly. The following day was considered to be the first day after drainage (DAD).

The Manaoag soil is relatively well drained which meant that flooded conditions could not be maintained into the middle of the dry season. Consequently, this site had been sown to mungbean after the wet season rice crop. Shortly before the experiment began, the mungbean was harvested and the site was flooded and puddled by two cattle-drawn ploughings and harrowings. The site was allowed to drain overnight before measurements were started the following morning.

During the experiments, the sites were kept free of vegetation by regular weeding and cutting of rice ratoons.

The sites were divided into seven plots (18 × 4 m at San Ildefonso; 14 × 2 m at Manaoag; 18 × 3 m at Maros and 6 × 1.7 m at Ngale). The second and fifth plots were used for crack measurements and the other five for other measurements.

Surface cracks

Surface cracks were measured in two plots using transects consisting of a series of six linked semicircles of 1 m diameter (Ringrose-Voase and Sanidad, in press). The length of crack per unit area, L_A, was estimated from the number of intercepts with cracks. The depth and width distributions were determined by measuring the first five cracks intercepted by each semicircle using a flexible ruler (i.e. 60 pairs of measurements in total). These data were used to estimate mean cross-sectional area, $\overline{X}$, assuming a triangular cross-section. The crack volume per unit area, V_A, can be estimated as $L_A\overline{X}$. The crack volume fraction, $V_V(d)$, profile can also be calculated from the data.

Soil moisture content and bulk density

On each sampling day soil moisture content, air-filled porosity and bulk density were measured using a single 10 cm diameter core taken from each of the five plots using a long coring tube and an electric jack hammer. The cores were divided into volumetric samples at depths of 0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm, 25–30 cm and 35–40 cm. Care was taken when positioning the corer to avoid any large surface cracks, since it was impossible to sample the crack pattern adequately. Since the volume of cracks was not included, the core samples tended to overestimate the moisture content and bulk density. The volumetric contents were corrected by multiplying by $(1-V_V(d))$, where $V_V(d)$ is the volume fraction of cracks in a given layer. For example for moisture content, θ_v:

$$\theta_v(corrected) = \theta_v(measured)\cdot(1 - V_V(d)) \qquad \text{Eqn 1}$$

Soil moisture potential

Soil moisture potential was measured using arrays of six tensiometers installed in the centres of the five plots at depths of 0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm, 25–30 cm and 35–40 cm. These were read by a pressure transducer. When the potential decreased beyond tensiometer range later in the experiment, cores (generally 10 cm diameter × 5 cm depth) were taken and the matric potential measured in the laboratory using the filter paper method (Greacen et al. 1989).

The moisture retention characteristic was also determined in the laboratory on five replicate cores (100 mm diameter × 50 mm depth) from the 0–10 cm, 15–20 cm and 30–35 cm layers at each site using a combination of tension and pressure plates (McIntyre 1974).

Evaporation from the soil surface

Evaporation from the soil surface was measured using a single mini-lysimeters in each of the five plots. These consisted of cores of 10 cm diameter taken from the soil surface in metal rings of 5–10 cm depth. The bases of the cores were sealed using plastic to prevent water movement between the cores and the surrounding soil. The cores were weighed and placed back in the soil until the next sampling day, when they were recovered and reweighed to determine the volume of water lost through evaporation.

Soil strength

Soil strength was measured using a Rimik recording penetrometer at 1.5 cm depth intervals to 50 cm depth. Measurements were made in triplicate within each of the five plots (i.e. 15 replicates in total). In addition, a sheargraph (Kirby et al. 1994) was used to measure the shear strength (cohesion and angle of internal friction) at three depths: in the puddled layer just below the surface; in the compacted layer at 15 or 20 cm depth; and in the subsoil at 30 cm depth.

Plot layout

Within each plot the volumetric samples, mini-lysimeters and soil strength measurements were all taken in close proximity to each other. These measurements are destructive and cause substantial disturbance in their proximity, especially in soft, puddled soil. In order not to disturb parts of the plots reserved for later sampling, they were not located randomly within each plot on any one day. Instead they were located near one end of the plot on the first sampling day and then progressed across the plot on subsequent sampling days. However, to ensure some randomisation, the locations for the first day were alternated between opposite ends of the plots. This sampling strategy also meant that tensiometer measurements, which were located in the centre of each plot, were not necessarily more closely related to the other measurements in the same plot than to those in the other plots. As a result, the hydraulic conductivity calculations (see below) were calculated using values for each parameter which had been averaged for the five replicates. Hence the calculations were performed only once for the whole experiment, rather than separately for each plot, which would have given some estimate of variability.

Hydraulic conductivity

Unsaturated hydraulic conductivities, $K(\Psi)$, were estimated for each site using a modification of the instantaneous profile method (Hillel 1980). The method was modified by allowing evaporation from the surface and measuring the amount of evaporation using mini-lysimeters, instead of preventing evaporation and setting the flux at the surface to zero. The calculations involved were as follows:

1. As discussed above, the layout of the experiment meant that it was not possible to perform the calculations for each plot independently in order to gain an estimate of variability. Instead the calculations were performed on the mean moisture contents and matric potentials for each sampling interval on each sampling day. Values for unsampled layers (20–25 cm and 30–35 cm) were estimated by linear interpolation between the adjacent layers. Moisture contents were corrected for the volume of unsampled cracks using Eqn 1. In addition, mean evaporation from the soil surface was calculated from the mini-lysimeters.
2. The total volume of water, $V_{i,j}$, between the surface and the lower boundary of each sampling layer, i, on each sampling date, j, was calculated as:

$$V_{i,j} = \sum_{I=1}^{i} \theta_{I,j} \cdot d_I \qquad \text{Eqn 2}$$

where $\theta_{I,j}$ is the volumetric water content in layer I on sampling date j and d is the sampling interval, in this case 50 mm.

3. The moisture contents were used to calculate the flux of water, $q_{i,j-1\rightarrow j}$, across the lower boundary of each sampling layer, i, between sampling dates j-1 and j as follows:

$$q_{i,j-1\rightarrow j} = \frac{(V_{i,j-1} - V_{i,j}) - E_{j-1\rightarrow j}}{(t_j - t_{j-1})} \qquad \text{Eqn 3}$$

where $E_{j-1\rightarrow j}$ is the volume of water lost by evaporation from the soil surface over the same period (measured using the mini-lysimeters) and t_{j-1} and t_j are the number of days since drainage on sampling dates j–1 and j. Note that positive fluxes indicate downward movement and negative fluxes upward movement.

4. The fluxes calculated relate to the period between sampling days. The flux *on* a sampling day, $q_{i,j}$, was calculated by linearly interpolating between the fluxes of the sampling periods before and after (i.e. $q_{i,j-1\rightarrow j}$ and $q_{i,j\rightarrow j+1}$) assuming these relate to the mid-points of the relevant periods, i.e. $(t_{j-1}+t_j)/2$ and $(t_j+t_{j+1})/2$:

$$q_{i,j} = q_{i,j-1\rightarrow j} + \left[(q_{i,j\rightarrow j+1} - q_{i,j-1\rightarrow j})\cdot\frac{(t_j - t_{j-1})}{(t_{j+1} - t_{j-1})}\right] \qquad \text{Eqn 4}$$

Clearly, $q_{i,i}$ could not be calculated for the first and last sampling days.

5. The potential gradient $(d\Psi/dZ)_{ij}$ across the lower boundary of the ith sampling layer on the jth sampling date was calculated from the tensiometer or filter paper measurements. Assuming the measured hydraulic potentials refer to the centres of the sampling layers, the gradient was:

$$\frac{d\Psi}{dZ_{i,j}} = \frac{2(\Psi_{i,j} - \Psi_{i+1,j})}{(Z_{i+1} - Z_{i-1})} \qquad \text{Eqn 5}$$

where $\Psi_{i,j}$ is the hydraulic potential (matric + gravitational) in the centre of the ith sampling layer on the jth sampling date and Z_i is the depth of the lower boundary of the ith sampling layer. Positive values indicate that potential decreases with depth (i.e. water will move downwards).

6. The hydraulic conductivity, $K(\Psi)_{i,j}$, at the bottom of the ith sampling layer on the jth sampling date was calculated as:

$$K(\Psi)_{i,j} = \frac{q_{i,j}}{\frac{d\Psi}{dZ_{i,j}}} \qquad \text{Eqn 6}$$

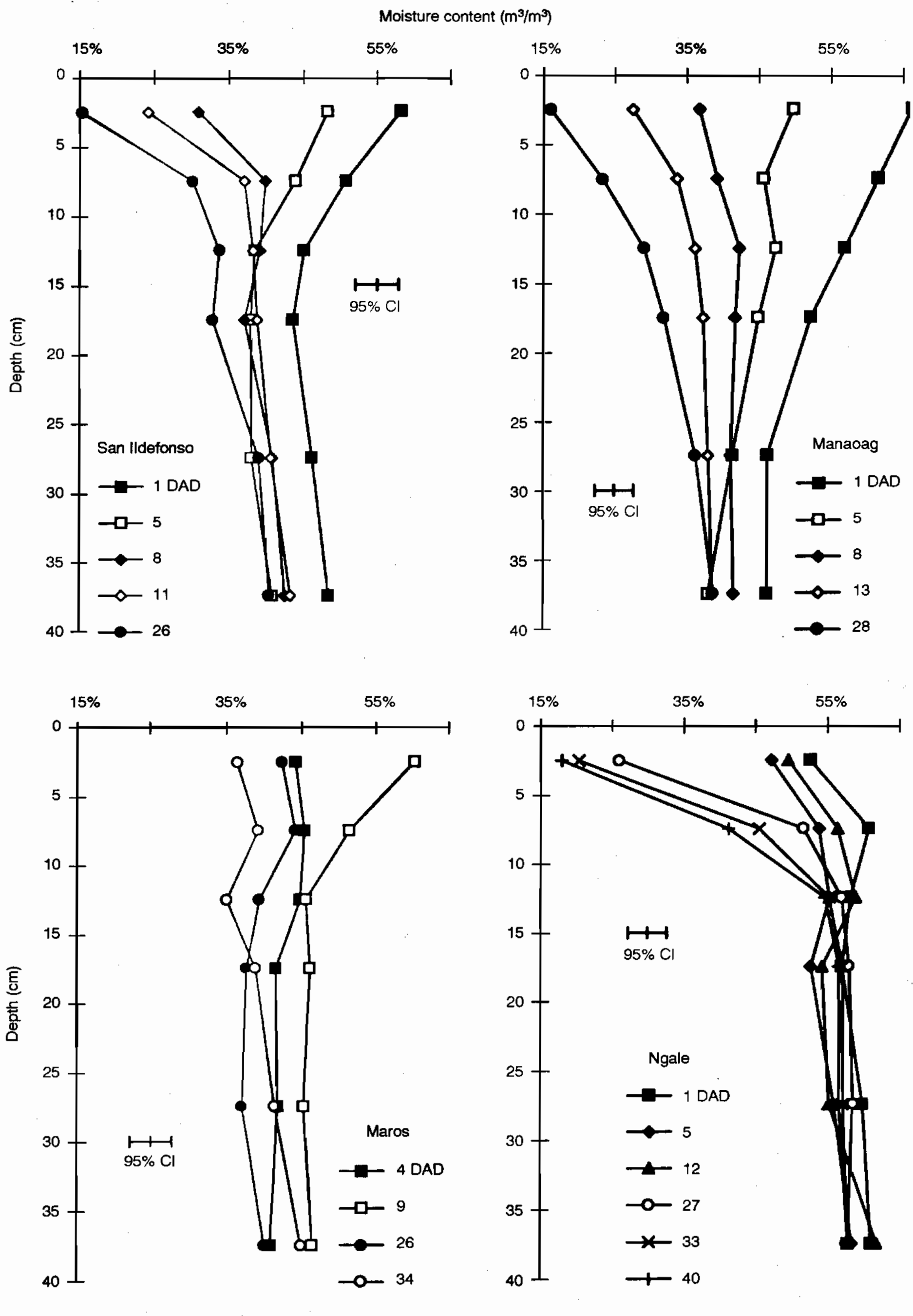


Figure 1. Development of the moisture content profile on different days after drainage (DAD). 95% CI: 95% confidence interval.

where the matric potential, $Y_{i,j}$, at the bottom of the ith sampling layer on the jth sampling date is estimated by linear interpolation between depths. Negative values sometimes resulted where the direction of the flux and the potential gradient were opposite. This was caused by field variation because moisture content and potential were not measured in the same location. Such values were ignored.

Results and Discussion

Moisture loss

The changes in the moisture contents, θ, at each site are shown in Figure 1. At the start of the experiment the soil was driest at Maros. However, heavy rain the day before the second sampling 9 DAD wetted the profile. Subsequent rain, including a heavy shower 25 DAD meant that drying was very slow.

There was no significant rain at the other sites during the experiments resulting in much greater drying of the surface layers. At San Ildefonso and Manaoag, the water used to re-flood the sites drained from the upper 40 cm between 1 and 5 DAD. Thereafter, there was less water loss from the sub-surface layers, presumably because they had reached field capacity. Drying occurred within the upper 10 cm at San Ildefonso and 20 cm at Manaoag.

At Ngale, drying was restricted to the upper 10 cm and virtually none occurred below this depth, despite the experiment being run for 40 days.

Crack development

At all sites except Maros, the length of crack per unit area, L_A, initially rose rapidly to a maximum of 30–35 m/m^2 (Fig. 2). The freshly puddled nature of the soil at Manaoag meant that there were no cracks to start with, so the maximum was reached later. The very rapid increase in crack length at Ngale was probably due to the self-mulching nature of the Ngale soil. After reaching a maximum the length of cracks decreased slightly as some cracks closed. This phenomenon was also observed by Hallaire (1984) and the authors on earlier occasions (unpublished data).

The increase in crack volume, $V_V(d)$, however, was quite different in the different soils (Fig. 3). At Manaoag the volume increased very rapidly because water loss was rapid and because shrinkage was due to consolidation of the freshly puddled soil as well as the presence of clay minerals with shrink/swell properties. At San Ildefonso and Ngale, the volume increased more slowly because the soil had already consolidated during the rice phase and shrinkage was due to the presence of clay minerals with shrink/swell properties. The greater volume at Ngale compared to San Ildefonso was due to the greater

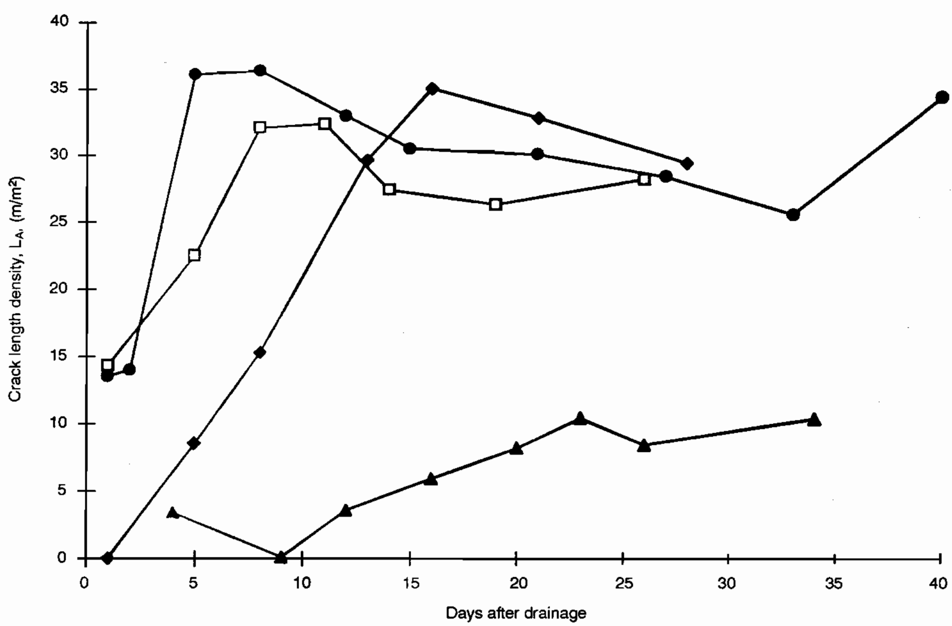


Figure 2. Development of crack length at the four E3 sites. □ San Ildefonso; ♦ Manaoag; ● Maros; ▲ Ngale.

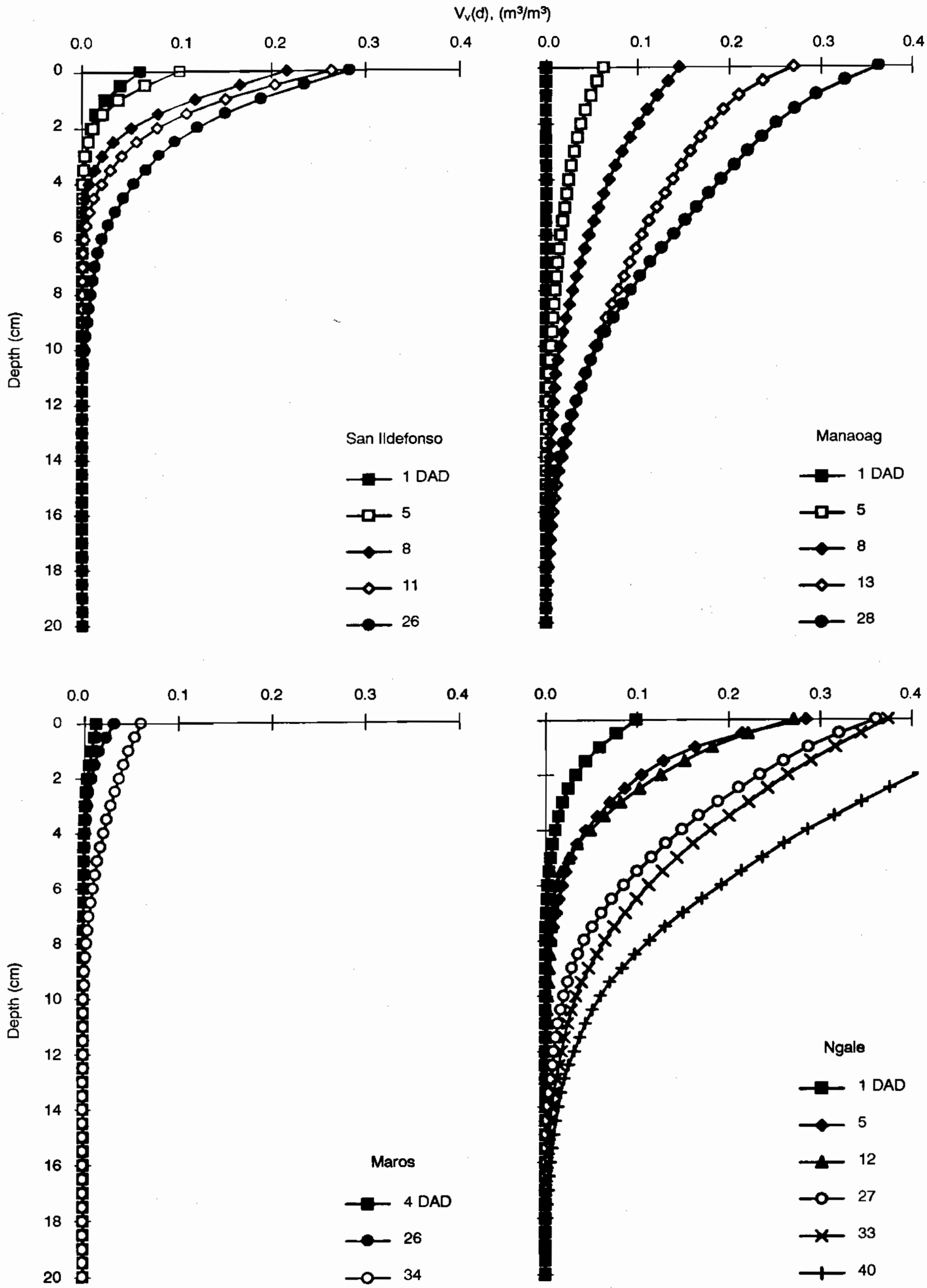


Figure 3. Development of the crack volume profile (i.e. crack volume/unit volume at each depth) on different days after drainage (DAD).

proportion of such clay minerals at Ngale (Table 1).

Further evidence for this explanation is given in Table 2 which compares the volume of cracks generated per unit loss of water in the 0–5 cm layer (as measured in the field) with the areal shrinkage calculated from LS_{mod}. LS_{mod} is largely dependent on the proportion of shrink/swell clay (Table 1). The two parameters are not strictly equivalent since the former is per unit loss of moisture content and the latter over a fixed matric potential range. However, comparison of the ratios of the two parameters indicate whether the shrinkage measured as cracks is accounted for by the differences in LS_{mod}. The ratios for San Ildefonso and Ngale were both about 2, indicating that the difference in shrinkage measured in the field could be attributed to the difference in the proportions of shrink/swell clay. The ratio at Manaoag was much higher indicating that some of the shrinkage in the field was due to other factors in addition to shrink/swell clay, probably consolidation.

Air-filled porosity (inter-crack)

The air-filled porosity (AFP) discussed here includes only the AFP between the cracks. Changes in AFP are shown in Figure 4. AFP values must be interpreted with care since any compaction of the sample during sampling would tend to affect AFP more than other soil components and would be greatest at the start of the experiment when the soil was softest.

Except at Manaoag, which had been freshly puddled, there was reasonable AFP in the surface layers at the start of the experiment indicating that field saturation was probably incomplete. The increase in AFP as moisture content decreased was tempered by increases in the crack volume. Thus at Ngale and Manaoag, which showed the greatest increase in crack volume per unit loss of moisture content (Table 2), there was correspondingly less increase in AFP. At San Ildefonso where there was less crack development, there was greatest development in AFP.

Table 2. Shrinkage characteristics of the 0–5 cm layer. The change in crack volume per unit loss of moisture, $\Delta V_V/\Delta\theta$, is the regression coefficient obtained by regressing crack volume (m^3/m^3) against loss of moisture content (m^3/m^3). Areal shrinkage is the area of cracks expected from the modified linear shrinkage (see Table 1). The ratio of these two indicates how much of the cracking measured in the field is explained by LS_{mod}.

Site	Increase in crack volume (m^3/m^3) per m^3/m^3 loss of water (A)	Areal shrinkage $= 2LS - LS^2$ (B)	A/B
San Ildefonso	0.261 ($r^2 = 0.96$)	0.137	1.91
Manaoag	0.551 ($r^2 = 0.90$)	0.183	3.01
Maros	0.119 ($r^2 = 0.57$)	0.098	1.22
Ngale	0.714 ($r^2 = 0.81$)	0.347	2.06

Soil strength

Figure 5 shows the penetration resistance profiles at the four sites as the profiles dried. The strengths of the surface layers increased as they dried. The strength of the upper 2 cm was usually weaker than immediately below. This was because a dry crust about 2 cm deep formed which was extensively cracked. Although the solid material between the cracks was probably stronger than that below, the cracking reduced the penetration resistance. In the surface layers, Ngale and Manaoag tended to be stronger than San Ildefonso and Maros.

Below 15 cm depth, strength changed very slowly because of the slow rate of drying. At Manaoag the subsoil tended to be stronger, because of the degree to which the profile had dried before it was reflooded for the experiment. Ngale tended to be weakest in the subsoil. The only profile to show any evidence of a plough pan was Maros, where there was an increase in strength at about 15 cm depth. In none of the soils did the strength of the sub-soil increase to more than 2 MPa, which is widely quoted as limiting root growth. Given that the sub-soils only dry very slowly in the absence of roots to extract water, it is likely that their strength will remain low until after roots have penetrated a layer. Hence, it is possible that sub-soil strength may not be limiting for post-rice crops.

Relationship between strength and moisture content —puddled layer

The strengths of different soils can only be compared in relation to moisture content, since it has an overriding effect on strength. Figure 6 shows the relationship between penetration resistance (*PR*) and moisture content (θ) for the surface soil at the four sites. The relationships are approximately linear, (although at Maros there is some evidence that it may be curvilinear), so a regression equation of the form $PR = -m\theta + c$ was fitted to the data for each site. The regression analyses are shown in Table 3. The fits were highly significant as shown by the F-statistic probabilities and account for 50–90% of the variation in penetration resistance. Fitting a multiple regression by including bulk density increased r^2 slightly at San Ildefonso and Manaoag and more so at Maros and Ngale, but in some cases implied that strength decreased with increasing bulk density, which is the opposite of what is expected. The addition of bulk density was deemed not to be valuable on an individual soil basis.

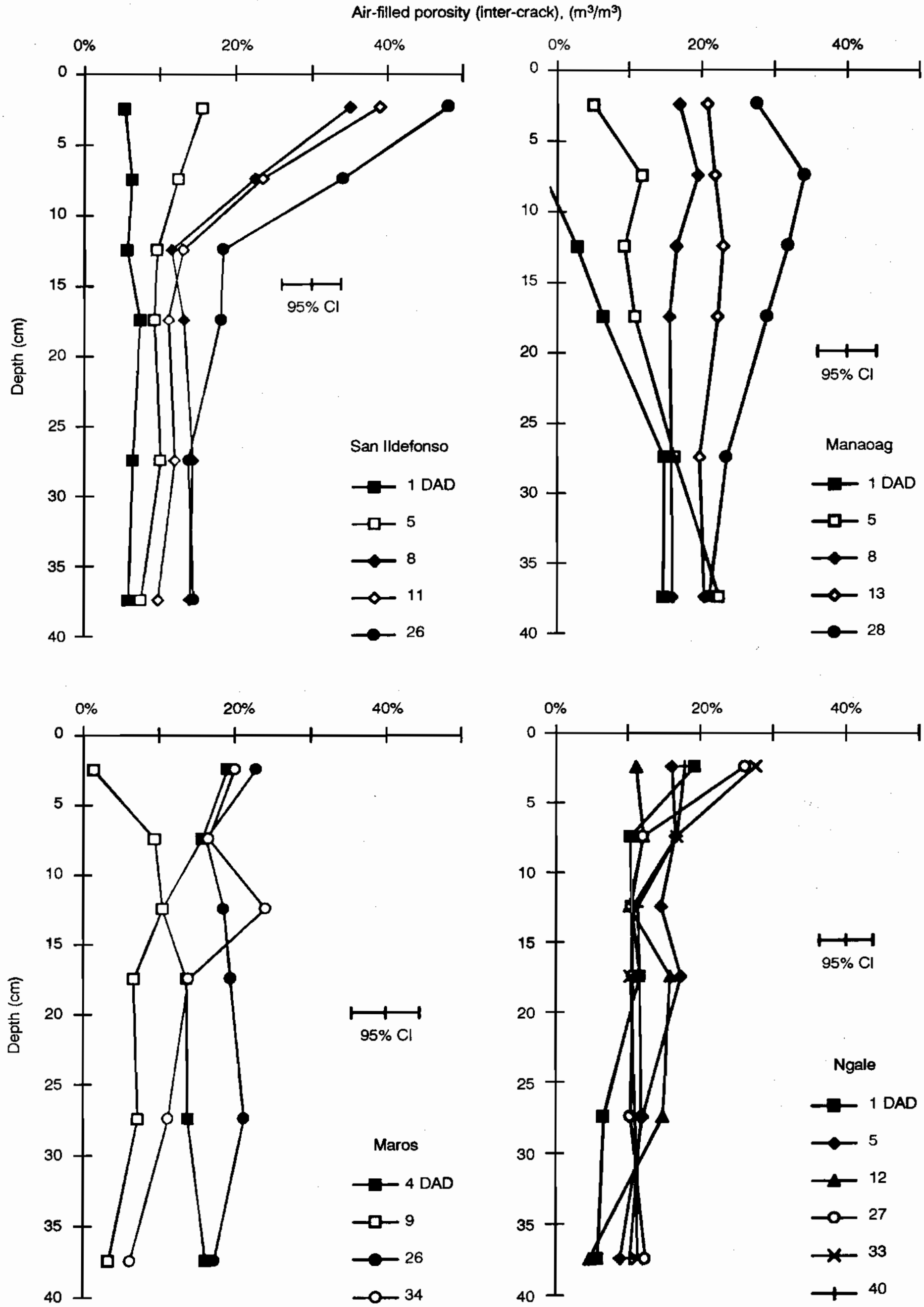


Figure 4. Development of the air-filled porosity profile on different days after drainage (DAD). 95% CI: 95% confidence interval.

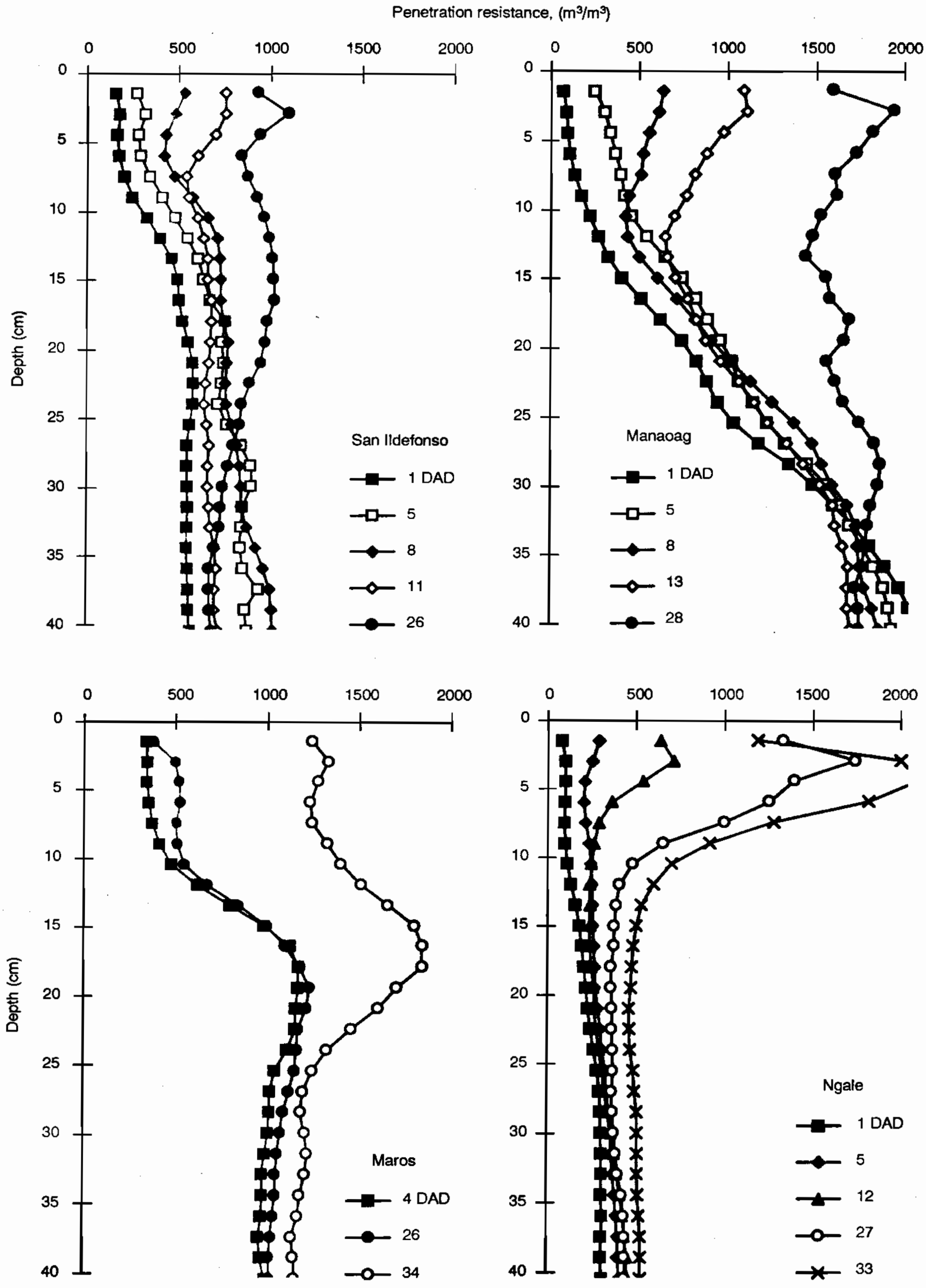


Figure 5. Development of penetration resistance on different days after drainage (DAD).

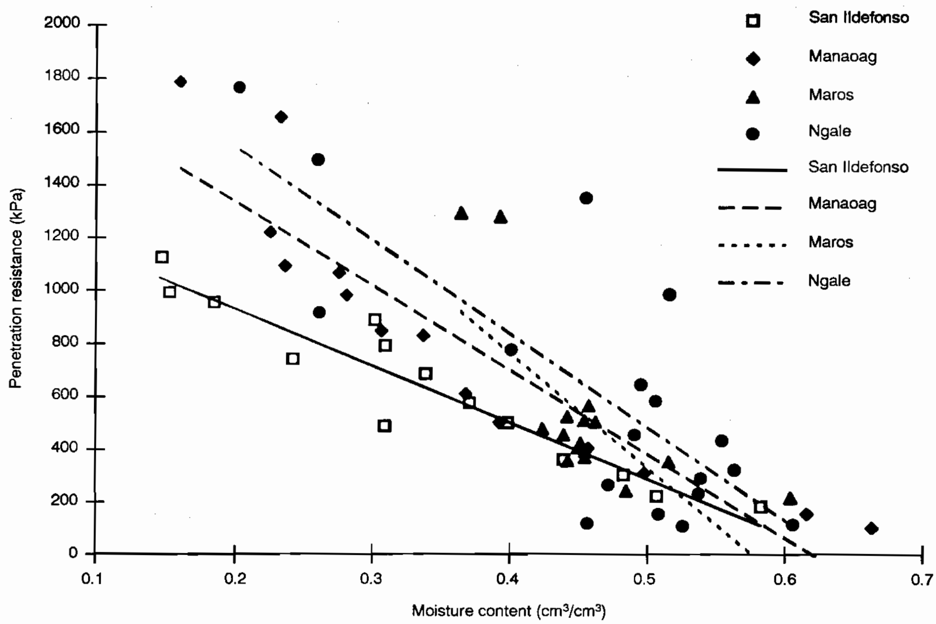


Figure 6. Regressions of penetration resistance for the 0–5 cm and 5–10 cm layers against moisture content. Symbols are data points, lines are fitted by linear regression as in Table 3.

Table 3. Regression analyses of the form $PR = -m{\bullet}\theta + c$ for the 0–5 cm and 5–10 cm layers of penetration resistance (*PR*, means of 3 depths/layer × 3 replicates/plot × 5 plots) against moisture content (θ, means of 5 replicate plots) for the four sites.

Site	*m* (se_m)	*c* (se_c)	r^2	F-statistic probability
San Ildefonso 0–10 cm	2168 (204)	1359 (74)	0.904	1.8×10^{-7}
Manaoag 0–10 cm	3203 (385)	1972 (150)	0.852	2.5×10^{-6}
Maros 0–10 cm	4347 (1108)	2492 (508)	0.524	1.6×10^{-3}
Ngale 0–10 cm	3553 (698)	2248 (333)	0.619	1.1×10^{-4}

San Ildefonso had lower penetration resistances than the other sites over most of the moisture content range with lower values of both *c* and *m*. Ngale was stronger than the other sites at most moisture contents. However, the *m* value (slope) for Maros was greater than that for Ngale and Manaoag so that its strength was similar to that at Ngale at low water contents (i.e. its *c* value is similar to Ngale). The greater strength of the Ngale soil at a given moisture content was because the soil has a large amount of tightly held water due to its high smectite content

Cohesion and friction angle as measured by the sheargraph also generally increase with decreasing moisture content (Figs 7 and 8), although the relationship is weak at Ngale. At the other sites, the relationship between cohesion and moisture content is weaker than that for friction angle. This is because cohesion is dependent on two opposing trends — that of strength increase of the soil matrix with drying, and that of strength decrease of the bulk soil with cracking. The friction angle is less affected by cracking, so the relationship with moisture content is stronger.

Relationship between penetration resistance and moisture content — subsoil

Unfortunately, the lack of subsoil drying during the experiment meant that penetration resistance and sheargraph parameters were only measured over a small range of moisture contents. The regression analyses accounted for less than 50% of the variation in resistance and were mostly insignificant.

In summary, differences in the penetration resistances at various depths in the four soils results from a complex interaction of the different relationships between strength and moisture content at each site and the different rates at which the profiles dry. The latter itself results from the interaction between moisture content, hydraulic potential and hydraulic conductivity, which are also different in each soil. The regression analyses probably allow prediction of penetration resistance from moisture content at least in the puddled layer. Therefore a reasonable model of the water balance for the soils could be used to predict soil strength as well.

Water movement

Figure 9 shows the rate of evaporation, $E_{j-1\rightarrow j}/(t_j - t_{j-1})$, from the surface as measured using the mini-lysimeters. The rate of evaporation declined as the surface soil dried and water movement from below was restricted by low hydraulic conductivity. Manaoag and Maros generally had higher rates than San Ildefonso and Ngale. At Manaoag this was because the freshly puddled soil had a high content of easily removed water. At Maros the higher rate may have been due to higher temperatures.

Figure 10 shows the fluxes through the profile, $q_{i,j-1\rightarrow j}$, over time calculated using Eqn 3. The sites generally followed a similar pattern, with relatively high downward fluxes as the soil returned to field capacity immediately after re-flooding. However, even in this early period, there was a zero-flux plane a few centimetres below the surface as water in the surface soil was removed by evaporation. This zero-flux plane moved down the profiles very rapidly as the profiles drained. This was followed by a period of moderate upward fluxes supplying the evaporative demand at the surface. The upward fluxes then declined as removal of water decreased the matric potential and $K(\Psi)$.

The pattern at Maros was rather different due to several heavy rainfalls. The heavy rainfall made it difficult to determine the flux at the surface, necessitating the omission of $K(\Psi)$ estimates calculated using such periods.

The values of $K(\Psi)$ calculated for various values of Ψ using Eqn 6 are shown in Figure 11.

Predicting water movement

As discussed, a model of the moisture profile in puddled soils as they dry after the rice harvest would be a useful tool for determination of probabilities of waterlogging occurring during crop establishment or of the soil having too little water for successful establishment. A model of one of the sites (Ngale) was developed in order to investigate the potential for using the data generated in the experiments in such a model.

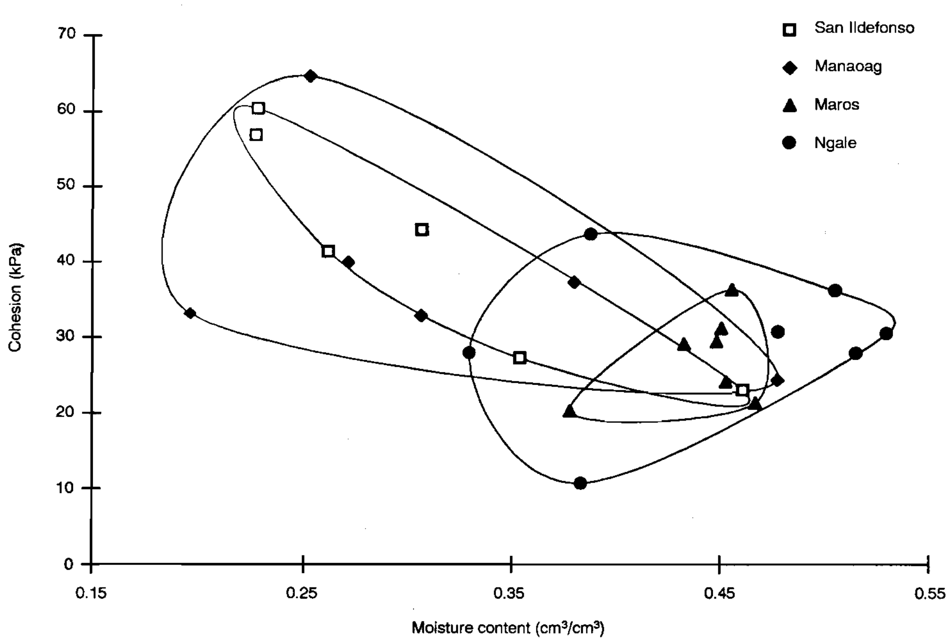


Figure 7. Cohesion as measured by sheargraph against moisture content at 5 cm depth.

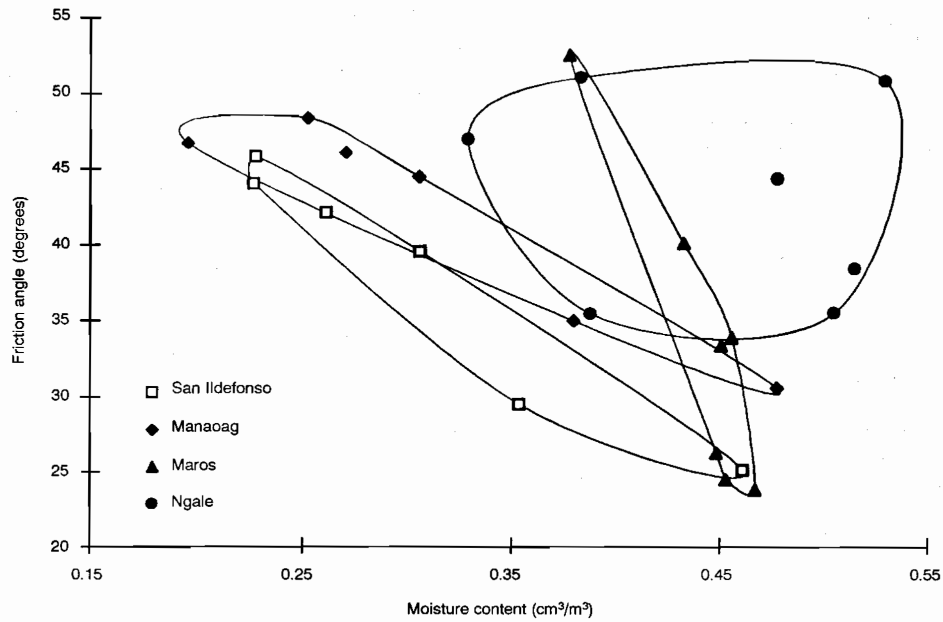


Figure 8. Friction angle as measured by sheargraph against moisture content at 5 cm depth.

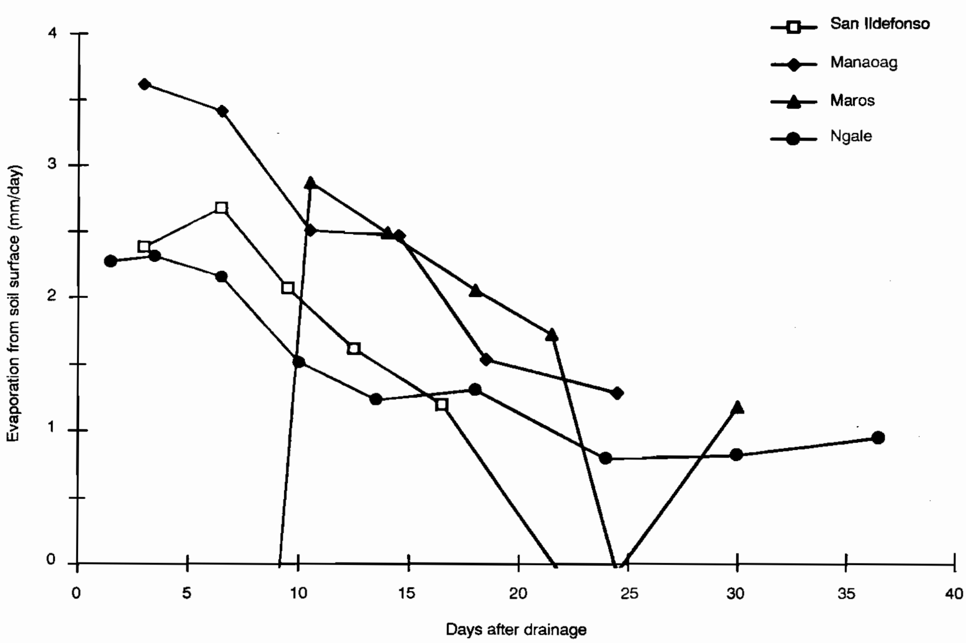


Figure 9. Evaporation from the soil surface at the four sites measured using mini-lysimeters. Negative values correspond to periods where rainfall exceeded evaporation.

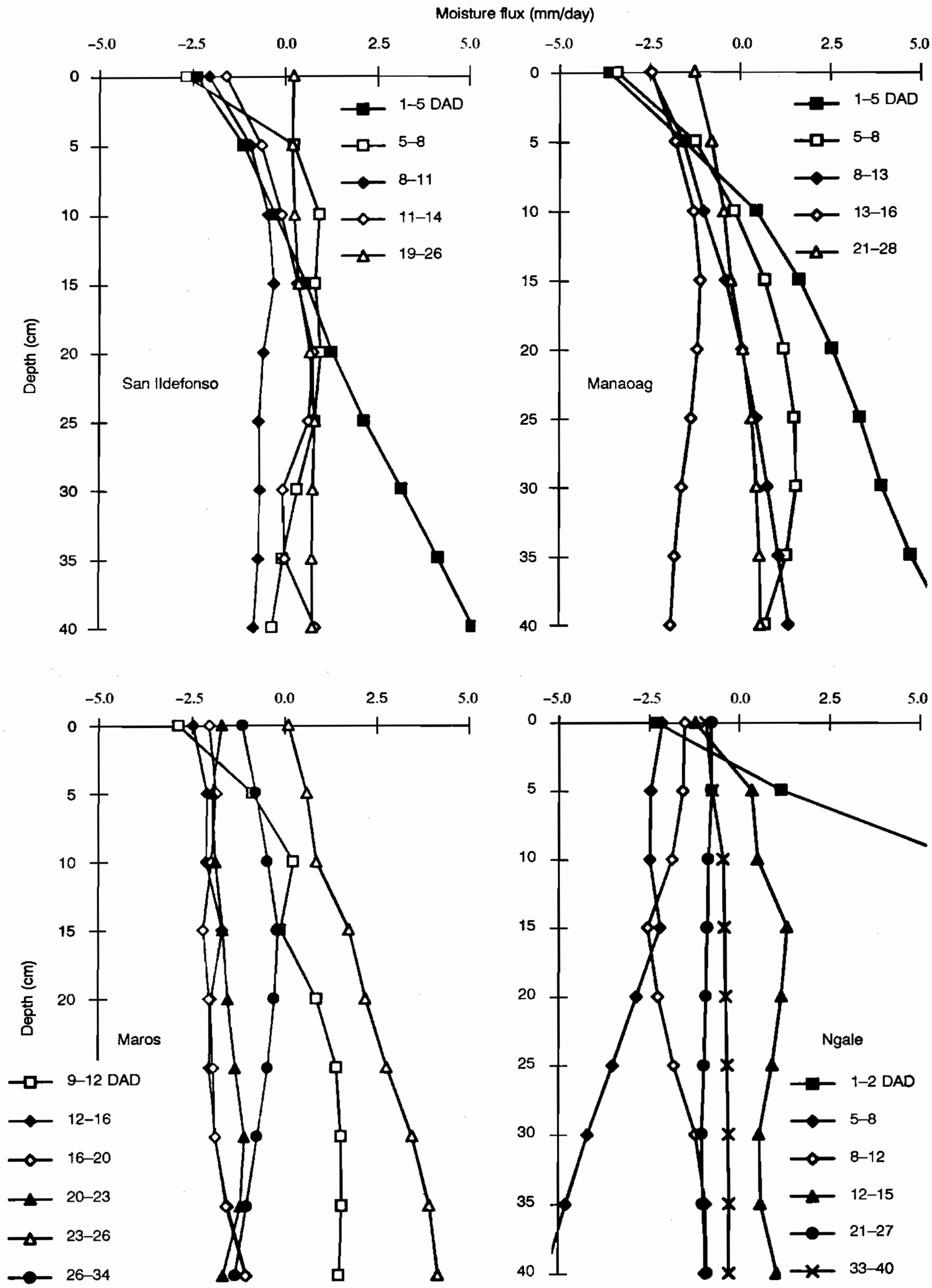


Figure 10. Moisture flux profiles between different days after drainage (DAD) at the four sites. Negative fluxes are upwards.

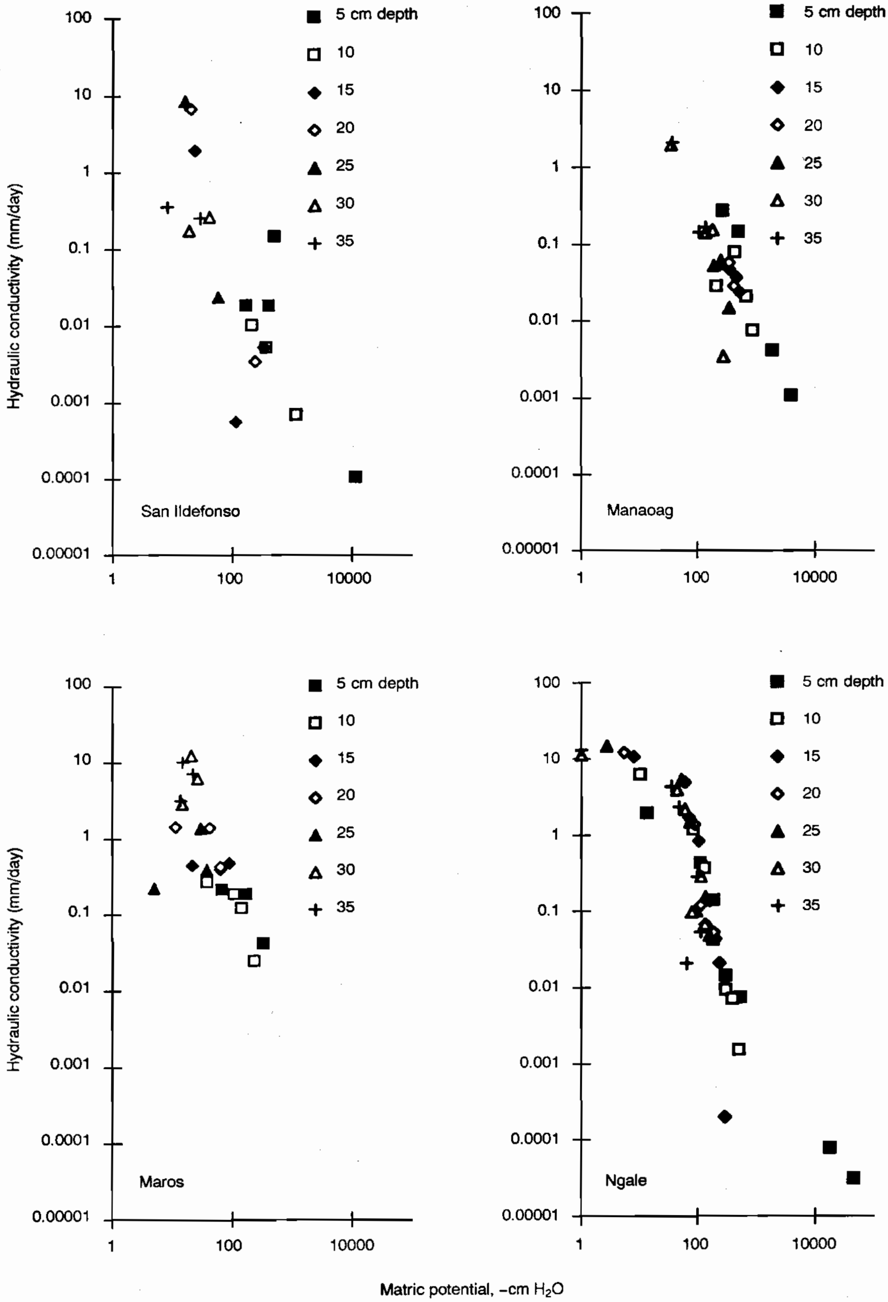


Figure 11. Hydraulic conductivity — matric potential relationships at the four sites.

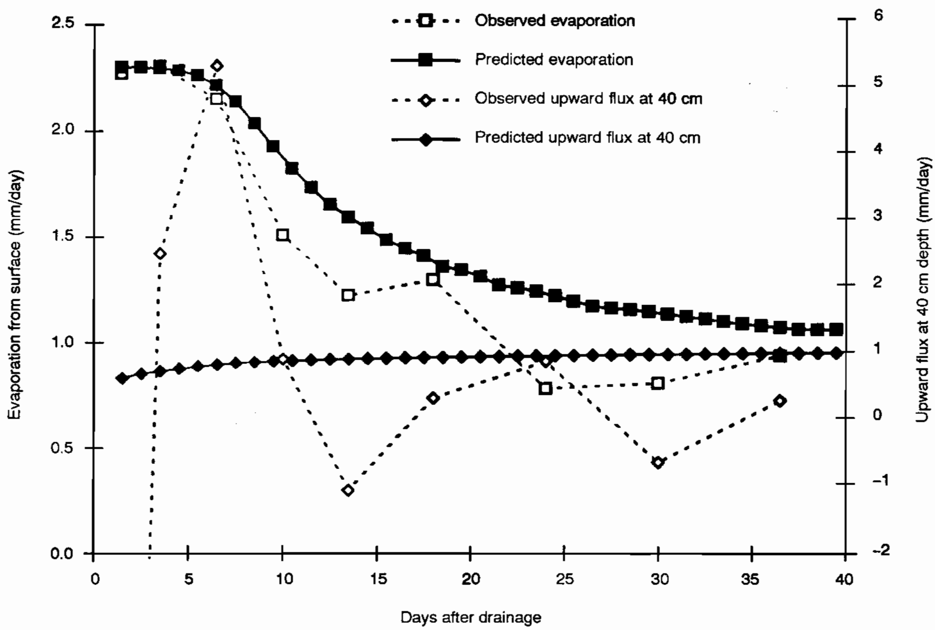


Figure 12. Upward fluxes from the surface and at 40 cm depth predicted by SWIM for the Ngale site (solid lines) compared to observed fluxes (dashed lines).

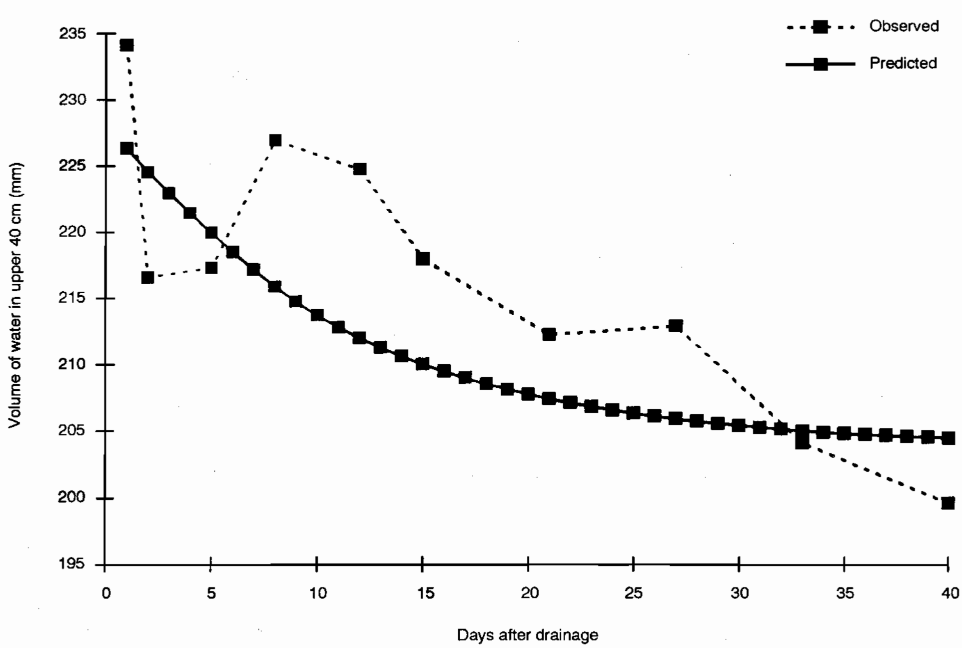


Figure 13. Change in the total volume of water between 0 and 40 cm depth predicted by SWIM for the Ngale site (solid line) compared to observed changes (dashed line).

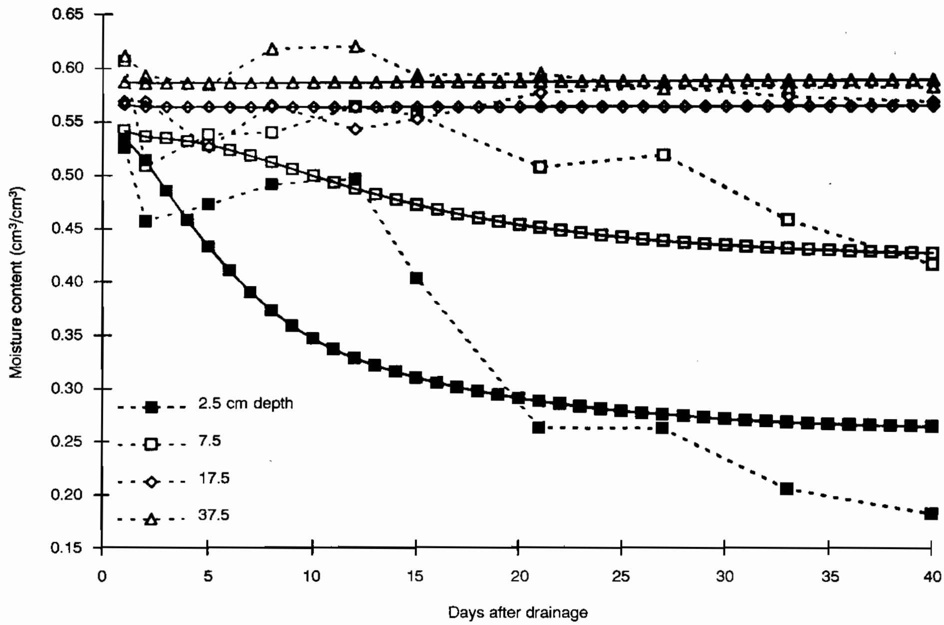


Figure 14. Changes in moisture content of various layers predicted by SWIM for the Ngale site (solid lines) compared to observed changed (dashed lines).

The hydraulic properties calculated above for the Ngale soil were parameterised for use in the SWIM (Soil Water Infiltration and Movement) model (Ross 1990) which is a one-dimensional soil water model based on Richard's equation. A Campbell function (Campbell 1985) was used to parameterise the moisture characteristic for the 0–10 cm, 10–25 cm and 25–40 cm layers. Hutson and Cass (1987) smoothing was used to smooth the retention curve around the air entry potential (Ψ_e). The moisture characteristic was then parameterised as:

$$\theta = \begin{cases} \theta_s\left(\frac{\Psi}{\Psi_e}\right)^{-1/b} & \Psi < \Psi_i \\ \theta_s(1 - c\Psi^2) & \Psi_i \leq \Psi < 0 \\ \theta_s & 0 \leq \Psi \end{cases} \qquad \text{Eqn 7}$$

where $\Psi_i = \Psi_e a^{-b}$, $c = (1-a)/\Psi_i^2$ and $a = 2b/(1+2b)$. The curve was fitted by minimising the residuals between observed and predicted θs.

Values of θ and Ψ measured in the field were too noisy to be able to determine the shape of the function. Therefore the moisture characteristics were also measured in the laboratory. However, the degree of saturation in the field was considerably less than in the laboratory, so that the laboratory curves were considerably above a plot of θ versus Ψ as measured in the field. Therefore the function was fitted in two stages. First it was fitted to the laboratory data to fix the shape of the curve, i.e. b and Ψ_e. Then it was fitted to the field data, using fixed values of b and Ψ_e derived from the first stage, in order to obtain a suitable value of θ_s.

The hydraulic conductivity-moisture content relationship was parameterised as:

$$K = K_s\left(\frac{\theta}{\theta_s}\right)^{bn} + K_m\left(\frac{\theta}{\theta_s}\right)^{bm} \qquad \text{Eqn 8}$$

This was fitted to the $K(\Psi)$ values calculated using the instantaneous profile method, using the values of Ψ_e, θ_s and b from the moisture retention curves.

To simulate soil water during the experiment, SWIM was set up with same initial moisture potentials as measured in the field. Layers were defined down to 150 cm depth. Layers below 40 cm were defined using parameters for the 35–40 cm layer. The lower boundary condition was set to a constant potential to allow water to move upwards from a theoretical watertable. The potential at

150 cm depth was adjusted so that the fluxes at 40 cm depth and at the surface matched those measured as closely as possible. This means the predictions made by SWIM are not entirely independent of the data used for validation. Figure 12 shows the fluxes when the potential at 150 cm depth was set to +70 cm (i.e. equivalent to a watertable at 80 cm depth), which proved a reasonable compromise. Lower potentials reduced upward fluxes so that the evaporation rate was closer to that measured but the flux at 40 cm was much too low. Higher potentials overestimated the evaporation rate. With a potential of +70 cm SWIM slightly overestimates evaporation and estimates the flux at 40 cm reasonably over the course of the experiment. However, it does not simulate the large fluctuations near the start very well.

SWIM predicted the amount of water between 0 and 40 cm depth reasonably well (Fig. 13). Its predictions of the distribution of the water within the top 40 cm were less accurate (Fig. 14), especially in the early stages. However, it should be noted that volumetric measurements during the early stages when the soil was soft were quite difficult.

Given that no allowances were made for vertical volume change, the predictions made using SWIM were reasonably good. However, it is necessary to have knowledge of the watertable depth so that the potential at the lower boundary can be set independently. Since SWIM cannot simulate watertables of fluctuating depths, its use may be limited in rice soils. The simulation shown here was intended to demonstrate that such models at least have potential in rice-based cropping systems.

Conclusion

Detailed measurements of the physical conditions in puddled soil as it dried after field drainage showed several features common to all four sites.

- There was rapid loss of water from the surface layer, but quite slow loss from sub-surface layers.
- Drying of the surface layers was accompanied by cracking and an increase in strength.
- The slow rate of drying of the sub-soil meant that sub-soil strength remained low. It is unlikely to become limiting to root growth until after roots have already penetrated a layer and begun to extract water.
- During the first few days water movement in the profile was downwards. However, a zero-flux plane rapidly developed and moved down the profile so that most of the time water movement in the top 40 cm was upwards driven by evaporation from the surface.
- The hydraulic conductivities of the soils were all relatively small and rarely exceeded 10 mm/day even near saturation. As the water content decreased, hydraulic conductivity fell to very low values.
- Once the surface layer had dried, water loss by evaporation was limited by the falling hydraulic conductivity.

It was possible to simulate the moisture profile at Ngale using SWIM. If this is possible at the other sites, it will be possible to model soil water and strength for a range of soil–climate combinations. This will help show where post-rice legumes can be established with a reasonable probability of success and allow different species and sowing dates to be tested. To do this it will be crucial to have better data on the critical soil physical conditions for successful establishment of DS legume species in terms of: the length of time for which they can tolerate waterlogging; the driest soil they are able to tolerate; and the greatest soil strength their roots are able to penetrate.

Acknowledgments

The authors thank ACIAR for funding this project and the following:

Bureau of Soils and Water Management, Philippines: Messrs Oscar Manaois, Ulyses Latoza and Jojo Ponce for help with field work and Director Godofredo Alcasid, Dr Perfecto Evangelista and Mrs Esperanza Dacanay for their support of the work.

Mr and Mrs Severo Arellano for use of their field (Manaoag) and for accommodation at their house.

Research Institute for Maize and Other Non-rice Cereal Crops, Maros, Indonesia: Messrs Mustari Basir, Rahmat Hanif Anasiru and members of the Agricultural Engineering Department for help with field work and Drs A. Hasanuddin and Bambang Prastowo for supporting the work.

Research Institute for Legume and Tuber Crops, Malang, Indonesia: Mr and Mrs Djarwo for providing accommodation and meals at the Ngale site; Messrs Prakoso and Suharto for help with field work and Dr Titis Adisarwanto for supporting the work.

Brawijaya University, Malang, Indonesia: Messrs Daniel Budiyono, Udji Dewantoro, Sugeng Riyadi, Riyanto and Budi Santoso for help with field work.

CSIRO Division of Soils, Canberra, Australia: Mr Bruce Blunden (now with NSW EPA) for help with field work in the Philippines; Messrs Inars Salins and Colin McLachlan for assistance with equipment and Messrs Rod Drinkwater and Tom Green for measuring the moisture retention characteristics of the soils.

References

Campbell, G.S. 1985. Soil Physics with BASIC. New York, Elsevier.

Greacen, E.L., Walker, G.R. and Cook, P.G. 1989. Procedure for the filter paper method of measuring soil water suction. CSIRO (Australia) Division of Soils, Divisional Report No. 108.

Hallaire, V. 1984. Evolution of crack networks during shrinkage of a clay soil under grass and winter wheat crops. In: Bouma, J. and Raats, P.A.C., ed., ISSS Symposium on Water and Solute Movement in Heavy Clay Soils. Wageningen, The Netherlands, ILRI Publication 37, 49–53.

Hillel, D. 1980. Fundamentals of Soil Physics. New York, Academic Press, 217–221, 227–232.

Hutson, J.L and Cass, A. 1987. A retentivity function for use in soil-water simulation models. Journal of Soil Science, 38, 105–113.

Kirby, J.M., McLachlan, C.B. and Blunden, B.G. 1994. Calibration of a sheargraph. Soil and Tillage Research, 31, 1–9.

McIntyre, D.S. 1974. Water retention and the moisture characteristic. In: Loveday, J. ed., Methods for Analysis of Irrigated Soils. Commonwealth Bureau of Soils Technical Communication 54. Farnham Royal, U.K., Commonwealth Agricultural Bureaux, 43–62.

McKenzie, N.J., Jaquier, D.J. and Ringrose-Voase, A.J. 1994. A rapid method for estimating soil shrinkage. Australian Journal of Soil Research, 32, 931–938.

Ringrose-Voase, A.J. and Sanidad, W.B. A method for measuring the development of surface cracks in soils: application to crack development after lowland rice. Geoderma (in press).

Ringrose-Voase, A.J., Hutka, J., Beatty, J., Raven, M.D. and Rath, H. 1995. Analyses of some Indonesian and Philippine soils for ACIAR Project 8938 'Management of clay soils for lowland, rice-based cropping systems'. CSIRO (Australia) Division of Soils Technical Report 11/1995.

Ross, P.J. 1990. SWIM — a simulation model of Soil Water Infiltration and Movement. Reference Manual. CSIRO (Australia) Division of Soils, Townsville, Australia.

Soil Puddling and Rice Growth

W.H. Utomo[1], B. Prastowo[2], T. Adisarwanto[3], E.V. Dacanay[4], G. Kirchhof[5] and H.B. So[5]

Abstract

An experiment to study the effect of soil puddling intensity on the growth and yield of rainfed lowland rice was conducted at five locations in Indonesia and the Philippines over three years. In Indonesia, the experiments were conducted at Ngale and Jambegede in East Java and Maros in Sulawesi. In the Philippines, experiments were carried out at Bulacan and Manaoag, north-north east of Manila.

Four degrees of puddling were imposed by different methods of puddling, namely: dry puddling, one wet ploughing and harrowing, two wet ploughings and harrowings using draught animals, and two wet cultivations using a rototiller. Treatments were arranged in a fully randomised block design with four replications.

The results showed that although differences were found in some soil physical properties, there were no effects on rice growth and yield, except on the lighter-textured soils where dry cultivation resulted in lower yield associated with increased water stress and competition from weeds.

THE use of a rainfed lowland cropping system for rice production represents approximately two-thirds of all rice cropping systems used in the countries of South and Southeast Asia (Huke 1982). Due to a shortage of water, most farmers in rainfed lowland areas do not grow secondary crops after rice. When they do, the yields of these crops are usually very low (Pasaribu and McIntosh 1985; Adisarwanto et al. 1989) and well below the potential yield of these crops (So and Woodhead 1987). These low yields are commonly associated with the adverse effects of soil physical conditions induced by puddling during land preparation for the rice crop (Pasaribu and McIntosh 1985; Adisarwanto et al. 1989).

The strength of puddled soil increases rapidly upon drying and this condition may restrict the growth of roots of the secondary crop. As a result, these crops cannot access the considerable amount of water that is stored in the subsoil after the prolonged period of inundation during the rice phase. To increase the yield and stability of yield of secondary crops after rice, it has been suggested that the effects of adverse soil physical conditions can be minimised by manipulation of soil puddling during land preparation for rice (Sharma and De Datta 1985; Utomo et al. 1985). Tranggono and Willatt (1988) showed that increasing the intensity of puddling resulted in increased maize yields on a Vertisol but decreased yields in a lighter-textured hardsetting Regosol in East Java. It is important that any manipulation of the puddling intensity should not affect the growth and yield of the primary rice crop.

In conventional rice growing systems, land preparation is usually done by two plowings and two harrowings under submerged conditions. This type of puddling is considered very important for growing lowland rice (Sanchez 1976). It makes transplanting of rice seedlings easier. Puddling is also required to reduce the loss of water and nutrients through excessive percolation, to reduce weeds and the reduced conditions enhance nutrient availability

[1] University of Brawijaya, Fakultas Pertanian, Jl. Mayjen Harjono 18, Malang 65145, Indonesia
[2] Research Institute for Legumes and Tuber Crops (RILET), Kendalpayak, PO Box 66, Malang 65101, Indonesia
[3] Research Institute for Maize and other Cereals, Jl. Dr Ratulangi, Maros 90514, Indonesia
[4] Bureau of Soil and Water Management, Cnr Elliptical Rd and Visayas Avenue, Quezon City 1100, The Philippines
[5] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia

(Ghildyal 1978; Sharma and DeDatta 1985). Despite these beneficial factors, the effect of puddling on rice yields is not clear. Puddling has been reported to increase the yield of rice (Van de Goor 1950; Sakanoue and Mizunuma 1962; Sanchez 1973; DeDatta and Kerim 1974). However, other reports have shown that puddling may not be necessary as it did not affect rice yields (Mabbayard and Buencosa 1967; Scheltema 1974; Utomo et al. 1985).

One major aspect of Project 8938 is to examine the effect of puddling intensity on the productivity of secondary crops after rice. It is imperative that any potential changes to current puddling practice should not affect the yield of rice. Therefore, the objective of the experiment described in this paper is to determine the effect of soil puddling intensity on the growth and yield of lowland rice in different soils and climatic conditions. It is assumed that the different puddling methods used would result in a range of different puddling intensities which can be ranked but it is not yet possible to quantify.

Materials and Methods

Five experiments were carried out in Indonesia and the Philippines. In Indonesia, the experimental sites were at Ngale and Jambegede, both in East Java, and Maros in South Sulawesi. In the Philippines, the experiments were conducted at Manaoag, Pangasinan and Bulacan, San Ildefonso, both north-north east of Manila. The soils and climatic conditions of these sites have been described by Schafer and Kirchhof (these Proceedings).

In Indonesia the rice crop was grown in the rainy seasons of 1991–92, 1992–93 and 1993–94, and in the Philippines it was grown in the rainy seasons of 1992, 1993 and 1994. The rainy seasons in the two countries differ by approximately 6 months, associated with the different monsoon seasons.

The puddling treatments comprised four degrees of puddling:

- T1: dry cultivation before submergence, approximately at the plastic limit of that soil;
- T2: one wet ploughing and harrowing using draught animals;
- T3: two wet ploughings and harrowings using draught animals;
- T4: wet cultivations using rototillers/hydrotillers.

The intensity of puddling increased from T1 to T4 and attempts were made to control the depth to 15 to 20 cm. These treatments were arranged in a fully randomised block design with four replications.

Uniform application of 300 kg urea, 150 kg TSP and 100 kg KCl per hectare was made before the last harrowing or cultivation for the rice crops. A second fertilizer application of 100 kg urea per ha was made at 30 days after transplanting.

Rice cv. IR 64 was used in East Java and the Philippines, and cv. Ciliwung at Maros. In all locations, rice was planted at a spacing of 20 × 20 cm. Hand weeding was done at 30 and 60 days after transplanting.

Measurements were made for soil properties and crop growth. Soil properties include the water stable aggregates of the wet soil (mean weight diameter (MWD)), depth of puddling/tillage, the sinkage capacity and the soils infiltration rates. Due to limited resources, not all measurements were made at all sites. Crop parameters measured include plant height, number of tillers, dry matter and grain yields.

Results and Discussion

Changes in soil properties

As discussed earlier, soil puddling is considered necessary to soften the soil for transplanting of rice seedling and to reduce water loss through excessive percolation (Ghildyal 1978). The measurement of the depth of tillage/puddling conducted at Maros showed that the different puddling intensities resulted in different depths of puddling (Table 1) and the results were consistent for the three seasons. The greatest depth of puddling at 17 cm was obtained with the two wet ploughings and harrowings. Although the two wet cultivations with a rototiller were considered to have a great puddling intensity, the floating nature of the machine kept puddling depth to a minimum of only 9.5 cm. The sinkage capacity measurement made at Jambegede showed a similar trend with the rototiller resulting in a depth of puddling of 10 cm (Fig. 1). At Jambegede the depth of puddling from the dry and wet cultivations using the draught animals was uniform at 20 cm. Strength of the wet surface soil or its sinkage capacity decreased with increasing degree of puddling except with the rototiller treatment which has a higher strength than the other two wet cultivations. The reason for this discrepancy is not clear at this stage. The sinkage capacity of all treatments is well below 100 kPa and there should be no difficulty in transplanting the rice seedings. Since transplanting is commonly done to a depth of 10 cm, the rototiller treatments should have adequate depth of puddled soil.

The measurement of MWD of the wet puddled surface soils for the Ngale and Jambegede soils showed that all treatments gave a similar range of water stable aggregates (Table 2). Dry cultivation on the soil from Ngale tends to create aggregates with a greater MWD but the difference is not significantly different. Whether the soil was cultivated dry or wet, under submerged conditions they break down to a similar range of water stable aggregates and it is possible that these aggregates are those that remained stable with the long history of wet cultivation of the soil prior to this experiment.

Table 1. Effect of puddling intensity on the depth of puddled soil at Maros. Means followed by the same letters are not significantly different at P = 0.05.

Treatments	Tillage depth (cm)		
	1992	1993	1994
T1	14.2 b	14.4 b	13.9 b
T2	16.6 c	16.4 c	16.4 c
T3	17.0 c	17.1 c	17.1 c
T4	9.2 a	9.4 a	9.5 a

Table 2. Effect of puddling intensity on the mean weight diameter (MWD) of soil for the 1994–95 experiment at Ngale and Jambegede.

Treatments	MWD (mm)			
	Ngale		Jambegede	
	11-12-94*	16-3-95	30-1-95*	13-2-95
T1	0.070	0.074	0.072	0.074
T2	0.062	0.054	0.074	0.070
T3	0.063	0.053	0.072	0.066
T4	0.065	0.052	0.074	0.073
	ns	ns	ns	ns

* Measurement done soon after the final harrowing.

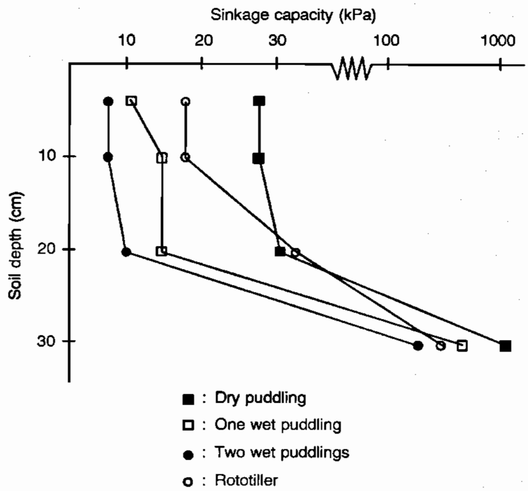


Figure 1. Effect of puddling methods on sinkage capacity (measured with hand penetrometer 'Daiki', 10 × 2.5 cm plate) at Jambegede.

Table 3 shows that, on the Vertisol at Ngale, the infiltration rates of the soil were negligible whether it was cultivated dry or wet. At Jambegede, puddling reduced the soil infiltration rates by a factor of 3 to a value of 0.04 cm/h or 9.6 mm/day. At Maros, the soil infiltration rates were not affected by the soil condition during cultivation with a value of 0.07 cm/h or 16.8 mm/day. These values of infiltration rates of the paddy are high except for the Vertisol, and well above the maximum value of 6 mm/day considered necessary for the maintenance of submerged conditions during the rainy season with rainfall >200 mm/month. At Maros, these high infiltration rates do not pose a problem as watertables are at or near the surface during the rice growing season. The measurements at Maros for three consecutive years indicate that the intensity of puddling does not have any effect on the infiltration rates of the rice bays.

Table 3. Effect of puddling intensity on the infiltration of paddy soils.

Treatments	Infiltration rate (cm/h)				
	Ngale 1994	Jambegede 1993	Maros 1992	Maros 1993	Maros 1994
T1	0.00	0.104[b]	0.08	0.08	0.08
T2	0.00	0.039[a]	0.06	0.07	0.07
T3	0.00	0.041[a]	0.08	0.08	0.07
T4	0.00	0.039[a]	0.07	0.07	0.07
	ns		ns	ns	ns

Rice growth and yield

The results given in Table 4 show that except for plant height at Maros in 1993 and 1994, puddling intensity did not significantly influence crop growth. Puddling intensity did not affect the number of tillers per plant.

Table 5 shows clearly that except for Manaoag in 1993 and 1994, puddling intensity did not affect rice yield in all other sites. At Manaoag, the light-textured soil has a high infiltration rate and this combined with the short wet season (Table 6) results in surface water draining rapidly. This happened on several occasions resulting in increased water stress, increased weed infestation and reduced growth in the dry cultivation treatments. Puddling decreased the infiltration rates of this soil and increased its capacity to maintain submerged conditions and reduce weed competition. The soils at Maros have a similar texture with a high infiltration rate. The lack of puddling in the T1 treatment did not reduce yield, most probably because surface water did not drain, associated with the high watertables in these soils during the rainy season. There was a tendency for slightly reduced yield associated with higher weed populations in the T1 treatment on all sites.

Table 4. Effect of puddling intensity on plant height and number of tillers.

Treatments	Plant height (cm)				No. of tillers per hill					
	Maros			Manaoag	Ngale	Jambegede	Maros			Manaoag
	92	93	94	92	91–92	91–92	92	93	94	92
T1	100.8	71.6ab	81.1a	90.4	14.8	12.9	13.5	10.3	11.9	11.0
T2	98.2	74.0a	83.6b	92.2	14.4	10.7	12.5	11.4	12.3	12.0
T3	102.1	72.7ab	86.5b	94.4	13.1	10.2	14.9	10.7	13.5	11.0
T4	100.0	69.9b	79.2a	93.8	12.8	10.1	13.2	11.1	12.1	12.0
	ns			ns	ns	ns	ns	ns	ns	ns
CV(%)		3.3		4.0				12.5		4.1

Table 5. Effect of puddling intensity on rice yields.

Treat-ment	Rice yields (t/ha)																				
	Bulacan				Manaoag				Maros				Ngale				Jambegede				**Mean**
	92	93	94	**mean**	92	93	94	**mean**	92	93	94	**mean**	92	93	94	**mean**	92	93	94	**mean**	
T1	6.5	5.1	2.6	**4.7**	4.2	2.9	2.9	**3.3**	6.2	5.1	5.3	**5.5**	6.6	5.4	3.8	**5.3**	6.2	4.5	3.9	**4.9**	**4.7**
T2	7	5	2.7	**4.9**	4.1	4	3.3	**3.8**	5	5.6	5.7	**5.4**	7	5.9	4.2	**5.7**	6.4	4.9	4.5	**5.3**	**5.0**
T3	6.8	5	2.5	**4.8**	4.4	4.3	3.8	**4.2**	7.3	5.1	5.8	**6.1**	7.1	6	4	**5.7**	6	4.3	4.7	**5.0**	**5.1**
T4	6.7	5.3	2.9	**5.0**	4.4	3.7	3.1	**3.7**	5.8	5.1	5.2	**5.4**	6.6	5.9	4.1	**5.5**	6.3	4.8	4.4	**5.2**	**5.0**
LSD 5%	ns	ns	ns	ns	ns	0.8	0.9	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
MEAN	**6.8**	**5.1**	**2.7**	**4.8**	**4.3**	**3.7**	**3.3**	**3.8**	**6.1**	**5.2**	**5.5**	**5.6**	**6.8**	**5.8**	**4.0**	**5.5**	**6.2**	**4.6**	**4.4**	**5.1**	**5.0**

Table 6. Mean monthly rainfall (mm) for the five experimental sites. The years of available data are indicated for each site. For Manaoag, the 11 years of data were taken from three nearby weather stations and should be viewed as an estimate of the mean rainfall. Wet months are those with rainfall >200 mm, dry months <100 mm.

Month	Ngale 1981–95	Jambegede 1983–95	Maros 1976–93	Bulacan 1988–95	Manaoag 11 years
January	346	464	724	8	56
February	320	312	543	11	32
March	297	367	379	20	92
April	236	219	224	31	135
May	117	106	136	198	99
June	80	73	80	304	154
July	28	23	44	388	192
August	20	37	11	364	305
September	59	37	26	288	217
October	118	150	92	303	69
November	284	213	322	126	39
December	253	273	541	32	11

Conclusion

The results of this experiment, conducted on five soils over a period of three years, show that the intensity of puddling did not affect the growth and yield of rice, except on the lighter-textured soil. Puddling is necessary on these soils to reduce percolation rates and ensure that submerged conditions can be maintained. On the heavier-textured soils, puddling is not necessary and minimising cultivation may represent a significant energy saving to the farmer. The absence of puddling did not increase the percolation rates nor did it affect the ease of transplanting of rice seedlings. The occurrence of high watertables may also reduce the need to puddle soils because maintenance of submerged conditions is governed by landscape hydrology.

References

Adisarwanto, T., Santoso, B., Manshuri, G. and Floyd, C. 1989. Agronomic survey of MK1 soybean on sawah in East Java (Jember to Madiun), 21–24 June 1989. Malang Research Institute for Food Crops, E. Java, Indonesia.

De Datta, S.K. and Kerim, M.S.A.A.A. 1974. Water and nitrogen economy of rainfed rice as affected by soil puddling. Soil Sci. Soc. Am. Proc. 38, 515–518.

Ghildyal, B.P. 1978. Effect of compaction and puddling on soil physical properties and rice growth. In: Soil Physics and Rice. IRRI, Los Baños, Philippines.

Huke, R.E. 1982. Rice area by type of culture: South, Southeast and East Asia. IRRI, Los Baños, Philippines, 32 p.

Mabbayad, B.B. and Buencosa, I.A. 1967. Test on minimal tillage of transplanted rice. Philippine Agric. 51, 541–551.

Pasaribu, D. and McIntosh, J.L. 1985. Increasing tropical soybean production with improved cropping systems and management. In: Shanmugasundaram, S. and Sulzberger, E.W., ed., Soybean in Tropical and Subtropical Cropping Systems, Asian Veg. Res. and Dev. Centre, Taiwan, 1–11.

Sakanoue, Y. and Mizunuma, Y. 1962. Effect of harrowing upon the behaviour of nitrogen in well drained paddy field with gravel layer. J. Sci. Soil Manure 33, 386–390.

Sanchez, P.A. 1973. Puddling tropical rice soils. II Effects of water losses. Soil Sci. 115, 303–308.

— 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons, New York.

Scheltema, W. 1974. Puddling against dry plowing for lowland rice culture in Surinam. Agr. Res. Rep. 828, Centre for Agricultural Publishing and Documentation, Wageningen, Netherlands, 241 p.

Sharma, P.K. and De Datta, S.K. 1985. Effect of puddling on soil physical properties and processes. In: Soil Physics and Rice. IRRI, Los Baños, Philippines, 217–234.

So, H.B. and Woodhead, T. 1987. Alleviation of soil physical limits to productivity of legumes in Asia. In: Wallis, E.S. and Byth, D.E., ed., Food legume improvement for Asian Farming Systems. ACIAR Proceedings series No. 18, 112–120, Canberra.

Tranggono, R. and Willatt, S.T. 1988. The growth of maize after wetland rice in East Java. Proceedings 11th ISTRO Conference, 10–15 July 1988, Edinburgh, U.K., 903–908.

Utomo, W.H., Islami, T. and Murdoko, B. 1985. The effect of tillage method on the growth and yield of lowland rice. Paper presented at the National Congress of Indonesian Soil Science Society, Bogor, Indonesia.

Utomo, W.H., Suendarti, M. and Islami, T., 1993. The effect of azolla inoculation on the soil physical properties and soybean yield planted after rice. Agrivita 19, 86–92.

Van de Goor, G.A.W. 1950. Research on rice irrigation. Contr. Gen. Agr. Sta. Bogor, Indonesia No. 112, 34 p.

The Effect of Soil Puddling on Post-rice Rainfed Legumes

E.V. Dacanay[1], T. Adisarwanto[2] and B. Prastowo[3]

Abstract

Experiments were conducted on five sites in Indonesia and the Philippines over a period of three years to investigate the effect of pre-rice soil puddling intensity on post-rice rainfed legumes. Puddling treatments used, in increasing order of puddling intensity, were dry cultivation prior to submergence, one and two passes using draught animals, and two passes using a mechanical rototiller. These treatments were coupled with subfactors according to local traditional practices such as drainage versus no drainage in Indonesia and zero-till-dibble versus plough-broadcast-harrow in the Philippines. Although these subfactors were not significant in either experiment, possibly due to insufficient draining systems used and unreliable sowing techniques applied, both can be improved through further research. Puddling had no significant effect on post-rice legume production. However, trends showed that dry cultivation prior to submergence tended to reduce mungbean yield on light-textured soils because sowing occurred under dry conditions. Dry cultivation of lighter-textured, well-drained soils also tended to require more intensive weed control compared to higher puddled treatments, and weed infestation was the largest contributing factor for reduced mungbean yield in the dry season on a silty clay loam. Yields of long-term legumes (peanut and soybean) tended to be reduced on highly puddled light-textured soils, but increased on heavy-textured soils. In general, rainfall during the crop establishment phase appeared to have a larger effect on soil water content changes and thus seedling emergence and crop establishment, compared to soil puddling.

RICE in tropical Asia is grown mostly under lowland conditions with one to three crops per year, depending on the rainfall or the availability of irrigation water and the use of modern, short-term varieties. A common feature of lowland areas is that there is sufficient water stored in the soil after rice to grow a dry season crop on stored water alone, without irrigation, because of the long-term submerged conditions for rice (Pasaribu and McIntosh 1985). However, if irrigation for a dry season crop is not available, it carries a high risk of failure due to adverse soil conditions induced through the soil preparation for rice, soil puddling. Consequently, rainfed dry season crop production receives little attention or investment. Yield of dry season crops is generally low when grown after rice due to poor and uneven establishment caused by adverse soil physical conditions of previously puddled soils (Pasaribu and McIntosh 1985; Adisarwanto et al. 1989).

Wet cultivation or puddling is synonymous with rice culture in Asia and is used in the transplanting of rice seedlings, to reduce water and nutrient loss and to control weeds (Sharma and DeDatta 1985). Puddling breaks down and disperses soil aggregates into individual particles. The degree of dispersion for a given puddling effect is dependent on the structural stability of the soil. It is likely to affect the regeneration of soil structure after rice, which in turn will affect the dry season crop. The effects of degree of puddling prior to the rice phase on structure regeneration and growth of the dry season crop after rice depend on soil type. For example, increasing intensity of puddling resulted in increased maize yield on a Vertisol but decreased yields in lighter-textured Regosols (Willatt and Tranggono 1987). Similarly,

[1] Bureau of Soil and Water Management, Cnr Elliptical Rd and Visayas Avenue, Quezon City, the Philippines
[2] Research Institute for Legume and Tuber Crops, Kendalpayak, PO Box 66, Malang 65101, Indonesia
[3] Research Insitute for Maize and other Cereals, Jl. Dr Ratulangi, Maros 90514, Indonesia

intensive puddling increased mungbean yield on a clay loam but decreased it on a sandy loam (IRRI 1988). These differences were attributed to clay content and mineralogy. The concept of partially controlling soil structure regeneration after rice through the puddling treatment prior to the rice phase should be investigated further by determining which soil types are responsive.

The physical limitation imposed by puddling soil has been recognised as the major cause of poor establishment and yield of post-rice crops in Asia, including soybean in East Java (Adisarwanto et al. 1989) and mungbean in the Philippines and other Asian countries (IRRI 1984; So and Woodhead 1987; Woodhead 1990; Varade 1990; Mahata et al. 1990). Puddling is associated with dispersion of aggregates during wet cultivation (Adachi 1990; Sharma and De Datta 1985) and results in a massive structure after rice. This study therefore tries to determine puddling effects on post-rice legumes grown under rainfed conditions. It is part of, and a continuation of, the study reported by Utomo et al. (these Proceedings).

Materials and Methods

Field experiments were conducted on five sites in Indonesia and the Philippines over a period of three years to assess the effect of four different puddling intensities. With increasing intensity of puddling, these treatments were: dry cultivation prior to submergence (T1), wet cultivation using draught animals, one pass (T2), and two passes (T3), and wet cultivation using two passes with a mechanical rototiller (T4). Two of the five experimental sites were located in East Java (Jambegede and Ngale), one in South Sulawesi (Maros) and two in the Philippines (Bulacan and Pangasinan Provinces in Luzon). Post-rice treatments included drainage versus no drainage in the Indonesian sites, both using dibbling as the sowing technique. In the Philippines, no drainage treatments were superimposed on the puddling treatments, but zero-till-dibble versus plough-broadcast-harrow were compared. These additional treatments corresponded to locally used practices. Details of the experimental design are given by So et al. (these Proceedings) and a description of soils is given by Schafer and Kirchhof (these Proceedings). The post-rice indicator crop used was mungbean on all sites, and additionally soybean at the site in Ngale and peanut in Jambegede.

Results and Discussion

Legume yields across all five sites and the years of experimentation, yearly and site averages, as well as grand averages are given in Table 1. There were no significant effects of soil puddling on post-rice rainfed legume yields except in one out of a total of 15 experiments conducted. The sub-factors investigated, drainage versus no-drainage, and zero-till-dibble versus plough-broadcast-harrow, were not significant and only averages for both sub-factors are given in Table 1. The lack of a drainage effect, however, was not expected and it is possible that the surface drains installed were inadequate. Further research will be needed to assess different soil drainage techniques. In the Philippines, the lack of a tillage effect (i.e., zero-till-dibble versus plough-broadcast-harrow) indicated that sowing method may not have a large effect on yield. However, it can also be interpreted that both sowing methods were equally unsuitable, in particular, at the Bulacan site where yields were very low.

Mungbean yield was significantly reduced in the dry season of 1992–93 on the silty loam soil at Manaoag, Pangasinan Province. The trend of decreased yields due to low puddling intensity was consistent in the other dry season at the same site. Lack of rainfall around sowing time on the well-drained soil at Manaoag resulted in fairly dry soil conditions following rice harvest in treatment T1, i.e., dry cultivation prior to submergence. During the 1992–93 dry season, this resulted in weed infestation and concomitant competition for soil water, resulting in depressed yield. Although competition by weeds can be regarded as a limiting factor in this dry season, weeds were controlled adequately in the following seasons. However, observations of a trend of reduced yield due to low puddling intensity persisted, which was in contrast to earlier findings of Willatt and Tranggono (1987) and IRRI (1988) where legume yields were reduced on lighter-textured soils due to high pre-rice soil puddling. Rice harvest at Manaoag tends to occur at the start of the dry season (Kirchhof and So, these Proceedings) when the soil surface is already dry. The well-drained soil, if not puddled, may have already lost too much water and become too hard for subsequent root growth to tap subsoil water reserves. Experiments by IRRI (1988) and Willatt and Tranggono (1987) were conducted under conditions where the soil was still submerged during rice harvest, thus still relatively wet when post-rice legumes were sown. Under those conditions, poor soil structure induced by soil puddling probably resulted in aeration problems leading to yield reduction. These contrasting findings emphasise the importance of soil water conditions, which are affected by climatological conditions towards the end of the rice phase and at the start of the legume phase.

Table 1. The effect of soil puddling on post-rice rainfed legume yields.

Site	Year	Treatment				Mean	lsd 5%
		1. Dry cultivation	2. One wet ploughing and harrowing	3. Two wet ploughings and harrowings	4. Two wet rototiller cultivations		
Mungbean				(Units in t/ha)			
Bulacan	1992–93[1]	0.19	0.26	0.24	0.25	0.24	ns
	1993–94	0.16	0.16	0.31	0.18	0.20	ns
	1994–95	0.22	0.18	0.21	0.24	0.21	ns
	Mean	*0.19*	*0.20*	*0.25*	*0.22*	*0.22*	*ns*
Manaoag	1992–93	0.91	1.07	1.10	1.13	1.05	0.17
	1993–94	0.74	0.83	0.87	0.82	0.82	ns
	1994–95	0.81	0.91	0.84	0.84	0.85	ns
	Mean	*0.82*	*0.94*	*0.94*	*0.93*	*0.91*	*ns*
Maros	1992	0.33	0.32	0.35	0.37	0.34	ns
	1993	0.30	0.25	0.27	0.30	0.28	ns
	1994	0.72	0.61	0.63	0.63	0.65	ns
	Mean	*0.45*	*0.39*	*0.42*	*0.43*	*0.56*	*ns*
Ngale	1992	1.67	1.66	1.69	1.68	1.67	ns
	1993	0.92	0.92	0.81	0.88	0.88	ns
	1994	0.52	0.55	0.55	0.56	0.55	ns
	Mean	*1.04*	*1.04*	*1.02*	*1.04*	*1.04*	*ns*
Jambegede	1992	0.94	1.12	0.86	0.95	0.97	ns
	1993	0.32	0.34	0.28	0.32	0.32	ns
	1994	0.15	0.14	0.12	0.16	0.14	ns
	Mean	*0.47*	*0.53*	*0.42*	*0.48*	*0.48*	*ns*
AVERAGE		0.59	0.62	0.61	0.62	0.61	ns
Soybean							
Ngale	1992	1.39	1.32	1.22	1.16	1.27	ns
	1993	0.69	0.67	0.62	0.53	0.63	ns
	1994	Failed due to very late sowing				n/a	
Peanut							
Jambegede	1992	2.52	2.49	2.54	2.31	2.46	ns
	1993	1.35	1.41	1.23	1.24	1.31	ns
	1994	Failed due to very late sowing				n/a	

[1] = Total biomass.
ns = Not significant.
n/a = Not available.

A trend of reduced yield due to low puddling intensity was also observed on the clay loam soil in Maros, but only in the 1994 dry season. The same mechanism as for the Manaoag site probably applied to the reduced yield in 1994. In the 1992 and 1993 growing seasons, climatological conditions coupled with poor crop establishment were the overriding factors leading to very low yields regardless of pre-rice soil puddling intensity, which was also the case at the Bulacan site.

Although mungbean yields were not affected by soil puddling in Ngale and Jambegede, soybean yields tended to be increased, and peanut yields tended to be reduced by high puddling intensity on the Vertisol in Ngale and the Hapludand in Jambegede (Table 1). However, the trend of reduced yield in Jambegede in 1993 can only be regarded as marginal. These trends correspond to the findings by IRRI (1988) and those by Willatt and Tranggono (1987). The lack of response to soil puddling on mungbean may be due to the different lengths of the cropping cycle, approximately two months for mungbean and three months for soybean and peanut. Species with a longer growing season appeared to exhibit a larger reliance on subsoil water use, which becomes of greater importance as the dry season continues (Priyono et al., these Proceedings). It is possible that the mechanism described by Willatt and Tranggono (1987), i.e. faster soil structural regeneration of cracking clay soils if puddled with high intensity, versus massive structure formation on lighter-textured soils if puddled intensively, resulted in improved and restricted root growth to depth on the heavy clay and loamy soil, respectively. Subsequent growth during the dry season was therefore restricted due to roots being less able to tap subsoil water reserves. The failed yields of peanut and soybean were attributed to very late sowing during the dry season.

Conclusion

The results of these experiments showed that:

- puddling had no significant effect on post-rice legume production, **but trends showed that**:
- dry cultivation prior to submergence tended to reduce mungbean yields on light-textured soils if sowing occurred under dry conditions;
- dry cultivation of lighter-textured, well-drained soils may require more intensive weed control compared to higher puddled treatments;
- rainfall during the crop establishment phase appeared to have a larger effect on soil water content changes compared to soil puddling;
- yields of long term legumes (peanut and soybean) tend to be reduced on highly puddled light textured soils, but increased on heavy textured soils.

References

Adachi, K. 1990. Effects of rice-soil puddling on water percolation. In: Trans. 14th International Congress of Soil Science, Kyoto, Japan, I, 146–151.

Adisarwanto, T., Sanoso, B., Manshuri, G., and Floyd, C. 1989. Agronomic survey of MK1 soybean on Sawah in East Java (Jember to Madium), 21–24 June 1989. Malang Research Institute for Food Crops, East Java, Indonesia.

IRRI 1984. Annual report for 1983. International Rice Research Institute, Los Baños, Laguna, the Philippines.

— 1988. Annual report for 1987. International Rice Research Institute, Los Baños, Laguna, the Philippines.

Mahata, K.R., Sen, H.S., Pradhan, S.K. and Mandal, L.N. 1990. No-till and dry ploughing compared with puddling for wet season rice on alluvial sandy clay loam in eastern India. J. Agric. Sci. 114, 79–86.

Pasaribu, D. and McIntosh, J.L. 1985. Increasing tropical soybean production with improved cropping systems and management. In: Shanmugasundaram and Sulzberger, E.W. ed., Soybean in Tropical and Subtropical Cropping Systems, Taiwan, Asian Vegetable Research and Development Centre, 1–11.

Sharma, P.K. and DeDatta, S.K. 1985. Effects of puddling on soil physical properties and processes. In: Soil Physics and Rice, 217–234. International Rice Research Institute, Los Baños, Laguna, the Philippines.

So, H.B. and Woodhead, T. 1987. Alleviation of soil physical limits to productivity of legumes in Asia. In: Wallis, E.S. and Byth, D.E. ed., Food Legume Improvement for Asian Farming systems. ACIAR Proceedings Series No. 18, Canberra, 112–120.

Varade, S.B. 1990. Establishment of non-rice crops in previously puddled soils. In: Trans. 14th International Congress of Soil Science, Kyoto, I, 170–174.

Willatt, S.T. and Tranggono, R. 1987. Puddling, its effect on soil physical properties. In: Coughlan, K.J. and Truong, P.N. ed., Effect of Management Practices on Soil Physical Properties, Queensland Department of Primary Industries Conference and Workshop Series QC87006, Brisbane, Australia.

Woodhead, T. 1990. Problems and opportunities in soil physical management in rice-based cropping systems. In: Trans. International Congress Soil Science, Kyoto, I, 140–145.

Effect of Puddling on Root Growth and Subsoil Water Use of Rainfed Legumes after Rice

Sugeng Priyono[1], G. Kirchhof[2], H.B. So[2] and W.H. Utomo[1]

Abstract

Field experiments were conducted during the dry season of 1993 on two different soils in East Java to assess the effect of soil puddling on post-rice crop water use and root proliferation. Post–rice crops used were mungbean, soybean and peanut grown on a Vertisol in Ngale and a silty clay loam in Jambegede. Soil puddling intensity did not significantly affect root growth and depth. However, soil water depletion tended to be smaller in the plough layer that was cultivated under wet conditions compared to pre-rice dry land preparation. Soil water extraction was small and root proliferation was to 40 cm depth only under wet conditions where plant water requirements were met from seasonal rainfall which kept the topsoil sufficiently moist. Root proliferation was to a deeper depth and soil water use greater during dry climatological conditions. On both sites, small amounts of subsoil water use resulted in substantial yield increases ranging from 3 to 24 kg per mm of soil water used.

PRODUCTION of wet culture rice in the tropics traditionally requires soil puddling prior to rice transplanting. Puddling reduces hydraulic conductivity, saves water, keeps the paddy weed-free if it remains inundated, and makes transplanting easier. However, puddling destroys soil structure and puddled soils become very hard on drying after the wet season (Pasaribu and McIntosh 1985). In the absence of irrigation during the dry season, paddy fields are generally left fallow because the hard puddled layer prevents root growth to depth and subsequent use of subsoil water reserves from the previous wet season.

Reports of plant water requirements vary but generally range from 300 to 1000 mm (Doorenbos and Kassam 1979). It depends on crop type, duration of growth, evaporative demand of the atmosphere and crop characteristics. Water requirement of a 70–day mungbean crop was estimated to be 375 mm, for a peanut crop growing for 90 days, 500 mm and for a soybean crop of 100 days, 450 mm. However, Angus et al. (1979) cited by Zandstra (1982) found that acceptable yields for mungbean, soybean and peanut on a dryland soil at IRRI were achieved with only 198–364 mm of water. The much larger estimate of Doorenbos and Kassam (1979) probably did not take exploitable soil depth into account. Depth of soil water depletion can be used as indirect measurement for plant root activity in soil profiles (Stone et al. 1976). Provided roots access subsoil water during the dry season, moderate to high yields can be expected in the absence of rain and irrigation.

Materials and Methods

Field experiments were conducted in East Java on paddy soils near Jambegede and Ngale to investigate the effect of degree of soil puddling for rice production on the growth of roots and water use of three legumes, mungbean, soybean and peanut, following wet rice culture. Treatments comprised (i) dry cultivation prior to submergence, one wet ploughing followed by one wet harrowing, (ii) two wet ploughings followed by two wet harrowings, and (iii) wet cultivation using a rototiller. Experimental details,

[1]University of Brawijaya, Fakultas Pertanian, Jl. Mayjen Harjono 18, Malang 65145, Indonesia
[2]Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia

description of the soils and climatological records are given elsewhere in these Proceedings.

Soil water contents were monitored during the post-rice cropping phase using a Wallingford neutron probe type IH-III/DIDCOT. The probe was calibrated at both sites but a common calibration equation to determine volumetric water content (θ_v) from count ratio (CR), independent of depth of measurement, was derived:

$$\theta_v = 0.884\, CR, \quad R = 0.905, \quad n = 108$$

Measurements were taken at 20, 30, 40, 60 and 100 cm depth. Soil water content in the topsoil at 5 and 15 cm was determined gravimetrically.

The total soil water used during the growth of plants was calculated from the difference in total soil water stored between planting and harvest.

Root samples were collected from mungbean plots only. Soil cores, 10 cm diameter, were collected to a depth of 1 m. Root lengths were determined after soil and roots were separated. Roots were scanned using a hand scanner; computer image analysis was used to obtain length of roots by analysing the digital root images (Kirchhof and Pender 1992).

Results and Discussion

Soil water use and root growth

Rainfall during the growing season of mungbean and soybean in Ngale 1993 was uniformly distributed with a total of 363 mm for the mungbean crop and 377 mm for the soybean crop. Rainfall in Jambegede was 143 mm, considerably lower than in Ngale. Differences in soil water extraction were related to pre-rice puddling intensity. There was a consistent trend of larger soil water use for the treatment with the lowest puddling intensity, i.e. dry cultivation prior to submergence (Table 1). For mungbean in Jambegede, this larger uptake was associated with a greater difference in soil water uptake at 10 cm depth and uptake occurred over greater depth (Figs 1 and 2). Therefore, soil puddling under submerged conditions may potentially limit soil water use and reduce yields of the following dry season crop, where soil strength of the puddled layer restricts root growth into the subsoil.

Total soil water use from the heavy Vertisol in Ngale was small compared to the rainfall during the growing period of soybean and mungbean (Table 1). The high rainfall during the growing season resulted in relatively shallow root proliferation. Most roots were observed in the top 20 cm depth and root growth was not detected with the sampling procedure used beyond 40 cm depth (Figs 3 and 4) probably associated with anaerobic conditions of the soil in combination with high rainfall. The plant water requirement was almost entirely met by rainfall, and use of stored subsoil water was limited. Under the drier conditions in Jambegede, however, subsoil water use was higher. This was reflected in higher root length densities and root growth to greater depth (Figs 1 and 2). However, even under these dry conditions, root growth could not be detected beyond 60 cm depth.

Comparing the climates at the two sites suggested that roots use subsoil water reserves under conditions where rainfall is insufficient to satisfy plant water requirements. It emphasised the need to create soil conditions with appropriate management techniques that enable plant roots to penetrate and to explore subsoil water reserves under dry conditions. Climatological conditions clearly interact with soil water

Table 1. Rainfall, soil water depletion, and yield of grain.

Location	Crop	Total	Puddling treatments				Yield (t/ha)
			T1	T2	T3	T4	
Ngale	Mungbean	Rain (mm)	363	363	363	363	0.88
		$\Delta\theta$ (mm)	39	48	36	36	
		Rain + $\Delta\theta$	*402*	*412*	*399*	*399*	
	Soybean	Rain (mm)	377	377	377	377	0.63
		$\Delta\theta$ (mm)	128	94	90	80	
		Rain + $\Delta\theta$	*505*	*471*	*467*	*457*	
Jambegede	Mungbean	Rain (mm)	134	134	134	134	0.32
		$\Delta\theta$ (mm)	122	110	102	108	
		Rain + $\Delta\theta$	*256*	*244*	*236*	*242*	
	Peanut	Rain (mm)	134	134	134	134	1.31
		$\Delta\theta$ (mm)	213	212	183	194	
		Rain + $\Delta\theta$	*347*	*346*	*327*	*328*	

$\Delta\theta$ = difference in soil water storage, sowing to harvest.

content changes. Unfavourable conditions induced by wet cultivation may restrict root growth and water uptake as indicated by the lower soil water uptake from the puddled layer in Jambegede. The most critical stage for root penetration can be expected at and after the crop establishment phase where roots grow in, and if successful, through the puddled layer to tap subsoil water for future growth.

Soil water use and yield

The total amount of soil water used was related to biomass or grain yield produced. At Ngale, mungbean used 399–412 mm of water (Table 1) with an average yield of 0.88 t/ha, whereas at Jambegede, water used was 236–256 mm with a mean yield of 0.3 t/ha. At Ngale, rain during the growing season maintained reasonably high soil water content near the soil surface which was adequate to supply the plant's water requirements. At Jambegede, inadequate rain forced the crop to use subsoil water with increasing water stress levels and reduced growth and yield.

If the total amount of soil water used was separated into water used from different depth intervals, significant relationships between yield and water use were observed. The relationships gave the highest level of correlation if soil depths 0–65 cm and 65–125 cm were separately related to grain

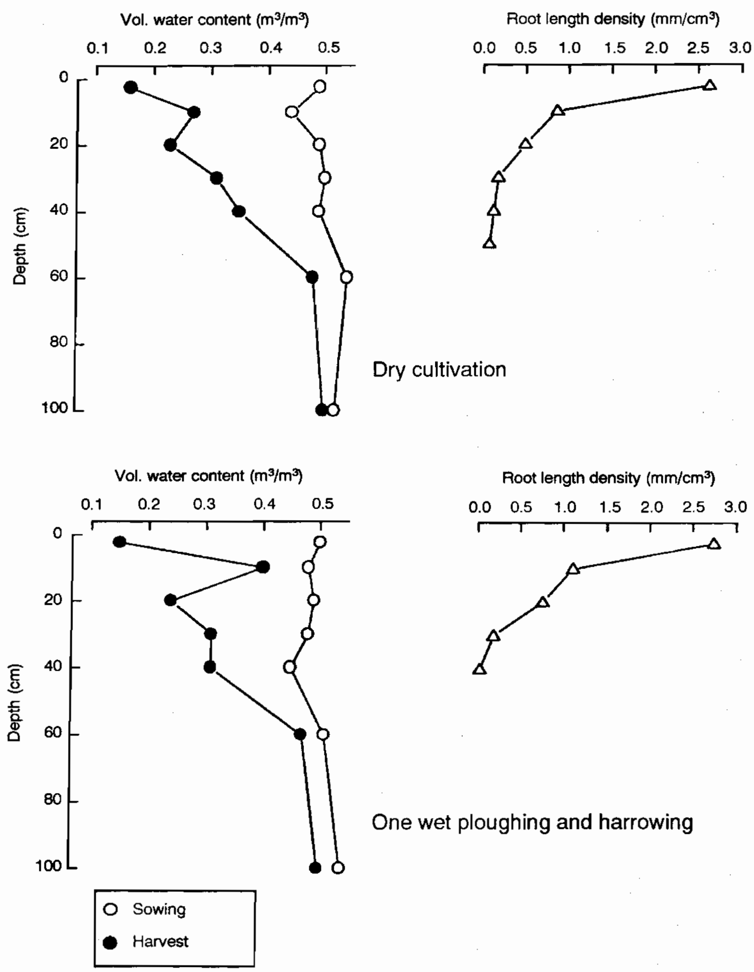


Figure 1. Effect of dry cultivation and wet ploughing + harrowing on soil water depletion and root growth in Jambegede for mungbean.

yield. However, there was no relationship between mungbean yield and water used in the 0–65 cm depth interval (Table 2). Soil water contents within this layer were controlled by rainfall events and determined the base level of grain yield while the water from 65–125 cm depth determines the additional yield obtained from subsoil water use. The intercept of the regression line can be interpreted as the yield that would be obtained irrespective of soil water use from this layer. However, legumes with longer growth periods, such as peanut and soybean, grow longer into the dry season when rainfall decreased considerably (Kirchhof et al., these Proceedings) and the significant relationship between yield and water use from the deeper layers indicates that yields were limited by the soil water storage.

Subsoil water usage from depth layers below 65 cm to 125 cm was closely related to grain yield for all three legumes on both soil types (Table 2). This high correlation indicated that changes in soil water content were associated with root activity and not drainage, although root activity could not be detected below 65 cm depth with the sampling method used. It is important to note that yield increases from subsoil water use were substantial despite relatively small absolute changes in soil water contents below 65 cm depth, in particular at the Ngale site. Yield increases were in the order of 3–24 kg for the different legumes (Fig. 5) and subsoil water from 65–125 cm was responsible for yield differences between treatments of 13% to 27% of the mean yield. These figures compare well to reports by IRRI (1985, 1986) where yield increases of 4–7 kg/mm for mungbean were observed due to an increase in root exploitable soil depth. These relationships show the importance of getting roots

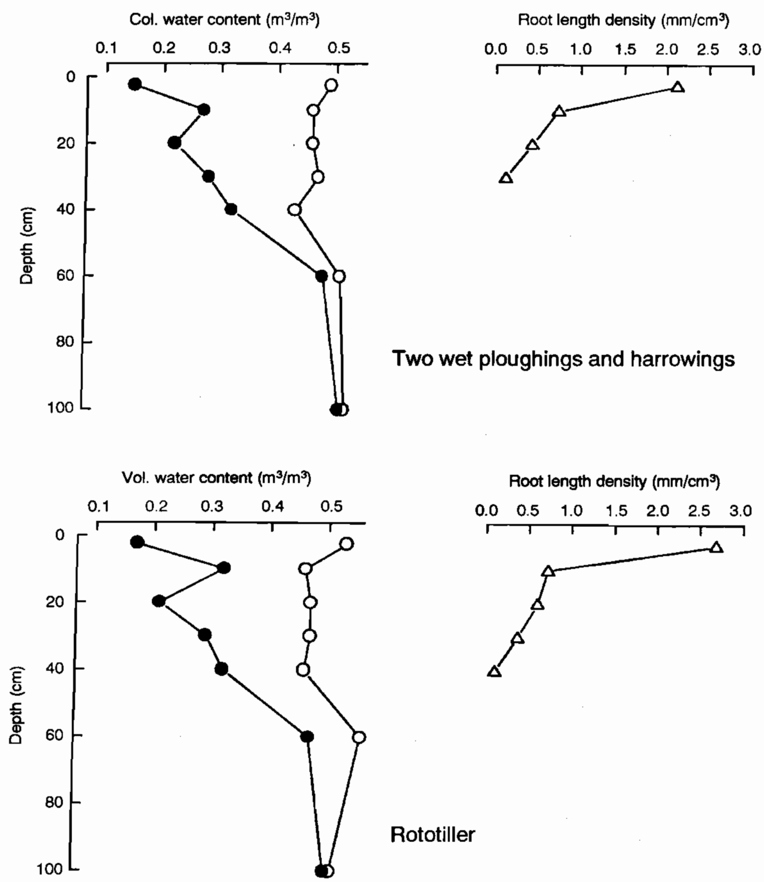


Figure 2. Effect of two ploughings + harrowings and rototiller cultivation on soil water depletion and root growth in Jambegede for mungbean.

into the subsoil for increased yields of dry season crops and all soil or agronomic management practices should aim at promoting rooting depth.

Although analysis shows that yields were statistically not different between treatments (Kirchhof et al., these Proceedings) Figure 5 shows a consistent trend where the low puddling intensity (T1 and T2) consistently gave higher yields, though small, than the high puddling treatments (T3 and T4). These trends supported the findings of Utomo et al. (these Proceedings) that high puddling intensity was not necessary for rice and minimising cultivation could represent increased farm income through energy savings.

Table 2. The relationship between yield (t/ha) and water use (mm).

Location	Crop	Depth (cm)	r	Equation
Ngale	Mungbean	00–60	0.15	Y = 0.006 X + 0.763
		65–125	0.73	Y = 0.024 X + 0.430
	Soybean	00–60	0.6	Y = 0.004 X + 0.312
		65–125	0.65	Y = 0.008 X + 0.484
		0–125	0.63	Y = 0.003 X + 0.365
Jambegede	Mungbean	00–60	0.03	Y = –0.001 X + 0.366
		65–125	0.78	Y = 0.003 X + 0.281
	Peanut	00–60	0.75	Y = 0.014 X – 0.908
		65–125	0.8	Y = 0.008 X + 0.959
		0–125	0.85	Y = 0.005 X + 0.197

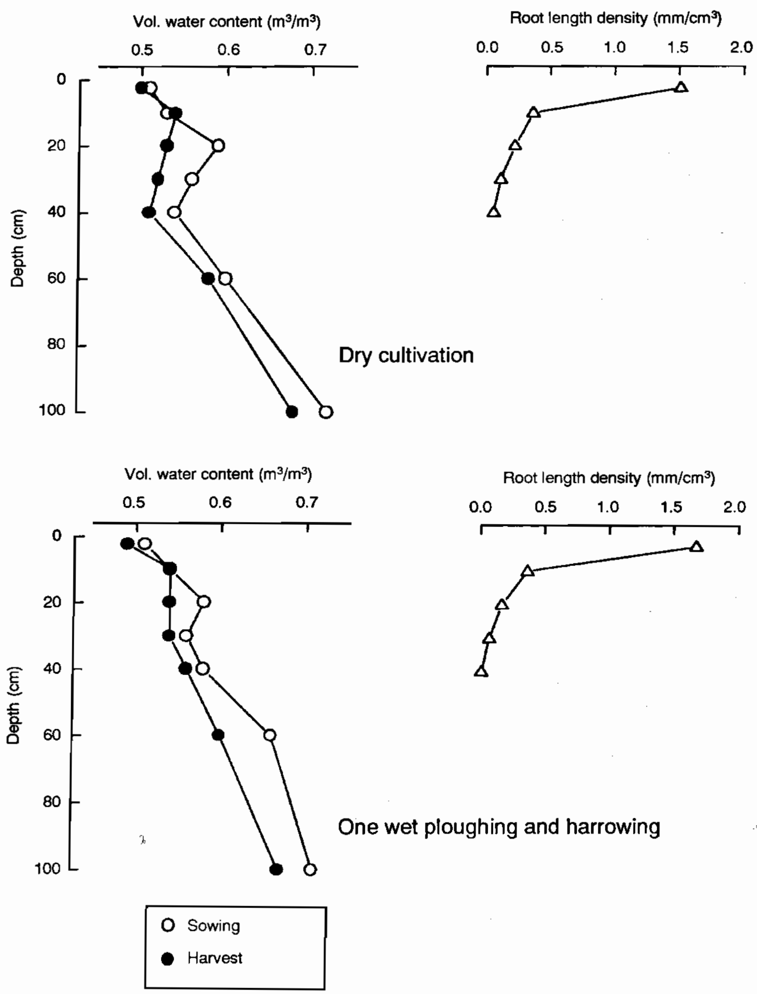


Figure 3. Effect of dry cultivation and one wet ploughing + harrowing on soil water depletion and root growth in Ngale for mungbean.

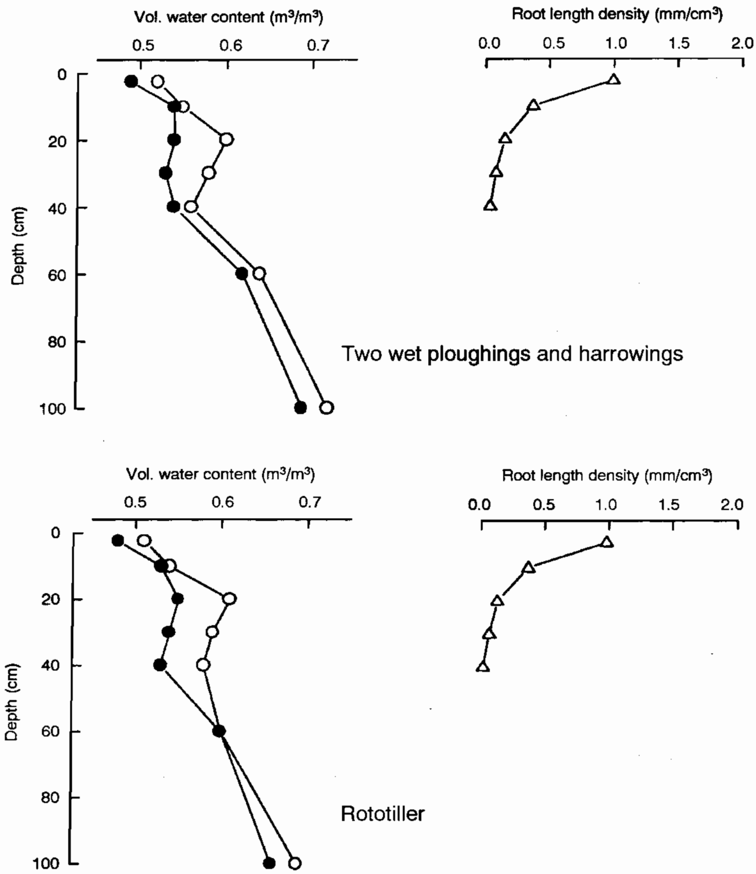


Figure 4. Effect of two ploughings + harrowings and rototiller cultivations on soil water depletion and root growth in Ngale for mungbean.

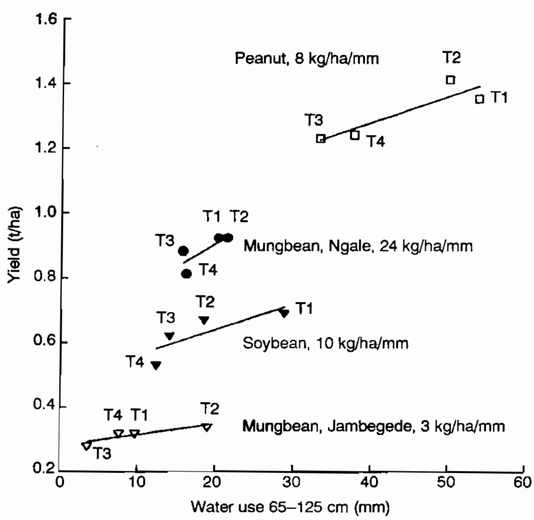


Figure 5. The effect of soil water usage from the subsoil on grain yield of pulses (T1 to T4 denote puddling treatments).

Conclusions

- Soil water use tended to be lower when soils were cultivated under wet conditions.
- Small differences in subsoil water use between treatments resulted in substantial yield differences ranging from 13% to 27%.
- At Ngale, water use by legumes was confined to the surface soil and these legumes grew well with water supplied by rainfall. At Jambegede, the legumes survived on both rainfall and stored water.

References

Doorenbos, J. and Kassam, H. 1979. Yield response to water, Food and Agriculture Organization, Rome, Irrig. Drainage, Pap. 33.

IRRI, 1985. International Rice Research Institute Annual Report for 1984, International Rice Research Institute, Los Baños, Philippines, 329 p.

— 1986. International Rice Research Institute Annual Report for 1985, International Rice Research Institute, Los Baños, Philippines, 299 p.

Kirchhof, G. and Pender, C. 1992. Sci-Scan Image Analysis System, Ver 1.0. CSIRO, Griffith, Australia.

Pasaribu, D. and McIntosh, J.L. 1985. Increasing tropical soybean production with improved cropping systems and management. In: S. Shanmugasundaram and E.W. Sulzberger, ed., Soybean in Tropical and Subtropical Cropping Systems, Asian Veg. Res. and Dev. Centre, Taiwan, 1–11.

Stone, L.R., Teare, I.D., Nickell, C.D. and Mayaki, W.C. 1976. Soybean root development and soil water depletion, Agron. J., 68, 677–680.

Zandra, H.G. 1982. Effect of soil moisture and texture on the growth of upland crops after wetland rice. Report of a workshop on cropping systems research in Asia, IRRI, Los Baños, Philippines, 43–54.

CROP ESTABLISHMENT

Crop Establishment of Legumes in Lowland Rice-based Cropping Systems

A.A. Rahmianna[1], H.B. So[1], G. Kirchhof[1], Sumarno[2] and T. Adisarwanto[2]

Abstract

A field experiment was conducted under a rainshelter at Jambegede and Ngale to investigate the effects of soil water content/potential and cultivation on the germination and emergence of legumes under continuous, drying conditions. Different soil water content/potentials were expected to be associated with periods of delay in sowing legumes after the rice harvest.

The results indicated that mungbean at Jambegede and soybean at Ngale were significantly affected by seed rot, presumably resulting from resident fungal population in the soil associated with the cropping history of the soil. Increasing the period of delay in sowing resulted in lower soil water potentials and an increased opportunity for fungal infection. The effect of cultivation on emergence was significant on soils where cultivation resulted in cloddy soils and increased rate of soil drying. The application of mulch had little effect on the emergence of legumes.

Field observations were compared with germination predicted from laboratory-based data on the relationship between germination, water potential and temperature. The agreement between observed and predicted germination was reasonably good.

WET conditions due to rain during the early part of the dry season after rice harvest is the main cause of water logging in rainfed lowland rice cropping systems. The consequence of wet conditions is generally poor land preparation for upland crops. Water logging and poor land preparation are common problems encountered at planting time and during early upland crop growth.

Saturated soil gives rise to poor seed germination and crop establishment, since conventional seeding methods can be practiced only on drained soils with adequate bearing capacity for tillage or seeding implements (IRRI, 1992). In turn, poor crop establishment results in low plant populations, reflected then in low yields particularly of single tiller plants.

[1] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia

[2] Research Institute for Legume and Tuber Crops (RILET), Kendalpayak, PO Box 66, Malang 65101, Indonesia

Considerable research has been conducted to increase dry season grain legume crop yields (Sumarno 1991). Most was focused on irrigated crops, with less attention given to those under rainfed conditions after rice. ACIAR Project 8938, 'Management of Clay Soils under Lowland Rice-based Cropping Systems', was initiated in December 1991. The objective was to develop soundly-based soil management technologies that can overcome soil physical limitations to dry season crop production after rainfed lowland rice.

The project indicated that the major problems limiting yield of dry season crops were (a) poor establishment and/or survival associated with the physical properties of puddled soils and the dibbling technique used, and (b) uncharacteristic seasonal conditions with rain/storms after rice harvest on all sites, making it difficult to interpret and compare results from various sowing delays which was expected to affect the soil water content in the seed placement zone (So et al. 1993). Based on these conditions, there was a need to conduct an experiment with no interference from rain. The objective of this experiment was to monitor the soil condition after rice in relation to the germination and establishment of dry season crops in two management practices — delay of planting and type of cultivation — both under continuous drying conditions.

Materials and Methods

To ensure continuous and progressive drying conditions, a 15 m × 6 m PVC rain shelter was set up over selected ricefields at Ngale and Jambegede. These fields were adjacent to the ongoing E2 experiments of Project 8938 (So et al., these Proceedings). At Ngale, these experiments were conducted on a Vertisol and at Jambegede on an Andosol (Schafer, these Proceedings). The ricefields were drained one week before harvest and harvesting was carried out after the rain shelter had been set up, to maintain soil water conditions at harvest as close to those expected outside the rainshelter.

A split-split plot experiment was set up with treatments similar to those in the E2 experiment of Project 8938, except for the gypsum treatment which was left out. The treatments consisted of 3 cultivations × 3 periods of sowing delay × 3 legume species × 3 replicates resulting in a total of 81 plots. Delay in sowing was the main plot with cultivation as subplot and species as sub-subplot. The delay in sowing was 3, 10 and 17 days after rice harvest at Ngale and 4, 11 and 18 days at Jambegede. Cultivation treatments consisted of zero tillage, zero tillage with mulch (5 t/ha dry rice straw) and cultivation by a hand-operated hoe to 12.5 cm depth. The three legume species used were mungbean *cv.* Walet, peanut *cv.* Kelinci and soybean *cv.* Wilis.

Each subplot was 1.5 m × 1.5 m and seeds were planted with a spatial arrangement of 15 × 15 cm with 2 seeds/hole. Planting was conducted using an ordinary sharpened dibbling stick which created a hole 5 cm deep and 4 cm wide at the top. Seeds were placed in the hole and covered by moist sand. Drainage ditches were provided around plots. Side covers of the shelter were left open, but closed during rainfall events to prevent rain entering the shelter.

Rice harvest at Ngale occurred on 20 March 1994 and at Jambegede on 23 April 1994.

Emergence was recorded daily, starting at four days after sowing (DAS) until 14 DAS. At 14 days, seeds which failed to germinate or to emerge were counted and the cause of failure noted. Measurement of soil physical properties was limited to soil temperature and water content. Soil temperature at the soil surface, 2.5, 5 and 10 cm soil depths was measured using thermocouples buried in the field at corresponding depths. During the first 48 hours, readings were made every hour to obtain the temperature diurnal cycle during 24 hours as well as the time when the maximal temperature occurred for each depth. On the following days, daily recording was done at these times. Soil water content in every centimetre for the first 10 cm, and every 2.5 cm between 10 and 20 cm of soil depths was measured by gravimetric method.

The seed viability (potential for germination) was determined in the laboratory using the standard germination test (ISTA, 1985).

Results and Discussion

Tables 1 and 2 show the data on emergence (the appearance of the seedling at the soil surface), germination (radicle has pierced the seed coat) and emergence failures for Jambegede and Ngale. The latter refers to germinated seeds that failed to emerge (i.e. germination minus emergence). In almost all cases, the failure of seeds to germinate was greater than the failure to emerge, indicating that germination rather than emergence was limiting. Table 3 shows the range of soil water potentials during the first 4 days and 14 days after sowing for the two sites. In general, the heavy clay soil at Ngale was lower in water potential than the lighter soils of Jambegede although visually the Ngale soil may appear wetter.

A comparison of the three legume species shows that the emergence of mungbean was excellent in the lower soil water potentials at Ngale (92.9 ± 4.25%), followed by soybean (80.9 ± 14.8%) and peanut (64.1 ± 23%). In the higher soil water potentials at Jambegede, soybean performed best (94.8 ± 2.7%) followed by mungbean (70.7 ± 8.7%) and peanut (69.9 ± 7.7%). The viability of the seedlots was tested in the laboratory using sandboxes and the results indicated that the germination of mungbean was 96%, soybean 81.7% and peanut 88.7%.

So (1987) pointed out that for germination to be successful, the seed had to take up water at a sufficiently rapid rate and reach a critical water content necessary for germination processes to be initiated before other factors (such as fungal or bacteria infection) prevent it from completing the process. On the basis of seed size, critical water content and the associated rates of germination (Dart et al. 1992), it was expected that establishment would be best and most rapid in mungbean followed by soybean and peanut. The sequence between mungbean and soybean was, however, reversed in the wetter soil of Jambegede as a result of the high incidence of seed rot (Table 1) at 19.4% compared to 5.5% at Ngale. A higher incidence of seed rot was also observed with soybean at Ngale (10.9%) compared to 3.3% at Jambegede, probably associated with the cropping

Table 1. Emergence data for Jambegede.

Treatments		Mungbean			Peanut			Soybean		
Delay of plant.	Type of cult.	% Emerg.	% Failure of germ.	% Failure to emerg.	% Emerg.	% Failure of germ.	% Failure to emerg.	% Emerg.	% Failure to germ.	% Failure to emerg.
D0	C1	78.9 (9.59)	16.6 (9.82)	4.4 (3.14)	82.2 (5.66)	7.8 (4.14)	10 (2.71)	94.4 (1.60)	3.3 (2.72)	2.2 (3.14)
	C2	83.3 (4.71)	11.1 (6.85)	5.6 (4.16)	82.2 (4.15)	11.1 (3.13)	6.7 (4.71)	96.7 (2.74)	3.3 (2.72)	0 (0)
	C3	76.7 (7.22)	16.6 (2.69)	6.6 (7.17)	72.3 (12.84)	15.5 (6.27)	12.2 (6.85)	91.1 (6.86)	4.4 (4.15)	4.4 (3.14)
Average (D0)		79.6	14.8	5.5	78.9	11.5	9.6	94.1	3.7	2.2
D1	C1	64.5 (4.17)	25.5 (1.58)	10 (5.42)	61.2 (18.51)	25.5 (13.69)	13.3 (8.17)	96.7 (4.71)	2.2 (3.14)	1.1 (1.56)
	C2	66.3 (2.3)	32.2 (1.58)	1.1 (1.57)	65.6 (12.54)	26.6 (11.84)	7.8 (1.57)	94.4 (4.16)	1.1 (1.57)	4.4 (4.16)
	C3	80 (9.43)	14.4 (6.84)	5.6 (4.16)	66.7 (7.18)	22.2 (6.86)	11.1 (4.13)	91.1 (3.11)	5.6 (3.14)	3.3 (0)
Average (D1)		70.3	24	5.6	64.5	24.8	10.7	94.1	3	2.9
D2	C1	62.2 (5.66)	na	na	60 (7.21)	na	na	97.8 (1.56)	na	na
	C2	67.8 (1.56)	na	na	72.2 (4.15)	na	na	98.9 (1.56)	na	na
	C3	56.7 (5.43)	na	na	66.7 (7.22)	na	na	92.2 (6.32)	na	na
Average (D2)		62.2	na	na	66.3	na	na	96.3	na	na
Mean C1		68.5	21.1	7.2	67.8	16.6	11.7	96.3	2.8	1.7
Mean C2		72.5	21.7	3.4	73.3	18.9	7.3	96.7	2.2	2.2
Mean C3		71.4	15.5	6.1	68.6	18.9	11.7	91.5	5	3.9
Overall mean (species)		70.7 (10.68)	19.4* (9.2)	5.5* (2.65)	69.9 (12.54)	18.1* (11.17)	10.18* (2.33)	94.8 (4.92)	3.3* (3.33)	2.6* (1.64)

LSD 5% for
species: 5.01
delay of planting: 7.49
cultivation: 4.35
*: averaged from 2 treatments (D 0 and D 1)
na: not available

history of the region where soybean is a common crop after rice, indicating the presence of soil-borne diseases specific for soybean.

At Jambegede, mungbean is a common crop and the appropriate fungus is likely to be present in that soil. The high incidence of germination failure in peanuts was not associated with fungal infection, but rather with poor seed soil contact as seeds were generally intact. In peanut, a significant proportion of germinated seeds failed to emerge (10% to 13%) probably as a result of the high soil strength at the time of emergence. Even though the germination of these three legumes occurred at around the same time, peanut emergence was a lot slower than the other legumes (the emergence for mungbean and soybean started at 3–4 DAS compared to 6–7 DAS for peanut).

In the absence of rain, an increasing period of delay in sowing legumes after the rice harvest generally reduced the emergence and establishment of legumes at both Jambegede and Ngale except for mungbean at Ngale and soybean at Jambegede.

Table 2. Emergence data for Ngale.

Treatment		Mungbean			Peanut			Soybean		
Delay of plant.	Type of cult.	% Emerg.	% Failure of germ.	% Failure of emerg.	% Emerg.	% Failure of germ.	% Failure of emerg.	% Emerg.	% Failure of germ.	% Failure of emerg.
D0	C1	96.1 (1.56)	2.8 (1.57)	1.1 (1.57)	82.8 (4.12)	3.3 (0.005)	13.9 (4.15)	94.4 (1.60)	0 (0)	5.6 (1.57)
	C2	98.9 (1.56)	0 (0)	1.1 (1.57)	71.1 (8.65)	11.1 (5.14)	17.8 (8.23)	96.1 (0.80)	1.7 (2.36)	2.2 (1.57)
	C3	91.1 (5.64)	5.5 (3.38)	3.3 (2.36)	58.3 (13.84)	25.6 (13.07)	16.1 (0.80)	90.6 (4.79)	3.3 (1.36)	6.1 (4.38)
Average (D0)		95.4	2.8	1.8	70.7	13.3	15.9	93.7	1.7	4.6
D1	C1	93.9 (2.08)	6.1 (2.08)	0 (0)	90 (4.88)	4.4 (2.08)	5.6 (4.16)	87.2 (4.37)	8.3 (2.36)	4.5 (2.08)
	C2	94.5 (2.08)	5.6 (2.08)	0 (0)	87.8 (6.32)	5.4 (4.54)	6.9 (3.54)	80 (17.04)	8.9 (6.15)	11.1 (11.1)
	C3	90.6 (6.27)	8.9 (6.70)	0.6 (0.78)	62.2 (9.08)	27.2 (1.58)	10.6 (7.50)	71.7 (14.29)	20 (12.07)	8.4 (3.61)
Average (D1)		93.0	6.9	0.2	80	12.3	7.7	79.6	12.4	8
D2	C1	94.4 (0.80)	5 (1.36)	0.6 (0.78)	54.5 (10.35)	30 (5.91)	15.5 (5.66)	82.8 (8.16)	6.1 (5.13)	11.1 (8.62)
	C2	93.4 (2.36)	3.3 (1.36)	3.3 (2.72)	61.1 (11.3)	25.6 (11.56)	13.3 (3.58)	81.7 (2.74)	9.4 (4.37)	8.9 (2.84)
	C3	82.8 (4.37)	12.8 (3.9)	4.4 (0.79)	9.4 (5.53)	73.9 (3.96)	16.7 (2.36)	44.4 (12.28)	40.6 (11)	15 (2.74)
Average (D2)		90.2	7	2.8	41.7	43.2	15.2	69.6	18.7	11.7
Mean C1		94.8	4.6	0.6	75.8	12.5	11.7	88.1	4.8	7.1
Mean C2		95.6	2.9	1.5	73.3	14	12.7	85.9	6.7	7.4
Mean C3		88.2	9.01	2.7	43.3	42.2	14.5	68.9	21.3	9.8
Overall mean (species)		92.9 (4.25)	5.5 (3.46)	1.6 (1.54)	64.1 (23.0)	22.9 (20.69)	12.9 (4.09)	80.9 (14.79)	10.9 (11.84)	8.1 (3.72)

LSD 5% for
species: 4.81
delay of planting: 9.99
cultivation: 4.05

Increasing the period of sowing delay results in lower water potentials (Table 3). Therefore, the rate of water uptake by the seed and hence germination will be reduced and the opportunity for fungal infection will be increased.

However, Bewley and Black (1985) reported that germination is not affected by soil water potential (pF) unless pF values are very high and if biotic factors are controlled. This is probably the case with mungbean at Ngale and soybean at Jambegede, where specific fungi were most likely absent at that time. Thus, it appeared that under the conditions of this experiment, the reduction in establishment with delay in sowing was strongly associated with increased opportunity for fungal infection due to the reduced rate of germination. Therefore, in such cases the use of appropriate fungicides for seed treatment may alleviate some or all of the problem. It should be noted that this experiment was carried out in East Java where the transition from the rainy season to the dry season is gradual. Therefore, drying conditions during the experiment were relatively mild. The effect of increasing delay in sowing on seed germination and emergence will most likely be greater if the rate of soil drying is increased, e.g. in drier areas with an abrupt end to the rainy season.

The effects of cultivation and mulch on legume establishment were not clear from this experiment. Cultivation on the top 12.5 cm with the traditional hoe (treatment C3) resulted in greater rate of soil drying and higher pF values. This effect was greater in the lighter textured soil of Jambegede (Table 3). The soil at Jambegede, with a plant available water capacity (PAWC) of 0.14 m^3/m^3, was higher in water potentials than Ngale immediately after rice harvest, but after 17 days it became lower in water potential than the Ngale soil which can hold a greater amount of water (PAWC of 0.32 m^3/m^3).

The use of 5 t/ha of rice straw as soil mulch was intended to preserve water at the surface; however, the data show that it did not affect the soil water potential at the seed placement zone to any significant extent. With the increased drying rate of the soil, cultivation results in reduced germination and emergence particularly on the heavy clay soils at Ngale which tends to produce a cloddy surface soil. The failure to germinate in this soil under the C3 treatment is largely associated with poor seed soil contact due to the loss of sand cover into the broken seed hole and therefore reduced rate of water uptake. Cultivation has very little effect on the germination or emergence of any of the legumes in the Jambegede soils, probably because this soil displays more friable surface conditions as a result of cultivation, with better seed soil contact. The use of mulch on the two soils had very little effect on seed emergence and was consistent with the negligible effect on soil water potential.

The data reported in this paper can be extrapolated to other soil conditions with different environmental constraints if a generalised model of establishment can be developed from this data set. In the absence of biotic constraints, controlled laboratory experiments have shown that germination of mungbean, soybean and peanut was strongly related to soil water potentials and temperatures, assuming seed soil water contact was not limiting. The relationship between these two factors and germination was expressed by the equations:

Mungbean:

$$Y = -21.235 + 9.185T - 0.165T^2 + 52.453pF - 17.295pF^2,\ r^2 = 0.865,\ n = 30$$

Soybean:

$$Y = 14.254 + 7.837T - 0.164T^2 + 53.931pF - 17.339pF^2,\ r^2 = 0.843,\ n = 30$$

Peanut:

$$Y = -40.221 + 11.654T - 0.223T^2 + 33.855pF - 13.202pF^2,\ r^2 = 0.843,\ n = 30.$$

A similar relationship was obtained with Australian cultivars (Rahmianna 1993). Soil temperatures during the experiment were relatively constant at around 28–33 °C. In Figure 1, the predicted germination as a function of soil water potential (pF) was plotted for temperatures between 28 and 33 °C using the equations above. The agreement of actual to predicted data is good, except at the lower pF values (i.e. higher soil water potentials). The data from Jambegede at low pF values were significantly lower than predicted because of increased fungal infections on mungbean at these low pF values. In peanut the data tended to be lower than predicted, largely associated with poor seed soil contact resulting in 18% to 23% of germination failure (seeds failed to swell).

Table 3. The range of soil water potentials as pF scale in the various combinations of sowing delay and type of cultivation at Jambegede and Ngale for the periods of 0 to 4 days and 14 days after sowing (DAS).

Treatments		Range of water potential (pF scale) after sowing			
Sowing delay	Type of cultivation	Jambegede		Ngale	
		0–4 DAS	0–14 DAS	0–4 DAS	0–14 DAS
D0	C1	0–1.65	0–2.4	2.25–2.35	2.25–2.75
	C2	0	0–2.55	2.7–2.65	2.7–2.9
	C3	0–2.2	0–3.75	2.55–2.45	2.55–3.05
D1	C1	2.3–2.55	2.3–2.55	2.65–2.6	2.65–2.85
	C2	2.2–2.15	2.2–2.55	2.65–2.8	2.65–3.3
	C3	3.05–3.25	3.05–3.85	2.85–3.2	2.85–3.3
D2	C1	2.4–2.65	2.4–3.15	2.75–2.8	2.75–3.45
	C2	2.55–2.6	2.55–2.95	2.9–2.9	2.9–3.45
	C3	3.75–3.9	3.75–4.8	3.05–3.45	3.05–4.05

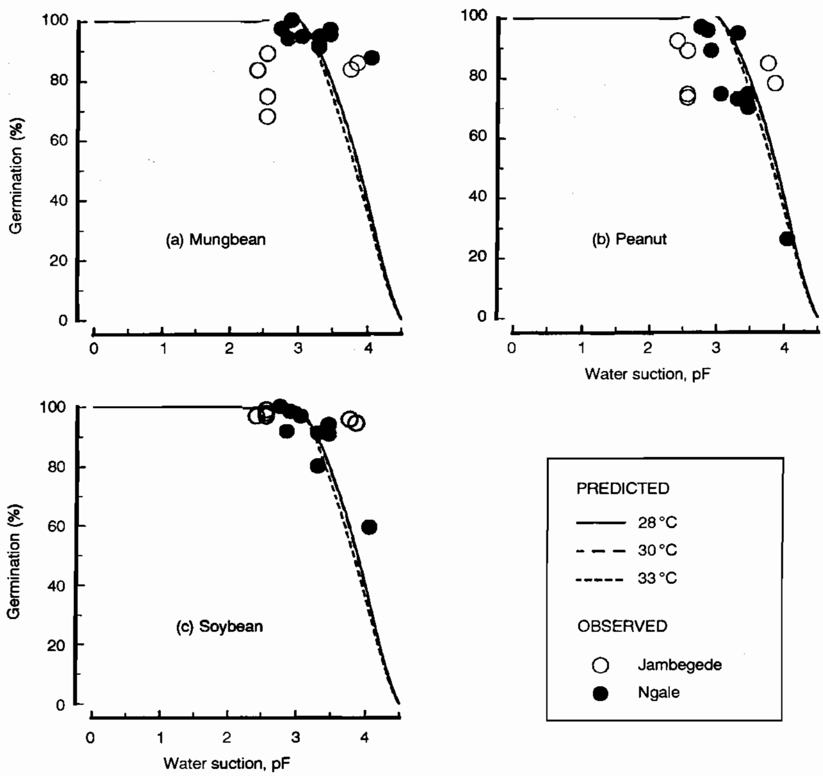


Figure 1. The relationship between germination and water potential for 3 different legumes. (Observed germinations were derived as the sum of % emergence and % failure to emerge in Tables 1 and 2.)

Conclusion

Establishment of legumes following rainfed lowland rice can be an important constraint to legume yield, particularly in the more arid areas of the tropics. The success of germination and emergence of dry season legumes after rice harvest is strongly affected by the rate of water uptake by the seed. This in turn may be affected by the period of sowing delay, cultivation of the surface soil if it increased the rate of soil drying and the application of mulch if it reduced the rate of soil drying. The emergence of these legumes can be predicted with reasonable accuracy from laboratory based germination characteristics of the seed.

Acknowledgment

The senior author is currently on an Australian Agency for International Development (AusAID) postgraduate award and the work was funded by the Australian Centre for International Agricultural Research (ACIAR).

References

Bewley, J.D., and Black, M. 1985. Seeds. Physiology of Development and Germination. New York. Plenum Press. 367 p.

Dart, I.K., So, H.B., and Schafer, B.M. 1992. The effect of temperature, water potential and seed contact area on the germination and subsequent shoot growth of sunflowers, soybeans and sorghum. Proceedings of the Sunflower Conference, 27–30 April 1992, Yeppoon, Queensland.

International Rice Research Institute (IRRI). 1992. Program Report for 1991. Los Baños, IRRI, 56 p.

International Seed Testing Association (ISTA). 1985. International rules for seed testing. Rules 1985. Seed Science and Technology, 13, 299–355.

Rahmianna, A.A. 1993. The interactive effect of water potentials and temperatures on seed germination under controlled condition. Diploma Agriculture Studies thesis, The University of Queensland (unpublished), 35 p.

So, H.B. 1987. Soil physical factors limiting crop establishment. In: Wood, I.M., Hazard, W.H., and From, F.R. ed., Crop Establishment Problems in Queensland: Recognition, Research and Resolution. Proceedings of a Workshop held at Queensland Agriculture College. Lawes, Queensland, 28–30 September 1987. Brisbane. 154–165.

So, H.B., Ringrose-Voase, A.J., Utomo, W.H., Adisarwanto, T., Prastowo, B., and Alcasid, G. 1993. Annual Report 15 Feb.–31 Dec. 1993. ACIAR Project 8938. Management of clay soils under lowland rice based cropping systems. 37 p.

Sumarno. 1991. Production Technique for Food Legumes and Coarse Grains in Indonesia. Paper presented at the Working Group's Planning and Consultative Meeting of RAS/89/040 Project. Regional Coop. Program for Improvement of Food Legumes and Coarse Grains in Asia. FAO-UNDP Project. Chiang Mai, Thailand, 29 July–3 August 1991. 9 p.

Sowing Techniques for Grain Legumes Planted after Lowland Rice in the Philippines

W.B. Sanidad[1]

Abstract

Traditionally the farming technique used by the Filipino farmer is broadcasting mungbean after rice harvest followed by harrowing. Combined with low management inputs, this technique usually results in low yields of mungbean ranging 0.45–0.8 t/ha. New improved practices have been introduced resulting in significantly higher mungbean yields. Two studies comparing the traditional and improved practices are discussed.

FARMERS in the Philippines usually adopt new technology in a piece-by-piece manner depending on what suits their current interest most. Commonly the production components adopted are crop variety and the method of planting. New or altered sowing methods are often adopted more readily and before modern varieties are adopted over and above traditional varieties.

Traditional Farmers' Management Practice (FP)

Traditionally local mungbean varieties and seed from the previous harvest are used by Filipino farmers. Mungbean is grown during the dry season (sowing in November to December) after rice harvest and it matures into increasingly drier conditions during the dry season. Sowing during the drier months, February to April, when the probability of typhoons occurring has decreased, often results in water stress (Cagampang et al. 1977; Ronduen et al. 1992).

Following the wet season rice crop, mungbean is usually broadcast planted or plough-broadcast-harrow (PBH) planted. The crop water requirements must be met by residual soil water left over from the flooded rice crop and dry season rainfall if irrigation is not available. Due to the relatively high chance of low yields or the risk of losing the crop, management input is kept low. Fertilisation of legumes, including mungbean, is normally not practised. Cultural practices are simple and inexpensive, with low yield levels generally ranging from 0.45 to 0.8 t/ha (Herrera et al. 1977). Low yields are caused by poor stand and low management input. Sometimes other seeding practices are used where seeds are placed in furrows, on ridges or dibbled between previous rice hills (which is laborious). Disadvantages for furrow seeding are increased chances of waterlogging following rainfall, accelerated soil drying on ridges and increased risk of early water stress.

Weed control is a problem affecting all types of sowing. However, if optimum plant density for maximum yield of 400 000 to 500 000 can be achieved, weeds are controlled by the mungbean crop itself. Average yield for these population densities is about .45 t/ha (Cagampang et al. 1977).

The Improved Practice (IP)

Use of improved practices for mungbean planting was initiated as the 'Mungbean Development Action Project of the Philippines' from 1987–89. Improvements over traditional mungbean culture practice included the use of an improved variety (BPI Mg 9), rhizobium inoculation, and the drill or dibbling method for planting. The drill method for planting places 18–22 seeds per metre. After seedlings are established they are thinned to 15–20 plants per metre to optimise population density. Distance between rows is 50–70 cm (Ronduen et al. 1992).

Due to its short growing period of 60 to 65 days, mungbean can be grown on residual moisture following wetland rice (Zandstra 1982) and it is regarded as the most common upland crop grown after rice. In the Philippines, annual production area for mungbean is 37 000 ha with a total yield of about 26 000 t (Tenedora et al. 1990).

[1] Bureau of Soil and Water Management, Cnr Elliptical Rd and Visayas Avenue, Quezon City 1100, Philippines

Experiments have been conducted to identify improved techniques for the production of upland crops. Emphasis was placed on improved crop establishment for a better crop stand and to reduce the turnaround time between crops. Studies on planting methods for mungbean following transplanted rice in the Philippines are presented below.

Dibbling Planting Methods vs Farmers' Practice (FP)

The three-year pilot trial of the Philippine 'Mungbean Development Project' compared traditional farmers' practice of planting (FP) with the improved method, IP (i.e., mungbean variety (BPI Mg 9), addition of rhizobium, no irrigation, no fertilisation and dibbling). Table 1 shows the yields obtained using FP and IP at different locations in the provinces of East Northern Luzon (Nueva Viscaya, Isabela, Cagayan). In 1987, highest yields recorded were greater using IP compared to FP, but little differences were observed in 1988. Lowest yields recorded were similar in both years for IP and FP. These results indicate that IP is no guarantee of higher yields but that the yield potential is higher using IP compared to FP. It is possible to propose that IP has little effect on yield under difficult climatic conditions but that improved yields can be expected under favourable climatic conditions. This was probably the main reason why farmers changed to IP in 1989 (Table 1).

In another study, the Philippine Bureau of Soils and Water Management (BSWM) in collaboration with ACIAR (Project 8938) investigated the effects of degree of puddling on soil physical properties, growth and yield of dry season crops following wetland rice. Four degrees of puddling were imposed during soil preparation for rice crops grown on medium and heavy-textured soils in Pangasinan (Manaoag) and Bulacan (San Ildefonso) provinces, respectively. Puddling treatments were: P1 — dry cultivation prior to submergence; P2 — one wet ploughing and harrowing using a draught animal; P3 — two wet ploughings and harrowings using a draught animal; P4 — two wet cultivations with a rototiller. The puddling treatments were combined with two tillage treatments (zero till–dibbled vs (ZTD) PBH) for the mungbean crop.

Table 1. Grain yield (t/ha) of BPI Mg 9 under two planting methods (Ronduen et al. 1992).

Year	FP	IP	FP	IP	FP	IP
	Lowest		Highest		Average	
1987[1]	0.25	0.31	1.88	2.56	0.816	1.24
1988[2]	0.16	0.19	1.96	1.96	1.050	1.36
1989[3]	—	0.40	—	2.60	—	1.36

[1] No irrigation/no fertilisation.
[2] Average of 65 ha area involving 93 cooperators (Isabela).
[3] Average of 112 ha involving 267 farm cooperators (Region 2). No data gathered for FP due to increasing number of farmer cooperators shifting to IP.

Table 2 summarises the mungbean yields obtained during the three-year study. Puddling intensity had no effect on the grain yield of mungbean on both sites, except during the first year on the light-textured soil at Manaoag (Pangasinan) where yields tended to be increased by increasing puddling intensity in the PBH treatments. There were no significant differences between ZTD and PBH (Table 2). Average yield in Manaoag for PBH was 0.92 t/ha and for ZTD 0.88 t/ha, for Bulacan 0.17 and 0.24 t/ha respectively for PBH and ZTD. This suggested that the conventional farmers' practice of PBH in Manaoag does not increase yields; in contrast the trend for using ZTD as part of an improved sowing method tends to depress yields. This confirmed an earlier study by Ronduen et al. (1992) who reported that the farmers were not left behind in terms of technology in growing legumes after rice. In

Table 2. Grain yield (t/ha) of Pagasa #7 as affected by four puddling treatments in combination with two tillage treatments.

	Pangasinan						Bulacan					
	1992–93		1993–94		1994–95		1992–93*		1993–94		1994–95	
	PBH	ZTD	PBH	ZTD	PBH	ZTD	PBH	ZTD	PBH	ZTD	PBH	ZTD
P1	0.86	0.95	0.78	0.69	0.87	0.75	0.16	0.10	0.18	0.13	0.20	0.24
P2	1.13	1.07	0.85	0.82	1.07	0.68	0.14	0.11	0.16	0.22	0.20	0.17
P3	1.05	1.15	0.91	0.83	0.69	0.84	0.09	0.67	0.33	0.28	0.10	0.33
P4	1.02	1.25	0.83	0.81	1.00	0.67	0.09	0.10	0.21	0.14	0.18	0.36
Mean	1.01	1.11	0.84	0.79	0.91	0.74	0.12	0.25	0.22	0.19	0.17	0.28

*Total biomass.
Differences are not significant.

Bulacan, yields were too low to be economical, even though ZTD tended to perform better compared to PBH. However, on both sites the crop stand tended to be better when mungbean was dibbled between rice rows instead of broadcast. Advantages for using PBH were better weed control compared to ZTD, but ZTD decreases turnaround time between crops, and so reduces water loss.

Tillage/planting Methods for Legumes Following Irrigated Rice in Previously Puddled Soil

A multi-agency study was conducted to investigate the use of post-rice residual soil moisture by dry season mungbean. It was carried out at Friar Lands River Irrigation System (FLRIS) and at Sta Cruz RIS (SCRIS) in the province of Laguna in 1988 and funded by the Rockefeller Foundation involving the BWSM, IRRI, National Irrigation Administration (NIA) and Central Luzon State University (CLSU). The effects of seeding delay, seeding method and tillage on grain yield were evaluated. Three tillage methods were applied: None; conventional ploughing and harrowing; and deep strip tillage to 35 cm depth along the seedlings to promote deep rooting and effective use of residual soil moisture. Manual seeding and seeding by an inverted T-seeder were compared. Mungbean was sown 12, 16, and 20 days after field drainage. Table 3 shows that deep strip tillage combined with manual precision seeding gave the highest grain yield of 1.9 t/ha. It is important to note that this was achieved without irrigation, no fertilizer, only 10 mm rainfall and with the watertable below 0.7 m (Tenedora et al. 1990). It clearly showed that high yields are possible even if the crop relies on residual soil water from the rice crop.

The effects of tillage, mulch application and irrigation on growth and yield of dry season mungbean were evaluated in trials at the Upper Talavera RIS (UTRIS) in the province of Nueva Ecija. The tillage/seeding methods used were: (1) tillage followed by row planting of mungbean; (2) farmers' method of ploughing the field then broadcasting the seeds and then harrowing; (3) conventional ploughing and harrowing followed by row planting; and (4) deep strip tillage followed by conventional tillage with row planting of mungbean. Tillage treatments were coupled with mulch and irrigation treatments. A no-mulch application was compared with rice-straw mulch at the rate of 1.6 t/ha, dryland was compared with irrigation of 80 mm at 38 days after sowing. The soil was fine, loamy, mixed Isohyperthermic Typic Tropaquept.

Results for 1988 for the mungbean crop are summarised in Table 4. To be able to compare yields between tillage treatments, yields were adjusted for equal plant population. The average response to deep or conventional tillage was an increase of 40% with an uncertainty of 20%. However, deep tillage without mulch application decreased yield by 20% with an uncertainty of 20%. Mulching had a relatively small effect on emergence and plant height but increased yields by 26%. This increase is largely due to water conservation and increased water availability towards the end of the growing cycle. The large response to irrigation showed that soil water was the major limiting factor. Together with mulching, irrigation increased yield by 49%. The constraints that caused the low yields under no-tillage, no-mulch and unirrigated were low emergence because of high seed zone strength, low fertility and heat stress in the hot Nueva Ecija environment (Tenedora et al. 1990).

Table 3. Use of post-rice residual soil moisture by dry season CES-1d-21 mungbean; effects on grain yield of seeding delay, seeding method, and tillage, FLRIS and SCRIS, Laguna, (Tenedora et al. 1990, unpublished data).

Tillage method	Seeding method	Seeding delay (days)			
		12[a]	16[a]	20[b]	20[c]
		Grain yield (t/ha)[d]			
None	Manual	1.5	1.0	1.6	1.6
Conventional	Manual	1.4	0.8	1.5	1.3
Deep strip[e]	Manual			1.6	1.9
None	INV-T	1.1	1.1		
Conventional	INV-T	1.0	0.9		
Standard error of difference		0.1	0.2	0.1	0.1

[a]FLRIS, 1988. [b]FLRIS, 1987. [c]SCRIS, 1987. [d]no irrigation, no fertilizer, 10 mm rainfall, watertable below 0.7 m. [e] Tillage to 35 cm depth along seedlines to promote deep rooting and effective use of residual soil moisture.

Table 4. Effect of tillage, irrigation and seedling mulch on the yield of CES-id-21 dry season mungbean, Upper Talavera River Irrigation System, Nueva Ecija, 1988 (Tenedora et al. 1990, unpublished data).

Tillage response:					
For yield adjusted for equal plant populations:					
Average response to deep or conventional tillage:		+40 ± 20%			
Except non-mulched, deep tilled (deep cracks):		−20 ± 20%			
Mulch response:					
Emergence: +9%;	Plant height:	+9%		Yield:	+26%
Irrigation response:					
	Plant height:	+20%;		Yield:	+21%
Interactions:					
Mulch irrigation:		Yield: +49%			
Nontilled, nonmulched, nonirrigated:		0.33 ± 0.03 t/ha			
Deep tilled, mulched, irrigated:		0.69 ± 17 t/ha			
PBH: Mulch more effective than irrigation					
Plant height higher with mulch if irrigated					
Plant height unchanged by mulch if not irrigated					
Constraints on yield:					
Emergence (seed zone strength); fertility; heat stress					

Future Research

Mungbean grown with low levels of management after rice offers considerable potential for using underutilised land resources. This can provide food for the ever increasing population of Asia. However, a better understanding of factors influencing sustainable food legume production systems for different production systems, soils and farm resources is needed. Development of planting methods that will stabilise grain yield of legumes to economic levels deserves greater attention.

References

Cagampang, I.C., Samson, O.F. and Micosa, J.C. 1977. Some studies on production management of mungbean in UPLBCA. In: Cowell, R., ed., Proceedings First International Mungbean Symposium. AVRDC, Taiwan.

Herrera, W.T., Zandstra, H.G. and Liboon, S.P. 1977. The management of mungbean in rice-based cropping systems. In: Cowell, R., ed., Proceedings First International Mungbean Symposium. AVRDC, Taiwan.

Ronduen, A.A., Perdido, V.C., Olinares, R.B., de Guzman, L.A. and Doca, F.O. 1992. Mungbean development project. Philippine Agricultural Research Journal V.1 No. 1.

Tenedora, M.E., Savares-Sarile, T.R. and Woodhead, T. 1990. Tillage and soil-water management for high production of legumes following irrigated lowland rice. Paper presented to the IRRI seminar. February, 1990.

Zandstra, H.G. 1982. Effect of soil moisture and texture on the growth of upland crops after wetland rice. In: Report of a workshop on cropping systems research in Asia. International Rice Research Institute, Los Baños, Laguna, Philippines, 43–54.

An Examination of the Dibbling Technique for Sowing Legumes after Rice

A.A. Rahmianna[1], H.B. So[2], G. Kirchhof[2], Sumarno[3] and T. Adisarwanto[4]

Abstract

Normal dibbling using an ordinary sharpened stick which creates a hole with a width of approximately 4 cm at the top, without depth control, and improper seed cover, is the common dibbling technique used by farmers in Indonesia. An experiment to evaluate the success of this traditional dibbling technique was conducted in rainfed lowland rice-based cropping systems at Ngale and Jambegede, East Java. The results showed that the farmers' dibbling technique used for planting grain legumes after rainfed lowland rice was appropriate for East Java conditions. Deeper seed placement (up to 7 cm depth) was not detrimental and also resulted in good germination. Seed quality was the major factor for the success of emergence. However, low levels of establishment observed on farmers' fields should be researched further to investigate the effect of seed quality, biotic factors such as fungal and pest attacks and abiotic factors, in particular, the soil physical conditions.

THE methods for sowing seed can be divided into two categories: (1) surface sowing and (2) drilling the seed into the soil (Pratley and Corbin 1994). Many reports concluded that there is not one sowing method which is better than others, since the success of any one sowing method in terms of germination and establishment is not consistent on all soil types, soil water relationship, plant species and climatic conditions.

One of the major problems in growing grain legumes in a rice-based cropping system is obtaining a good crop stand. However, plant establishment is generally poor. Inferior seed quality, inadequate land preparation, fungal and pest attacks, poor soil drainage as well as inappropriate methods of planting contribute to poor establishment. Broadcasting mungbean or soybean seeds into a standing rice stubble before or immediately after harvest is common among farmers in Indonesia, Philippines and Thailand because of its simplicity (Syarifuddin 1982; Irawan and Lancon 1992; Bastari 1992; Chainuvati 1992; Sumarno and Adisarwanto 1992; Adisarwanto et al. 1994; Radjit 1994).

In Indonesia, broadcasting is recommended when the soil is not adequately drained (Suyamto et al. 1989), even though this method may reduce the number of plants by 30% because of the failure of the seeds to germinate (Syarifuddin 1982; Sumarno et al. 1988). In the Philippines and Thailand, farmers on small plots often plant by hand and cover the seed using simple implements, e.g. a twig (Sarobol et al. 1992) or a foot (IRRI 1982). Seed placement as well as depth of seeding together with maximum length of hypocotyl may affect seedling emergence.

Dibbling legume seeds into the soil, either in rows, randomly or directly into the rice stubble, is practised in many places in Indonesia and Thailand (Sumarno et al. 1988; Irawan and Lancon 1992; Virakul 1992; Benjasil et al. 1992; Gypmantasiri 1992; Sarobol et al. 1992). A recommended practice is to sow grain legumes after lowland rice by dibbling into well-drained soil (Suyamto et al. 1989; Sumarno 1991; Irawan and Lancon 1992). This is preferred over the broadcast method which is associated with poor spatial distribution, poor seed–soil

[1] Department of Agriculture, The University of Queensland, Brisbane, 4072 Australia
[2] Currently on leave from MARIF
[3] The Director of MARIF until April 1995
[4] Grain-legume Coordinator at MARIF

contact, and excessive seed loss caused by ants and birds (Cardwell 1984; Pratley and Cobin 1994). However, dibbling is time-consuming, labour-intensive and requires extra expenses for ash/compost/straw to ensure adequate seed cover (Benjasil et al. 1992; Gypmantasiri 1992).

This paper reports on the results from a dibbling trial on the tropical grain legumes mungbean, peanut and soybean. The objective of the trial was to determine the factors affecting the success of the currently used dibbling technique.

Materials and Methods

The experiment was conducted on a Vertisol at Ngale and on an Andosol at Jambegede in East Java, Indonesia (Schafer, these Proceedings) adjacent to the E2 trial (So et al., these Proceedings). Due to rainfall at Ngale, planting was delayed until 11 days after rice harvest (3 April 1994) when the soil was judged ready for dibbling. At Jambegede, it was started sooner, seven days after rice harvest (1 May 1994).

A strip plot design was used to set up the experiment. The treatments consisted of 6 types of dibbling technique × 3 species × 5 replicates resulting in a total of 90 plots. The six dibbling methods were made up of a combination of depth control, soil cover and shape of hole. These were:

(1) normal dibbling, with no depth control and no soil cover (farmers' practice);
(2) normal dibbling, with no depth control, with soil cover;
(3) normal dibbling, with depth control, with no soil cover;
(4) normal dibbling, with depth control and soil cover;
(5) similar to (4) plus spike (to assist roots to penetrate the soil); and
(6) narrow dibbling hole, with depth control and soil cover.

Normal dibbling was produced using an ordinary sharpened dibbling stick which created a hole with a width of 4 cm at the top. A planting depth of 5 cm was used for the depth control treatments. The non-depth control treatment represented the farmers' practice, seed placement depths varied from 4 cm to 7 cm and were mostly greater than 5 cm deep. Moist sand was used as seed cover. The spike was made with a wire 2 mm in diameter and 10 cm long, and it was applied at the centre of the seed hole where the seeds were placed afterwards. The narrow dibbling hole was produced by a small stick with a width of 1 cm at the top and the seed was planted at 5 cm deep. The three legumes species, mungbean *cv.* Walet, peanut *cv.* Kelinci and soybean *cv.* Wilis were used in these experiments. Each plot was 3 × 2 m and seeds were planted with a spatial arrangement of 15 × 15 cm with two seeds/hole except for the narrow dibbling with one seed/hole.

Measurements of soil temperatures were taken at the soil surface, 2.5, 5 and 10 cm depths using thermocouples. The recordings of temperature were made daily at the same time when the maximum temperature occurred for each depth, obtained from hourly recordings during the first 48 hours. Soil water content in every centimetre for the first 10 cm, and every 2.5 cm between 10 cm to 20 cm of soil depth was measured by gravimetric method. Emergence was recorded daily starting at four days after sowing (DAS) until 14 DAS. At 14 DAS, seeds which failed to germinate or emerge were counted and the cause of failure recorded.

Results and Discussion

Data on germination (radicle has pierced the seed coat), emergence (the appearance of the seedling at the soil surface) and the failure of emergence (the germinated seeds that failed to emerge) for mungbean, soybean and peanut planted at Jambegede and Ngale are presented in Tables 1 and 2. The number of peanut and soybean seeds that emerged was smaller than the number of germinated seeds. Hence the main limitation to establishment was the strength of the dry surface soil or sand. The number of mungbean seedlings that failed to emerge was low, whereas the number that failed to germinate was high for all dibbling types at Jambegede. Table 3 shows the range of soil water potentials during the first four days and 14 days after sowing for the two sites. Similar to what had been obtained from the crop establishment trial run inside the rainshelter (Rahmianna et al., these Proceedings), the soil water potentials at Jambegede were slightly higher compared to the soil at Ngale, although there was more rainfall at Ngale which had 76 mm, while there was only 49 mm of rainfall at Jambegede during the first 14 days. Soil water potentials did not limit seedling establishment.

Comparing the emergence of the three species tested (Tables 1 and 2), mungbean performed best (94% ± 3.83%), followed by peanut (69.1% ± 13.41%) and soybean (52.5% ± 18.21%) in the lower water potentials at Ngale. In the higher water potentials at Jambegede, soybean performed best (84.2% ± 15.17%), followed by mungbean (72.4% ± 7.91%) and peanut (50.5% ± 13.3%). Compared to the emergence at Ngale, mungbean emergence at Jambegede was reduced by 21.6%. For soybean, however, there was a sharp increase (32% approximately). The success of emergence of mungbean at

Table 1. Emergence data for Jambegede.

Treatments	Mungbean			Peanut			Soybean		
	% Emerg.	% Failure of germ.	% Failure to emerge	% Emerg.	% Failure of germ.	% Failure to emerge	% Emerg.	% Failure of germ.	% Failure to emerge
T 1	71.2 (8.45)	**22.4**	6.4	44.2 (7.3)	19.7	35.4	92.6 (3.83)	3.3	4.1
T 2	72.8 (7.86)	20.4	6.8	46.6 (9.69)	10	43.4	95.8 (2.71)	1.1	**3.1**
T 3	69.2 (12.43)	25.7	**5.1**	41.2 (14.5)	28.7	**34.1**	84.6 (5.43)	5.7	9.7
T 4	74.8 (5.15)	18.0	7.2	45.8 (9.45)	8.5	43.1	91.2 (3.25)	4.4	4.4
T 5	75.2 (4.53)	16.9	7.9	60.8 (7.47)	14.9	24.3	87.8 (4.31)	2.4	9.8
T 6	71.0 (3.58)	18.2	**10.8**	64.6 (9.48)	10.5	26.9	53.2 (8.47)	5.7	**41.1**
Average	72.4 (7.91)	20.31	7.34 (3.13)	50.5 (13.3)	15.38 (8.99)	34.53 (12.78)	84.2 (15.2)	3.77 (2.76)	12.04 (14.21)

LSD 5% for species: 7.65
dibbling technique: 10.22

Table 2. Emergence data for Ngale.

Treatments	Mungbean			Peanut			Soybean		
	% Emerg.	% Failure of germ.	% Failure to emerge	% Emerg.	% Failure of germ.	% Failure to emerge	% Emerg.	% Failure of germ.	% Failure to emerge
T 1	95.4 (2.06)	**1.1**	3.5	55.4 (13.8)	5.2	39.4	65.0 (4.64)	6.7	28.3
T 2	95.4 (1.36)	4.6	0	77.8 (4.96)	1.2	21	62.6 (8.96)	8.2	29.2
T 3	95.2 (1.94)	4.8	0	52.2 (6.46)	5.9	41.9	56.8 (15.8)	7.3	35.9
T 4	93.4 (4.59)	6.6	0	78.2 (2.40)	0.5	21.3	58.6 (12.4)	13.0	28.4
T 5	96.6 (1.02)	3.4	0	74.4 (5.08)	0.7	24.9	52.2 (5.04)	12.4	35.4
T 6	88.2 (3.12)	**3.0**	8.8	76.6 (8.64)	6.5	16.9	**19.8 (6.91)**	26.3	53.9
Average	94 (3.83)	3.94 (2.61)	2.04 (3.48)	69.1 (13.41)	3.34 (3.96)	27.57 (10.72)	52.5 (18.21)	12.33 (7.91)	35.17 (12.98)

LSD 5% for species: 6.69
dibbling technique: 11.29

Table 3. The range of soil water potentials as pF scale in the various dibbling types at Jambegede and Ngale for the periods of 0 to 4 days and 14 days after sowing (DAS).

Treatments	Range of water potential (pF scale) after sowing			
	Jambegede		Ngale	
	0–4 DAS	0–14 DAS	0–4 DAS	0–14 DAS
T1: Normal dibbling, no depth control, no soil cover	2.4	2.45	2.55	2.75
T2: Normal dibbling, no depth control, soil cover	2.27	2.54	2.6	2.75
T3: Normal dibbling, depth control, no soil cover	2.2	2.4	2.55	2.75
T4: Normal dibbling, depth control, soil cover	2.45	2.4	2.55	2.8
T5: Normal dibbling, depth control, soil cover, spike	2.11	2.05	2.45	2.65
T6: Narrow slit, depth control, soil cover	2.23	2.42	2.55	2.75
Amount of rainfall during the first 14 days	49 mm		76 mm	

Ngale and soybean at Jambegede planted after rice are similar whether they are planted in the absence or presence of rain after sowing (Rahmianna et al., these Proceedings). It showed that germination and emergence of mungbean were susceptible to wet conditions while soybean was better able to cope with wet conditions.

Low emergence of mungbean at Jambegede was associated with high germination failure caused by a high incidence of seed rot (16.3%). The combination of wet soil and warm conditions (soil temperature at 5 cm depth ranged from 30 to 36 °C, mostly 31 °C at Jambegede and 33 °C at Ngale) would have promoted fungal growth. The low emergence of soybean at Ngale was mainly caused by the high number of seedlings (30.9%) unable to emerge (curling growth). This was caused by the failure of hypocotyl or radicle to penetrate the hard soil.

Peanut performed better at Ngale compared to Jambegede. There was higher germination failure on the wetter soil at Jambegede. Seed rot (6.0%), seed disappearance (2.9% possibly scavenged by birds or grubs), and incomplete imbibition (seed intact 5.1%) were observed as the main causes for this failure. At both sites, low emergence was caused by the failure of the new seedlings to grow further (20.6% and 9.4% at Jambegede and Ngale respectively) and the failure of the hypocotyl to emerge through soil surface (curling) by 9.4% and 16.6% at Jambegede and Ngale successively.

Treatment responses of mungbean were similar at both locations, but not for peanut and soybean. Mungbean emergence was not affected by the depth of planting, seed cover and the size of the dibbling hole. Small seeds completed germination rapidly and emergence was good even with very wet soil around the seeds. The emergence of peanut and soybean varied for each dibbling technique at both sites. Normal dibbling with or without depth control and with or without soil cover did not influence soybean emergence. Planting soybean at 5 cm soil depth using a narrow dibbling (T6), however, significantly reduced its emergence both at Jambegede and Ngale. The main causes of the low soybean emergence at Ngale were high germination failure caused by seed rot (up to 23.3%), high emergence failure caused by seedlings rot (17.2%) and the failure of the seedlings to come up to surface soil (28.1%).

Warm temperature and high relative humidity within seed holes (especially in narrow dibbling holes) were suitable for fungal growth and, combined with massive soil structure, were the most likely causes of failure. In Jambegede, the cause of low emergence was the failure of the seedlings to emerge through the surface soil (29.3%). It can be concluded that normal dibbling as recommended was appropriate for planting soybean after rainfed lowland rice.

The response of peanut emergence to dibbling techniques was different from soybean (Tables 1 and 2). Soil cover significantly increased the emergence (24.2% on average) at Ngale. High evaporation from the large exposed surface of the seed reduced the rate of imbibition and growth rates decreased resulting in failure of seeds to germinate or grow. At Jambegede the size of seed hole played an important role in governing the success of emergence. Small or narrow holes significantly increased emergence (ranging from 3.8% up to 23.4%) compared with normal/larger holes, probably associated with better soil-seed contact.

The effect of sowing depth on establishment is expected to be through its effect on soil water content and temperatures. To quantify this effect it will be useful to compare the performance of the seeds in the field with that measured in the laboratory. Using equations derived from laboratory studies (Rahmianna et al., these Proceedings) germination was predicted for a range of soil water potentials at the mean soil temperature of 31 °C for Jambegede and 33 °C for Ngale (Figs 1, 2 and 3). The agreement between observed and predicted germination was very good.

In the farmers' fields, depth of planting varied between 4 cm and 7 cm and generally tended to be deeper than 5 cm. However, Figures 1, 2 and 3 show that depth of planting under the conditions at Jambegede and Ngale was not limiting and should result in approximately 100% establishment. Observed deviations may be associated with reduced seed soil contact and seed vigour.

Figures 1, 2 and 3 also show that seed cover did not affect emergence except in the case of peanut where there was increased failure to germinate (incomplete imbibition) in the absence of soil cover.

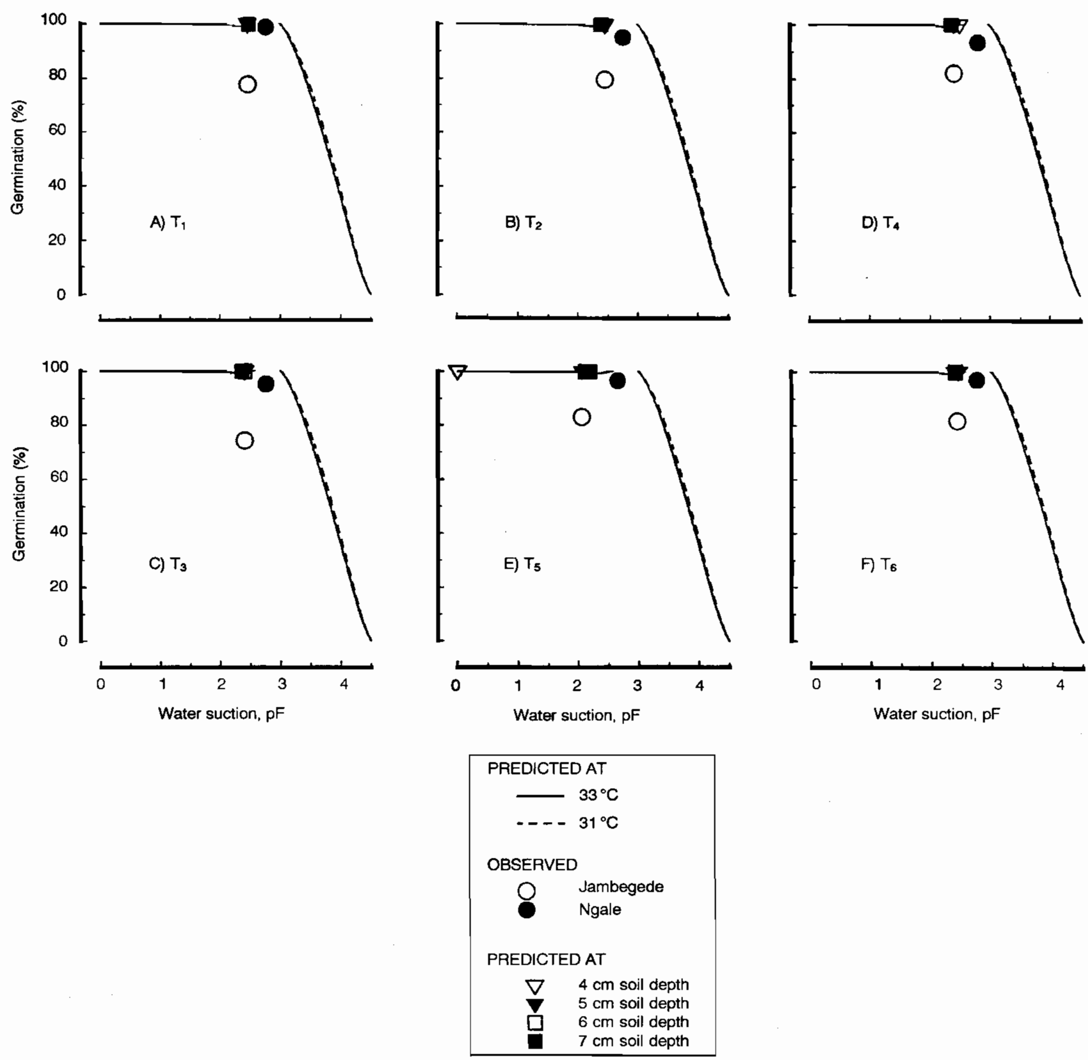


Figure 1. The relationship between germination and water potential for mungbean with six different dibbling techniques.

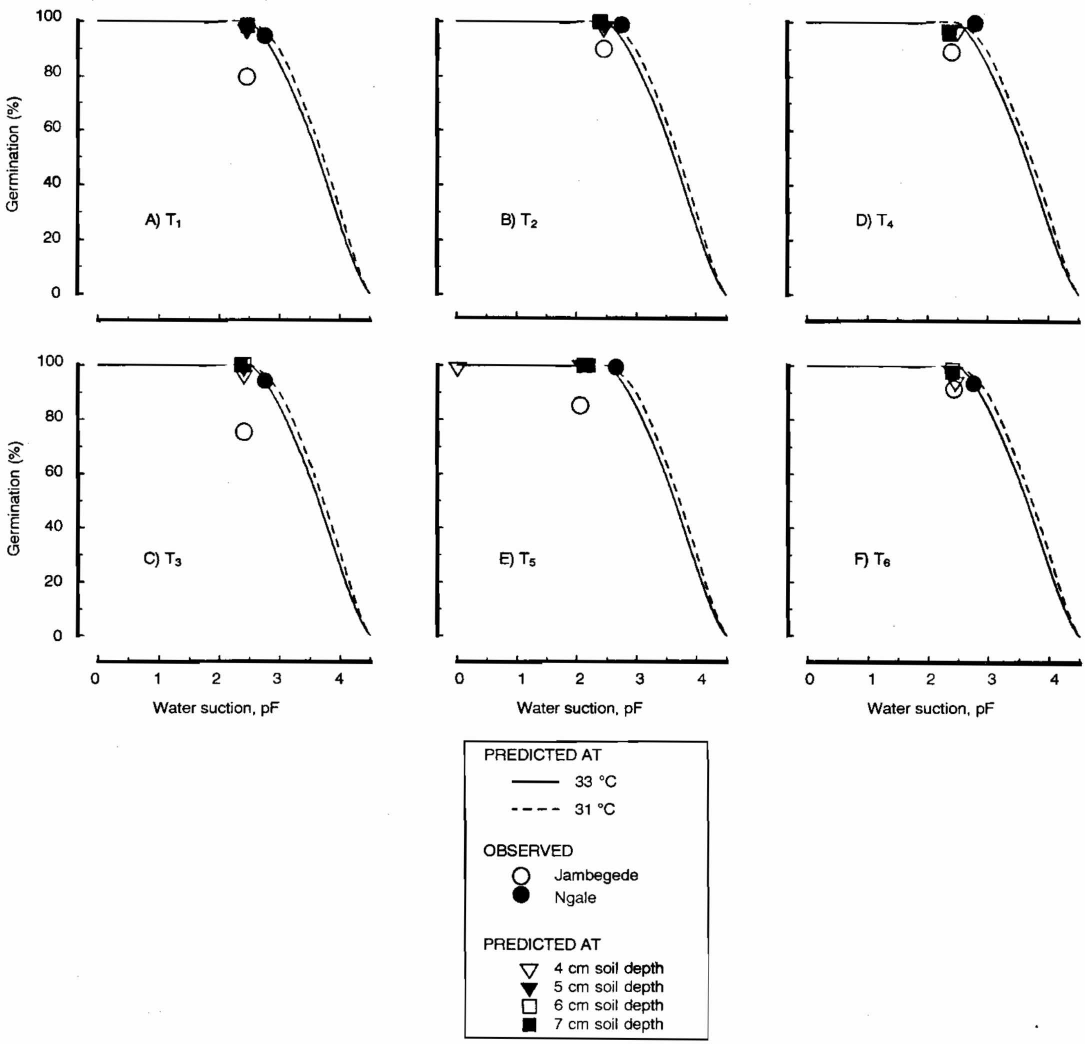


Figure 2. The relationship between germination and water potential for peanut with six different dibbling techniques.

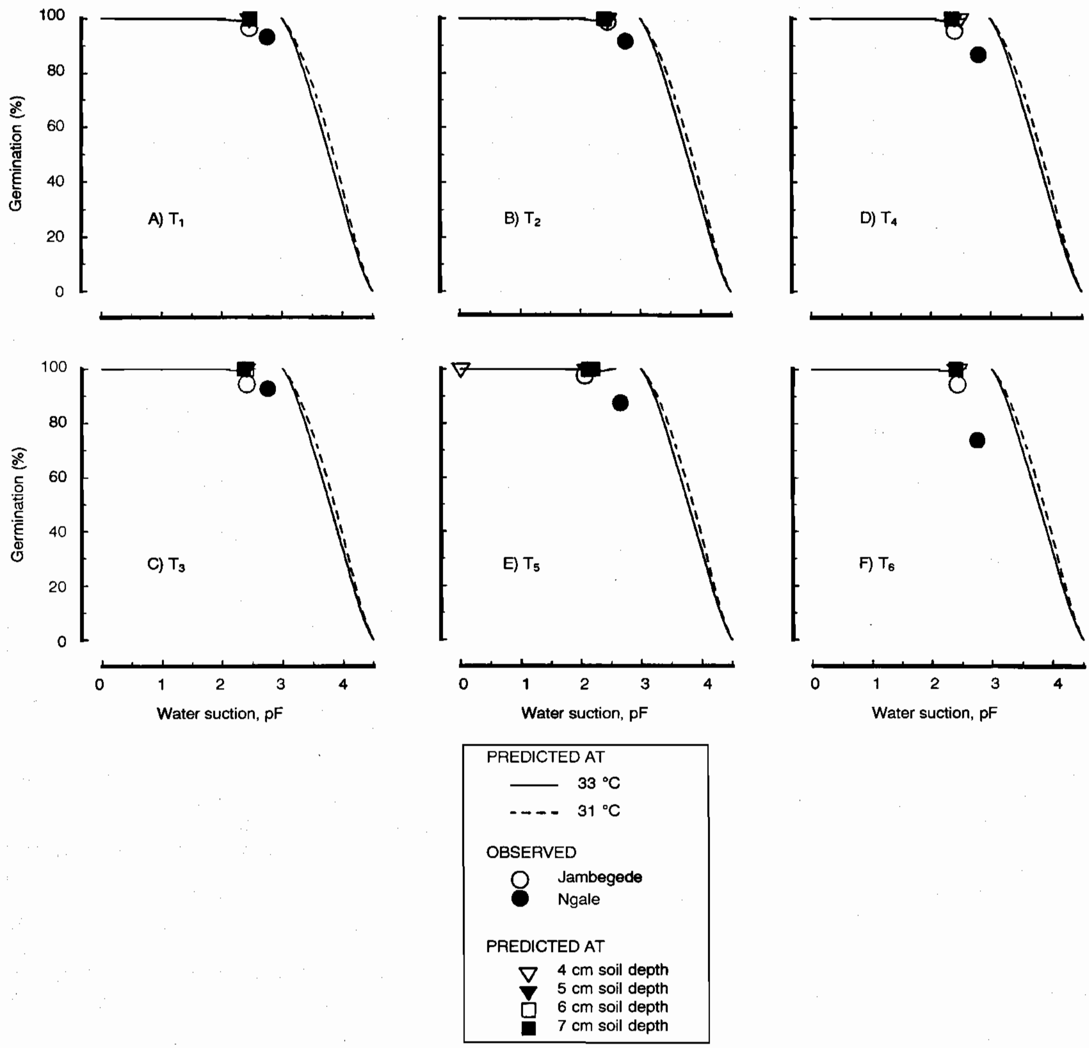


Figure 3. The relationship between germination and water potential for soybean with six different dibbling techniques.

Conclusion

The current dibbling method for planting grain legumes in rainfed lowland after rice used by farmers in East Java was suitable for the prevailing conditions. Its success was closely related to the soil water availability, which fully depends on rainfall, and on planting time and good quality of seeds. It should be noted that legumes were sown in the later part of the rainy season and the current dibbling technique may not be as successful under drier conditions. The low levels of observed establishment at the farmers' fields need to be researched further to investigate the effect of seed quality, biotic factors such as fungal and pest attacks and abiotic factors, in particular, the soil physical conditions.

References

Adisarwanto, T., Soegito, Santosa, B., and Sumarno. 1994. Soybean package-technology invention for East Java. In. Radjit, B.S., Betty, Y.A., Sunardi and Winarto, A. ed., Proceedings of a Communication of Technology to Increase Food Crops Production In East Java. Indonesia. Malang Research Institute for Food Crops (In Indonesian).

Bastari, T. 1992. Constraints faced by soybean farmers in Indonesia. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

Benjasil, V., Pintongkam, S., Seradee, I., Potan, N., Tongprew, N., Nattriphob, P. and Kajornmalee, V. 1992. Technology available for increasing soybean production and farmers' incomes in the north of Thailand. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

Cardwell, V.B. 1984. Seed germination and crop production. In: Tesar, M.B. ed., Physiological Basis of Crop Growth and Development. Madison. ASA, CSSA. 53–92.

Chainuvati, C. 1992. Soybean extension program in Thailand. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

Gypmantasiri, P. 1992. Soybean farming systems in the upper north of Thailand. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

Irawan, B., and Lancon, F. 1992. The constraints in growing soybean and their impact on the efficiency of soybean cultural practices: The case of Japanan in East Java. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

IRRI. 1982. Research Highlight for 1981. International Rice Research Institute. Los Baños. 111–112.

Pratley, J.E. and Corbin, E.J. 1994. Cultural practices. In: Partley, J. ed., Principles of Field Crop Production. 3rd edn, Melbourne. Oxford University Press. 302–348.

Radjit, B.S. 1994. Mungbean package-technology invention for East Java. In: Radjit, B.S., Betty, Y.A., Sunardi and Winarto, A. ed., Proceedings of a Communication of Technology to Increase Food Crops Production In East Java. Indonesia. Malang Research Institute for Food Crop (In Indonesian).

Sarobol, N., Uttayopas, A., Sewatasai, R. and Cnanaseni, C. 1992. Farmers' practices relating to soybean production technology and planting methods. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

Sumarno. 1991. Production Technique for Food legumes and Coarse Grains in Indonesia. Paper presented at the Working Group's Planning and Consultative Meeting of RAS/89/040 Project. Regional Cooperative Program for Improvement of Food Legumes and Coarse Grains in Asia. FAO-UNDP project. Chiang Mai, Thailand 29 July–3 August 1991. 9 p.

Sumarno and Adisarwanto, T. 1992. Soybean research to support soybean production in Indonesia. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

Sumarno, Oka, I.M., Sunarlim, N., Makarim, A.K., Sharma, D., Syam, M. and Manwan, I. 1988. National Coordinated Grain Legumes Research Program. Central Research Institute for Food Crops. Bogor. 64 p.

Suyamto, Sumarno, Fagi, A.M. and Suwardjo, H. 1989. Choice of crop and its management for planting following rice in puddled soils. Paper presented on 20th Asian Rice Farming System Working Group Meeting. Bogor 2–6 October 1989. 27 p.

Syarifuddin, K.A. 1982. Tillage practices and methods of seeding upland crops after wetland rice. In: Report of a Workshop on Cropping Systems Research in Asia. Los Baños. International Rice Research Institute. 302–348.

Virakul, P. 1992. Economic returns on choices of input technology: An experience from SYGAP. In: Priorities for Soybean Development in Asia. Proceedings of a Workshop held in Bogor, Indonesia, 3–6 December 1991. Bogor: CGPRT Centre, 1992.

DRY SEASON CROPS

Changes in Soil Mechanical Properties Resulting from Different Soil Management Practices for Rice-based Cropping Systems

R. Tranggono and Gunomo Djoyowasito[1]

Abstract

Soil strength measurements were made in two field experiments investigating soil management for lowland rice-based cropping systems. In experiment E1 various puddling treatments were applied before the rice crop and their effect measured during the subsequent dry season mungbean crop. In experiment E2 the puddling treatment was kept constant and various treatments including soil amendments (none, gypsum, organic matter mulch), sowing delays and tillage were applied after rice harvest for the mungbean crop. The experiment was conducted at two sites in East Java at Ngale and Jambegede. Few significant differences in soil strength were found between treatments, possibly due to high variability. More intense puddling was found to decrease soil strength during the rice crop and early in the mungbean crop. However, these effects had disappeared by the flowering stage, possibly indicating that strength increased more rapidly as the soil dried in more intensely puddled soil. Organic matter mulch decreased soil strength due to increased soil moisture. Gypsum had no effect. Tillage also decreased soil strength. None of the effects on soil strength were reflected in mungbean yields. This may have been due to the soil strength being non-limiting during root exploration.

THE clay soils of paddy fields have the distinctive characteristic of being alternately dried and submerged. When dried they become hard, compact and cracked and when submerged lose bearing capacity. In order to improve the management of such soils, including the most appropriate tillage for 'sawah' (wetland rice) and 'palawija' (non-rice crop planted after rice), soil strength measurements were made in experiments E1 and E2 of ACIAR Project 8938 as described by So et al. (these Proceedings).

Materials and Methods

Experiments E1 and E2 were conducted between November 1991 and December 1994 at the Jambegede and Ngale experimental farms. The soils are described in Schafer and Kirchhof (these Proceedings).

[1]Department of Agricultural Technology, University of Brawijaya, Fakultas Pertanian, Jl. Mayjen Harjono 18, Malang 65145, Indonesia

E1 investigated the effect of degree of puddling on soil physical and mechanical conditions during both the rice phase and during the subsequent dry season (DS) crop of mungbean. Four puddling treatments were used: T1, dry cultivation; T2, one pass with an animal-drawn plough and harrow; T3; two passes with an animal-drawn plough and harrow and T4, two passes with a mechanical rototiller.

E2 studied the effect of DS crop management on soil properties and crop performance. The DS crop was mungbean. Puddling for the rice phase involved two wet, animal-drawn ploughings and harrowings (equivalent to T3 in E1). Treatments were applied to the DS crop and included amendments (none, A0; gypsum, AG, and organic matter, AOM), cultivation (zero, C0, and cultivation, C1) and length of sowing delay after rice harvest (0 weeks, D0; 1 week, D1, and two weeks, D2). These were combined as follows: T1 (C0 A0 D1), T2 (C0 A0 D1), T3 (C0 AG D1), T4 (C0 AOM D1), T5 (C0 A0 D0), T6 (C0 A0 D2), T7 (C1 A0 D1) and T8 (C1 A0 D2). All treatments had adequate fertilizer applied except T1 (which is not considered further in this paper).

In both E1 and E2, the treatments were laid out in a randomised block design with four replications. Bearing capacity and depth of ploughing were measured in E1 in 1993 during the rice phase at one week after transplanting. Penetration resistance and shear strength (with zero normal stress) were measured in E1 and E2 during the DS crop at planting, vegetative and flowering stages. Penetration strength was measured with a different penetrometer in 1992 to that used in 1993 and 1994, so the results are not directly comparable. Soil strength measurements were made in only three of the four replicates of each treatment for logistical reasons using three replicate measurements per plot.

Results

A. Experiment E1

A.1. Effect of degree of puddling on bearing capacity during the rice crop

Table 1 shows the bearing capacity in E1 during the 1993 rice phase. The statistical analyses show there was no significant effect of the puddling treatments at either Ngale or Jambegede. However, the bearing capacity tends to decrease with puddling intensity, although in the case of the rototiller this was only in the upper 5 cm. In addition, comparison of the average bearing capacity between sites (Table 1) shows that greater yields of rice were generally associated with lower bearing capacity. At Jambegede treatment T2 had the lowest bearing capacity and gave the highest yield (4.86 t/ha). Similarly, at Ngale treatment T3 gave the highest yield (6.04 t/ha) and had the lowest bearing capacity.

A.2. Effect of puddling on soil strength during the DS crop at Jambegede

Penetration resistance and shear strength of the soil during the DS crop at Jambegede are shown in Table 2. Both shear strength and penetration resistance were not affected by puddling treatments, except in 1993. The lower penetrometer resistance at planting in the highest puddled treatment (T4) was probably due to higher soil water contents caused by reduced drainage of the structurally degraded, highly puddled soil. By the vegetative stage, the highly puddled treatment (T4) had the greatest increase in strength at 10 cm due to the greater degree of destruction of the soil structure. The highest soil strength at the vegetative stage, however, was observed in the least intense puddling treatment (T1). This was possibly due to superior drainage compared to more intensely puddled treatments and concomitant high hydraulic conductivity that would result in faster soil drying.

In 1992, the average soil strength decreased between planting and the vegetative stage due to rainfall. This probably resulted in superior growth and yield compared to 1993, where smaller amounts of rain fell and the soil strength increased slightly between planting and the vegetative stage. The relationship between plant growth and soil mechanical properties is clearly related to the effect of soil water on soil strength and penetrometer resistance.

A.3. Effect of puddling on soil strength during the DS crop at Ngale

Penetration resistance and shear strength of the soil during the DS crop at Ngale are shown in Table 3. In

Table 1. Effects of degree of puddling on bearing capacity, depth of ploughing (DP) and rice yield in E1 at Jambegede and Ngale in 1993. Values in same column followed by the same letter are not significantly different.

Treatment	Bearing capacity (MPa)				DP (cm)	Rice yield (t/ha)
	5 cm	10 cm	15 cm	20 cm		
E1 Jambegede 1993						
T1	0.021 a	0.063 a	0.082 a	>0.100	17	4.46
T2	0.016 a	0.023 a	0.067 a	>0.100	19	4.86
T3	0.019 a	0.036 a	0.057 a	0.091	21	4.28
T4	0.012 a	0.063 a	0.098 a	>0.100	18	4.76
Mean	0.017	0.046	0.076	>0.100	19	4.59
E1 Ngale 1993						
T1	0.037 a	0.032 a	0.039 a	0.042 a	15	5.40
T2	0.031 a	0.038 a	0.033 a	0.042 a	16	5.87
T3	0.023 a	0.025 a	0.029 a	0.038 a	17	6.04
T4	0.029 a	0.029 a	0.036 a	0.043 a	16	5.92
Mean	0.03	0.031	0.034	0.041	16	5.81

most years, soil strength at planting of the DS crop appeared to be higher when the soil had been cultivated dry before the rice crop (T1) than when puddled. However, there were few differences by the time the mungbean crop had reached the vegetative stage. Similar to Jambegede, soil strength and yield differences between years seemed to be related to rainfall between planting and the vegetative stages. The highest yields were observed in 1992 where seed was sown in relatively dry soil as indicated by the highest soil strength compared to the other years. Following sowing into relatively hard soil, rainfall increased soil water content with concomitant decrease in soil strength. In 1993 and 1994, however, soil strength remained low due to persistent high soil water content which may have resulted in anaerobic conditions leading to restricted growth and reduced yield.

B. Experiment E2

Results from E2 are presented separately for three groups of treatments: a) soil amendment (T2, T3, T4); b) sowing delay (T5, T2, T6) and c) cultivation × sowing delay (T2, T6, T7, T8).

Table 2a. Effects of degree of puddling on penetration resistance and mungbean yield in E1 at Jambegede in DS. Values for the same year in the same column followed by the same letter are not significantly different. Only means are reported if differences were not significant.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E1 Jambegede 1992[a]							
Mean	2585	1575	2780	1950	3683	4223	1
E1 Jambegede 1993[b]							
T1	200 a	402 a	890 b	>1250	>1250	>1250	0.32
T2	209 a	293 b	982 a	>1250	>1250	>1250	0.35
T3	212 a	255 b	926 b	>1250	>1250	>1250	0.28
T4	185 b	322 a	919 b	>1250	>1250	>1250	0.32
Mean	202	318	929	>1250	>1250	>1250	0.32
E1 Jambegede 1994[b]							
Mean	259	—	—	—	—	—	0.14

[a]Measured with a Stiboga penetrometer with 1 cm^2 cone area (uncalibrated units).
[b]Measured with Daiki penetrometer with 2 cm^2 cone area.

Table 2b. Shear strength and mungbean yield in E1 at Jambegede in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E1 Jambegede 1992							
Mean	701	485	1022	326	1157	—	0.97
E1 Jambegede 1993							
Mean	184	586	696	724	1560	—	0.32
E1 Jambegede 1994							
Mean	351	1127	—	—	—	—	0.14

Table 3a. Effects of degree of puddling on penetration resistance and mungbean yield in E1 at Ngale in DS. Values for the same year in the same column followed by the same letter are not significantly different. Only means are reported if treatment differences were not significant.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E1 Ngale 1992[a]							
Mean	675	370	724	—	—	—	1.67
E1 Ngale 1993[a]							
T1	161 a	177 a	209 a	177 a	232 a	279 a	0.92
T2	167 a	141 a	220 a	156 a	207 a	253 a	0.92
T3	128 b	142 a	192 a	155 a	219 a	292 a	0.81
T4	134 b	143 a	208 a	163 a	236 a	293 a	0.88
Mean	147	151	207	163	224	279	0.88
E1 Nagle 1994[a]							
T1	178 a	172 a	208 b	384 a	440 a	448 a	0.52
T2	167 a	156 a	420 a	388 a	417 a	448 a	0.55
T3	156 a	173 a	202 b	412 a	482 a	466 a	0.55
T4	138 b	147 a	193 b	373 a	520 a	515 a	0.56
Mean	160	162	256	389	465	469	0.55

[a]Measured with Daiki penetrometer with 2 cm^2 cone area.

B.1. Effect of DS crop management on soil strength at Jambegede

B.1.a. Soil amendment

Table 4 shows that penetration resistance and shear strength were generally lower after addition of an organic matter mulch (T4, AOM) compared to the addition of no amendment (T2, A0) or gypsum (T3, AG). This effect seems to have been maintained through the mungbean crop at least as far as flowering. Since the organic matter was added as a mulch to the soil surface to reduce evaporation, it is likely that the lower strength results from the soil in T4 having a higher moisture content than T2 or T3. However, the treatment had no effect on mungbean yield.

B.1.b. Sowing delay

Soil strength during mungbean crops planted with different delays after rice harvest is shown in Table 5. There is a tendency for the soil to be weaker after shorter delays, presumably because the soil has a higher moisture content. However, in most cases this is not statistically significant. One factor confounding the results is that rain could alter the moisture content between measurement dates for the various treatments.

B.1.c. Tillage × sowing delay

Table 6 compares soil strength under various combinations of zero tillage (C0) and tillage (C1) before the DS crop and one (D1) and two week (D2) sowing delays. (The no delay treatment, D0, was too wet to allow tillage). There is a tendency for the soil at 5 cm and 10 cm to be weaker after tillage, although this effect was only significant in 1993.

B.2. Effect of DS crop management on soil strength at Ngale

B.2.a. Soil amendment

Table 7 shows that penetration resistance and shear strength were generally slightly lower after addition of an organic matter mulch (T4, AOM) although less so than at Jambegede. However, none of the differences were statistically significant.

B.2.b. Sowing delay

In 1993 the soil was weaker after shorter delays (Table 8). In the other years there was no effect.

B.2.c. Tillage × sowing delay

Like at Jambegede, soil strength was lower after tillage, but this was only significant in 1993 (Table 9). There is slight evidence of an interaction with delay, in that the reduction in strength is greatest for D1.

Table 3b. Shear strength and mungbean yield in E1 at Ngale in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E1 Ngale 1992							
Mean	212	296	318	214	261	384	1.67
E1 Ngale 1993							
Mean	149	238	310	246	334	439	0.88
E1 Ngale 1994							
Mean	206	268	336	559	593	654	0.55

Table 4a. Effects of soil amendments on penetration resistance and mungbean yield in E2 at Jambegede in DS. Values for the same year in the same column followed by the same letter are not significantly different. Only means are shown if treatment differences were not significant.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Jambegede 1992[a]							
T2 (A0)	2660 a	1150 a	2620 b	2190 a	4720 a	3720 a	0.55 a
T3 (AG)	2620 a	1580 a	3070 a	2380 a	4240 a	4060 a	0.47 a
T4 (AOM)	2300 a	1160 a	2550 b	1500 a	3520 b	4120 a	0.47 a
E2 Jambegede 1993[b]							
T2 (A0)	231 a	553 b	1109 b	1044 a	1226 a	>1250	0.60 a
T3 (AG)	216 a	752 a	1244 a	1101 a	1226 a	>1250	0.67 a
T4 (AOM)	230 a	353 c	1067 b	501 b	1140 b	>1250	0.50 a
E2 Jambegede 1994[b]							
Mean	281	330	764	572	704	985	0.83

[a]Measured with a Stiboga penetrometer with 1 cm^2 cone area (uncalibrated units).
[b]Measured with Daiki penetrometer with 2 cm^2 cone area.

Table 4b. Effects of soil amendments on shear strength and mungbean yield in E2 at Jambegede in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Jambegede 1992							
T2 (A0)	851 b	412 a	1057 a	599 a	1226 a	—	0.55 a
T3 (AG)	500 b	513 a	956 a	527 a	1355 a	—	0.47 a
T4 (AOM)	432 a	446 a	782 b	428 a	1083 a	—	0.47 a
E2 Jambegede 1993							
Mean	442	703	1302	619	1126	1129	0.59
E2 Jambegede 1994							
Mean	290	336	680	628	884	1110	0.83

Table 5a. Effects of sowing delay on penetration resistance and mungbean yield in E2 at Jambegede in DS. Values for the same year in the same column followed by the same letter are not significantly different.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Jambegede 1992[a]							
T5 (D0)	2150 a	1550 a	2480 a	2510 a	3550 b	4060 a	0.78
T2 (D1)	2660 a	1150 a	2620 a	2190 a	4720 a	3720 a	0.55
T6 (D2)	2100 a	1900 a	2690 a	2090 a	3960 b	4120 a	0.53
E2 Jambegede 1993[b]							
T5 (D0)	248 a	254 b	916 b	1104 a	1226 a	>1250	0.57 a
T2 (D1)	231 a	553 a	1109 ab	1044 a	1226 a	>1250	0.60 a
T6 (D2)	—	506 a	1162 a	931 a	1226 a	>1250	0.17 b
E2 Jambegede 1994[b]							
T5 (D0)	237 a	293 a	742 a	529 a	833 a	981 a	1.13
T2 (D1)	323 a	310 a	731 a	627 a	814 a	891 a	0.84
T6 (D2)	215 a	327 a	882 a	451 b	857 a	1018 a	0.61

[a]Measured with a Stiboga penetrometer with 1 cm^2 cone area (uncalibrated units).
[b]Measured with Daiki penetrometer with 2 cm^2 cone area.

Table 5b. Effects of sowing delay on shear strength and mungbean yield in E2 at Jambegede in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Jambegede 1992							
T5 (D0)	797 a	383 a	991 a	477 a	1198 a	—	0.78 a
T2 (D1)	851 a	412 a	1057 b	599 a	1226 a	—	0.55 b
T6 (D2)	635 a	348 a	893 a	566 a	1425 b	—	0.53 b
E2 Jambegede 1993							
T5 (D0)	513 a	796 a	1364 a	603 a	1123 a	1275 a	0.57 a
T2 (D1)	390 a	698 a	1277 a	680 a	1164 a	1181 a	0.60 a
T6 (D2)	319 a	1086 b	1341 a	656 a	1118 a	1267 a	0.17 b
E2 Jambegede 1994							
T5 (D0)	210 a	333 a	665 a	780 a	1058 a	1223 a	1.13 a
T2 (D1)	288 a	308 a	665 a	628 a	878 b	1073 b	0.84 b
T6 (D2)	247 a	327 a	540 a	588 a	918 b	1075 b	0.61 b

Table 6a. Effects of tillage × sowing delay on penetration resistance and mungbean yield in E2 at Jambegede in DS. Values for the same year in the same column followed by the same letter are not significantly different.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Jambegede 1992[a]							
T2 (C0 D1)	2660 a	1150 a	2620 a	2190 a	4720 a	3720 a	1.99 a
T6 (D0 D2)	2100 a	1900 a	2690 a	2090 a	3960 b	4120 a	1.55 b
T7 (C1 D1)	1400 a	1760 a	2600 a	1890 a	4460 ab	3750 a	1.81 ab
T8 (C1 D2)	1160 a	1660 a	2510 a	2070 a	4260 ab	4210 a	1.74 ab
E2 Jambegede 1993[b]							
T2 (C0 D1)	231 a	553 ab	1109 ab	1044 a	1226 a	>1250	0.60 a
T6 (C0 D2)	—	506 ab	1162 a	931 a	1226 a	>1250	0.17 b
T7 (C1 D1)	128 b	410 b	943 c	657 b	1222 a	>1250	
T8 (C1 D2)		638 a	1039 b	490 b	1185 a	>1250	
E2 Jambegede 1994[b]							
T2 (C0 D1)	323 a	310 a	731 a	627 a	814 a	891 a	—
T6 (C0 D2)	215 b	327 a	882 a	451 b	857 a	1018 a	—
T7 (C1 D1)	562 a	214 a	607 a	436 a	773 a	964 a	—
T8 (C1 D2)	493 a	255 a	691 a	373 a	705 a	957 a	—

[a]Measured with a Stiboga penetrometer with 1 cm^2 cone area (uncalibrated units).
[b]Measured with Daiki penetrometer with 2 cm^2 cone area.

Table 6b. Effects of tillage × sowing delay on shear strength and mungbean yield in E2 at Jambegede in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Jambegede 1992							
T2 (C0 D1)	851 b	412 a	1057 a	599 b	1226 a	—	1.99 a
T6 (C0 D2)	635 a	348 a	893 a	566 b	1425 a	—	1.55 b
T7 (C1 D1)	589 a	434 a	944 a	115 a	1037 a	—	1.81 ab
T8 (C1 D2)	638 a	312 a	1067 a	206 a	1174 a	—	1.74 ab
E2 Jambegede 1993							
T2 (C0 D1)	390 a	698 b	1277 a	680 b	1164 a	1181 b	0.60 a
T6 (C0 D2)	319 a	1086 b	1341 a	656 b	1118 a	1267 b	0.17 b
T7 (C1 D1)	319 a	324 a	1087 a	443 b	1027 a	1442 b	
T8 (C1 D2)	392 a	420 a	1099 a	286 a	1027 a	1094 a	
E2 Jambegede 1994							
T2 (C0 D1)	288	308 b	665 b	628 b	878 b	1073 a	—
T6 (C0 D2)	247	327 b	540 b	588 b	918 b	1075 a	—
T7 (C1 D1)	—	192 a	552 b	438 a	752 a	1032 a	—
T8 (C1 D2)	—	253 b	672 b	477 a	802 ba	1035 a	—

Table 7a. Effects of soil amendments on penetration resistance and mungbean yield in E2 at Ngale in DS. Values for the same year in the same column followed by the same letter are not significantly different. Only means are shown if treatment differences were not significant.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Ngale 1992[a]							
T2 (A0)	244 b	320 a	925 a	515 a	740 a	860 a	1.08 a
T3 (AG)	380 a	400 a	735 a	395 a	628 a	740 a	1.07 a
T4 (AOM)	293 ab	310 a	665 a	478 a	650 a	955 a	1.13 a
E2 Ngale 1993[a]							
Mean	163	217	278	187	241	319	0.86
E2 Ngale 1994[a]							
Mean	153	162	195	165	210	242	0.65

[a] Measured with Daiki penetrometer with 2 cm^2 cone area.

Table 7b. Effects of soil amendments on shear strength and mungbean yield in E2 at Ngale in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Ngale 1992							
T2 (A0)	180 b	349 a	359 a	173 a	294 a	487 a	1.08 a
T3 (AG)	199 b	366 a	424 a	190 a	301 a	543 a	1.07 a
T4 (AOM)	159 a	349 a	377 a	190 a	262 a	442 a	1.13 a
E2 Ngale 1993							
Mean	178	—	—	—	—	—	0.86
E2 Ngale 1994							
Mean	214	276	355	289	381	491	0.65

Table 8a. Effects of sowing delay on penetration resistance and mungbean yield in E2 at Ngale in DS. Values for the same year in the same column followed by the same letter are not significantly different. Only means are reported if differences were not significant.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Ngale 1992[a]							
T5 (D0)	398 a	250 a	605 a	560 a	653 a	760 a	0.87 a
T2 (D1)	244 b	320 a	925 a	515 a	740 a	860 a	1.08 a
T6 (D2)	333 ab	425 a	850 a	545 a	873 a	755 a	1.10 a
E2 Ngale 1993[a]							
T5 (D0)	232 a	138 b	177 b	213 a	251 a	287 a	1.09 a
T2 (D1)	161 a	225 a	283 ab	198 a	242 a	291 a	0.89 ab
T6 (D2)	151 a	213 a	253 a	193 a	249 a	282 a	0.64 b
E2 Ngale 1994[a]							
Mean	140	187	210	189	226	256	0.86

[a]Measured with Daiki penetrometer with 2 cm^2 cone area.

Table 8b. Effects of sowing delay on shear strength and mungbean yield in E2 at Ngale in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Ngale 1992							
T5 (D0)	223 b	336 a	390 a	213 b	285 a	448 a	0.87 a
T2 (D1)	180 a	349 a	359 a	173 a	294 a	487 a	1.08 a
T6 (D2)	178 a	332 a	394 a	249 b	330 a	579 a	1.10 a
E2 Ngale 1993							
T5 (D0)	263 b	—	—	—	—	—	1.09 a
T2 (D1)	179 b	—	—	—	—	—	0.89 b
T6 (D2)	155 a	—	—	—	—	—	0.64 a
E2 Ngale 1994							
T5 (D0)	179 a	287 a	362 a	322 a	433 a	557 a	0.80 a
T2 (D1)	225 b	255 a	332 a	302 a	402 a	495 a	1.03 a
T6 (D2)	142 a	307 a	382 a	273 a	358 a	460 a	0.76 a

Table 9a. Effects of tillage × sowing delay on penetration resistance and mungbean yield in E2 at Ngale in DS. Values for the same year in the same column followed by the same letter are not significantly different. Only means are reported if differences were not significant.

Treatment	Penetration resistance (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Ngale 1992[a]							
T2 (C0 D1)	244 b	320 a	925 a	515 a	740 a	860 a	1.08 a
T6 (D0 D2)	333 ab	425 a	850 a	545 a	873 a	755 a	1.10 a
T7 (C1 D1)	300 ab	535 a	665 a	395 a	579 a	890 a	0.99 a
T8 (C1 D2)	375 a	450 a	850 a	552 a	685 a	770 a	1.12 a
E2 Ngale 1993[a]							
T2 (C0 D1)	161 a	225 ab	283 a	198 a	242 a	291 a	0.89 a
T6 (C0 D2)	151 ab	213 ab	253 a	193 a	249 a	282 a	0.64 a
T7 (C1 D1)	168 a	194 b	257 a	227 a	246 a	294 a	0.91 a
T8 (C1 D2)	123 b	241 a	287 a	201 a	228 a	274 a	0.74 a
E2 Ngale 1994[a]							
Mean	149	166	191	172	206	244	0.63

[a]Measured with Daiki penetrometer with 2 cm^2 cone area.

Table 9b. Effects of tillage × sowing delay on shear strength and mungbean yield in E2 at Ngale in DS.

Treatment	Shear strength (kPa)						Yield (t/ha)
	Planting	Vegetative		Flowering			
	5 cm	10 cm	20 cm	10 cm	20 cm	30 cm	
E2 Ngale 1992							
Mean	174	322	372	204	301	532	1.07
E2 Ngale 1993							
Mean	165	—	—	—	—	—	0.80
E2 Ngale 1994							
T2 (C0 D1)	225	255 b	332 a	302 a	402 b	495 a	1.03
T6 (C0 D2)	142	307 b	382 a	273 a	358 a	460 a	0.76
T7 (C1 D1)	—	250 a	338 a	318 a	410 b	517 a	0.30
T8 (C1 D2)	—	302 b	387 a	282 a	388 a	478 a	0.75

Discussion

In these experiments there were few statistically significant effects on soil strength of either puddling or soil management for the DS crop. In many cases, any effects were only weak and not expressed in all years. The lack of significant effects was probably the result of both high variability and variations in daily rainfall patterns between years.

When considering any effects of soil treatments on soil strength it is important to remember that they could be caused by changes to the inherent strength of the soil or by changes to moisture content. The change of soil strength with moisture content is discussed by Ringrose-Voase et al. (these Proceedings).

Effects of puddling intensity

Different results have been reported regarding the effect of puddling on growth and yield of rice. The differences may be partly due to bearing capacity and depth of puddled layer. Tranggono (1989) mentioned that there was a positive correlation between rice and depth of puddled layer on both a Regosol (Mojosari) and a Vertisol (Ngale). The maximum rice yield (6.42 t/ha) occurred on the Vertisol (Ngale) with 24 cm depth of puddling. With greater depths there was less yield.

Increased puddling intensity reduced soil strength in the earlier part of the dry season, but these effects were only slight and no longer apparent by the time the mungbean had reached the vegetative stage. At Jambegede, this was because the soil had dried such that its strength was beyond the measuring capabilities of the instruments. At Ngale, the strength did not increase so markedly, presumably because the soil was slower to dry than at Jambegede or because of rain. Any wetting and drying of the soil at Ngale, which has high shrink/swell potential (Ringrose-Voase et al. 1995), would be expected to remove the effects of puddling.

It would be expected that the more intensely puddled soils would become stronger than the less puddled ones as they dry. (i.e., the strength of the puddled soils increases more rapidly as the soil dries). This might also be the reason why there are no differences in strength by the vegetative stage. If strength could be measured as the soil dried further, it is possible that the more puddled treatments would have become stronger.

Comparison of Tables 2 and 3 show that soil strength at Ngale was generally lower than at Jambegede. This could be due either to Ngale retaining more water than Jambegede because of its high clay content or to more intense cracking at Ngale. Ringrose-Voase et al. (these Proceedings) show that at Ngale a large volume of cracks develops in the upper 15 cm as the soil dries and that there is little drying below this depth. Unfortunately, they did not make equivalent measurements for Jambegede.

Effects of soil amendments

Application of an organic matter mulch before the mungbean crop reduced soil strength significantly at Jambegede and slightly at Ngale. Since the soil in AOM and A0 had received the same treatment, the reduction in strength probably resulted from the mulched treatment having a greater moisture content. In turn, the higher moisture content could be a result of decreased evaporation from the soil surface because of the mulch or decreased water extraction caused by poorer crop growth or establishment under the mulch. The lesser impact of the mulch at Ngale could have been due to differences in rainfall or the slowness with which the Ngale soil dries.

Gypsum did not appear to have any significant effects. The exchange complex of both soils is dominated by divalent cations and neither is dispersible. This and the lack of any effect of gypsum suggests that physico-chemical dispersion was not occurring in these soils. Puddling these soils is more likely to result in physical breakdown of the aggregates into smaller aggregates rather than into primary particles in a manner similar to that discussed by Ringrose-Voase et al. (these Proceedings).

Effects of tillage and sowing delays

Sowing delay had no consistent effect on soil strength probably because the moisture content differences between treatments was slight. Tillage generally reduced soil strength as would be expected, but the reduction was only significant in 1993, possibly because of environmental factors such as rainfall. Obviously, wetting and drying could reduce strength of the soil.

Conclusions

Employing the methods used in these experiments, only weak effects of soil management practices on soil strength were observed. More intense puddling reduced soil strength in the early part of the DS crop. Application of an organic matter mulch and tillage both reduced soil strength. However, in no case did soil strength appear to be having an effect on mungbean yield. One reason for this is that initially these soils are relatively weak, so that strength would not be limiting. Soil treatments that affect soil strength would only be expected to have an effect on the crop when the soil has dried sufficiently for strength to become limiting. However, as Ringrose-Voase et al. (these Proceedings) note, these soils dry relatively slowly unless roots are present to extract the moisture, because of their high clay contents and low hydraulic conductivities. Once roots have penetrated a soil layer, its strength becomes less important.

References

Ringrose-Voase, A.J., Hutka, J., Beatty, J., Raven, M.D. and Rath, H. 1995. Analyses of some Indonesian and Philippine soils for ACIAR Project 8938 'Management of clay soils for lowland, rice-based cropping systems'. CSIRO (Australia) Division of Soils Technical Report 11/1995.

Tranggono, R., 1989. Optimum soil physical condition as affected by tillage on wetland rice. Proc. Second Joint Seminar on Agric. Eng. and Tech. Bogor, Indonesia.

Response of Food Legume Crops to Different Soil Management Practices after Rainfed Lowland Rice in East Java

T. Adisarwanto[1], W.H. Utomo[2], G. Kirchhof[3] and H.B. So[3]

Abstract

Food legume crops which are grown after rainfed lowland rice-based cropping systems usually have low yields due to several factors. Field experiments were conducted at Jambegede and Ngale Experimental Stations after rainfed lowland rice during the dry seasons of 1992, 1993 and 1994 to impose various sowing dates, fertilizer applications, soil amendments and tillage treatments and to investigate their effect on the production of three food legume crops (soybean, mungbean and peanut). The results showed that NPK fertilizer applications increased soybean yield in 1992 and 1993 by 41% and 110%, mungbean yield in 1993 and 1994 by 141% and 129% respectively. Addition of rice straw mulch at the rate of 5 t/ha also increased soybean yield by 153% in 1993. Yields of all crops were reduced significantly by delayed sowing. Tillage before sowing had no effect on yield of legumes grown after the harvest of rainfed lowland rice.

LEGUMES, with their adaptability to different rice-based cropping systems, offer opportunities to increase and to sustain productivity and income of rice farmers with small holdings in Indonesia. Puddling the soil and flooding are the common management systems for growing lowland rice under both rainfed or irrigated conditions. For Indonesia, rainfed lowland rice covers a total area of 3 million hectares and makes up approximately one third of the total lowland rice area (Huke 1982). In the irrigated lowland areas, legumes (soybean, peanut and mungbean) are generally grown in rotation of rice–rice–legume or rice–legume–legume with two or more irrigations during the season (Sumarno et al. 1988). In the rainfed lowland rice systems, it is not uncommon that the land is left fallow during the dry season. However, legumes are occasionally grown as an opportunity crop with very little input and yields are therefore very low. Yields of 0.3 to 0.8 t/ha for soybeans and 0.5 t/ha for mungbeans are not uncommon and are well below their potential yields (So and Woodhead 1987).

In lowland areas, the growing conditions required for rice are entirely different from those required for legumes. Rice is grown best under puddled and reduced conditions, legumes require un-puddled and oxidised conditions. The two conditions are associated with large differences in physical, chemical and biological properties of the soil. The puddled condition of the soil is a major cause of the poor stand and performance of secondary crops after rice (Syarifuddin 1979; Sumarno et al. 1988). Early sowing and minimum tillage systems appear to be more reliable than conventional tillage systems (Suyamto et al. 1989). For peanut on light-textured soils (Adisarwanto 1993) or soybean (Sumarno et al. 1988), intensive tillage is not neccessary before sowing.

Each production area has a different optimum time for sowing legumes and is determined by the interaction between crop growth and environmental conditions. In many cases, the soil may be too wet after rice harvest and, if sowing is delayed too long,

[1] Research Institute for Legume and Tuber Crops, Kendalpayah, PO Box 66, Malang, Indonesia
[2] Department of Soil Science, University of Brawijaya, Malang 65101, Indonesia
[3] Department of Agriculture, The University of Queensland, Brisbane 4072, Australia

the soil may be too hard for the development of the seedling. The optimum window for sowing is generally rather narrow. It is possible to use tillage, fertilizers, soil amendments and mulch to improve the management of the soil and to widen the window of opportunity for sowing legumes.

The objective of this study was to determine the effect of these management practices on the growth and yield of three food legume crops (mungbean, soybean and peanut) grown after rainfed lowland rice.

Materials and Methods

Field experiments were conducted with food legumes on rice-based cropping systems from March to early June in 1992, 1993 and 1994 at the experimental stations at Jambegede, near Malang (22 km) and Ngale, near Madiun (180 km from Malang) in East Java Province. Treatments were laid out as a randomised incomplete block design with four replications. The treatments included combinations of amendments (none — A0, gypsum — AG and organic matter mulch — AOM); cultivation (zero-till-dibble — C0 and rotovator-dibble — C1) and sowing delay (no delay — D0, 1 week delay — D1 and 2 weeks' delay — D2) and were as follows:

T1:	C0	A0	D1	no fertilizer (Farmers' practice in Indonesia)
T2:	C0	A0	D1	adequate fertilizers
T3:	C0	AG	D1	adequate fertilizers
T4:	C0	AOM	D1	adequate fertilizers
T5:	C0	A0	D0	adequate fertilizers
T6:	C0	A0	D2	adequate fertilizers
T7:	C1	A0	D1	adequate fertilizers
T8:	C1	A0	D2	adequate fertilizers

Originally D0 was to be immediately after harvest, but the appropriate sowing of D0 was left to the judgement of the local managers. At Ngale and Jambegede, in 1992 it was 9 and 7 days after harvest (DAH), in 1993 it was 23 and 1 DAH respectively and in 1994 it was both 1 DAH.

Mungbean was planted as the common crop on both sites, with the addition of soybean at Ngale and peanut at Jambegede. The latter two legumes were the main secondary crops in those regions. Each plot was 5 m × 4 m, plant spacings were 40 cm × 10 cm with 2 seeds/hill in 1992–1994 for soybean and peanut and for the 1992 mungbean, but 30 cm × 20 cm for mungbean in 1993 and 1994 giving a plant density of 330 000 plants/ha. Basal fertilizer applications were 50 kg urea, 50 kg TSP and 100 kg KCl per ha. Weeding was done when required but usually twice in a season. Insecticide was applied at 10, 20, 40 and 60 days after sowing (DAS) for pest and fungicide was applied at 40 and 50 DAS for disease control, in particular leaf rust.

Gypsum application was made seven days before rice harvest and organic mulch at a rate of 5 t/ha of rice straw was applied at sowing time. Tillage was carried out with a hoe to a depth of 20 cm.

Agronomic characteristics were measured on five randomly selected plants and yield was determined from a harvested area of 2.5 m × 2 m.

Results and Discussion

Effect of fertilizer application

A comparison of treatments T1 and T2 in each experiment provides a measure of the effect of fertilizer application on the yield of the three legumes and the results are shown in Figure 1. In almost all cases at Ngale, there was a significant effect of fertilizer on yield except for soybean in 1994. Yield increases were substantial at 42%, 141% and 128% for mungbeans in 1992, 1993 and 1994 respectively. For soybean, the increases in yield for 1992 and 1993 were 41% and 110%. Mean yields of mungbean were similar for the three years but for soybean, yields for 1993 and 1994 were approximately half of 1992. Mungbean is a 65–70 day crop whereas soybean is an 80–90 day crop. In all three years, adequate rain fell during the mungbean growth cycle, but during the last 20 to 30 days of the soybean crop, rain fell only in 1992 (65 mm). This is most probably the reason for the higher mean yield in 1992.

At Jambegede, a fertilizer effect was observed only in 1993 for peanut. Overall yields were relatively low, indicating that water stress was probably the dominant factor determining the yield of legumes under rainfed conditions on these lighter-textured soils. Its water holding capacity is lower than that of the soil at Ngale (Rahmianna et al., these Proceedings).

Effect of soil amendment

The effect of soil amendments on yield is shown in Figure 2 and the results were not consistent. For mungbean, the application of gypsum or rice straw mulch did not affect yield, except in 1994 when mulch reduced yield at Ngale. Yield of mungbean under mulch was very low at 0.19 t/ha compared to 1.03 and 0.73 t/ha for the nil amendment and gypsum treatments respectively. Lower yield was associated with lower crop establishment due to high rainfall after sowing.

For soybean, gypsum did not affect yield, but mulch increased yield in 1993 and 1994, probably associated with a reduction in evaporative loss of soil

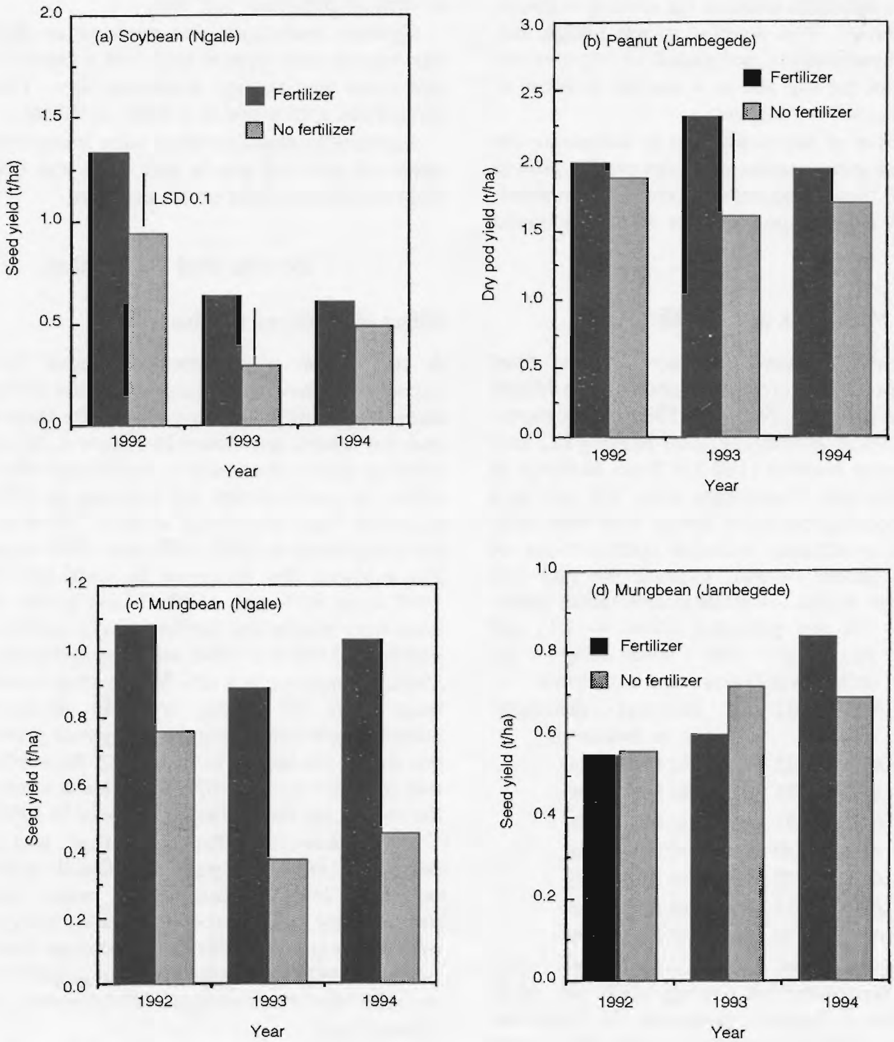


Figure 1. Effect of fertilizer on yield.

water during the last month of the soybean growing season when rainfall was absent (Kirchhof and Schafer, these Proceedings) and consequently the mean yields for both years were lower than in 1992.

For peanut, a significant effect of both gypsum and mulch was observed in 1994 only.

Effect of sowing delay

The effect of period of sowing delay on yield is shown in Figure 3. The different periods of sowing delay were originally intended to provide progressively drier conditions with increasing sowing delay. If crops are sown too early after rice harvest, high soil water content is thought to be too high, resulting in waterlogging of seeds. On the other hand, if sowing is delayed too long, high soil strengths may develop upon drying of the puddled topsoil and establishment may fail or roots may not be able to penetrate to depth, resulting in poor growth. However, in all years varying amounts of rain fell after each sowing, thus confounding the effect of sowing delay, and increasing sowing delay is not necessarily associated with decreased soil water content.

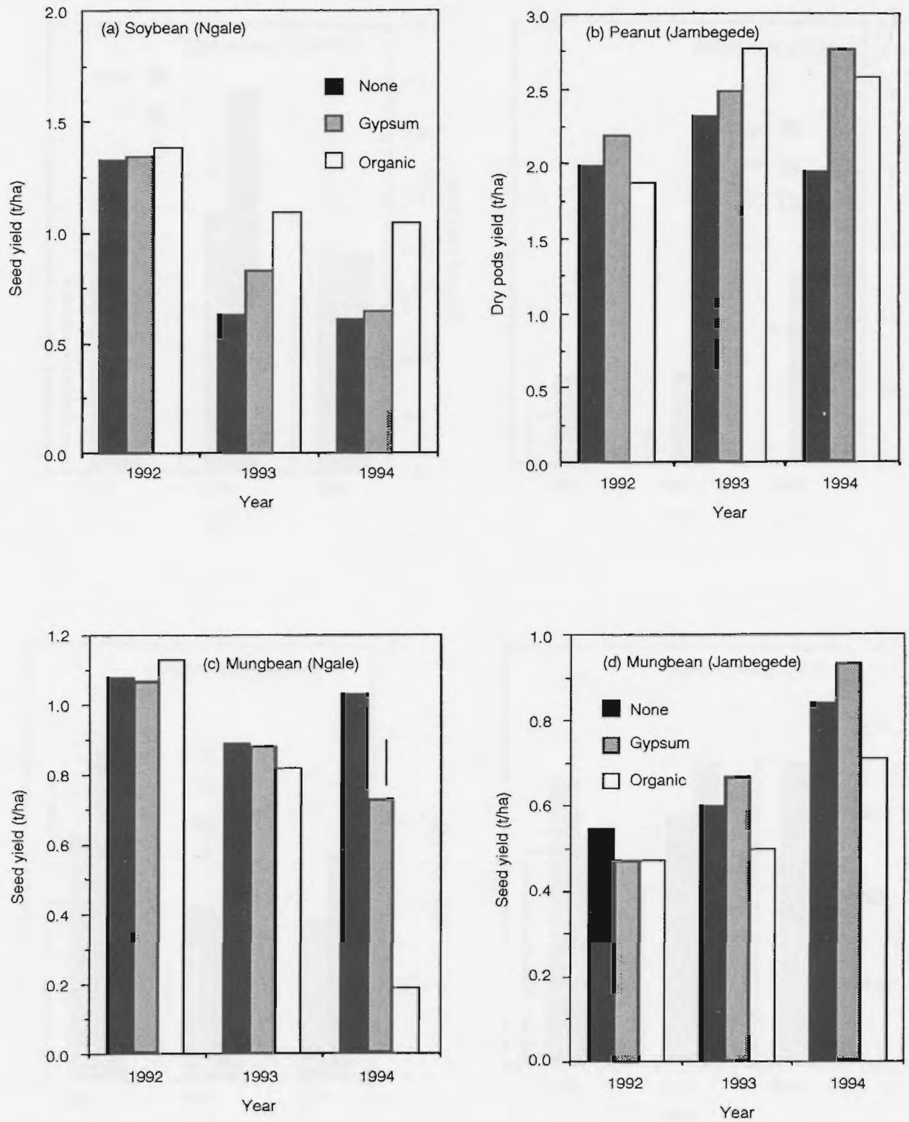


Figure 2. Effect of soil amendments.

The results show that, except for Ngale in 1992, increasing the delay in sowing legumes after rice harvest does show a tendency to reduced yield of all legumes. The reason for the decrease is not clear, but appears to be associated with excessive rainfall after sowing. At Ngale, 1992 had drier conditions at sowing than 1993 or 1994. However, a 50 mm rainstorm after D0 resulted in poor establishment (40%) compared to D1 (95%) and D2 (96%). The amount of rainfall at sowing in 1993 and 1994 was higher, resulting in low rates of establishment and low yields. On the lighter soils at Jambegede, poor establishment appears to be associated with a lack of rain after sowing, e.g., in 1993 D2 gave 29% establishment when there was no rain after sowing. In all three years, the D0 treatments were preceded or followed by high rainfall resulting in the highest establishment rates and highest yields.

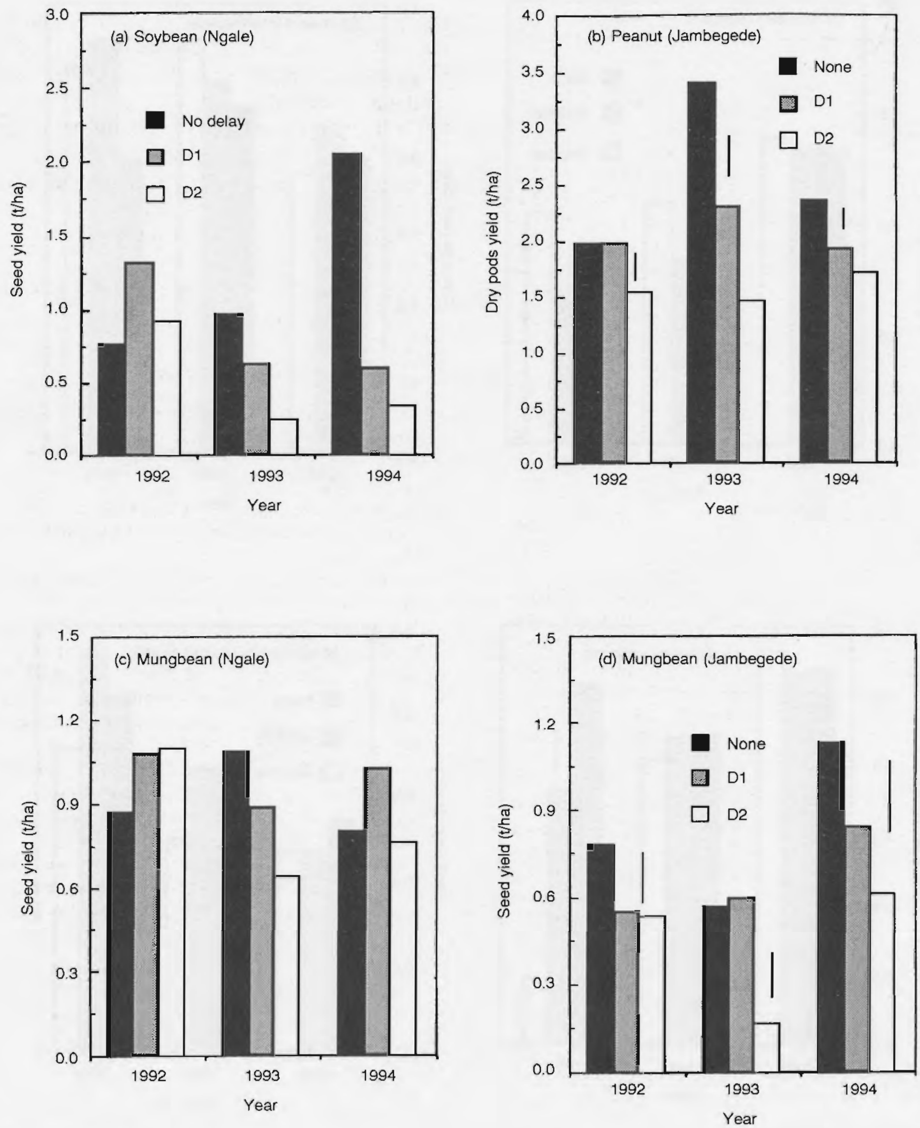


Figure 3. Effect of delayed sowing.

No doubt low yields were partly associated with the rate of survival but data were inadequate to draw any definite conclusion on this matter. However, even when survival rates are not different, increasing the sowing delay appears to reduce yield, probably associated with greater difficulty for roots to penetrate the compacted layer below the puddled zone. This would result in a reduced depth of rooting and water extraction.

Effect of tillage

Tillage had no effect on the yield of mungbean at either Ngale or Jambegede. Similarly at Ngale, soybean did not respond to tillage. However, at Jambegede, peanut yielded higher when the soil was cultivated (Table 1) because peanut requires good soil physical conditions for pod development. The interaction between tillage and sowing delay was not significant.

Table 1. Effect of tillage on soybean, peanut and mungbean yield.

Treatments			Yield (t/ha)		
			1992	1993	1994
a: Ngale			Soybean		
D1	C0		1.33 a	0.63 b	0.61 a
D1	C1		1.43 a	0.91 b	0.72 a
D2	C0		0.92 b	0.25 d	0.34 a
D2	C1		0.87 b	0.38 d	0.34 a
		LSD 0.1	0.34	0.31	0.51
		CV(%)	12.2	19.2	26.79
b. Jambegede			Peanut		
D1	C0		1.99 a	2.32 a	1.94 b
D1	C1		1.81 bc	2.75 a	3.03 a
D2	C0		1.55 c	1.47 c	1.72 c
D2	C1		1.74 bc	2.00 ad	2.89 a
		LSD 0.1	0.32	0.48	0.84
		CV(%)	8.5	10.2	20.49
c. Ngale			Mungbean		
D1	C0		1.08 a	0.89 a	1.03 a
D1	C1		0.99 a	0.91 a	0.30 c
D2	C0		1.10 a	0.64 a	0.76 a
D2	C1		1.12 a	0.74 a	0.75 a
		LSD 0.1	ns	ns	0.38
		CV(%)	9.14	15.86	25.46
d. Jambegede					
D1	C0		0.55 a	0.60 a	0.84 a
D1	C1		0.43 a	0.42 a	0.89 a
D2	C0		0.53 a	0.17 b	0.61 ab
D2	C1		0.45 a	0.11 b	0.48 b
		LSD 0.1	ns	0.22	0.32
		CV(%)	22.57	23.36	28.60

Conclusion

The results indicated that in general, under rainfed lowland rice conditions, the yield levels of legumes were lower compared to the potential yield. The results also indicated that:

1. fertilizer application consistently increased yields of soybean and mungbean on Vertisol;
2. amendments had little effect on the growth and yield of legumes after rice;
3. delayed sowing significantly reduced legume yield;
4. tillage was not neccessary for legumes grown after lowland rice.

References

Adisarwanto, T. 1993. Effect of intensive tillage for rice on growth and yield of groundnut. In: Proceeding Food Crops Research Results 1992. MARIF. 107–112 (Indonesian).

Huke, R.E. 1982. Rice area by type of culture: South, Southeast, and East Asia. IRRI, Los Baños, Philippines, 32 p.

Sumarno, Oka, I.M., Sunarlin, N., Makarim, A.K., Sharma, D., Syam, M. and Manwan, I. 1988. National Coordinated Grains Legumes Research Program. Central Research Institute for Food Crops. Bogor 64 p.

Suyamto, H., Effendi, G. and Riwanodja. 1989. Interaction between irrigation, tillage systems and mulch on peanut after lowland rice. In: Proceeding Food Crops Research Results 1989. MARIF 23–27 (Indonesian).

Syarifuddin, A.K. 1979. Establishment and performance of rainfed maize (*Zea mays* L) and soybean (*Glycine max* (L) Merill) in the dry season after puddled rice. PhD thesis. UPLB Philippines. 354 p.

So, H.B. and Woodhead, T. 1987. Alleviation of soil physical limits to productivity of legumes in Asia. In: Wallis, E.S. and Blyth, D.E. ed., Food Legume Improvement for Asian Farming Systems. Canberra, ACIAR Proceedings Series No. 18, 112–120.

Legume Yields and Soil Management Systems, Sulawesi

Mustari Basir, Tabran M. Lando, Subandi and Bambang Prastowo[1]

Abstract

Experiments were conducted on a farmers field near Maros, South West Sulawesi over three years to evaluate the effect of soil management systems on growth and yield of rainfed mungbean following harvest of lowland rainfed rice. Mungbean yields were increased by the application of fertilizer, indicating that residual fertilizer from the previous rice phase was inadequate. Application of straw mulch increased yield through conservation of soil water and weed control. Soil tillage tended to increase yields but yield improvement was relatively small and may not warrant the extra labour required. By far the largest effect on yield was related to the time of sowing. The choice of optimum time for sowing after rice harvest was more affected by rainfall during the crop establishment phase than by delay after rice harvest.

RAINFED lowland rice cropping in Sulawesi comprises an area of 0.3 million hectares. It represents an underutilised land resource for post-rice cropping due to adverse soil physical conditions induced by pre-rice soil puddling. The major factors constraining farmers along the west coast of Sulawesi from planting secondary crops following rice is either high soil water content after rice harvest at the end of the wet season or extremely dry conditions soon after the onset of the dry season. The area affected is estimated to be around 9000 ha (Anon. 1989). Management of plant ecological factors as well as selection of adapted species and varieties may results in more efficient use of these resources (Irsal Las et al. 1991).

Materials and Methods

Field experiments to assess a range of post-rice soil management techniques on dry season rainfed mungbean following lowland rainfed rice were conducted at the village of Buloe, Subdistrict Maros Baru, South Sulawesi. Post-rice management treatments included fertilisation, application of soil amendments (none, straw mulch and gypsum), sowing delay following rice harvest and tillage. Details of the experimental design, soils and climate are given elsewhere (So et al., these Proceedings). This paper describes and discusses the effect of soil management on mungbean growth and yield and yield components, and root growth in three experiments conducted in the dry seasons from 1991–92 to 1994.

Results and Discussion

Fertilizer application

Grain yields and vegetative biomass production were significantly increased through the application of fertilizer (Table 1) except during the growing season in 1991–92. Yield increase was mainly due to an increase in the number of pods per plant and to a lesser degree to an increase in the number of seeds per pod (Table 2). This was also reflected in plant height which served as an indicator of growth during the vegetative and maturity stages (Table 3). Root growth was observed to a depth of 40 cm. During the vegetative stage, root growth was increased by fertilizer application up to 30 cm deep but at maturity differences in root growth due to fertilizer had disappeared.

The lack of fertilizer response in the first year of experimentation (1991–92) was probably due to inappropriate time of fertilizer application immediately after sowing. Fertilizer probably did not dissolve and

[1] Research Insitute for Maize and other Cereals, Jl. Dr Ratulangi, Maros 90514, Indonesia

Table 1. The effect of management practices on mungbean after rice during the three seasons from 1991 to 1994.

Treatments	Grain yield (t/ha)				Dried straw (t/ha)			
	1991–92	1992–93	1993–94	Mean	1991–92	1992–93	1993–94	Mean
Fertilisation								
T1, none	0.29^{b}	0.34^{d}	0.42^{cd}	0.35	0.81^{a}	0.58^{d}	0.83^{b}	0.74
T2, full	0.28^{b}	0.42^{c}	0.54^{bc}	0.41	0.83^{a}	0.74^{cd}	0.91^{b}	0.82
Amendment								
T2, none	0.28^{b}	0.42^{c}	0.54^{bc}	0.41	0.83^{a}	0.74^{cd}	0.91^{b}	0.82
T3, gypsum	0.28^{b}	0.52^{b}	0.57^{b}	0.46	0.85^{a}	0.82^{bc}	0.89^{b}	0.85
T4, mulch	0.30^{b}	0.53^{b}	0.76^{a}	0.53	0.82^{a}	0.88^{abc}	1.18^{a}	0.96
Sowing date								
T5, no delay	0.44^{a}	0.50^{bc}	0.21^{e}	0.38	0.80^{a}	0.82^{bc}	0.51^{e}	0.71
T2, 1 week delay	0.28^{b}	0.42^{c}	0.54^{bc}	0.41	0.83^{a}	0.74^{cd}	0.91^{b}	0.82
T6, 2 weeks delay	0.37^{a}	0.67^{a}	0.37^{d}	0.47	0.82^{a}	0.95^{ab}	0.71^{b}	0.83
Tillage × sowing date								
T2, no delay, no till	0.28^{b}	0.42^{c}	0.54^{bc}	0.41	0.83^{a}	0.74^{cd}	0.91^{b}	0.82
T6, no delay, tillage	0.37^{a}	0.67^{a}	0.37^{d}	0.47	0.82^{a}	0.95^{ab}	0.71^{b}	0.83
T7, 1 week, no till	0.43^{a}	0.52^{b}	0.50^{bcd}	0.48	0.86^{a}	1.05^{a}	0.89^{b}	0.93
T8, 1 week, tillage	0.41^{a}	0.71^{a}	0.46^{bcd}	0.46	0.88^{a}	0.92^{ab}	0.81^{b}	0.87

Values followed by different letters denote significant differences ($P < 0.05$).

Table 2. The effect of management practices on mungbean yield components during the three seasons from 1991 to 1994.

Treatments	Number of pods per plant				Number of seeds per pod			
	1991–92	1992–93	1993–94	Mean	1991–92	1992–93	1993–94	Mean
Fertilisation								
T1, none	9.2^{a}	3.7^{e}	5.3^{cd}	6.1	7.9^{b}	6.2^{ab}	6.4^{bc}	6.8
T2, full	9.1^{a}	6.2^{cd}	7.6^{bc}	7.6	7.9^{b}	7.0^{ab}	7.1^{ab}	7.3
Amendment								
T2, none	9.1^{a}	6.2^{cd}	7.6^{bc}	7.6	7.9^{b}	7.0^{ab}	7.1^{ab}	7.3
T3, gypsum	8.8^{a}	7.6^{cd}	7.9^{ab}	8.1	6.4^{b}	6.7^{ab}	6.7^{bc}	7.1^{a}
T4, mulch	8.8^{a}	8.4^{a}	9.2^{a}	8.8	6.0^{b}	7.9^{b}	7.9^{s}	7.4
Sowing date								
T5, no delay	9.3^{a}	7.4^{cd}	4.7^{e}	7.1	11.6^{a}	5.9^{b}	4.5^{d}	7.3
T2, 1 week delay	9.1^{a}	6.2^{cd}	7.6^{bc}	7.6	7.9^{b}	7.0^{ab}	7.1^{ab}	7.3
T6, 2 weeks delay	8.8^{a}	11.3^{b}	6.5^{cd}	8.9	8.8^{b}	6.3^{ab}	5.7^{c}	6.9
Tillage × sowing date								
T2, no delay, no till	9.1^{a}	6.2^{cd}	7.6^{bc}	7.6	7.9^{b}	7.0^{ab}	7.1^{ab}	7.3
T6, no delay, tillage	8.8^{a}	11.3^{b}	6.5^{cd}	8.9	8.8^{b}	6.3^{ab}	5.7^{c}	6.9
T7, 1 week, no till	9.0^{a}	5.3^{de}	6.4^{cd}	6.9	11.0^{a}	6.3^{ab}	6.5^{bc}	7.9
T8, 1 week, tillage	8.7^{a}	14.7^{a}	7.3^{bc}	10.2	11.5^{a}	7.3^{a}	6.3^{bc}	8.4

Values followed by different letters denote significant differences ($P < 0.05$).

therefore remained unavailable to the crop. During the two years (1992 to 1994), fertilizer was applied after the rice harvest to ensure that it dissolved and reached the root zone sufficiently rapidly. The average response to fertilizer was a 17% yield increase over non-fertilised plots, and showed that residual fertilizer from the rice was inadequate to supply crop requirements.

Soil amendment

Application of mulch increased grain yield and total biomass in all three experiments (Table 1). Compared to a no-mulch situation, these yield increases were substantial in the last two growing seasons, i.e., 26% and 33%. Yield increases were largely due to a greater number of pods per plant (Table 2). Despite the relatively large effect on yield, differences in root growth due to mulch application could not be observed from the root sampling procedures used (Table 4). The mechanism through which mulch application increased yield is probably twofold: conservation of soil water through reduced evaporation rates, and improved weed control.

The impact of the use of gypsum as a soil ameliorant to improve soil structure was not clear from the experiments conducted. There was no effect in the experiments during the first and last year, but gypsum application improved yield to the same extend as mulch applications during the second year. Despite high base saturation, the soil at MORIF is hardsetting and gypsum application may potentially assist to restore soil structure. However, the conditions under which benefits from gypsum application can be expected are not known and require additional work for clarification.

Sowing date

Sowing delay had by far the strongest effect on grain yield and biomass (Table 1). The overall trend was an increase in yield with increasing delay of sowing after rice harvest. Such a pattern, however, was not consistent if individual years were considered. Highest yields were observed at zero delay in year one, two weeks delay in year two and one week delay in year three. Highest yields in year three were concomitant with highest root length densities at all depths (Table 4). This inconsistency is attributed to rainfall events that determine soil water conditions following rice harvest rather than time following rice harvest, per se. It appeared that yields were highest if sowing occurred during periods of relatively dry conditions (Kirchhof and So, these Proceedings). Under wet conditions and the dibbling technique used in this area, seeds or seedlings are easily waterlogged and crop establishment fails or is low, due to lack of oxygen in the seedling zone and the onset of fungal growth. It appeared that an improved method for sowing may alleviate some problems of poor crop establishment in this area.

Tillage and sowing delay

Tillage increased yield in all three years of experimentation (Table 1). It appeared to give the farmer more flexibility for deciding when to plant because differences due to planting delay where reduced if the soil was cultivated. This is probably due to improved drainage of excess water from the dibbling hole if cultivated. However, it remained unclear whether the additional yield gained from tillage would warrant the additional labour required.

Soil Strength and Root Growth

Root growth was measured in the 1994 mungbean season at the vegetative stage and related to soil strength and depth (Fig. 1). Root length density decreased with depth which was concomitant with an increase in soil strength with depth. Under normal conditions, soil strength tends to remain constant or decrease as soil water content or bulk densities increase. Considering the magnitude of soil strengths observed in the topsoil, reasonably high soil water content can be assumed, and this suggested that the increase in soil strength was due to a large increase in bulk density with depth, which in turn restricted root growth. However, due to the continuity in bulk density increase with depth, the suggested increase in bulk density may not be due to the presence of a structurally degraded puddled layer, as this should result in a discontinuous change in soil strength at the interface of puddled layer and the soil below.

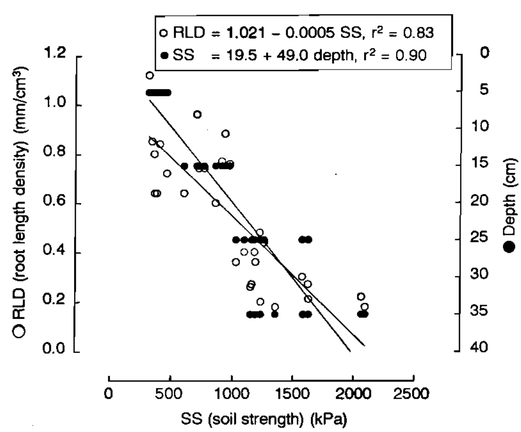


Figure 1. The relationship between soil strength, root length density and depth at the vegetative stage in 1994.

Table 3. Mungbean plant height at the vegetative and maturity stages as affected by soil management practises during the three seasons from 1991 to 1994.

Treatments	Height during vegetative stage (cm)				Height during maturity stage (cm)			
	1991–92	1992–93	1993–94	Mean	1991–92	1992–93	1993–94	Mean
Fertilisation								
T1, none	23.7[a]	18.0[b]	23.8[bc]	21.8	28.1[a]	20.3[b]	29.6[a]	26.0
T2, full	26.0[a]	23.9[a]	30.2[ab]	26.7	29.7[a]	23.4[ab]	30.2[a]	27.8
Amendment								
T2, none	26.0[a]	23.9[a]	30.2[ab]	26.7	29.7[a]	23.4[ab]	30.2[a]	27.8
T3, gypsum	26.2[a]	24.2[a]	29.8[ab]	26.7	31.8[a]	28.4[a]	31.0[a]	30.4
T4, mulch	25.1[a]	26.1[a]	31.2[a]	27.5	29.9[a]	30.0[a]	23.3[b]	30.4
Sowing date								
T5, no delay	24.5[a]	23.9[a]	21.8[d]	23.4	29.3[a]	27.0[a]	27.2[ab]	26.7
T2, 1 week delay	26.0[a]	23.9[a]	30.2[ab]	26.7	29.7[a]	23.4[ab]	30.2[a]	27.8
T6, 2 weeks delay	25.6[a]	27.8[a]	26.0[d]	26.5	29.3[a]	30.4[a]	27.2[ab]	29.0
Tillage × sowing date								
T2, no delay, no till	26.0[a]	23.9[a]	30.2[ab]	26.7	29.7[a]	23.4[ab]	30.2[a]	27.8
T6, no delay, tillage	25.6[a]	27.8[a]	29.0[b]	26.5	29.3[a]	30.4[a]	27.2[ab]	29.0
T7, 1 week, no till	27.7[a]	25.3[a]	27.2[bc]	26.7	33.5[a]	28.6[a]	31.4[a]	31.2
T8, 1 week, tillage	25.0[a]	25.0[a]	27.5[bc]	25.8	28.1[a]	27.4[a]	29.8[a]	28.5

Values followed by different letters denote significant differences ($P < 0.05$).

Table 4. The effect of management practices on root growth of mungbean after rice during the dry season of 1994.

Treatments	Root length density (mm/cm^3)							
	Vegetative stage				Maturity stage			
Depth (cm):	0–10	10–20	20–30	30–40	0–10	10–20	20–30	30–40
Fertilisation								
T1, none	0.85[bc]	0.77[b]	0.30[ab]	0.22[ab]	1.02[ab]	1.06[b]	0.46[ab]	0.28[a]
T2, full	1.05[a]	0.76[a]	0.48[a]	0.20[ab]	1.12[a]	1.10[ab]	0.52[ab]	0.26[ab]
Amendment								
T2, none	1.05[a]	0.76[a]	0.48[a]	0.20[ab]	1.12[a]	1.10[ab]	0.52[ab]	0.26[ab]
T3, gypsum	0.80[bcd]	0.64[b]	0.40[ab]	0.34[a]	0.98[ab]	1.00[b]	0.52[ab]	0.31[a]
T4, mulch	1.12[a]	0.96[a]	0.40[ab]	0.26[ab]	1.14[a]	1.24[a]	0.54[a]	0.30[a]
Sowing date								
T5, no delay	0.61[d]	0.58[b]	0.27[b]	0.11[b]	0.80[c]	0.84[c]	0.38[ab]	0.17[a]
T2, 1 week delay	1.05[a]	0.76[a]	0.48[a]	0.20[ab]	1.12[a]	1.10[ab]	0.52[ab]	0.26[ab]
T6, 2 weeks delay	0.64[d]	0.60[b]	0.27[b]	0.18[bab]	0.94[bc]	1.00[b]	0.36[b]	0.28[a]
Tillage × sowing date								
T2, no delay, no till	1.05[a]	0.76[a]	0.48[a]	0.20[ab]	1.12[a]	1.10[ab]	0.52[ab]	0.26[ab]
T6, no delay, tillage	0.64[d]	0.60[b]	0.27[b]	0.18[ab]	0.94[bc]	1.00[b]	0.36[b]	0.28[a]
T7, 1 week, no till	0.72[cd]	0.74[b]	0.36[ab]	0.15[bc]	0.98[ab]	1.06[b]	0.51[ab]	0.20[a]
T8, 1 week, tillage	0.94[ab]	0.74[b]	0.44[ab]	0.24[ab]	1.06[ab]	1.05[b]	0.49[ab]	0.30[a]

Values followed by different letters denote significant differences ($P < 0.05$).

The regression equation to express root growth as a function of depth had a coefficient of determination of 0.79. A best subset regression procedure was used to determine which other factors affected root length density significantly. *Dummy* variables, according to the treatments applied such as fertilisation, soil amendment, delay and tillage, were included in the data array. Using these dummy variables, treatments were given a rating of 0 if the treatment was not applied or 1 if the treatment was applied. Thus all fertilised treatments would be given the value 1, and the non-fertilised treatment number 1, the value 0. Mulch application improved the coefficient of variation from 0.79 to 0.90, the variable had a significance level of 0.021 and was the only variable that contributed significantly to reducing variation for the prediction of root length density. The beneficial effect of mulch on root proliferation was through the effect of mulch on soil water content, where high soil water contents resulted in lower soil strengths.

Conclusion

The experiments showed that reasonable yield levels are possible at 0.3 to 0.7 t/ha. A major problem appeared to be poor crop establishment. Yields potentially can be increased by improved seeding techniques that increase crop establishment or by raising the plant population density. Observation showed that:

- residual fertilizer from the rice phase is insufficient for post-rice mungbean and additional fertilizer application increased mungbean yield;
- mulch application tends to increase yield, probably through soil water conservation, weed control and improved root growth;
- correct timing of sowing is crucial for crop establishment and yield;
- tillage tended to increase yield but the additional labour required may not be justified.

References

Anon. 1989. Laporan Tahunan Statistik Tanaman Pangan Propinsi Sulawesi Selatan. Departemen Pertanian. Ujung Pandang.

Irsal Las, Makarim, A.K., Hidyat, A. and Ibrahim Manwan, 1991. Peta Agroekologi Utama Tanaman Pangan di Indonesia. Pusat Penelitian Tanaman Pangan. Badan Penelitian dan Pengembangan Pertanian. Departemen Pertanian.

Grain Yield Response of Mungbean *(Vigna Radiata)* to Different Soil Management Practices after Wetland Rice in the Philippines

W.B. Sanidad, E.V. Dacanay, C.F. Serrano, V.G. Estoconing, D.T. Elicano, V.E. Castaneda, G.I.P. Urriza and G.N. Alcasid, Jr.[1]

Abstract

Field experiments on the effects of soil management practices on the grain yield responses of mungbean grown after wetland rice were conducted during the dry seasons from 1992–93 to 1994–95 in the Central Soil and Water Resources Center of the Philippine Bureau of Soils and Water Management, San Ildefonso, Bulacan, and in farmers' fields of Barangay, Calmay, Laoac, Pangasinan. These included fertilisation, sowing dates after rice harvest, addition of soil amendments, and cultivation. Result of the three-year study on the two experimental sites showed that surface-applied fertilizer gave no significant grain yield response. Use of rice straw as surface mulch improved yield through conserving soil water and improving weed control. Optimum time of sowing was governed by climatological conditions following rice harvest and not by delay of sowing after rice harvest, per se. Yields of up to 1 t/ha were achieved in the absence of rainfall provided roots grew to a soil depth of about 1 m and made use of residual water following the rice phase.

IN a tropical rice-growing country like the Philippines, opportunities to increase cropping frequency are abundant. In both puddled lowland and rainfed rice production systems, a significant amount of water remains stored in the soil profile following rice harvest. This water could be used for the production of a subsequent fallow or upland crop, provided this crop could be quickly established and its roots could penetrate through the drying puddled layer, and its associated compacted zone, to the moist subsoil.

Experiments at the International Rice Research Institute (IRRI 1985, 1986) have shown that dry season mungbean planted immediately following rice, if well established, can achieve grain yields of 2.0 t/ha without fertilizer or irrigation. Although legumes grown as a secondary crop after rice are normally not fertilised in the Philippines, potential yield increases due to additional fertilizer application are possible if residual fertilizer from the rice phase is inadequate. Yield increases ranging from 42% to 140% were reported by Adisarwanto and Suhartina (1994) in experiments conducted in East Java, Indonesia.

A major constraint to the production of dry season upland crops after rice is crop establishment in poorly structured seedbeds. Immediately after wetland rice harvest, the soil will be wet and in a reduced condition. Sowing under these conditions is likely to result in waterlogging and inhibit emergence and root growth. As the puddled layer dries out, soil strength increases rapidly. Crop establishment and root proliferation through the puddled and compacted layer become increasingly more difficult. Time of sowing is therefore crucial for successful dry season cropping following rice. Soil mechanical constraints and lack of aeration can be alleviated by tillage, although this may accelerate topsoil water loss (Zandstra 1982), and increase the time interval between rice harvest and seeding of the upland crop, both of which may lead to reduced emergence. Although tillage can potentially be used to improve soil physical conditions, it is expensive, time consuming and often wasteful in terms of residual moisture (Gomez and Zandstra 1977). Zero tillage

[1] Bureau of Soil and Water Management, Cnr Elliptical Rd and Visayas Avenue, Quezon City 1100, the Philippines

could therefore be beneficial (Syarifuddin 1982). Other difficulties for post-rice dryland pulses include insect damage. Under unfavourable conditions, too wet, too dry or excessively high temperatures, seedlings are prone to damage by Empoasca leaf-hopper and flea beetles (Bandong and Listinger 1976).

This study was conducted to study the effects of various soil management practices on the growth and yield of mungbean after lowland rice, and to provide guidelines as to the optimum soil conditions to give production levels that are substantially higher than farmers' levels (typically 0.5 t/ha).

Materials and Methods

Field experiments were conducted over three years in the dry season following wet culture rice from 1992–93 to 1994–95. The sites were located near Manaoag (Pangasinan province) and San Ildefonso (Bulacan province) on a silty clay loam and medium clay, respectively. The effect of post-rice soil management strategies on growth and yield of mungbean were evaluated. Treatments included fertilizer application, application of soil amendment (gypsum or mulch), sowing delay following rice harvest and tillage combined with delay after rice harvest. Details about the experimental sites and soils, prevailing climatic conditions during the mungbean phase and experimental layout are given elsewhere in these Proceedings.

Results and Discussions

Effect of fertilizer application

Table 1 shows the effect of fertilizer application on the two experimental sites for the three cropping years. Yield responses were not significant. The dry soil conditions and absence of rain during the growing season probably prevented the dissolution of the surface applied fertilizer and consequently these failed to reach the root zone. Application of the fertilizer prior to rice harvest may probably show some response.

Table 1. Effect of fertilizer application on the grain yield (t/ha) of mungbean grown after wetland rice for the three cropping years.

Site	Year[1]	No fertilizer	Complete fertilizer
Bulacan	1992–93[2]	0.014	0.019
	1993–94	0.392	0.141
	1994–95	0.170	0.180
Pangasinan	1994–95	0.610	0.510

[1]Treatment means are statistically not significant. Complete fertilizer = 30 kg of nitrogen, 40 kg of phosphorus and 30 kg of potassium per ha. [2]Total biomass.

Effect of soil amendments

Table 2 shows the effect of soil amendments applied before and after sowing of mungbean. Application of rice straw at the rate of 5 t/ha as surface mulch reduced weed infestation and significantly increased yield during the first year (1992–93) and tended to increase yield in all cases except in the last year (1994–95) at the Pangasinan site. Mulch probably resulted in lower soil strength and wetter soil conditions during the establishment stage of the crop, enabling it to exploit the available moisture of the profile at greater depths. Application of gypsum one month before rice harvest showed no effect on grain yield of mungbean for the three cropping years, except for the first year at Pangasinan where yields were suppressed. Similar to the application of fertilizer, dry conditions probably prevented the dissolution of gypsum, and potential benefits due to improved soil structural condition in the puddled layer were not forthcoming. Due to the high base saturation and low exchangeable sodium levels of the soil at the two experimental sites, application of gypsum may not have the desired effect even if it dissolves and penetrates the puddled layer.

Table 2. Effect of Soil amendment application on the grain yield (t/ha) of mungbean grown after wetland rice for the three cropping years.

Site	Year	No amendment	Gypsum[2]	Mulch[3]	LSD 5%
Bulacan	1992–93[1]	0.19	0.09	0.47	0.28
	1993–94	0.44	0.35	0.52	ns
	1994–95	0.17	0.25	0.32	ns
Pangasinan	1992–93	0.72	0.25	0.94	0.13
	1993–94	0.77	0.81	1.00	ns
	1994–95	0.51	0.62	0.52	ns

[1]Total biomass. [2]Gypsum was applied at the rate of 5t/ha one month before rice harvest. [3]Rice straw as mulch was applied at the rate of 5t/ha. ns = statistically not significant, LSD = least significant difference.

Effect of sowing date

Increasing delay of sowing following rice harvest tended to decrease yields at the Bulacan site. This was probably due to very poor soil physical conditions of the Vertisol soil under dry conditions. It is hardsetting and becomes extremely hard very fast upon drying. It appeared that crop establishment can only be adequate if sowing occurs while the soil is in a wet condition when soil strength is still low. However, climatic conditions during the end of the wet season in this area are often erratic and the chances of heavy rainfall and typhoons occurring are high. Early planting on this soil can therefore result in crop failure if the establishing plants are struck by heavy rains or typhoons. Provision of adequate drainage may overcome this problem. However, if sowing is delayed, then failure due to radiply increasing soil strength is high, resulting in a narrow window of sowing opportunity with a high risk of failure. Mungbean yields were very low (<0.4 t/ha). This area or soil type is not suitable for the introduction of legumes into the rice cropping system.

There was no pattern for an optimum delay on the silty clay loam at the Pangasinan site (Table 3). The rainy season is short, the soil well drained and usually already dry during rice harvest. Soil water conditions in the topsoil are therefore largely governed by rainfall. The best suited time for sowing depended on climatic conditions, and not on the time of sowing after rice harvest. Mungbean yields at Pangasinan were reasonable, averaging 0.6 to 0.87 t/ha.

Root growth

There were treatment effects on the growth of roots during the flowering stages on both sites (Figs 1–3). Except in year three, root growth on the Vertisol at the Bulacan site was limited to 30 cm depth. The limited depth of root proliferation and concomitant lack of subsoil water use was reflected in the poor yield on this site (0.01 to 0.4 t/ha). In contrast, on the silty soil at the Pangasinan province, root growth to 1 m deep was observed. Yields were high and associated with greater use of residual subsoil water. It is important to note that high yields were achieved even under dry conditions largely in the absence of rainfall during the mungbean phase.

Conclusions and Recommendations

The study assessed the response of mungbean to different management practices which included fertilisation, soil amendments, sowing date, and cultivation when grown after rainfed wetland rice. Based on the results obtained from the three-year study, the following conclusions can be drawn.

1. Fertilizer had no effect on the grain yield of mungbean.
2. Use of rice straw as surface mulch tended to increase grain yield through conservation of soil water and concomitant lower soil strength and weed control.
3. Prescribing a suitable planting time is very difficult because soil water content at planting is affected by both delay after rice harvest and rainfall. There is still a clear need to assess the rainfall probability after rice harvest to assist farmers in selecting suitable times for sowing to avoid waterlogging and excessively high soil strength.
4. The different soil management practices showed no significant effect on root growth and distribution. However, roots proliferated to about 1 m deep on a silty clay loam with subsequent high yield through use of residual subsoil water reserves.
5. High yields are possible under dry conditions in the absence of rainfall, provided roots penetrate the subsoil and use residual soil water from the previous rice crop.

Table 3. Effect of sowing date on the grain yield (t/ha) of mungbean grown after wetland rice for the three cropping years.

Site	Year	No delay[2]	Delay 1[3]	Delay 2[4]	LSD 5%
Bulacan	1992–93[1]	0.03	0.02	0.02	ns
	1993–94	0.62	0.41	0.17	0.23
	1994–95	0.24	0.17	0.11	ns
Pangasinan	1992–93	0.46	0.73	0.85	0.13
	1993–94	0.96	0.77	0.89	ns
	1994–95	0.77	0.54	0.54	ns

[1] Total Biomass. [2] Sowing immediately after rice harvest. [3] Sowing one week after rice harvest. [4] Sowing two weeks after rice harvest. ns = statistically not significant, LSD = least significant difference.

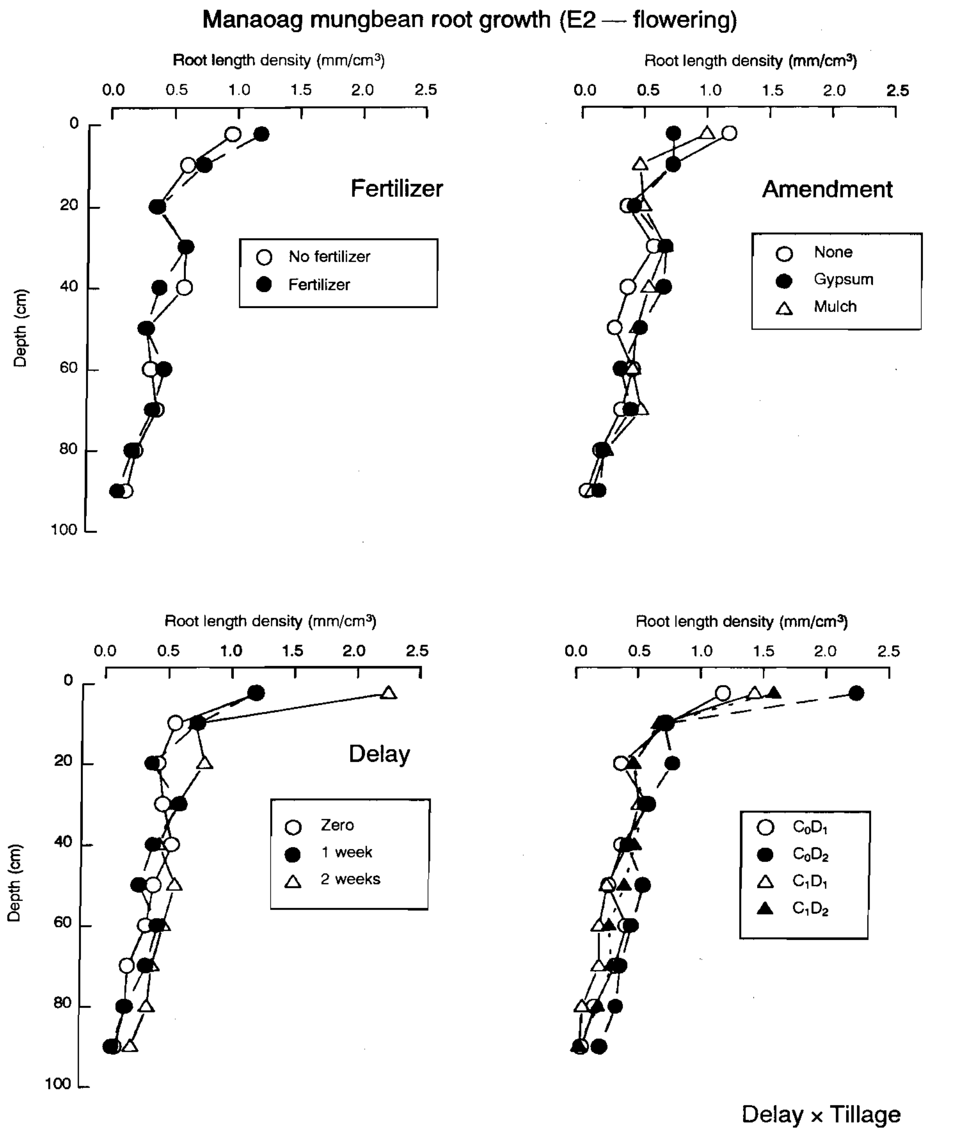


Figure 1. Root length density of mungbean at flowering in Manaoag as affected by the different soil management practices (1992–93, year 1).

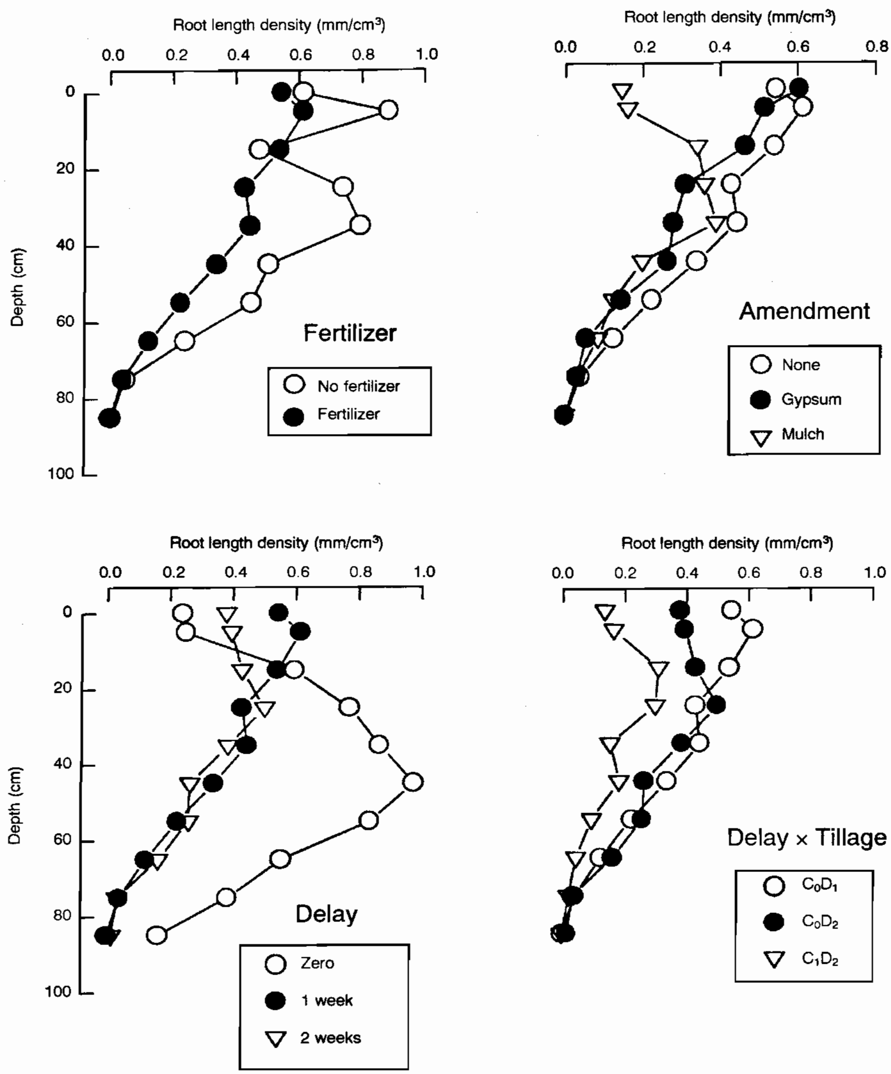


Figure 2. Root length density of mungbean at flowering in Manaoag as affected by the different soil management practices (1994–95, year 3).

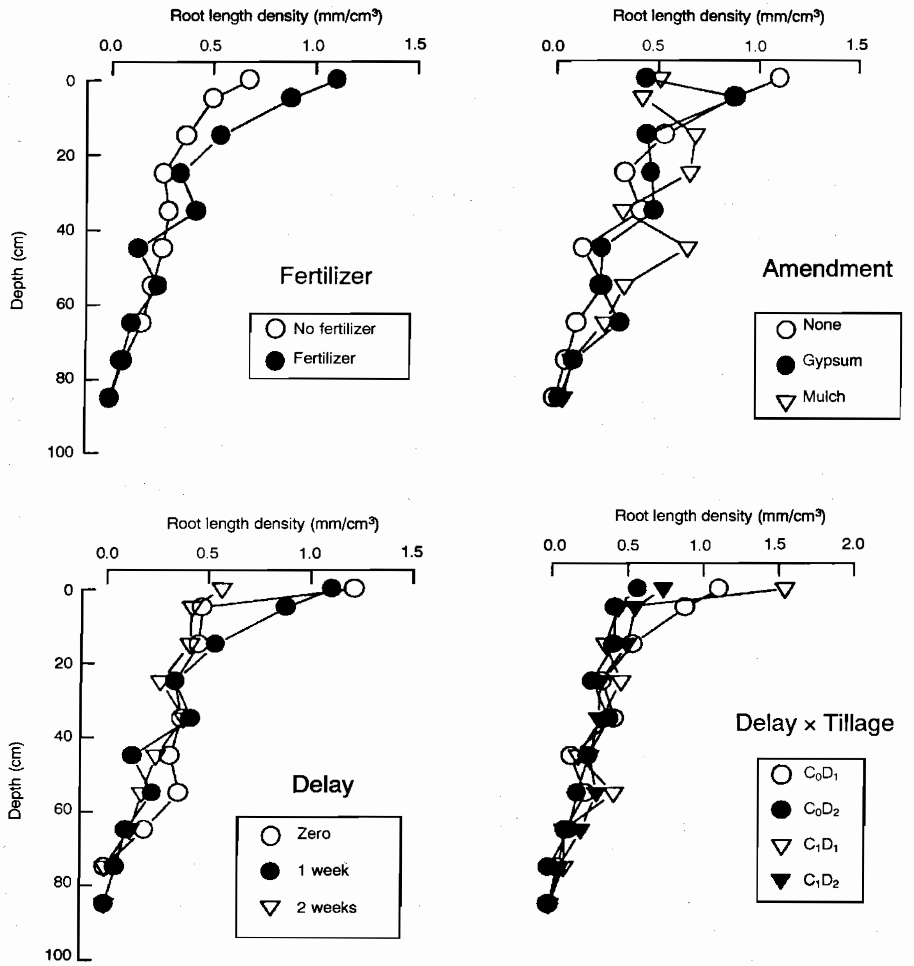


Figure 3. Root length density of mungbean at flowering in Bulacan as affected by the different soil management practices (1994–95, year 3).

References

Adisarwanto, T. and Suhartina, 1994. The Response of Three Grain Legumes to Different Soil Management Practices After Wetland Rice. Paper presented in the review ACIAR 8938 at UNIBRAW, 15–19 June 1994.

Bandong, J.P. and Listinger, J.A. 1976. Crop Protection of Field Crops After Rice. Report of research trial in Manaoag, Pangasinan, Philippines, IRRI, Los Baños, Laguna.

Gomez, A.A. and Zandstra, H.G. 1976. An analysis of the role of legumes in multiple cropping, 81–95. In: Exploiting the Legume–Rhizobium Symbiosis in Tropical Agriculture. Proceedings of a Workshop, August 1976.

IRRI, 1985. International Rice Research Institute Annual Report for 1984, International Rice Research Institute, Los Baños, Philippines, 329 p.

— 1986. International Rice Research Institute Annual Report for 1985, International Rice Research Institute, Los Baños, Philippines, 299 p.

Syarifuddin, A.K. 1982. Tillage practices and methods of seeding upland crops after wetland rice. In: Report of a workshop on cropping systems research in Asia, IRRI, Los Baños, Laguna, Philippines.

Zandstra, H.G. 1982. Effect of soil moisture and texture on the growth of upland crops after wetland rice. In: Report of a workshop on cropping systems research in Asia. IRRI, Los Baños, Philippines.

Post-rice Climatic Variability and Legume Yields

G. Kirchhof[1], H.B. So[1], T. Adisarwanto[2], W.H. Utomo[3], S. Priyono[3], B. Prastowo[4], M. Basir[4], T.M. Lando[4], E.V. Dacanay[5] and D. Tan-elicano[5]

Abstract

Crop establishment, survival and yield of rainfed post-rice legumes were related to rainfall variability and soil properties from trials conducted over three years at five different locations in tropical Southeast Asia. Crop establishment was the most important factor determining mungbean yields. Crop survival was closely related to crop establishment indicating that conditions that determine crop establishment equally affect crop survival. The success of post-rice cropping was therefore governed largely by conditions occurring around the crop establishment phase. Rainfall during the dry season crop had relatively little effect on yield indicating that subsoil water storage is of greater importance as a plant water reserve than rainfall. This was supported by the finding that yields tended to increase with increasing clay content through increased soil water storage capacity.

RAINFED crop production following lowland rice is adversely affected by poor soil physical conditions induced by pre-rice soil puddling. Despite high subsoil water contents following prolonged periods of inundation during the rice phase in the wet season, during the dry season root growth into the subsoil is often restricted and so the crop cannot use subsoil water reserves, and yields are unreliable, poor or non-existent. Immediately following drainage and rice harvest, the top soil is very wet and sowing under these conditions is likely to result in crop establishment failure due to anaerobic conditions and potential fungal infections of the seed or seedling. Upon drying the puddled soil is likely to become dry rapidly and roots would have difficulty penetrating zones of high soil strength and may subsequently fail to reach subsoil water reserves. The optimum time period for sowing, between too wet and too dry, is therefore potentially narrow. A turnaround time of one to two weeks between rice harvest and sowing of the post-rice crop is generally regarded as optimum. It is perceived as the time necessary to dry the soil adequately and to avoid excessively high soil strength. However, over and above time after rice harvest, compounding factors that determine suitable soil water contents for sowing are the rate at which the soil dries out and the amount of rainfall occurring after rice harvest. Provided the optimum soil water content for sowing is known, the time required to reach such a water content can be estimated if the hydraulic properties of the soil, rainfall and evaporation are known. Modelling of soil water content changes, using long-term meteorological data, can give insight into how many sowing opportunities existed within the timeframe the model was run.

Of equal importance are the climatological conditions following sowing. Even if sowing occurred at suitable soil water contents it does not guarantee that crop establishment will be successful. To assess the

[1] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia
[2] Research Institute for Legume and Tuber Crops (RILET), Kendalpayak, PO Box 66, Malang 65101, Indonesia
[3] University of Brawijaya, Fakultas Pertanian, Jl. Mayjen Harjono 18, Malang 65145, Indonesia
[4] Research Insitute for Maize and other Cereals, Jl. Dr Ratulangi, Maros 90514, Indonesia
[5] Bureau of Soil and Water Management, Cnr Elliptical Rd and Visayas Avenue, Quezon City 1100, the Philippines

risk for dry season cropping it is necessary firstly to find the number of sowing opportunities, and secondly to determine how likely it is that the crop will survive. In practice, the latter is of greater importance because the farmer makes a conscious decision as to whether the soil water content is suitable for planting. The unknown factors are the climatological conditions following sowing. Probabilities can be calculated to assess the risk for crop failure using soil water balance models and long-term climatological data, provided conditions leading to crop failure are defined.

Using data derived from ACIAR Project 8938 (these Proceedings) this paper discusses the effect of soil properties and climatic conditions during the dry season phase on crop establishment, crop survival and yield. Its aim is to determine a preliminary guide to climatic conditions that are conducive or detrimental to rainfed dry season crop production after rice. These conditions can then be used in conjunction with soil water balance models for an overall risk assessment for crop production following rice.

Materials and Methods

Crop establishment, crop survival and yield data from the field experiments of ACIAR Project 8938 were related to soil properties and rainfall patterns during the sowing and growing periods of the rainfed post-rice mungbean crop. *Crop establishment* was obtained from the number of seedlings that needed to be thinned to obtain the prescribed population density of 333 000 plants/ha (i.e. plant spacing of 20 x 30 with two plants/hill). *Survival* was expressed as the number of plants at harvest per population density of 333 000. The additional term *net-survival* was calculated as the product of establishment and survival to estimate conditions in farmers' fields without over sowing to reach the prescribed population density. Depending on variables used in the regression analysis and availability of data, the number of observations that could be included in the analysis ranged from 55 to 41. Correlation matrices were constructed and included the relationship between establishment, survival, net-survival, yield, daily rainfall during the week prior to sowing, the week following sowing and rainfall during the remainder of the growing season. Multivariate regression analysis was used to predict the yield, survival and crop establishment from the variables listed above and clay content of the soil.

Results and Discussion

Rainfall totals following rice harvest and throughout the legume season are shown in Figures 1 to 5 for the experimental sites. Oldeman (1975) suggested that 200 mm rainfall a month is required to maintain submerged conditions and to meet the evapotranspirational demand of the submerged rice crop. A dry month has less than 100 mm rainfall. Using Oldeman's criteria, the climate at Jambegede and Ngale would fall in the C2 class (6 wet and 4 dry months), Maros and Bulcan in class C3 (6 wet and 5 dry months), while Manaoag, Pangasinan would be classified as D4 (3 wet and 8 dry months).

Long-term weekly rainfall data in relationship to the weekly rainfall during the three months at which crop establishment, i.e. sowing and early growth, occurs are given in Figures 6 to 10. At Jambegede rainfall during the year-long trial period was within the variation of rainfall that can be expected (Fig. 6). However, there was a tendency during the three years for conditions to be slightly wetter than average. The same applies to Ngale (Fig. 7), except that the late wet season in 1994 tended to be wetter than average. Maros weekly rainfall (Fig. 8) was also well within what can be expected, except for a wet period in 1992. At the sites in the Philippines (Figs 8 and 9), rainfall was within the expected magnitude. In summary, rainfall during the trial period did not deviate substantially from long-term data.

Local practices were followed in terms of when rice and post-rice crops were planted/harvested. It is interesting to note that post-rice legumes were planted in the latter part of the rainy season at Jambegede, Ngale and Maros (Indonesian sites) but at the start of the dry season at the Philippine sites, Bulacan and Pangasinan (see Figs 1 to 5 in Schafer and Kirchhof, these Proceedings). It is clear that rainfall occurring during the time of planting is a major factor determining the water contents of the soil and hence the success of crop establishment. At Ngale and Jambegede, there was good rainfall during the mungbean crop in all three years, but the other sites had none or very little rainfall during the last month of the post-rice crop. At Maros, mungbean received some rainfall whereas at Bulacan and Manaoag mungbean grew almost entirely on stored water. Therefore it is not surprising that yields were moderate to high at Jambegede and Ngale (Adisarwanto, these Proceedings) as rainfall supplied most of the water requirement at Ngale and approximately half at Jambegede (Priyono et al., these Proceedings). Yields were low to very low at Maros and Bulacan as root growth was inadequate through the hard, puddled and compacted layer of these soils and access to subsoil was poor. At Manaoag, the plants relied on stored water and roots had no difficulty in growing to a depth of 1 m (Sanidad et al., these Proceedings) in this well-drained soil.

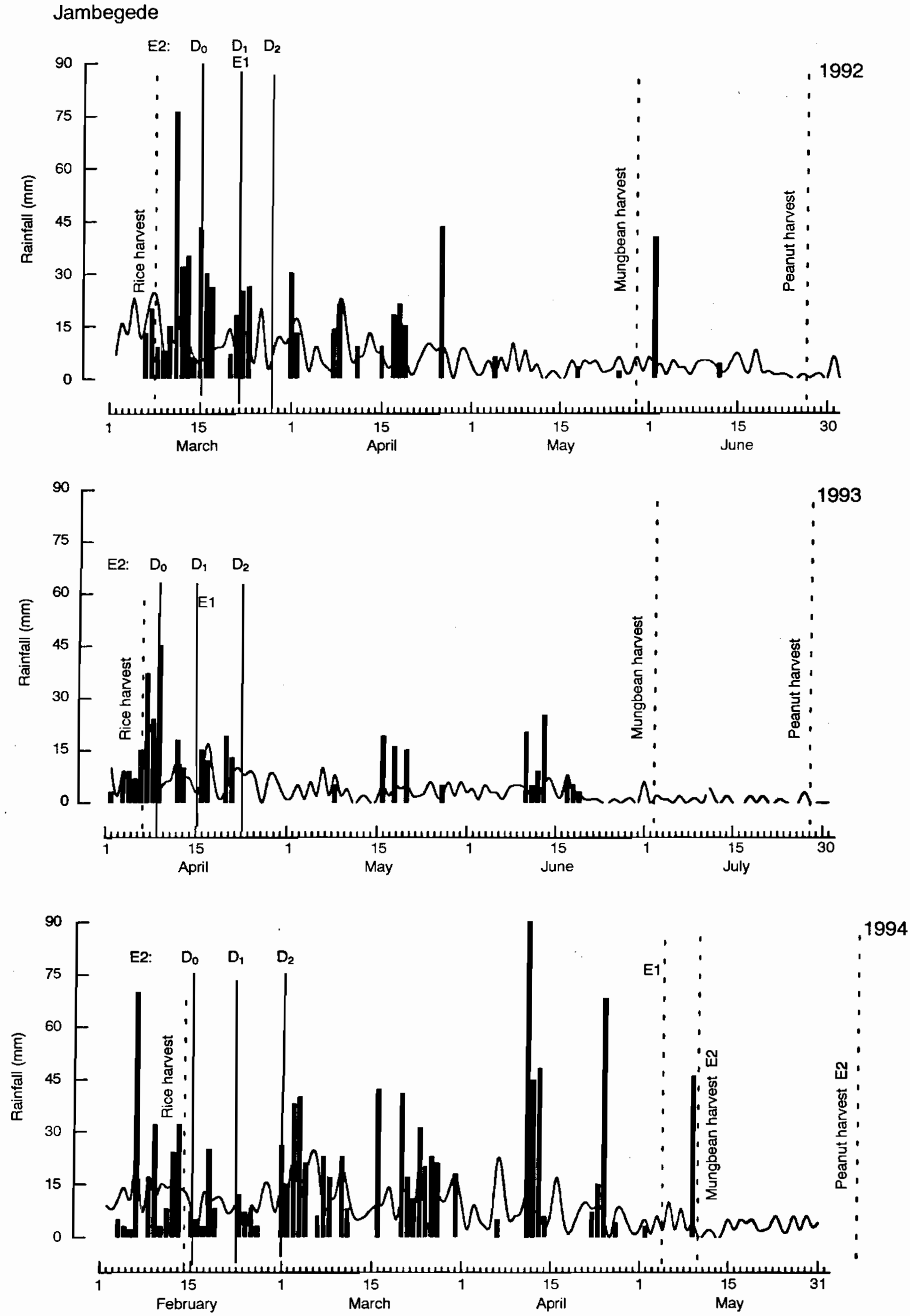


Figure 1. Rainfall at Jambegede, East Java during the mungbean phase 1992–1994 and long-term average (rainy season November to April).

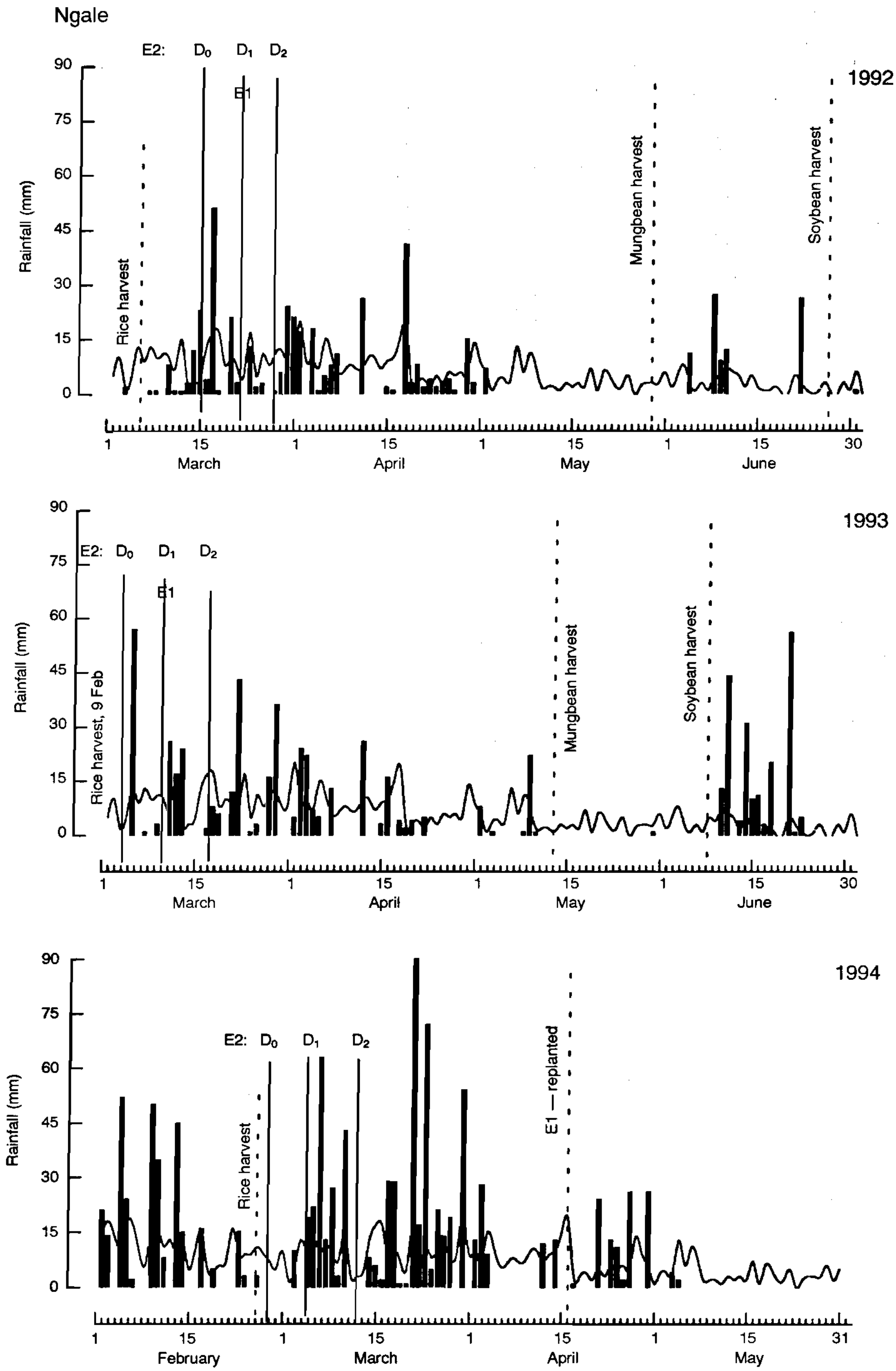


Figure 2. Rainfall at Ngale, East Java during the mungbean phase 1992–1994 and long-term average (rainy season November to April).

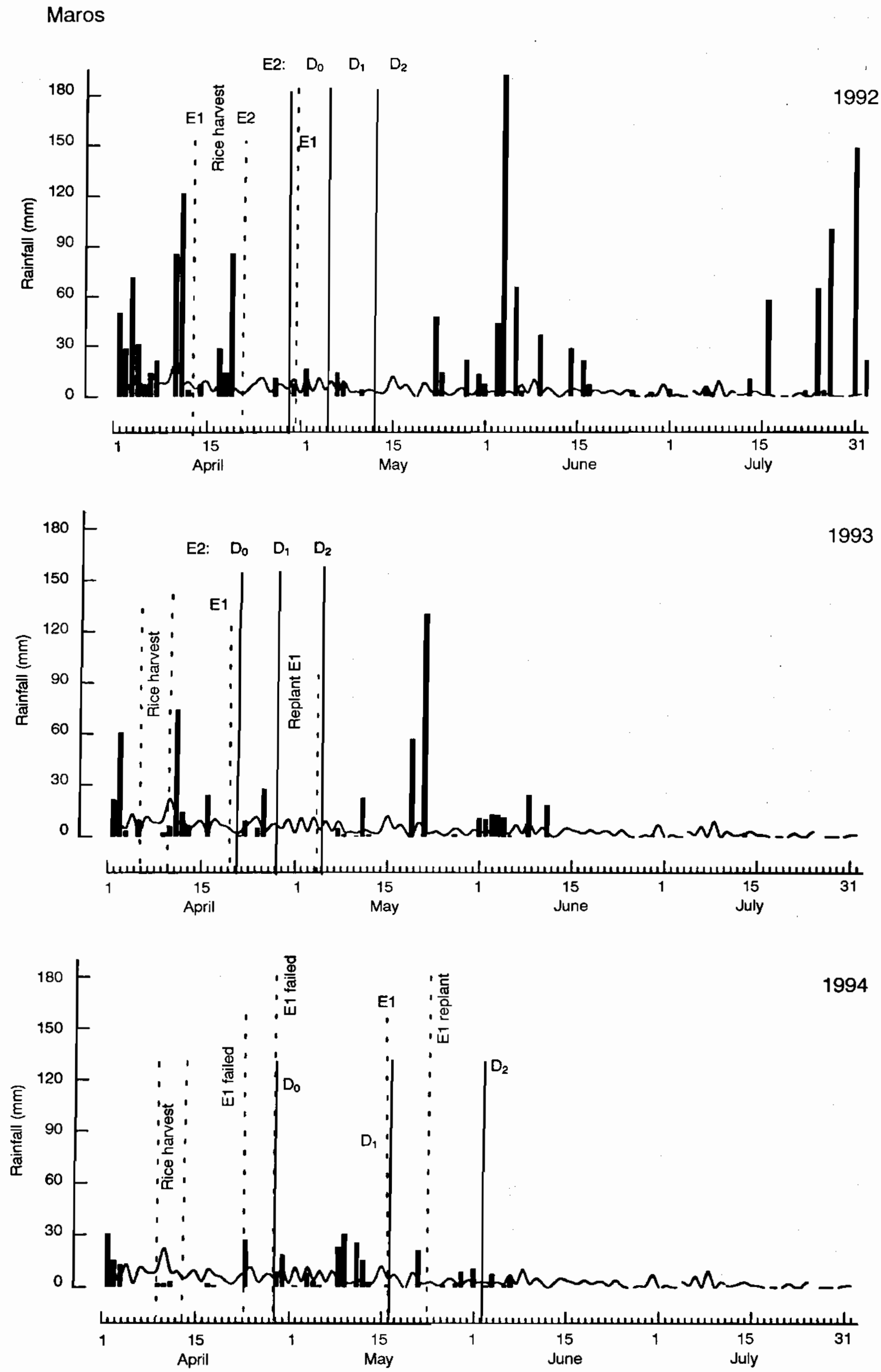


Figure 3. Rainfall at Maros, South Sulawesi during the mungbean phase 1992–1994 and long-term average (rainy season November to April).

Bulacan

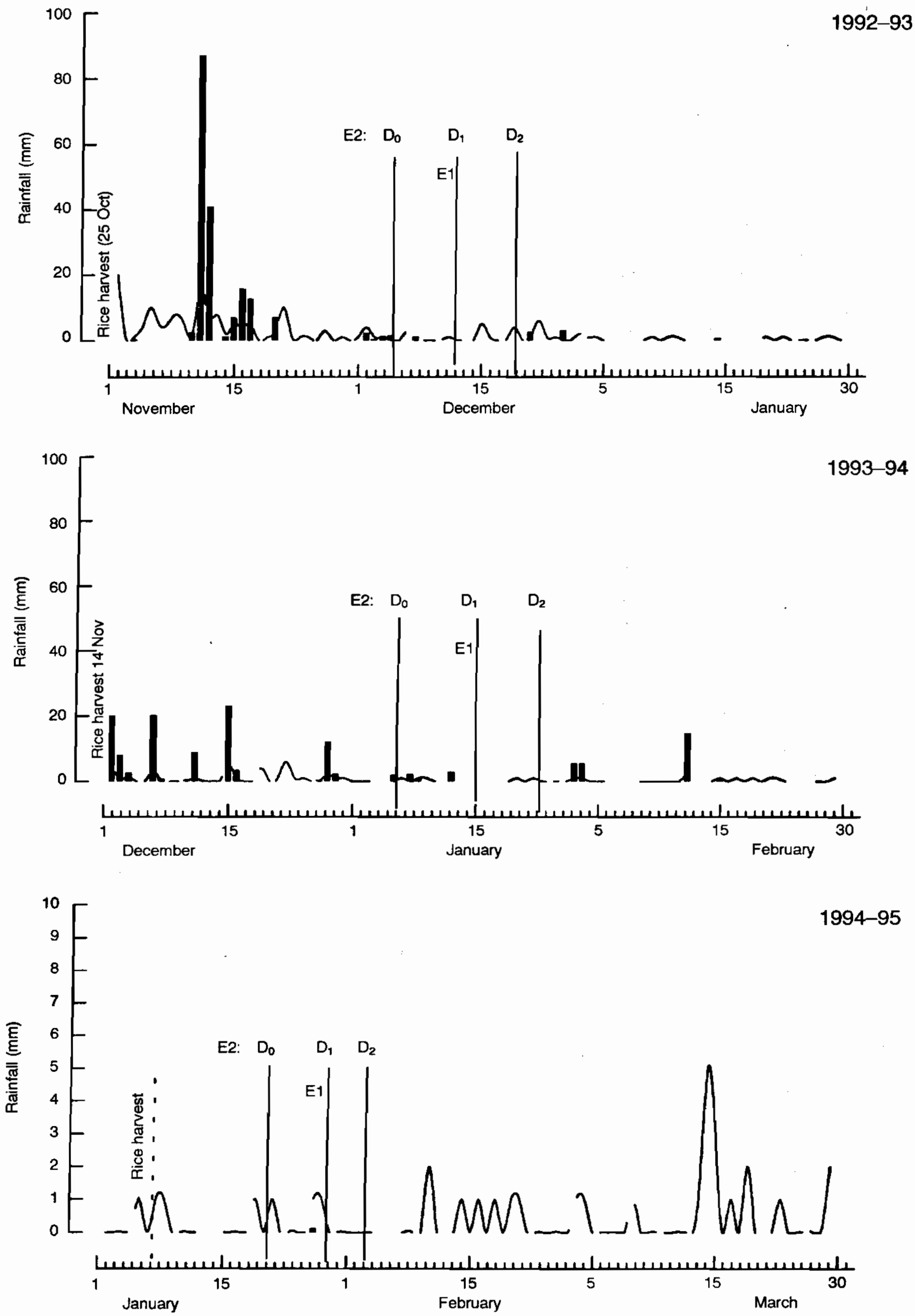
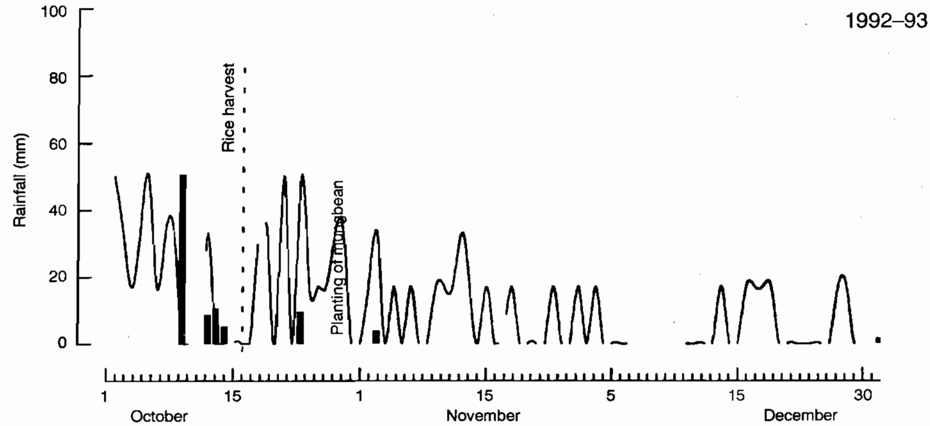
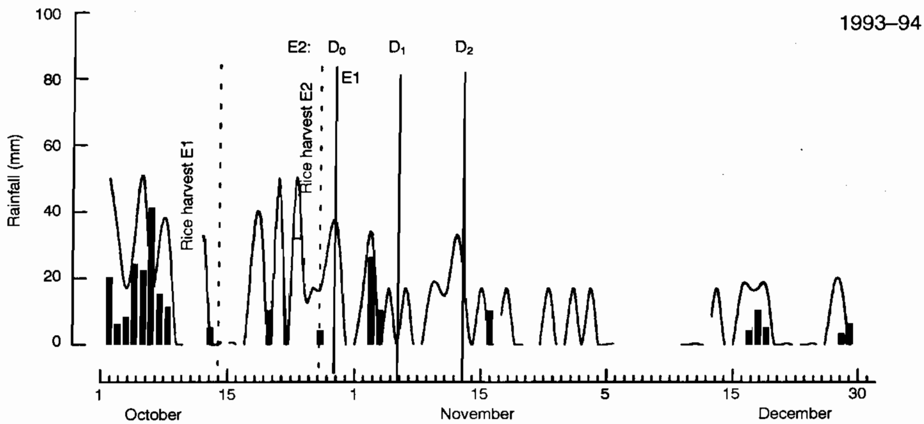


Figure 4. Rainfall at San Ildefonso, Bulacan during the mungbean phase 1993–1995 and long-term average (rainy season June to October).

Manaoag





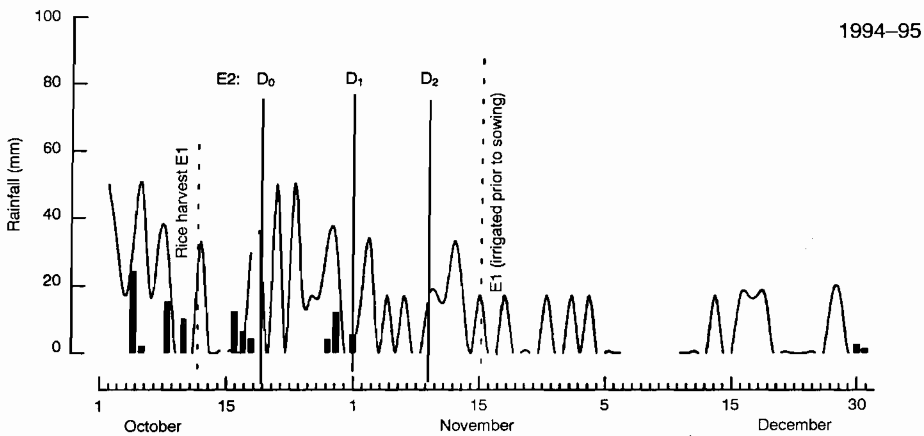


Figure 5. Rainfall at Manaoag, Pangasinan during the mungbean phase 1993–1995 and long-term average (rainy season July to September).

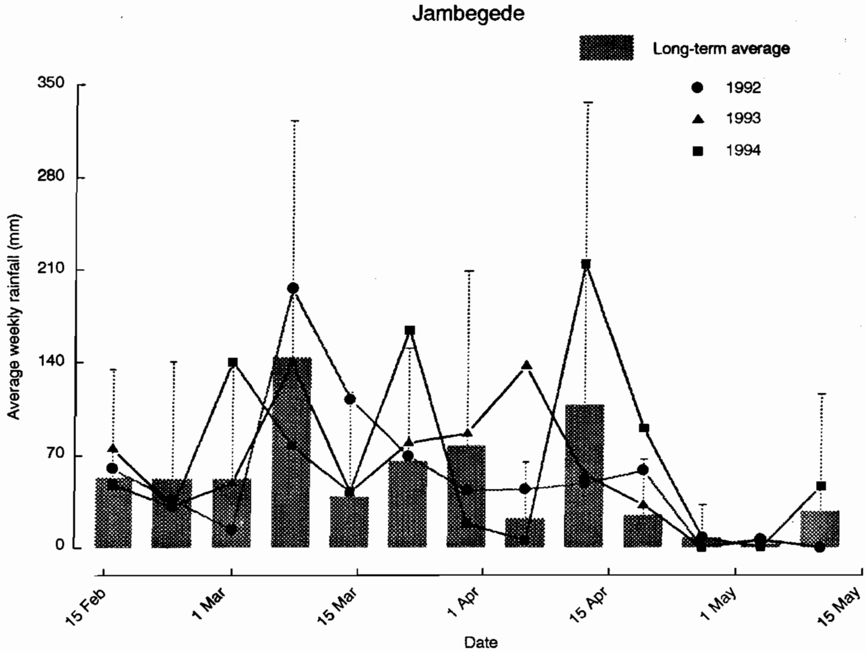


Figure 6. Long-term weekly rainfall in comparison to weekly rainfall during the trial period at Jambgede.

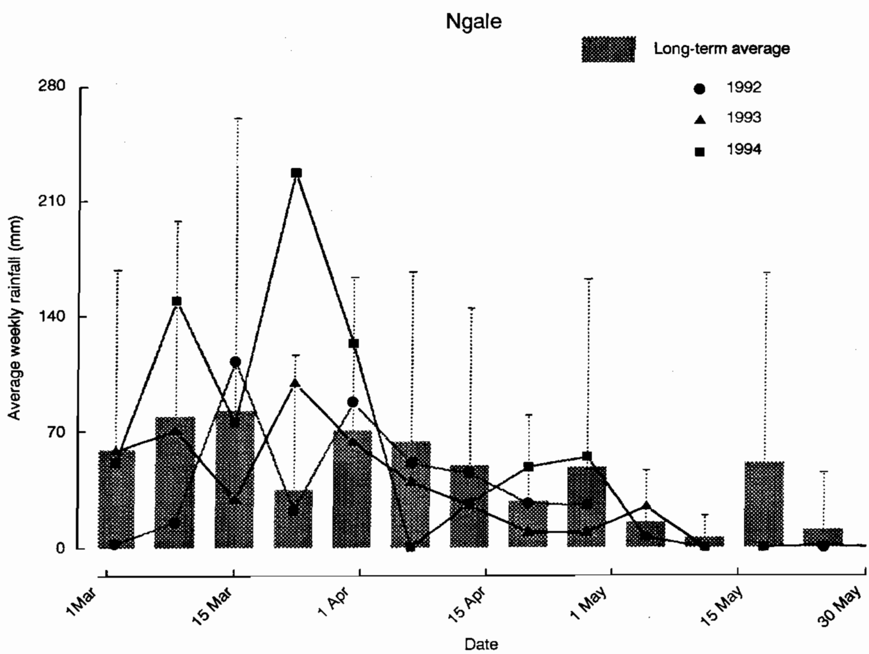


Figure 7. Long-term weekly rainfall in comparison to weekly rainfall during the trial period at Ngale.

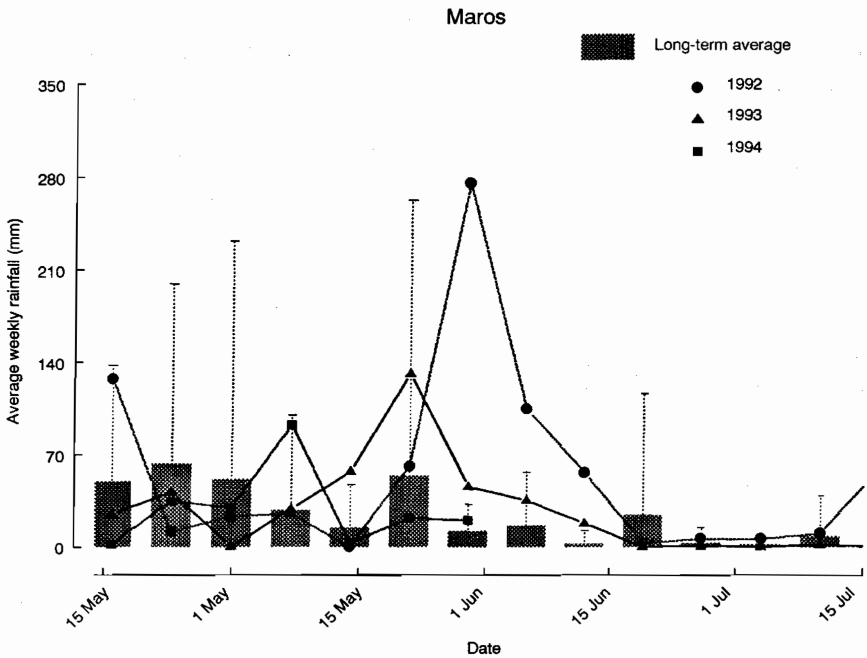


Figure 8. Long-term weekly rainfall in comparison to weekly rainfall during the trial period at Maros.

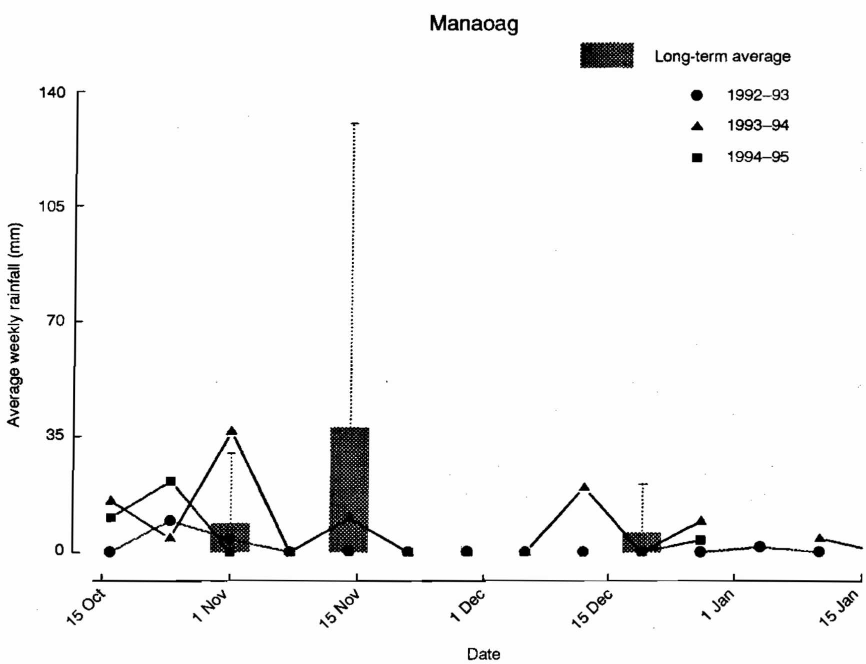


Figure 9. Long-term weekly rainfall in comparison to weekly rainfall during the trial period at Manaoag.

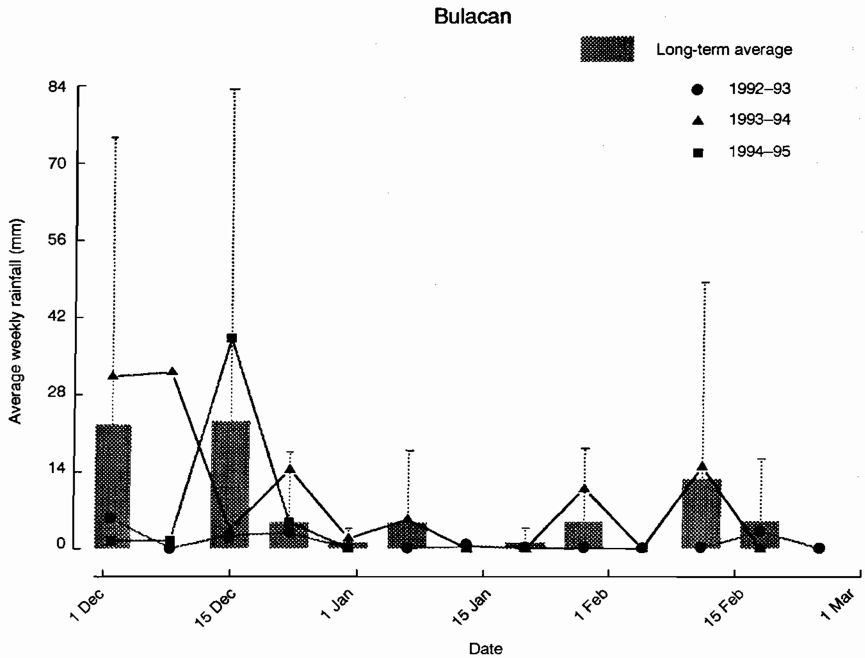


Figure 10. Long-term weekly rainfall in comparison to weekly rainfall during the trial period at Bulacan.

To obtain an indication of how well crop establishment, crop survival, yield and seasonal rainfall were related, a correlation matrix for these variables was calculated and given in Table 1. Crop establishment, survival and yield were strongly related to each other and showed the importance of establishment or survival for adequate yield. This was consistent with findings of Bolton et al. (1984) with mungbean and Carangall (1985) with soybean who showed a linear increase in yield with increasing population density in the tropics. It is important to note that crop establishment and survival, as measured in these experiments, were independent from each other. The strong relationship between these two parameters indicated that a similar proportion of established seedlings survived at all sites. Thus across the sites, survival appeared to be largely a crop characteristic. It may be dependent to a lesser extent on soil and climate within each site. Thus crop establishment is a reasonable measure for plant population density and thus a major factor determining yield.

Crop survival is generally determined by both soil and climatic conditions that prevail after the crop is established. However, Table 1 shows that there was no relationship between rainfall following sowing and crop survival. But crop establishment and survival were both significantly related to rainfall before sowing. The relationship between survival and rainfall before sowing is due to the strong relationship between crop establishment and survival. It indicated that conditions leading to adequate crop establishment will result in adequate survival.

Table 1. The regression coefficients for the relationship between crop establishment, survival, yield and rainfall during the dry season phase.

Regression coefficient with n from 55 to 43	Crop establishment	Crop survival	Yield
Crop survival	0.845**		
Yield	0.638**	0.752**	
Rainfall in period:			
1 week before sowing	0.447*	0.406*	0.360
1 week after sowing	0.122	0.131	0.234
2 weeks after sowing	0.192	0.275	0.327
3 weeks after sowing	0.106	0.146	0.278
4 weeks after sowing	0.066	0.106	0.228
Sowing to harvest	0.049	0.108	0.191

*significant at P < 0.005, **Significant at P < 0.001.

The relationship between crop establishment and survival can probably be improved if establishment is further classified to include how well seedlings are established. Vigorous seedlings can be expected to penetrate and access subsoil water reserves more readily than weak seedlings. The relationship between crop establishment and rainfall before sowing showed that an assessment of the soil water content and its suitability for sowing is the first step toward determining yield. It is a conscious decision the farmer is likely to make before sowing. The lack of a relationship between establishment and rainfall after sowing is probably due to insufficient data being available.

Inclusion of additional climatic variables and clay content (as an indicator of soil property) did not result in relationships that would allow a reliable prediction of crop survival or establishment (Table 2). The use of soil water content or potential (Rahmianna et al., these Proceedings) would be more appropriate and may improve the relationships.

Table 1 shows that yield is strongly related to crop establishment and survival. For a particular plant density, it is reasonable to assume that yield will be determined by the amount of water available to the crop. The inclusion of clay content as a surrogate of plant available water capacity and seasonal rainfall improved the relationship significantly (Table 3),

Table 2. Best subset regression analysis to predict survival and establishment from rainfall and clay content.

Independent variables	✔ = included independent variable				
	Dependent variable: *survival percentage*				
Rain 1 week before sowing	✔	✔	✔	✔	✔
Rain 1 week after sowing					✔
Rain 2 weeks after sowing				✔	
Rain sowing to harvest					
Rain 4 weeks before harvest					
Clay content topsoil			✔		
Clay content subsoil		✔			
r^2 for included (✔) variables	0.177	0.190	0.190	0.188	0.185
	Dependent variable: *establishment percentage*				
Rain 1 week before sowing	✔	✔	✔	✔	✔
Rain 1 week after sowing			✔		
Rain 2 weeks after sowing					✔
Rain 3 weeks after sowing		✔			
Clay content topsoil				✔	
r^2 for included (✔) variables	0.203	0.208	0.207	0.205	0.205

Table 3. Best subset regression analysis to predict yield from survival or establishment, and rainfall and clay content (values are the coefficients for the independent variables in the appropriate regression equation).

Independent variables	Factor for included dependent variable			
Constant	−0.4705	−0.5236	−0.4778	−0.5328
Survival percentage	0.0102	0.0102	0.0095	0.0095
Rain 1 week before sowing			0.0011	0.0012
Rain sowing to harvest	0.0003	0.0004	0.0003	0.0003
Clay content topsoil	0.0082		0.0082	
Clay content subsoil		0.0083		0.0084
r^2 for included variables	0.747	0.744	0.757	0.754
Constant	−0.7320	−0.6649		
Establishment percentage	0.0080	0.0079		
Rain sowing to harvest		0.0004		
Rain 4 weeks before harvest	0.0008			
Clay content topsoil	0.0127	0.0110		
r^2 for included variables	0.702	0.698		

Table 4. The range of possible yield contribution from rainfall, crop establishment and survival, and clay content.

Variable	Average factor	Range of variable		Range of yield contribution (t/ha)	
		Minimum	Maximum	Minimum	Maximum
Survival percentage	0.0099	0	96.3	0	0.95
Establishment percentage	0.0080	0	100	0	0.80
Rain 1 week before sowing	0.0012	0	215	0	0.26
Rain 4 weeks before harvest	0.0008	0	443	0	0.35
Rain sowing to harvest	0.0003	0	754	0	0.23
Clay content topsoil	0.0100	28.1	78.0	0.28	0.78
Clay content subsoil	0.0084	32.9	82.3	0.28	0.69

with the best relationship accounting for 76% of the variability in yield.

It would be informative to deduce the range of possible contributions to mungbean yield from the relevant factors shown as crop establishment, survival, rainfall and clay content. The results in Table 4 show that plant population (crop establishment or survival) has potentially the largest effect on yield followed by the soil's clay content as a measure of plant available water, and rainfall.

Conclusions

- Crop establishment is the main determining factor for yield of rainfed dry season crops after rice.
- Climatic conditions around sowing time determine the success of crop establishment.
- Crop survival rates were similar for all sites and are independent of the soil and climatic conditions.
- Subsoil water store was the second largest contributor to yield.

Further research is needed to define adequately the conditions which are conducive to crop establishment. If these conditions are known, a risk analysis may be possible using soil water balance models to delineate areas and climates at which successful post-rice cropping is likely.

References

Bolton, F.R., Morris R.A. and Vivekanandan, P. (1985). Soil-water relations in rice-based cropping systems. In: Soil Physics and Rice. International Rice Research Institute. 131–146.

Carangall, V.R. 1985. Soybean in rice based farming systems. The IRRI experience. In: Shumugasnudaram, S. and Salzberger, E.W. ed., Soybean in Tropical and Subtropical Cropping Systems. Proc. Symp. At Tsukuba, 1983.

Oldeman, L.R. (1975). An Agro-climatic Map of Java. Central Res. Inst. Agric. Bogor, No. 17, 22 p.

Response of Food Legume Crops to Different Soil Management Practices after Rainfed Lowland Rice: A Summary

T. Adisarwanto[1], H.B So[2] and G. Kirchhof[2]

FIELD experiments were conducted over a three-year period in Sulawesi (Basir et al., these Proceedings), East Java (Adisarwanto et al., these Proceedings) and the Philippines (Sanidad et al., these Proceedings) to investigate the response of post-rice soil managements on growth and yield of legumes after lowland rice under rainfed conditions. The response and magnitude of the effects from different management systems on legumes were closely related to the climatic conditions prevailing during the crop establishment phase (Kirchhof et al., these Proceedings).

The application of fertilizer strongly increased yield on the sites in East Java. Yield increase was small in Sulawesi and there was no effect on the sites in the Philippines. This response seems to be associated with rainfall patterns during the legume phase.

Fertilizer was applied to the soil surface and needed adequate water for its dissolution and subsequent movement into the root zone. Gentle rain at the end of the rainy season in East Java provided wet conditions which dissolved the fertilizer and made it available within the root zone.

In Sulawesi, legumes were planted at the start of the dry season and rain was inadequate to move the fertilizer into the root zone.

Due to the dry conditions during the legume season in the Philippines, applied fertilizer did not enter the root zone and thus yield remained unaffected. However, these results indicated that residual fertilizer from the rice crop was probably insufficient and can be a limiting factor where water supply (rainfall or irrigation) is non-limiting.

The effect of mulch application was directly opposite to the effect of fertilisation. It increased yield in the drier areas (Philippines and Sulawesi), but had no effect in the wetter areas (East Java). If water is limiting, mulch will be beneficial by decreasing soil evaporation rates and thus conserving soil water.

Delay of sowing is often used to prescribe an optimum time after harvest when legumes should be sown. Recommendations on the turnaround time for sowing legumes are based on the assumption that the soil will steadily dry after rice harvest.

Results from these experiments showed that delay per se was a poor indicator for describing soil water content at sowing. Paddies are generally drained about one week prior to harvest to allow easy access for harvesting. At harvest the soil is usually wet. However, in the Philippines soil conditions were dry during harvest. Rainfall following rice harvest determines the soil water content and not time after harvest. It is important to note that a reduction in yield at Ngale (East Java) was observed with increasing delay due to increasingly wet conditions, and not drier conditions. An appropriate time for sowing can therefore only be determined by taking the prevailing climatic conditions into account.

[1] Research Institute for Legume and Tuber Crops, Kendalpayak, PO Box 66, Malang 65101, Indonesia
[2] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia

INTERNATIONAL RESEARCH ON LOWLAND RICE-BASED CROPPING SYSTEMS

Rainfed Lowland Rice-based Cropping Systems in the Philippines: A Review

W.N. Obcemea[1], M.P. Lucas [2], S.R. Pascua [2], E.O. Agustin [2], T.F. Marcos[2], J.K. Ladha[3] and S.R. Obien [1]

Abstract

Crop diversification is for optimising productivity of small farms. Out of 47 dominant cropping systems in the Philippines, 25 are rice-based systems (i.e. wet season rice production followed by a non-rice dry season crop). Several factors influence farmers to shift to rice-based farming systems, namely: income stability, increasing demand for non-rice crops, and high profitability per unit area. Constraints such as inadequate water, land suitability and climatic conditions are additional factors resulting in a shift to rice-based cropping systems.

Limited availability of irrigation water to support rice in irrigated areas usually forces farmers to diversify to non-rice crops. Rice–rice cropping patterns lead to pressure on water resources during the dry season and farmers switch to crops other than rice (e.g. corn and mungbean) to conserve water. The most profitable non-rice crops, for example, were garlic in Ilocos, hybrid corn in Tarlac, and onion in Nueva Ecija. However, in some parts of Mindanao and in Aklan (Visayas) rice production under irrigated conditions was more profitable than corn.

Installation of small water pumps in the rainfed areas enabled farmers to diversify to non-rice crops during the dry season. Rice-based cropping systems such as rice–corn, rice–garlic, rice–mungbean, rice–sweet pepper, and rice–tomato were evaluated from 1991 to 1995 in Ilocos Norte. These trials were conducted using high application rates of NPK fertilizers (normally 138–50–60 kg/ha). The highest NPK fertilizer rate (295–142–100 kg/ha) was applied in sweet pepper, but no fertilizer in mungbean. Although the average area planted to cash crops was small, farmers obtained high net income from them. Rice yields varied 2–5.8 t/ha during the wet season. Among the dry season cash crops, tomato yields ranged 34–46 t/ha and sweet pepper yields 5–15 t/ha. Yield ranges for garlic, corn, and mungbean were 1–2 t/ha, 3.5–5.4 t/ha, and 0.3–0.5 t/ha, respectively.

One of the major constraints in rice-based cropping systems is low soil fertility. Long-term effects of fertilizers were monitored to assess the nutrient sustainability for different cropping sequences. Results indicated that intensive cropping in rainfed areas is only sustainable if soil fertility is maintained. Indigo (*Indigofera tinctoria*), a promising rainfed green manure, was evaluated as an intercrop with a dry season crop and used as fertilizer for the rice crop to improve soil fertility and to reduce nitrate leaching caused by the use of inorganic fertilizers. Rice yields in the rice–tomato, rice–tobacco, and rice–garlic cropping systems were significantly increased by indigo incorporation while rice–corn was not affected.

NATURAL and climatic conditions are the most important factors in influencing the selection of cropping patterns and crop varieties in the tropics (Kamiya 1989). Small-scale farming is caused by high population density and limited land available for agriculture. With the introduction of new farming techniques agriculture has grown. In food production, foodgrain is still a mainstay of Philippine agriculture. However, some of the food production areas were shifted to cash crops and non-farm production owing to urbanisation and industrialisation

[1]Philippine Rice Research Institute (PhilRice), Maligaya, Muñoz, Nueva Ecija 3119, Philippines
[2]Mariano Marcos State University (MMSU), Batac, Ilocos Norte 2906, Philippines
[3]International Rice Research Institute (IRRI), Los Baños, Laguna 4031, Philippines

resulting in the relative decline/decrease of foodgrain in the total agricultural production.

In the Philippines, crop diversification in rice-based cropping systems started in the 1970s when researchers began to focus on developing technologies and strategies for optimising small farm productivity (Galvez 1990). The purpose of this paper is to review the rice-based cropping system in the Philippines for optimising small farm productivity and the various factors that influence farmers to adopt crop diversification under inadequate supply of irrigation water and under rainfed conditions with the use of supplemental irrigation.

Dominant cropping systems

Out of 47 dominant cropping systems practised in the rainfed and upland areas of the Philippines (Table 1), 25 are predominantly rice-based patterns with rice as the main crop followed by another rice crop (Adriano 1989). The other important cropping patterns are corn, coconut, rootcrop, and fruit tree-based patterns. Depending on the rainfall and availability of water, elevation and land features of the micro-environment, there is a wide range of crop species that can be grown after rice in the different regions. In Luzon, Region I, aside from rice–garlic, rice–corn, and rice–tobacco, vegetables such as cabbage, carrots, and other vegetables are planted with white potato after rice. In other regions in Luzon, non-rice crops such as mungbean, corn, tobacco, peanut, and vegetables such as squash, watermelon, tomato, and sweet pepper are planted after rice.

The three major farming systems in the Visayas are rice, corn and coconut-based (Ly Tung et al. 1989). In Mindanao, the dominant cropping systems are rice-based, corn-based, and coconut-based. Crops such as banana, pineapple and fruit trees are also commercially grown. Water stress during the dry season due to lack of availablity of irrigation is among the major limitations for rainfed crop production after rice.

Factors for diversification

There are several factors that influence farmers to diversify to non-rice crops or shift to rice-based farming systems. Income stability is the major consideration in diversification to non-rice crops (Miranda and Maglinao 1990). Increasing demand for vegetables and non-rice crops and higher profitability per unit area have also been identified as major driving forces to diversify to non-rice crop production (Galvez 1990). Economic factors affecting crop diversification are market supply and demand, stability of prices, cost of input, and quality of non-rice products (Caluya and Acosta 1989).

Other factors are availability of adequate irrigation water, land suitability, climatic conditions, availability of management technology, time constraints caused by the presence of the rice crop, farmers' preference, resource base, influence of neighboring farmers or extension agents, and land tenure. Choice of crops primarily depends on the availability of irrigation water during the dry season (Caluya and Acosta 1989).

Profitability

Profitability and economic aspects of diversified cropping during the dry season under irrigated and

Table 1. Dominant cropping pattern in the different regions in the Philippines (adapted from Adriano 1989).

Region	Cropping pattern
I/Car	Rice–rice, rice–garlic, rice–tobacco, corn–corn, white potato–cabbage–rice–legume, white potato–vegetable
II	Rice–garlic, corn–corn, rice–rice, corn–legumes
III	Rice–rice, rice–legumes, rice–fallow
IV	Rice–rice, rice–fallow, coconut–coffee–pineapple, rice–tomato–coconut monocrop
V	Rice–rice, rice–corn, coconut+rice, coconut+rootcrops, coconut+corn
VI	Rice–rice, rice–corn, rice–fallow, sugarcane monocrop
VII	Corn–corn, rice–rice, rice–fallow, corn–rootcrops
VIII	Rice–rice, rice–fallow, coconut monocrop, corn–fallow
IX	Coconut monocrop, rice–rice, cassava–fallow, corn–fallow
X	Rice–rice, corn–corn
XI	Rice–rice, corn–corn, coconut
XII	Corn–corn–corn, coconut, rice–rice

Source: Bureau of Agricultural Research (BAR 1989);
National Agricultural Research and Extension Agenda (NAREA).

Table 2. Mean returns above variable cost Pesos ('000/ha) of irrigated and rainfed crops planted in the different systems during 1986–1988 (adapted from Adriano 1989).

Irrigation system[a]	Rice	Mungbean	Corn		Garlic	Onion
			Hybrid	Native		
			Irrigated crops			
Ilocos	6.35	4.68	—	—	11.06	—
Ilocos	5.64	4.79	—	—	13.15	—
Tarlac	4.65	0.23	5.97	—	—	—
Nueva Ecija	7.32	—	—	—	—	28.29
Mindanao	6.57	—	3.29	2.5	—	—
Aklan	5.95	—	4.29	—	—	—
			Rainfed crops (within or near the system)			
Ilocos	—	2.94	—	—	—	—
Ilocos	—	2.90	—	—	—	—
Tarlac	—	0.39	1.4	—	—	—
Nueva Ecija	—	—	—	—	—	—
Mindanao	—	—	1.99	2.19	—	—
Aklan	—	—	2.57	2.59	—	—

[a]In Ilocos region: Laoag-Vintar river irrigation systems and Bonga Pump No 2 irrigation system; in Tarlac: Tarlac-san Miguel-O'Donnel Irrigation system; in Nueva Ecija: Talavera River irrigation system; in Mindanao: Allah river irrigation system; in Aklan: Visayas Banga river irrigation system.

rainfed conditions are summarised in Table 2. Results of cost and returns analysis in the production of different crops in the 1986–1988 dry seasons showed that garlic was the most profitable non-rice crop for farms in the Ilocos region (Adriano 1989). The returns from garlic cultivation were more than those of irrigated rice. High yields and returns from hybrid corn cultivation in Tarlac province (Central Luzon) indicated the potential of hybrid corn as an alternative crop to rice in this area. In Nueva Ecija, the returns from onion cultivation were greater than those of irrigated rice. On the other hand, in Mindanao and Aklan (Visayas), returns from irrigated rice were greater than those of irrigated hybrid or native corn.

Total production costs in garlic and onion cultivation were two to four times higher than those of irrigated rice (Adriano 1989). The price fluctuation of onion during and between seasons usually resulted in larger variations in income. In rice cultivation, the input cost did not differ during or between seasons but tended to be labor-intensive when water was limiting during the dry season (Marzan 1989). Inadequate water was more of a problem among rice farmers than onion farmers. Higher production costs may either prevent farmers from planting these crops or may force them to plant a very limited area as compared with rice.

A comparison of profitability of selected diversified crops in the Ilocos region (Ilocos Norte province) with that of irrigated rice was done by Caluya and Acosta (1989). The predominant cropping patterns in the area were rice–garlic–mungbean and rice–rice–mungbean. Returns over the variable cost for irrigated garlic were higher than those of irrigated rice. On the other hand, returns for irrigated rice were higher than those of irrigated mungbean. Returns did not widely vary between irrigated and rainfed mungbean because of the ability of the mungbean crop to use soil residual moisture.

Irrigation water

According to Wickham and Sen (1978), water requirement for lowland rice is the sum of evaporation (ET), seepage and percolation (S&P) and water needed for land preparation. ET usually ranges from 4–9 mm/day for most rice-growing areas, S&P about 0–6 mm/day and for land preparation about 500–600 mm (Table 3). The basic water requirement for rice, ET, is similar for most plants, including rice (FAO 1979) and high water requirement for rice is therefore due to large water losses during rice culture. Limited availability of irrigation to support rice in the irrigated areas therefore forces farmers to

Table 3. Basic water requirement of rice and some dry-land crops (FAO 1986).

Crop	Growing period	Basic water requirement (mm)[a]
Rice	90–150	350–700
Peanut	90–140	500–700
Corn	100–140	500–800
Onion	100–140[b]	350–550
Sorghum	100–140	450–650
Soybean	100–130	450–700
Sugarcane	270–365	1500–2500
Sunflower	270–365	600–1000
Tobacco	90–120[b]	400–600
Tomato	90–140[b]	400–600

[a] Evapotranspiration
[b] plus about one month nursery period.

diversify to non-rice crops (Galvez 1990) and productivity under limited water conditions is increased through cultivation of corn and other non-rice crops (Moya and Miranda, 1989).

Integration of component technology for non-rice crops, improved cropping sequence (i.e., rice–corn–mungbean) would increase farmers' income over existing cropping patterns. Gines and co-workers (1989) reported that the rice–rice cropping pattern in Nueva Ecija led to undue pressure on water resources during the dry season and a second crop of rice could not be planted (Table 4). If farmers switch to upland crops such as corn and mungbean during the dry season, it would be possible to cultivate 75% to 100% of the service area at 50% to 80% water-use efficiency.

In the Philippines, 44% (1.4 million hectares) of the total rice area (3.2 million hectares) is rainfed, where the rainfed lowland rice average yield is 2 t/ha (PhilRice 1993). About half a million hectares of the rainfed area are drought-prone. Installation of small water pumps in the rainfed areas in the Ilocos region enables farmers to diversify to non-rice crops during the dry season.

Rainfed lowland rice-based cropping systems such as rice–corn, rice–garlic, rice–mungbean, rice–sweet pepper, and rice–tomato were evaluated from 1991 to 1995 in Ilocos Norte as part of the Rainfed Lowland Rice Research Consortium (RLRRC), which is implemented by MMSU, PhilRice, and IRRI. Although the average area planted to cash crops was low (0.18 to 0.94 ha), farmers obtained a high net income of P 2 600–73 880 depending on the non-rice crops grown (Table 5). Rice yields varied from 2 to 5.8 t/ha depending on the rainfall distribution during the wet season. Among the cash crops, tomato yields ranged 34–46 t/ha and 5–15 t/ha for sweet pepper (Table 6). Yields of garlic ranged 1–2 t/ha; corn, 3.5–5.4 t/ha; and mungbean, 0.3–0.5 t/ha. High rates of fertilizers were usually applied to achieve high yields of non-rice crops (Table 7). The highest fertilizer rate was usually applied in sweet pepper, while no fertilizer was applied in mungbean.

Table 4. Crop yield (t/ha) in rice–corn–mungbean and rice–rice–mungbean cropping patterns for three crop years under partially irrigated environment, Guimba, Nueva Ecija (Adapted from Gines et al. 1989).

	Crop year		
Cropping pattern (a)	1984–85	1985–86	1986–87
1. Rice	3.97	4.70	5.02
2. Maize	2.59	4.45	4.48
3. Mungbean	0.91	1.1	1.07
1. Rice	4.03	4.26	4.9
2. Rice (b)	1.91	—	—
3. Mungbean (c)	—	—	—

(a) Rice yields are average of IR varieties such as IR36, IR42, IR54, IR56, IR58, and IR64; Corn, hybrid MC 305 and IPB varieties; Mungbean, Pagasa 1. (b) Establishment of a second crop of rice was suspended in years 1985–86 and 1986–87 due to low supply of irrigation water during the dry season. (c) Mungbean was not planted due to waterlogging.

Table 5. Average net income in Pesos ('000/ha) of the farmer-cooperators in Ilocos Norte, Philippines, 1991WS–1995DS (unpublished data of RLRRC).

	Year			
Crop sequence	1991–92	1992–93	1993–94	1994–95
Rice–corn	29.15	19.55	21.80	18.81
Rice–garlic	64.50	29.41	15.29	36.20
Rice–mungbean	11.63	7.93	3.58	2.61
Rice–sweet pepper	73.88	61.44	11.74	41.96
Rice–tomato	37.89	36.27	40.60	55.14

Declining soil fertility

Low soil fertility is also a major productivity constraint. Long-term effects of fertilizers were monitored to assess the nutrient sustainability for the different cropping sequences. Results indicated that since the non-rice crops took up such quantities of macronutrients from the soil, and since the micronutrients were correspondingly taken up, the need to replenish all the nutrients to maintain the soil fertility

Table 6. Dry season crop yields (t/ha). Ilocos Norte, Philippines, 1992–1995 (unpublished data of RLRRC).

Crop sequence	Year 1992	1993	1994	1995
Rice–corn	4.0	3.50	5.37	3.94
S.D.	2.9	1.6	3.75	2.95
Rice–garlic	2.02	1.36	1.45	1.10
S.D.	1.1	1.2	0.73	0.80
Rice–mungbean	0.46	0.67	0.36	0.30
S.D.	0.25	1.0	0.11	0.17
Rice–sweet pepper	14.78	9.00	4.93	5.12
S.D.	2.5	8.2	2.88	5.08
Rice–tomato	34.09	36.53	40.00	46.50
S.D.	27.0	27.00	13.1	17.57

Table 7. Average rate of NPK fertilizers (kg/ha) applied to rice and dry season crops by farmer-cooperators, Ilocos Norte, Philippines, 1991–1995 (unpublished data of RLRRC).

Crop sequence	Rice N-P-K	Dry season crop N-P-K
Rice–corn	159–22–18	140–43–43
Rice–garlic	135–42–25	114–45–28
Rice–mungbean	135–40–22	nil
Rice–sweet pepper	86–28–14	295–142–100
Rice–tomato	130–32–20	157–62–110
Mean	129–33–20	138–50–60[a]

[a] Mungbean and sweet pepper not included.

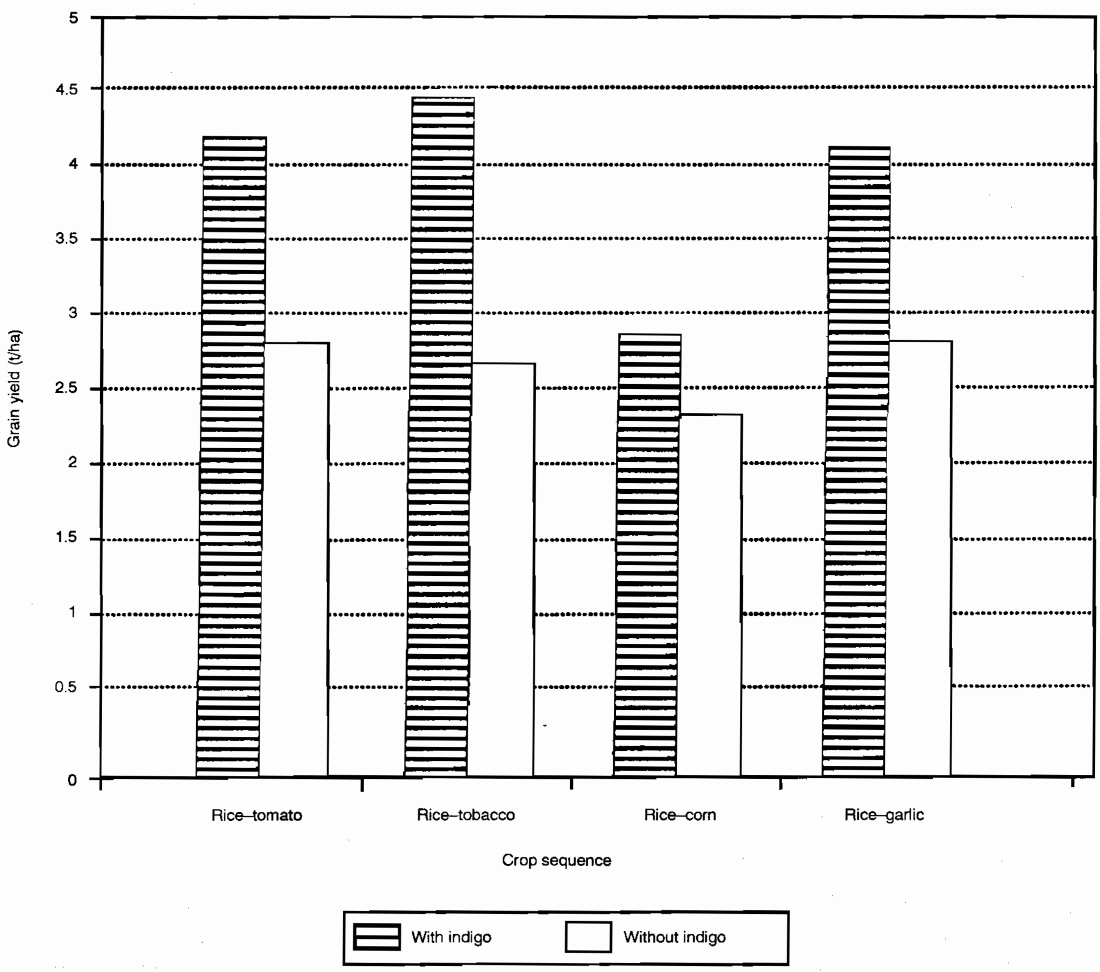


Figure 1. Grain yield of rice (BPI Ri 10) under different cropping sequences. 1994 WS.

of rainfed areas must be taken into consideration. Current evidences suggest that residual fertilizer in the soil not utilised by the rice crop is also taken up by the subsequent non-rice crops.

Because of declining soil fertility and the nitrate leaching to the groundwater caused by continuous use of inorganic fertilizers, indigo (*Indigofera tinctoria*), a promising rainfed green manure, was evaluated as an intercrop with dry season crops and used as fertilizer for the rice crop. Rice yields in the rice–tomato, rice–tobacco, and rice–garlic cropping patterns were significantly increased by indigo incorporation while rice–corn was not affected (Figure 1). The difference was 1.4 t/ha in rice–tomato cropping sequence, 2.8 t/ha in rice–tobacco, and 1.29 t/ha in rice–garlic.

Recommendations

Implications and recommendations for policy are focused on the provisions of support services to give farmers more incentives to grow the crops. Incentives include credit facilities, storage and processing facilities, technical assistance, strengthening of cooperatives, and the research and development (R&D) activities such as breeding of new varieties of the crops, design of farm tools for labor intensive non-rice crops like onions and garlic, and development of local and foreign markets for the diversified crops (Adriano 1989).

References

Adriano, L.S. 1989. Farming system approach and rural development: Philippine case. International seminar on agricultural change and development in Southeast Asia. 20–23 November 1989. 25–51.

Adriano, M.S. 1989. Implications for policy of the studies on profitability of irrigated non-rice production: A synthesis. Proc. National Workshop on Crop Diversification in Irrigated Agriculture in the Philippines. International Irrigation Management Institute, Digana Village, Via Kandy, Sri Lanka. 134–142.

Bureau of Agricultural Research (BAR), Department of Agriculture. 1989. NAREA, The National Agricultural Research and Extension Agenda. 1988–1992. BAR. Quezon City. Philippines.

Caluya, M.P. and Acosta, C.G. 1989. Comparative economic analysis of diversified crops under irrigated and rainfed conditions and their irrigated performance versus irrigated rice. Proc. National Workshop on Crop Diversification in Irrigated Agriculture in the Philippines. International Irrigation Management Institute, Digana Village, Via Kandy, Sri Lanka. 93–100.

FAO (Food and Agriculture Organisation). 1979. Yield response to water. FAO, Rome, Italy.

— 1986. Yield response to water. FAO Irrigation and Drainage Paper No. 33. FAO, Rome, Italy.

Galvez, J.A. 1990. Management arrangement for diversifying in inherently rice-crop-based irrigated systems in the Philippines. Proc. First Prog. Review and Coordination Workshop of Research Network on Irrigation of Crop Diversification in Rice-based Farming System. Philippines, 10–14 December 1990. 83–94.

Gines, H.C., Moya, T.B., Pandey, R.K. and Carangal, V.R. 1989. Crop diversification: Problems and prospects in partially irrigated rice-based farming systems. Proc. National Workshop on Crop Diversification in Irrigated Agriculture in the Philippines. International Irrigation Management Institute, Digana Village, via Kandy, Sri Lanka. 147–166.

Kamiya, M. 1989. Economic development in Southeast Asia with special reference to farming system on food and cash crops. International seminar on agricultural change and development in Southeast Asia. 20–23 November 1989. 3–14.

Marzan, E.G. 1989. Profitability analysis of rice and onion planted during the dry season under irrigated conditions. Proc. National Workshop on Crop Diversification in Irrigated Agriculture in the Philippines. International Irrigation Management Institute, Digana Village, Via Kandy, Sri Lanka. 71–74.

Miranda, S.M. and Maglinao, A.R. 1990. Irrigation management for rice-based farming systems in Indonesia, Bangladesh and the Philippines: A synthesis of findings under the IIMI-IRRI collaborative project. Proc. First Prog. Review and Coordination Workshop of Research Network on Irrigation of Crop Diversification in Rice-based Farming System. Philippines, 10–14 December 1990. 139–151.

Moya, T.B. and Miranda, S.M. 1989. Socio-technical issues in diversifying rice-based irrigation systems. Proc. National Workshop on Crop Diversification in Irrigated Agriculture in the Philippines. International Irrigation Management Institute, Digana Village, Via Kandy, Sri Lanka. 4–19.

PhilRice. 1993. Rice Production Technoguide. Philippine Rice Research Institute. xii-xiii.

Tung, Ly, Abit, S.E. and Alcober, D.L. 1989. Farming systems on food and cash crops in Eastern Visayas, Philippines. International seminar on agricultural change and development in Southeast Asia. 20–23 November 1989. 176–189.

Wickham, T.H. and Sen, C.N. 1978. Water management for lowland rice: Water requirements and yield response. In: Soils and Rice. International Rice Research Institute, Laguna, Philippines. 337–358.

Rice-based Cropping Systems in Australia: Constraints to Non-rice Crops

W.A. Muirhead[1] and E. Humphreys[1]

Abstract

In Australia, rice is generally grown in rotation with other crops, pastures and fallow. Waterlogging, caused by low soil permeability and flood irrigation, is the major constraint to the productivity of non-rice crops and pastures. Waterlogging can be reduced by more efficient irrigation. This can be achieved by improved irrigation layout, laser grading, raised beds and pressurised irrigation systems. Soil salinity is increasing as a constraint to the productivity of non-rice crops and pastures in the rice-growing areas, due to rising watertables. To lower watertables, deep percolation from rice and other enterprises must be controlled by increasing water-use efficiency.

Winter cereals established immediately after rice harvest increase water-use efficiency by using water stored in the profile and winter rainfall. Winter cereals can be direct seeded into burnt stubble soon after rice harvest, and this practice is financially attractive. Sowing as soon as possible after harvest increases the chance of success. However, traditional cultivation after rice seriously exacerbates waterlogging during a wet winter. Nitrogen fertilizer and irrigation can be used to increase yield provided that the plant density is adequate. Despite the advantages, few farmers sow winter cereals after rice.

Crops sown in the summer following a rice harvest can suffer from 'rice stubble disorder' due to phosphorus deficiency. This is caused by adsorption of fertilizer phosphate on the amorphous ferric hydrous oxides formed after the rice fields are drained. The crystalline ferric hydrous oxides present in the soil before the rice crop are reduced during flooding, and oxidation after draining results in amorphous rather than crystalline forms. The phosphorus adsorption capacity of the amorphous form is 100 times that of the crystalline form. Adequate phosphorus availability for summer crops sown after rice can be achieved by banding the phosphorus fertilizer rather than mixing it in the soil.

IN AUSTRALIA, rice is grown on about 120 000 ha with average yields of about 8.6 t/ha (average of 4 years to 1993–94) (Brennan et al. 1994). It is grown with flood irrigation in a semi-arid environment between 34°S and 36°S latitude. The rice-growing soils are transitional red-brown earths (Stace et al. 1968) or Xeralfs (Soil Survey Staff 1975) and grey, brown and red clays (Xererts) (Willett 1988). The latter soils can be either self-mulching or non-self-mulching. Groundwater levels are now within 2 m of the soil surface in 40% of the rice-growing areas, and this is predicted to double to 80% by 2015 (Anon. 1988). Van der Lely (1994) estimates that up to 25% of the irrigated areas will be affected by salt within 30 years. Furthermore, it is estimated that rice has contributed up to 50% of the accessions to the groundwater within the irrigation areas (Dwyer Leslie 1992).

Rotations are seen as a strategy for reducing the environmental pressures of salinity, waterlogging and chemical residues associated with rice production. This paper reviews the constraints to the productivity of non-rice crops sown in rotation with rice, and the benefits of the inter-rice rotation to the sustainability of irrigated agriculture in Southeast Australia.

[1]CSIRO Division of Water Resources, Griffith Laboratory, PMB No. 3, Griffith, NSW 2680, Australia

Winter Crops Established Immediately After Rice Harvest

Winter cereals sown after rice are considered to be opportunistic crops. Each year, on average, between 10% and 20% of the rice stubble is sown to a winter cereal. Irrigation and fertilizer inputs depend on seedling establishment and growth. A winter cereal sown after rice can utilise winter rainfall and so reduce accessions to the groundwater. This is considered to be beneficial to the environment.

The major constraint to productivity of cereals sown after rice is establishment of the cereal crop. The soil is often too wet or too dry. In a wet autumn, sowing can be delayed by up to four months (Muirhead 1967). Harvesting machinery can leave the field rutted, and difficult to sow without cultivation (Murray et al. 1994). In contrast, in a dry autumn, the soil may be too dry for germination and sowing is delayed until rain.

Rice stubble is generally cut about 10 cm above the ground, and then burnt before sowing. This practice reduces the volume of rice stubble which otherwise shades the winter cereal seedlings, reducing dry matter production by 50% (Muirhead 1967). Cultivation delays sowing and generally has little effect on yield (Muirhead 1967; Humphreys et al., these Proceedings), except when followed by rain. The cultivated soil has far greater capacity to trap rain with lower run-off compared to uncultivated soil, causing waterlogging and reduced yield through reduced establishment and/or growth.

Winter cereals sown immediately after rice harvest which achieve satisfactory plant populations require nitrogen fertilizer and irrigation to achieve high yields (Table 1). Muirhead and White (1978) concluded that anhydrous ammonia at 50 kg N/ha produced more grain than the same amount of nitrogen applied as urea, ammonium nitrate or ammonium sulphate. Nitrogen fertilizer applied at the tillering stage or earlier was equally effective in increasing crop yield.

The release of nitrogen from the soil for the cereal crop depends on the history of the field before the cereal crop. The available nitrogen can vary from 35 kg N/ha after several rice crops to 75 kg N/ha where a legume-dominated pasture existed for several years before the rice crop (Stapper 1987). To achieve a target yield of 5 t/ha, Stapper (1987) estimates that at least 150 plants/m^2 are required and 450 shoots/m^2 at stem elongation. The quantity of nitrogen fertilizer required will vary 50–100 kg N/ha, depending on the previous history.

Few studies have examined the effect of a winter cereal sown after rice on the level of the watertable. Muirhead (1978) showed that barley (not irrigated), significantly increased the depth to the watertable when compared with an uncropped control; however, the effect was small. The watertable fell from 30 cm below the surface to 150 cm in the unsown treatment. The barley crop lowered the watertable to 170 cm. Muirhead (1978) estimated that, of the 45 cm lost by evapotranspiration on the barley treatment, 18 cm was derived from soil water depletion, 17 cm from rainfall and 10 cm from capillary flow.

Research has shown that wheat can be successfully grown in rice stubble immediately after rice harvest. The practice appears to be financially attractive. However, few farmers are including this in their rotation. Perhaps active farmer participation in this research would have either led to better adoption of this research or researchers would have had a better understanding of the factors which have prevented its adoption.

Table 1. Response of cereal crops to nitrogen fertilizer when they are sown in rice stubble.

Crop	Yield (no nitrogen) (t/ha)	Yield (nitrogen) (t/ha)	Added N rate (kg/ha)	Reference
Barley	1.1	1.5	50	Muirhead (1967)
Wheat	1.1	3.0	100	Muirhead et al. (1976a)
Wheat	2.3	5.2	100	Muirhead and White (1978)
Wheat 1974	1.8	5.0	120	Dear et al. (1979)
Wheat 1975	1.9	4.7	120	
Wheat 1978	0.8	2.1	210	Bacon and Cooper (1985)
1979	1.7	3.0	140	
1981	1.1	2.0	100	
1981	0.7	1.6	100	
Wheat	1.9	5.1	100	Bacon et al. (1989)

Waterlogging

Rice in Australia is restricted to soils where deep percolation is less than about 3 mm/day (van der Lely 1994). Consequently, these soils have poor internal drainage. Virtually all irrigation of non-rice crops is by flood which leaves the soil waterlogged for varying periods after application. Grieve et al. (1986) estimated that the yield loss from waterlogging in irrigation areas in the Murray Valley ranged from 12% in annual pasture, 20% in winter cereals and 25% for perennial pasture.

Reducing the effects of waterlogging can be achieved by a range of strategies. In the traditional layout, rice is grown in bays separated by banks (bunds) constructed on contours with a vertical separation of 5 to 10 cm. This layout is not well suited to the irrigation of crops and pastures grown in rotation with rice. Water moves from one bay to the next down the slope, thus drainage of surface water is slow and exacerbates waterlogging. Swinton and Beale (1990) recommend using a side ditch so that each bay can be irrigated and drained separately to allow faster irrigation and drainage. This modification of the traditional layout will reduce waterlogging to give more productive pastures and cereal crops.

Removing the contour banks after rice harvest, and laser landforming to give either rectangular contour bays or a border check layout for the inter-rice rotation, is often practised. Marshall and Jones (1993) predicted increases in the productivity of non-rice enterprises ranging from 33% for annual pasture to 75% with sod-sown wheat. They concluded that landforming was economically advantageous on rice farms.

Bed farming, which is usually practised on laser-graded fields, effectively provides shallow surface drains in the form of irrigation furrows between the beds. These furrows quickly remove excess water from the 15 cm of soil in the bed. Virtually all summer crops and vegetables grown in rotation with rice are produced on beds or hills. Permanent beds are increasing in popularity because they reduce tractor operations and improve the timeliness of operations (Maynard et al. 1991). They also restrict wheelings to the furrows and reduce compaction (and so waterlogging) in the bed.

Nevertheless, waterlogging beneath beds can still reduce crop yield. Under high watertable conditions, Muirhead et al. (1995) demonstrated that mole drains increased the gas-filled porosity in the bed and this was associated with a 38% increase in onion yield. The most effective system to minimise the effects of waterlogging would be permanent beds with either sprinkler or drip irrigation and mole drains beneath the beds to remove excess rainfall. Rice is likely to be desirable in rotation as a phytosanitory crop, especially where vegetables are grown.

Salinity

Surface soil salinity is slowly increasing in the rice-growing areas in Australia. In the Murrumbidgee Irrigation Areas (MIA), van der Lely (1993) estimated that 17% of the area now has salt levels which are reducing crop and pasture production. Salt, either occurring in the profile before irrigation or added with the irrigation water, is being redistributed in the landscape as groundwaters rise. Deep percolation under the rice crop is estimated to contribute about 50% of the water added to the groundwater within the irrigation areas each year (Dwyer Leslie 1992). A variety of best management practices should be used to minimise these accessions. These strategies include puddling (Humphreys et al., these Proceedings) and exclusion of elevated land and fields with high water use (van der Lely 1994). In other enterprises, irrigation efficiency must also be improved to minimise the amount of deep percolation occurring.

Rice Stubble Disorder

With the adoption of shorter rice rotations, some farmers replaced pasture with summer and winter crops. For summer crops, the banks between rice bays are flattened, the field is landformed to a uniform gradient, and the crop is sown on hills or beds and flood irrigated via furrows. However, crops such as maize, sorghum and sunflowers often made poor growth when sown in the spring after rice harvest (Sheldon 1979). Examination of these crops showed that the poor growth was restricted to plants growing where water was ponded during the rice crop. The young, stunted plants were deficient in phosphorus, often despite the application of seemingly adequate levels of phosphorus fertilizer (Sheldon 1979). These symptoms were called 'rice stubble disorder' (Muirhead et al. 1973). Considerably better growth occurred on the location of the former banks.

Muirhead (1975) postulated that the organised (crystalline) ferric oxides in the soil act as an electron acceptor in the respiration of micro-organisms during the ponded phase of rice culture. This releases ferrous iron and adsorbed phosphates. On draining the rice crop, the ferrous iron is oxidised and precipitates as an amorphous (non-crystalline) ferric oxide in the soil. This material has a large surface area and can adsorb up to 100 times as much soluble phosphate as the crystalline form of ferric oxide. Those commercial crops with rice stubble disorder had had the phosphorus fertilizer incorporated into the soil and this would expose the fertilizer to adsorption on the amorphous iron oxides.

Field studies have shown that mixing phosphorus fertilizer in the cultivated soil after a rice crop reduces P uptake and yield of summer crops. Muirhead et al. (1976b) reported that 30 kg P/ha mixed in the soil produced a similar maize yield to the unfertilised control. However, when the same amount of fertilizer was banded either with the seed or 10 cm below it, the yield increased by 30%. About one month after emergence, the plants growing on the banded treatment were up to seven times as large as those growing on the mixed treatment. Tasselling was 7–10 days earlier on the banded than on either the mixed or the control treatments. Muirhead et al. (1976b) reported similar results in sunflowers, except that the time to anthesis was not influenced by the treatments.

Willett (1982) examined the effect of phosphorus added before and after flooding on phosphorus uptake by wheat after 46 days. He showed that phosphorus added before flooding was immobilised to a greater degree than phosphorus added after flooding. Soils differed in their response and this appeared to depend on the amount of reducible iron present. In contrast with crops sown in the following summer after rice, the yield of wheat sown soon after rice harvest does not appear to be affected by rice stubble disorder (Dear et al. 1979; Muirhead et al. 1976a). The lower phosphorus uptake rate required for winter crops and their lower yield potential may contribute to the difference in response.

A new generation of farmers and advisors has appeared in Australia since this research was carried out and who are unaware of it. Many have experienced yield loss through rice stubble disorder in a range of summer cereal, pulse and vegetable crops. The challenge now is to ensure that farmers in the future will not suffer unnecessary crop loss through the immobilisation of fertilizer phosphorus caused by soil changes occurring during a recent rice crop.

Acknowledgments

The senior author is indebted to The University of Queensland and ACIAR who sponsored this presentation at this workshop.

References

Anon. 1988. Draft salinity and drainage strategy. Discussion Paper No. 1. Murray–Darling Basin Ministerial Council, Canberra, Australia 12 p.

Bacon, P.E. and Cooper, J.L. 1985. Effect of rice stubble and nitrogen fertiliser management on yield of wheat sown after rice. Field Crops Research, 10, 241–50.

Bacon, P.E., Hoult, E.H., McGarity, J.W. and Alter, D. 1989. Crop growth and nitrogen transformations in wheat (*Triticum aestivum* L.) planted after wetland rice (*Oryza sativa* L.). Biology and Fertility of Soils, 7, 263–68.

Brennan, J.P., Lewin, L.G., Marshall, G.R. and Reinke, R.F. 1994. An economic assessment of rice breeding in New South Wales. Australian Journal of Experimental Agriculture, 34, 889–96.

Dear, B.S., McDonald, D.J. and Falconer, G. 1979. Nitrogen and phosphorus requirements of wheat sown by minimum tillage into rice stubble and the effect of rice stubble treatment. Australian Journal of Experimental Agriculture and Animal Husbandry, 19, 488–94.

Dwyer Leslie 1992. Rice 2000 Project: Environmental Policy Paper. Dwyer Leslie Pty Ltd Canberra, ACT. 68 p.

Grieve, A.M., Dunford, E., Marston, D., Martin, R.E. and Slavich, P. 1986. Effects of waterlogging and soil salinity on irrigated agriculture in the Murray Valley, a review. Australian Journal of Experimental Agriculture 26, 761–77.

Marshall, G. and Jones, R. 1993. Economics of laser landforming for MIA rice farmers. IREC Farmers' Newsletter (Large Area), No. 141, May 1993, 17–19.

Maynard, M., Beattie, B., Hutchins, N. and Muir, J. 1991. Permanent beds — their potential role in soil management for the future. IREC Farmers' Newsletter (Large Area), No. 137, April 1991, 14–18.

Muirhead, W.A. 1967. The growth of annuals sown in rice stubble. MAgSc thesis, University of Adelaide, Adelaide, S.A. 185 p.

— 1975. Factors causing the poor growth of summer crops after rice. Department of Agriculture NSW, Regional Research Conference, Wagga, 3 p.

— 1978. Effect of crops sown after rice on salt distribution above a high water table. In: Storrier, R.R. and Kelly, I.D. ed., The Hydrolgeology of the Riverine Plain I South East Australia, Proceedings of a Symposium, Griffith, NSW 28–29 July, 1977. Australian Society of Soil Science Inc., Riverina Branch, 155–67.

Muirhead, W.A., Humphreys, E., Jayawardane, N.S. and Moll, J. 1995. Shallow subsurface drainage in an irrigated vertisol with a perched water table. Agricultural Water Management (in press).

Muirhead, W.A., Melhuish, F.M. and Clough, R. 1973. Rice stubble disorder in summer crops. IREC, Farmers' Newsletter (Large Area) No. 87 (July 1973), 14–17.

Muirhead, W.A., Melhuish, F.M. and Higgins, M.L. (1976a). Response of wheat grown in rice stubble to fertiliser. Report to the IREC Wheat Investigation Subcommittee, 12 August 1976. 4 p.

Muirhead, W.A., Melhuish, F.M. and White, R.J.G. (1976b). The influence of placement techniques on crop growth and recovery of applied fertiliser. Riverina Branch Soils Conference, Wagga, May 1976, Australian Society of Soil Science Incorporated.

Muirhead, W.A. and White, R.J.G. 1978. Nitrogen requirements of wheat sown in rice stubble. IREC Farmers' Newsletter (Large Area) No. 106, April 1978, 9–12.

Murray, E.A., Humphreys, E., Townsend, J.T. and Wells, T. 1994. Lockup and drainage for rice-grower survey results. IREC Farmers' Newsletter (Large Area) No. 143, 22–24.

Sheldon, B. 1979. Understanding rice stubble disorder. Rural Research No. 105 (December 1979), CSIRO, Australia, 21–24.

Soil Survey Staff 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA Handbook 436, Washington, DC, USA.

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. 1968. Handbook of Australian Soils. Rellim Technical Publications, Glenside, South Australia.

Stapper, M. 1987. SIRAGCROP — Irrigated wheat management — nitrogen requirements. IREC Farmers' Newsletter (Large Area) No. 130, April 1987, 23–7.

Swinton, R. and Beale, P. 1990. Contour layouts for rice and pasture. IREC Farmers' Newsletter (Large Area), No. 136, Nov. 1990, 14–15.

van der Lely, A. 1993. Present and future salinity conditions in the MIA. Water Resources, Murrumbidgee Region, Leeton, NSW. 20 p.

— 1994. Management of environmental impacts on rice growing in south east Australia. Proceedings, Temperate Rice conference Yanco 1994. NSW Agriculture, Griffith Australia, 297–304.

Willett, I.R. 1982. Phosphorus availability in soils subjected to short periods of flooding and drying. Australian Journal of Soil Research, 20, 131–38.

— 1988. Soil used for rice growing in Australia. Fifth International Soil Management Workshop, Taiwan.

Problems of and Prospects for Soil Management for Lowland Rice–pulse Rotations

B. Chandrasekharan [1], H.C. Bhattacharyya [2], J.K. Gogoi [2] and S. Sankaran [1]

Abstract

The developing world is facing the ramifications of such problems as population pressure, shrinkage of non-renewable resources, energy crises and growing food demand. In the vast majority of lowland rice lands, the objectives of food production, which are ecologically sustainable, economically competitive, climatologically efficient, environmentally sound and socially equitable, can be met through efficient land use in rice–pulse systems. Soil physical conditions following land submergence and erratic rainfall patterns cause problems for crop establishment and root and shoot growth, and result in low yields of pulses growing on puddled rice soils in rainfed lowlands. Soil physical requirements are in sharp contrast for rice and pulses and represent a challenge for researchers to find appropriate soil and other management practices for a sustainable cropping system. This paper reviews various climatic and soil-related constraints, along with soil management practices. The most important aspects dealt with are tillage, drainage and residue management which can provide a congenial growing condition for the pulse crops after wetland rice production.

Introduction

THE world population may grow to 7.2 billion by 2010 from the 5.3 billion of 1990 (FAO 1993) and to over 10 billion by 2050 (UN 1992). Despite the progress made in food production, there could still be 200 million people undernourished in Southern Asia alone by 2010 (FAO 1993). There will be little land for expansion beyond 2010 to increase food grain production to meet the growing demand. Since there is little scope for increasing rice area, productivity needs to be improved by more efficient use of resource bases such as water, restoring soil health and adopting technological innovations.

Protein supply largely depends on legume production. An increase in legume production is possible through additional area coverage on rainfed rice lands. This may not only increase pulse production but may also offer a unique system for sustaining rice productivity by exploiting the benefits of biological nitrogen fixation and green manuring. The rice–pulse system, however, faces a number of climatic and soil related limitations. Pulses after wetland rice production are constrained by poor stand and growth due to heavy soil texture and excessive soil strength after drying, and restricted root growth due to the presence of plough pans. Drought as well as excess moisture restrict legume production due to low and erratic rainfall during the dry season. Management practices therefore need to be reviewed for enhancing the productivity of these systems.

Lowland Rice–pulse Systems

Food legumes have long been very important components of multiple cropping systems due to their tolerance to drought, short life-cycle, ability to fix atmospheric nitrogen, ability to grow well under poor soil and management systems, multifarious uses like food, feed, firewood and vegetables, good price and market, storability, high nutritive value and

[1] Soil and Water Management Research Institute, Tamilnadu Agricultural University, Tanjore, Coimbatore — 641 003, Tamilnadu, India

[2] Regional Agricultural Research Station, Assam Agricultural University, Titabar, Jorhat — 785 630, Assam, India

importance in the diet of farm households. In areas where monthly rainfall is high (>200 mm) for 4 to 5 months, legumes can be grown following lowland rice (Zandstra 1976). In rainfed lowlands, which comprise about 40% of the total rice area in South and Southeast Asia, production of the second rice crop is restricted to areas of longer growing rainy season or with supplemental irrigation. Pulses can be grown either in the post-monsoonal period following rice (Zandstra 1982) or in the pre-monsoonal period preceding rice. Legume production between wheat and rice is also becoming popular in India (Singh 1988).

Of the 18 food legume species grown in developing countries, soybean, mungbean, groundnut and cowpea are mostly grown on rice lands (Buresh and De Datta 1991). Soybean, mungbean, groundnut, cowpea and pigeon pea prevail in tropical areas, whereas chickpea, lentil and peas predominate in subtropical areas. These crops are normally part of indispensable traditional food and provide a high quality protein to the diet of rice farmers (Pandey 1985; McWilliam and Dhillon 1986). Short duration pulses such as mungbean and cowpea are beneficial for human consumption as well as providing crop residues for green manuring (Yadvinder-Singh et al. 1994).

Land Resources

Land is a non-renewable natural resource. The continuous increase in the number of farm families and competition from non-agricultural land uses constantly decrease the per capita land availability in the developing countries. The objective of arriving at nutritional, economic and ecological security therefore has to be met by increased productivity per unit area by efficient and judicious use of this valuable resource. There is growing concern now to bring about a shift in the land use pattern which will be sustainable, economically competitive, climatically efficient and environmentally sound and equitable.

Back-to-back cereal monoculture rotation, soil erosion, overexploitation of ground water in some areas, elimination of a fallowing system due to shrinkage of arable land, unsuitable use of fragile land and deforestation have resulted in increased land degradation. Growing pulses after lowland rice not only provides high value protein production, but also aids restoration of soil fertility and helps to prevent land degradation. However, there are numerous climatological and soil-related constraints associated with rice lands where rice is either preceded or followed by pulses.

Problems in the System

The major constraints in the lowland rice–pulse systems are water availability and poor soil physical conditions. Rice is usually grown under lowland conditions where soils are puddled; pulses are upland crops and soil conditions induced by soil puddling are often detrimental to successful pulse production. Numerous climatic and soil-related problems are therefore encountered in rice–pulse rotations.

Climatic constraints

Rainfall is the largest constraint to successful rainfed farming. Rice-based cropping systems are particularly dependent on reliability and amount of rainfall. In India, for example, rainfall has shown an exceptional variability during the past decade (ICRISAT 1988). In low rainfall areas, the coefficient of variation in rainfall occurrence varied between 25% and 30% and in some cases may exceed 50% (Katyal et al. 1994, Table 1). During the past 120 years, there were 425 occurrences of drought in 29 out of 35 agrometeorological divisions of India (Katyal et al. 1994). On 70 occasions, the intensity of drought was classified as severe. Arable land in India has an average probability of 39% for perennial drought (Ramachandran, cf. Katyal et al. 1994). This reduces the yield of the main crop, rice, and makes growing of a subsequent crop impossible. Cereals and other high value crops are grown in double cropping systems that have sufficient rainfall. Pulses after rice are restricted to areas with low and erratic rainfall, soil and socioeconomic constraints.

Table 1. Effect of mean annual rainfall on coefficient of variation (CV) and probability of occurrence of deficit rainfall.

Station	Mean annual rainfall (mm)	Annual rainfall CV (%)	Probability (%) of occurrence of deficit rainfall (<75% of normal)
Jodhpur	369	55	51
Anantpur	568	30	38
Hyderabad	769	29	31
Varanasi	1026	25	25
Ranchi	1434	21	20
Shilong	2415	15	7

Source: Katyal et al. 1988.

Lowland rice is grown during the main monsoon period when water supply is adequate. Upland crops including pulses are grown during the period of pre-monsoon and post-monsoon including the dry season. While pulses grown during the pre-monsoon period are prone to drought stresses at early growth stages due to initially dry soil conditions and delayed onset of monsoon, those grown during the post-monsoon season are affected by excess water in the early stage and by drought at later stages. Soil and water management in the rice–pulses system therefore requires special considerations compared to normal upland cropping if food production under rainfed conditions is to be increased.

Soil related constraints

Soil–climate interactions are of particular importance to the productivity of lowland rice soils. In areas where rainfall and waterholding capacity of the soils allow a long cropping season, an early rainy season pulse crop, a mid-late or post-rainy season crop can be grown (Willey et al. 1981). When the crop is grown at the onset of the rains, seeds are placed in the dry soils resulting in low seed germination and poor establishment. In the mid-late rainy season, high soil water content makes land preparation and sowing difficult and excessive soil water affects establishment and crop growth. During the post-rainy season sowing of pulses, soil conditions can change rapidly from wet to dry, depending on the land, soil type and rainfall conditions. Both excess and deficit soil water conditions are frequently experienced in the post-rainy season pulse crop. Due to lack of rainfall during the dry season they depend on residual moisture from the wet season crop. Fertilizers are often not applied, crops depend on the native fertility and may face nutritional constraints (Patanothai and Ong 1987). Pulses grown after lowland rice can be affected by excess water during vegetative phases and subsequent moisture stress during the reproductive phases (Buresh and De Datta 1991, Fig. 1). Post-rice pulses often depend on residual soil moisture and the ability of root systems to tap subsoil water reserves or to follow a receding watertable (Timsina 1989). The pre-rice pulse crop, on the other hand, encounters water deficit during the reproductive phase (Timsina 1989).

Puddling is beneficial for rice production. It makes transplanting of seedlings easy, assists root establishment, controls weeds and helps to maintain submerged conditions. Following drainage and rice harvest, the soil remains wet and chemically reduced for a few days (Melhuish et al. 1976) but becomes hard with concomitant high bulk density during and after drying (Sanchez 1976). Such conditions are unfavourable for timely and adequate land preparation and often result in poor establishment of the pulse crop. High mechanical strength of a drying puddled soil has been reported to slow root and shoot extension rate in mungbean by 30% when mungbean was sown 20 days after rice harvest (i.e. turnaround period, TAP, of 20 days). Crop establishment was totally prevented when the TAP was 30 days (Woodhead et al. 1986).

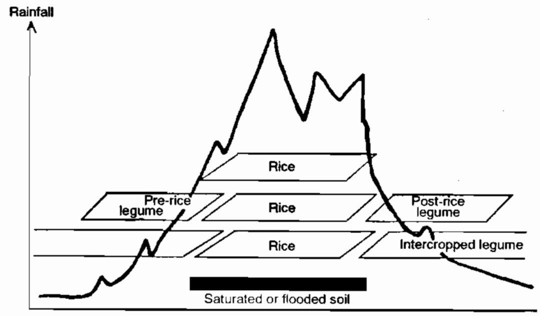


Figure 1. Rainfed lowland rice cropping patterns in tropical Asia. Source: Buresh and De Datta, 1991.

Soil Management

Rice is generally grown on heavy soils with low permeability and the crop has a shallow root system. Pulses, like other upland crops, require deep and well-drained soils. Soil management for rice lands is therefore in direct contrast to that of rice-pulse systems.

Puddling is a soil management practice for rice to reduce percolation and preserve submerged conditions (Sanchez 1973; De Datta and Kerim 1974; Ghildyal 1978; Sharma and De Datta 1985). Puddling eases transplanting of seedlings, favours fast establishment of roots and controls weed growth (De Datta 1981; Sharma and De Datta 1985). It destroys soil structure and lowers permeability by reducing macroporosity and increasing microporosity (Ghildyal 1978) and helps to maintain reduced conditions. Puddling reduces percolation rate, soil strength and soil temperature in lowland rice (Woodhead et al. 1986).

Pulses need tillage for fine tilth to ensure adequate seed-soil contact and aeration. However, after puddling for wetland rice, the soil becomes hard with high bulk density upon drying (Sanchez 1976). This hinders land preparation and reduces crop establishment of pulses. Although delayed sowing of the legume, i.e. waiting for the optimum moisture conditions, can be practised to obtain a friable seed bed after tillage, the increased TAP may make the crop suffer from drought stress at later growth stages.

Farmers tend to sow legumes using reducing tillage to take advantage of the residual soil moisture for seed germination. This saves time and capital and helps to maintain higher soil water content longer, compared to tillage (Ruhendi and Litsinger 1982). Appropriate soil and crop management techniques are needed to obtain desired soil physical conditions to allow adequate crop establishment, growth and development of the pulse crop after wetland rice.

Tillage

Conventional tillage for upland crops following lowland rice usually results in lower yields than zero, minimal or strip tillage techniques. Zandstra (1982) attributed this to greater water loss from cultivated soils compared to compact soil under zero or minimum tillage. Therefore farmers normally established legumes using reduced tillage techniques (Saxena 1976). Ruhendi and Litsinger (1982) listed the following reduced tillage practices as those commonly practised for legumes after wetland rice:

- broadcasting seed into recently harvested rice fields with erect stubble;
- cutting rice straw and using it as a mulch after broadcasting seeds;
- spreading straw over planted fields and burning (for weed control and as a source for nutrients);
- placing seeds in a wedge made with a hand-tool at the base of the stubble after harvest.

Despite larger soil water loss using tillage, its loosening effect and resulting lower soil strength can enhance root growth. Tillage can be carried out with tractor-driven rototillers, but farmers on small holdings break soil clods manually (Prihar et al. 1985). Deep tillage can be used to reduce high bulk density of subsoil hard pans that restrict root growth (Prihar et al. 1985). Culture of wetland rice usually leads to the formation of a structure of a puddled layer and a compacted layer below. Clay translocation during and after puddling can further worsen such conditions. Prasadini et al. (1993) improved peanut yields after rice using a tractor-driven plough to break up subsoil hard pans. However, tillage after rice harvest may be detrimental if carried out under too high soil-water conditions where the soil's bearing capacity is low. This applies equally to animals and tractors (Brammer 1977). Unger et al. (1984) conducted tillage experiments on a Pullman clay loam soil and found that bulk density in the top 7.5 cm depth was not affected by mouldboard ploughing, compared with burn-list, disc or rotary tillage. However, mouldboard ploughing reduced subsoil bulk densities to 1.5 Mg/m^3 compared to 1.7 Mg/m^3 in the other tillage methods. Bhusan et al. (1973) on the other hand, compared disc ploughing with rotary tillers and reported a reduction in bulk density to 1.06 Mg/m^3 using disc ploughing but no effect on bulk density using rotary tillers.

Tillage systems influence soil structure and can therefore have an effect on water stable aggregation through alteration in the spatial distribution of organic matter and crop residues within the soil matrix (Gerard et al. 1988). Unger et al. (1973) reported that water stable aggregation of clay loam soil at 12–15 cm depth tended to be higher if crop residue was incorporated using rotary or disc tillage compared to listing, mouldboard ploughing or burning of crop residue. The mean weight diameter (MWD) of topsoil aggregates (0–30 cm depth) on a clay loam soil after wheat was highest (23 mm) for mouldboard tillage, intermediate (15 and 14 mm) for disc and rotary tillage and the lowest (9 and 7 mm) for sweep and no tillage treatments (Unger 1984). In an experiment in Southern India, MWD of seed zone aggregates was affected by tillage practices for peanut in a rice–peanut system (Prasadini et al. 1993). The soil surface was cloddiest with a MWD of 45 mm using the country plough while the rototiller created a fine, uniform seed bed with a MWD of 16 mm.

Disc and mouldboard ploughing created relatively large aggregates and voids between them. Due to the large exposed surface area of the clods, evaporation was increased compared to tillage techniques that created a finer seed bed (Bhusan et al. 1973). Germination of peanut was increased using a rototiller in a rice–peanut system because resulting aggregate size distribution created good seed–soil contact and high soil moisture retention compared to country plough and disc (Prasadini et al. 1993). Soil penetration resistance at pegging stage was also decreased in the rototiller-tilled soil.

In India, non-inversion tillage such as disc ploughing is widely practised to break soil crusts and to incorporate crop residue into the topsoil. Practising minimum tillage through a combination of one discing and one harrowing up to 15 cm depth and mulching, Bhatnagar et al. (1983) reported improved water conservation and increased grain yield of wheat and peanut in Punjab. In studies using zero tillage at IRRI, a close relationship between percentage of soybean establishment and soil water content (0–5 cm layer) at planting was observed (Syarifuddin 1979). Maximum stand of soybean was recorded at soil moisture content of 50% to 56% in the 0–5 cm layer at planting under zero tillage after puddled rice (Fig. 2).

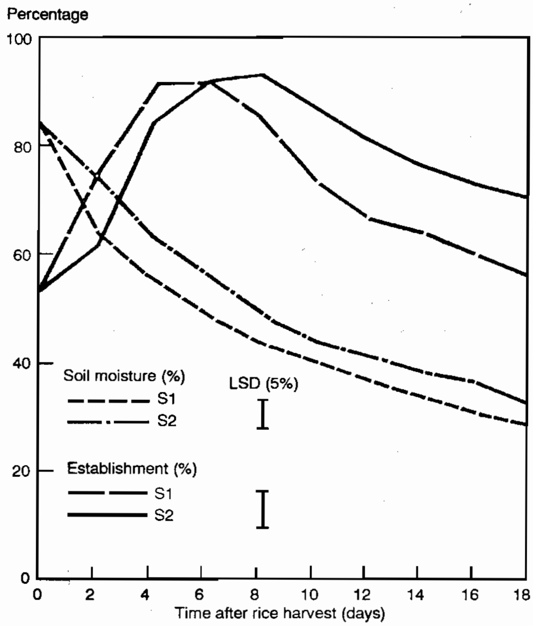


Figure 2. Relationship of soil moisture content of the 0–5 cm layer at planting and percentage of established soybean.
S1 = Straw removed at rice harvest,
S2 = Straw removed at soybean planting, IRRI, 1978 dry season.
Source: Syarifuddin, 1979.

Drainage

Saturated soil after rice harvest is unsuitable for tillage and depresses crop establishment, particularly on heavy soils. Following surface drainage of rice fields, soil water loss through evaporation is high during the first two days and approaches potential evaporation (Syarifuddin 1979). Water loss was 41 mm after 5 days drainage and 48 mm after 10 days drainage. Standing rice stubble in the field reduced water loss in the 0–15 cm layer.

A suitable method to control excess water is a broad bed and furrow system with a distance between furrows of 150 cm. Narrower spacings of 75 cm amplitude were found to be unstable, particularly on alfisols (ICRISAT 1977). On Vertisol this broad bed system has the additional advantage of reducing erosion and runoff (Table 2).

Crop residue

Crop residue is an important source of organic matter, which can improve soil physical conditions when incorporated but may have little or no effect on bulk density (Bhatnagar et al. 1983). Soil structure was maintained, infiltration rates increased and root growth promoted through the use of surface residues and controlled traffic (Sojka et al. 1984). Restoring good tilth after a lowland rice crop is more difficult in soils with low organic carbon compared to humic soils with similar texture and clay mineralogy (Moorman and Van Breemen 1978). Fine-textured soils tend to break into large, hard clods that make a poor seedbed for upland crops after wetland rice. Organic matter addition through crop residues can improve the tilth of such soils.

Mulching reduces evaporation from the soil surface, controls weeds and decreases soil temperatures. Soybean and mungbean can produce high yields with zero tillage and mulching after wetland rice (Lantican 1977). The effect of mulching on soybean in zero tilled plots after rice was greater than in rototilled plots as rototillage already reduced water loss from lower soil layers (Syarifuddin and Zandstra 1978).

Table 2. Effect of land management[a] on runoff, erosion and yields of sequential cropping of maize and chickpea on deep Vertisols, 1977.

Land treatment	Runoff (mm)	Erosion (kg/ha)	Yield kg/ha	
			Maize	Chickpea
Flat planting	141	240	2740	490
Narrow ridges	77	110	3240	450
Broad beds	110	170	3170	740

[a] Furrows in the ridges and broad bed treatments were maintained at a 0.6% grade; the drill rows under flat planting had the same slope (ICRISAT 1977).

Summary and Conclusion

Lowland rice culture is a sustainable system that has supported high population density in South and Southeast Asia. It has become imperative now to meet the growing need for food and protein from the rice lands without their degradation. A suitable soil management system for lowland rice–pulse systems will have to allow ease in transplanting, good anchorage to roots and reduced water and nutrient losses through percolation for wetland rice and to allow ease in sowing, better seed–soil contact, lesser resistance to root growth, retention of high soil moisture and better aeration at the same time for pulses after rice. Efficient tillage practices, drainage systems for heavy soils, residue and crop management practices for the rotation will not only increase food production, but also maintain sustainability of the ecosystem. Much remains to be done in respect of soil management for lowland rice–pulse systems. The future research strategy may include some of the following aspects:

- detailed study of the changes in soil physico-chemical properties with varied tillage practices, drainage systems and residue management systems for both crops;
- long-term changes in soil chemical properties due to various soil physical management practices and their effects on growth and development of both crops;
- crop management practices including methods of establishment, integrated nutrient management and soil physical management practices in the whole system and their effects on soil physical properties and growth, weed, pest and disease infestation, root growth, biological N_2 fixation in pulses and yield of both crops.

References

Bhatnagar, V.K., Chaudhary, T.N. and Sharma, B.R. 1983. Effect of tillage and residue management on properties of two coarse textured soils and on yield of irrigated wheat and groundnut. Soil Till. Res. 3, 27–37.

Bhusan, L.S., Varade, S.B. and Gupta, C.P. 1973. Influence of tillage properties on clod size, porosity and water retension. Indian J. Agric. Engineering. 43, 466–471.

Brammer, H. 1977. Incorporation of physical determinants in cropping pattern design. In: Cropping Systems Research and Development for the Asian Rice Farmers, IRRI, Los Baños, Philippines. 83–95.

Buresh, R.J. and De Datta, S.K. 1991. Nitrogen dynamics and management in rice-legume cropping systems. Advances in Agronomy. 45, 1–59.

De Datta, S.K. and Kerim, M.S.A.A.A. 1974. Water and nitrogen economy of rainfed rice as affected by soil puddling. Soil Sci. Soc. Am. Proc. 38, 515–518.

De Datta, S.K. 1981. Principles and Properties of Rice Production. John Wiley & Sons. New York.

FAO (Food and Agriculture Organization) 1993. Agriculture: towards 2010. Conference, 6–25 November, 1993. Food and Agriculture Organization of the United Nations, Rome, Italy. 320 p.

Gerard, C.J., Unger, P., Bordovsy, D., Gorick, T., Hons, F. and Matocha. 1988. Conservation tillage effects on soil physical properties, 16–28. In: Hons, F.M. ed., Conservation Tillage in Texas. Res. Monogr. 15. Texas Agric. Exp. Stat. College Stat. Texas.

Ghildyal, B.P. 1978. Effect of compaction and puddling on soil physical properties and rice growth. 317–336. In: IRRI, Soils and Rice, Los Baños Philippines.

ICRISAT (International Crop Research Institute for the Semi Arid Tropics) 1977. Annual Report, ICRISAT, Hyderabad, India.

— 1988. Characterising Resources. 281–293. In: Annual Report 1987, Resource Management Program. Patancheru, AP., India.

Katyal, J.C., Deb, S.K., Korwar, G.R. and Osman, M. 1994. Technology for irrigating stresses: Alternative land uses. 291–305. In: Virmani S.M., Katyal, J.C., Eswaran, H. and Abrol, J.P. ed., Stressed Ecosystems and Sustainable Agriculture. 1994. Oxford and IBH Publishing Co. Pty. Ltd. New Delhi.

Lantican, R.M. 1977. Fields crops breeding for multiple cropping patterns. 349–357. In: Cropping systems research and development for the Asian rice farmers. IRRI, Los Baños, Philippines.

McWilliam, J.R. and Dhillon, J.L. 1986. Food legume crop improvement: progress and constraints. 22–33. In: Wallis, E.S. and Byth, D.E. ed., Food Legume Improvement for Asian Farming Systems. ACIAR, Canberra.

Melhuish, F.M., Muirhead, W.A. and Higgins, H.M.L. 1976. Current views on effect of cropping history on nutrient availability in irrigated soils. Paper presented at Australian Soil Science Conference, Wagga, May, 1976.

Moorman, F.R. and Van Breeman. 1978. Rice: Soil, Water, Land. IRRI, Los Baños, Philippines.

Pandey, R.K. 1985. Food legumes in rice based farming systems. Lecture at the Orientation cum Training Program on improving the income and employment potential of rice farming systems, 21–30 January, 1985, IRRI, Los Baños, Philippines. 8 p.

Patanothai, A. and Ong, C.K. 1987. Limits imposed by management in rainfed farming systems. 77–82. In: Wallis, E.J. and Byth, D.S. ed., Food legumes improvement for Asian farming systems. Proc. International Workshop. Sept. 1–5, 1982 KhanKaon, Thailand.

Prasadini, P.P., Rao, C.N., Rao, S.R. and Rao, M.S. 1993. Soil physical conditions improvement project, Andhra Pradesh Agricultural University, Hyderabad, India. IRRN 18, p. 1.

Prihar, S.S., Ghildyal, B.P., Painuli, D.K. and Sur, H.S. 1985. Physical properties of mineral soils affecting rice-based cropping systems. In: Soil Physics and Rice. IRRI, Los Baños, Philippines.

Ruhendi and Litsinger, J.A. 1982. Effect of rice stubble and tillage methods on preflowering insect pests of grain legume. 85–88. In: Cropping Systems Research in Asia. IRRI, Los Baños, Philippines.

Sanchez, P.A. 1973. Puddling tropical soils. I. Growth and nutritional aspects. Soil Sci. 115, 149–158. II. Effects of water losses. Soil Sci. 115, 303–308.

— 1976. Properties and Management of Soils in the Tropics. John Wiley & Sons Inc., New York. 618 p.

Saxena, M.C. 1976. Soybeans in India. 226–231. In: Goodman, R.M. ed., Expanding the use of soybeans. Proc. Conf. for Asia and Oceania, Chiang Mai, Thailand. INTSOY Series 10, 261p.

Sharma, P.K. and De Datta, S.K. 1985. Effects of puddling on soil physical properties and processes. In: Soil Physics and Rice. IRRI, Los Baños, Philippines. 217–235.

Singh, R.B. 1988. In: Mungbean: Proc. of the second International Symposium, 16–20 Nov. 1987. 552–559. Asian Vegetables Res. Dev. Cent., Taipei, Taiwan.

Sojka, R.E., Langdale, G.W. and Karlen, D.L. 1984. Vegetative technique for reducing water erosion of cropland in the Southeastern United States. Adv. Agron. 37, 155–181.

Syarifuddin, A.K. and Zandstra, H.G. 1978. Growing rainfed corn and soybeans after puddled flooded rice: Soil physical conditions and management. IRRI Saturday seminar paper, 4 November (mimeo).

Syarifuddin, A.K. 1979. Establishment and performance of rainfed maize (*Zea mays*) and soybean (*Glycene max* (L) Merrill) in the dry season after puddled flooded rice. PhD thesis, University of Philippines, Los Baños, Philippines.

Timsina, J. 1989. Adaptation of diverse cowpea (*Vigna unguicualta* (L) Walp) cultivars to excess moisture and drought in rice land. PhD thesis, UPLB, L.B.

UN (United Nations). 1992. Long range World Population Projections. United Nations, New York.

Unger, P.W. 1984. Tillage effects on surface soil physical conditions and sorghum emergence. Soil Sci. Soc. Am. J. 48, 1423–1432.

Unger, P.W., Allen, R.R. and Parker, J.J. 1973. Cultural practices for irrigated winter wheat production. Proc. Soil Sci. Soc. Am. 37, 437–442.

Willey, R.W., Rao, M.R. and Natragen, M. 1981. Traditional crop management with P.P. and their improvement. Proc. International Workshop on P.P., ICRISAT/ACIAR. Vol.1. ICRISAT, Patancheru, India.

Woodhead, T., De Dutta, S.K., Painuli, D.K., Sharma, P.K. and Mombani, B. 1986. International Program Review: Program area 408. Feb–March, 1986. IRRI Research Program Review (Mimeo).

Yadvinder-Singh, Ladha, J.K., Singh, B. and Khind, C.S. 1994. Management of nutrient yields in green manure systems. 125–153. In: Green Manure Production Systems for Asian Ricelands. IRRI, Los Baños, Philippines.

Zandstra, H.G. 1976. Cropping systems research in IRRI, Paper presented at the Cropping Systems Seminar for Administrators, 26–28 Jan., 1976, IRRI, Los Baños, Philippines.

— 1982. Effect of soil moisture and texture on the growth of upland crops after wetland rice. In: Report, workshop on cropping systems research in Asia. 43–54. IRRI, Los Baños, Philippines.

Problems and Management of Rice–wheat Rotation

Bhajan Singh[1] and I.P. Abrol[2]

Abstract

Rice–wheat rotation is practised on about 23 million hectares of land mainly in China, India, Pakistan, Nepal and Bangladesh, with the two crops mostly meeting the food needs of Asian countries. But this rotation, besides having several advantages, has implications for soil health and the environment. Yields are very low (less than 5 t/ha) in some areas while quite high yields (8 t/ha) are obtained in south China and in the north-western states of India. This variation is due to differences in infrastructure development and adoption of technology. This paper discusses constraints to the system in north-western India. The trends in area and productivity suggest that rice–wheat rotation will stay. However, there is a need to increase efficiency in the use of energy, nutrients and water, and to manage soil physical problems and restrict insects and pests effectively. This paper reviews these issues and the adoption level of technology. This can facilitate the transfer of technology to similar areas in other parts of the Indo-Gangetic Plains. The researchable issues are also listed.

RICE–WHEAT is the main cropping system of the sub-tropical agro-eco zones where assured irrigation is available. The advent of high input responsive dwarf varieties of rice and wheat in the 1960s gave a fillip to the expansion of rice–wheat systems. Apart from providing staple food for billions of Asians, rice–wheat rotation has been a source of income and employment for the farming community. This system is practised on about 23 million hectares comprising 10.3 million hectares in China, 10.5 million hectares in India, 1.5 million hectares in Pakistan, 0.5 million hectares each in Nepal and Bangladesh and 0.05 million hectares in Bhutan. The productivity of this system is less than 5 t/ha in most of the areas. However, in southern China and some parts of north-western India, productivity is quite high. The wide variability in productivity is mainly due to variation of infrastructure development (irrigation and other inputs) and adoption of improved technology. To feed the ever-growing population of Asia, rice–wheat will continue to play a dominant role. Besides several advantages, this system has great implications for soil health and the environment. It is, therefore, imperative to maximise productivity of the rice–wheat system on a sustainable basis without adversely affecting the fragile agro-eco system. The major constraints of the rice–wheat system in north-western India are discussed along with their management.

The area under rice–wheat rotation is mainly concentrated in the Indo-Gangetic Plains consisting of Punjab, Haryana, Bihar, Uttar Pradesh and West Bengal (Fig. 1). The soils of these plains vary from loamy sand to silty clay loam, and are mostly neutral to alkaline in reaction. Rice–wheat rotation is also practised on sodic soils with pH around 9 to 10 when brought under reclamation. The fertility status of this region is low to medium, low to high and medium high with respect to available nitrogen, phosphorous and potassium, respectively. The maximum and the minimum temperature of the region during the sowing period of the rice crop is 42 °C and 28 °C, respectively, with a mean temperature of 35 °C. Eighty per cent of the precipitation is received during the rice-growing period, for instance, at Ludhiana about 550 mm of rainfall is received during the rice-growing period of the total 657 mm annual rainfall.

[1]Department of Soils, Punjab Agricultural University, Ludhiana 141 004, India
[2]Rice–wheat Consortium for the Indo-Gangetic Plains, ICRISAT, 23 Golf Links, New Delhi 110003, India

In India, of 10.5 million hectares, 1.5 million hectares are under scented rice. The main rice-based cropping systems are:

1. rice–wheat: upper and middle plains;
2. rice–potato or peas–wheat or sunflower: Upper Gangetic Plains;
3. rice–wheat–maize + cowpea (fallow)/cowpea (fallow)/green manure/green gram: upper and middle plains;
4. rice–jute: Lower Gangetic Plains;
5. rice–wheat–rice: Lower Gangetic Plains;
6. rice–rice: Lower Gangetic Plains.

Trends in area and production

The area under rice and its productivity have continued to increase over the years in India as well as in Punjab and Haryana. The rate of expansion of rice over different periods depicted in Table 1 indicates that the maximum rate of increase in productivity per unit area was during 1971–80 in Punjab and Haryana with an almost similar trend in area planted to rice (Kaur 1995). The area and yield continued to increase during 1981–90 but the rate was less compared to 1971–80. In wheat, the increase in productivity per unit area continued during 1981–90 (Table 2) despite a decrease in area during this period compared to 1971–80 (Kaur 1995). The area as well as yield and production of rice (Fig. 2) and wheat (Fig. 3) have increased over past decades and are likely to increase in the future. The rice–wheat system is therefore likely to stay for the reasons outlined here.

Factors For and Against the Rice–wheat System

This system has high productivity and profitability. Both crops in rotation have wide adaptability to different soil and weather conditions. They are also reasonably tolerant to salts, and rice can withstand

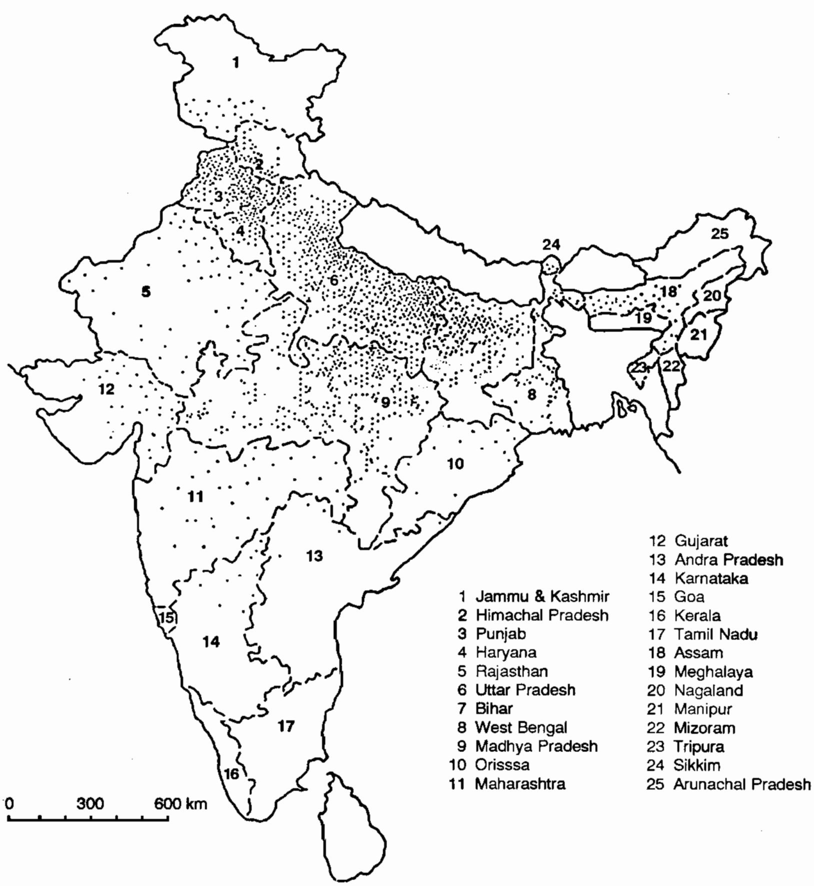


Figure 1. Rice–wheat sequence area for all India.

Table 1. Growth rate of rice in some parts of India.

State	1961–70	1971–80	1981–90	1961–90
Punjab				
Production	−0.17ns	18.82	6.09	10.92
Area	4.17ns	6.22	4.80	6.06
Yield	−4.34	12.61	1.29	4.86
Haryana				
Production	—	13.32	3.24	7.20
Area	—	8.05	2.72	4.88
Yield	—	5.27	0.52ns	2.32
Uttar Pradesh				
Production	−0.61ns	1.45ns	5.87	4.27
Area	1.10	1.07	0.13ns	0.99
Yield	−1.71	0.38ns	5.74	3.28

Kaur (1995).

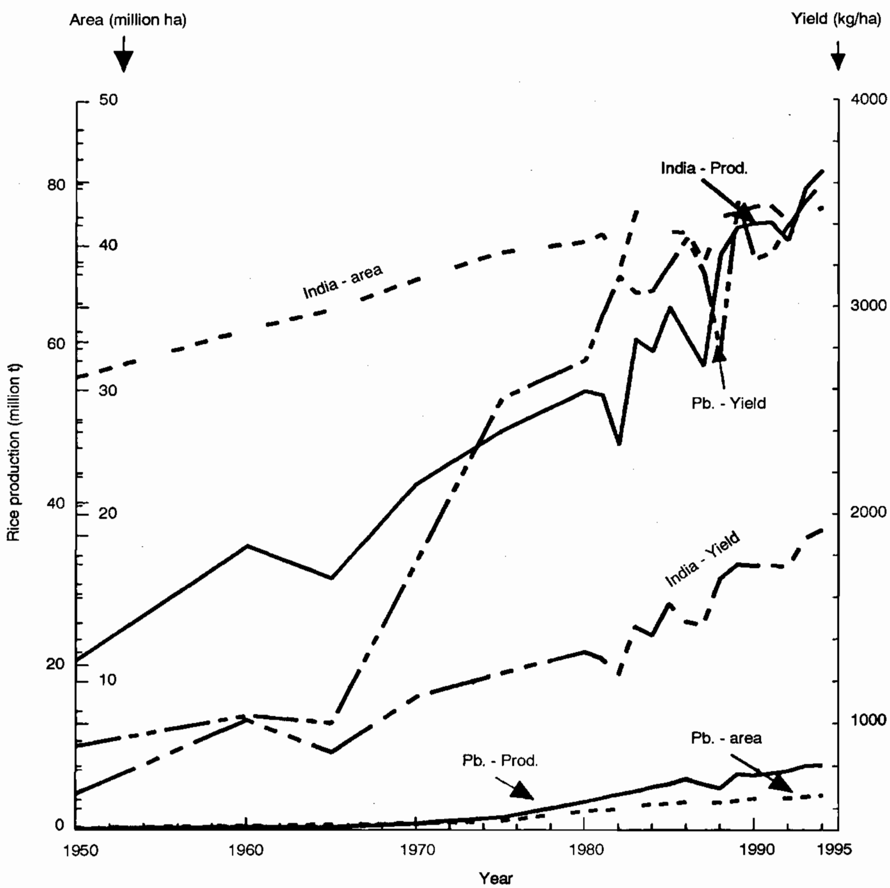


Figure 2. Rice production, area and yield from 1950 to 1995 (Pb: Punjab).

Table 2. Growth rate of wheat in some parts of India.

State	1961–70	1971–80	1981–90	1961–90
Punjab				
Production	6.08	4.58	4.25	5.98
Area	−1.93ns	2.29	1.22	1.97
Yield	8.01	2.30	3.01	4.07
Haryana				
Production	—	8.22	5.14	6.90
Area	—	3.52	0.93	2.55
Yield	—	4.70	4.18	4.04
Uttar Pradesh				
Production	5.57	4.65	5.32	6.36
Area	3.96	2.45	1.46	3.11
Yield	1.61	2.20	3.86	3.25

Kaur (1995).

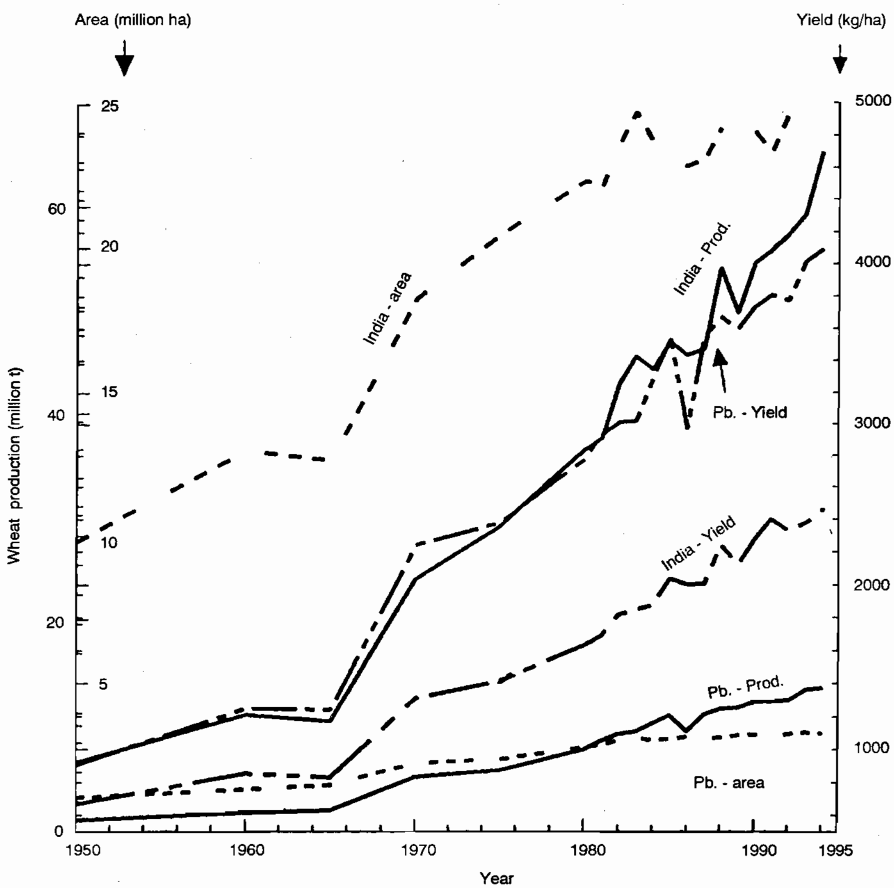


Figure 3. Wheat production, area and yield from 1950 to 1995 (Pb: Punjab).

Table 3. Energy input (MJ/ha) for raising rice and wheat in Punjab.

Input/operation	Rice	Wheat
Irrigation	18282 (54.7%)	3518 (18.8%)
Fertilizer	8586	8143
Seedbed preparation	586	1456
Harvesting and threshing	784	3171
Others	4172	3171
Total	33410	18762

high watertable conditions. The marketing of these cereal crops is easy. However, this system may create some soil health and environmental problems such as high input energy, nutrition and water requirements, puddling-induced soil problems and residue management. Table 3 shows that about 55% and 26% of the total energy input in rice is spent on irrigation and fertilizer respectively, compared to 19% and 24% in the case of wheat (Singh et al. 1990). The rice–wheat system yielding a total of 8.8 t/ha has been reported (Velayuthum 1995) to remove about 663 kg nutrient per hectare per year (Table 4).

Nutrient consumption

There is a close relationship between nutrient consumption and foodgrain production, both in India and the State of Punjab (Fig. 4). The per unit nutrient productivity of foodgrain production is higher in Punjab than in India. Despite an increase in the use of NPK fertilizers over the years (Table 5) it has not been able to match their removal by this system and still leave a negative balance of 4.31 million t of nutrients during 1993–94 (Velayuthum 1995).

Nutrient management

Nitrogen: the major constraint to the productivity of the system is N deficiency and both rice and wheat respond to the application of up to 120 kg N/ha on medium soils. However, on soils low in available N the rice responds up to 180 kg N/ha. Wheat also responds to 120 kg N/ha. The delay in sowing not only adversely affects wheat yields but also decreases N use efficiency.

P and K: wheat, being a winter crop, is more responsive to direct P application than rice. The application of P (60 kg P_2O_5 /ha) to wheat only in a rice–wheat system results in 1.0 t/ha extra yield, compared to its application to rice only. Application of P (60 kg P_2O_5 /ha) to both the crops does not increase the yield further, indicating that P application to wheat in the rotation is sufficient to meet the requirement of both the crops (Saggar et al. 1985). In northern India the dominant clay mineral is Illite and the response to K application has not been consistent and its application has been recommended only to soils testing low in available K.

Micronutrients: zinc deficiency is widespread in the Indo-Gangetic Plains and rice is more sensitive to its deficiency than wheat and other crops (Table 6). Application of 60 kg zinc sulphate per hectare is recommended to correct the deficiency (Singh et al. 1995). Keeping in view the profitability of the rice–wheat system the farmers have extended the cultivation of rice to coarse-textured soils. This has resulted in the appearance of Fe deficiency in rice (Singh et al. 1995). The adoption of this system on coarse-textured soils has not only increased the Zn and Fe deficiencies, but also resulted in the appearance of Mn deficiency in the following wheat crop. The magnitude of the deficiency at some locations was so severe that yield increase up to 2.9 t/ha has been reported with foliar application of Mn (Nayyar et al. 1990).

Integrated approach

Organic matter is another limiting factor in the sustainability of this system. Green manuring of 50–60-day-old sesbania or cowpea or crotalaria before transplanting rice along with 60 kg N//ha resulted in

Table 4. Average nutrient removal by some of the selected cropping systems in India.

Cropping systems	Yield t/ha	Nutrient uptake (kg/ha/yr)			
		N	P_2O_5	K_2O	Total
Rice–wheat	8.8	235	92	336	663
Rice-rice	7.7	220	87	247	554
Rice–wheat-green gram	8.2	306	62	278	646
Rice–wheat-cowpea[1]	9.6 + 3.9[1]	272	153	389	814
Rice–wheat-maize + cowpea[1]	9.3 + 29[1]	305	123	306	734

[1]fallow

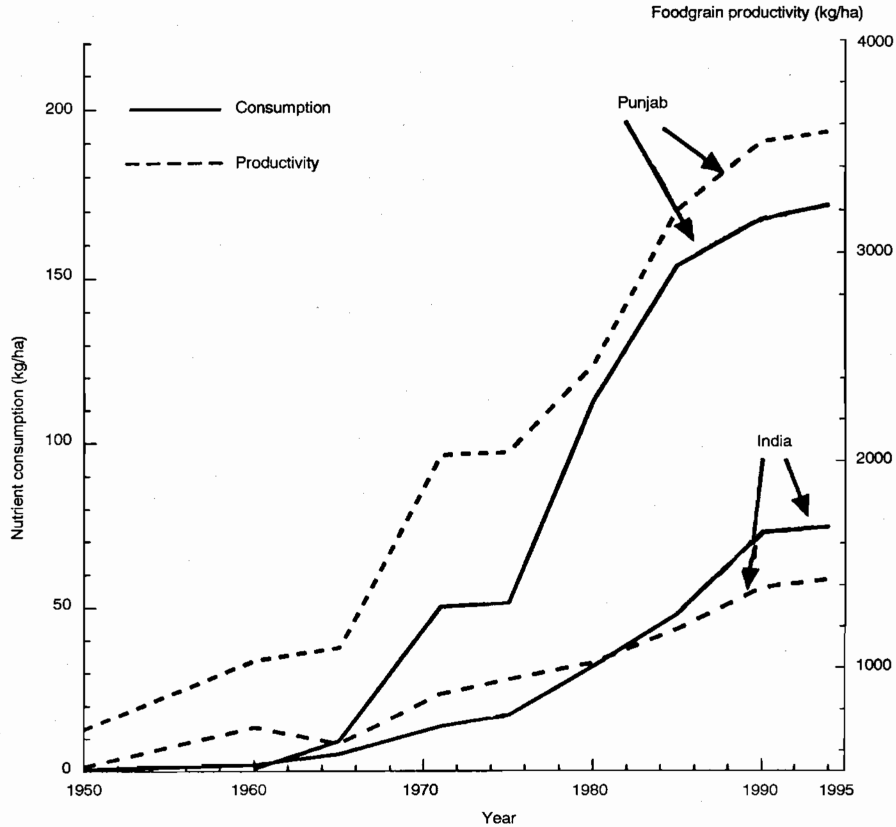


Figure 4. Nutrient consumption and foodgrain productivity from 1950 to 1995.

Table 5. Consumption of fertilizer nutrients and their extraction (million t) by rice and wheat crops.

Year	Fertilizer consumption			Nutrient removal			Net removal
	Rice	Wheat	Total	Rice	Wheat	Total	
1974–75	0.81	0.71	1.52	3.86	1.8	5.74	4.22
1984–85	2.62	2.21	4.83	5.64	3.4	8.07	3.24
1993–94	4.0	3.35	7.35	7.66	4.0	11.66	4.31

$N + P_2O_5 + K_2O$

an increase of 2.6 t/ha of paddy over 60 kg N alone (Table 7), but was at par with the yield obtained with 120 kg N/ha (Kolar et al. 1993).

Residue management

About 60% of rice and 20% of wheat in Punjab is harvested by combine, and residue management is another major problem of this system. At present rice straw is mostly burnt which causes air pollution. The experiments suggest that higher yields (Table 8) are obtained where rice straw is burnt followed by rice straw removal and rice straw incorporation (Beri et al. 1995). The decrease in yield may be due to excess residue load when the residue of both the crops is incorporated, and this experiment was conducted on a sandy loam soil. Probably incorporation of residue may prove better on fine-textured soils where poor aeration in wheat is observed after first or second irrigation.

Table 6. Average response of crops to applied zinc.

Crop	Response (q/ha)
Rice	9.5
Maize	7.1
Wheat	3.6
Groundnut	2.5
Raya	2.7
Bajra	4.1
Potato	28.6

Water management

There is a wide variability in different States in the utilisation of groundwater resources. Maximum utilisation is in Punjab and Haryana and lowest in M.P. and low quality water is also being used (Velayuthum 1995). The rice–wheat system has resulted in lowering of the water table in Ludhiana and Amritsar districts (Table 9). This is through a favourable trend for Amritsar district because the watertable has gone from less than 5 metres to 5–10 metres while in Ludhiana district the watertable has fallen below 10 metres, which is seriously affecting the water balance and expenses of pumping water. On the other hand, the watertable in the districts of Bathinda and Faridkot is rising (Khaper and Sondhi 1992). Experiments on the irrigation requirements of rice have shown that the application of irrigation water after a drainage gap of two days results in 44 kg grain/ha/cm water-use efficiency and saves 65 cm of irrigation water without adversely affecting the yield (Sandhu et al. 1980). In the case of wheat, irrigation at IW/PAN-E ratio of 0.75 compared to irrigation at five growth stages resulted in a saving of 13 cm of water and about 14 kg grain/ha/cm increased water-use efficiency (Prihar et al. 1976). Several agronomic practices (date of transplanting, date of seeding, closer spacing, etc.) also affect water and nutrient use efficiency.

Poor quality water

The use of poor quality water results in the accumulation of salts and where this water contains a high sodium content there also results sodicity of the soil. Under a rice–wheat system, the deterioration of the soil is faster than under a maize–wheat or millet–wheat system. The application of sodic water results in ammonia loss from N fertilizers and also lowers crop yields. The amelioration of such waters with amendments or conjunctive use of these waters with canal water helps in minimising the deleterious effect. The raising of crops in the system on such soils or with brackish water needs special fertilizer and other management practices (Singh et al. 1995). The rice–wheat system also induces Se toxicity (Table 10) in wheat where its content in underground water is high (Dhillon and Dhillon 1990). Such pockets have been found in Hoshiarpur and Jalandhar districts of Punjab State (Singh et al. 1995).

Physical properties

Puddling of soil for the rice crop in a rice–wheat system (Tables 11 and 12) results in the deterioration of soil physical properties (Gill 1992). The root distribution pattern in wheat is also adversely affected under a rice–wheat system (Fig. 5) and wheat roots are more concentrated in the surface layer compared to a maize–wheat system due to the formation of hardpan (Sur et al. 1981).

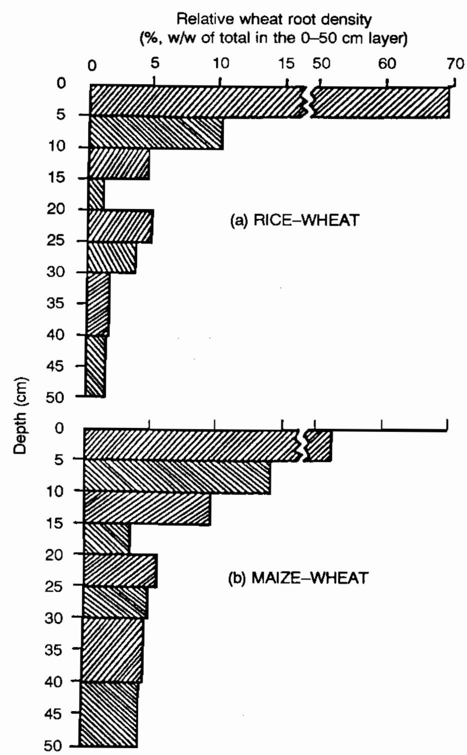


Figure 5. Relative root length density for wheat in a rice–wheat (a) and maize–wheat (b) rotation.

Table 7. Three-year mean paddy yield (t/ha) as influenced by green manuring and N levels.

Green manure crop	Age at incorporation (DAP)	Nitrogen applied (kg/ha)			
		60	90	120	Mean
		Paddy yield (t/ha)			
Fallow	—	5.8	7.2	8.0	7.0
Sesbania	40	8.1	8.4	8.5	8.3
	50	8.4	8.6	8.4	8.5
	60	8.4	8.6	8.3	8.4
Cowpea	40	8.6	8.8	8.7	8.7
	50	8.4	8.4	8.5	8.5
	60	8.5	8.4	8.2	8.4
Crotalaria	40	8.2	8.3	8.4	8.3
	50	8.3	8.5	8.6	8.5
	60	8.4	8.5	8.7	8.5

LSD (P = 0.05): Differences between yields at each N level = 0.71; difference between mean yield at all N levels = 0.80.

Table 8. Effect of long-term crop residue management on grain yields (t/ha) of rice and wheat.

Crop residue	N applied (kg/ha)			
	60	120	180	Mean
Rice (mean of 10 years)*				
Burned	4.65	5.65	6.42	5.57
Removed	4.46	5.50	6.04	5.33
Incorporated	3.62	4.63	5.26	4.50
Wheat (mean of 11 years)**				
Burned	3.46	4.26	4.64	4.12
Removed	3.48	4.14	4.42	4.02
Incorporated	2.94	3.87	4.34	3.72
Mean	3.29	4.10	4.47	

Critical difference (5%)
*Residue = 0.55; nitrogen = 0.16; residue × nitrogen: N.S.
**Residue = 0.25; nitrogen = 0.22; residue × nitrogen = N.S.

Table 9. Area under different watertable depths in some districts of Punjab.

District	<5 m		5–10 m		< 10 m	
	June 1973	June 1990	June 1973	June 1990	June 1973	June 1990
	('000 ha)					
Amritsar	221	26	264	434	24	49
Ludhiana	98	79	271	205	169	102
Sangrur	199	39	312	318	—	154
Bathinda	138	154	165	295	251	107
Faridkot	154	266	222	248	167	92

Table 10. Selenium content (mg/kg) in wheat and soil as influenced by cropping system.

Cropping system	Amount of irrigation water applied	Wheat (45–60-day-old shoots)	Soil	
			Available	Total
Rice–wheat (n = 31)	200	162 ± 115.8	1.87 ± 0.92	0.047 ± 0.018
Corn–wheat (r = 37)	60	8.2 ± 11.8	0.44 ± 0.28	0.022 ± 0.022

Table 11. Physical characteristics of the soil determined on completion of three years of two rotations.

Soil characteristics	Rotation	
	Corn–wheat–mungbean	Rice–wheat–mungbean
Soil bulk density, g/cm^3	1.66 ± 0.042	1.79 ± 0.005
Modulus of rupture, dynes/cm^3	43.5 x 10^4	45.5 x 10^4
Dispersion ratio	0.54	0.59
Water storage in 0–180 cm soil	43.2	37.8
Per cent water stable aggregate		
0.50 mm	2.0	3.7
0.50 mm–0.25 mm	4.1	2.1
0.25 mm–0.10 mm	6.4	2.6
Intake rate, cm/h	2.76	1.86

Weed and pest management

Weed infestation adversely affects the yield of rice and wheat. Use of chemical herbicides (Table 13) is more effective than conventional methods for their control (Gill 1992).

Insects like stem borer, white backed planthopper, leaf folder and thrips have increased over time and it is not possible to have a good crop of rice without controlling these insects. At present, there is no serious insect in the case of wheat except termite and aphids.

The common diseases in rice are bacterial leaf blight, sheath blight and sheath rot.

Table 12. Effect of crop rotations (after six years of cropping) on bulk density and hydraulic conductivity of soil.

Soil depth (cm)	Bulk density (g/cm^3)		Hydraulic conductivity (cm/min)	
	Rice–wheat	Maize–wheat	Rice–wheat	Maize–wheat
0–5	1.53	1.60	0.17	0.11
5–10	1.65	1.62	0.08	0.14
10–15	1.69	1.63	0.06	0.13
15–20	1.81	1.68	0.02	0.04
20–25	1.73	1.64	0.03	0.08
25–30	1.65	1.64	0.06	0.08

Table 13. Effect of herbicides on grain yield.

Treatment	Grain yield (q/ha)	
	Paddy	Wheat
Treatment with herbicide	6.0	5.1
Conventional	5.5	3.8
Unweeded	3.7	3.4

Adoption of Production Technology

The rapid adoption of the production technology by the enterprising peasantry of the State of Punjab has helped in maintaining high yield despite soil constraints. In a survey conducted in the State (Chatha et al. 1990, 1994) it was observed that more than 60% of the farmers use the recommended doses of N and P. In the case of micronutrient deficiency correction adoption is more than 90% where deficiency has been noticed. Another interesting observation is that 19% of farmers incorporate rice residue before sowing wheat. Thirty-two per cent of farmers have reported lodging incidences in rice and 68% of farmers observed insect attack in this crop. Combine harvesting has facilitated the operation and 54% of rice and 24% of wheat is harvested with combines.

Issues that Need Attention

A. Integrated nutrient management:

- rescheduling of fertilizer requirement for the system as a whole;
- feasibility of green manuring or growing of grain legume or cowpea fodder in the cropping system;
- efficient ways to incorporate crop residue (particularly rice straw) with and without the use of green manures.

B. Increasing efficiency of fertilizer nutrient use:

- calibration and extensive adoption of soil test based fertilizer use;
- better fertilizer management practices like source, rate, method/mode under different agro-ecosystems;
- detailed understanding of nutrient dynamics in terms of losses, build-up, depletion, plant uptake and residual effect at benchmark sites for extrapolation to the other experimental regimes of operation;

- scheduling of fertilizer recommendations according to availability of water;
- identification of nutrient efficient crop cultivars.

C. Long-term experimentation to monitor:

- periodic soil health in terms of chemical, physical and biological properties and soil organic matter content/status;
- pollution problems from use of chemicals.

D. Development of production technology and fertilizer management practices for:

- direct seeded rice;
- wheat sown with minimum tillage;
- different plant populations;
- residue incorporation.

E. Tillage/puddling studies in relation to soil characteristics and crop establishment particularly in heavy soils and late sown conditions.

F. Integrated pest management:

- timely forecast of pest appearance;
- surveillance of pests;
- minimising pesticides residue problems;
- interaction of nutrient management practices on the incidence of pest and diseases and nutrient uptake by weeds.

G. Water management:

- developing water management strategies for minimising nitrogen losses and accretion to groundwater;
- devising practices for increasing water-use efficiency at all levels;
- refining irrigation schedules;
- recharge of groundwater;
- development of management practices for efficient use of brackish waters and or sodic soils.

H. Conducting on-farm monitoring research for adoption pattern of:

- rice–wheat cultivation technology and production constraints.

I. Development of machinery for rice plantation, straw management and herbicide and insecticide sprays.

References

Beri, V., Sidhu, B.S., Bahal, G.S., and Bhat, A.K. 1995. Nitrogen and phosphorous transformation as affected by crop residue management practices and their influence on crop yield. Soil Use and Management. 11: 51–54.

Chatha, I.S., Singh, J. and Grewal, S.S. 1990. A study on adoption of wheat technology in Punjab. Punjab Agric. Univ. Ludhiana.

Chatha, I.S., Singh, J. and Grewal, S.S. 1994. A study on adoption of rice technology in Punjab. Punjab Agric. Univ. Ludhiana.

Dhillon, K.S. and Dhillon, S.K. 1990. Selenium toxicity in soil-plant-animal system — A case study. Trans. 14th Inter. Cong. Soil Sci. Comm. IV Vol.4: 300–305.

Gill, K.S. 1992. Research on rice–wheat cropping systems in the Punjab. Communication Centre, Punjab Agric. Univ. Ludhiana.

Kaur, Tajinder. 1995. MSc. Thesis, PAU, Ludhiana.

Khaper, S.D. and Sondhi, S.K. 1992. Water resources development and management problems and strategies for irrigated agriculture in Punjab. Water Resources Day. Proc. Vol. I: 11–37.

Kolar, J.S., Grewal, H.S. and Singh, Bhajan. 1993. Nitrogen substitution and higher productivity of rice–wheat cropping system through green manuring. Tropical Agriculture (Trinidad) 70: 301–304.

Nayyar, V.K., Bansal, R.L. and Chhiba, I.M. 1990. Management of manganese deficiency in wheat. Progressive Farg. 26: 17–18.

Prihar, S.S., Khera, K.L., Sandhu, K.S. and Sandhu, B.S. 1976. Comparison of irrigation schedules based on pan evaporation and growth stages in winter wheat. Agron. J. 68: 650–653.

Saggar, S., Meelu, O.P. and Dev, G. 1985. Effect of phosphorous applied to different phases in rice–wheat rotation. Indian J. Agron. 30: 199–206.

Sandhu, B.S., Khera, K.L., Prihar, S.S. and Singh, B. 1980. Irrigation needs and yield of rice on a sandy loam soil as affected by conditions of intermittent submergence. Indian J. Agric. Sci. 50: 432–436.

Singh, S., Singh, M.P. and Bakshi, R. 1990. Unit energy consumption for paddy-wheat rotation. Energy Conserv. Magmt. 30: 121–125.

Singh, Bhajan, Chhiba, I.M. and Brar, J.S. 1995. Salient Research Findings of Practical Utility. Ludhiana Chapter Indian Soc. Soil Sci., Dept. Soils, Punjab Agric. Univ. Ludhiana.

Sur, H.S., Prihar, S.S. and Jalota S.K. 1981. Effect of rice–wheat rotations on water transmission and wheat root development in sandy loam soil of Punjab, India. Soil and Tillage Research 1: 361–371.

Velayuthum, M. 1995. Keynote address. Symposium on 'Soil Sustainability Under Rice–wheat System' held at Punjab Agricultural University Ludhiana. Nov. 2–5, 1995.

Effect of Soil Management on Selected Physical Properties and Performance of Upland Crops after Wetland Rice

V.P. Singh[1], Mohammed Mujeeb Khan[2], K. Borkakati[1] and C.M. Siota[1]

Abstract

To alleviate the soil physical constraints inflicted by puddling on the productivity of rice-based cropping systems, field experiments on soil management were conducted in medium and heavy-textured soils under puddled and unpuddled and irrigated and rainfed conditions. Soil puddling for rice resulted in unfavourable physical properties related to moisture retention and transmission for the growth and yield of subsequent upland crops — corn, mungbean, blackgram and peanut. The establishment and germination of these crops were, however, not affected by the altered physical properties. Results show that all soil management treatments — deep tillage and pulverisation of the ploughed surface soil (*deep-till-pulv-DTP*), shallow tillage and pulverisation of surface soil (*shallow-till-pulv-STP*), or deep tillage only (*deep-till-DT*) significantly improved soil physical properties over no tillage (*zero-till-ZT*), in all soils under both irrigated and rainfed situations. These improvements, however, were not effective for crop growth especially in rainfed conditions where soil moisture was severely limiting throughout the growth period. Irrigating crops was more effective in promoting crop growth than the improvements in other soil physical properties through tillage operations. Therefore, the authors conclude that the performance of upland crops is more affected by moisture deficiency than the adverse soil physical properties resulting from puddling.

POPULATION pressure, under-nutrition and decreasing agricultural land resources compel Asian farmers to grow more food through crop diversification and optimum resource utilisation. Growing non-rice crops after rice has been found beneficial for nutrition, soil health and sustainability of the agricultural systems. Soil puddling for previous rice crop(s) to ease transplanting, facilitate root establishment, effect weed control and to lessen percolation losses of water has been reported to cause difficulties in land preparation and stand establishment for the subsequent non-rice crops.

Puddling destroys soil aggregates resulting in decreased volume of transmission pores and decreased bulk density. The puddled soil remains wet and reduced for a few days (Meluish et al. 1976; IRRI 1986 and 1987), which upon drying becomes hard and has high bulk density causing difficulties in the tillage for the following non-rice crop. The destruction and recreation of soil structure for a rice–non-rice crop sequence becomes a cyclic event and improper soil management may lower the productivity of both the crops (Zandstra 1982).

This study was, therefore, conducted to develop a soil management system and crop growing techniques suitable for a range of upland crops.

Materials and Methods

Under irrigated conditions, two experiments were conducted in medium-textured, irrigated and puddled (*medium-irrig-pudd-MIP*) soil and in heavy-textured, irrigated and puddled (*heavy-irrig-pudd-HIP*) soil in a strip-plot design with three replications. Four tillage treatments, viz., zero tillage (*zero-till-ZT*), shallow tillage and pulverised tilled soil (*shallow-till-pulv-STP*), deep tillage (*deep-till-DT*), and deep

[1] Agronomy, Plant Physiology and Agroecology Division, The International Rice Research Institute, PO Box 933, Manila 1099, Philippines

[2] Saline Water Section, Agriculture College Farm, Andhra Pradesh Agricultural University, Baptla, Andhra Pradesh, India

tillage and pulverised tilled surface soil (*deep-till-pulv-DTP*) were used as horizontal factors, and growing of mungbean, blackgram, corn, and peanut in each tillage treatment as vertical factors. All the crops in both these experiments were irrigated at 15–20 mm water depth per application at 15 days interval.

Under rainfed conditions, two experiments were conducted in puddled rainfed medium-textured (*medium-rain-pudd-PRM*) and unpuddled rainfed medium (*medium-rain-unpudd-URM*) textured rice soils in a strip-split plot design with three replications. Three tillage treatments (*zero-till, shallow-till-pulv* and *deep-till-pulv*) were used as horizontal factor; three sowing time management practices (*sow-time*) for the upland crops as vertical factor, and upland crops (mungbean and corn) as sub-plot factor.

The sowing time management practices included the following.

S1 Sowing immediately after completing the respective tillage treatments i.e. in *zero-till* only one day after harvesting rice, in *shallow-till-pulv* 4 days after harvesting rice, and in *deep till pulv* 8 days after harvesting rice because *zero-till* took no time for tillage, *shallow-till-pulv* 4 days and *deep-till-pulv* 8 days for completing the tillage. No irrigation was provided under S1 in any tillage treatment.

S2 Simultaneous sowing in all tillage treatments (*zero-till, shallow-till-pulv, deep-till-pulv*) on the day when *deep-till-pulv* was completed. The crops under S2 in all tillage treatments including *zero-till* and *shallow-till-pulv* were sown 8 days after harvesting rice although these were ready earlier. No irrigation was provided under S2 in any tillage treatment.

S3 Same as S2, but with two irrigations, i.e. simultaneous sowing in all tillage treatments on the day when deep-till-pulv was completed, 8 days after harvesting rice. The first irrigation was provided immediately after sowing of upland crops and the second irrigation 30 days later.

Under *zero-till*, seeds of mungbean and blackgram were dibbled to a depth of 2.5 cm in 30 cm apart rows at 5 cm spacing between seeds, corn to a depth of 3 cm in 75 cm apart rows at 20 cm spacing and peanut to a depth of 3 cm in 22.5 cm apart rows at 10 cm spacing immediately after harvesting rice. In other treatments the fields were allowed to dry for 3–12 days after rice harvest in order to carry out the respective tillage operations, after which the seeds of all the crops were sown as described in *zero-till*.

The soil chemical and physical properties were analysed before and after rice harvest, before the application of tillage treatments and at certain intervals thereafter. Soil samples for physical analyses were drawn by a core sampler at an incremental depth of 5 cm from 0–15 cm soil layer for *medium-irrig-pudd* and *heavy-irrig-pudd* soils, and from 0–30 cm layer for *medium-rain-unpudd* and *medium-rain-pudd* soils. Samples for chemical analyses were drawn from 0–15 and 15–30 cm depth from all the soils. The samples were prepared and analysed for different properties as per standard methods. The other soil and plant measurements were made in situ.

Saturated hydraulic conductivity was measured by a constant head method using a Guelph permeameter. Total nitrogen (for *medium-irrigated-pudd* and *heavy-irrigated-pudd* soils) was analysed by the micro-Kjeldahl digestion method and available nitrogen (for the *medium-rain-unpudd* and *medium-rain-pudd* soils) by the colorimetric estimation with indophenol blue using an autoanalyser system. Available phosphorus was analysed as Olson P.

Results and Discussion

The *medium-irrig-pudd* and *heavy-irrig-pudd* soils were classified as sandy clay loam and clayey, respectively, whereas the *medium-rain-pudd* and *medium-rain-unpudd* soils were classified as silty clay loam. The chemical properties of experimental soils are presented in Table 1. The *medium-rain-unpudd* soil had lowest pH in both, 0–15 and 15–30 cm layers, while the *medium-irrig-pudd* soil had the highest pH value. The electrical conductivity was highest in *heavy-irrig-pudd* soil, intermediate in *medium-irrig-pudd* and *medium-rain-unpudd* soils, and lowest in *medium-rain-pudd* soil. The organic matter, nitrogen, phosphorus and potassium contents were highest in *heavy-irrig-pudd* soil.

Soil bulk density

The initial bulk density values were highest in *medium-irrig-pudd* soil (Fig. 1), followed by *medium-rain-pudd* and *medium-rain-unpudd* soils (Fig. 2), and were lowest in *heavy-irrig-pudd* soil (Fig. 1). The values of bulk density at different stages of measurements indicated a relationship with the soil texture, history of soil management, and the tillage treatments. The soil bulk density was generally lower in heavy-textured (1.0 Mg/m^3) soil than medium-textured soil (1.4 Mg/m^3), and in unpuddled soil condition (1.0 Mg/m^3) than the puddled soil condition (1.2 Mg/m^3).

The bulk density increased with soil depth. The highest values were recorded in 10–15 cm layer in both the soils that were puddled and in 25–30 cm layer of the soils that were not puddled during the previous years for rice cultivation.

Table 1. Some properties of the soils of experimental sites before the application of tillage treatments.

	Medium-irrig-pudd		*Heavy-irrig-pudd*		*Medium-rain-unpudd*		*Medium-rain-pudd*	
	Soil depth (cm)							
Soil property	0–15	15–30	0–15	15–30	0–15	15–30	0–15	15–30
Chemical								
• pH (1:1 H_2O)	8.00	8.38	7.71	8.19	6.33	6.47	7.00	7.13
• EC (dS/m)	0.35	0.14	0.45	0.25	0.33	0.34	0.13	0.12
• Organic carbon (%)	0.50	0.52	1.75	1.67	1.08	1.08	0.94	0.90
• Available N (kg/ha)	227.96	223.44	245.00	239.75	—	—	—	—
• N (%)	—	—	—	—	0.10	0.10	0.08	0.07
• Available P (ppm)	5.80	5.79	9.89	9.85	7.57	8.03	8.30	7.73
• Available K (kg/ha)	135.00	153.60	1020.30	937.04	—	—	—	—

	Soil depth (cm)											
Physical	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30
Sand (%)	67.33	66.67	65.00	20.67	15.33	14.67	3.67	3.67	3.33	3.00	3.00	3.00
Silt (%)	8.00	8.33	9.33	15.33	19.33	19.33	71.33	68.33	62.67	70.00	66.33	63.67
Clay (%)	24.67	25.00	25.67	64.00	65.34	66.00	25.00	28.00	34.00	27.00	30.67	33.33
Soil texture	Sandy clay loam			Clay			Silt	Silty loam		Silty clay loam		

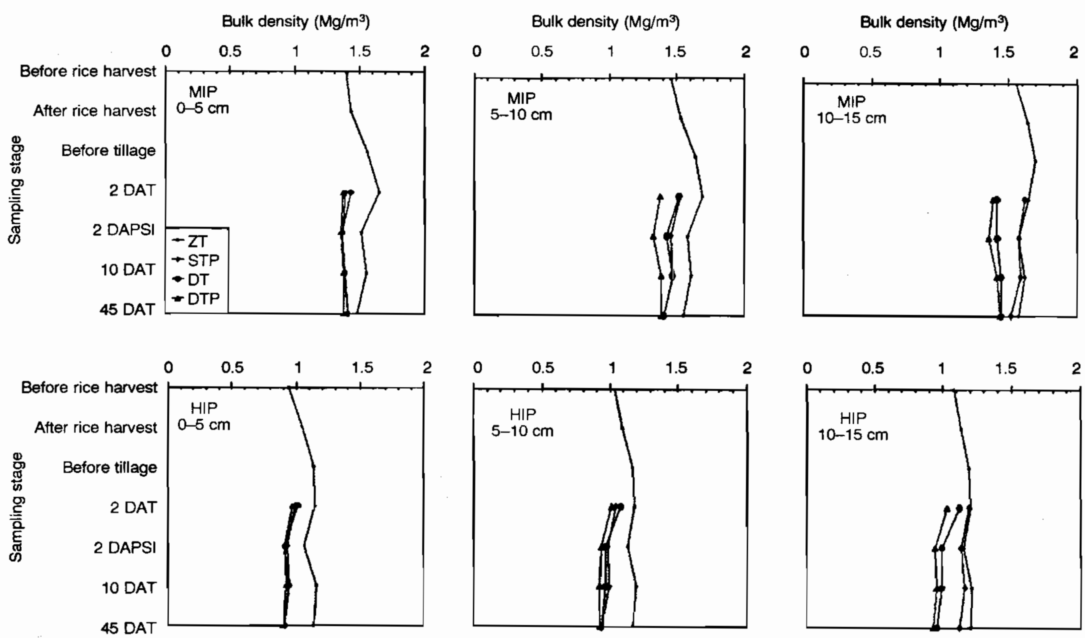


Figure 1. Bulk density of medium-textured irrigated puddled and heavy-textured irrigated puddled rice soils as influenced by tillage levels.

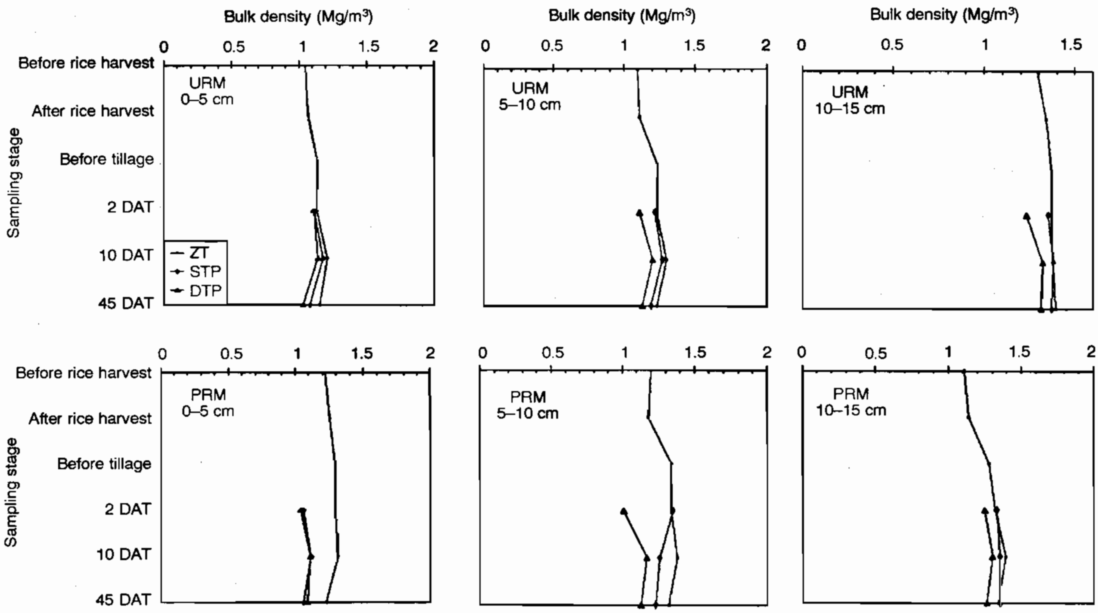


Figure 2. Bulk density of puddled rainfed medium-textured and unpuddled rainfed medium-textured rice soils as influenced by tillage levels.

Tillage treatments significantly reduced the soil bulk density in the tilled zone; up to 10 cm in *shallow-till-pulv* and 20 cm in *deep-till-pulv* and *deep-till*. The soil pulverisation evidently had more impact in reducing the bulk density than ploughing only in all the soils.

Soil bulk density, measured two days after the application of tillage (*days-after-till*), was lower as compared to the measurements made before the application of tillage, or without it (Figs 1 and 2). A significant decrease was noted through *deep-till-pulv* in all the three layers (0–5, 5–10 and 10–15 cm) and through *shallow-till-pulv* or *deep-till* as compared to *zero-till* in 0–5 cm layer of *medium-irrig-pudd*, *heavy-irrig-pudd* and *medium-rain-pudd* soils. In these three soils, also the average bulk density of the three layers was significantly lower in *deep-till-pulv* than in *zero-till*, *shallow-till-pulv* and *deep-till*. The interaction effect of tillage levels and soil depths was highly significant in affecting the bulk density.

In *medium-rain-unpudd* soil, both *shallow-till-pulv* and *deep-till-pulv* treatments resulted only in a slight and insignificant decrease in the bulk density. In all the different layers of this soil, *zero-till*, *shallow-till-pulv* and *deep-till-pulv* treatments had approximately the same values (Fig. 2). The tillage level and soil depth interaction was also non-significant.

The differences in soil bulk density among the tillage treatments during the subsequent stages of measurement (2, 10 and 45 *days-after-till*) remained at the same level as recorded at two *days-after-till*. This indicates that any possible change in the bulk density was achieved immediately after the completion of tillage operation, and that this effect was persistent till 45 *days-after-till*. The results are in accordance with the findings of Bhushan et al. (1973) and Alegre et al. (1986).

Soil moisture content

At all stages of measurement, the soil moisture content, as expected, was highest in *heavy-irrig-pudd* soil, followed by *medium-irrig-pudd*, *medium-rain-pudd* and *medium-rain-unpudd* soils (Figs 3 and 4). The soil moisture content generally was higher in deeper soil layers compared to surface layers in most of the treatment combinations of all the soils.

At two *days-after-till*, the soil moisture content in *heavy-irrig-pudd* soil ranged from 18–32% in 0–5 cm; 26–42% in 5–10 cm, and 26–48% in 10–15 cm soil layers. It was significantly higher in *zero-till* as compared to *shallow-till-pulv* in 0–5 and 5–10 cm layers and also to *deep-till* and *deep-till-pulv* in all the three soil layers. In *medium-irrig-pudd* soil, it ranged between 12–22% in 0–5 cm, 25–45% in 5–10 cm and 20–42% in 10–15 cm layer. It was significantly higher in *zero-till* than other tillage treatments in all the three soil layers, and in *shallow-till-pulv* treatment than *deep-till* and *deep-till-pulv*, but only in 5–10 and 10–15 cm layers. Syarifuddin and Zandstra (1981) have also reported similar findings. At

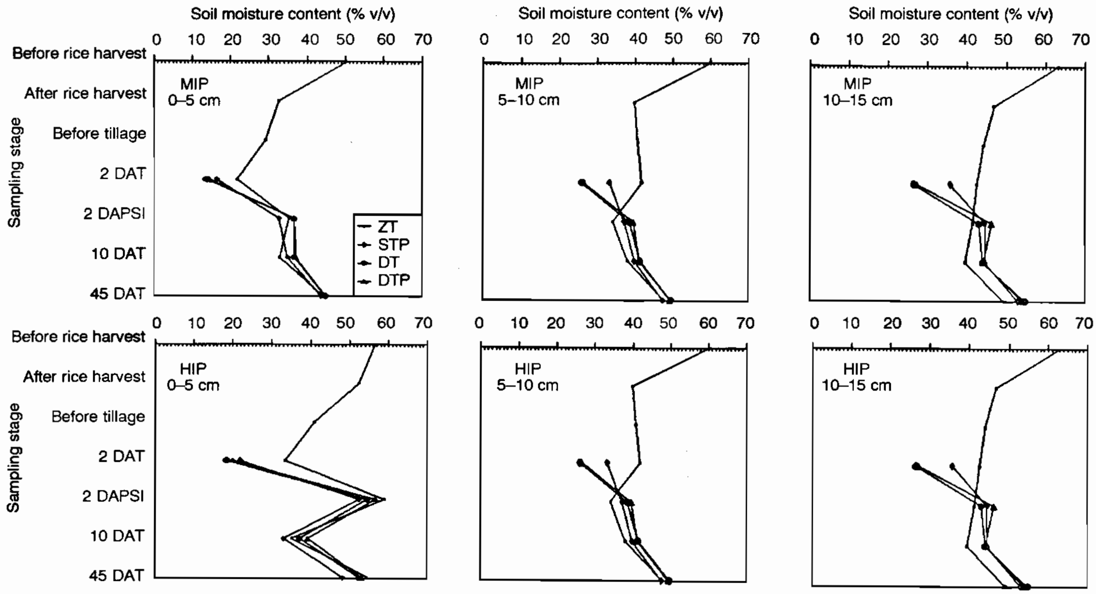


Figure 3. Moisture content in medium-textured irrigated puddled and heavy-textured irrigated puddled rice soils as influenced by tillage levels.

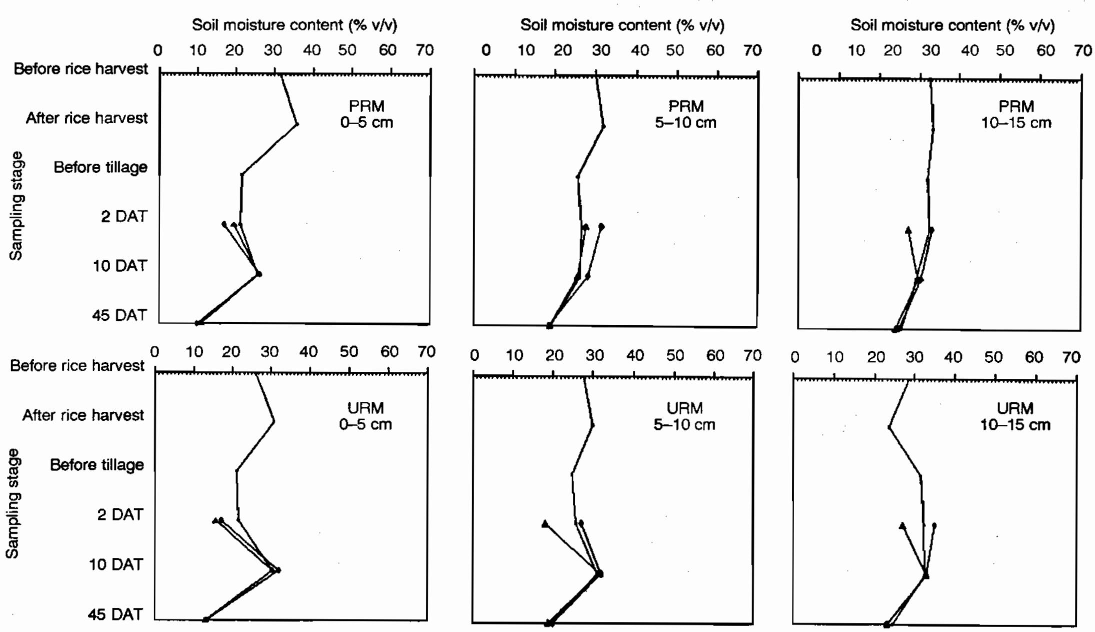


Figure 4. Moisture content in puddled rainfed medium-textured and unpuddled rainfed medium-textured rice soils as influenced by tillage levels.

other sampling stages, the moisture content was identical in all the treatments.

In *medium-rain-pudd* and *medium-rain-unpudd* soils the moisture content generally did not differ significantly among the tillage treatments, as observed separately for each of the upland crops in each *sow-time* practice and soil layers. However, the moisture content in these soils was significantly affected by *sow-time* practices. It was significantly higher in S3 plots than S2 and *no-irrig* plots in both the soils, mainly because of the supply of irrigation water in S3. It should be mentioned that in *medium-rain-pudd* soil, the higher soil moisture content in S3 plots was at matric potentials –0.50 to –0.30 MPa, whereas in *medium-rain-unpudd* soil, it was at –0.3 to –0.03 MPa in *no-irrig* and S2 plots, the lower moisture content was at –1.5 MPa in both the soils.

Saturated hydraulic conductivity

In this study, the saturated hydraulic conductivity (K) was measured at 30 *days-after-till* in 0–15 cm soil layer in all the experiments. The K values differed greatly among the four soils. The average K values (tillage and upland crops in *medium-irrig-pudd* and *heavy-irrig-pudd* soils; and tillage, sowing time management practices and upland crops in *medium-rain-pudd* and *medium-rain-unpudd* soils) were highest in *medium-rain-unpudd* soil (4.5 cm/h) and lowest (0.4 cm/h) in *heavy-irrig-pudd* soil. The *medium-irrig-pudd* soil had 3.6 cm/h and *medium-rain-pudd* soil 3.4 cm/h values (Fig. 5).

The K values were significantly influenced by different tillage treatments in all the four soils. In *medium-irrig-pudd* soil, it was highest in *deep-till-pulv* (5.1 cm/h) compared with other three tillage treatments; *zero-till* (2.0 cm/h), *shallow-till-pulv* (2.8 cm/h) and *deep-till* (4.3 cm/h). The differences in K values between *deep-till* and *zero-till*, *deep-till* and *shallow-till-pulv*, and *shallow-till-pulv* and *zero-till* in all the four upland crop plots were also significant. The differences in K values among the upland crop plots were not significant in any of the tillage treatments except in *deep-till-pulv*, where corn had significantly higher values than mungbean, blackgram, and peanut. Tillage and upland crop interaction was not significant.

In *heavy-irrig-pudd* soil, the K value was significantly lower than *medium-irrig-pudd* soil (Fig. 5). Also in this soil, the tillage treatments significantly affected the K value. It was higher in *deep-till-pulv* (0.61 cm/h) and *deep-till* (0.53 cm/h) as compared

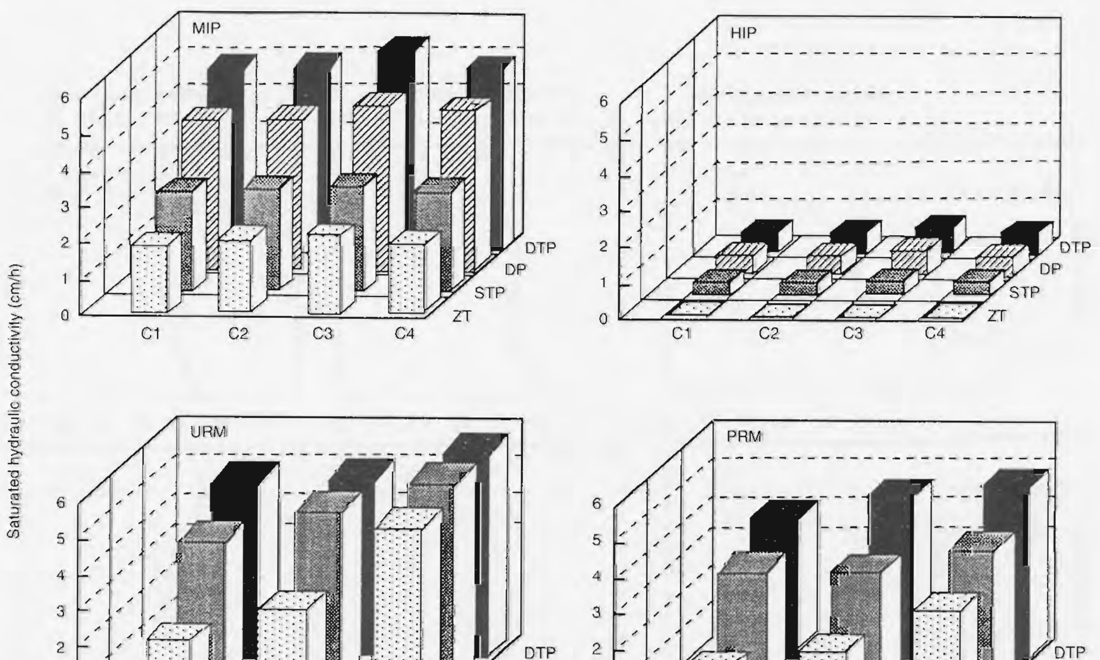


Figure 5. Saturated hydraulic conductivity at 30 DAT as influenced by tillage levels and upland crops in medium-textured irrigated puddled and heavy-textured irrigated puddled and by tillage levels and sowing time management in puddled rainfed medium-textured and unpuddled rainfed medium-textured rice soils.

with *zero-till* (0.03 cm/h) and *shallow-till-pulv* (0.34 cm/h) in all the four upland crop plots. The differences in K values between *deep-till-pulv* and *deep-till* were not significant, but between *shallow-till-pulv* and *zero-till* were significant in each of the crop plots. The differences in K values among the upland crop plots were not significant in *zero-till* and *shallow-till-pulv* treatments; whereas, in *deep-till* and *deep-till-pulv* treatments, they were significantly higher in corn as compared with other crop plots. Tillage and upland crop interaction was not significant.

In *medium-rain-pudd* soil (Fig. 5), the average K value (average of three *sow-time* practices) was significantly higher in *deep-till-pulv* (4.5 cm/h) as compared with *zero-till* (2.08 cm/h) and *shallow-till-pulv* (3.50 cm/h), and in *shallow-till-pulv* as compared with *zero-till*. Same differences were also noted in each of the *sow-time* plots separately. Among the *sow-time* practices, the K values were significantly greater in S3 (3.9 cm/h) than *no-irrig* (2.9 cm/h) and S2 (3.3 cm/h) in all the three tillage treatments. Tillage and *sow-time* interaction was significant.

In *medium-rain-unpudd* soil (Fig. 5), the K values were similar to *medium-irrig-pudd* soil. They were significantly higher in *deep-till-pulv* and *shallow-till-pulv* as compared to *zero-till* in *no-irrig* and S2 plots, and in *deep-till-pulv* than in *shallow-till-pulv*, but only in *no-irrig* plot. In S3 plots, there were no significant differences in K values among the tillage treatments. The average K values (average of three *sow-time* practices) were significantly higher in *deep-till-pulv* (5.3 cm/h) and *shallow-till-pulv* (4.9 cm/h) as compared to *zero-till* (3.4 cm/h). Among the sowing time management practices, the K value was significantly higher in S3 (5.6 cm/h) as compared to *no-irrig* (3.7 cm/h) and S2 (4.3 cm/h). Tillage and *sow-time* interaction was significant.

Seedling emergence

Seedling emergence expressed as a percentage of seeds germinated one week after sowing of upland crops is shown in Tables 2 and 3. Application of tillage treatments did not create any beneficial seedbed conditions for the emergence of all the crops in irrigated situations (Table 2). In fact, the germination of all the crops was significantly lower in *deep-till* than other treatments in both *medium-irrig-pudd* and *heavy-irrig-pudd* soils. The same trend was maintained for plant density at seven days after emergence (*days-after-emer*) and at harvest.

At par, emergence of these crops in all the treatments is presumably because of dibbling of seed which provided better seed–soil contact, thereby enabling the seed to get sufficient moisture from the soil for its germination. In *deep-till* treatment, the lower emergence of these crops was because of lesser seed–soil contact due to a higher percentage of large size aggregates and soil crust formation over the seeds due to the slacking of large aggregates after the application of irrigation water. These results are consistent with the findings of Bhushan et al. (1973), Khan and De Data (1983) and Takahashi et al. (1986).

The emergence of mungbean in *medium-rain-pudd* and *medium-rain-unpudd* soils was higher in S3 plots under all the tillage treatments where post-sowing irrigation was applied (Table 3). The emergence was reduced by 10–13% in *no-irrig* plots and by 15–25% in S2 plots, apparently due to the paucity of soil moisture in the seed zone. The plant density at seven *days-after-emer* and at harvest followed the same trend.

The lowest emergence of mungbean in *zero-till* as compared to *shallow-till-pulv* and *deep-till-pulv* treatments, particularly in S2 plots, was probably a result of suboptimal soil physical environment — high mechanical impedance coupled with rapid soil moisture loss through evaporation due to the soil pore continuity. In *shallow-till-pulv* and *deep-till-pulv* treatments, ploughing and pulverisation provided a soil mulch which might have reduced the loss of stored soil moisture loss through evaporation.

The significantly lower corn emergence in *zero-till* than in *shallow-till-pulv* and *deep-till-pulv* treatments in *medium-rain-pudd* soil is also attributed to the soil moisture loss and a high level of mechanical impedance. The corn seed may also have required a longer time for the imbibition because of its harder seed coat than the mungbean seed, due to which the corn seed suffered from considerably more loss of soil moisture. The decrease in soil moisture increased the soil bulk density, and thereby the mechanical impedance, which caused lower germination in the *zero-till* treatment. This observation is supported by the increased plant density at seven *days-after-emer*.

The *medium-rain-unpudd* soil generally had lower bulk density, lesser mechanical impedance and favorable moisture retention and transmission characteristics as compared to *medium-rain-pudd* soil, and hence it had a higher percentage of seedling emergence of corn. The application of post-sowing irrigation (S3) further helped attain a higher percentage of corn seedling emergence (>95%) in all the tillage treatments.

The lower corn emergence in *zero-till* and *deep-till-pulv* treatments, in both the *medium-rain-pudd* and *medium-rain-unpudd* soils, could be attributed to a higher soil moisture loss due to pore continuity in *zero-till* treatment, and due to the direct exposure of

Table 2. Seedling emergence and plant population density[1] of different upland crops as influenced by tillage levels (*zero-till, shallow-till-pulv, deep-till* and *deep-till-pulv*) in medium-textured irrigated puddled (*medium-irrig-pudd*) and heavy-textured irrigated puddled (*heavy-irrig-pudd*) rice soils.

Tillage level	Mungbean	Blackgram	Corn	Peanut
		Medium-irrig-pudd soil Seedling emergence (%)		
Zero-till	92.3 a	92.0 a	100.0 a	91.3 a
Shallow-till-pulv	90.3 a	92.3 a	100.0 a	90.3 a
Deep-till	86.3 b	88.7 b	92.7 b	86.7 b
Deep-till-pulv	89.7 a	91.0 ab	97.3 a	90.3 a
		Plant density (%) at *15 days-after-emer*		
Zero-till	94.3 a	94.7 a	100.0 a	92.3 a
Shallow-till-pulv	94.3 a	94.0 a	100.0 a	91.7 a
Deep-till	88.3 b	89.7 b	96.7 b	86.0 b
Deep-till-pulv	93.0 a	93.7 a	100.0 a	92.7 a
		Plant density (%) at harvest		
Zero-till	90.0 a	92.7 a	100.0 a	87.3 a
Shallow-till-pulv	89.6 a	92.3 a	100.0 a	86.0 a
Deep-till	83.6 b	87.3 b	96.7 b	81.3 b
Deep-till-pulv	91.3 a	92.0 a	98.7 ab	87.3 a
		Heavy-irrig-pudd soil Seedling emergence (%)		
Zero-till	94.3 a	93.0 a	100.0 a	87.0 b
Shallow-till-pulv	92.0 b	91.7 b	100.0 a	86.0 b
Deep-till	79.3 c	79.7 c	88.3 b	78.0 c
Deep-till-pulv	92.3 b	91.0 b	100.0 a	89.7 a
		Plant density (%) at *15 days-after-emer*		
Zero-till	93.6 a	93.7 a	100.0 a	85.3 b
Shallow-till-pulv	93.3 a	91.7 b	100.0 a	84.7 b
Deep-till	80.6 b	79.3 c	87.3 b	76.0 c
Deep-till-pulv	93.6 a	92.7 ab	100.0 a	88.7 a
		Plant density (%) at harvest		
Zero-till	86.6 b	90.0 a	100.0 a	81.0 b
Shallow-till-pulv	85.0 c	88.3 b	100.0 a	81.7 b
Deep-till	78.0 d	78.0 c	84.0 b	73.3 c
Deep-till-pulv	90.3 a	90.7 a	100.0 a	86.3 a

[1]Separately for each soil and each parameter, mean values in a column followed by a common letter are not significantly different at the 5% level by DMRT.

entire ploughed layer to sunshine in *deep-till-pulv* treatment. In this treatment, even the pulverisation of the surface ploughed layer could not help conserve the moisture in underneath layers because it was depleted from the entire ploughed layer. The shallow ploughing and pulverisation of only the surface soil layer in *shallow-till-pulv* provided a soil mulch which prevented the moisture loss from underneath layers and thus improved the corn emergence in this treatment. This result is consistent with the findings of Takahashi et al. (1986).

Grain yield

In *medium-irrig-pudd* and *heavy-irrig-pudd* soils, the corn and mungbean yield in all tillage treatments was significantly greater than in *medium-rain-unpudd* and *medium-rain-pudd* soil (Table 4). In fact in the latter soils, corn practically failed to produce any grain yield. The differences in crop yields between these two groups of soils were mainly because of moisture availability. These crops in farmer soils were irrigated. In the latter soils, they were rainfed

Table 3. Mungbean and corn seedling emergence and plant population density[1] as influenced by tillage levels (*zero-till, shallow-till-pulv, deep-till-pulv*) and sowing time managements (*no-irrig*, S2, S3) in puddled rainfed medium-textured (*medium-rain-pudd*) and unpuddled rainfed medium-textured (*medium-rain-unpudd*) rice soils.

Tillage level	Sowing time management				Sowing time management			
	no-irrig	S2	S3	Mean	*No-irrig*	S2	S3	Mean
				MUNGBEAN				
	Medium-rain-pudd soil				*Medium-rain-unpudd* soil			
				Seedling emergence (%) at 7 *days-after-emer*				
Zero-till	83.3 a	65.7 b	90.0 a	79.7	89.8 a	69.7 b	98.0 a	85.8
Shallow-till-pulv	81.0 a	80.0 a	95.0 a	85.3	87.0 a	89.7 a	100.0 a	92.2
Deep-till-pulv	81.3 a	77.7 a	91.3 a	83.4	84.0 a	75.3 b	94.0 a	84.4
Mean	81.8	74.4	92.1	82.8	86.9	78.2	97.3	87.5
				Plant density (%) at 15 *days-after-emer*				
Zero-till	93.3 a	74.0 b	100.0 a	89.4	95.3 a	78.3 b	100.0 a	91.2
Shallow-till-pulv	89.2 a	89.5 a	100.0 a	92.9	95.0	96.3 a	100.0 a	97.1
Deep-till-pulv	88.3 a	85.0 a	100.0 a	91.1	86.3 a	90.0 a	98.3 a	91.5
Mean	90.3	83.2	100.0	91.2	92.2	88.2	99.4	93.3
				Plant density (%) at harvest				
Zero-till	80.7 b	66.6 b	92.8 a	80.0	93.0 a	65.8 b	98.7 a	85.8
Shallow-till-pulv	90.3 a	85.3 a	88.2 a	87.9	90.3 a	94.0 a	99.2 a	94.5
Deep-till-pulv	85.7 ab	67.3 a	92.7 a	81.9	90.0 a	90.2 a	96.3 a	92.2
Mean	85.6	73.1	91.2	83.2	91.1	83.3	98.1	90.8
				CORN				
				Seedling emergence (%) at 7 *days-after-emer*				
Zero-till	35.6 c	34.6 b	58.7 b	43.0	75.7 a	53.1 b	96.1 a	80.0
Shallow-till-pulv	60.1 a	56.4 a	91.8 a	69.4	81.0 a	78.2 a	98.9 a	86.0
Deep-till-pulv	48.3 b	47.4 a	94.7 a	63.5	75.7 a	66.6 ab	100.0 a	80.8
				Plant density (%) at 15 *days-after-emer*				
Zero-till	43.3 b	36.3 b	68.8 b	49.5	66.0 b	72.4 a	100.0 a	79.5
Shallow-till-pulv	61.3 a	58.5 a	99.5 a	73.1	82.7 a	86.3 a	100.0 a	89.7
Deep-till-pulv	52.3 ab	48.7 a	98.2 a	66.4	84.1 a	79.7 a	100.0 a	87.9
				Plant density (%) at harvest				
Zero-till	22.3 b	14.6 b	55.4 b	30.8	53.7 b	55.2 b	92.3 a	67.1
Shallow-till-pulv	50.1 a	33.1 a	90.1 a	57.7	67.0 a	70.9 a	90.2 a	76.0
Deep-till-pulv	29.2 b	27.4 a	91.0 a	49.2	79.7 a	70.0 a	97.7 a	82.5

[1]Separately for each soil and each parameter, mean values in a column followed by a common letter are not significantly different at the 5% level by DMRT.

and suffered severely from moisture stress. A significant increase in grain yield of mungbean was observed in tilled plots, particularly in *deep-till-pulv* in *medium-irrig-pudd* and *heavy-irrig-pudd* soils, and in *shallow-till-pulv* in *medium-rain-unpudd* and *medium-rain-pudd* soils without irrigation (Table 4). These results imply that under better moisture supply conditions, *zero-till* is as good as *shallow-till-pulv* and *deep-till-pulv* treatments. Hossain et al. (1990) also reported a similar pattern of mungbean grain yield with deep, zero and minimum tillage. Blackgram grain yield also showed a similar response to tillage treatments but only in *heavy-irrig-pudd* soil. The peanut pod yield was significantly higher in both the pulverisation treatments, i.e. *shallow-till-pulv* and *deep-till-pulv* than *zero-till* and *deep-till* in both *heavy-irrig-pudd* and *medium-irrig-pudd* soils.

The higher corn grain yield in all the tillage treatments in *heavy-irrig-pudd* and *medium-irrig-pudd* soils suggests the advantage of tillage in overcoming the adverse effects of puddling in rice soils. However, much greater differences in corn as well as mungbean yields between irrigated and rainfed crops, even in *zero-till* treatments, suggest a superior advantage of irrigation than tillage. This is further supported by the higher yield of both these crops in S3 than *no-irrig* and S2 in *medium-rain-pudd* as well as *medium-rain-unpudd* soils. The yields in S3 plots in both these soils were 8 to 10 times higher than in *no-irrig* and S2 plots, which had no irrigation. Very low yield levels (0.02 to 0.88 t/ha) of corn, almost a crop failure in *medium-rain-pudd* and *medium-rain-unpudd* soils as compared to *medium-irrig-pudd* and *heavy-irrig-pudd* soils, particularly in *no-irrig* and

Table 4. Grain yield[1] of different crops under different soils as afffected by tillage levels and sowing time management practices (NO-IRRIG, S2, S3).

Tillage levels	Soils											
	Medium-irrig-pudd			*Heavy-irrig-pudd*			*Medium-rain-pudd*			*Medium-rain-unpudd*		
							No-irrig	S2	S3	*No-irrig*	S2	S3
	Mungbean	Blackgram	Peanut	Mungbean	Blackgram	Peanut	Mungbean					
Zero-till	1.25 b	1.01 a	1.98 b	1.44 b	1.10 b	2.16 b	0.39 c	0.23 b	0.87 a	0.66 a	0.29 b	1.50 a
Shallow-till-pulv	1.28 b	1.04 a	2.44 ab	1.46 b	1.12 b	2.61 a	0.75 a	0.56 a	0.82 a	0.57 a	0.58 a	1.41 a
Deep-till	1.23 b	1.04 a	1.95 b	1.45 b	1.20 b	1.90 b	—	—	—	—	—	—
Deep-till-pulv	1.45 a	1.21 a	2.56 a	1.60 a	1.40 a	2.72 a	0.52 b	0.29 b	0.85 ab	0.55 a	0.48 a	1.41 a
					Corn							
Zero-till	—	3.51 b	—	—	4.00 c	—	0.02 a	0.02 a	0.46 b	0.14 b	0.12 b	2.46 a
Shallow-till-pulv	—	4.37 ab	—	—	5.08 b	—	0.04 a	0.03 a	0.83 a	0.18 b	0.17 b	1.57 c
Deep-till	—	4.60 a	—	—	5.05 b	—	—	—	—	—	—	—
Deep-till-pulv	—	4.85 a	—	—	5.50 a	—	0.02 a	0.02 a	0.88 a	0.44 a	0.52 a	1.87 b

[1]Values in a column followed by a common letter are not significantly different at the 5% level by DMRT.

S2 plots, under all tillage treatments, further proved the sensitivity of this crop to moisture scarcity and the greater role of irrigation than tillage in enhancing the yields in puddled rice soils.

From the above findings, it may be concluded that any significant change in soil physical properties due to puddling of soils for rice may affect many aspects and processes of the successively grown upland crops. Their effects are more moisture-related than the physical conditions per se. Their cumulative influence is on growth, yield components, and ultimately on grain yield of upland crops, but not on crop establishment and emergence. The adverse effects of puddling on upland crops can be easily overcome by providing the irrigation rather than tillage.

References

Alegre, J.C., Cassel, D.K. and Bandy, D.E. 1986. Reclamation of an ultisol damaged by mechanical land clearing. Soil Sci. Soc. Am. J. 50: 1026–1031.

Bhushan, L.S., Varade, S.B. and Gupta, C.P. 1973. Influence of tillage practices on clod size, porosity and water retention. Indian J. Agric. Engineering 43: 466–471.

Hossain, M.A., Karim, M.F. and Maniruzzaman, A.F.M. 1990. Response of summer mungbean to levels of field management. Appl. Agric. Res. 5: 289–292.

IRRI. 1986. Tillage and management of soil physical condition. IRRI Annual Report for 1985. The International Rice Research Institute, Los Baños, Philippines. 279–304.

IRRI. 1987. Tillage and management of soil physical condition. IRRI Annual Report for 1986. The International Rice Research Institute, Los Baños, Philippines. 377–390.

Khan, A.R. and De Datta, S.K. 1983. Effect of aggregate size on water uptake by peanut seeds. Soil Tillage Res. 3: 171–184.

Melhuis, F.M., Muirhead, W.A. and Higgins, H.M.L. 1976. Current views on effect of cropping history on nutrient availability in irrigated soils. Paper presented at Australian Soil Sci. Conf. Wagga, May 1976.

Syarifuddin, A.K. and Zandstra, H.G. 1981. Soil fertility, tillage and mulching effects on rainfed maize grown after rice. IRRI Research Paper Series No. 66. International Rice Research Institute, Los Baños, Philippines. 1–10.

Takahashi, H., Sasiprapa, V. and Bangliang, S. 1986. Soil pulverisation and germination of upland crops. Technical Bulletin No. 20. Tropical Agricultural Research Centre, Japan. 44–55.

Zandstra, H.G. 1982. Effect of soil moisture and texture on the growth of upland crops after wetland rice. Report of a Workshop on Cropping Systems Research in Asia. International Rice Research Institute, Los Baños, Philippines. 43–54.

Puddling in Mechanised Rice Culture: Impacts on Water Use and the Productivity of Rice and Post-rice Crops

E. Humphreys, W.A. Muirhead, B.J. Fawcett, J.T. Townsend and E.A. Murray[1]

Abstract

A puddling technique was developed to reduce accessions to the watertable (deep percolation) from flooded rice in southern New South Wales (NSW). Puddling consisted of rotary hoeing the soil, in a single pass, to a depth of about 100 mm, while there was very shallow water ponded on the surface.

In replicated experiments and large bay trials, puddling dramatically reduced water use in 'high water use' rice paddocks, i.e., those paddocks using considerably more than the allowed local limit of 1600 mm per rice crop (compared with average evapotranspiration of 1200 mm). The few data obtained in small plots and bays using around 1600 mm also suggested that puddling can reduce water use in these paddocks. However, when evaluated on a whole-paddock scale (20 to 70 ha), puddling sometimes failed to reduce water use enough, i.e., to below 1600 mm.

Rice establishment, growth and yield with puddling or conventional cultivation are comparable, provided some well-defined traps are avoided. For example, the main agronomic constraint is turbidity, which can be minimised by careful water management at the time of puddling. At one site it appears there were serious problems with uneven distribution of nitrogen fertilizer following puddling, causing uneven maturity and reduced yield. Where the tilth of the soil was a low strength, structureless soil/water mass (i.e. too sloppy) after puddling (in a cultivated fallow paddock), inadequate seedling anchorage resulted in poor establishment and yield loss. With better management these latter two problems can also be avoided.

There was no evidence that the growth and yield of crops (wheat, Canola) sown immediately after rice were impaired by puddling prior to rice for one or two consecutive rice crops. However, longer-term monitoring of non-rice crops and soil properties, after several years of puddling, has not been evaluated. Longer-term evaluation is needed to determine if there are any detrimental effects of repeated puddling on post-rice crop productivity and on soil structure, such as the formation of a compacted plough pan, or of massive, hard-setting topsoil.

One of the constraints against the adoption of puddling is the longer time (person, tractor) it takes to puddle a paddock compared with conventional cultivation. However, with puddling, it has been shown that one pass seedbed preparation is possible, reducing overall preparation time when compared with about four passes for conventional cultivation. In pasture paddocks where pre-sowing nitrogen fertilizer is not required, puddling after spraying and grazing produced excellent crops. In stubble paddocks, the stubble can be incorporated while puddling, and it is also possible to apply nitrogen (ammonia) behind the rotary hoe while puddling.

Considerable effort has gone into demonstration and promotion of puddling. In 1993–94, 12 growers tested puddling, and six of these puddled the majority of a paddock. Their main reason for adoption was to keep a rice paddock that would otherwise be excluded from rice production because of high water use. The current lack of interest in evaluating or adopting puddling implies that it is not an attractive option to rice growers. Farmer perceptions of puddling need to be assessed to identify constraints to adoption, to determine whether it might be possible to overcome these constraints, and if so, how. A key factor influencing further adoption will probably be the importance placed on reducing rice paddock water use in the land and water management plans currently being developed.

[1] CSIRO Division of Water Resources, PMB No. 3, Griffith, NSW 2680, Australia

WATERTABLES in the rice-growing areas of southern NSW have risen over the past 30 to 70 years, from pre-irrigation levels of around 20 m to less than 2 m below the soil surface. With current land use practices, 20% to 30% of the agricultural land in these areas could become salinised as a result of rising watertables (van der Lely 1993). About half of the accessions to watertables has been attributed to rice growing (GHD 1985; Dwyer Leslie 1992). Flooded rice is the dominant crop, providing about two-thirds of farm income (Lacy 1995).

If economic and environmental sustainability are to be achieved, techniques for decreasing deep percolation from rice are urgently needed. Since the mid-1940s, rice growing in NSW has been subjected to a range of 'environmental restrictions' (Humphreys et al. 1994a). For land to be approved for rice growing, it has to have at least 2 m of medium to heavy clay in the top 3 m. In 1985 it was also decided that rice should not be grown in paddocks where water use exceeds 1600 mm, which is 400 mm more than average evapotranspiration over the 150-day ponding period (Humphreys et al. 1994b). However, strict enforcement of the limit would see large areas of previously approved land withdrawn from rice production in some locations (Humphreys et al. 1992), causing significant economic hardship.

Cultural options for decreasing deep percolation from rice include soil modification (puddling, compacting, smearing), intermittent irrigation (flood or sprinkler), and growing shorter duration rice varieties (Humphreys and Muirhead 1991). This paper briefly summarises work to develop and evaluate puddling as a method for reducing deep percolation from aerial sown (water seeded) rice. The impact of puddling for rice on the productivity of post-rice crops was an important component of this work. A more detailed account is available in Humphreys et al. (1995).

Results and Discussion

Puddling technique

A puddling technique was developed and evaluated in collaboration with several farmers. The technique consists of rotary hoeing the soil, to a depth of about 100 mm, while there is very shallow floodwater. While a range of machinery has been successfully used, a good combination is a 75 kW (100 h.p.) front wheel assist tractor with a 2.5 m rotary hoe with L-shaped blades. A seedbed suitable for aerial sown rice can be prepared with only one pass of the rotary hoe, and without any prior cultivation if desired. Stubble or trash can be effectively incorporated at the same time. Nitrogen fertilizer can also be applied in the same operation by injecting anhydrous ammonia (Coldflow) behind the rotary hoe, at the base of the puddled layer (Kealey et al. 1994). In comparison, conventional preparation for rice typically involves stubble burning, approximately two shallow cultivations (to a depth of about 50 mm) with a scarifier or offset discs, drilling in urea, and grading or rolling.

Effect of puddling on ponded infiltration

Infiltration was calculated from total water use minus evapotranspiration. Evapotranspiration was determined from direct measurement of water use in planted evaporation pans (diam. 1.2 m) sunk about 150 mm into the soil and backfilled with the excavated soil, or it was estimated from potential evapotranspiration (Humphreys et al. 1994b). Total water use was determined at four scales of measurement: rings, small plots, full-size bays, and whole paddocks.

1.2 m diameter rings

The rings were connected to 200 L Mariotte tanks to maintain a constant water depth in the ring. Water use was generally determined on a weekly basis, from shortly after flooding until draining. These experiments showed that puddling reduced average infiltration by an order of magnitude on high water use sites, and that there was enormous spatial variability in infiltration rates over distances of a few metres (Fig. 1).

Small plots with earthen banks (approx. 20 m × 20 m)

Total water use was determined throughout the whole season, by measuring the volume of water pumped onto each plot, using both depth pegs and flowmeters. There were four replicates. Puddling reduced total water use from 1740 mm to 1500 mm, and infiltration from 510 mm to 270 mm, on a Willbriggie clay loam (Vertisol, Xeralf). This was an important result as it suggested that water use on areas using around the limit of 1600 mm could also be reduced using puddling.

Bay tests in full-size bays (up to 3.5 ha)

Total water use was measured over a few days on one to three occasions during the season, by blocking the flow of water between the bays and measuring the drop in water depth (Humphreys 1992). Many comparisons of puddling and conventional cultivation in full-size bays were carried out in at least 12 paddocks over three years. Farmers did the puddling using their own rotary hoes and tractors. On high water use paddocks, bay tests showed dramatic reductions in infiltration with puddling compared with conventional cultivation (Table 1). Generally, infiltration was reduced sufficiently to achieve the 1600 mm target, but there were exceptions. On two paddocks where water use was already relatively low there was a trend to a reduction of about 100 mm with puddling.

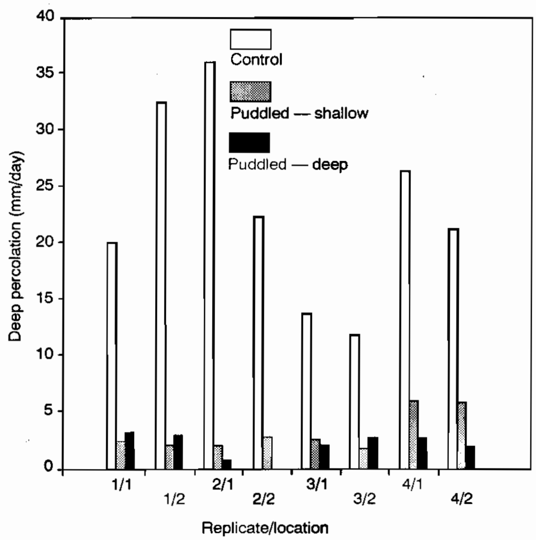


Figure 1. Infiltration in 1.2 m diameter rings as affected by puddling depth on Wunnamurra clay (Vertisol, Entic Pelloxererts). Plot size 15 m × 20 m, rings at two locations in each plot. Data are means for each ring over the whole season.

Paddock water use (20 to 70 ha)

Paddock water use was determined from Dethridge wheel measurements for the whole season. Eight farmers puddled the majority of a paddock in one or two seasons. The water use in these paddocks after puddling was compared with water use in the recent past when puddling was not used. In 1992–93 puddling was associated with large reductions in water use in all paddocks. In 1993–94 results were inconsistent. The reasons for the apparent failure of puddling in some paddocks are uncertain: feedback from farmers suggests that poor rotary hoe configuration (e.g. missing blades) and low rotor speed relative to forward speed could be implicated.

Effect of puddling depth on deep percolation

Puddling reduced deep percolation from an average of 3400 mm in the control to 500 mm (shallow puddling — around 100 mm depth) or 300 mm (deep puddling — around 200 mm depth). However, the difference between the depth treatments was not significant (Fig. 1), as might be expected for a soil with a high clay content throughout the profile.

Carryover effect of puddling to second rice crop

Bay tests were used to compare water use in bays puddled two years in a row with bays puddled in the first year only. The effect of puddling in the first year did not carry over to the second year (e.g. Table 1 — all bays were puddled in 1992 prior to rice sowing, while in 1993 only alternate bays were puddled prior to rice sowing). There was a long dry period during autumn and winter after the first rice crop was drained, enabling the soil to dry and crack.

Table 1. Infiltration in adjacent puddled or conventionally cultivated bays of a rice paddock — results of two bay tests in November and December.

Bay	Cultivation treatment	Average infiltration (mm/day) 18–21 Nov. 1993	Average infiltration (mm/day) 16–20 Dec. 1993
1	Puddled	2.6	3.5
2	Conventional	11.3	10.7
3	Puddled	4.8	3.4
4	Conventional	15.3	15.9
5	Puddled	1.8	3.4
6	Conventional	6.9	6.7
7	Puddled	2.8	5.9
8	Conventional	13.4	14.7
	Puddled mean ± std	**3.0 ± 1.3**	**4.1 ± 1.2**
	Conventional mean ± std	**11.7 ± 3.6**	**12.0 ± 4.2**

Effect of puddling on rice establishment, growth and yield

Replicated experiments

There were no adverse effects of puddling on rice establishment and growth (Fig. 2), and yields were generally unaffected (Table 2). In two experiments there was a 10% yield decline with puddling. In one case the yield decline was probably an artifact due to lower header efficiency in the puddled plots, caused by more straw production and a significantly lower harvest index.

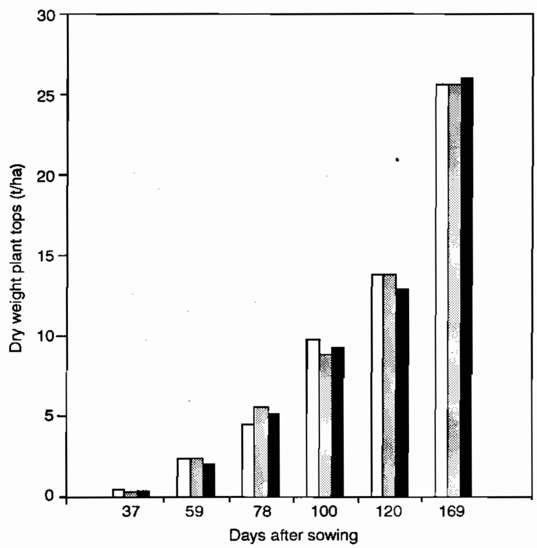


Figure 2. Effect of puddling depth on dry weight of above-ground rice plants on Wunnamurra clay (Vertisol, Entic Pelloxererts).

Full size bays

Establishment, growth and yield of commercial crops after puddling appeared to be as good as after conventional cultivation, provided some well-defined problems were avoided, for instance, a rotary hoe needs to be wide enough to cover wheel tracks. The main agronomic constraint is turbidity, which can be minimised by careful water management at the time of puddling, but this can be difficult for farmers at a busy time of the year. At one site there appeared to be problems with uneven distribution of nitrogen fertilizer following puddling. This first appeared as green and yellow striping, then as uneven maturity, and the farmer thought that yield of the puddled bays was significantly lower. Another farmer achieved his best yield (13.3 t/ha) from a puddled 3.5 ha bay, after a good legume/grass pasture. The bay had been sprayed, grazed, then flooded and puddled (i.e. one pass soil preparation).

Effect of puddling on establishment, growth and yield of crops sown after rice

Wheat after one rice crop with puddling

On a Willbriggie clay loam (Vertisol, Xeralf) the puddled plots were thoroughly puddled with two passes of the rotary hoe. There was also a compaction treatment with a vibrating roller, and a conventionally cultivated control treatment. After rice harvest and stubble burning, the plots were divided in half and one half was cultivated prior to sowing wheat, while the other half was direct drilled.

Table 2. Rice yield in replicated small plot experiments (t/ha at 14% moisture).

Year	Variety	Yield CONTROL	Yield PUDDLED
1990–91	Pelde	9.7	8.7*
1990–91	Amaroo	10.6	10.4
1991–92	Amaroo	12.2	11.1*
1991–92	Amaroo	13.1	13.8
1991–92	Amaroo		
	— no applied N	9.6	9.6
	— 60 kg N/ha	11.8	12.1
1992–93	Amaroo	7.7	10.5**[A]
1992–93	Amaroo — *2nd rice crop, 4 tmts*		
	never puddled	9.8	
	puddled in year 1		9.8
	puddled in year 2		9.8
	puddled years 1 & 2		9.5

* significant difference (P<0.05); ** significant difference (P<0.01)
[A] comparison may be misleading — control plots became established from seed carried over from previous harvest, and were a couple of weeks ahead of puddled plots.

There were no interactions between puddling treatment and wheat sowing method for any of the crop parameters measured. Puddling or compaction did not affect dry weight of the plant tops (Fig. 3) or tiller density at any stage. Header grain yields were high in all treatments, ranging from 4.9 to 6.3 t/ha. There were no significant grain yield differences, although there was a strong trend to higher yields in the control compared with the puddled treatment for direct drilled wheat. The apparent decline in yield of direct drilled wheat in the puddled and compacted treatments was possibly due to incorrect adjustment of the seeder, which placed a lot of the seed on the flat soil surface, causing poor establishment. Seed burial was better on the cloddy surface of the control treatment. The trend to lower header yields with puddling and compaction was absent from the dry weight and tillering results (Fig. 3) as the hand harvests were taken from areas where establishment was satisfactory.

Wheat and Canola after two consecutive rice crops with puddling

Plots with a history of 0, 1, or 2 consecutive years of puddling prior to rice sowing had been established on a Willbriggie/Yooroobla clay (Xeralf/Xererts). After harvest of the second rice crop followed by stubble burning, the site was divided in half, and Canola and wheat were each direct drilled into one half. There was no significant effect of puddling on establishment, dry weight of plant tops, tiller density, yield (Table 3) or any other parameter measured. Yields were relatively high in all treatments, ranging from 4.5 to 5.0 t/ha for wheat and 2.1 to 2.7 t/ha for Canola.

Soil water status was measured using tensiometers (to 1 m), neutron counts (to 1.6 m) and time domain reflectometry (0–0.15 m). There were no significant differences in soil water status between the control and puddled (two consecutive years) treatments at any stage (Fig. 4).

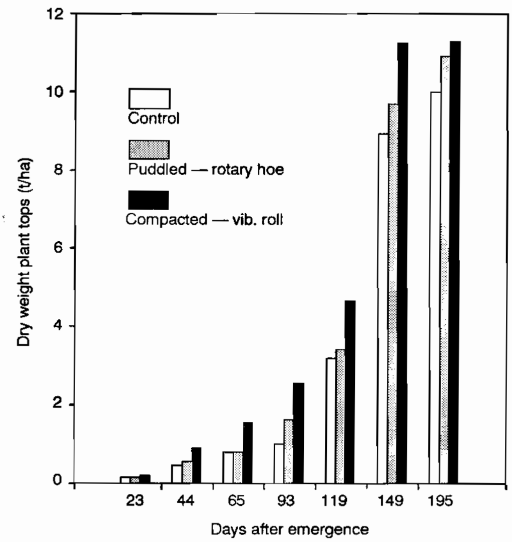


Figure 3. Effect of puddling for rice on dry weight of above-ground wheat plants sown after rice on Willbriggie clay loam (Vertisol, Xeralf). Data are means for direct drilled and cultivated drilled wheat.

Table 3. Effect of puddling for rice on grain yield (t/ha) of wheat (12% moisture) and Canola (9% moisture) sown shortly after rice harvest.

Crop	Rice soil treatment				
	After one rice crop				
	Control	Puddled 2 passes	Vibrating roller		LSD (P=0.05)
Wheat — direct drilled	6.3	5.2	4.9		n.s.
Wheat — cultivated	5.7	5.3	5.6		n.s.
	After two consecutive rice crops				
	Control	Puddled in 1991	Puddled in 1992	Puddled in 1991 and 1992	
Wheat — direct drilled	4.6	4.9	4.5	5.0	n.s.
Canola — direct drilled	2.2	2.6	2.7	2.1	n.s.

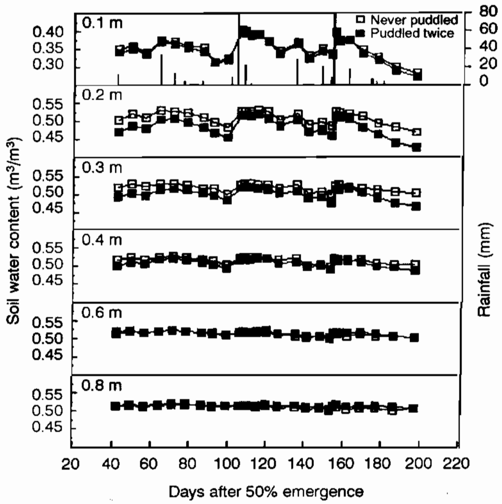


Figure 4. Effect of puddling on soil water content during a Canola crop direct drilled after rice, on Willbriggie/Yooroobla clay (Xeralf/Xererts). Data are from neutron counts at six depths from 0.1 m to 0.8 m.

Conclusions

Puddling has great potential for reducing deep percolation from flooded rice fields in mechanised rice culture. The technique has application in assisting rice growers to meet the current rice paddock water use target of 1600 mm. The few data available suggest that the technique also has the potential to reduce deep percolation in paddocks using around the current target. A widespread reduction of 100 mm in deep percolation from rice would have a significant impact on regional watertables.

The technique needs further refinement to achieve the desired effect on sites where it has not reduced deep percolation sufficiently, including heavy cut areas. This would involve further evaluation of factors such as rotor speed, ground speed and the number of passes.

One or two years of puddling for rice did not impair the productivity of non-rice crops sown shortly after rice harvest. However, longer term evaluation after several years of puddling is needed.

Acknowledgments

This work was supported with funds from the Land and Water Resources Research and Development Corporation (LWRRDC), the Rice Research and Development Committee, and the Rural Industries Research and Development Corporation (RIRDC). The authors are grateful to the many rice growers who cooperated in this project. The authors also thank AusAID for providing funds, through the International Seminars Support Scheme, to enable Liz Humphreys to attend this workshop.

References

Dwyer Leslie 1992. Rice 2000: Environmental Policy Paper. ACT, Australia, Dwyer Leslie Pty Ltd, 68 p.

GHD 1985. Waterlogging and Land Salinisation in Irrigated Areas of NSW. Vol. 1, The Problems. Sydney, NSW, Gutteridge, Haskins and Davey for the Water Resources Commission, 150 p.

Humphreys, E. 1992. Lockup bay test guidelines. Farmers' Newsletter Large Area 140, 45–46.

Humphreys, E. and Muirhead, W.A. 1991. Agronomic options for reducing recharge under rice. Australian Journal of Soil and Water Conservation 4(4), 22–29.

Humphreys, E., Muirhead, W.A., Fawcett, B.J. and Townsend, J. 1992. Minimising deep percolation from rice. Farmers' Newsletter Large Area 140, 42–44.

Humphreys, E., van der Lely, A., Muirhead, W.A. and Hoey, D. 1994a. The development of on-farm restrictions to minimise recharge from rice in New South Wales. Australian Journal of Soil and Water Conservation 7(2), 11–20.

Humphreys, E., Meyer, W.S., Prathapar, S.A. and Smith, D.J. 1994b. Estimation of evapotranspiration from rice in southern New South Wales: a review. Australian Journal of Experimental Agriculture 34, 1069–1078.

Humphreys, E., Muirhead, W.A., Ringrose-Voase, A.J. and Kirby, J.M. 1995. Minimising Deep Percolation from Rice. Griffith, NSW, CSIRO Division of Water Resources Consultancy Report No. 95/15, 45 p.

Kealey, L.M., Humphreys, E., Black, A.S. and Muirhead, W.A. 1994. Presowing nitrogen fertiliser management for aerial sown rice on puddled soil. Australian Journal of Experimental Agriculture 34, 1013–1020.

Lacy, J. 1995. Business management for rice farmers. Farmers' Newsletter Large Area 145, 32–33

van der Lely, A. 1993. Present and Future Salinity Conditions in the MIA. Leeton, NSW, Dept Water Resources Technical Report 5TR370, 20 p.

Effects of Puddling on the Structure of Clay Soils Used for Rice in Australia

A.J. Ringrose-Voase[1], J.M. Kirby[1], B.G. Blunden[1,3], E. Humphreys[2] and W.A. Muirhead[2]

Abstract

Percolation under rice fields in southeast Australia is a major cause of rising groundwater, which, in turn, is causing waterlogging and salinisation in parts of the region. Two experiments were conducted on a clay soil to investigate the feasibility of puddling in Australian rice culture. The first experiment studied the effects of various puddling treatments on percolation, soil physical properties and soil structure. All treatments were imposed on recently flooded soil. Rotovation or rolling significantly reduced percolation. Rolling created denser, stronger soil and destroyed macropores. Rotovation weakened and loosened the soil, creating a crumb structure. Some crumbs appeared to be weakened by the rotovator so that they slaked on reflooding and blocked macropores with microaggregates. A vibrating, winged tine was partially successful in reducing percolation. It too created looser, weaker soil, but the crumbs did not collapse on reflooding. The second experiment studied the effects of puddling for two consecutive rice crops on structure during the post-rice crop compared to conventional tillage. No differences in mechanical properties or permeability were found. Structural differences were seen at the end of the second rice crop but these had largely disappeared by the end of the post-rice crop.

In the irrigation areas of the Riverina region of southeast Australia, water percolation beneath rice fields is a major contributor to rising groundwater, which, in turn, is causing waterlogging and salinisation of many areas (Muirhead et al. 1990). Although rice is grown on the more poorly drained, clay soils, many rice fields have percolation rates exceeding 3 mm/day. Rice water use is monitored and rice growing is not permitted where water use exceeds 16 million litres per hectare, which is equivalent to a percolation rate of about 3 mm/day. These restrictions would cause considerable economic disruption in some areas if they were strictly enforced; hence the need to find ways to reduce percolation.

In Australia, soil is usually prepared for rice by shallow cultivation when dry. After flooding, seed is sown from aircraft and the soil kept flooded during growth of the crop. Rice crops are commonly high yielding. The high percolation rates not only contribute to rising groundwater but also result in low water-use efficiency.

A project was carried out between 1989 and 1994 to investigate whether puddling techniques could be used to reduce percolation in Australian rice fields (Humphreys et al., these Proceedings). The project studied the effects of puddling on rice yields, percolation and soil physical properties. It also studied the residual effects on post-rice crops and soil properties, since rice is usually grown in rotation with pasture, winter cereals and summer crops (Muirhead and Humphreys, these Proceedings). This paper describes the soil physical aspects of some of the experiments undertaken for the project.

Materials and Methods

Site

The experiments were located in the Colleambally Irrigation Area, New South Wales, Australia. The soils at the site are Wunnamurra clay and

[1]CSIRO Division of Soils, GPO Box 639, Canberra, 2601, Australia
[2]CSIRO Division of Water Resources, PMB 3, Griffith, 2680, Australia
[3]Present address: NSW Environmental Protection Authority, PO Box 498, Grafton, 2460, Australia

Willbriggie/Yooroobla clay (Van Dijk and Talsma 1964), which are classified, respectively, as an epicalcareous, self-mulching, grey Vertisol and an epicalcareous, self-mulching, brown Vertisol (Isbell, in press) or as a Typic Haploxerert and a Chromic Haploxerert (Soil Survey Staff, 1994). Particle size and mineralogy are given in Table 1. Both soils had low levels of exchangeable sodium and low electrical conductivity.

Experiment 1

This experiment studied the effects of various puddling techniques on soil properties during the rice phase and was conducted on the Wunnamurra clay. The site had last grown rice in the 1987–88 season and had grown self-sown pasture since. It was grazed bare before the experiment started in November 1989. Its water use during the 1987–88 rice crop was 27.5 mL/ha, which is equivalent to a percolation rate of about 11 mm/day and is well in excess of the 16 mL/ha limit.

The field experiment consisted of 5 × 5 m plots separated by earthen banks. The plots were flood irrigated for three days before the following tillage treatments were applied.

- C *Control* — no tillage, but drained for 2 days.
- Rd *Rotovation (drained)* — drained for 2 days then cultivated by two passes of a Howard rotary hoe to about 20 cm depth.
- Rf *Rotovation (flooded)* — flooding maintained, then cultivated as Rd.
- SR *Sheep's foot roller* — drained for 2–3 days then rolled by four passes of a 1280 kg Wacker WDH86-110 vibrating roller, with two sheep's foot drums.
- T *Winged tine* — drained for 3–4 days then cultivated by one pass of a Yeoman's plough to about 20 cm depth. The Yeoman's plough had tines with 40 cm wide wings which overlapped.
- Tv *Winged tine with vibrator* — as for T but with vibrator.

Differences in the duration of drainage before the various tillage treatments reflect the time needed for the soil to gain adequate traction for the tractor carrying out each operation.

After application of the treatments all plots were flooded, which was maintained for 12 weeks, without any crop.

Undisturbed samples were taken immediately after the treatments had been applied and before the plots had been reflooded. A second batch of samples was taken five weeks later. Treatment T was not sampled on the second occasion.

Samples were taken in thin-walled metal tubes inserted with a guide tube to minimise disturbance. In flooded plots, samples were taken within metal barriers pushed into the soil and bailed out. Samples (100 mm diameter × 75 mm depth) for micromorphological analysis were taken on both sampling dates at depths of 0–75 mm and 75–150 mm in most cases. Those taken on the first sampling date were also used to measure air permeability. Three replicate samples were taken at each depth for each treatment from the same plot. Samples (100 mm diameter × 100 mm depth) for determination of soil mechanics properties were taken only on the first sampling date at 0–10 cm depth.

Infiltration was measured in ponded rings (1.2 m diameter) with water supplied by 200 L drums set up as Mariotte bottles. Eight replicates were used per treatment. Measurements were made over 11 weeks. Evaporation was measured using similar rings sealed at the bottom. Infiltration was estimated as total water use — evaporation.

Experiment 2

The second experiment investigated the effects of puddling by rotovation (equivalent to Rf above) on

Table 1. Particle size and semi-quantitative mineralogy of the clay fraction at the experimental site.

Depth	Coarse sand 200–2000 µm	Fine sand 20–200 µm	Silt 2–20 µm	Clay <2 µm	Mica	Kaolinite	IS mica /smectite[a]	Quartz
cm	%				% clay fraction			
Wunnamurra Clay								
0–10	13	31	13	43	38±8	18±4	40±10	4±1
20–30	9	21	14	56	29±6	16±3	51±13	4±1
Willbriggie/Yooroobla Clay								
0–10	12	25	15	48	41±8	20±4	35±9	4±1
20–30	8	16	13	63	35±7	22±4	39±10	4±1

[a] Interstratified mica/smectite.

soil properties during post-rice cropping. Treatments sampled had either been conventionally cultivated for both the 1991–92 and 1992–93 rice crops or puddled for both crops. After the second rice crop either wheat or Canola was sown. Undisturbed samples were taken in March 1993 shortly before harvest of the second rice crop, in May 1993 shortly after sowing the post-rice crop, in September 1993 and in December 1993 after harvest from depths of 0–10 cm, 10–20 cm and 20–30 cm.

Soil mechanics samples (100 mm diameter × 100 mm depth) were taken on the May, September and December sampling dates. There were 12 replicate measurements of each parameter for each treatment/depth/date combination. These samples were also used to measure air permeability and oxygen diffusion.

Micromorphological samples (100 mm diameter × 75 mm depth) were taken only in March and December. On each occasion, three replicate samples were taken at each depth for each treatment from different replicate plots.

Preparation of thin sections and images of macropore space

Samples were dehydrated by solvent replacement to minimise shrinkage and impregnated under vacuum with polyester resin containing a small quantity of fluorescent dye to make the impregnated pore space fluorescent (Salins and Ringrose-Voase 1994). However, impregnation was incomplete in the centre of some samples because the high clay content and puddled nature of some samples meant that resin penetration was slow.

After hardening the samples were cut vertically and the polished faces photographed under ultraviolet light to give images of the pore space (Ringrose-Voase 1991). A vertical thin section (40 × 60 mm) was then made from one block from each treatment/depth/sampling date combination.

Mechanical tests

Mechanical measurements were made at field moisture contents. Uniaxial compression tests using a lever arm loader were used to measure compressibility, λ, pre-consolidation stress, Pc, and the void ratio at the preconsolidation pressure, e_{pc}. The initial void ratio, e, was also measured. Shear modulus, G, was measured using a direct shear box. Further details are given by Blunden et al. (1993).

Preconsolidation stress is the maximum normal stress which has previously been exerted upon the soil. At pressures greater than Pc the volume decreases markedly (i.e. compression starts); λ is the reduction in void ratio for an order of magnitude increase in stress above Pc (i.e. the slope of the void ratio versus log stress line). e_{pc} is the void ratio at Pc; G is the amount of extra shear stress needed for a unit increase in shear strain (i.e. the slope of the stress/strain curve) at the onset of shear and is a measure of soil stiffness or its resistance to shear deformation in the elastic range. (Shear strain is the horizontal displacement of the sample during shearing divided by the initial height of the sample.)

Air permeability and oxygen diffusion

Air permeability, k_a, was measured after cores had been equilibrated to a potential of −100 cm H_2O using the method of Blackwell et al. (1990). It was not measured on treatments flooded at the time of sampling, since equilibration would have altered the soil structure.

Oxygen diffusion was measured in samples from Experiment 2 using the method of Hodgson and MacLeod (1989).

Results and Discussion

Experiment 1

Mechanics, permeability and infiltration

The field moisture contents ranged 0.24–0.31 g/g and did not differ significantly between treatments. The liquid and plastic limits were 0.41 g/g and 0.22 g/g respectively. Table 2 summarises the results for experiment 1. In terms of reducing water use, the rotovation and rolling treatments performed best, reducing infiltration by an order of magnitude. The vibrating winged tine was partially successful and the winged tine unsuccessful.

The mechanics and physics data show that the treatments acted in quite different ways. For each parameter shown the treatments have been ordered from those with stronger/denser values to those with weaker/looser ones. Although Pc did not vary significantly between treatments, both λ, e and e_{pc} did. In general, the sheep's foot roller produced stronger, denser soil than the control with higher λ and lower e and e_{pc}. Conversely, the tine and rotovator treatments all weakened and loosened the soil, decreasing λ and e and e_{pc}. The exception is for the flooded rotovator treatment in which λ was lowered. This was because the soil was near saturation. k_a reflects the same trends and was increased by the tine and rotovator treatments and decreased by the roller.

In contrast, the shear tests indicated that the rotovation and roller treatments weakened the soil and lowered G, whereas the tine treatment did not. As will be shown below, shear fabrics were observed

Table 2. Properties of Wunnamurra clay after various puddling treatments (Experiment 1). (a) Mechanical properties on first sampling date where analysis of variance found the treatment means significantly different at P<0.05 (from Blunden et al. 1993, Table 1). (b) Air permeability on the first sampling date (from Kirby et al. 1992) and infiltration measured in the field over the whole season (from Humphreys et aL 1990) where analysis of variance using a log transform found the treatment means significantly different at P<0.05. Overall mean is shown where there were no significant differences.

a) Parameter		← Stronger/denser				Weaker/looser →		LSD (P = 0.05)
e	Treatment	SR	T	C	Rf	Rd	Tv	
0–10 cm	Mean	0.97	1.09	1.10	1.12	1.23	1.34	0.12
Pc (kPa)	Treatment			All treatments				—
0–10 cm	Mean			20				
λ	Treatment	SR	Rf	C	Rd	T	TV	
0–10 cm	Mean	0.059	0.076	0.100	0.156	0.187	0.216	0.029
e_{pc}	Treatment	SR	C	Rf	Tv	T	Rd	
0–10 cm	Mean	0.91	0.97	1.19	1.28	1.33	1.43	0.11
G (kPa)	Treatment	Tv	T	C	Rd	SR	Rf	
0–10 cm	Mean	1353	1085	1082	945	726	708	390
b) Parameter		**← Less permeable**				**More permeable →**		
k_a (m/s)	Treatment	SR	C	Rd	Tv	T		*
0–7.5 cm	Mean	0.0165	0.689	3.86	53.1	70.5		
k_a (m/s)	Treatment			All treatments				*
7.5–15 cm	Mean			0.026				
Infltration	Treatment	Rf	Rd	SR	Tv	T	C	*
mm/day	Mean	1	1	2	8	17	18	

*LSDs not shown because analysis of variance was on a logarithmic scale.

microscopically in the rotovation and rolling treatments but not in the tine treatment.

Soil structure

The macropore images (Table 3) show how the various treatments have acted upon the structure. The roller treatment destroyed macroporosity in the surface soil. Reflooding had little effect. The drained rotovator treatment produced porous crumbs in an open packed structure. After reflooding, the crumb structure settled with more closely packed, smaller crumbs (<10 mm diameter). Many of the packing pores had become disconnected, irregular vughs (<3 mm width). The tine treatments initially produced a crumb structure similar to the rotovator treatment. However, after reflooding the soil had, rather suprisingly, a more apedal structure.

Examination of the thin sections using a polarising microscope (Table 3) showed that the soil in the control treatment had a typical clay fabric with a porphyric distribution fabric with small flecks of oriented clay (insepic) together with the occasional longer stripe (masepic). After reflooding many ferrans were found, which are caused by mobilisation of iron in reduced conditions and subsequent immobilisation on reoxidation. Few differences to this fabric were obvious in the other treatments indicating that the puddling treatments had relatively low stress regimes. In the roller treatment, the surface soil had a unistrial orientation fabric near the surface caused by the compacting and shearing action of the roller aligning the clay particles parallel to the surface. In the rotovation treatments some crumbs had omnisepic orientation fabric, indicating that the clay particles had been aligned by shearing. This was not found in the tine treatments. After reflooding there was evidence of some of the crumbs collapsing since some of the inter-crumb pore space was filled with a loosely packed 'slurry' of microaggregates (<10 μm). Argillans were not found in any treatment, suggesting that dispersion, as opposed to slaking, was not occurring during puddling.

Effectiveness of treatments

Although the roller and rotovation treatments both successfully reduced percolation, they did so in quite different ways. The roller treatment lowered percolation by destroying the macropore space by compaction and, near the surface, shearing. However, because the soil was stronger it is unlikely to provide a suitable environment for maximum growth of rice roots.

The rotovation treatment initially loosened the soil as evidenced by the mechanical properties and air permeability. After reflooding the crumbs created by rotovation slumped so that the macropore space became less connected. In addition, some of the crumbs appeared to collapse, blocking the macropore space with a slurry of fine aggregates. In other micromorphological observations at the same site, evidence of a smeared layer at the base of the puddled layer was also found. Thus reduction in percolation was a result of macropore disruption by slumping on reflooding, blocking of macropores with fine aggregates and smearing at the base of the plough layer.

The tine treatment was partially successful in reducing percolation when used with the vibrator. Like the rotovator treatment it created a loose crumb structure that settled on reflooding. However, there was no evidence of the crumbs slaking upon reflooding and macropores evidently remained unblocked. The tine treatment was, in fact, intended to create a smeared layer at the base of the plough layer without causing too much disruption to the remainder of the soil. However, this was not observed, either because it was missed by the samples or because it was not created by the particular type of tine used. Nevertheless, there is potential for redesigning the tine to create more smearing (Spoor et al. 1985).

The difference in the behaviour of the crumbs in the tine and rotovator treatments on reflooding suggests that the relatively high energy input of the rotovator weakened the crumbs. Further evidence is the lower G value and the presence of omnisepic orientation fabric in some crumbs after rotovation. It is possible that the tine created a crumb structure by breaking the soil into natural aggregates. In contrast, the crumbs in the rotovator treatment were a mixture of natural aggregates and ones of remoulded clay created by the shearing action of the rotovator blades and which fell apart on reflooding.

It is also interesting to note that the treatments in which shear fabrics (omnisepic and unistrial) were found, namely rotovation and rolling, corresponded to those with reduced G.

TERMINOLOGY FOR TABLES 3 AND 5

Structure

Massive:	No discernible structural units (peds or crumbs) so pore space does not define such units.	
Crumb:	Consists of loosely packed crumbs created by tillage and defined by packing pores.	
Subangular blocky:	Peds with flat to rounded faces with limited accommodation with neighbouring peds and separated mainly by fissures.	
Platy:	Dominated by horizontally oriented cracks defining horizontally oriented platy peds.	

Grade of development (after MacDonald et al. 1990)

Strong:	Structural units distinct and comprising more than 2/3 soil volume.
Moderate:	Units well formed and comprising 1/3–2/3 of soil volume.
Weak:	Units indistinct and comprising less than 1/3 of soil volume.

Pores

Channels:	Generally cylindrical and well connected; formed by roots or soil fauna.
Vughs:	Irregularly shaped and poorly connected; often result from settling of a packing structure.
Cracks:	Generally sheet-like and well connected; formed by mechanical stresses and shrinkage.

Boundary (after MacDonald et al. 1990)

Distinctness	Sharp:	<5 mm.
	Abrupt:	5–20 mm.
	Clear:	20–50 mm.
Shape	Smooth:	almost a plane surface.
	Wavy:	undulations wider than they are deep.
	Irregular:	undulations deeper than they are wide.

Microfabric (after Brewer and Sleeman, 1988)

Distribution fabric:	Arrangement of coarse and fine particles, e.g.	
	Porphyric:	sand grains embedded in a matrix of finer particles.
Orientation fabric:	Patterns of preferred orientation of elements of the fabric, e.g.	
	Insepic:	small flecks of oriented clay.
	Masepic:	long stripes of oriented clay.
	Unistrial:	whole clay matrix is oriented with single preferred orientation.
	Omnisepic:	whole clay matrix is oriented with many preferred orientations.
Cutans:	Coatings of various features, e.g.	
	Argillans:	dispersed clay redeposited as coatings on pore walls.
	Ferrans:	iron impregnation of pore walls.

Table 3. Structure and microfabric (in italics) of Wunnamurra clay after various puddling treatments (Experiment 1).

Treatment	First sampling	Second sampling
C	0–2 cm depth: Weakly developed, blocky structure (5–10 mm size) with many fissures (<0.5 mm width); *porphyric distribution fabric with main-sepic orientation fabric*; abrupt, wavy boundary to 2–15 cm depth: Massive structure with many fissures (<0.5 mm width) and channels (<1 mm)	As for first sampling *except for common ferrans*
SR	0–7 cm depth: Massive structure with few horizontal fissures; *microfabric as C except for unistrial orientation fabric near surface*; clear, smooth boundary to 7–15 cm depth: As C	As for first sampling *except for common ferrans*
Rd	0–7 cm depth: Moderately developed crumb structure (mixture of sizes >10 mm) with interpedal pores and well connected packing pores (<5 mm); *microfabric as C except for omnisepic fabric in some crumbs*; abrupt, wavy boundary to 7–15 cm: As C	0–5/10 cm depth: Weakly developed crumb structure (mixture of sizes <10 mm) with poorly connected packing pores and vughs (<3 mm); *microfabric as first sampling except for microaggregates (<10 (m) filling some pores between crumbs and common ferrans*; abrupt, wavy boundary to 5/10–15 cm depth: As for first sampling
Rf	Not available	Not available
Tv	0–2/7 cm depth: Moderately developed crumb structure (mixture of sizes >10 mm) with well connected packing pores (<5 mm); *microfabric as C*; abrupt wavy boundary to 2/7 cm: As C	0–7 cm depth: Massive to weakly developed blocky structure, with horizontal fissures (<5 mm); *microfabric as first sampling except for common ferrans;* clear, wavy boundary to 7–15 cm depth: As first sampling
T	As Tv	Not available

Experiment 2

Mechanics, permeability and oxygen diffusivity

The results of the mechanical, permeability and oxygen diffusivity measurements made on the puddled twice and conventionally cultivated treatments are shown in Table 4 as the probability that the treatment means were not significantly different. Only 10 comparisons found significant differences at the 0.05 level between the treatments at any stage after the second rice crop. The direction of the differences in terms of which treatment mean is greater shows no consistent trend, although there is a suggestion that Pc is greater after puddling indicating that the soil is stronger. In summary, there is little evidence that puddling for two consecutive rice crops resulted in poorer mechanical or physical properties than conventional cultivation. Indeed, Humphreys et al. (these Proceedings) found in an adajcent field that the reduction in percolation achieved by puddling for the first rice crop was not carried through into the second rice crop if it was not repuddled.

Soil structure

Examination of the macropore images and thin sections is summarised in Table 5. At the end of the second rice crop there were clear differences in the structure of the two treatments. In the conventionally cultivated treatment, the self-mulching ability of the soil had created a 3 cm deep layer of fine crumbs, with a wide range of sizes less than 10 mm. This process was less advanced in the puddled treatment and structural units were larger. In the puddled treatment, there were zones in the matrix dominated by sand-sized quartz grains and others lacking such grains. This separation into coarse and fine particles suggests that there had been some aggregate breakdown with subsequent sedimentation of particles of different sizes at different rates. As in Experiment 1, no argillans were observed indicating that aggregate breakdown was due not to clay dispersion but more likely to slaking into clay microaggregates. On consolidation of the puddled layer, zones of clay microaggregates formed into the clay rich zones, without the coats of parallel oriented clay that would be expected if dispersion had occurred.

Table 4. Probability that various properties of the Willbriggie/Yooroobla clay are not significantly different after being puddled twice or conventionally tilled twice. Values ≤0.05 are usually considered to indicate that the difference between means is significant. + indicates that the mean of the twice puddled treatment was greater than the conventionally cultivated treatment. – indicates that the mean was less in the twice puddled treatment.

Sampling date	Probability that treatment means are not significantly different				
Sample depth	Pc	λ	e	k_a	Relative oxygen diffusivity
May					
1–10 cm	0.27 +	0.40 +	0.69 +	0.08 +	+[a]
10–20 cm	0.13 +	0.30 +	0.55 +	0.75 –	+[a]
20–30 cm	0.31 +	**0.02 +**	0.09 +	0.64 +	+[a]
September					
1–10 cm	1.00	**0.01 –**	0.75 –	0.08 +	**0.02 –**
10–20 cm	0.15 +	0.21 –	0.22 –	**0.01 +**	0.19 –
20–30 cm	**0.04 +**	0.81 +	0.69 +	0.11 –	0.07 –
December					
1–10 cm	0.50 +	**0.03 –**	0.29 –	0.09 –	**0.02 –**
10–20 cm	0.30 +	**0.05 –**	0.16 –	**0.03 –**	0.09 –
20–30 cm	0.75 +	**0.02 –**	0.96 –	0.22 –	0.25 +

[a]Probability of the difference not determined because only one result was available for each treatment.

Table 5. Structure of a Willbriggie/Yooroobla clay just before harvest of second rice crop and after harvest of subsequent post-rice crop with various pre-rice tillage treatments as seen in pore space images and thin sections (in italics).

Pre-rice tillage	Before harvest of second rice crop after field drainage	After harvest of post-rice crop	
		Canola	Wheat
Conventional tillage before both rice crops	0–3 cm depth: Strongly developed crumb structure (mixture of crumb sizes <10 mm); *no separation of coarse and fine particles*; sharp, wavy boundary to 3–10 cm depth: Weakly developed platy structure with many root channels (<1 mm) and few vughs (mainly <0.5 mm) 10+ cm depth: Massive structure with very few channels (<0.5 mm), vughs (<0.5 mm) and fissures (<0.5 mm)	0–2/5 cm depth: Moderately developed crumb structure (mixture of crumb sizes <10 mm); *no separation of coarse and fine particles*; clear, irregular boundary to 2/5+ cm depth: Massive structure with few channels (<0.5 mm), vughs (<0.5 mm) and fissures (<0.5 mm)	*As for Canola*
Puddling by rotary hoe before both rice crops	0–7/10 cm depth: Massive to weakly developed crumb structure (mixture of crumb sizes 5–20 mm with few <5 mm) with many channels (<1 mm), vughs (<5 mm) and fissures (<2 mm); *some separation of coarse and fine particles;* abrupt, irregular boundary to 7/10+ cm depth: Massive structure with very few channels (<0.5 mm), vughs (<0.5 mm) and fissures (<0.5 mm)	*As for conventional tillage*	0–2/10 cm depth: Weakly developed crumb to sub-angular blocky structure (mixture of structural unit sizes 5–20 mm with few <5 mm) with many channels (<1 mm) and vughs (<2 mm); *no separation of coarse and fine particles*; clear, irregular boundary to 2/10+ cm depth: Massive structure with few channels (<0.5 mm), vughs (<0.5 mm) and fissures (<0.5 mm)

By the end of the post-rice crop these differences had largely disappeared. The surface of all treatments except wheat following puddling had a fine crumb structure. The puddled treatment followed by wheat had a slightly less well developed structure with larger structural units. The zones of separated particles found at the end of the rice crop had presumably been mixed by the self-mulching activity of the soil as it went through wetting/drying cycles. In all treatments the subsurface layers were massive, although there were slightly more channels and vughs after the post-rice crop.

Conclusions

Experiment 1 shows that there are several methods of reducing percolation below rice fields using cultivation of wet soil. These operate in different ways. Rolling destroys macropore space while rotovation causes aggregate breakdown, which blocks macropores, and disruption of pore continuity at the base of the puddled layer by smearing. The winged tine with vibrator is less efficient at reducing percolation. It does not cause aggregate breakdown and relies on smearing at the base of the puddled layer, which was not found in this experiment. However, the tine could be redesigned to cause more smearing.

The fact that percolation can be reduced in a number of ways means that there is scope for selecting or designing equipment that not only reduces percolation, but also fulfils other criteria such as having the minimum power requirement, creating the most favourable conditions for rice growth or having the least deleterious carry-over effects on post-rice crops. It is likely that rotovation creates better conditions for rice than rolling because it loosens and weakens the soil.

Experiment 2 showed that in clay soils with high shrink/swell potential, most effects of puddling by rotovation relative to conventional cultivation do not persist into post-rice crops. There was some evidence that restructuring by the soil's own self-mulching activity was slowed by puddling so that there were differences in structure at the end of the rice crop. However, by the end of the first post-rice crop such differences had all but disappeared.

Humphreys et al. (these Proceedings) found that puddling had no effect either on rice yield nor on post-rice yield.

It is likely that the rapid disappearance of any differences due to puddling is due to the self-mulching nature of this soil. It is not known at this stage whether the effects of puddling would persist for longer in soil with a lower clay content or a lower content of shrink/swell minerals. In addition, only two consecutive years of puddling were used in Experiment 2. Whether longer periods have a deleterious effect is unknown.

Acknowledgments

The authors thank IREC/MREC Rice Research Committee and the Land and Water Research and Development Corporation for funding this work. They also thank: Jeff Wood (CSIRO Biometrics Unit) for advice regarding statistical analyses; Colin McLachlan for performing the mechanics tests; Inars Salins for preparation of the micromorphological samples; Jim Beatty for soil particle size and chemistry analyses; Graham Riley and Paul Fazey for mineralogical analyses; and Brad Fawcett, Elaine Murray and John Townsend for help with field work.

References

Blackwell, P.S., Ringrose-Voase, A.J., Jayawardane, N.S., Olsson, K.A., McKenzie, D.C. and Mason, W.K. 1990. The use of air-filled porosity and intrinsic permeability to characterize macrostructure and saturated hydraulic conductivity of clay soils. Journal of Soil Science, 41, 215–228.

Blunden, B.G., Kirby, J.M., Humphreys, E. and Muirhead, W.A. 1993. Mechanical properties of a grey clay used for rice production in Australia. Soil and Tillage Research, 26, 55–67.

Brewer, R. and Sleeman, J.R. 1988. Soil Structure and Fabric. Adelaide, CSIRO (Australia) Division of Soils, 173 p.

Hodgson, A.S. and MacLeod, D.A. 1989. Oxygen flux density, air filled porosity and bulk density as indices of Vertisol structure. Soil Science Society of America Journal, 53, 540–544.

Humphreys, E., Muirhead, W.A. and Steer, C.M. 1990. Reducing deep percolation on rice soils in south-east Australia. In: Proceedings of 14th International Congress of Soil Science, Kyoto, Japan, August 1990. 1, 354.

Isbell, R.F. The Australian Soil Classification. Melbourne, CSIRO Publishing. In press.

Kirby, J.M., Ringrose-Voase, A.J., Humphreys, E., Blunden, B.G. and Muirhead, W.A. 1992. The effects of different soil preparation techniques on physical properties and structure of a cracking clay soil used for rice production in Australia. In: Murty, V.V.N. and Koga, S., ed., Soil and Water Engineering for Paddy Field Management. Bangkok, Asian Institute of Technology, 242–251.

MacDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. 1990. Australian Soil and Land Survey Field Handbook. 2nd Edition. Melbourne, Inkata Press, 160 p.

Muirhead, W.A., Jaywardane, N.S., Humphreys, E. and van der Lely, A. 1990. Deep percolation under rice: its importance, measurement and on-farm management. In: Humphreys, E., Muirhead, W.A. and van der Lely, A., ed., Management of Soil Salinity in S.E. Australia. Proceedings of a conference, Albury NSW, 18–20 September 1989. Australian Society of Soil Science Inc., Riverina Branch, 321–331.

Ringrose-Voase, A.J. 1991. Micromorphology of soil structure: description, quantification, application. Australian Journal of Soil Research, 29, 777–813.

Salins, I. and Ringrose-Voase, A.J. 1994. Impregnation techniques for soils and clay materials — the problems and overcoming them. CSIRO (Australia) Division of Soils Technical Report 6/1994.

Soil Survey Staff. 1994. Keys to Soil Taxonomy, 6th edition. USDA-SCS.

Spoor, G., Cochran, B.J. and Chakkaphak, C. 1985. Implement design for lowland rice-based cropping systems. In: Soil Physics and Rice. International Rice Research Institute, Los Baños, Philippines.

Van Dijk, D.C. and Talsma, T. 1964. Soils of the Southern Portion of the Colleambally Irrigation Area, NSW. Soils and Land Use Series No. 47. Melbourne, CSIRO.

Direct Seeding Technology in the Philippines

R.T. Cruz[1], S.R. Serrano[1], M.C. Casimero[1], P.R. Casayuran[1] and S.R. Obien[1]

Abstract

A recent survey has indicated that within the past few years, the percentage of rice farmers adopting wet direct seeding or broadcast seeding increased from 25% to 48% in irrigated areas. Average pre-harvest labour utilisation was lower and returns above all costs were higher for direct seeded than for transplanted rice. Varieties commonly used in transplanting have been used for direct seeding. Average seeding rate was 160 kg/ha, and pre-germinated seeds were usually sown one day after the final land preparation. The greater percentage of farmer respondents in Neuva Ecija Province, Central Luzon, used N rates of 61 to 90 kg/ha, P rates of 0 to 60 kg/ha and K rates of 0 to 40 kg/ha during dry and wet seasons. However, reported grain yields of 4 to 5 t/ha were lower than yields obtained under experimental conditions at PhilRice. At PhilRice, Neuva Ecija Province, average grain yield was 6 t/ha at 0–40–40 kg NPK/ha and 7 t/ha at 90–40–40 Kg NPK/ha. Such yields were obtained with seeding rates of 80 or 160 kg/ha, and N applied in split doses at two or three growth stages. Discrepancies in yields obtained from farmers' and experimental fields could be attributed to differences in N level and management, pest management, and crop establishment. At PhilRice, 'anaerobic seeding' or sowing pre-germinated seeds immediately after the final land preparation (ploughing, harrowing and levelling) resulted in better seedling establishment. Anaerobic seeding could minimise biotic and abiotic stresses.

THE availability of water supply, relatively inexpensive herbicides, short-duration modern varieties, and increased labour costs have encouraged many farmers in the Philippines, Malaysia, Thailand, and other rice-growing countries in both tropical and temperate areas to switch from transplanting to broadcast or wet direct seeding i.e., pre-germinated seeds broadcast onto puddled soil (De Datta and Nantasomsaran 1991).

In the Philippines, 25% of the rice farmers surveyed practised direct seeding (BAS 1993) and by regional proportion 21% in Central Luzon, 28% in Central Visayas, 86% in Western Visayas, and 25% to 34% in Mindanao areas (Fig. 1). Average data for the Philippines indicated that from 1992 to 1995 the percentage of farmers adopting direct seeding increased from 25% to 48% in irrigated areas but decreased from 58% to 33% in rainfed areas (PhilRice 1995). In Nueva Ecija Province alone (in the Central Luzon Region), the percentage of farmers adopting wet direct seeding during the dry season was less than 5% in 1982, 55% in 1991 and 70% in 1995 (Erquiza et al. 1990, PhilRice 1995). Average pre-harvest total labour use for the Philippines ranged from 29 to 33 man-days/ha for direct-seeded rice and 72 to 79 man-days/ha for transplanted rice (PhilRice 1995, Table 1). Average returns above all costs was higher for direct-seeded than transplanted rice under irrigated dry season conditions (Table 2) and for irrigated and rainfed conditions during the wet season (PhilRice 1995).

However, the shift from transplanting to direct seeding is not without problems. Although soil puddling reduces weed problems, significant reduction in yield can be brought about by uncontrolled weed growth (Casimero et al. 1994). Rice varieties and management practices specifically adapted to direct seeding are needed, rather than relying on spillover benefits from using transplanted rice technology (De Datta and Nantasomsaran 1991).

This paper presents results of surveys on the status of direct seeding in the various regions in the Philippines, and describes management practices for direct-seeded rice under PhilRice experimental conditions.

[1] Philippine Rice Research Institute (PhilRice) Maligaya Muñoz, Nueva Ecija 3119, Philippines

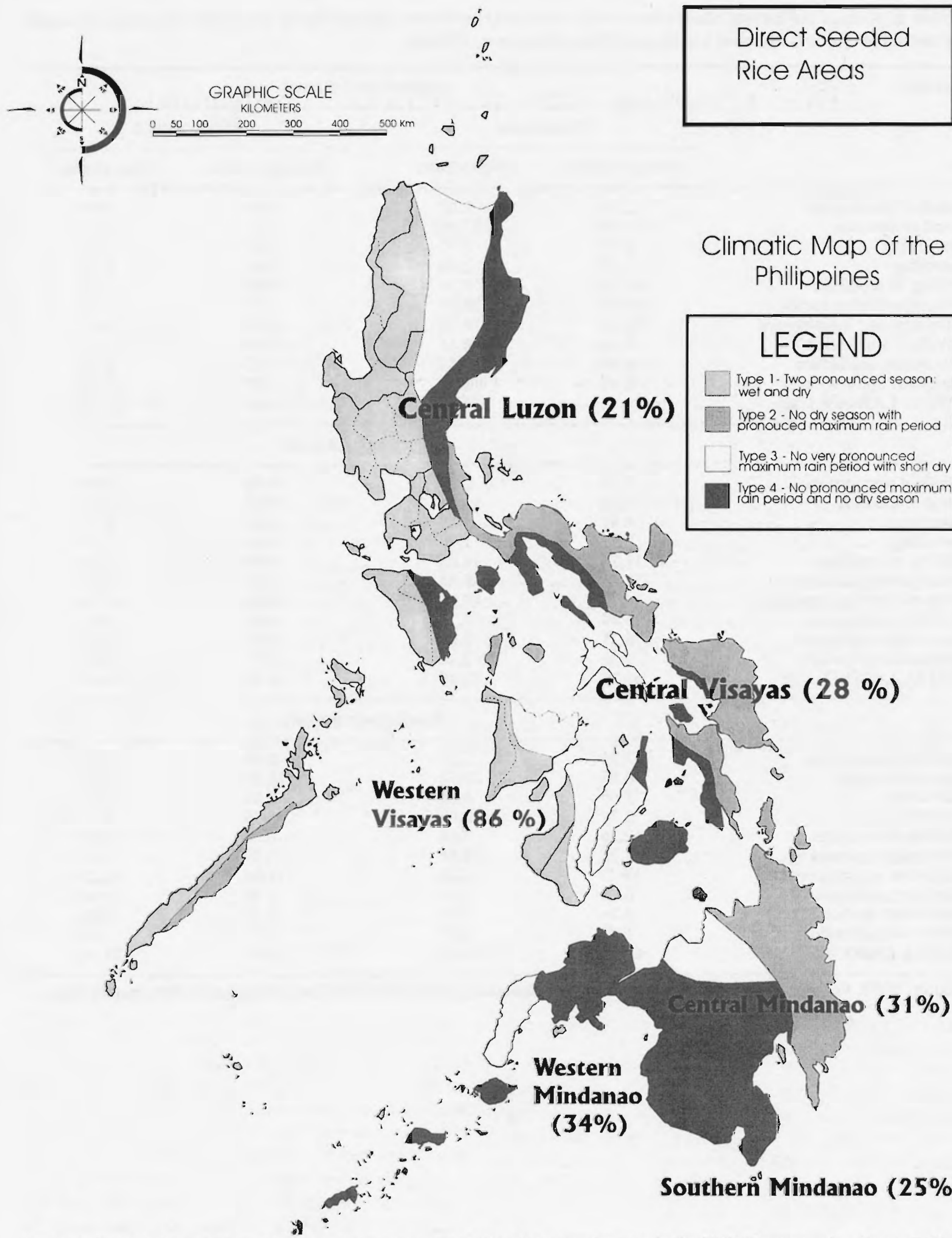


Figure 1. Regional proportions of direct-seeded rice areas: 25% of the rice farmers in the Philippines practise direct seeding (BAS, 1993).

Table 1. Average pre-harvest labour utilisation (in man-days) per hectare, by activity, by source, by ecosystem, by season, by method of crop establishment and by yield level, Philippines, 1992–93.

Activity	Irrigated (wet season)			
	Transplanted		Direct-seeded	
	Average yielder	High yielder	Average yielder	High yielder
Seedbed preparation	2.59	2.62	0.00	0.00
Land preparation	19.29	15.81	17.01	13.56
Harrowing	5.83	5.53	5.87	3.87
Levelling	3.77	2.98	2.61	2.20
Pulling of seedlings	11.26	9.74	0.00	0.00
Transplanting/broadcast	29.97	30.81	2.57	2.48
Crop care and maintenance	16.61	18.76	15.30	15.21
Fertilizer application	7.16	8.15	6.19	6.13
Insecticide application	6.97	8.19	6.53	6.50
Herbicide application	2.48	2.42	2.58	2.58
TOTAL LABOUR USE	79.72	77.74	34.89	31.25
	Irrigated (dry season)			
Seedbed preparation	2.35	2.90	0.00	0.00
Land preparation	17.52	15.68	14.11	14.05
Harrowing	4.82	5.10	3.82	5.38
Levelling	3.75	2.73	2.63	2.55
Pulling of seedlings	11.24	10.88	0.00	0.00
Transplanting/broadcast	22.44	28.74	3.01	2.69
Crop care and maintenance	14.73	17.29	13.98	17.26
Fertilizer application	6.46	7.18	6.01	7.94
Insecticide application	6.21	7.91	5.26	6.66
Herbicide application	2.06	2.20	2.71	2.66
TOTAL LABOUR USE	68.28	75.49	31.10	34.00
	Rainfed (wet season)			
Seedbed preparation	2.54	2.17	0.00	0.00
Land preparation	16.55	20.52	16.26	14.34
Harrowing	5.60	6.04	3.66	3.51
Levelling	2.79	2.60	2.08	2.75
Pulling of seedlings	12.26	7.69	0.00	0.00
Transplanting/broadcast	21.76	28.08	3.09	2.13
Crop care and maintenance	13.70	16.20	11.06	11.27
Fertilizer application	6.08	7.33	4.85	4.44
Insecticide application	5.74	6.30	4.44	4.88
Herbicide application	1.88	2.57	1.77	1.95
TOTAL LABOUR USE	66.81	73.83	30.41	27.74

Source: SSPR Regular Monitoring of Rice-based Farm Household 1992–1993. PhilRice, Maligaya, Muñoz, Nueva Ecija.

Table 2. Rice production costs (Peso) and returns (in crop establishment and by yield level).

Items	Irrigated (dry season)			
	Transplanted		Direct seeded	
	Average yielder	High yielder	Average yielder	High yielder
N (kg/ha)	160	185	105	177
Average farm size (ha)	1.80	2.13	1.91	2.02
Average yield (t/ha)	2.80	5.43	2.96	5.55
Gross return (per farm)	27397.48	61888.30	30488.10	60991.74
Cash Costs	9411.39	13387.19	9083.66	11480.40
Seeds	634.74	825.16	1116.75	1414.97
Fertilizer	1745.24	2749.09	2505.90	3611.77
Insecticide	1000.33	1498.79	1110.50	1123.47
Herbicide/fungicide/molluscicide	496.29	874.56	797.18	1051.96
Irrigation	534.37	724.25	685.08	696.13
Interests on loan	1258.29	1762.62	461.21	716.04
Transportation	189.92	378.09	98.63	131.58
Fuel	200.04	451.66	205.21	418.84
Land tax	76.03	150.95	160.95	139.98
Hired labour				
Seedbed preparation	51.83	81.18	0.00	0.00
Land preparation				
Ploughing	431.61	421.66	274.53	247.67
Harrowing	240.94	168.84	178.92	156.68
Levelling	140.77	75.57	125.08	102.12
Crop care and maintenance	242.74	320.12	273.14	365.42
Hauling	61.38	139.58	110.16	186.41
Drying	54.07	143.54	37.96	42.83
Storage	0.79	0.19	2.89	37.52
Pakyaw	208.20	387.76	796.99	763.74
Non-cash costs	4052.92	5949.04	4268.54	6320.25
Landlord share	1686.84	1854.69	1781.84	1819.00
Harvesters and threshers' share	2315.08	3991.85	2436.70	4376.24
Hired labour	51.00	102.50	50.00	125.00
Imputed costs				
Operator/family/exchanged labour	367.93	342.89	439.65	517.11
Total costs	13832.24	19679.12	13791.84	18317.76
Returns above cash costs	5809.43	15668.35	6878.70	18713.53
Return above cash and non-cash costs	1756.51	9719.31	2610.17	12393.28
Return above all costs	1388.58	9376.42	2170.52	11876.17

Source: SSPR Regular Monitoring of Rice-based Farm Household 1992–93. PhilRice, Maligaya, Muñoz, Nueva Ecija.

Materials and Methods

Survey

Methods of crop establishment, seeding rates, variety and fertilizer used, pre-harvest labour utilisation, rice production costs and returns in the various ecosystems and seasons for Luzon, Visayas and Mindanao were obtained from the 1992–1993 survey conducted by the Social Science and Policy Research (SSPR) Division (PhilRice 1995). Other information on crop management practices was obtained from studies of Erquiza et al. (1990) and Casimero et al. (1993, 1994).

PhilRice experiments

In a PhilRice-IRRI collabourative study (Yamauchi et al. 1994), pre-germinated seeds were broadcast from 0 to 3 days after puddling to determine the relationship between time of broadcast and percentage seedling establishment. In this manner, anaerobic broadcast seeding or sowing pre-germinated seeds immediately after field puddling were tested. Anaerobic cultivars were tested. Anaerobic drill seeding was accomplished with the use of a commercial seeder. Standard management practices were followed.

During the 1995 dry season, a field experiment was set up and arranged as a randomised complete block with split plot treatments. Three NPK rates (0–40–40, 90–40–40 and 180–40–40 kg/ha), four N-split applications (2/3 basal + 1/3 at panicle initiation or PI, 2/3 at 10 days after seeding or DAS + 1/3 at PI, 1/3 at 10 DAS + 2/3 at PI, and 1/2 at 10 DAS + 1/3 at PI and 1/6 at flowering) and three seeding rates (80, 160 and 240 kg/ha), were used. The field was ploughed once and harrowed twice. Pre-germinated seeds of Philippine Seed Board variety PSB Rc14 were broadcast immediately after puddling and levelling. Protection against birds and snails was maximum.

Results and Discussion

Method of crop establishment, seeding rate and variety

In Luzon Island, 23% of the rice farmer respondents practised direct seeding in irrigated wet seasons, 42% in irrigated dry seasons, and 20% in rainfed wet seasons (Table 3). In the Visayas Island, 53% practised direct seeding in irrigated wet seasons, 50% in irrigated dry seasons and 74% in rainfed wet seasons. In Mindanao Island, 35% practised direct seeding in irrigated wet seasons, 43% in irrigated dry seasons and 37% in rainfed wet seasons. In these three islands, a small percentage of farmers practised a combination of direct seeding and transplanting.

Table 3. Method of crop establishment used by rice farmer respondents by island and by ecosystem, Philippines, 1992 WS and 1993 DS. N = number of respondents.

	Irrigated wet season		Irrigated dry season		Rainfed wet season	
	N	%	N	%	N	%
Method			Luzon			
Transplanting	296	74.37	219	55.87	212	78.81
Direct seeding	93	23.37	166	42.35	53	19.70
Both	9	2.26	7	1.79	4	1.49
Total	398	100.00	392	100.00	269	100.00
			Visayas			
Transplanting	54	47.37	57	50.00	32	26.45
Direct seeding	60	52.63	57	50.00	89	73.55
Both						
Total	114	100.00	114	100.00	121	100.00
			Mindanao			
Transplanting	105	64.02	95	59.76	36	59.02
Direct seeding	57	34.76	65	39.63	24	39.34
Both	2	1.22	1	0.61	1	1.64
Total	164	100.00	164	100.00	61	100.00
			Philippines			
Transplanting	455	67.31	374	55.82	280	62.08
Direct seeding	210	31.07	288	42.99	166	36.81
Both	11	1.63	8	1.19	5	1.11
Total	676	100.00	670	100.00	451	100.00

Source: SSPR Regular Monitoring of Rice-based Farm Household 1992–1993. PhilRice, Muñoz, Nueva Ecija.

In Luzon, average seeding rate was 2 cavans/ha or 100 kg/ha in irrigated wet seasons, 2.3 cav/ha in irrigated dry seasons and 4.1 cav/ha in rainfed wet seasons (Table 4). In Visayas, average seeding rate was 4.2 cav/ha or 210 kg/ha in irrigated wet seasons, 4.1 cav/ha in irrigated dry seasons and 4.2 cav/ha in rainfed wet seasons. In Mindanao, average seeding rate was 3.9 cav/ha or 195 kg/ha in irrigated wet seasons, 4.6 cav/ha in irrigated wet seasons and 3.9 cav/ha in rainfed wet seasons. On the average, direct seeding rate was higher than transplanted seeding rate by 33% in Luzon, 68% in Visayas and 95% in Mindanao (Table 4).

Field studies showed that seedling establishment was 88% when pre-germinated seeds were immediately sown after final land preparation (puddling and levelling) and decreased to 70% when sown three days after final land preparation, and that biomass accumulation and percentage seedling establishment was strongly correlated with r = 0.84 (Yamauchi et al. 1994). Broadcasting seeds immediately after the final land preparation is also termed anaerobic seeding because seeds sink to some depth below the puddled saturated soil and oxygen concentration is low. Anaerobic seeding, by virtue of soil depth, could reduce water stress, lodging, and pest damage due to birds, rats and snails. However, farmers in Nueva Ecija and Iloilo provinces broadcast pre-germinated seeds one day after the final land preparation because they observed greater seedling emergence. Hence the use of anaerobic tolerant cultivars and anaerobic seeding (Yamauchi et al. 1994) needs to be evaluated because of better crop establishment and less damage due to biotic and abiotic stresses.

Time of seeding in relation to pest and disease is also critical. Based on surveys and reseachers' experience at PhilRice, if direct seeding dates were not in synchrony with seeding dates of neighboring fields (transplanted or direct-seeded), crops would be

Table 4. Average seeding rate used by farmer respondents by island, by ecosystem and by season, Philippines, 1992 WS and 1993 DS. N = number of respondents; Seeding rate = cavan/hectare.

Seeding rate	Irrigated wet season	Irrigated dry season	Rainfed wet season
		Luzon	
Transplanting N	296	219	212
Average seeding rate	2.71	1.97	1.59
Direct seeding N	93	166	153
Average seeding rate	2	2.32	4.06
		Visayas	
Transplanting N	54	57	32
Average seeding rate	1.59	2.1	1.38
Direct seeding N	60	57	89
Average seeding rate	4.16	4.12	4.16
		Mindanao	
Transplanting N	105	98	36
Average seeding rate	2.32	2.21	1.69
Direct seeding N	57	65	24
Average seeding rate	3.92	4.63	3.87
		Philippines	
Transplanting N	455	374	280
Average seeding rate	2.49	2.05	2.88
Direct seeding N	210	288	266
Average seeding rate	3.14	3.20	4.08

Source: SSPR Regular Monitoring of Rice-based Farm Household 1992–1993. PhilRice, Muñoz, Nueva Ecija.

infested with rice tungro virus, resulting in substantial yield loss. Other pests like stem borer, snails (during crop establishment) and birds (during crop establishment and maturity stage) have to be managed properly.

Modern varieties (for example IR64, IR72 and PSB Rc2) that have been developed for transplanting were also used for direct or broadcast seeding. Based on field experiments wherein semi-dwarf IR rices were direct seeded, basic plant type for direct seeded flooded tropical rice has been described by Dingkuhn et al. (1991). Dingkuhn et al. (1991) indicated that components of a new plant type for greater resource use efficiency and yield potential include:

a) enhanced foliar growth during crop establishment, in combination with reduced tillering;
b) less foliar growth and enhanced assimilate export from leaves to stems during late vegetative and reproductive growth, along with sustained high foliar nitrogen (N) concentration;
c) a steeper slope of the vertical N concentration gradient in the leaf canopy, with more N present in the uppermost stratum;
d) expanded capacity of stems to store assimilates; and
e) improved reproductive sink capacity, with a prolonged ripening period.

Fertilizer and grain yield

In Nueva Ecija Province, Central Luzon, about 40% of the farmers used nitrogen (usually urea) rates of 61 to 90 kg/ha during the dry and wet seasons (Fig. 2). A lower percentage of the farmers used rates of 0 to 30 and 120 or more kg N/ha during the dry and wet seasons. Phosphorus rates ranged from 0 to 60 kg/ha and potassium rates ranged from 0 to 40 kg/ha during the dry and wet seasons (Casimero et al. 1993). Fifty per cent of farmers in Nueva Ecija and Iloilo (in Visayas island) reported grain yields of up to 5 t/ha during the wet season (Fig. 3). A lower percentage of the farmers reported yields of 4 to 8 t/ha during the wet season. In the dry season, about 60% of the farmers reported yields of 5 t/ha and a lower percentage with yields of 4 to 9 t/ha (Fig. 4).

The field study at PhilRice showed that when N rate was increased from 0 to 90 kg/ha, average grain yield of PSB Rc14 increased from 6 t/ha (Fig. 5) to 7 t/ha (Fig. 6). The different seeding rates i.e., 80 to 240 kg/ha, and the different N split applications at 90 kg/ha (Figs 5 and 6) did not statistically influence grain yield. Hence, seeding rates of 80 to 100 kg/ha appear to be optimum under experimental and farmers' field conditions, and that information on soil available N and crop demand for N can guide a more effective N split application scheme.

It is interesting to note that the average grain yields obtained under PhilRice experimental conditions (Figs 5 and 6) were higher than yields

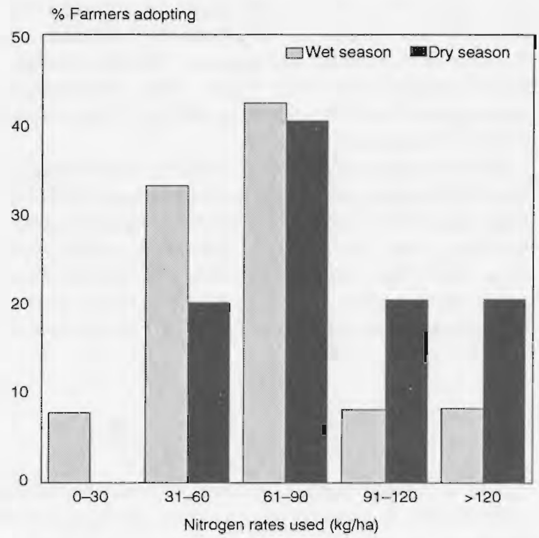


Figure 2. Amount of nitrogen fertilizer applied by farmers adopting wet-seeding, Nueva Ecija Province, Philippines, 1993. Source: Casimero et al. 1993.

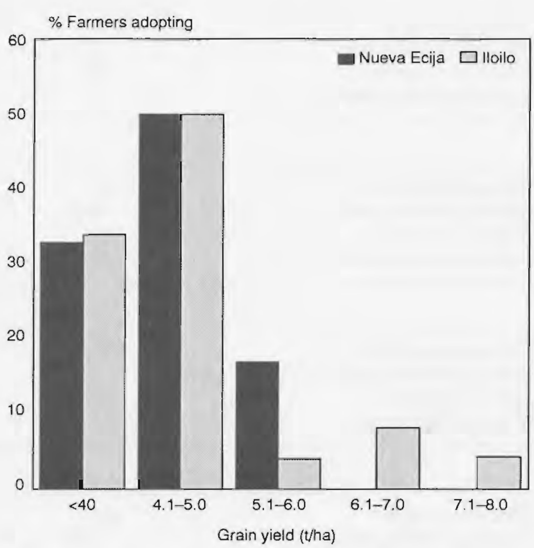


Figure 3. Grain yield on farms after adoption of wet-seeding in Nueva Ecija and Iloilo Provinces, Philippines, 1993 wet season. Source: Casimero et al. 1993.

obtained in farmers' fields in Nueva Ecija and Iloilo provinces (Figs 3 and 4) and average yields in the Philippines (Table 2). Such yield discrepancies could be attributed to N supply and management, pest (weeds, insects, snails, birds and others) management, and the use of adaptable varieties.

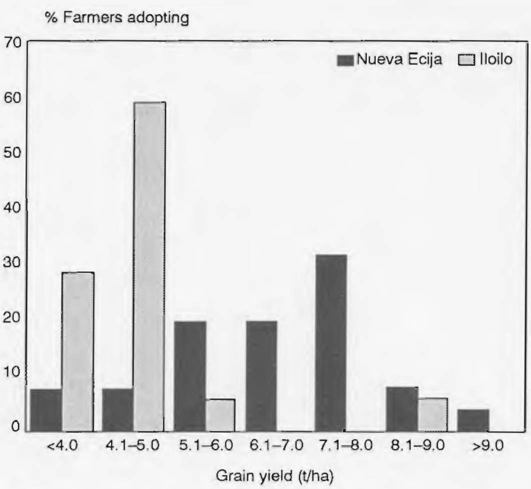


Figure 4. Grain yield on farms after adoption of wet-seeding in Nueva Ecija and Iloilo Provinces, Philippines, 1993 dry season. Source: Casimero et al. 1993.

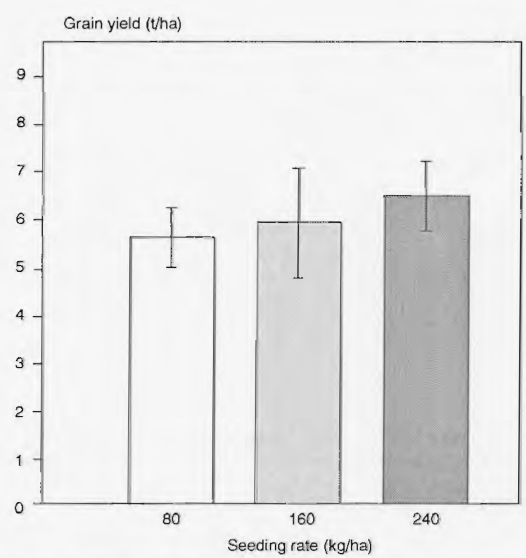


Figure 5. Yield of PSB Rc14 at different seeding rates at 0–40–40 NPK kg/ha, PhilRice, 1995 DS.

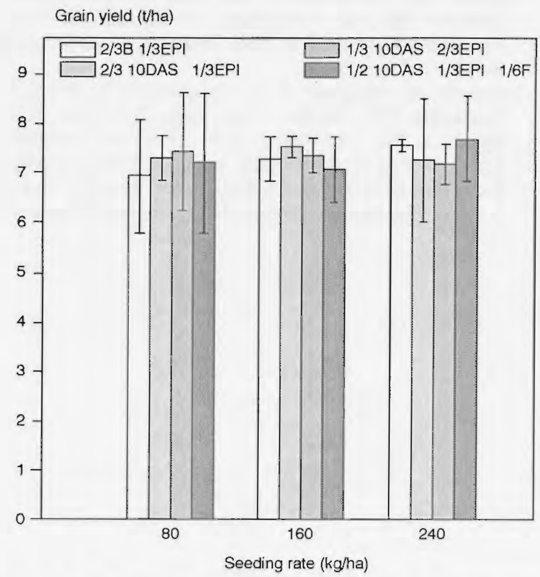


Figure 6. Yield of PSB Rc14 at different seeding rates and time of N application at 90–40–40 NPK kg/ha, PhilRice, 1995 DS.

References

BAS (Bureau of Agricultural Statistics) 1993. Handbook of Rice Statistics, Quezon City, Philippines.

Casimero, M.C., Panyakaew, T., Khotsimuang, S., Chhay, S., Badaruddin, S., Shen, G., Chu, H.V., Estorninos, Jr L.E., and Moody, K. 1993. Paper presented at the 25th Convention of the Pest Management Council of the Philippines, Cagayan de Oro City, 3–6 May 1993.

Casimero, M.C., Cruz, R.T. and Obien, S.R. 1994. Weed management in wet-seeded rice in the Philippines. In: Constraints, Opportunities, and Innovations for Wet-Seeded Rice, 31 May to 3 June 1994, Maruay Garden Hotel, Bangkok, Thailand.

De Datta, S.K. and Nantasomsaran, P. 1991. Status and prospects of direct seeded flooded rice in tropical Asia. In: Direct Seeded Flooded Rice in the Tropics. IRRI, Los Baños, Laguna, Philippines.

Dingkuhn, M., Penning de Vries, F.W.T., De Datta, S.K. and van Laar, H.H. 1991. Concepts for a new plant type for direct seeded flooded tropical rice. In: Direct Seeded Flooded Rice in the Tropics. IRRI, Los Baños, Laguna, Philippines.

Erquiza, A., Duff, B. and Khan, C. 1990. Choice of rice crop establishment technique: transplanting vs. wet seeding. IRRI Research Paper series 139. 10 p. Los Baños, Laguna, Philippines.

PhilRice 1995. Social Science and Policy Research (SSPR) Division Regular Monitoring of Rice-Based Farm Household from 1992 to 1993. PhilRice, Muñoz, Nueva Ecija.

Yamauchi, M., Aragones, D.V., Casayuran, P.R., Winn, T., Borlagdan, P.C., Aguilar, A.M., Asis, C.A., Cruz, R.T., Sta Cruz, P.C. and Quick, G.R. 1994. Rice anaerobic direct seeding in the tropics. In: Constraints, Opportunities, and Innovations for Wet-Seeded Rice, 31 May to 3 June 1994, Maruay Garden Hotel, Bangkok, Thailand.

Reducing Bypass Flow during Land Soaking of Cracked Rice Soils

T.P. Tuong and R.J. Cabangon[1]

Abstract

High water loss during land soaking of rice soils results from bypass flow through cracks. It was hypothesised that bypass losses could be reduced by measures which minimise the crack development or impede the flow of water in the cracks. The effect of straw mulching and shallow tillage during the fallow period on crack formation, total water required for land soaking and bypass losses was investigated at two Epiaqualf sites with relatively permeable subsoil (saturated hydraulic conductivity 0.1–0.5 m/d). Compared with the control, where no attempt was made to manage soil during the fallow period, straw mulching reduced the mean crack width from 40 mm to 27 mm. Mean crack depth decreased only slightly, from 115 mm to 105 mm, resulting in a non-significant reduction in total water input. Shallow tillage reduced 29–38% of the total water input for land soaking and 32–52% of the bypass flow losses. Small soil aggregates formed by shallow tillage blocked the cracks and made the crack flow discontinuous. Shallow tillage also allowed faster infiltration into the soil clods in the surface layer and reduced the amount of water to flow in the cracks. In rainfed areas, the introduction of this practice may lead to earlier crop establishment and therefore reduced risk of late-season drought. Water savings during land soaking may also allow an increase in the service area of an irrigation system.

RICE production is known to be less water-efficient than that of other crops. Given the growing demand for water for non-agricultural uses and high costs of development and maintenance of irrigation schemes, improving water-use efficiency is crucial for lowland rice production.

The first step in lowland rice production is land soaking. Rice fields are irrigated until the topsoil is saturated and a water layer of 10–50 mm depth is ponded on the field. Land soaking is followed by ploughing and harrowing operations under water saturated conditions to 'puddle' the topsoil to a depth of 0.15–0.20 m. After transplanting or direct rice seeding, the field is kept flooded throughout the growing season (about 50 mm water depth). To facilitate harvesting, irrigation is often stopped two weeks before the crop reaches maturity (De Datta 1981). Rice soil is often left dry during the fallow period prior to the next cropping season.

Drying of a puddled soil usually results in soil shrinkage and cracking. Cracks are especially prominent if expanding clay minerals are present, but they may also be clearly noticeable in kaolinitic soils (Moormann and van Breemen 1978). Ishiguro (1992) reported crack widths of about 2 cm and crack depths of 7–20 cm in puddled rice soil subjected to 20–30 days of drying. Wopereis et al. (1994) found cracks reaching a depth of 65 cm in a dry, previously puddled montmorillonitic rice soil.

Land soaking of the next rice crop thus usually starts with irrigation of cracked soils. Bypass flow losses (water that flows through the cracks to the subsoil) accounted for 41–57% of the total water for land soaking applied to the field (Tuong et al. 1995) and 94% in undisturbed soil cores (Wopereis et al. 1994). Reducing bypass losses during land soaking may greatly increase water-use efficiency of rice production systems.

The flow processes during land soaking are dominated by water flow in the cracks (Wopereis et al. 1994, Tuong et al. 1995). Water saving may focus on measures which affect the flow of crack water. Straw

[1] Soil and Water Sciences Division, International Rice Research Institute, PO Box 933, Manila, Philippines

mulching, by reducing evaporation from soil surface (Hundal and Tomar 1985), can minimise soil shrinkage, lessen crack development and therefore may reduce bypass flow losses. Wopereis et al. (1994) showed that shallow surface tillage (0–5 cm depth) reduced 45–60% of the bypass flow in undisturbed columns of cracked rice soils. This was due to soil aggregates which blocked the cracks and made them discontinuous. These measures, however, have not been tested in the field.

This paper reports on investigations into the effects of mulching and shallow surface tillage on crack development during the fallow period and on bypass flow losses during land soaking of dry, cracked and previously puddled rice soils in field conditions.

Materials and Methods

Experimental sites

The study was conducted during the 1993–1994 dry seasons using an experimental field (block E47) at the International Rice Research Institute (IRRI), Los Baños (14°30′ N, 121° 15′ E), and six farmers' fields in the Angat River Irrigation System, Bulacan (14° 47′ N, 120° 55′ E), Philippines. Both sites have two distinct seasons, i.e., wet from July to November and dry from December to June. According to soil taxonomy (Soil Survey Staff, 1992), the soil at the IRRI site was classified as an Aquandic Epiaqualf (H.U. Neue 1995, unpublished data) and at the Bulacan site as a Typic Epiaqualf (Miura et al. 1995). The topsoil at both sites was silty clay. Soil at IRRI was developed from volcanic ash, with montmorillonite as the dominant clay mineral (Bajwa, 1982) and soil at Bulacan from recent alluvial deposit. The fields were puddled to a depth of 0.2 m and flooded for rice cultivation in the previous seasons. Vertical saturated conductivity of the 0.3–0.5 m subsoil was 0.5 m/d at IRRI and 0.1 m/d at Bulacan. At the time of land soaking, ground water was 0.85 m deep in 1993, 1.1 m in 1994 at the IRRI fields and 0.5 m at the Bulacan site.

Treatments

At IRRI

The experiment was carried out in 6 m × 11 m plots surrounded by bunds (30 cm in width and 25 cm in height). The plots were hydraulically isolated by polyethylene sheets installed in the middle of the bunds and extending vertically to a depth of 0.7 m below the soil surface. At the start of the experiment, all plots were flooded, ploughed, puddled, and levelled (on 18–20 April 1993 and 23–25 January 1994) to attain similar soil conditions before the treatments were applied. Surface water from all plots was drained on 21 April 1993 and 26 January 1994. All fields were sun-dried during the fallow period until land soaking for the next rice crop was carried out on 31 May 1993 and 17 May 1994.

During the fallow period, three management treatments were imposed in a randomised complete block design with four replications.

- *Straw mulching.* 5 t/ha of rice straw was broadcast over the plot one day after drainage (DAD). The straw mulch remained on the soil surface during the fallow period.
- *Shallow surface tillage.* Plots were rototilled to 5–10 cm depth by two passes of IRRI-manufactured mini-rototiller at 18 DAD in 1993 and 14 DAD in 1994. The date of rototilling was decided on by the rototiller operator, basing his decision on there being adequate soil bearing capacity to support the implement. Shallow tillage resulted in a topsoil consisting of clods with an average diameter of about 20 mm.
- *Control.* No treatment was applied during the fallow period.

In the 1994 experiment, the straw mulching treatment was not included.

In Bulacan

The authors monitored the amount of water used in six farmers' fields from 17 June 1993 until land soaking of the last field was completed on 11 July. The fields measured 80–90 m × 120–165 m. They were harvested in the second week of March, 1993. Three fields were left fallow until land soaking on 10–11 July. In the other three fields, farmers rototilled the land to a depth of approximately 10 cm using rototillers drawn by four wheeled tractors. This shallow tillage was carried out on 12, 20 and 29 May 1993, i.e., at the onset of the rainy season. Land soaking in fields with shallow tillage was carried out on 28 June, 6 and 10 July 1993.

Measurement of soil moisture content and physical properties

All measurements in the IRRI plots were carried out from walk-boards installed across the plots to ensure minimum disturbance to the soil. Volumetric soil moisture content at 0–0.1 m, 0.1–0.2, 0.2–0.3 and 0.3–0.5 m was measured at 2–3 day intervals during the fallow period and at the completion of the land soaking.

In farmers' fields, watertable depth and soil moisture content were monitored at 0–0.2 m, 0.2–0.3 m, and 0.3–0.5 m depths at three stations along the centre transect of each field. Measurements were taken at the start of the monitoring program (17 June 1993), before and after land soaking.

Measurement of crack dimensions

At the IRRI fields, crack depth and width were monitored at 1–2 day intervals during the fallow period in one 1 m × 1 m subplot in each of the control and mulched plots. In the mulched plots, straw was removed from the subplots before and reinstalled after each measurement. Crack dimensions in farmers' fields were measured in two 1 m × 1 m subplots per field two to three days before land soaking.

In each subplot, a flexible wire (1.5 mm in diameter, 40 cm in length) and a ruler are used to measure crack width and depth at the intersections of the 20 cm spaced X–Y grid lines and the cracks as described by Lima and Grismer (1992) and Tuong et al. (1995). From the measurements, the mean crack widths and depths and the mean crack volume per unit field surface area could then be calculated (Tuong et al. 1995).

Water application and monitoring

Irrigation was applied from one end of each field, through a 7.5 cm pipe in the IRRI fields and from irrigation channels via two 15 cm culverts in farmers' fields in Bulacan. Application discharge was measured by a box-type 90° V-notch weir (IRRI fields) or a trapezoidal weir (farmers' fields). Discharge per unit width was 0.14–0.26 L/s/m at IRRI and 0.06 to 0.12 L/s/m in the farmers' fields. Water from the pipe (IRRI) or culverts (farmers' fields) was spread across the width of the field by a 0.3 m deep × 0.3 m wide distribution canal alongside the intake end of each field. Water overflowed the bank of the distribution canal and advanced to the other end of the field. Irrigation was stopped when the surface water reached the other end of the field.

Computation of water flow components

Water balance calculation was carried out during the land soaking at the IRRI fields. For the Bulacan fields, water balance was calculated for two periods: from 17 June to the land soaking and during the land soaking. Water flow components, expressed in mm of water over each field, can be quantified with the following equation:

$$I + R = S_s + S_c + A + E + BP$$

where: I = irrigation water; R = rainfall; S_s = surface water storage; S_c = crack storage, i.e., the amount of water that fills the cracks in the field; A = water absorbed in the topsoil matrix (0–0.2 m depth); E = evaporation from the field; and BP = flow component bypassing the topsoil matrix. I was calculated from the total volume of water applied (integral of flow discharge over time) divided by the field area. R was monitored with rain gauges installed at the experimental sites. S_s was the average depth of the surface water during the land soaking. S_c was the volume of cracks under the surface water, expressed in mm water depth. A was computed from the difference in soil moisture contents of the topsoil layer (0–0.2 m depth) at the beginning and at the end of the computing period.

At IRRI, evaporation losses (E) were neglected since water balance components were calculated for one day only (i.e., the day of land soaking). For Bulacan, evaporation losses had to be taken into account, because of the large time span (from 17 June to the end of the land soaking) over which measurements were taken. Evaporation losses from a dry, cracked, and previously puddled soil that is slowly wetted by rainfall are, however, difficult to determine. The topsoil water content in the Bulacan fields changed from dry to nearly saturated during the period before land soaking. Evaporation losses were estimated by multiplying open water evaporation losses (measured with a class A pan) by 0.5.

Losses due to bypass flow (BP) were derived from the difference between input (I + R) and surface storage, crack storage, soil absorption and evaporation ($S_s + S_c + A + E$).

Results and Discussion

Soil moisture content at the IRRI fields

For simplicity only soil moisture content at depths 0–0.1 m and 0.1–0.2 m are presented (Fig. 1). Sudden increases in soil moisture content from 10 DAD (1993) and 44 DAD (1994) were due to intermittent rains.

In the 1993 experiment, soil moisture content at depths 0–0.1 m and 0.1–0.2 m of the mulched plots was consistently higher than the control and shallow-tilled plots (Fig. 1). At 0.2–0.3 m depth, moisture content of the mulched plots was higher than other treatments until about 18 DAD. The difference at the later stage, being affected by intermittent rains, was not significant. Moisture content at 0.3–0.5 m depth did not differ in different treatments (data not shown). Straw mulch was effective in reducing soil surface evaporation (Hundal and Tomar 1985).

Water content of the 0–0.1 m depth of the tilled plots did not differ significantly from that of the control (Fig. 1, for the 1993 experiment). Soil moisture at depths 0.1–0.2 m (Fig. 1 for 1993) and 0.2–0.3 m (data not shown) in the tilled plots was significantly higher than that in the control plots. Shallow tillage formed a soil-mulch, reducing water losses from deeper layers.

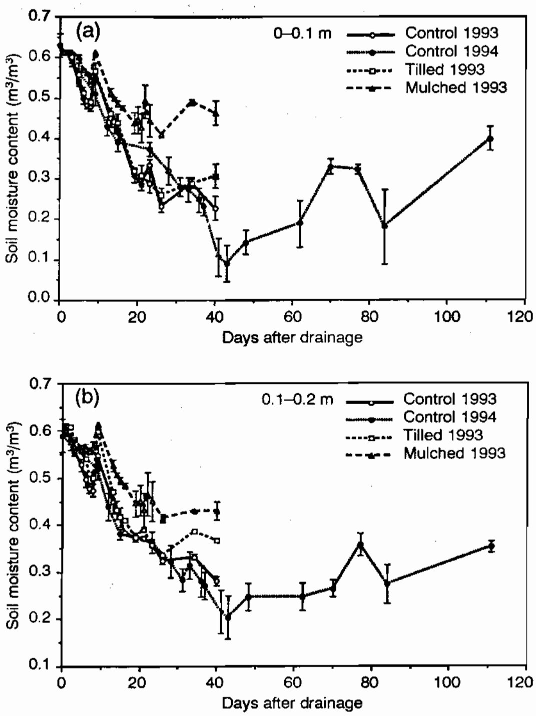


Figure 1. Soil moisture contents in different treatments after the field drainage at the IRRI fields, 1993 and 1994 dry seasons, (a) at depth 0–0.1 m and (b) at depth 0.1–0.2 m. Bars indicate standard errors of the mean values for three measurements.

Crack dimensions at the IRRI fields

Mean crack width and depth of the control (1993 and 1994 experiments) and the mulched plots (1993 experiment) are presented in Figures 2 and 3. Both crack width and depth increased more rapidly in the control plots than in the mulched plots. This is presumably due to the slower rate of soil drying in the mulched plots (Fig. 1). Initial increase in crack depth and width in the first 8–10 DAD in the control treatment (Fig. 2) corresponded to the rapid loss of moisture from the surface layer (Fig. 1). In the control treatment, a slower rate of increase in crack depth and width in the 1994 experiment compared to the 1993 experiment conformed with a slower rate of decrease in water content in soil layers in 1994 (Fig. 1). A similar relation between rate of soil drying and rate of crack development was reported by Ringrose-Voase and Sanidad (1995).

In the 1993 experiment, cracks in the control treatment reached a maximum mean depth of about 115 mm and width of about 40 mm at 19 DAD. Both mean crack depth and width did not change significantly afterward. At the end of the fallow period, the crack width of the mulch treatment was significantly lower than that in the control treatment (Fig. 2). The final crack depth in the mulch treatment was also less, but not distinctively (approximately 105 mm), than in the control treatment (Fig. 3). The difference in the final crack width presumably due to wide difference in the final soil moisture of the surface layer (Fig. 1a) in the two treatments. Crack depth (i.e. the formation of crack at lower depths) was influenced also by soil moisture at layers below the surface soil. Less pronounced differences in soil moisture at deeper soil layers from 20 DAD in the two treatments might have resulted in only slightly different crack depth.

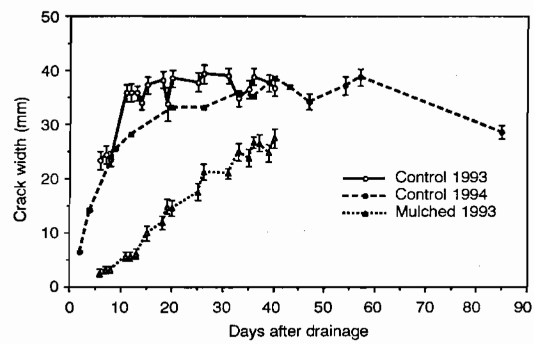


Figure 2. Mean crack widths in different treatments after the field drainage at the IRRI fields, 1993 and 1994 dry seasons. Bars indicate standard errors of the mean values for 55–161 measurements.

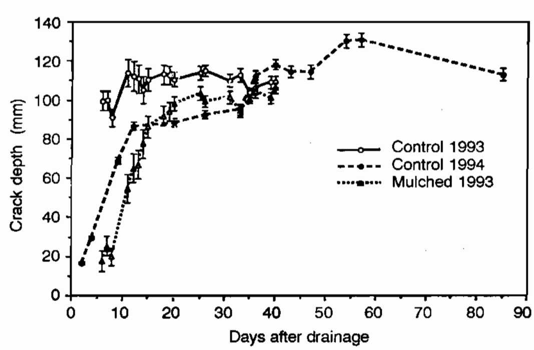


Figure 3. Mean crack depths in different treatments after the field drainage at the IRRI fields, 1993 and 1994 dry seasons. Bars indicate standard errors of the mean values for 55–161 measurements.

Crack width in the control plots in the 1994 and 1993 experiments were of about the same size (Fig. 3). The zero shrinkage portion of the shrinkage characteristic curve of a similar puddled soil began at a soil moisture content of 0.25 m^3/m^3 (Wopereis 1993). This implied that upon further drying, no more shrinkage would take place. In both years, soil moisture of the topsoil layer was below 0.25 m^3/m^3, implying maximum shrinkage had taken place. Crack depth was, however, greater in the 1994 experiment, reaching a mean value of about 140 mm (Fig. 3). This corresponded to lower soil moisture at the deeper soil layers (Fig. 1b for depth 0.1–0.2 m) in the 1994 experiment.

Water components

Table 1 presents water balance components computed for different treatments during the land soaking irrigation in the 1993 and 1994 experiments at the IRRI fields. The amount of irrigation water needed for land soaking ranged from 93 to 272 mm. Water balance components for the Bulacan fields are shown in Table 2. Total water input in the Bulacan fields (196–290 mm) included 57–70 mm of irrigation water and 139–220 mm of rain (139–170 mm prior to and 0–50 mm during the land soaking).

At the IRRI fields, the increase in water needed for land soaking in the control plots in 1994 compared to 1993 was caused mainly by increased bypass water loss (Table 1). This corresponded to deeper cracks (Fig. 3) and a deeper watertable in 1994.

In the 1993 experiment at IRRI, mulching did not reduce significantly the amount of irrigation water for land soaking (Table 1). By reducing the evaporation loss during the fallow period, mulching reduced the amount of water needed to saturate the surface soil layer. This amount was however a very small portion of the total water input (Table 1). Its reduction did not result in total water savings. In fact, due to higher soil moisture content before land soaking (Fig. 1) and smaller cracks in the mulched plots compared to the control plots, less water was absorbed in 0–0.2 m layer and stored in cracks during land soaking. This resulted in slightly higher bypass losses in the mulched treatment (Table 1).

In both years at the IRRI fields, the amounts of total irrigation water for land soaking and bypass flow in plots with the shallow tillage were significantly less than those in the control plots. Bypass flow from the shallow-tilled plots was 48% (20 mm : 41 mm in 1993 and 99 mm : 205 mm in 1994) of that from the control plots (Table 1). Corresponding values for the total irrigation water for land soaking were 63–71% (93 mm : 130 mm in 1993 and 172 mm : 272 mm in 1994). Findings at the IRRI fields were confirmed in farmers' fields. Shallow tillage reduced 32% (from 290 mm to 196 mm, Table 2) of the total water input and 38% (from 166 mm to 102 mm, Table 2) of the bypass loss. Wopereis et al. (1994) also reported that shallow tillage reduced about 45% to 60% of the bypass loss from large undisturbed soil columns.

Some of the smallest soil aggregates formed by tillage blocked the cracks, made them discontinuous and impeded the water flow in the cracks. Soil clods also increased infiltration surface area, allowing more water to absorb in the surface layer and reducing the amount of water that could flow into the cracks.

Table 1. Water balance components during land soaking as affected by surface soil management treatments at the IRRI fields in the 1993 experiment (in normal font) and 1994 experiment (in italic). All water components are expressed in mm of water over the area of the field. There was no rain and evaporation was neglected during land soaking.

	Year	Treatment		
		With mulch	With shallow tillage	Control
Irrigation water	1993	109ab†	93b	130a
	1994		*172a*	*272b*
Surface storage	1993	20	20	20
	1994		*25*	*21*
Crack storage	1993	9	0	13
	1994		*0*	*20*
Absorbed water in 0–0.2 m soil layer	1993	27	53	56
	1994		*48*	*26*
Bypass flow	1993	53a	20b	41a
	1994		*99a*	*205b*

† In the same row, means followed by a common letter (a, b) are not significantly different at 5% level by DMRT.

Table 2. Water balance components for land soaking as affected by tillage treatments in farmers' fields, Bulacan, 1993. All water components are expressed in mm of water over the area of the field. Total water inputs (values in brackets) are sum of irrigation water and rainfall.

Component	Without shallow tillage			With shallow tillage		
	Prior to	During		Prior to	During	
	Land soaking		Total	Land soaking		Total
Irrigation water	0	70	70	0	57	57
Rainfall	170	50	220	139	0	139
(Total water input)	(170)	(120)	(290a)†	(139)	(57)	(196b)
Evaporation	43	2	45	32	2	34
Surface storage	0	30	30	0	30	30
Crack storage	0	10	10	0	0	0
Absorbed water in 0–0.2 m soil layer	28	11	39	19	11	30
Bypass flow	99	67	166a	88	14	102b

†In the same row, means followed by a letter (a, b) are not significantly different at 5% level by DMRT.

Conclusions

Straw mulching helped conserve moisture in the soil profile, reduced crack development during the fallow period but did not reduce the bypass loss during land soaking. Shallow surface tillage reduced from 32–71% of the total water input for land soaking and 38–52% of the bypass loss compared to the control treatment. This resulted in about 100 mm of water savings in total water input for land soaking in farmers' fields. Shallow tillage makes cracks discontinuous, and retains water better in the topsoil. This practice can be an important measure to increase water-use efficiency of rice production in areas where water losses during land soaking and land preparation are high due to relatively permeable subsoil. In the rainfed areas, shallow surface tillage may lead to earlier crop establishment and therefore reduced risk of late-season drought. Water savings during land soaking may also allow an increase in the service area of an irrigation system.

References

Bajwa, M. 1982. Phosphorous status of Philippines rice soils with different clay mineralogical characteristics. Fertilizer Research 3, 435–438.

De Datta, S.K. 1981. Principles and Practices of Rice Production. John Wiley and Sons, New York.

Hundal, S.S. and Tomar, V.S. 1985. Soil-water management in rainfed rice-based cropping systems. In: Soil Physics and Rice, 337–349. International Rice Research Institute, PO Box 933, 1099 Manila, Philippines.

Ishiguro, M. 1992. Effects of shrinkage and swelling of soils on water management in paddy fields. In: Murty, V.V.N. and Koga, K., ed., Soil and Water Engineering for Paddy Field Management. 258–267. Irrigation Engineering and Management Program. Asian Institute of Technology, Bangkok, Thailand.

Lima, L.A. and Grismer, M.E. 1992. Soil crack morphology and soil salinity. Soil Sci., 153 2, 149–153.

Miura, K., Badayos, R.B. and Briones, A.M. 1995. Pedological characterization of lowland area in the Philippines. Univ. of the Phil. at Los Baños. 271 p.

Moormann F.R and van Breemen, N. 1978. Rice: Soil, Water, Land. International Rice Research Institute, PO Box 933, 1099 Manila, Philippines, 185 p.

Ringrose-Voase, A.J. and Sanidad, W.B. 1995. A method for measuring the development of surface cracks in soils: application to crack development after lowland rice. Geoderma (in press).

Soil Survey Staff, 1992. Keys to soil taxonomy. Soil Manage. Support Serv. Tech. Monogr. 19. Fifth ed. Pocahontas Press, Blacksburg, VA.

Tuong, T.P. , Cabangon, R. and Wopereis, M.C.S. 1995. Quantifying flow processes during land soaking of cracked rice soils. Soil Sci. Soc. Am. J., (Accepted).

Wopereis, M.C.S. 1993. Quantifying the impact of soil and climate variability on rainfed rice production. Ph.D. thesis, Wageningen University, ISBN 90-5485-147-3.

Wopereis, M.C.S., Bouma, J., Kropff, M.J. and Sanidad, W. 1994. Reducing bypass flow through a dry, cracked and previously puddled rice soil. Soil Till. Res., 29, 1–11.

Soil Compaction — Make It or Break It for Rainfed Lowland Ecosystems

L.J. Wade[1]

Abstract

In the rainfed lowlands, a hardpan may be considered beneficial if leaching loss is reduced, or detrimental if root access to resources deeper in the profile is denied. This paper contrasts research into the coarse-textured, permeable soils of northeast Thailand with research into the silty, compaction-prone soils of northwest Bangladesh. The former research has indicated a benefit to yield of rainfed lowland rice by compacting the subsoil, which reduces percolation losses and increases resource availability to the crop. In contrast, use of deep cultivation or a pre-rice legume to perforate the hardpan is resulting in higher yields of rainfed lowland rice in the latter. Recent research exploring variation among rice lines in their capacity to penetrate a hardpan is also reviewed. The results are discussed in relation to recent research which indicates that control of root development under the anaerobic-aerobic transitions of the rainfed lowlands is not clear. The paper concludes that further understanding is required of factors which control root system development under rainfed lowland conditions. Crop simulation would also assist definition of conditions in which making or breaking the hardpan may be beneficial, and in quantifying the associated probabilities for contrasting sites.

WATER stress is commonly considered the most severe limitation to productivity of rice in the rainfed lowland ecosystem. Because rainfed lowland rice is grown in bunded fields without water control, hydrologic conditions may fluctuate from submergence to drought, with major consequences for root growth, nutrient availability and weed competition (Garrity et al. 1986). Although a deeper root system has been advocated as being beneficial for accessing resources from deeper layers of the soil profile (Fukai and Cooper 1995), most data for rainfed lowland rice indicate the root system remains remarkably shallow (Pantuwan et al. 1995a,b; Samson et al. 1995). One factor which may be contributing to the shallow-rooted nature of this crop could be the capacity of the root system to penetrate non-puddled or compacted soil layers (Yu et al. 1995). If the roots do penetrate, however, would resources be available for capture of water from deeper layers of the soil profile below the hardpan? Conversely, when soils are permeable, development of a hardpan could be beneficial for reducing loss of resources (Sharma et al. 1995a).

On the coarse-textured, permeable soils of northeast Thailand, research is examining the effects of compacting the subsoil, reducing percolation losses of water and nutrients, and restricting the root zone on performance of rainfed lowland rice. In contrast, hardpans are common in the Barind tract of northwest Bangladesh, and perforation of the hardpan by deep cultivation or a pre-rice legume is being explored to determine whether resource availability would be increased in late season drought. Variation among rice lines in their capacity to penetrate a hardpan is also being examined. This paper discusses progress in this area and considers priorities for further research.

[1]Agronomy, Plant Physiology and Agroecology Division, International Rice Research Institute, PO Box 933, Manila 1099, Philippines

Making Hardpans for Rainfed Lowland Rice in Northeast Thailand

Rainfed, lowland rice is grown on about 5.0 million hectares in northeast Thailand, with an average yield of only 1.5 t/ha. Annual rainfall ranges from 1000 mm in the west to more than 2000 mm in the east, with high spatial and temporal variability (Saenjan et al. 1990). Soils are generally coarse-textured, with low cation exchange capacity, low water-holding capacity, and very high permeability (Herrera et al. 1995). In these conditions, water-use efficiency may be improved by reducing percolation. Although puddling may decrease permeability, it has not been effective on sandy soils (Sharma and De Datta 1986). A plastic sheet barrier at 40 cm depth has been used to conserve rainwater and increase productivity of rainfed lowland rice (Garrity and Vejpas 1992), but this technique was expensive, labour-intensive and impractical. The depth of the percolation barrier established an absolute limit to water storage in the root zone under extended drought (Parashar 1978). Soil compaction has been used to decrease percolation in irrigated lowland rice on sandy soils (Agrawal 1991). Recently, research has examined the use of subsoil compaction to reduce percolation and raise water-use efficiency in rainfed lowland conditions (Sharma et al. 1995a,b).

Typical characteristics for the experimental site at Ubon Ratchathani are indicated in Table 1. The soil was sandy, acid, and low in organic matter and buffering capacity. Data for three treatments are examined here, with further details provided by Sharma et al. (1995b). In dry tillage, soil was disc-ploughed to 15 cm depth before the rains. Puddling was achieved by mixing the wet soil using shovels and a wooden harrow. Nine passes of a 12 tonne Dynapac CA25 Road Roller with vibration were used to achieve subsoil compaction in 1992.

Tillage treatments differed in soil penetration resistance at depth (Fig. 1), measured using a recording cone penetrometer with a 1 cm^2 cone base. For dry tillage, penetration resistance remained below 1MPa throughout the profile. With subsoil compaction, penetration resistance was similar for the top 15 cm, but increased to about 3.0 MPa from 20 cm to 50 cm depth. Puddling was intermediate, with penetration resistance increasing to 1.5 MPa at 20 cm depth. Components of the water balance were affected by these tillage treatments (Table 2). Daily water use was halved by subsoil compaction, with daily percolation losses reduced by a factor of eight relative to dry tillage. Percolation was also reduced to some extent by puddling. Daily evapotranspiration (and seepage) increased for subsoil compaction and puddling, but this represented a smaller proportion of daily water use for puddling. Consequently with subsoil compaction, more water was available to the crop, so non-flood duration was shorter, and total dry weight and grain yield of rice were greater in both seasons. These changes were associated with a large increase in root length density with subsoil compaction (Fig. 2). The increase was due to much greater root proliferation in the surface layer, even though there were fewer roots at depth. It is not known for how long these effects of subsoil compaction in 1992 would persist.

Table 1. Annual rainfall and soil characteristics of the 0–10 cm soil layer for the Rainfed Lowland Rice Research Consortium key sites at Ubon Ratchathani in Thailand and Rajshahi in Bangladesh (after Sharma et al. 1995b; Ahmed et al. 1995b).

	Ubon Ratchathani	Rajshahi
Rainfall, mm	1500	1400
CEC, meq/100 g	3	15
pH, 1:1 H_2O	4.3	5.8
OM, g/kg	0.5	1.5
Bray-II P, mg/kg	5.0	15.0
Particle size distribution (%)		
Sand	76	5
Silt	18	51
Clay	6	44

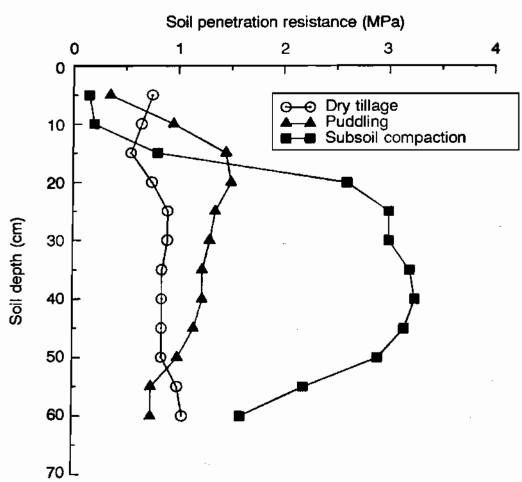


Figure 1. The effect of dry tillage, puddling and subsoil compaction on penetration resistance profiles in a loamy–sand soil at Ubon Ratchathani Thailand in the 1992 wet season (after Sharma et al. 1995b).

Table 2. The effect of dry tillage, puddling and subsoil compaction on components of water balance and productivity of rainfed lowland rice at Ubon Ratchathani, Thailand (after Sharma et al. 1995b).

	Dry tillage	Puddling	Subsoil compaction
Water balance components — 1992 wet season			
Percolation (mm/d)	11.8 a*	6.3 b	1.4 c
ET + Seepage (mm/d)	4.8 b	7.1 a	7.2 a
Water use (mm/d)	16.6 a	13.4 a	8.6 b
Non-flood duration (d)	63.0 a	39.0 b	17.0 c
Rice productivity — 1992 and 1993 wet seasons			
1992			
Dry weight (t/ha)	7.0 b	7.4 b	11.1 a
Grain yield (t/ha)	2.4 b	2.5 b	4.0 a
1993			
Dry weight (t/ha)	3.2 c	4.1 b	5.3 a
Grain yield (t/ha)	0.9 b	1.1 b	2.1 a

*Within a row, means followed by a common letter do not differ significantly (P=0.05).

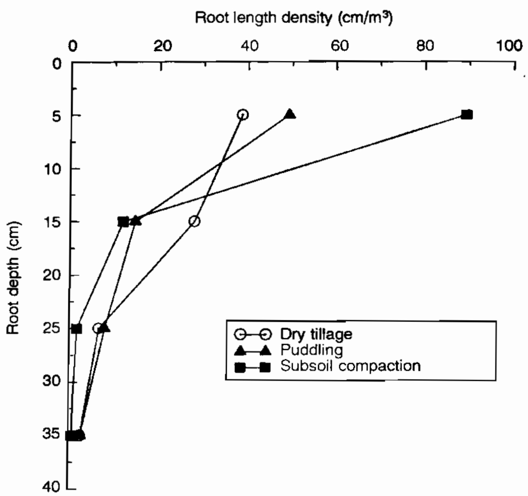


Figure 2. Root length density of rice cultivar KDML105 in response to dry tillage, puddling, and subsoil compaction in a loamy-sand soil at Ubon Ratchathani Thailand in the 1992 wet season (after Sharma et al. 1995b).

Breaking Hardpans for Rainfed Lowland Rice in Bangladesh

Rainfed lowland rice is grown in the Barind tract of northwestern Bangladesh, where hardpans are common at about 10 cm depth (Ahmed et al. 1995a). Typical characteristics of the experimental site at Rajshahi are shown in Table 1. The soil is less sandy and higher in organic matter and available phosphorus than the soil at Ubon, but pH is acid and cation exchange capacity is relatively low. Under normal cultivation, soil penetration resistance increases to 3 MPa at about 15 cm, with values exceeding 1.5 MPa common from 10 to 30 cm. In a 1991 survey, almost all of the root system of rainfed lowland rice was confined to the top 10 cm of soil (Ahmed et al. 1995a). Recently, research has examined the impact of breaking the hardpan on root penetration and growth of rainfed lowland rice (Ahmed et al. 1995b). Four treatments were compared in the 1993 wet season. Cultivation with a country plough to 6–8 cm was representative of farmer practice. Deeper tillage to 12–15 cm and 18–20 cm was achieved using shovels. A pre-rice daincha (*Sesbania aculeata*) crop was used to perforate the hardpan, with the tops severed and removed before normal country ploughing. Further details are provided by Ahmed et al. (1995b).

Soil penetration resistance was strongly influenced by treatment (Table 3). Although penetration resistance increased to 2.2 MPa below 10 cm with normal tillage, comparable values for deeper cultivation and daincha perforation were 1.5 and 1.0 MPa. Root mass density was not affected in the top 10 cm, but was nearly tripled by cultivation to 20 cm or daincha perforation. Nevertheless, the proportion of roots at depths greater than 10 cm only increased from 2% to 5% with rupture of the hardpan. As a result, dry weight and grain yield increased by 1.0 and 0.5 t/ha respectively. Unfortunately, water extraction was not obtained for all treatments, so it was not possible to examine the impact on water balance of the differing regimes.

Table 3. The effect of ploughpan management on penetration resistance, root mass density and productivity of rainfed lowland rice at Alimganj, Rajshahi, Bangladesh (after Ahmed et al. 1995b).

	Shallow tillage	Medium tillage	Deep tillage	Pre-rice daincha
Depth of cultivation (cm)				
	6–8	12–15	18–20	6–8 + perforation
Penetration resistance (MPa)				
0–5 cm	0.5	0.5	0.5	0.5
5–10 cm	2.0	1.5	1.0	0.7
10–15 cm	2.2	1.5	1.5	1.0
15–20 cm	2.2	1.0	1.0	1.2
Root mass density (kg/m³ at flowering)				
0–10 cm	3.73	3.75	3.57	3.84
10–20 cm	0.07	0.15	0.19	0.19
Rice productivity in 1993 wet season (t/ha)				
Dry weight	9.2	9.8	10.2	10.1
Grain yield	3.9	4.3	4.5	4.5

The experiment is currently being repeated, and data are being obtained to quantify water extraction and nutrient uptake. How severely does the hardpan need to be ruptured to permit entry and storage of water in deeper layers? Would less severe perforation by daincha permit water extraction from depth to be more effectively metered during late season drought? If the fertility of the subsoil is lower than the surface soil, does deep tillage lead to a decrease in nutrient supply, especially in the early stages of crop growth?

Exploring Root System Capacity to Penetrate Hardpans

Deeper roots have been advocated for drought avoidance, by permitting the plant to access additional reserves of soil water during drought periods (O'Toole 1982; Fukai and Cooper 1995). For upland rice, deeper roots have been demonstrated to be beneficial (Yoshida and Hasegawa 1982). Under rainfed lowland conditions, however, an enhanced capacity of the root system to penetrate restriction zones (hardpans, non-puddled layers) was considered essential for development of deeper roots (O'Toole 1982; Fukai and Cooper 1995). Consequently, much effort has recently been devoted to screening rice lines for capacity to penetrate a hardpan, using pots with a wax-petrolatum barrier at 20 cm (Yu et al. 1995). Lines differing in capacity to penetrate were then crossed, and doubled haploid (DH) and recombinant inbred (RI) lines developed for identification of molecular markers. Quantitative trait loci (QTL) for a number of root traits have recently been reported by Champoux et al. (1995), and a report is in press of QTLs for hardpan penetration capacity for RI lines derived from a cross between indica CO39 and upland japonica Moroberekin (Ray et al. 1995). Markers are currently being developed for hardpan penetration capacity for RI lines derived from rainfed lowland parents (H. Nguyen, Texas Tech Univ. and N. Huang, IRRI, pers. comm., 1995).

Identification of molecular markers relies on correlation of the observed phenotype with quantitative trait loci. Critical to success is the accuracy of phenotyping the lines, which in turn is dependent upon how effective the screening procedure is in consistently permitting expression of the desired traits. Recently, the parental lines used for development of molecular markers have been examined more closely in field and greenhouse studies to characterise root system response to drought under rainfed lowland conditions (Samson et al. 1995; Wade et al. 1996). Root systems remained shallow at Rajshahi Bangladesh, Ubon Ratchathani Thailand, and Tarlac Philippines, even for the lines identified as having an enhanced capacity to penetrate a hardpan. The line IR58821, whose roots were more effective in penetrating the wax-petrolatum barrier in the greenhouse, did have more roots below 10 cm at Rajshahi when a hardpan was present. Nevertheless, almost all roots were shallow at all sites, which was consistent with the few previous measurements of rice root systems in the rainfed lowlands. Samson et al. (1995) and Wade et al. (1996) concluded that control of root system expression was not clear under the anaerobic-aerobic transitions of the rainfed lowlands. These authors suggested that effort be directed to defining the effects of oxygen supply, nutrient distribution, rate of onset of stress, root signals and subsoil acidity on root development under rainfed lowland conditions.

Conclusions

The results indicate there are situations in which making or breaking a hardpan may be beneficial. In order to determine which strategy would be more appropriate in each circumstance, an understanding is required of the dynamics of storage and capture of nutrient and water resources over contrasting locations and seasons. Defining these conditions and quantifying the associated probabilities may be assisted by crop simulation modeling (Fukai et al. 1995). Further understanding is also required of factors which control root system development under the anaerobic-aerobic transitions of the rainfed lowland ecosystem (Wade et al. 1996).

References

Agrawal, R.P. (1991). Water and nutrient management in sandy soils by compaction. Soil and Tillage Research 19, 121–130.

Ahmed, H.U., Ali, M.L., Siddiqui, M.R., Islam, T., Quayyum, H.A., Hossain, N., Kabir, M., Zaman, S.K. and Miah, N.M. (1995a). Crop management and varietal characteristics needed to minimise drought stress for rainfed lowland rice. In: Ingram, K.T., ed., Rainfed Lowland Rice — Agricultural Research for High-Risk Environments. International Rice Research Institute, PO Box 933, Manila 1099, Philippines, 179–188.

Ahmed, H.U., Ali, M.L., Zaman, S.K., Kabir, M.A. and Miah, N.M. (1995b). Varietal characteristics and soil management to reduce drought stresses. In: Proceedings of the Third Technical Meeting, Rainfed Lowland Rice Research Consortium, Lucknow, India, March 1994 (in press).

Champoux, M.C., Wang, G., Sarkarung, S., Mackill, D.J., O'Toole, J.C., Huang, N. and McCouch, S.R. (1995). Locating genes associated with root morphology and drought avoidance in rice via linkage to molecular markers. Theoretical and Applied Genetics 90, 969–981.

Fukai, S. and Cooper, M. (1995). Review. Development of drought-resistant cultivars using physio-morphological traits in rice. Field Crops Research 40, 67–86.

Fukai, S., Rajatsasereekul, S., Boonjung, H. and Skulkhu, E. (1995). Simulation modeling to quantify the effect of drought for rainfed lowland rice in northeast Thailand. In: Tuong, T.P., ed., Fragile Lives in Fragile Ecosystems, Proceedings of the International Rice Research Conference, 13–17 February, 1995. IRRI, PO Box 933, Manila 1099, Philippines, 657–674.

Garrity, D.P. and Vejpas, C. (1986). Percolation barriers increase and stabilise rainfed lowland rice yields on well drained soil. In: Murty, V.V.N. and Koga, K., ed., Soil and Water Engineering for Paddy Field Management. Asian Institute of Technology, Bangkok, Thailand, 413–421.

Garrity, D.P., Oldeman, L.R., Morris, R.A. and Lenka, D. (1986). Rainfed lowland rice ecosystems: characterisation and distribution. In: Progress in Rainfed Lowland Rice. International Rice Research Institute, Los Baños, Philippines, 3–24.

Herrera, W.T., Garrity, D.P. and Vejpas, C. (1995). Sesbania rostrata management and its effect on rainfed lowland rice on an acid infertile soil in northeast Thailand. Field Crops Research (in press).

O'Toole, J.C. (1982). Adaptation of rice to drought-prone environments. In: Drought Resistance in Crops with Emphasis on Rice. IRRI, Los Baños, Laguna, Philippines, 195–213.

Pantuwan, G., Sharma, P.K. and Ingram, K.T. (1995a). Rice root growth in relation to soil physical characteristics and variety. In: Ingram, K.T., ed., Rainfed Lowland Rice — Agricultural Research for High-Risk Environments. International Rice Research Institute, PO Box 933, Manila 1099, Philippines, 69–78.

Pantuwan, G., Ingram, K.T. and Sharma, P.K. (1995b). Rice root systems development under rainfed conditions. In: Proceedings of the Third Technical Meeting, Rainfed Lowland Lowland Rice research Consortium, Lucknow, India, March 1994 (in press).

Parashar, K.S. (1978). Study on the use of polythene sheets in checking water losses for growing rice under rainfed conditions. Indian Journal of Agronomy 23, 387–388.

Ray, J.D., Yu, L., McCouch, S.R., Champoux, M., Wang, G. and Nguyen, H.T. (1995). Mapping quantitative trait loci associated with root penetration ability in rice (Oryza sativa L.). Theoretical and Applied Genetics (in press).

Saenjan, P., Garnier, B.J. and MacLean, P.A. (1990). Patterns of wet season rainfall in northeast Thailand. In: Remote Sensing, Soil and Water Management in Northeast Thailand, Technical Reporting Series, McGill University and Khon Kaen University, Thailand, 24 p.

Samson, B.K., Wade, L.J., Sarkarung, S., Hasan, M., Amin, R., Harnpichitvitaya, D., Pantuwan, G., Rodriguez, R., Sigari, T., and Calendacion, A.N. (1995). Examining genotypic variation in root traits for drought resistance. In: Tuong, T.P., ed., Fragile Lives in Fragile Ecosystems, Proceedings of the International Rice Research Conference, 13–17 February, 1995. International Rice Research Institute, Los Baños, Philippines, 521–534.

Sharma, P.K. and De Datta, S.K. (1986). Physical properties and processes of puddled rice soils. Advances in Soil Science 5, 139–178.

Sharma, P.K., Ingram, K.T., Harnpichitvitaya, D. and De Datta, S.K. (1995a). Management of coarse-textured soils for water conservation in rainfed lowland rice. In: Ingram, K.T., ed., Rainfed Lowland Rice — Agricultural Research for High-Risk Environments. International Rice Research Institute, PO Box 933, Manila 1099, Philippines, 167–177.

Sharma, P.K., Ingram, K.T. and Harnpichitvitaya, D. (1995b). Subsoil compaction to improve water use efficiency and yields of rainfed lowland rice in coarse-textured soils. Soil and Tillage Research (in press).

Wade, L.J., Moya, T.B., Pantuwan, G., Regmi, K.R. and Samson, B.K. (1996). Research on root systems of rice at IRRI. In: Morita, S. and Yamauchi, A., ed., Ideotype of Root System of Rice, World Scientific Publications, Singapore (in press).

Yoshida, S. and Hasegawa, S. (1982). The rice root system: its development and function. In: Drought Resistance in Crops with Emphasis on Rice. IRRI, Los Baños, Laguna, Philippines.

Yu, L., Ray, J.D., O'Toole, J.C. and Nguyen, H.T. (1995). Use of wax petrolatum layers for screening rice root penetration. Crop Science 35, 684–687.

CONCLUSION

Management of Clay Soils for Rainfed Lowland Rice-based Cropping Systems: Workshop Summary

H.B. So[1], W.H. Utomo[2] and E.V. Dacanay[3]

THIS workshop was originally intended to bring together the completed results from ACIAR Project 8938. It was also considered desirable that the workshop should be open to comments by international scientists with similar interests and for these scientists to be given an opportunity to present their work. Therefore, this workshop was envisaged as a forum for discussion on the problems and potential solutions to the various aspects of soil management within lowland rice-based cropping systems. In this summary, the authors attempt to bring these various experiences together.

The Cropping System

In presenting this summary, the authors stress that the system should be assessed as a whole rather than from the point of view of its individual components. Differences between sites are obvious, as shown in Figure 1.

The definition of the rainy season used follows that of Oldeman (1975) which is most relevant to a rainfed lowland system. Based on a mean daily water-use rate of 6 mm/day (4–5 mm/day evaporative losses and 1–2 mm/day of percolation losses), approximately 200 mm of rain will be required in a month to maintain submerged conditions on the paddy fields. The rainy season is the period where the mean monthly rainfall is greater than 200 mm. The dry season months are when the mean monthly rainfall is less than 100 mm and the water requirement of a dry season crop would not be met by rainfall. The site at Manaoag, Pangasinan changes abruptly from a rainy season to a dry season, whereas all other sites change gradually over a period of one month or more.

The main features shown in Figure 1 are:

(1) The seasons are opposite between Indonesia and the Philippines, associated with the different monsoons (northern and southern hemispheres).

(2) The sites selected in Indonesia have a rainy season of six months whereas the Philippine sites had shorter seasons of five to six months (Bulacan) and three months (Manaoag).

(3) The DS legumes in Jambegede and Ngale consist of mungbean (70 days), soybean (100–110 days) and peanuts (100–110 days). All other sites have only mungbeans (70 days).

(4) At Jambegede and Ngale, DS legumes were planted in the second half of the rainy season, whereas at Maros and the Philippine sites, they were planted at the beginning of the dry season or well into the dry season. At Maros, high watertables during the rainy season delay sowing of legumes. At Bulacan, planting of rice was timed so that harvest coincided with the end of the rainy season. However, planting was often delayed or repeated because of the typhoons. The rainy season at Manaoag was short and sowing of mungbean occurred at the start or well into the dry season. These differences introduce variability to the results particularly if comparisons are made across the various sites. The reasons for these differences are not clear: they are partly related to climate, availability of labour and the presence of high watertables.

A similar range of sowing time is found in other countries. A survey of farmers' practice in Iloilo, Philippines, is reported by Bolton et al. (1984) where the turnaround period (TAP) ranged from 10 to 61 days depending on the cropping system adopted. Its effect on yield is shown in Figure 2.

[1] Department of Agriculture, The University of Queensland, Brisbane, 4072, Australia
[2] Department of Soil Science, University of Brawijaya, Fakultas Pertanian, Jl. Mayjen Harjono 18, Malang 65145, Indonesia
[3] Bureau of Soil and Water Management, Cnr Elliptical Rd and Visayas Avenue, Quezon City 1100, Philippines

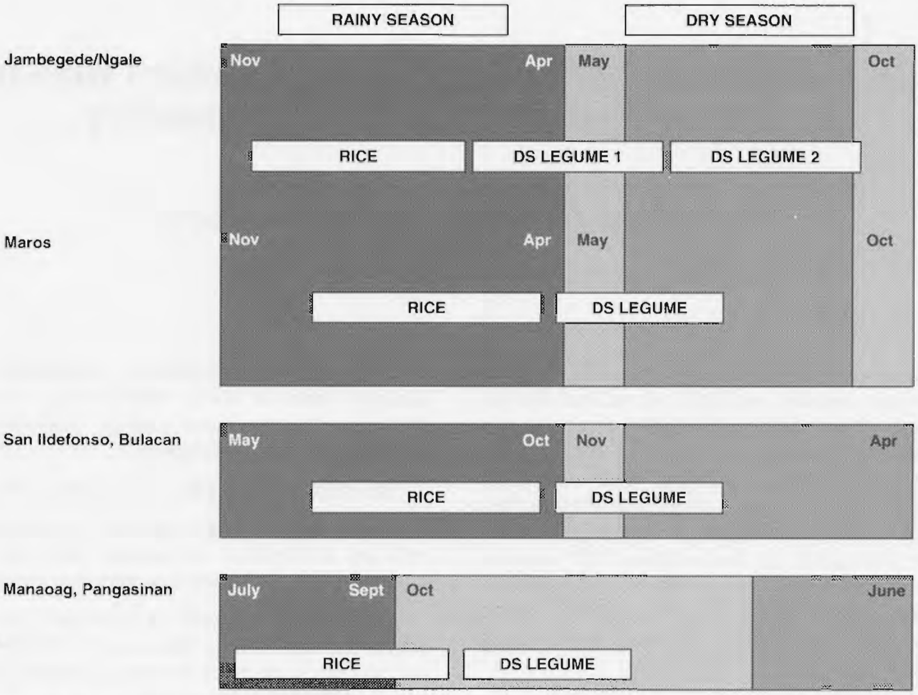


Figure 1. The annual cropping sequence at the five sites, following the local practice. At Jambegede and Ngale there are two DS legume crops. This trial is concerned with the first legume crop only.

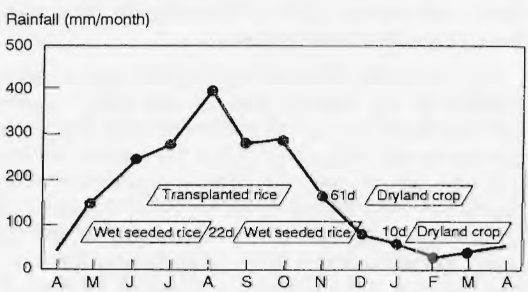


Figure 2. Mean turnaround period between crops in rice–dryland crop and rice–rice–dryland crop sequences, and mean monthly rainfall, Iloilo, Philippines, 1975–76 crop year. The numbers indicate days from harvest to planting. (Bolton et al. 1984)

In other areas different systems are practised. For example, in India, rice and wheat have already been part of an established irrigated cropping system (Singh and Abrol, these Proceedings), whereas in the south of India, pulses are grown as pre-rice or post-rice crops as either rainfed or with supplementary irrigation (Chandrasekaran et al., these Proceedings). In Australia, wheat is often grown following rice, both with irrigation (Muirhead and Humphreys, these Proceedings) and presumably the TAP is not an important constraint.

The Problem within a Rice-DS Crop Rotation System

The participants of the workshop are uninamous that *the fundamental problem is that puddling is suitable for lowland rice, but is not conducive to the DS crop.* As Dr Chandrasekaran noted in his paper, puddling is traditionally the single most important soil management practice for rice. The aim is to reduce percolation (Kirchhof and So, Humphreys et al., these Proceedings) and to maintain submerged conditions. It eases transplanting of rice seedlings, favours fast establishment of rice roots and controls weeds effectively (Chandrasekaran et al., these Proceedings).

However, puddling destroyed the structure of the soil (Kirchhof and So, Chandrasekaran et al., these Proceedings) and resulted in high soil strength when dry (Tranggono and Djoyowasito, Ringrose-Voase et al., these Proceedings) which potentially restricts seedling establishment and its root development. Although Ringrose-Voase et al. showed that within 30 days after rice harvest none of the soils at the sites reached strengths that would stop root growth completely, they will however slow root growth. Therefore *later sowing would result in increasingly restricted root systems.*

Under current management practices used in the developing countries, the risk associated with growing DS crops is high and therefore there is a reluctance to invest in these crops. It follows then that if the risk can be reduced, farmers may be interested to put more resources into the DS legume crop and improve their income and general nutrition.

Puddling for rice

If puddling is not conducive to the DS crop, it is appropriate to ask the questions: is puddling neccessary for the growth of rice? and can puddling for rice be avoided or reduced?

If practices are compared in developing countries (where puddling is synonymous with rice culture), rice yields as high as 6–7 t/ha (Utomo et al., these Proceedings) are possible and in countries with mechanised systems such as Australia (where puddling is not practised) where rice yields are as high as 8.5 to 12 t/ha (Humphreys et al., these Proceedings), it is clear that puddling is not neccessary for rice growth provided that submerged conditions can be maintained to maximise rice yields.

In Australia, rice production is permitted only on soils with low hydraulic conductivity (HC) of <3 mm/day (Muirhead and Humphreys, these Proceedings). More recently, puddling is being introduced to reduce the HC of rice fields to reduce water accession to the watertable (Humphreys et al., these Proceedings) which represents a salinity hazard when the watertable comes close to the surface. In the humid tropics, high watertables are often a seasonal feature and do not result in salinity problems.

Puddling is used to reduce the HC of the soils so that submerged conditions can be maintained. It is also intended to make transplanting easier into a soft puddled soil and to keep weed competition down.

The results from the project field trials (Utomo et al., these Proceedings), the mini-ricebeds (Kirchhof and So, these Proceedings) and the Australian field experience (Humphreys et al., these Proceedings) show clearly that *puddling intensity does not affect rice growth or yield* except on the lighter-textured soils which are more permeable. In the latter case, reduced yield from inadequate puddling was associated with greater weed competition which invaded the field during the temporary loss of surface water from the paddy fields (Utomo et al., these Proceedings). In contrast, on the sandy soils of Thailand, compaction is useful to reduce the risk of drought stress (Wade, these Proceedings).

In permeable soils such as the sandy loams, adequate puddling may be neccessary to reduce the soil hydraulic conductivity and to minimise the draining of surface water from the paddy fields. Where surface drainage occurs during the season, weed control may need to be intensified to prevent yield decrease due to competition.

If puddling can be minimised or omitted, would the intensity of puddling affect the growth of the DS crop? The results from the project field trials (Dacanay et al., these Proceedings), the mini-ricebeds (Kirchhof and So, these Proceedings) and the Australian experience (Humphreys et al., these Proceedings) show clearly that *puddling does not affect the growth or yield of DS crops following rice.*

However, when soil water, root growth and crop yield were monitored in detail at the Jambegede and Ngale sites (Priyono et al., these Proceedings), the results indicated that puddling does affect the yield of legumes and should be reduced. There was a significant trend towards reduced legume yields after rice as the intensity of puddling is increased and is associated with a reduced extraction of soil water. Yields were 13% to 27% higher on soils with the lower puddling intensities. Similar observations of increased yield were made by Tranggono and Willatt (1988) with maize at Ngale but they observed a decrease in yield on a hardsetting Regosol. *The uncertainties about the effect of puddling should be clarified because if these increases are real, benefits from a reduction in puddling intensity should be exploited to improve the growth and yield of the DS legumes and improve the sustainability of the rice–legume rotations.*

The only other reason for puddling the soil is to ease transplanting of rice seedlings. Traditionally the practice of transplanting was intended to save time when the growing season of rice was around five months or longer, particularly in areas where the rainy season is less than 5–6 months. Rice seeds can be germinated early in the rainy season when rainfall is still inadequate to submerge the whole field and to cultivate. While the seedlings are growing, soil preparation can be carried out. However, with the high-yielding modern short season (around 100 days) cultivars, the need for transplanting is obsolete and may in fact represent an increase in the growing season of rice (Tuong and Cabangon, Cruz et al., these Proceedings). Direct seeding appears to be the practice for the future.

Thus, providing submerged conditions can be adequately maintained, puddling can be minimised or avoided to reduce the cost of soil preparation and to reduce soil structural breakdown which may assist in maintaining better soil conditions for the dry season crop. This is particularly true where high watertables are present during the rainy season.

DS crop establishment

In the absence of irrigation, the dry season crop is an opportunistic crop in most areas and the major constraint is the establishment of the crop (Kirchhof and So, Muirhead and Humphreys, Chandrasekaran et al., these Proceedings). Thus, in developing countries, very little input is made once the crop is sown, whereas in mechanised countries like Australia, further input is dependent on the success of the establishment phase (Muirhead and Humphreys, these Proceedings).

For single tiller plants like legumes, there is no doubt that crop establishment is the first major constraint to the growth and yield of the DS crop. Crop establishment determines the plant population density and it is well established that yield of mungbean (Fig. 3) and soybean is linearly related to plant density (Carangal 1985; Bolton et al. 1984) until it reaches a density where individual plants compete with their neighbours for resources. The results from the ACIAR Project 8938 trials (on five sites over three years) confirm that *yield of mungbean is firstly dependent on crop establishment (Est %) followed by the total rainfall during the podfill stage (4 weeks before harvest) and the clay content of the topsoil* (Kirchhof and So, these Proceedings) and is given by the equation:

$$\text{Yield} = -0.73 + 0.008\ (\text{Est }\%) + 0.0008\ (\text{mm rain 4 weeks before harvest}) + 0.0127\ (\text{clay}) \text{ with an } r^2 = 0.702.$$

The last two factors are essentially surrogates for the combined capacity of the prevailing climate and soil to supply water to the plant, particularly during the podfill stage. The field trials, however, did not provide clear indications of the factors affecting crop establishment.

The experience from the ACIAR Project 8938 did show, however, that crop establishment and survival are highly variable across the five sites ranging from complete failures (0%) to an occasional 100% with an overall mean figure of 52%. The lowest figures were obtained at Maros and Bulacan and the highest at Ngale and Jambegede. Both establishment and survival are strongly correlated to each other with a correlation coefficient of 0.85 (Kirchhof and So, these Proceedings) and it was most interesting to find that the *survival of established seedlings into mature yielding plants did not differ across the five sites*, indicating that overall survival is determined by the crop characteristic rather than an environmental influence. Therefore, the level of crop established would be a reasonable measure of the final plant population density. Although soil and climatic effects on survival can be expected at each site, the current data available for each site were inadequate to determine these effects. The need for data on survival was generally not understood by the project participants and therefore was not monitored or monitored with inappropriate methodology.

It is important that the influence of the soil and climatic factors on survival be investigated further, if anyone is to manage the soil–crop–climate system for better survival after establishment. Perhaps there should be field trials specifically designed for that purpose.

It is reasonable to expect that establishment should be strongly influenced by the soil and climatic conditions at sowing. Establishment was highest under the wetter conditions at Ngale and Jambegede (establishment in the rainy season), but it was generally very poor at Maros and Bulacan (establishment at the start of or well into the dry season) and intermediate at Manaoag (at the start of the dry season). At each site, establishment was quite variable. At all sites, local experience and resources dictated the most appropriate time for sowing the DS legume crop. Therefore, it was possible to avoid the worst conditions for establishment, e.g. early sowing was avoided when rainstorms were anticipated or when the soil was too wet and known to cause waterlogging of the seeds.

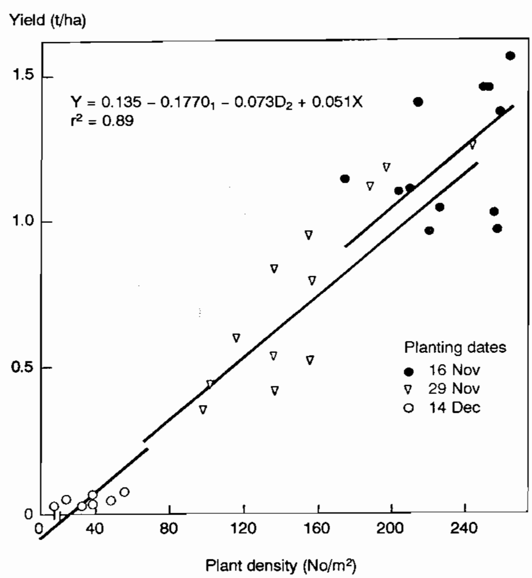


Figure 3. Effect of planting date on plant density and grain yield of mungbean, Manaoag, Pangasinan, Philippines, 1979. (Bolton et al. 1984)

Because soil water contents can be controlled by selecting appropriate sowing times, three sowing times, one week apart, were originally selected as treatments for the trial and intended to allow different length of evaporative conditions to create different soil water contents at the time of sowing. With the exception of Bulacan, where sowing was repeated several times due to damage by typhoons, the first sowing was conducted between one and 14 days after rice harvest. However, due to a variety of factors such as differences in sowing delay and seasonal differences between sites and soil types, the three sowing dates did not achieve the progressively drier conditions expected. Therefore, delayed sowing times in ACIAR Project 8938 could not be interpreted in terms of soil water contents of the surface soils.

The expectation that soil water contents should affect the success of establishment was, however, indicated by the weak but significant regression between crop establishment and total rainfall during the week before sowing (Kirchhof and So, these Proceedings). The current data from these field trials were inadequate and the relationship could not be improved by the inclusion of other climatic and soil parameters. Soil water contents or potentials of the surface soil at sowing were not available, again a result of a lack of understanding of the relevance of surface soil water contents to the process of establishment.

A more detailed and controlled work was therefore undertaken in the laboratory at the University of Queensland and in the field at Jambegede and Ngale by one of the junior scientists from MARIF (Rahmianna et al., these Proceedings). In the field, the confounding effect of rainfall was eliminated by the use of a rainshelter so that delayed sowing could be associated with drier soils.

In the laboratory where biotic factors were eliminated, the results show that germination is not affected until soil water potential reaches approximately −100 kPa for mungbean and soybean and −50 kPa for peanut. At lower soil water potentials, germination is reduced and the rate of germination is slower. In the field trials, the results show that increasing the delay period between rice harvest and sowing gives rise to lower soil water contents (Rahmianna et al., these Proceedings) and increased soil strengths (Ringrose-Voase et al., these Proceedings), resulting in slower germination/emergence which increased the opportunity for biotic factors (fungi) to attack the moist seed, leading to decreased establishment. Where there was a strong history of the same crop in the area (e.g. soybean in Ngale), there are presumably adequate resident microorganisms that readily attack the moist seeds. Where there were no suitable microorganisms, sowing delay did not affect establishment, consistent with many reports from laboratory studies using sterilised seeds. Excessively wet conditions three to four days after rice harvest did not affect germination and therefore the fear of waterlogging the seed is not supported by the data from the project, and these include days with significant amounts of rain before or after sowing. These conditions do however promote the development of fungi which may attack the seed when the opportunity arises. With the large seeded peanuts, seed-soil contact becomes a limiting factor to establishment. *Therefore the use of fungicide as a seed coating should improve the rate of establishment of the crop in the field.*

Cultivation also increased the rate of drying and significantly reduced the water contents of the surface soils (Rahmianna et al., these Proceedings). Under the prevailing experimental and environmental conditions at Ngale and Jambegede, the reduced water content decreased establishment only on soils that produce large surface clods such as the Ngale Vertisol. Large clods increased the rate of drying and this is consistent with data from India presented by Dr Chandrasekaran on the effect of different tillage implements, where the larger surface clods resulted in more rapid drying of the soil and decreased germination and yield of peanut after rice.

The use of mulch did not affect establishment in the humid environments, although in the drier areas it maintained higher water contents, resulting in better establishment (Basir and Prastowo, Sanidad et al., Chandrasekaran et al., these Proceedings).

ACIAR Project 8938 did not include organic matter incorporation. The earlier experience at IRRI showed that incorporation did not affect DS crop yield, but it affects the ease of tillage (Chandrasekaran, these Proceedings).

The field trials on establishment were conducted at the East Java sites in the rainy season. Therefore changes in surface soil water contents were not rapid. Under zero tillage, the surface soil water potential reaches a value of −70 kPa (Jambegede) and −500 kPa (Ngale) after 33 days of drying and −2 MPa (Jambegede) and −5 MPa (Ngale) when cultivated (see Figure 1, Rahmianna et al., these Proceedings). The Ngale soil reached a strength of 2 MPa after 33 days of drying (Ringrose-Voase et al., these Proceedings). For most years, the surface soil penetrometer strength at both sites was not limiting except for Jambegede in 1992 (Tranggono and Djoyowasito, these Proceedings). Therefore, when legumes are sown within several days after rice harvest, the seed and seedlings develop in conditions that are not limiting. However, *if these same soils are exposed to more severe drying conditions in the* *dry season, seeds and seedlings will be developing in much more severely limiting conditions and may not be able to emerge through the surface soil.* These severely limiting conditions were experienced at Maros and Bulacan, where sowing was arranged to coincide with the beginning of the dry season, thus resulting in low establishment and yield. Since the rainy season in these two sites covers a period of five to six months and the rice season covers a period of 100 days, *the cropping pattern could be adjusted to allow for sowing of mungbean in the rainy season.* Although this system is not generally practised due to a shortage of labour, observation has indicated that it is already successfully used by some farmers.

Seeding technology

It would be reasonable to expect that the success of establishment would also be dependent on the seeding technology used. In his review of the methods used in Indonesia and the Philippines, Sanidad concluded that the Philippine farmers' method of PBH (ploughing, broadcast and harrowing) gave similar results to the dibbling method, commonly used in Indonesia and recommended as an improved technology to the Philippine farmers. PBH tends to dry the surface soil and may be inferior during dry years. Earlier observations by Kirchhof (ACIAR 8938 annual report 1992) showed that the variability associated with dibbling may result in high variability in the establishment of mungbean at Maros. An examination of the factors controlling the success of the dibbling technique by Rahmianna et al. (these Proceedings) showed that for the humid conditions after rice harvest in East Java, the farmers' dibbling technique was appropriate and should result in good crop establishment. The effect of depth of seed placement, soil cover or the shape of the dibbling hole had only minor effects, and thus in this humid condition of Jambegede and Ngale, adequate rate of imbibition was achieved by the dibbling method practised by the farmers. This conclusion would not apply to drier conditions as shown by Kirchhof (ACIAR 8938 annual report 1992) and *further investigation is required to resolve this uncertainty as to the climatic conditions where these factors will be important in the success of crop establishment.*

The low levels of establishment actually observed on farmers' fields may be an effect of other factors such as seed quality, biotic factors or other soil physical factors. *A detailed survey of the farmers' practices would clarify and define the main factors limiting crop establishment at the farmers' level.*

It is generally accepted that successful germination requires sufficiently rapid absorption of water to reach the critical water content for germination before other environmental and biotic factors prevent the completion of that process (So 1987). Therefore the two most fundamental factors influencing the process of germination are temperature and water potential. Other factors rank behind these two in importance. The effect of temperature and water potential can be investigated in the laboratory and used to predict the level of germination in the field if all other factors are not limiting. A comparison between the predicted and actual measured establishment confirmed that these two factors were the controlling factors operating at Jambegede and Ngale (Rahmianna et al., these Proceedings). Some deviations can be explained by the incidence of seed rot from fungal infestation and some from poor seed soil contact. *This work will be continued at The University of Queensland toward the development of a general and simple crop establishment model that can be used as a framework for comparison of establishment between sites and climates as well as a means to develop improved soil management practices in relation to specific climatic conditions.*

Yield of the dry season crop and water availability

Besides crop establishment, the yield of the dry season crop is dependent on the availability of water in the surface soil and subsoil, and the fertility of the soil, which was not limiting except on the treatments representing farmers' practice.

The availability of water in the subsoil is a major factor that determines the amount of dry matter or yield that can be produced by an established crop (Kirchhof and So, Priyono et al., Singh et al., these Proceedings). Results from the mini-ricebeds in the glasshouse (Kirchhof and So, these Proceedings) and the field trials (see Figure 5 of Priyono et al., these Proceedings) showed that water in the subsoil at greater than 65 cm depth contributed 3–25 kg/ha of grain yield for every mm of water extracted. The amount available for extraction is largely a function of the soil's PAWC (plant available water capacity) or soil type. However, the amount of extraction depends on the ability of roots to grow and develop into the subsoil.

Conclusions

Although the project has not fully achieved its original objectives, it is believed that significant progress has been made in the past three years and that the following useful conclusions can be drawn.

(1) The traditional soil preparation of puddling for rice is not essential for the production of rice.

Neither does it affect the secondary crop after rice. However, indications are that decreasing the puddling intensity would favour the growth of secondary crops after rice. Exceptions are the more permeable rice soils, where puddling is necessary to reduce water percolation and to maintain submerged conditions.

Therefore, puddling can be avoided or minimised on the clay soils, which would save time and labour, reduce the cost of production and improve the timing of the secondary crop. If decreasing the puddling intensity improves the yield of legumes after rice, it will contribute towards a more sustainable intensified cropping system.

The significance of avoiding puddling becomes clear when the magnitude of savings is considered. As the cost of puddling is estimated to range between $30 and $50 per hectare, the potential savings from not puddling for Asia's 130 million hectares of lowland rice farms is enormous at $3.9 to $6.5 billion per annum.

(2) The results from the project clearly show that legumes can be grown successfully at three out of the five sites, i.e., Ngale, Jambegede and Manaoag (Table 1). These represent regions with a sufficiently long rainy season (Ngale and Jambegede) where legumes can be sown towards the end of the rainy season, and regions with a short rainy season (Manaoag) where the soil remains soft and reasonably friable for legumes despite puddling.

Table 1. The range of mungbean yields obtained at each site.

Site	Mungbean yield (t/ha)
Ngale	0.30–1.12
Manaoag	0.50–1.00
Jambegede	0.42–0.89
Maros	0.39–0.76
Bulacan	0.02–0.62

The sites at Maros and Bulacan have similar extended rainy seasons of 5–6 months. Sowing of legumes on these sites was carried out at the beginning of the dry season. Therefore, the current results indicate that these sites may not be suitable for legumes. However, if sowing can be moved forward by one or two months into the rainy season, these sites may well be suitable for legumes after rice. At Bulacan, this may avoid damage by typhoons. Some local farmers are already using early sowing with good success. Therefore, further work investigating the limitations associated with the time of sowing within the rainy season is necessary to provide appropriate guidelines to ensure the success of legumes grown after rainfed lowland rice.

(3) Crop establishment is generally good when sowing is carried out in the rainy season (e.g. at Ngale and Jambegede). Waterlogging of the seed was not observed, but biotic factors (e.g. fungal infections) may be high under wet conditions and may reduce establishment. Therefore, the use of fungicides may overcome this problem. Poor establishment in farmers' fields is likely to be a result of poor seed quality.

Crop establishment in the dry season is generally poor, particularly on the hardsetting soils (e.g. at Maros and Bulacan), associated with a combination of low water potential, poor seed–soil contact and high soil strength. It is clear that establishment of legumes after rice should aim at sowing in the rainy season.

Crop survival is highly correlated to establishment across the sites and crop characteristics appear to be the dominant factor. The environmental influence on crop survival could not be determined due to the high variability in the data.

It appears that legumes after rainfed lowland rice should be possible in areas where the rainy season is longer than four months if the legumes are sown in the rainy season immediately following rice harvest. Further strategic experiments are needed to confirm or refine this conclusion. If this conclusion is correct, it will provide a simple criterion for selecting areas suitable for legumes after rainfed lowland rice.

(4) The data in Table 1 were obtained with low plant populations ranging from <200 000 to 330 000 plants/ha. Increasing the plant population should increase yield proportionally to the point where competition between individual plants becomes significant which occurs at 660 000 plants/ha for irrigated soybeans (Carangal 1985). The current plant population is still on the linear part of the curve for dryland mungbean as shown in Figure 3 (Bolton et al. 1984). The optimum population may be different for each site and further agronomic experiments are needed to determine the appropriate range for each soil-climate combination.

(5) Mungbean yield is most strongly affected by crop establishment (plant population density) followed by the amount of water available to the crop, as represented by the rainfall during the podfill stage and the clay content (or PAWC) of the soil. Subsoil water from a depth greater than 45 cm contributes between 3 and 25 kg/ha per mm of water stored in the soil. Therefore, if access to this store of water can be improved, legume yield should increase significantly. Future research efforts into ways of improving root growth and development into puddled or compacted soils, including screening or

breeding for appropriate root characteristics, should provide cost-effective and lasting solutions to the problem of poor performance of legumes after rice. Benefits should flow on to the problems of poor root penetration into compacted and degradated soils in general.

(6) Management practices such as cultivation and the turnaround period affects the water potential of the soil around the seed and may significantly affect crop establishment, particularly in the dry season. These effects differ across the five sites and are not easily predicted. A simple establishment model currently being developed at The University of Queensland by an ACIAR-sponsored postgraduate student is needed to assist in determining the potential limitations of each soil-climate-seed crop combination and to predict what can be expected from a given set of conditions.

Thus, based on the current results of ACIAR Project 8938 and this workshop, the principle has been established that a successful crop of legume following rainfed lowland rice should be possible if high quality legume seeds, treated with a fungicide, are sown as early as possible in the rainy season with a plant population which is sufficiently high to ensure maximum water extraction. Early sowing of the legume can be assisted by an early sowing of the rice crop which can be achieved by one or more of the following practices:

- *reduction of the bypass flow from the early season rainfall (Tuong et al., these Proceedings);*
- *reduction of puddling;*
- *direct seeding of rice (Cruz et al., these Proceedings).*

Future Work Required to Achieve Project Objectives

It is clear from the conclusions that future work aimed at developing recommendations on management practices for successfully growing legumes after rainfed lowland rice should consider the whole cropping system and look at all options associated with the rice as well as the legume crop. Early sowing of rice and shortening of the rice season is possible and would contribute significantly towards early sowing of the legume. However, this aspect is well covered as IRRI and PhilRice are strongly involved in this area and future projects should concentrate on the dry season legume crop.

(1) **Crop establishment**. A high probability of success with crop establishment is a prerequisite for a successful crop. However, there are numerous factors controlling crop establishment in the field, and ACIAR Project 8938 was not able to determine the controlling factors for the different sites with the experimental arrangements adopted for the field trial. Unless these factors are well understood, the success of establishment can not be assured.

Experiments specifically designed to investigate aspects of crop establishment are required to improve the seeding technology. This would require the development of a crop establishment model (currently in progress at The University of Queensland) to guide the experimental work and to provide a framework for the interpretation of the experimental results. Simple experimental work is required to assess the importance of different factors in various soil-climatic regions, such as the turnaround periods, length of rainy season, depth of sowing, seed soil contact and soil water potential. Such work should also provide data to validate the model. *The work should not be confined to lowland rice-based systems and should include other upland crops, as the same problems exist and the same principles are applicable to these cropping systems.*

Poor establishment is also a major problem to Australian farmers and is considered as the second most important problem after erosion for summer crops in the arid and semi-arid regions. A resolution of this problem will be of great benefit to Australian farmers.

(2) **Root growth and water uptake**. Since the soil profile is fully recharged after prolonged inundation, the major concern is the ability of the root system to access that water. Root growth can be promoted by deep tillage, early sowing and the selection of legumes with strong root systems that can penetrate puddled and compacted soils. Deep tillage is shown to be costly and not appropriate for low input farming systems, but the selection of strong root systems would offer significant benefits to these farmers. This is the principle of biological deep tillage using appropriate plants and benefits from such work would flow to the Australian scientific and farming community.

Selection of deep penetrating roots may not necessarily ensure adequate water extraction from depth. So and Jayasekara (1990) at The University of Queensland and experience from the ACIAR peanut improvement project (G. Wright, pers. comm.) have shown that cultivars with similar root depths may have different capacities to extract water from depth and hence different potential productivity. Therefore, the characteristics of each deep root system for water extraction need to be defined as well.

(3) **Further agronomic work** is required to refine the findings of Project 8938 in the following areas:

a. effect of plant population density and sowing time on yield of mungbean, to determine the optimum planting density for each soil-climate combination;

b. time of sowing legumes in relation to the end of the rainy season, to determine the length of the rainy season where dry season legumes can be grown successfully after rainfed lowland rice.

References

Bolton, F.R., Morris, R.A. and Vivekanandan, P. (1985). Soil water relations in rice-based cropping systems. In: Soil Physics and Rice. Intl. Rice Research Institute, Los Baños, Philippines, 131–146.

Carangal, V.R. (1985). Soybean in rice-based farming systems. The IRRI experience. In: Shanmugasundaram, S. and Schulzberger, E.W., ed., Soybean in Tropical and Subtropical Cropping Systems. Proc. Symp. at Tsukuba, Japan, 1983.

Oldeman, L.R. (1975). An agro-climatic map of Java. Contr. Central Res. Inst. Agric. Bogor, No. 17, 22 p.

So, H.B. (1987). Soil physical factors limiting crop establishment. In: Wood, I.M., Hazard, W.H. and From, F.R., ed., Crop Establishment in Queensland: Recognition, Research and Resolution. AIAS Occasional Publication No. 34, 154–165.

So, H.B. and Jayasekara, K.S. (1990). The effect of shoot/root ratios on the water relations of sorghum (Sorghum bicolor L Moench). In: Michael and Persson, ed., Plant Roots and their Environment. Development in Agricultural and Managed Forest Ecology. Elsevier, 543–552.

Tranggono, R. and Willatt, S.T. (1988). The growth of maize after wetland rice in East Java. In Proc. 11th Conference of the International Soil Tillage Research Organisation, Edinburgh, U.K. 10–15 July, 1988. 903–908.