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PROJECT DEVELOPMENT ASSESSMENT: AN ECONOMIC EVALUATION OF THE POTENTIAL BENEFITS OF INTEGRATING APOMIXIS INTO HYBRID RICE†

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INTRODUCTION

1.1 Outline of the paper

This paper describes Phase 1 of a project-development assessment of a 3-phase research activity, ACIAR-supported Project PN95125 ‘Molecular Tools for Achieving Apomixis in Rice’. Section 1.2 provides some background information on rice; Section 2 briefly outlines the project and its objectives; Section 3 discusses the approach used in the evaluation of the project; Section 4 discusses the results of the project-development assessment, and Section 5 concludes.

1.2 Background information

The four main challenges confronting international rice research at present are:

- To meet the food needs of rapidly growing populations in the less developed countries;
- To increase the social equity for poor rice-farming and rice-consuming families;
- To protect the environment; and
- To conserve natural resources for future generations.

Rice is the most important food crop in developing countries and is the major staple for 2.7 billion people in Asia, providing between 35 and 60 percent of calories consumed. In sub-Saharan Africa and Latin America, rice provides approximately 8 percent of the food energy, and is a relatively new staple in the diet. Demand for rice in these regions is increasing rapidly. In West Africa, per capita consumption has doubled over the past two decades, and now accounts for almost 20 percent of calorie intake. In Latin America it increased by about 15 percent.

The world’s biggest producers of rice are China, India and Indonesia. Production is concentrated in Asia which accounts for 93 percent of output and 90 percent of the rice area cultivated in developing countries. China accounts for 23 percent of the rice area and 38 percent of the rice output. Latin America and the Caribbean account for 3.9 percent of rice production, sub-Saharan Africa for 1.6 percent and West Asia

Rice is grown in four major production environments or ‘ecosystems’ which are broadly defined on the basis of water regime: irrigated; rainfed lowlands; uplands; and deepwater/tidal. Irrigated areas account for 71 percent of rice output, rainfed lowlands for 19 percent, uplands for 7 percent and deepwater/tidal areas for 4 percent. Table 1 shows the distribution of rice by ecosystem as a percentage of total area.

Table 1. Total area planted to rice and distribution of rice by ecosystem (% area) in 1991, for Australia and selected Asian countries

Country	Total area	Irrigated ('000 ha)	Rainfed lowland	Deepwater/Tidal	Upland
Bangladesh	10940	22	47	23	8
India	42200	45	33	7	15
Pakistan	2060	100			
Myanmar	4830	18	52	24	6
China	33100	93	5	0	2
Indonesia	10187	72	7	10	11
Philippines	3423	61	35	2	2
Thailand	10000	7	86	6	1
Vietnam	6295	53	28	11	8
Australia	89	100			

Source: IRRI (1993).

Average yields vary widely among regions, countries and ecosystems. Over the past few decades, the nature of growth in rice production has changed significantly. Since the 1960s, the major source of output has shifted from expansion in crop area to increase in yield (David, 1991). During the 1980s however, the rate of growth of yield increments has slowed down considerably in the favourable areas of Asia. Table 2 shows average yields for selected countries for each of the three decades from 1961 to 1991.

Table 2. Rough (paddy) rice yield (t/ha) in Australia and selected Asian countries[a], 1961

Year	1961	1971	1981	1991
World	1.87	2.36	2.82	3.50
Asia	1.86	2.38	2.88	3.59
Bangladesh	1.70	1.60	1.95	2.67
China	2.08	3.31	4.33	5.64
India	1.54	1.71	1.96	2.61
Indonesia	1.76	2.41	3.49	4.35
Myanmar	1.61	1.72	2.94	2.28
Pakistan	1.39	2.33	2.60	2.32
Philippines	1.23	1.60	2.30	2.82
Thailand	1.86	2.01	2.65	3.02
Vietnam	1.90	2.23	2.20	3.11
Australia[b]	6.10	7.40	7.30	8.90

Sources: [a]IRRI (1995) [b]ABARE (1995)

Growth in rice areas has slowed, particularly in Asia where 90–95% of all rice is consumed and produced. Increased population has increased the demand for rice, and efforts have been made to increase rice productivity by the adoption of high yielding modern varieties (MV). IRRI made a technological breakthrough in 1966 when the first high yielding MV, IR8, was developed and released. Since then, a large number of IR-parented varieties have been released by IRRI through various national rice programs. MVs are rice cultivars that are short, stiff-strawed, fertilizer-responsive, photoperiod-insensitive, and have short-to medium growth duration (100 – 130 days). Farmers get two to three times higher yields from these varieties than from traditional cultivars. The increase in rice yield has come mainly from gradual reallocation of land from traditional to the high-yielding modern varieties. In South and Southeast Asia MVs are now grown in more than half the rice crop area (IRRI 1995). Because the MVs are generally suited to irrigated areas and are more fertilizer- responsive than traditional varieties, they have raised the profitability of irrigation investments and fertilizer use and have indirectly induced greater public investment in irrigation and increased fertilizer application (Hayami et al. 1976; David 1976).

Rice production will have to rise by about 70% over the next 30 years to keep pace with population growth (Hossain and Fischer 1995). A vast amount of research has gone into production of hybrid rice which has higher yields than modern varieties. Hybrids are cross-breeds, and involve either removing or making the male anthers non-functional because the male and female reproductive organs exist on the same plant. Hybrid seed production is therefore very tedious and costly. Yield advantages obtainable with hybrid rice are 15–20% more than elite inbred line and their use is seen as one of the most effective and environmentally friendly ways of increasing productivity with current management practices (Virmani 1994).

Production problems and complexities mean that hybrid seed cannot be produced readily by farmers. Furthermore, they must purchase fresh hybrid seed each season as replanting seed from a hybrid seed crop harvest leads to inbreeding, homozygosity and loss of the higher yield advantage. The cost of hybrid seed is 10 times higher than the cost of ordinary rice seed. Farmers costs would be reduced, and a higher productivity maintained per hectare if they could use seed from their harvest, year after year, and maintain the hybrid seed advantage. This paper evaluates the economic impact of investing in the development of such a technology— a hybrid seed that can be reproduced asexually— by apomixis, i.e. the seed produced is identical to the mother plant.

Hybrid cultivars are widely used in agricultural production. They are the first-generation progeny (F1) between two genetically different plants or inbred lines. F1 hybrid plants are heterozygous, normally uniform within the group, and may exhibit hybrid vigour, which is a sought-after feature. Hybrid cultivars cannot be used as seed sources in the next generation (F2) because this generation would be extremely variable as a result of genetic segregation. Hybrid vigour is also reduced in the F2 generation. Parental stocks for hybrid seed production need to be maintained and the cross must be continuously repeated. Control of apomixis would enable the fixation of hybrid vigour and the development of true-breeding hybrids in a particular breeding program. Seed could be produced for many generations without loss of vigour or genotype alteration. Hybrid seed production would be simplified because line isolation would not be necessary to produce F1 seed or to maintain parental lines, and the use of male-sterility lines could be avoided. Outcross contamination in hybrid seed programs lacking good male-sterility lines would also be eliminated. Overall, apomixis would enable a significant reduction in hybrid seed production costs. (Koltunow et al. 1995).

2. THE PROJECT AND ITS OBJECTIVES

The objective of the ACIAR-supported project ‘Molecular Tools for Achieving Apomixis in Rice’, is to facilitate the adoption of a yield-increasing agricultural innovation (hybrid rice) by reducing the cost of its adoption. This project is Phase 1 of a 3-phase activity. The first phase, is the isolation of molecular tools for use in the development of apomixis in rice. Phase two will be the development of these tools and the detailed manipulation of the rice plant to achieve apomictic rice. The third and final phase of the research will focus on the integration of apomixis into hybrid rice programs.

3. THE ELEMENTS OF THE CONCEPTUAL FRAMEWORK

This paper uses a standard economic-surplus framework (Davis et al. 1987) in the economic evaluation of this project. The framework has the following components:

- linear supply and demand functions for rice;
- the after research shift in the supply function for rice;
- the before-research and after research equilibrium;
- the national producer and consumer benefits;
- the applicability of the new technology;
- initial, adaptation research lags and the adoption pattern;
- adoption of the new technology;
- technological spillovers between countries;
- world price spillovers; and
- the initial research, adaptation and research extension costs.

The following sections discuss each of these components in the context of this project development assessment.

3.1 Linear supply and demand functions for rice

The research-evaluation model used in the analysis is based on a linear demand function for rice and two supply functions: a supply function describing farm-level supply of rice before research and a supply function describing farm-level supply of rice after research in a given country or region.

3.2 The after research shift in the supply function for rice

After research there is a vertical shift in the farmer's supply function. The distance is a measure of the unit- cost saving from research and is referred to by the symbol '*k*'.

In this paper, the estimation of the unit-cost saving '*k*' is based on a cost analysis of rice production in nine of the major rice producing countries in South and Southeast Asia, namely India, China, Bangladesh, Pakistan, Myanmar, Indonesia, Philippines, Thailand, Vietnam, and in Australia. The cost analysis involved the following steps:

- estimating the before-research, farm-level costs for rice growers;
- estimating the after research, farm-level costs for rice growers; and
- estimating the unit-cost reduction and thus the vertical shift in the rice grower's supply function.

3.2.1 The unit cost of production before research

The International Rice Research Institute provided data on the farm-level costs incurred by rice growers in all major regions of Asia, both irrigated and dryland. The NSW Department of Agriculture and ABARE provided farm-level costs incurred by rice growers in Australia. Costs of production have been estimated for both irrigated and dryland (where applicable) systems. This information is summarised in Table 3.

Table 3. A before-research cost analysis of the production of rice in selected countries and regions. Total input costs per hectare, $A 1991.

	China Irrigated	China Hybrid	South Asia Irrigated	South Asia Dryland	Southeast Asia Irrigated	Southeast Asia Dryland	Australia Irrigated
Fertilizer	159	177	71	36	88	34	141
Chemicals	30	36	12	7	25	12	82
Others	55	54	13	23	39	22	629*
Current Inputs	**244**	**267**	**95**	**66**	**152**	**68**	**852**
Rented	112	106	166	13	72	28	0
Owned	30	40	31	55	54	46	0
Fixed Capital	**142**	**147**	**197**	**69**	**125**	**74**	**81**
Hired			80	102	140	73	0
Owned			155	125	66	104	0
Labour	**232**	**277**	**234**	**227**	**207**	**178**	**234**
Rented			87	133	78	86	0
Owned			238	184	520	139	0
Land		**23**	**325**	**319**	**598**	**225**	**315**
Total costs	**618**	**691**	**851**	**681**	**1083**	**545**	**1483**

Sources: IRRI (1996), ABARE (1996), Cochrane (1996).
* This includes machinery operations, irrigation, cartage, crop insurance

The rice producer incurs operating costs, which include fertilizers, chemicals, irrigation costs, etc, and fixed costs. For all countries except Australia, the fixed costs were calculated as follows:

Fixed costs

- *Fixed Capital:* includes both rented and owned. Owned fixed capital is valued on the basis of prevailing rents.
- *Labour:* includes both rented and owned. Owned labour is valued based on prevailing wage rates.
- *Land:* includes both rented and owned. Land is estimated as residual i.e. gross return minus current inputs, fixed capital and labour. The cost of rented land is computed by dividing the total land rent paid by share tenants and fix renters by total sample area. That is:

L_a = Gross return – (current inputs –fixed capital – labour)

$L_a = L_{a1} + L_{a2}$

L_{a1} = (total land rent paid by share tenants and fix renters)/(by total sample area)

$L_{a2} = L_a - L_{a1}$

where

L_a = Land costs

L_{a1} = Rented land costs

L_{a2} = Owned land

For Australia, costs were from ABARE (1996) and NSW Dept of Agriculture (Cochrane 1996). Rice growers produce other crops in addition to rice and therefore costs for rice alone had to be estimated. Fixed capital and land costs were annualised over a 30-year period. The majority of rice grown in Australia is medium-grain, aerial sown.

Table 4 lists the average yields used in the before-research analysis. The dryland yields were calculated by weighting the harvested rice areas and yields in rainfed lowland, upland and flood-prone areas.

Table 4. Average yields, 1991

Country	Production system	Yield (t/ha/year)
China	Irrigated	5.9
Pakistan	Irrigated	2.4
India	Irrigated	3.6
	Dryland	1.8
Myanmar	Irrigated	4.2
	Dryland	2.4
Indonesia	Irrigated	5.3
	Dryland	2.0
Philippines	Irrigated	3.4
	Dryland	1.9
Thailand	Irrigated	4
	Dryland	1.8
Vietnam	Irrigated	4.3
	Dryland	1.7
Bangladesh	Irrigated	4.6
	Dryland	2.1
Australia	Irrigated	8.9

Sources: IRRI (1993), ABARE (1995)

3.2.2 The unit cost of rice production after research.

When estimating the unit cost of rice production after research, three scenarios were examined.

Introducing apomixis where:

1 Hybrid rice is grown

- resulting in decreased seed and labour costs. In this analysis China is the only country growing hybrid rice which accounts for 50% of the total area planted there.

2. Varieties are grown under irrigation

- resulting in increased yield and decreased seed cost.

3. Varieties are grown under dryland conditions

- resulting in increased yield and decreased seed cost.

Cost analyses made by IRRI indicate that the percentage of seed costs to total cash costs is 8, 6 and 9.2% for irrigated, dryland and hybrid systems, respectively. It is assumed in the analysis that the farmer will have to purchase seed every 4 years.

The yield advantage obtainable with hybrid rice is an increase of 10–20% over elite inbred lines (Virmani 1994). A yield increase of 15% for the base case is used in the analysis.

The after research costs of production and yields are shown in Table 5.

Table 5. An after research cost analysis of the production of rice in selected countries and regions. Total input costs per hectare, $A 1991.

	China Irrigated	China Hybrid	South Asia Irrigated	South Asia Dryland	Southeast Asia Irrigated	Southeast Asia Dryland	Australia Irrigated
Fertilizer	150	165	66	35	83	33	133
Chemicals	28	33	11	7	24	12	77
Others	52	50	12	22	37	21	592
Current Inputs	**229**	**248**	**89**	**63**	**143**	**65**	**801**
Rented	112	98	166	13	72	28	0
Owned	30	37	31	55	54	46	0
Fixed Capital	**142**	**137**	**197**	**69**	**125**	**74**	**81**
Hired			80	102	140	73	0
Owned			155	125	66	104	0
Labour	**232**	**232**	**234**	**227**	**207**	**178**	**234**
Rented			87	133	78	86	0
Owned			238	184	520	139	0
Land		**21**	**325**	**319**	**598**	**225**	**315**
Total costs	**604**	**617**	**851**	**681**	**1083**	**545**	**1431**

Sources: IRRI (1996), ABARE (1996), Cochrane (1996).

3.3 The before research and after research equilibrium

The data on production levels before research are from FAO (1994). These data are summarised in Appendix 1. Farm-gate prices were obtained from IRRI (1996) and ABARE (1995) and are summarised in Table 6. Table 6 also provides information on the elasticities of demand and supply used in the analysis.

The next section briefly discusses the equations used in estimating the rate of return to the project.

3.4. The annual producer and consumer benefits

The total annual benefit to research is equal to the change in economic surplus (ΔES) which is estimated by the following equation:

$$\Delta ES = kQ_0 + 0.5\,k\,(Q_1 - Q_0) \qquad (1)$$

The total benefit from a research-induced supply curve is equal to the cost savings on the initial output Q_0 plus the economic surplus due to the increment to production and consumption of the commodity. In equation (1), the cost saving on Q_0 is equal to Q_0 times the unit cost reduction, *k*.

Table 6. The key assumptions made in the project-development assessment.

	Bangladesh	India	Pakistan	Myanmar	China	Indonesia	Philippines	Thailand	Vietnam	Australia
Farm gate price/tonne (A$)[a],[b]	218	143	205	205	143	244	235	189	205	187
Elasticity of supply	0.26	0.30	0.25	0.30	0.30	0.30	0.26	0.30	0.30	0.30
Elasticity of demand	0.30	0.10	0.30	0.10	0.30	0.10	0.30	0.10	0.10	0.30
Cost reduction due to research (A$/t)										
- Irrigated	33.06	32.20	33.23	27.60	15.83	34.10	61.00	30.61	20.03	26.72
- Dryland	43.50	50.75		38.06		44.99	56.60	22.21	33.95	
- Hybrid	24.06	23.44	24.19	20.09	12.44	24.82	44.40		14.58	19.45
Ceiling adoption level (%)	40	47	45	37	67	47	42	45	30	65
Yield increase (%)[a]	15	15	15	15	15 0 (hybrid)	15	15	15	15	15
Seed costs (% of total variable costs)										
- Irrigated	8	8	8	8	8	8	8	8	8	8
- Dryland	6	6	6	6	6	6	6	6	6	6

[a]Based on yields in Table 4
[b]Prices for India, Myanmar, Pakistan and Vietnam were calculated as the average of all available prices.
Sources: IRRI (1996), ABARE(1995, 1996

Solving for Q_1 in terms of the parameters of the demand and supply functions and substituting this in equation (1) leads to the following algebraically alternative but numerically equivalent expression for the total benefit:

$$\Delta ES = kQ_0 + 0.5(Q_0/P_0)\ [\varepsilon_s\varepsilon_d k^2/(\varepsilon_s+\varepsilon_d)\ ] \tag{2}$$

where *k* is the absolute value of the cost reduction

ε_s is the elasticity of supply

ε_d is the elasticity of supply.

The consumer surplus is given by equation (3):

$$\Delta CS = Q_0 k\varepsilon_{s/}(\varepsilon_s+\varepsilon_d)+0.5(Q_0/P_0)\ [k\varepsilon_{s/}(\varepsilon_s+\varepsilon_d)]^2\varepsilon_d \tag{3}$$

The producer surplus is in turn given by equation (4)

$$\Delta PS = Q_0 k[1-\varepsilon_{s/}(\varepsilon_s+\varepsilon_d)\ ] + 0.5(Q_0/P_0)\ k^2[1-\varepsilon_{s/}(\varepsilon_s+\varepsilon_d)][k\varepsilon_{s/}(\varepsilon_s+\varepsilon_d)]\varepsilon_d \tag{4}$$

Equations (1) – (4) are for a closed economy. However, as Table 1 and Table 2 indicate, rice is a traded commodity. Thus, an economic evaluation of a project focusing on rice needs to take into account the international traded nature of the commodity. Therefore, the evaluation uses generalisations of equations (1) which were developed by Davis et al.(1987).

3.5 The applicability of the new technology

This element of the framework requires the estimation of the proportions of agricultural production which are likely to be affected by the research in the different countries. The new apomictic hybrid rice may take longer to be adapted to the different growing areas, especially the dryland areas, but it is assumed in this analysis that it will be applicable to both irrigated and dryland areas in the nine specified countries. The new technology will also be applicable to other rice-growing countries but this has not been included in the analysis.

3.6. Initial research and adaptation research lags and the adoption pattern for the new technology

In evaluating the net impact of this research project, account was taken of four time lags:

- the research lag — the time between the start of the project and the completion of research;
- the adaptive research lag period — this corresponds to the time needed to trial the new higher yielding rice varieties before they are released to farmers;
- adoption pattern — adoption levels may in the initial periods be very low and may grow slowly as farmers become familiar with, and have access to, the hybrid rice;
- ceiling adoption level — this gives the maximum proportion of farmers who are likely to adopt the new technology. It is rare that all farmers will adopt a new technology.

The research and adaptive research lag is assumed to be 15 years. This includes:

- Phase 1 — the isolation of molecular tools for use in the development of apomixis in rice — five years;

- Phase 2 — the development of these tools and the detailed manipulation of the rice plant with these tools to achieve apomictic rice — five years; and
- Phase 3 — the integration of apomixis into hybrid rice programs — five years.

Given that the adoption pattern at this early stage is unknown, ceiling adoption rates were obtained from the Economic Evaluation Unit's database which contains adoption rates for generic rice technologies. They are summarised in Table 8.

In this paper, it is assumed that all nine countries will adopt the research results. Thus, the costs of producing rice are assumed to fall in these nine countries. Since rice is a traded product, this paper applies a traded good, multi-country model which makes it possible to identify those countries that lose, and those that gain as a result of this new technology.

3.7. The world price spillovers

There is international trade in rice with price-related spillovers to those regions trading in rice. These spillovers are obtained through changes in the world or regional price of the commodity. The shift in the supply function in the country or region where research is undertaken leads to changes in the world or regional price. This in turn generates benefits to both the country where research was undertaken and to other countries trading in the commodity targeted in the research project. This phenomenon, where research in one region or country leads to benefits in some other region through changes in the regional or world prices of the commodity, is referred to as the price spillover effect. Generally, producers in exporting countries who do not collaborate in the development/adoption of the new technologies are likely to lose, while consumers in all countries trading in the commodity are likely to gain from research.

3.8. The initial research and adaptation costs

Having estimated the benefit side of a research project, it is necessary to determine the costs of research. As mentioned above, costs are incurred over 15 years. Costs for phase 2 were assumed to be the same as that of phase 1 (Anna Koltunow, pers. comm. 1996). Costs for phase 3 were estimated by examining the NSW Dept Agriculture paper, 'Costing of Australian Rice Breeding Program'.

The research costs and time frames used in the analysis are as follows:

Phase 1— Cost A$1.4 million — time 5 years

Phase 2— Cost A$1.6 million — time 5 years

Phase 3— Cost A$0.6 million for each country — time 5 years

4. PROJECT-DEVELOPMENT ASSESSMENT RESULTS

4.1 The Base Case

In estimating the net present value and the internal rate of return of this project, a 30-year planning horizon and an 8 per cent discount rate are assumed. The discount rate of 8 percent is based on a recommendation by the Australian Commonwealth Department of Finance (1991). Production data used in the analysis are summarised in Appendix 1. Table 6 gives the base care assumption for the analysis. Table 7 summarises the benefits and cost flows generated by the project based on those assumptions.

Under these assumptions, the project is estimated to increase economic surplus by about $A8.59 billion, of which India (3.2 billion), China (2.3 billion) and Indonesia (1.1 billion) accrue the most. The low level of benefit accruing to Australia (19 million) is due to the small scale of the rice industry here.

Overall, the project is estimated to generate an internal rate of return of 79 per cent and a net present value of $A8.59 billion.

The realised total benefits may be higher, given that not all rice-producing countries were included. Apomictic rice may be applicable to all rice-growing countries of the world. The countries included in this analysis, however, account for 84% of total rice production so the total will be only marginally higher.

4.2 Sensitivity Analysis

The estimates of benefits to research discussed in this paper depend on a number of assumptions. This section discusses a set of analyses to assess the extent to which variations in key assumptions are likely to affect the net benefits from research. The assumptions assessed are:

- yield increase which affects total cost reduction;
- seed cost which affects total cost reduction;
- adoption rates; and
- increase in area of hybrids grown over the 15 year period of research.

Table 7. Flow of benefits accruing to the 10 countries in the analysis and the rest of the world: The introduction of apomixis into rice, $A Million, 1991.

	Year No.	Year	China	Bangladesh	India	Pakistan	Burma	Indonesia	Philippines	Thailand	Vietnam	Australia	Rest of world	Total benefits	Research costs	Net benefits
Start Phase 1	1	1991	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	2	1992	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	3	1993	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	4	1994	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	5	1995	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
Start Phase 2	6	1996	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	7	1997	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	8	1998	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	9	1999	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
	10	2000	0	0	0	0	0	0	0	0	0	0	0	0	0.3	– 0.3
Start Phase 3	11	2001	0	0	0	0	0	0	0	0	0	0	0	0	1.0	– 1.0
	12	2002	0	0	0	0	0	0	0	0	0	0	0	0	1.1	– 1.0
	13	2003	0	0	0	0	0	0	0	0	0	0	0	0	1.2	– 1.0
	14	2004	0	0	0	0	0	0	0	0	0	0	0	0	1.3	– 1.0
	15	2005	0	0	0	0	0	0	0	0	0	0	0	0	1.4	– 1.0
Start of adoption																
	16	2006	176	74	311	11	33	109	36	26	33	1	0	810	0	810
	17	2007	353	148	623	21	66	219	72	51	67	3	0	1623	0	1623
	18	2008	531	222	936	32	99	329	109	77	100	4	0	2440	0	2440
	19	2009	708	297	1251	43	122	439	145	103	100	6	0	3215	0	3215
	20	2010	886	297	1472	48	122	517	164	108	100	7	1	3723	0	3723
	21	2011	1064	297	1472	48	122	517	164	108	100	9	1	3902	0	3902
	22	2012	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
	23	2013	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
	24	2014	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
	25	2015	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
	26	2016	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
	27	2017	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
	28	2018	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
	29	2019	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
End of planning horizon																
	30	2020	1189	297	1472	48	122	517	164	108	100	10	1	4028	0	4028
Net Present Value			2322	677	3219	106	283	1,130	361	244	241	19	1	8603	4	8599
IRR																79%

Table 8 summarises the results from these sensitivity analysis.

Table 8. Results of sensitivity analysis

	NPV (A$ Million)	IRR (%)
Base case (assumptions as outlined in Section 4.1)	8599	79
10% yield increase	6425	76
5% yield increase	4057	71
20% yield increase	10601	82
Seed cost		
Irrigated- 6% total variable costs		
Dryland - 4% total variable costs	8403	79
Adoption rate		
80% adoption rate	11884	80
20% adoption rate	4139	76
Hybrid production		
2% annual increase in hybrid production	7305	77
(28% of total irrigated area by year 15)		
3% annual increase in hybrid production		
(42% of total irrigated area by year 15)	7162	77
3% annual increase in hybrid production		
(52% of total irrigated area by year 15)	7018	77

Yields

In the sensitivity analysis, the yield increases achievable from apomixis were changed to 5, 10 and 20 percent. Increasing the yields observed will have the effect of increasing the cost reduction achievable from apomixis and vice versa. An increase in yield of 10% and 5% reduces the net present value (NPV) from $8.6 billion to $6.4 billion and $4.1 billion respectively. The internal rate of return (IRR) decreases from 79% to 76% and 71%, respectively. A yield increase of 20% increases the NPV from $8.6 billion to $10.6 billion and the IRR from 79% to 82%.

Seed Costs

Seed costs do not appear to have a substantial effect on the NPV. A decrease in the total cost of seed from 8% to 6% of total variable costs for irrigated rice and a decrease in the total cost of seed from 6% to 4% of total variable costs for dryland rice has the effect of decreasing the NPV from $8.6 billion to $8.4 billion. As mentioned earlier, seed costs are significantly higher for hybrid crops than traditional or MVs, and a change in seed cost for these latter two will therefore not have such a great impact on total cost reduction. Given that seed costs are higher for hybrids, a change in seed cost will have a greater effect, but given the yield does not increase, the total cost reduction will be less.

Adoption Rates

As would be expected, the higher the adoption rate the higher the NPV and IRR. An increase in adoption rate to 80% for all countries, increases the NPV from $8.6 billion to $11.9 billion. A decrease in adoption rate to 20% for all countries decreases the NPV to $4.2 billion.

Area of hybrids

In the base case it is assumed that the areas of irrigated, rainfed and hybrid rice (China only) will remain the same throughout the period. However, during the 15-year period of research it is likely that the area of hybrids will gradually increase in irrigated areas. Comparing the cost reductions for hybrid vs irrigated rice in China, a 27% difference was noted. Given that there are no data available for comparing hybrid rice in other countries, this figure of 27% was applied to all other countries (i.e., the assumed hybrid cost reduction was 27% less that of irrigated rice cost reduction).

As would be expected, the greater the area of hybrid rice, the less the total benefit.

5.0 CONCLUDING REMARKS

This paper reports the results of a project-development assessment of a 3-Phase process proposing to introduce apomixis into rice. The assessment shows that there are significantly large benefits to be derived for all rice-growing countries in the world. These high returns are due to the massive production of rice worldwide.

The assumptions used in the analysis are considered to be conservative and as mentioned previously not all rice-growing countries have been included. The returns therefore could be marginally higher.

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APPENDIX 1

The production of rice (thousands of tonnes) in 70 regions or countries of the world:1981-1990.

Country	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Bangladesh	13290	13861	14145	14257	14662	15022	15028	15155	17761	17872
Bhutan	0	0	0	0	0	0	0	0	0	0
India	51924	46002	58531	56909	62281	59007	55470	69140	72245	73125
Nepal	1664	1191	1792	1761	1823	1542	1938	2134	2203	2276
Pakistan	3344	3359	3256	3232	2846	3399	3160	3120	3140	3183
Sri Lanka	1449	1401	1614	1569	1730	1682	1383	1610	1341	1650
Burma	9195	9343	9287	9266	9306	9182	8866	8559	8975	9077
Indonesia	21303	21829	22947	24789	25371	25822	26051	27090	29072	29366
Kampuchea	754	910	1105	1280	1365	1300	1206	1560	1625	1560
Laos	751	710	715	859	907	942	785	652	913	969
Malaysia	1313	1224	1127	1022	1202	1136	1105	1159	1134	1076
Philippines	5279	5025	5097	5330	5913	5823	5551	5831	6148	6058
Thailand	11553	10971	12707	12938	13172	12264	11978	13821	13115	11245
Vietnam	8070	9354	9576	10093	10319	10402	9817	11050	12343	12496
China	93571	105040	109762	115866	109570	111946	113269	109921	118960	124636
Mongolia	0	0	0	0	0	0	0	0	0	0
Fiji	11	13	11	14	18	16	15	21	21	17
Papua New Guinea	0	0	0	0	0	0	0	0	0	0
Samoa (West)	0	0	0	0	0	0	0	0	0	0
Solomon Is.	9	7	6	5	4	2	6	5	4	2
Tonga	0	0	0	0	0	0	0	0	0	0
Vanuatu	0	0	0	0	0	0	0	0	0	0
SPac-Other	0	0	0	0	0	0	0	0	0	0
Ethiopa	0	0	0	0	0	0	0	0	0	0
Kenya	26	24	24	25	32	25	26	29	38	38
Malawi	23	24	17	23	22	24	18	21	30	29
Mozambique	51	52	53	55	56	60	59	60	62	63
Tanzania	130	208	228	231	278	356	418	400	468	481
Uganda	10	12	14	13	12	14	13	15	18	40
Zambia	2	3	6	6	7	7	5	6	8	6
Zimbabwe	0	0	0	0	0	0	0	0	0	0
Zaire	160	163	176	186	193	200	207	214	222	224
Ivory Coast	254	293	234	334	351	364	377	397	413	447
Ghana	63	23	26	42	44	45	52	62	48	53
Nigeria	807	813	832	845	930	921	1157	1353	1300	1625
Cameroon	33	50	58	40	41	35	29	37	36	39
Angola	13	13	14	14	14	13	13	13	13	12
Madagascar	1307	1280	1396	1385	1415	1450	1416	1397	1547	1573
Sudan	8	3	2	1	1	1	1	1	0	1
Africa-2	302	294	312	252	347	378	378	450	507	462

(cont'd) The production of rice (thousands of tonnes) in 70 regions or countries of the world:1981-1990.

Country	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Africa-3	882	927	810	868	834	950	920	895	888	847
Africa-4	12	12	9	12	9	7	8	10	11	11
Africa-5	10	9	10	17	16	20	22	27	29	29
Africa-6	2	1	1	2	2	2	2	2	2	2
Africa-7	9	9	10	10	10	10	10	10	10	10
Turkey	215	228	205	182	176	179	179	171	215	150
Egypt, Arab	1454	1586	1587	1454	1502	1589	1481	1386	1741	2059
Africa-1	13	3	3	4	2	14	33	23	4	22
WA/NA Other	1429	1386	1090	1252	1457	1470	1510	1236	1564	1843
Brazil	5348	6327	5032	5868	5866	6743	6772	7676	7179	4822
Colombia	1221	1315	1179	1115	1132	989	957	1155	1225	1376
Peru	494	537	519	741	571	472	760	734	709	628
Venezuela	443	396	292	265	307	209	243	249	204	260
Bolivia	66	56	40	108	113	89	107	111	147	137
Ecuador	282	250	178	284	258	374	508	620	564	546
Mexico	418	332	270	315	525	354	384	296	414	256
Argentina	186	284	180	312	260	285	241	270	305	304
Chile	65	85	75	107	102	82	96	105	120	88
Paraguay	29	41	47	52	63	41	68	53	57	55
Uruguay	215	272	210	221	273	256	218	247	349	336
Latin-Amer1	1273	1302	1406	1417	1400	1351	1306	1306	1308	1249
Latin-Amer2	190	205	170	208	196	170	164	166	177	119
Asia-Developed	9840	10113	10362	10343	10272	10165	10032	10509	10291	9646
Australia	473	555	337	412	562	465	395	488	523	550
Canada	0	0	0	0	0	0	0	0	0	0
USA	5388	4530	2940	4093	3979	3932	3821	4714	4555	4602
USSR	1618	1605	1690	1765	1672	1711	1744	1863	1664	1607
Japan	8336	8345	8423	9651	9476	9463	8635	8072	8407	8531
Developed1-2	1140	1210	1105	1257	1375	1447	1365	1394	1312	1489
Developed3-4	13	18	25	23	40	39	35	42	69	79
Total World	267732	275435	293277	305000	306683	306259	301815	319116	337750	341355

Source: FAO (1994)

The consumption of rice (thousands of tonnes) in 70 regions or countries of the world: 1981 to 1990.

Country	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Bangladesh	14045	14169	14486	14661	14521	15990	16601	16496	16965	19343
Bhutan	0	0	0	0	0	0	0	0	0	0
India	53098	51245	51170	55480	56808	63426	61172	61830	62627	63652
Nepal	1464	1504	1618	1743	1769	1835	1968	2144	2203	2276
Pakistan	2137	2436	2378	2005	2149	2123	1927	1947	2311	2462
Sri Lanka	1589	1544	1643	1735	1883	1760	1627	1761	1687	1773
Burma	7786	7918	8080	8378	8256	8591	8779	8814	8866	9089
Indonesia	21462	22192	22663	23420	24719	24864	26166	27630	30188	27874
Kampuchea	1018	1058	1178	1280	1370	1417	1500	1560	1584	1580
Laos	738	717	787	822	847	874	903	915	958	987
Malaysia	1587	1570	1574	1497	1540	1531	1506	1453	1539	1506
Philippines	5191	5400	4808	5563	5781	5869	5854	6027	6490	6692
Thailand	8411	8606	8818	8882	8872	9095	9070	8895	8714	8542
Vietnam	8273	9152	9572	10035	10392	10712	10679	10915	11148	11349
China	93260	104801	107332	111927	111709	111337	112786	111512	115911	120526
Mongolia	12	12	14	10	14	13	14	15	13	19
Fiji	25	28	28	28	25	30	30	37	36	35
Papua New Guinea	81	92	101	103	118	144	136	140	141	153
Samoa (West)	2	2	2	2	2	2	4	3	3	2
Solomon Is.	9	9	8	9	11	12	11	12	14	13
Tonga	0	0	0	0	0	0	0	0	0	0
Vanuatu	4	4	5	6	6	6	6	6	6	6
SPac-Other	13	12	13	13	15	14	13	17	17	17
Ethiopa	8	5	21	9	12	10	13	10	39	19
Kenya	37	68	68	25	33	84	64	40	69	78
Malawi	16	21	17	21	22	24	23	17	23	30
Mozambique	119	129	128	127	135	152	142	126	142	133
Tanzania	185	335	291	295	331	472	487	472	493	498
Uganda	19	18	21	21	19	20	20	15	24	40
Zambia	4	10	15	17	10	13	9	6	8	6
Zimbabwe	5	2	19	15	6	6	16	15	15	20
Zaire	184	195	208	222	233	278	280	283	307	289
Ivory Coast	636	635	701	591	704	742	775	716	797	705
Ghana	91	81	99	81	107	103	125	127	148	156
Nigeria	1350	1334	1344	1189	1193	1233	1311	1352	1549	1544
Cameroon	67	60	81	75	71	73	77	103	118	127
Angola	61	44	60	67	71	79	101	86	73	75
Madagascar	1464	1499	1573	1579	1587	1561	1590	1529	1618	1674
Sudan	16	22	27	30	35	40	40	40	39	39
Africa-2	821	939	960	1110	1093	1132	1197	1154	1249	1348
Africa-3	1168	1190	1175	1139	1187	1212	1248	1299	1450	1361
Africa-4	29	33	34	42	47	39	39	42	39	49
Africa-5	16	14	16	26	24	29	32	24	32	34
Africa-6	6	5	7	9	9	10	10	10	10	10

(cont'd) The consumption of rice (thousands of tonnes) in 70 regions or countries of the world: 1981 to 1990.

Country	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Africa-7	155	183	171	173	171	168	180	181	189	182
Turkey	243	250	216	274	268	269	349	269	453	354
Egypt, Arab	1446	1475	1499	1504	1507	1512	1503	1514	1605	1684
Africa-1	86	77	86	85	90	93	100	107	108	115
WA/NA Other	2297	2320	2392	2509	2582	2712	2747	2903	2937	3021
Brazil	5826	5954	5992	6106	6472	6550	6861	7080	7030	7303
Colombia	1151	1220	1173	1175	1196	1177	1187	1194	1192	1228
Peru	516	549	529	513	589	660	742	839	964	897
Venezuela	282	347	305	395	323	198	256	275	179	307
Bolivia	59	59	79	115	112	111	112	112	136	143
Ecuador	274	258	267	296	318	386	478	522	440	565
Mexico	400	389	410	473	432	402	349	482	472	582
Argentina	100	168	165	160	172	177	234	231	209	230
Chile	98	107	106	111	110	119	117	131	126	122
Paraguay	29	41	47	52	63	41	68	53	57	55
Uruguay	42	45	48	44	51	55	48	56	62	63
Latin-Amer1	1395	1440	1494	1512	1523	1596	1497	1541	1549	1651
Latin-Amer2	231	282	284	307	320	279	225	236	263	252
Asia-Developed	11523	11506	11546	11533	11560	11140	10724	10502	10428	10242
Australia	148	99	163	171	292	310	239	232	231	410
Canada	94	102	101	105	109	122	126	130	134	146
USA	1727	1877	1904	1815	1545	1744	2328	2482	2706	2784
USSR	2386	2344	2289	2163	2155	2158	2272	2339	2242	1776
Japan	9048	8943	8932	8898	8830	8790	8664	8614	8544	8781
Developed1-2	1259	1296	1314	1361	1368	1527	1578	1492	1495	1549
Developed3-4	850	847	880	888	956	966	990	1017	1024	1029
Total World	268174	281287	285536	297024	300843	310219	312326	314127	324440	331605

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