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Final report

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1 Acknowledgments

The research team wishes to thank the ACIAR Program Coordinators who have worked with us on the project. Dr Tony Fischer worked as hard as any of the project team during our project development meetings, and several aspects of the project are the result of his insights. Dr Christian Roth had the difficult task of taking on the project mid-stream. His experience in working with farmers (and his directness in working with his fellow scientists) induced a paradigm shift in the project team and our success in this aspect of the work owes much to his intervention. We refer to the early part of the project as BC (Before Christian).

2 Executive summary

One of the primary aims of the project has been to overcome nutritional limitations in the soybean / wheat cropping system used on Vertisols in the monsoonal environment of Madhya Pradesh and on similar soils in subtropical Australia. In the first year, omission trials (where one nutrient at a time is omitted from the fertilizer mix) were used to identify nutrients limiting crop growth. In the subsequent years, fertilization regimes to address the nutrient deficiencies identified were developed and evaluated. Throughout the project, our aim has been to develop practices which are acceptable to farmers. To ensure this, there has been a high level of engagement with farmers; all experiments have been conducted on farmer's fields, and farmer's field days have regularly been conducted in order to understand farmer's perceptions of the work.

The project has developed two fertilizer management strategies. The first is an integrated nutrient management (INM) approach, where the use of farm yard manures (FYM) is combined with inorganic fertilizer. The traditional practice has been to apply a large application of manure (20 t/ha) infrequently. The research conducted in this project has demonstrated that substantial benefits can be gained from a smaller application (5 t/ha), permitting farmers to treat a larger area with manure each year. Even at this reduced rate of FYM application (5 t/ha), there is insufficient FYM for application to all of the cropped area, hence there is the need for the second management strategy, an inorganic fertilizer regime termed balanced fertilization (BF).

Following development of the INM and BF strategies in replicated, scientist managed experiments on farmers' fields, these fertilization regimes were further evaluated using a "Baby Trial" strategy. A total of 95 trials was established, distributed across 10 villages in three districts. The 95 trial sites used were typical of farms on Vertisols throughout Madhya Pradesh. These baby trials were conducted by farmers, with each trial consisting of three treatments; INM, BF, and farmer's practice. The aim was to confirm the experimental results obtained in researcher conducted trials, to assess the robustness of the technology (would different farmers obtain comparable results?), and to begin the process of extending these new fertilizer management practices to farmers. In the karif (monsoon season) soybean crop, BF produced yields 23% greater than the farmer's practice while the INM approach produced yields 46% higher than the farmer's practice. The mean wheat grain yield showed that the INM produced 24% more than the farmers' practice, while BF increased the wheat grain yield by 30% over the farmers' practice.

In Australia, our initial aim was to reduce the potential adverse effects of excessive applications (typically 20 to 50 t/ha) of feedlot manure (FLM), by determining the appropriate rate of FLM application to meet crop nutrient demand. This effort to reduce manure application rates was aided by the development and adoption of equipment capable of spreading manure at lower application rates. A second facet of the Australian work has been to undertake a preliminary investigation of the potential to manipulate N availability in horticultural crops using inputs of high C:N ratio urban green waste. This waste can immobilize NO_3-N reducing the risk of denitrification or leaching.

Much of the land suitable for cultivation in Madhya Pradesh is left uncultivated during the kharif season because of waterlogging (e.g. 20-25% in Vidisha district). Even though some waterlogged fields are sown with soybean, the yields are very low due to poor establishment. A preliminary evaluation of the use of broad bed and furrow (BBF) as an agronomic strategy to overcome some of the adverse effects of waterlogging was made. The integration of BBF with BF produced 40 to 50% higher soybean yield compared to a flat field with the same fertilizer regime. While this is a good result, it is important to note that the area only received about 70% of normal monsoon rainfall. Thus the yields on flat fields would be lower in a normal year, and the effectiveness of the BBF approach must be established in a wetter year. Nevertheless, the BBF approach has attracted the attention of many farmers.

3 Background

Madhya Pradesh (MP) in India has a monsoonal climate (about 1000 mm of annual rainfall), the altitude moderate (300-600 m), and the cropping soils predominantly vertisols deeper than 120 cm. Wheat and soybean are the most important crops grown, either in the form of a soybean-wheat cropping sequence where there is supplemental winter irrigation for the wheat, or soybean- chickpea where there isn't, or as component crops of other sequences (Government of MP 2000). At the initiation of the project, soybean was grown on 4 to 4.5 Mha in MP. This had increased from less than 1 Mha in 1980, with the area of production further increasing throughout the life of the project. The area devoted to soybean in India is continuing to increase steadily; 8.85 Mha in 2007 and 9.45 Mha in 2008 (USDA 2008). It is noteworthy that MP produced 66% of India's total soybean production for the four year period 2003 to 2006, with the adjoining state of Maharashtra producing a further 23%. Low yield expectation, and indeed low average yield, was particularly pronounced for the monsoon season soybean crop. The average farmer's yield of 1.2 t/ha was only one half the yield obtained in experimental plots and that predicted for the area by crop models. The cause of these low yields on farmer's fields was not known, and there seemed to be considerable scope for advancement. Clearly improvement in the yield of the crop would have a substantial impact on India's supply of this commodity and enhanced cash flow to farmers.

Negative nutrient balances are typical of many Indian farming systems, with the gap between fertilizer inputs (both organic and inorganic) and nutrient removal remaining relatively constant over time despite the increase in fertilizer consumption (Tandon 1990). Unfortunately, nutrient balance data are frequently presented as aggregated total nutrient (commonly in India as N + P2O5 + K2O, but throughout this report N + P + K), preventing the identification of balances for individual nutrients. Another deficiency of the majority of published nutrient balance studies is that they report balances for crops produced on research stations grown using recommended fertilizer rates, and hence they are of limited value as a representation of the situation in farmers' fields. There are also considerable differences between farming systems, necessitating studies at a regional scale. A desktop study undertaken as part of ACIAR Project LWR2/1998/136 calculated that MP produces 18.8 Mt of food grains from 15.2 Mha, and removes in produce 1.6 Mt of N, P and K annually (Final report, cited as Dalal et al. 2002). With N, P and K replacement of only 0.7 Mt from fertilizers, manure, and legume N, additional nutrient inputs are needed to reduce the negative nutrient balance of 0.9 Mt a year for sustainable crop production.

Part of the farm nutrient demand is met through the use of FYM, and it may be possible to increase the return of nutrients to the field by improving the efficiency of manure storage and use. India produced 280 Mt of FYM in 1980 and will produce an estimated 396 Mt of FYM in 2010 (Tandon 1997), with estimated NPK amounts of 7 Mt. However, cattle dung is also valued as a household fuel, reducing the resource available for the production of FYM (FYM is a compost made in the kharif from cattle dung, household waste and crop residues generally having less that 1% N and less than 0.3% P). As an example, MP currently produces 25 Mt of cattle dung annually from a livestock population of 37 million. In spite of the low fertility of the soils in MP, and cattle dung being a potential nutrient source, only 50% is used as FYM, resulting in about 19 Mt of FYM. Livestock population will increase due to increasing demand for dairy products from the increasing human population, so that MP has a potential to produce 30 Mt of cattle dung by 2010, with an estimated FYM production of 45 Mt per annum. However, the increase in cattle numbers will largely be in peri-urban areas, so use of this increased supply of dung and FYM will be limited to these areas due to local demand and increasing transportation costs.

At the initiation of the project, the nutrients supplied by FYM in MP were worth $245 million per year (150 kt N, 40 kt P and 130 kt K at a conservatively cost of $500/t of N, $1000/t of P and $1000/t of K) assuming that FYM nutrients were fully equivalent to fertilizer ones. Since FYM is an important source of crop nutrients, it was timely to assess the processes of FYM production and use to ensure that the returns of nutrients to agricultural fields were maximized. Other benefits of FYM on crops, such as improvement in soil physical conditions and possible increase in water holding capacity (Acharya et al. 1998) and long-term carbon sequestration in soil, also needed to be considered in this assessment.

Queensland, at project initiation, produced annually 382,000 tonnes of feedlot manure (on dry matter basis); in contrast to India, this was (and is currently) largely uncomposted dung (but in this document it is referred to as FYM for simplicity). Under the Environmental Protection Act (1994), it is considered a waste product in feedlots and, therefore, it must be safely removed to minimize environmental pollution. However, it is a significant nutrient resource, containing more than 2% N, 1% P and 2% K. Small lot-feeders usually applied manure to land at the rate of 20-50 t/ha, since smaller quantities could not be uniformly spread. Often no account was taken of the nutrient supply from the applied feedlot manure for adjusting fertilizer rates. On many soils including Vertisols, there was the potential for adverse environmental impacts from feedlot manure, especially from nitrates and high concentrations of phosphates in streams, dams and groundwater. This was especially the case within the sensitive Murray-Darling Basin. The regulation of the land application of feedlot manure was based on the limited current scientific data. This project was intended to provide data (both through experimentation, and through access to existing Indian experimental data) to permit the development of an Environmental Audit framework for assessing the environmental consequences of feedlot manure use.

4 Objectives

The objectives of the project were to:

1. Assess integrated nutrient management strategies for soybean / wheat systems (inorganic and FYM) and identify any agronomic constraints that may be restraining productivity in these systems
    - Identify nutritional constraints to production at a number of representative sites.
    - Evaluate the agronomic practices used for the major crops (soybean and wheat) of the farming system (viz., weeding, INM, seed dressing of fungicide, insecticidal spray at vegetative stage, and Rhizobium inoculation), and assess pest and disease impacts.
2. Assess FYM production and characterize the benefits of FYM use in cropping systems.
    - Investigate nutrient release characteristics of FYM.
    - Quantify nutrient losses during FYM production and use, identify loss pathways, and develop practical strategies to limit nutrient loss.
    - Evaluate biophysical benefits such as infiltration, water holding capacity, and quality and quantity of organic carbon following FYM application.
3. Assess adverse environmental impact of FYM in fields and landscapes and develop an Environmental Audit framework for the safe utilisation of feedlot manure.
    - Quantitative and qualitative assessments of the adverse effects of FYM on field and landscape scales are to be made to ensure the cost effective and environmentally sustainable use of this resource.
4. Develop practical tools and action-learning modules for nutrient management practice, including the most efficient utilisation of FYM.
    - Practical methods and learning tools are to be developed and delivered to farmers and advisors to enable them to recognise limitations to crop production, and to apply outcomes from this project. For example, anticipated modules may include; effective production and use of FYM in cropping systems, optimal fertilizer management, and management of crop waterlogging of soybean.

5 Methodology

The research strategy adopted for the project was underpinned by farmers' surveys to determine the problems and opportunities surrounding integrated manure and fertilizer management in MP (and in southeast Queensland). These surveys were undertaken in a preliminary phase - LWR2/1998/136. The project then exploited the farming contacts made, and the knowledge obtained, in the preliminary phase (and from elsewhere) to develop and test ways of improving nutrient harvesting from manure by crops, as well as maximizing the physical and C sequestration benefits of FYM for cropping soils.

An incremental approach was adopted, with experiments during the first year aimed at identifying crop production constraints that were then investigated in detail during subsequent years. Therefore, nutritional constraints were identified initially through the use of omission trials. Appropriate fertilization regimes were then developed and evaluated in a limited number of replicated experiments. Finally, the results were confirmed and the process of extension begun using an un-replicated "baby trial" program.

Wherever possible (and appropriate), the experimental work was conducted in collaboration with farmers. In this way it was anticipated that the research outcomes would be interpreted, and ultimately delivered to farmers in an acceptable manner. While the research was undertaken with farmers and on farmer's fields, this was not intended in itself to be a development activity. Our intention was to ensure that the problems addressed were ones that the farmers considered important, and to ensure that strategies developed to address these problems were ones that farmers will readily adopt.

The general research approaches to be used (e.g. field-based plant nutrition studies, fertilizer equivalence testing of organic wastes, nutrient mass balance, and agronomic practices) are well established approaches, but have the particular advantage in this setting of providing results that are tangible and readily interpreted. In Australia, these approaches were complimented by use of laboratory and field gas sampling and analysis to determine the effects of organic inputs on the evolution of greenhouse gasses.

5.1 Locations:

In MP, the initial phase of experimentation focused on villages which had been included in the preliminary phase study; viz. Geelakhedi (Rajgarh district), Mugaliahat (Bhopal district) and Rangai (Vidisha district). The geographical coverage was extended later in the "baby trial" program to 10 villages in the Raisen, Vidisha and Rajgarh districts. This area conforms to the high rainfall / low yield typology, demonstrated by Deosthali et al. (2005) to be typical of the majority of districts in MP. These districts are all within reasonable travel distance of the IISS and BAIF in Bhopal, permitting the scientists and community workers to maintain a high level of involvement with the trials.

In Australia, we conducted field trials at Dalby and Gatton. Soils at these sites are typical of the soils of the eastern Darling Downs, a focus area for feed-lotting operations. Irrigation was available at the Gatton site, though aquifer exhaustion during the prolonged drought (2001 - 2007) limited the amount of irrigation water available.

5.2 Nutrient Management Research Experiments

While changes in the method of FYM production and use may result in a greater return of nutrients to agricultural fields, this strategy alone is insufficient to overcome the nutrient deficit. Clearly, increased inputs of inorganic fertilizers will be required to achieve a nutrient balance. Farmers are already accustomed to the use of mineral fertilizers, but the low rates of application used reflect low yield expectation and the farmers' mixed attitudes toward inorganic fertilizer. In the survey of MP farmers, 78% of farmers agreed with the statement “Since adequate quantity of organic manure is not available, use of fertilizer is a must”, indicating the farmers' willingness to use inorganic fertilizer. However, strong negative perceptions of inorganic fertilizers value were also prevalent; 79% of farmers agreeing with the statement “Continuous use of fertilizers without organic manure decreases soil fertility and thereby crop productivity”, while 44% of farmers believed that “Fertilized food crops have harmful effects on health”. While the perception that fertilized crops are harmful to health may be overcome by education, the belief that fertility cannot be sustained by inorganic fertilization alone may indicate the use of an inappropriate fertilizer regime. Typically, farmers apply N alone, or N and P, as inorganic fertilizer, and this is frequently broadcast rather than banded (30 to 50% of farmers). Nitrogen and P are certainly deficient in MP soils, but crop yield may be limited by other nutrients, such as Zn, which was of low availability in the majority of soil samples tested during the conduct of ACIAR Project LWR2/1998/136.

5.2.1 Nutrient Omission Trials (India)

While the soils of MP were understood to be generally deficient in N and P, with S and Zn as less commonly encountered deficiencies, the soils of the focus area had not been specifically evaluated. The omission approach was employed for this assessment for several reasons. Firstly, we wished to encourage both researchers and farmers to consider each nutrient separately (there is a tendency to make comparisons of rates of fertilizer mixes – NP or NPK). Secondly, the relatively unambiguous nature of the results obtained (a reduction in yield relative to the control is a clear indication of deficiency) can easily be interpreted by farmers. It was considered that this simply interpreted trial would afford a good first base of interaction between researchers and farmers. It would also ensure that limiting nutrients would be individually addressed.

Six field experiments on farmers’ fields in Geelakhedi (Rajgarh district), Mugaliahat (Bhopal district) and Rangai (Vidisha district) villages (two experiments in each village) were established to assess nutritional constraints for wheat (cv. Lok – 1) production using a nutrient omission approach (termed nutrient skip in India). Field experiments were laid out with 3 replications on each farmer’s field in a randomized block design (RBD) with seven treatments, namely, All, -P, -K, -S, -Zn, farmers’ practice (FP) and an All+micronutrients (BFeCuMnMo) treatment. Response to nitrogen application was not tested, as this nutrient is recognised by farmers as being deficient, and is routinely applied as fertilizer. Plot size was 60 x 4.3 m. In the case of farmers’ practice treatment, only N and P were applied as per the farmers’ rates of application to wheat in the region (80 kg N and 22 kg/ha). In other treatments N, P, K, S and Zn were applied at recommended rates (N 120 kg/ha, P 26 kg/ha, K 17 kg/ha, S 20 kg/ha, and Zn 5 kg/ha). In the All+micronutrients treatment, B, Mo, Cu, Mn and Fe were applied to soil at recommended rates (B 0.75 kg/ha, Mo 0.2 kg/ha, Cu 7.5 kg/ha, Mn 40 kg/ha, and Fe 15 kg/ha).

Collection and analysis of plant samples: At the ear emergence stage, flag leaves (indicator tissue) from randomly selected 30 plants in each plot were collected and washed gently under a running tap and air-dried. Then flag leaves were dried in an oven at 70° C. Finally ground leaf samples were stored in an oven set at 60°C until further analysis. Total N concentration in leaf samples was determined by digesting leaf samples using the semi-Kjeldahl method of Bremner and Mulvaney (1982) and NH_4-N formed was measured using an auto analyzer. For the determination of total P, K and S in leaf samples, sub samples were digested in 4:1 nitric: perchloric acid (HNO_3 : $HClO_4$) mixture. Total P and K were determined in the digests using the vanado-molybdate yellow colour method and by flame photometer, respectively (Jackson, 1973). The S concentration in digests was determined using the turbidimetric method (Chesnin and Yien 1951). Regression analysis was used to determine the relationship between nutrient concentration in indicator tissue and grain yield. The optimum nutrient concentration in indicator tissue (i.e. that required to get optimum wheat grain yield) were established from the regression equations by differentiation. Grain and straw yields of wheat were recorded at full maturity, at which time grain and straw samples were collected and analyzed for total N, P and K concentrations as described above. Total content of nutrients measured (i.e. nutrients removed by both grain and straw) was computed.

Soil analyses: Surface soil samples (0-15 cm depth) from experimental plots were collected before experimentation and after harvesting the wheat crop. After collection, samples were air-dried at room temperature, ground to pass through a 2mm sieve and stored for chemical analysis. Potentially available (mineralizable) N was determined by distilling the soil with alkaline potassium permanganate solution and measuring the NH_4-N in the solution (Subbiah and Asija 1956). Available P was determined by extracting soil with 0.5 mol/L $NaHCO_3$ (Olsen et al. 1954). Available K (1 mol/L ammonium acetate extractable) was determined according to the procedure of Hanway and Hiedel (1952). Organic C was determined by the wet oxidation procedure of Walkley and Black (1934). Available Zn was extracted in 0.005 mol/L DTPA-$CaCl_2$, at pH 7.3 (Lindsay and Norvell 1978) and its concentration in the extracts was determined by atomic absorption spectrophotometry. Available S was extracted using 0.01M $CaCl_2$ (Williams and Steinbergs 1959) and the S concentration in extracts was determined using the turbidimetric method (Chenin and Yien 1951). The experimental soils at all the sites were low in available N, P, S, and Zn but high in available K, Fe, Cu, and Mn (Table 5.1). The experimental soils at 4 sites (Site 1, 2, 5 & 6) were low in available Zn but those of the remaining sites were high with respect to available Zn.

Table 5.1. Initial nutrient status of experimental soils

Site	Organic C (%)	$KMnO_4$-N (kg/ha)	Olsen P (kg/ha)	NH4oAc-K (kg/ha)	$CaCl_2$-S (mg/kg)	DTPA-Zn (mg/kg)	Hot water soluble B (mg/kg)
Site1	0.49	151	9.42	365	8.00	0.43	0.636
Site2	0.50	163	8.74	362	4.50	0.35	0.544
Site3	0.54	136	9.33	397	9.83	0.56	0.432
Site4	0.47	126	6.94	457	7.98	0.65	0.520
Site5	0.47	142	10.70	475	6.72	0.22	0.723
Site6	0.48	163	8.51	466	4.48	0.26	0.704

5.2.2 Integrated Nutrient Management and Balanced Fertilization Trials (India and Australia)

Indian Trials

The omission trial program identified P, S and Zn as deficient, with N also recognised as deficient, but showed that adequate levels of the other nutrients were present. The response to P on several of the field sites, despite regular applications of phosphatic fertilizer, indicated that the rate of application used has only been sufficient to maintain production, and that no reservoir of P had accumulated. Using this output, integrated nutrient management (INM - the combination of nutrient supply from organic matter and inorganic fertilizers) and balanced fertilization (BF - where the nutrient demands of the crop are met through the use of inorganic fertilizers) trials were designed and conducted in Raigarh and Bhopal districts (two replicated trials in each district). Treatment regimes were developed to evaluate inorganic fertilization, organic fertilization, and a combination of inorganic fertilizer and organic fertilization for the soybean/wheat cropping system. In the kharif season, the treatments used for the soybean crop included inorganic N, P, K, S and Zn at recommended rates, 5 t/ha FYM + 50% of the recommended rate of inorganic fertilizer, 5 t/ha FYM + 50% inorganic fertilizer + rhizobium inoculation, and an organic matter treatment of 5 t/ha FYM. Other treatments evaluated the effectiveness of phosphorus solubilising bacteria, and Azotobacter (a free living N fixer). A farmers' practice treatment was also included (Table 5.2, Table 5.3).

Table 5.2. Details of treatments for INM experiments

Treatment	Application to soybean	Application to wheat
T1 BF[a]	100% RR[b] of NPKSZn	100% RR of NPKS
T2 INM[c]	50% RR of NPKS+5 t/ha FYM/ha	75% of RR of NPKS
T3 Complete INM	50% RR of NPKS+5 t/ha FYM/ha +Rhizobium	75% of RR of NPKS+PSB[d]
T4 Farmers' Practice (FP)	N (12kg/ha) + P (13 kg P/ha)+2t FYM/ha	FP
T5 INM	100% RR of KSZn+50% of N + 75% of P+Rhizobium+PSB	75% of RR of KS+75% of NP + Azotobacter+PSB
T6 Organic	5 t/ha FYM/ha+Rhizobium+PSB	8 t/ha FYM/ha+Azotobacter + PSB
T7 Organic	5 t/ha FYM/ha (0.75%N, 0.2% P)	8 t/ha FYM/ha

[a] BF - balanced fertilization

[b] RR - recommended rate

[c] INM - integrated nutrient management

[d] PSB – phosphate solubilizing bateria

Table 5.3. Rates of nutrient application to soybean and wheat

Nutrient	Soybean		Wheat		Source
	Recommended rate (kg/ha)	Farmers' practice (kg/ha)	Recommended rate (kg/ha)	Farmers' practice (kg/ha)	
N	25	12	120	80	Urea & DAP
P	26	13	26	23	DAP
K	17	0	17	0	KCl
S	20	0	20	0	Gypsum
Zn	5	0	0	0	ZnSO4

Australian Trials

The field experiments conducted on vertosols at Dalby and Gatton consisted of 11 treatments, arranged in a complete randomised block design with 4 replications. Three crops were grown in sequence: sorghum-wheat-sorghum (Sorghum 2005 sown in December 2005, Wheat 2006 sown in June 2006 and Sorghum 2006 sown in December 2006) over the 18 months' period. The treatments applied were: (1) control, (2) 10 t/ha of feed lot manure (FLM) applied to sorghum crops (FLM10), (3) 20 t/ha of FLM applied once to the first sorghum crop (FLM20 -once), (4) 20 t/ha of FLM applied to sorghum crops (FLM20), (5) 10 t/ha green waste compost (GWC) to sorghum crops (GWC10), (6) 20 t/ha GWC to sorghum crops (GWC20), (7) 10 t/ha of FLM and 10 t/ha GWC to sorghum crops (FLM10GWC10), (8) 5 t/ha of FLM and 15 t/ha of GWC to sorghum crops (FLM5GWC15), (9) 75 kg N/ha as urea for each crop (N75), (10) 150 kg N/ha as urea for each crop (N150), and (11) 20 kg P/ha as mono-ammonium phosphate fortified with 1 kg Zn/ha applied to sorghum crops (P20). The FLM contained 2.4-2.6% N and 17% lignin, whereas GWC contained 0.8-1.3% N and 22-24% lignin. The C/N ratio of the organic materials varied from 12 to 38, and lignin/N ratio varied from 6 to 30.

Three crops were grown in a sequence of sorghum-wheat-sorghum from December 2005 to April 2007. The first crop, sorghum (Sorghum 2005) (cv. Pioneer 86G87) was sown on 22 December 2005, followed by a second crop of wheat (Wheat 2006) (cv. Kennedy), sown on 16 June 2006. The third crop, sorghum (Sorghum 2006) (cv. Pioneer 86G87), was sown on 21 December 2006.

Soil sampling was undertaken at the beginning and end of each crop to 1.5 m depth. Plots were stratified and sampled following applications of FLM and GWC in January 2006, May 2006, November 2006 and May 2007. Two cores were collected from each plot by a hydraulically operated core sampler with a 50-mm diameter steel tube. Cores were sectioned into 6 depth intervals, 0-0.1, 0.1-0.3, 0.3-0.6, 0.6-0.9, 0.9-1.2, and 1.2-1.5 m depths and the samples from respective depth intervals were combined. Four additional samples were randomly taken from the 0-10 cm depth using a manual core sampler and bulked with the other 0-10 cm composite sample. In-crop sampling of soil was undertaken of the 0-10 depth only for the second sorghum crop (Sorghum 2006) and during the following fallow period, from December 2006 to December 2007. Four samples were collected at random over the length of each plot using a core sampler for soil moisture, and NH_4-N and NO_3-N determinations to correlate with N_2O measurements during this period.

Table 5.4. Composition of feed-lot manure (FLM) and green waste compost (GWC) on an oven-dry weight basis

Property	Feed-lot manure		Green waste compost	
	2005	2006	2005	2006
H_2O content (%)	28.2	28.2	37.9	37.9
Organic C (%)	31.3	27.8	29.1	24.6
Total N (%)	2.61	2.40	0.76	1.29
C/N ratio	12.0	11.6	38.3	19.0
NH_4-N (mg/kg)	4241	1092	41	48
NO_3-N (mg/kg)	0	0	135	3
Mineral N (mg/kg)	4241	1092	176	51
Lignin (%)	16.7	17.3	24.4	21.9
Lignin/N ratio	6.4	7.2	29.5	17.0
Acid digestible fibre (%)	33.8	36.4	41.5	36.7
Cellulose (%)	17.1	19.1	17.1	14.9
Polyphenolics (mg/kg)	1641	1270	166	113
Ash (%)	16.3	20.9	36.0	43.1
pH	7.3	7.3	7.0	7.7
EC (dS/m)	10.0	10.2	1.8	3.4
$NaHCO_3$-extractable P (mg/kg)	1705	1915	416	864
Al (mg/kg)	9910	10000	19900	19900
B (mg/kg)	20.35	16	7.6	14.7
Ca %	2.29	2.37	1.25	2.26
Cu%	28.4	31.4	89.4	164
Fe (mg/kg)	15200	16500	17500	17000
K%	2.515	2.54	0.197	0.411
Mg%	0.89	0.916	0.176	0.418
Mn (mg/kg)	372	365	235	352
Na%	0.7065	0.687	0.105	0.28
P%	0.7825	0.771	0.202	0.34
S%	0.6305	0.642	0.319	0.513
Zn (mg/kg)	185	193	839	407

Gas samples were collected from static closed chambers (n = 2 per plot; 36 chambers total) positioned 4-5m apart (~ 10m between plots). In brief, modified PVC chamber bases were inserted approximated 50-100mm into the soil to act as 'collars' that were permanently positioned along the transect throughout the sampling campaign and removed temporarily only during harvest. Periodically throughout the sampling period, chamber heights were measured to ensure accurate determination of chamber volume. Gas samples were collected between 9.00 and 11.00 h, with gas samples collected around the same time of day for all sampling events. Preliminary studies showed that gas flux during this period approximates mean daily gas flux. At the time of gas sampling, lids were placed on the chambers to form a gas-tight seal. During the closure period (~ 1h, see below), 25 mL gas samples were taken intermittently from a sampling tube fitted with a 3-way stopcock and transferred to 12 mL pre-evacuated exetainers (Labco, UK) and transported to the laboratory for analysis.

Plant sampling was undertaken at both anthesis and physiological maturity for which 1m lengths of representative rows from each plot were cut at ground level with secateurs. Plant samples were placed in coarse woven Hessian bags and dried at 60 °C until no change in weight was observed. Heads were removed prior to cutting mature plants and stored separately. Grain heads were threshed using a rotor style manual feed thresher with adjustable draught for particle removal. The grain was weighed for harvest index calculations (grain / (grain + straw)). Based on the number of plants (stubble) ground for analyses, a similar number of empty heads (post threshing) were ground and mixed with the stubble for chemical analysis.

The crop was harvested using a 2.5 m trial header. A subsample of grain from each plot was taken for N and P analyses and moisture determination (60°C) for yield estimates to 12% moisture. Nitrogen and phosphorus concentrations of straw and grain samples at harvest were determined by acid digestion (Crooke and Simpson 1971). Grain protein for wheat was calculated by multiplying the grain N concentration by 5.7. Crop N and P yields were calculated from N uptake by grain and straw.

5.2.3 Laboratory-based mineralization / immobilization experiments

Laboratory based incubation studies were undertaken to determine the mineralization / immobilization characteristics of Indian FYM and Australian FLM under controlled conditions. These materials were compared to other organic residue materials. In India, the experiment primarily focused on mineral N release (NH_4 and NO_3) (this experimental methodology is described in detail below), while in Australia the study considered mineral N release, and gaseous N release (this aspect is described in detail).

Indian Study

Soil: The study was conducted using the surface (0-15 cm) layer of a Vertisol, collected field-moist soil from a cultivated site. A portion of field-moist soil was taken for laboratory incubation, while another portion was air-dried, crushed to pass through a 2 mm sieve, then stored in an air-tight plastic container at room temperature. A sub-sample of this material was finely ground to pass a 100-mesh sieve.

Organic materials*:* Farmyard manure was collected in bulk from a local dairy farm, and poultry manure was collected from a poultry producer. Subabul (*Leuceana leucocephala*) and gliricida (*Gliricidia sepium*) cuttings were collected from 1-year old green manure crops and were chopped into pieces (1.5-2.5 mm long). Straw from soybean (*Glycine max*), chickpea (*Cicer arietinum*) and wheat (*Triticum aestivum*) crops were collected from farmers' fields immediately after harvest and finely ground. The composition of these materials is presented in Table 5.5.

Analytical procedures: The pH was determined on 2 mm sieved soil using a glass electrode in 1:2.5 soil:water suspension. Soil organic C was determined on 100 mesh ground material using wet oxidation (Walkley and Black 1934). Total N was determined on 100 mesh soil and ground plant material using the semi-micro Kjeldahl method (Bremner and Mulvaney 1982), with the NH_4^+ formed quantified colorimetrically. Total C in organic materials was determined by the weight loss on ignition method. Lignin in the organic materials was determined using the acid detergent fibre (ADF) method (Rowland and Roberts 1994). Total soluble polyphenol in the organic materials was determined by the Folin-Ciocalteau method (Constantinides and Fownes 1994).

Incubation experiment: All the organic materials were applied to soil at a rate of 5 g/kg on dry weight basis. For each treatment, a sample of 500 g of the soil was hand mixed with 2.5 g of organic material, then transferred to a plastic bottle. Soil water retention at field capacity (-0.03 MPa) was determined for each treatment mixture using pressure plate apparatus. The treatment mixtures were maintained at field capacity throughout the incubation by replacing any loss of water with the appropriate volume of distilled water after every sampling. The soil and organic material mixtures were incubated at 30°C for 16 weeks in duplicate in a laboratory incubator. Four of the organic materials used contained less than 2% N (chickpea straw, soybean straw, wheat straw, FYM). For these materials an additional treatment was included where mineral N as urea was added to raise the N concentration to the equivalent of 2% in these materials. Thus the incubation study consisted of 12 treatments (7 organic material amended soils, 4 urea+organic material amended soils, and one unamended soil (i.e. control)). Soil samples were taken at 1, 2, 4, 6, 8, 10, 12 and 16 weeks after incubation, and analysed for inorganic N (NH_4-N + NO_3-N). Mineral N was determined by steam distillation of 2 M KCl extracts obtained immediately after sampling. The data were corrected for moisture content and are reported on an oven-dry weight basis. The N released from the different materials during each interval was calculated as: mineral N in the organic matter amended soil minus mineral N in control soil, and expressed as a percentage of the total N added in the organic material. The N release data was fitted to a first-order rate constant equation, $N_m = N_o[1-(\exp^{-kt})]$ to compute the potentially mineralizable N pool (N_o), and the release rate constant (k), where N is the amount of N released in a time period (t in weeks).

Table 5.5. -Composition (dry-weight basis) of the organic manures and crop residues

Organic Material	Total C (%)	Total N (%)	C:N	Lignin (%)	Poly-phenols (%)	Amount of N added (mg/kg)
Gliricidia	33.0	2.74	12.0	5.5	1.48	137.0
Subabul	36.0	2.85	12.6	4.2	2.18	142.5
Chickpea Straw	37.1	1.20	31.0	11.0	1.88	60.0
Soybean Straw	36.6	1.09	33.6	8.5	1.98	54.5
Wheat Straw	44.8	0.57	78.6	16.5	1.08	28.5
Poultry manure	31.5	2.23	14.1	10.6	2.92	111.5
Farmyard manure	25.4	0.87	29.1	22.0	1.32	43.5

Australian Study

A comparable incubation study to that undertaken in India was performed in Australia. This is presented in less detail, as it was generally comparable to the Indian study. However, in Australia gaseous emissions were also evaluated, necessitating the use of a different incubation approach. Details of the treatments and gas sampling are detailed here, in other respects the experiment can be considered comparable to the Indian experiment described in detail above.

Incubation chambers: Constructed from 90 mm PVC pipe (Vinidex Pty Ltd) cut to 150 mm lengths and sealed with PVC bottom end caps. Similar size caps were used to cover the top of the chamber but had a 12 mm hole in the centre of the lid to allow gas exchange. The hole was plugged with a rubber septum for 1h whenever N_2O was collected.

Incubation experiment: In Australia the experiment consisted of 7 treatments: (i) Control, (ii) FLM applied at 10 t/ha (FLM10), (iii) FLM applied at 20 t/ha (FLM20), (iv) GWC applied at 10 t/ha (GWC10) (v) GWC applied at 20 t/ha (GWC20), (vi) FLM and GWC applied together at 10 t/ha each (FLM10GWC10), and (vi) FLM and GWC applied together at 5 t/ha and 15 t/ha, respectively (FLM5GWC15). Incubation chambers were set-up in a completely randomized block design. Three replicate chambers were established for each treatment. A complete set of 21 chambers was prepared for each soil sampling period at 0, 1, 2, 4, 8, 16, 32 and 64 weeks of incubation (168 chambers).

Gas sampling was undertaken on a sub-set of chambers that were scheduled to be destructively sampled at week 64 of the study. The inside vertical rim of the chamber lids was smeared with vacuum grease to create a positive seal between the container and the lid, preventing gas diffusion. Prior to gas sampling, chamber lids were removed for 15 min to circulate air within the chamber head space, and fresh vacuum grease was applied to the chamber lids. Once an adequate seal between the chamber base and lid was established, the chamber lid openings were sealed with rubber septum for 60 minutes. Gas within the head-space was sampled using a 50 mm syringe fitted with a 2 way valve. Prior to drawing the gas sample from the head-space, 50 mL air within the headspace was mixed gently 4 times using the syringe. Thereafter, 25 mL of gas was sampled from each chamber headspace for analysis of CO_2, CH_4 and N_2O using gas chromatography (3800, Varian, Netherlands) (Allen et al. 2007).

5.3 Baby trial program (India)

Integrated and balanced nutrient management technologies were developed in participatory experiments on farmers' fields in the villages of Bhopal, Rajgarh, and Vidisha districts during the years 2005-06, 2006-07 and 2009-2010. The experimental trials were considered as "Mother Trials" which were replicated and managed by scientists and farmers. These experimental trials led to development of an inorganic fertilizer regime (BF) and an INM technology that comprises of "50% NPKS+5 t/ha FYM + Rhizobium to soybean and 75 % NPKS to wheat" which, on an average, produced 11% higher grain yield in soybean and 25% higher yield in wheat as compared to the farmers' practice. In response to a Government initiative, phosphorus solubilizing bacteria (PSB) were included in this treatment, even though this addition did not significantly increase yield in the initial experiments.

During 2007-08, 95 "Baby Trials" on farmers' fields in 10 villages of Raisen, Vidisha and Rajgarh districts (Table 5.6) were conducted to demonstrate and popularize the BNM and INM technologies in M.P., and to confirm the initial experimental results across a broader range of environments and management regimes. In these trials, two nutrient management options viz., BF through inorganic fertilizers alone (100% NPKSZn to soybean and 100% NPKS to wheat) and a INM module (50% NPKS+5 t/ha FYM +Rhizobium to soybean and 75 % NPKS+PSB to wheat) were compared with the farmers' practice. Soybean (cv. JS 335) was grown in the kharif season and wheat (cv. Lok –1) was grown in the rabi season. The quantity of nutrients applied to soybean and wheat in farmers' practice, balanced fertilization and INM options are given in Table 5.7. The N and P were supplied through urea and DAP, with K supplied as muriate of potash, S as gypsum and Zn as zinc sulfate.

In the rabi (winter) season, four crops out of the 95 planted could not be harvested, due to lack of irrigation water. Out of 91 harvested trials, 45 farmers used 3-4 irrigations, 12 farmers irrigated twice, and remaining 34 farmers could only irrigate once.

The initial soil fertility status of 95 trial sites showed that all sites were low in available N. About 48% sites were low in available P and 41% were low in available sulfur (Table 5.8). Available Zn was low in 52% of the sites whereas 47% of sites were low in organic carbon. About 32% field sites were deficient in four nutrients namely; N, P, S and Zn. At maturity, soybean and wheat crops were harvested from a net area of 12 m^2 from each treatment -plot and grain yield data was recorded

Table 5.6. Location of Baby Trials

District	Village	No. of trials	
		2007-2008	2009-2010
Vidisha	Rangai	20	7
	Berkheda	5	
	Karayya	12	
	Gagandhaba	6	
	Shair		21
	Powanala		29
Raisen	Dakhna		19
	Kamapar	9	
	Naunakheda	10	
	Sanchi	7	
	Sunari		11
Rajgarh	Geelakhedi	16	11
	Sanwas	4	
	Turkipura	6	
Total No. of trials		95	98

Table 5.7. Details of Nutrient Management Options

Nutrient Management Option	Nutrients applied (kg/ha)					FYM (t/ha)
	N	P	K	S	Zn	
To Soybean in kharif season						
Farmers' practice	12	13	0	0	0	2
BF (100%* NPKSZn)	25	26	17	20	5	0
INM (50%** NPKS + 5t FYM+ Rhizobium)	12.5	13	8	10	0	5
To Wheat in rabi season						
Farmers' practice	80	22	0	0	0	0
BF (100% NPKSZn)	120	26	17	20	0	0
INM (75% NPKS + PSB)	80	20	12	15	0	0

* - 100% of Recommended rate; ** - 50% of the Recommended rate

Table 5.8. Initial fertility status of baby trial sites (N = 95)

Value	Available nutrient status					Organic C (%)
	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (mg/kg)	Zn (mg/kg)	
Lowest	100.4	5.6	461	3.8	0.3	0.33
Highest	240.1	56.6	1283	27.8	1.68	0.90
Mean	137.4	16.8	765	13.5	0.55	0.54
Sd (±)	37.7	9.8	186	6.0	0.24	0.14
% samples deficient	100	48	0	41	52	47

One recommendation from the final review of the project was to extend the Baby trial program to additional farmers and ideally to other villages. This recommendation was accepted by ACIAR and an extension of the project funded to support one year of additional Baby trials (2009-2010) IISS and BAIF conducted 100 baby trials during the year 2009-2010, with IISS utilizing unspent funds the initial project, and BAIF provided with additional funds for this activity. The main aim of conducting 100 more baby trials was to popularize the balanced and integrated nutrient management among the farmers growing soybean–wheat system in new villages.

Baby trials were conducted in different villages of Rajgarh, Vidisha and Raisen districts during the year 2009-10 (Table 5.6). Ninety eight trials out of 100 trials conducted were successfully harvested during both kharif (monsoon) and rabi (winter) seasons. The trials conducted were identical to those in the earlier year, with details provided in Table 5.7.

5.4 Environmental audit of feedlot manure (Australia)

An environmental audit of FLM was undertaken using a dataset collected by the Australian Feedlot Association and collated and analysed by ABARE, The Australian Bureau of Agriculture and Resource Economics. The dataset contains the number of feedlots and their head count at a given time. Feedlot locality (town/placename) data was sourced from MLA (Meat and Livestock Australia) and matched with the georeferenced name database ‘Gazeteer’ as provided by Geosciences Australia. Estimating manure production from cattle numbers on feed and quarterly turnoff rates (ALFA 2007) provides only rough estimates. In addition to the lack of accuracy in converting ‘numbers of cattle on feed’ to manure production, there is also a lack of understanding of how long an individual animal may be on feed for across the whole feed lot industry.

Estimates of market value of FLM, transportation and spreading costs were obtained from the key feedlots and involved contractors in Queensland. The potential nutrient value of the FLM was estimated from a typical concentration of major plant nutrients contained in FLM, and the estimated nutrient release rates. Soil type/s near the feedlots were utilised to prepare a nutrient budget from FLM application, including the potential NO_3 leaching, and the possibility of P leaching into ground water.

Spatial representation of the location and feeding intensity of Australian feedlots was achieved through using feedlot location data (MLA) containing “address location” fields, that were matched with locality data from the Australian Gazeteer (Geosciences Australia). Feedlot capacity and location was mapped over an underlying land use layer of 50 m grid raster data (Bureau of Rural Sciences, Australian Government, Combined Catchment Scale Land Use Mapping). Geographical Information System was used to prepare maps showing the potential areas for FLM application in Queensland and Australia.

5.5 Compost pit nutrient mass balance

While it is generally accepted amongst Indian researchers that N is lost from compost pits, we could find no published studies of nutrient mass balance for the open pit system typically used in villages. To provide an indication of the extent of nutrient loss from the pits, a mass balance study was undertaken, where nutrient input to the pit was measured throughout the nine month pit filling period, and this was compared with the nutrient content of the pit when emptied.

Prior to initiating the study, a focus group of farmers was organized in the Geelakhedi village to discuss the different types of organic materials that are being put into the FYM pits. These discussions revealed that there are five different materials, viz., cattle dung, cattle shed wastes/straw, vegetable wastes, ash, and house hold wastes.

A FYM pit in Geelakhedi village was selected for a simple mass balance study. This pit was used by a typical farmer, Mr Hukum Singh, whose stock consisted of 5 indigenous breed cattle. The depth of this pit was about 1.2 m. Fresh weights of the five different types of materials were recorded separately once in a week (every Wednesday) during July to March, 2006 and samples of these materials were also collected for chemical analysis in the laboratory. Moisture content of the materials was determined to express their quantities on dry weight basis. For each month dried samples of each type of materials were pooled together to obtain a composite sample which were ground and analysed for total N, P, K, and C. The total amount of each nutrient input into the FYM pit was calculated at the end of the filling period, based on the nutrient concentrations of different types of materials. When the pit was emptied in May, the total weight of the field moist FYM produced from the pit was recorded and FYM samples were collected for the laboratory analyses. Dry weight of the FYM was recorded after adjusting for the moisture content. The total amount of each nutrient output from the FYM pit was calculated based on the nutrient concentrations of FYM.

5.6 Evaluation of broad bed and furrow cultivation

About 20-25% of land suitable for cultivation in Vidisha district is left uncultivated by farmers during the kharif season due to waterlogging. Even though farmers sow some waterlogged fields with soybean, the yields are very low due to poor crop establishment. Most of the fields in this district were also deficient in N, P, S, and Zn. Therefore, three field trials were conducted on waterlogged fields in Rangai village, Vidisha district to assess and demonstrate the beneficial effects of integration of farmer friendly drainage techniques and farmers practice of land configuration with balanced fertilization on soybean. These soils were low in available N, P, S and Zn but high in available K (Table 7). The beneficial effect of integration of broad bed furrow (BBF) with BF (100% NPKSZn) on soybean seed yield was compared with that of farmers' practice of land configuration (1 furrow after every 12 rows of soybean; Row to row spacing was 30 cm) with balanced fertilization on waterlogged fields which could not be cultivated in most of the previous years. The width from the centre of the one furrow to the centre of another furrow was 1.5 m in the case of BBF. The depth of furrow was 45 cm.

Broad beds formed during the kharif season became almost flattened by the time of harvest of soybean. The wheat crop was grown on normal flat land in the rabi season. Fertilizers were applied as a BF option to the wheat crop. Wheat crop received 3 flood irrigations at all the three sites.

Table 5.8. Initial fertility status of BBF trial sites at Rangai village

Site	Farmer	Available nutrient status					Organic C (%)
		N (kg/ha)	P (kg/ha)	K (kg/ha)	S (mg/kg)	Zn (mg/kg)	
1	Rammanohar	147	6.5	620	6.8	0.35	0.47
2	Pramodverma	170	10.7	525	9.4	0.48	0.50
3	Sanjiv Verma	125	8.5	502	5.5	0.50	0.42

6 Achievements against activities and outputs/milestones

Objective 1: To assess integrated nutrient management strategies for soybean / wheat systems (inorganic and FYM) and identify any agronomic constraints that may be restraining productivity in soybean/wheat systems.

no.	**activity**	**outputs/ milestones**	**completion date**	**comments**
1.1	Identify nutritional constraints to production	Nutritional limitations for a range of representative sites	05	Omission trials carried out and completed on-farm for wheat (2 trials x 3 villages) in 04/05 and soybeans (1 trial) in 05. Very consistent results indicating deficiencies in N, P, S, Zn. Information from omission trials used to design INM trials. BAIF consider that the omission trial approach is simple, and that the results are clear to farmers, making this a potential extension tool.
1.2	Evaluate the agronomic practices used in the farming system, with particular reference to the soybean phase	Improved agronomic practices, including pests and soil-borne diseases; contribution of N from soil, fertilizer and fixation quantified.	04 05 ongoing 06 08 ongoing	Extensive literature review by Pax Blamey documented in trip reports, formulating key hypotheses to be followed up (nutrient deficiencies; water logging, end of monsoon moisture deficit; radiation input) to address possible yield constraints. Farmer consultations on issues and approaches to improve soybean productivity carried out by BAIF +IISS staff, identifying a range of constraints and farmer input into design of INM and BBF trials. INM trials carried out in soybean season 05 and 06, and wheat 05/06 and 06/07. In both years, soybean, treatment 3 – 5 t FYM +50% inorganic + rhizobia gave best yield, treatment 1 – 100% inorganic also good. In wheat, treatment 1 was best, treatment 2 and 3 comparable. Yield increase compared to farmers' practice is around 10%. Economic analysis demonstrates that the high yields achieved by T1 and T2 and 3 are also economically attractive. INM and inorganic fertilization validated in 07-08 for soybean and wheat across a range of environment and management conditions through the use of baby trials In 05/06, BAIF initiated on-farm evaluation of Broad Based Furrow systems in soybeans, to address water logging. IISS conducted trials in 06/07. While the initial results were attractive to farmers, limitations in the field trial layout constrain interpretation of the results. Replicated trials conducted in 07/08 have confirmed the earlier indication of benefits, but in a monsoon season with relatively low rainfall (70% of average)

PC = partner country, A = Australia

Objective 2: To assess the benefits of FYM in cropping systems

no.	activity	outputs/ milestones	completion date	comments
2.1	Investigate nutrient release characteristics of FYM	Nutrient release rate for high C:N ratio FYM	05 ongoing 07 ongoing ongoing	Detailed studies of N release from a range of C:N materials carried out in incubation experiments in India. Relationships between C:N ratio and mineralization determined, yielding robust functions for Indian FYM materials. Studies of mineralization from organic waste and soil mixtures used in the Australian trials also carried out in a similar incubation experiment. Both N release, and N_2O release assessed. Reduction in N_2O release following addition of high C:N ratio material was an unexpected result, and may represent a means of controlling greenhouse gas emissions in high input systems such as horticulture. A PhD student, Ms Sarah Vaughan, was recruited in late 07 to develop this work. Detailed modelling studies are using APSIM are currently in progress as part of a JAF. This work has confirmed that the “manure” module within APSIM provides a reasonable description of N dynamics for a range of organic substrates. The work in this area will now move to understanding the N dynamics in the context of the cropping system. Considerable preliminary work on the growth and nutrient uptake characteristics of the soybean crop in this environment has already been undertaken to support this study.

2.2	Quantify nutrient losses during FYM production and use, identify loss pathways, and develop practical strategies to limit nutrient loss	Knowledge of extent of nutrient loss. More efficient FYM production and use	ongoing	Simple mass balance of FYM pits determined by measuring the weight of components added to pit on a weekly basis, and determining the composition of these materials. This total input value was compared with the content of the pit at emptying calculated by sub-sampling and analysis of the compost. Five input components identified – dung, left over fodder, kitchen waste, ash, sweeping. Measurement of N, K, and P. Mass balance results show loss of N 40%, P 23%, K 36%, and C 56%. Loss of N from pits to the groundwater represents a potential health risk. Nitrate concentrations in village well waters exceed WHO limits, but this limit is questionable. Farmers are not concerned, as household water purification systems are becoming widespread. Detailed investigation of loss pathway in pit and above ground compost system was made in 07/08, but in view of the low rainfall monsoon, this work will be repeated in 08/09.
2.3	Biophysical benefits such as infiltration, water holding capacity, and quality and quantity of organic carbon following FYM application will be quantified.	Knowledge of non-nutritional benefits of FYM Knowledge of the rate and frequency of application required to obtain these benefits	07 ongoing	Infiltration rates on various treatments on INM trial conducted using infiltrometers. Increased infiltration rate as the application rate of FYM is increased. This effect is apparent at all soil depths to 15 cm.

PC = partner country, A = Australia

Objective 3: To assess any adverse environmental impact of FYM in fields and landscapes.

no.	activity	outputs/ milestones	completion date	comments
3.1	Qualitative and quantitative assessment of the adverse effects of FYM on field and landscape scale.	Knowledge of the extent of air and water pollution resulting from high application rates use on Australian farms		Execution of this activity using field trials in Gatton and Dalby has been severely hampered by ongoing drought. Results to date indicate that mixing feedlot manure (FLM) with municipal green waste compost (GWC) may reduce the generation of N_20.
3.2	Environmental Audit framework on FYM use developed	Framework of nutrient balance and budget for safe utilisation of FYM		Changes in manure handling and spreading have overcome the constraints that resulted in manure spreading at excessive rates. Application rates now supply nutrient at levels comparable to inorganic fertilization (or less). Environmental audit was undertaken using data on feedlots size and location, relative to soil type and farming system distribution (detailed in supplement 1 of this report). Given that to some extent our initial goals are now much less relevant, part of our effort in this aspect of the project has been recast to evaluate to what extent low C:N ratio materials can be used to manipulate N availability, reducing the risk of N leaching loss, and gaseous emissions in intensive horticultural production systems. This research is being undertaken within a PhD program supported by the project, and by the Queensland Dept of Primary Industries.

Objective 4: To develop practical tools and action-learning modules for most efficient utilization of FYM.

no.	activity	outputs/ milestones	completion date	comments
4.1	Practical learning tools to be developed and delivered to farmers	Learning modules dealing with fertilizer and FYM use.		Results of initial INM trials were well received by farmers, and were considered by the BAIF community workers to be of sufficient value that a combined extension and research activity was suggested. The use of baby trials across a number of villages was undertaken in 07/08 and has demonstrated the benefits of increased nutritional inputs across a range of management conditions. It should be noted that this demonstration that increased use of fertilizer can produce greater yields, and increase farm profitability, comes at a time of rapid increase in the cost of fertilizer, while, within India, the value of the grain produced is not rising in parallel with the international price of these commodities. This will necessitate recalculation of the net benefit of greater fertilizer use. It is also important to consider that the increased cost of inputs increases the economic risk to farmers.

7 Key results and discussion

7.1 Nutrient Management Research Experiments

7.1.1 Nutrient Omission Trials (India)

Omission of P and S resulted in a significant reduction in wheat grain yield, relative to the All treatment at four of the six sites. This occurred also at 3 sites when Zn was not applied. Nitrogen is recognised as limiting, and was not evaluated. Application of Fe, Mn, Cu, B and Mo at recommended rates along with NPKSZn had no significant effect on grain yield, indicating that these nutrients were not limiting yield. The results of experiments clearly indicated that higher wheat grain yields could be sustained by encouraging farmers to correct N, P, S and Zn deficiencies by adopting appropriate nutrient management practices. Treatment effects on wheat straw yield were typically similar to those on grain yield. In a subsequent experiment, the same nutrients (P, S and Zn) were shown to limit soybean growth and grain yield.

Application of nutrients to the All treatment at recommended rates produced significantly higher wheat grain yields as compared to farmers' practice at all sites. This indicates that farmers in the region are not able to realize the full yield potential of wheat by applying low rates of fertilizer.

The use of nutrient omission trials on farmers' fields was shown to be a successful research and extension tool. This approach is most commonly used for glasshouse pot trials, and is seldom employed at field scale. The omission approach was employed for several reasons. Firstly, we wished to encourage both researchers and farmers to consider each nutrient separately (there is a tendency to make comparisons of rates of fertilizer mixes – NP or NPK). Secondly, the relatively unambiguous nature of the results obtained, a reduction in yield relative to the All treatment, is a clear indication of deficiency, and can easily be interpreted by farmers. It was considered that this simply interpreted trial afforded a good first base of interaction between researchers and farmers besides demonstrating to farmers which nutrient deficiencies limit crop yield on their farm.

7.1.2 Integrated and Balanced Nutrient Management Trials (India and Australia)

India

Soybean. In the kharif season of 2005, INM, the use of 50%NPK+5t FYM/ha+Rhizobium, increased the soybean seed yield by 11% over the BF (100% NPKSZn) and by 25% over farmers' practice (Table 7.1), and a similar pattern of results was obtained in the second year of experimentation (Table 7.1), though the yield was lower as it was a particularly wet year (Site 1 was lost to heavy waterlogging). Rhizobium inoculation with the INM treatment produced 6% higher yield over the same treatment without inoculation. The experiment also evaluated two varieties of soybean, a traditional variety, JS335, and an improved, shorter season variety JS9305. Irrespective of the nutritional module, soybean var JS 9305 (2.09 t/ha) produced more yield than JS 335 (1.98 t/ha). The amounts of each nutrient removed by both soybean grain and straw (i.e. content) were added together and referred as the total nutrient removed by the soybean (Table 7.2). The effect of different treatments on the total nutrient content of N, P and K by soybean followed a similar trend to that observed in case of soybean grain and straw yields. Specifically, treatments T1 (BF), T2 (INM) and T3 (INM+Rhizobium) had a significantly higher nutrient content of soybean over the Farmers' Practice (T4) (Table 7.2). As with the yield data, similar patterns of nutrient content were recorded in the second year of experimentation (Table 7.2)

Table 7.1 Effect of nutritional treatments on soybean grain yield (t/ha) at the four experimental sites.

2005	T1	T2	T3	T4	T5	T6	T7	lsd (5%)
Site 1	2.17	2.27	2.38	1.85	1.98	1.90	1.80	0.17
Site 2	2.20	2.31	2.43	1.99	2.01	1.90	1.81	0.15
Site 3	2.09	2.20	2.33	1.86	1.91	1.85	1.82	0.21
Site 4	1.93	2.02	2.15	1.76	1.89	1.79	1.66	0.20
Mean	**2.10**	**2.20**	**2.33**	**1.86**	**1.95**	**1.86**	**1.77**	**0.18**
2006								
Site 2	1.80	1.90	2.10	1.67	1.77	1.67	1.59	0.14
Site 3	1.82	1.93	2.03	1.57	1.66	1.64	1.51	0.16
Site 4	1.81	1.89	1.98	1.54	1.65	1.58	1.50	0.11
Mean	**1.81**	**1.90**	**2.04**	**1.59**	**1.69**	**1.63**	**1.53**	**0.14**

Table 7.2 Effect of nutritional treatments on the total N, P and K uptake (kg/ha) of soybean. Values are the mean across four experimental sites.

2005	T1	T2	T3	T4	T5	T6	T7	lsd (5%)
N	178	189	199	151	162	152	141	16.7
P	19	20	21	16	17	16	15	1.9
K	97	104	115	80	87	79	73	13.0
2006								
N	146	157	170	123	134	127	116	12.4
P	15	16	18	13	14	13	12	1.4
K	73	80	88	60	66	61	55	8.7

Wheat: Effects of nutritional treatments on wheat yield in winter (rabi) season: The trend of effect of different treatments on wheat grain and straw yields was similar to that of soybean in monsoon (kharif) season. The first three treatments (detailed in Table 5.2), namely T1 (BF - 100% NPKSZn to both soybean and wheat), T2 (INM - 50%NPK+5 t FYM/ha to soybean and 75%NPKS to wheat) and T3 (INM - 50%NPK+5 t FYM/ha +Rhizobium to soybean and 75%NPKS+phosphate solubilzing bacteria, PSB to wheat) produced similar wheat grain and straw yields that was significantly higher than that of T4 (i.e. FP). Wheat grain and straw yields produced by T5 (reduced NP +PSB) , T6 (organic + PSB) and T7 (organic) were not different to those of farmers' practice (T4). The INM treatment produced 16.3% higher wheat grain yield over the farmers' practice.

The amounts of each nutrient removed by both wheat grain and straw were added together and referred as the total nutrient removed by the wheat (Table 7.3). The effect of different treatments on the total nutrient uptake of N, P and K by wheat followed the similar trend that observed in case of wheat grain and straw yields. There was significantly higher nutrient removal by wheat over the FP (T4) by the T1 (BF - 100% NPKSZn to both soybean and wheat), T2 (INM - 50%NPK+5 t FYM/ha to soybean and 75%NPKS to wheat) and T3 (INM - 50%NPK+5 t FYM/ha +Rhizobium to soybean and 75%NPKS+ PSB to wheat) treatments.

This INM module produced a wheat yield similar to that of BF applied to both soybean and wheat, and in doing so saved 42 kg N, 20 kg P, 17 kg K, 15 kg S and 5 kg Zn/ha during a soybean-wheat system.

Table 7.3 Effect of nutritional treatments on the yield, straw biomass (t/ha), and total N, P and K uptake (kg/ha) of wheat. Values are the mean across four experimental sites.

2005	T1	T2	T3	T4	T5	T6	T7	lsd (5%)
Grain	5.00	4.78	4.79	4.12	4.14	4.03	3.94	0.34
Straw	5.58	5.28	5.28	4.51	4.38	4.25	4.14	0.37
N	130	120	120	98.6	98.9	93.3	90.2	16.6
P	19.5	17.5	17.8	13.0	14.0	12.8	12.3	3.6
K	113	103	104	83.6	83.8	793	76.7	19.8
2006								
Grain	5.17	4.94	4.95	4.21	4.23	4.09	3.99	0.35
Straw	7.01	6.60	6.71	5.47	5.51	5.24	4.89	1.2
N	134	123	124	99	101	94.5	90.1	17.6
P	20.1	17.6	18.4	14.1	14.3	13.0	11.9	2.8
K	117	106	107	86	85	81	77	21.0

Economic analysis of fertilizer treatments: The economic analysis of the options in soybean revealed that the T3 (INM - 50%NPK+5 t FYM/ha +Rhizobium to soybean and 75%NPKS+ PSB to wheat) produced the highest net returns (Rs15030/ha) to the farmer that was significantly higher than the FP (Table 7.4a). The benefit:cost ratio of this treatment (1.42:1) was also higher as compared to FP (1.1:1) BF (T1 - 100% inorganic).

Economic analysis of the treatments in wheat revealed that the treatment T1 (BF - 100% NPKSZn to soybean and 100%NPKS to wheat) registered the highest net returns (Rs. 49172/ha) to the farmer among all the treatments (Table 7.4b). However the INM treatment T3 produced the highest benefit:cost ratio of 4.2:1 which was higher than the T2 as well as FP (T4). This INM treatment (T3) produced 20% higher net returns over the FP.

Table 7.4a. Economics of treatment effects in soybean

Treatment	Mean soybean yield (kg/ha)	Gross income (Rs/ha)	Total cost (Rs/ha)	Net return (Rs/ha)	B:C ratio
T1	2099	23089	10919	12170	1.11
T2	2198	24178	10520	13658	1.29
T3	2325	25575	10545	15030	1.42
T4	1864	20504	9693	10811	1.11
T5	1945	21395	10628	10767	1.01
T6	1860	20460	9710	10750	1.10
T7	1774	19514	9660	9854	1.02

Table 7.4b. Economics of treatment effects in wheat

Treatment	Mean wheat yield (kg/ha)		Gross income (Rs/ha)	Total cost (Rs/ha)	Net return (Rs/ha)	B:C ratio
	Grain	Straw				
T1	5001	5581	59921	11749	49172	4.1
T2	4783	5275	57184	11047	46137	4.2
T3	4792	5282	57286	11076	46210	4.2
T4	4121	4508	49195	10742	38453	3.6
T5	4142	4383	49150	11166	37984	3.4
T6	4029	4252	47786	10672	37114	3.5
T7	3939	4148	46701	10621	36080	3.4

Table 7.4c. Economics of treatment effects in a soybean-wheat system

Treatment	Mean grain yield (kg/ha)		Gross income (Rs/ha)	Total cost (Rs/ha)	Net return (Rs/ha)	B:C ratio
	Soybean	Wheat				
T1	2099	5001	83010	22668	60342	2.66
T2	2198	4783	81362	21567	59795	2.77
T3	2325	4792	82861	21621	61240	2.83
T4	1864	4121	69699	20435	49264	2.40
T5	1945	4142	70545	21794	48751	2.24
T6	1860	4029	68247	20382	47864	2.35
T7	1774	3939	66215	20281	45934	2.26

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Crop Yield; N and P budget In the Gatton experiment, there was no effect of either organic amendments or fertiliser N application on sorghum grain yield in 2005 (Figure 7.1). In the following wheat crop, however, FLM applied at both 10 t/ha and 20 t/ha to the previous sorghum crop increased wheat grain yield compared to that on the unamended soil. Fertiliser P application had no effect on wheat grain yield (Figure 7.1).

In the sorghum crop following wheat in 2006, the second FLM application at both 10 t/ha and 20 t/ha increased sorghum yield compared to the unamended soil (Figure 7.1). The second application of GWC at 10 t/ha had no effect on sorghum grain yield, but the higher application of GWC at 20 t/ha increased grain yield. Fertiliser N application at both 75 kg N/ha and 150 kg N/ha produced the highest sorghum grain yield.

Sorghum grain N content varied from 91.5 kg N/ha to 115.9 kg N/ha (Table 7.5). Similar to grain yield, sorghum grain N content values were essentially similar for all treatments. The only difference was that grain N content was lower in the GWC 20 t/ha treatment than in the FLM applied at 10 t/ha. There was a much broader range in wheat grain N content, from 54 kg N/ha in the control treatment to 96 kg N/ha where FLM was applied at 20 t/ha. Grain N content by the second sorghum crop ranged between 104 kg N/ha (control) and 131 kg N/ha (urea applied at 150 kg N/ha).

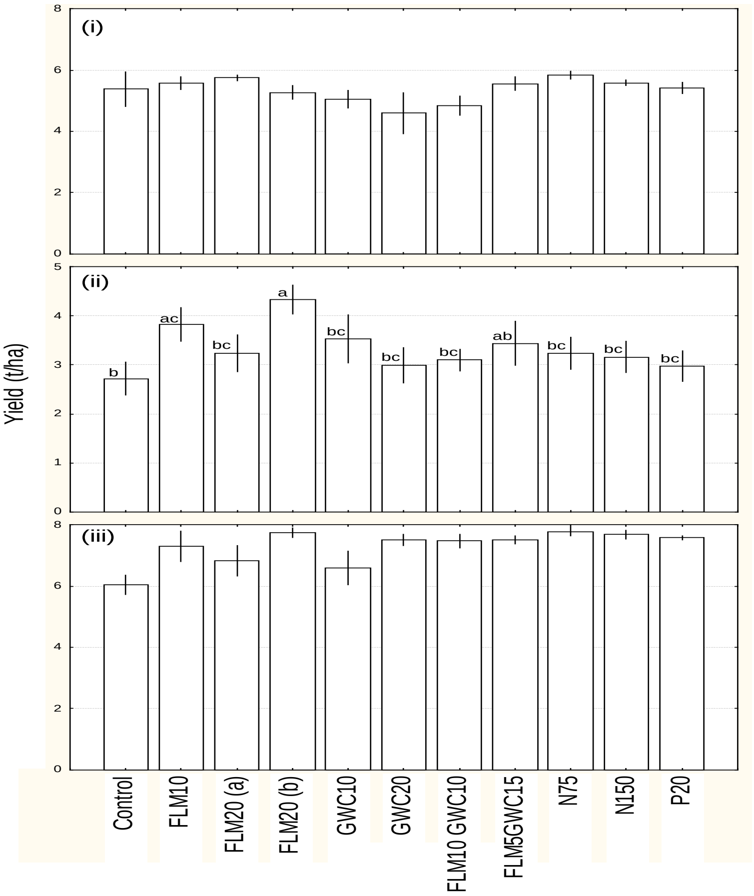

Figure 7.1. Grain yield of (i) Sorghum 2005, (ii) Wheat 2005 (iii) Sorghum 2006. Bar heights show SE. Significant differences at P<0.05 level are shown by different letters.

Total N content of the first sorghum crop was similar in all treatments, about 145 kg N/ha (Table 7.5). However, total N content of wheat from the unamended soil was lowest, and from the 150 kg N/ha application was the highest, this being similar to FLM applied at 20 t/ha. Similarly, total N content of sorghum was lowest from the unamended soil and highest from 150 kg N/ha fertiliser application.

Table 7.5. Sorghum 2005, Wheat 2006 and Sorghum 2006 grain N uptake and total N uptake (significant differences at P<0.05 level are shown by different letters).

Treatment	Grain N content (kg/ha)			Total N content (kg/ha)		
	Sorghum 2005	Wheat 2006	Sorghum 2006	Sorghum 2005	Wheat 2006	Sorghum 2006
Control	103.2ab	53.6a	103.7a	149.1a	64.4a	174.1a
FLM 10 t/ha (repeat)	115.9b	76.7abc	120.8abc	160.1a	97.9bc	193.5ab
FLM 20t/ha (once)	107.6ab	64.6ab	117.6abc	144.4a	76.9ab	190.6abc
FLM 20t/ha (repeat)	103.2ab	95.9c	127.4bc	150.4a	111.3c	201.4abc
GWC 10t/ha	99.6ab	74.3abc	113.3ab	139.5a	86.5abc	186.1ab
GWC 20t/ha	91.5a	63.6ab	127.4bc	133.9a	77.1ab	192.9abc
FLM 10t/ha+GWC10t/ha	100.0ab	62.5ab	123.9bc	135.7a	72.0ab	187.1ab
FLM 5t/ha+ GWC15t/ha	113.2ab	70.4abc	118.4a	153.6a	84.2abc	199.5abc
Urea 75 kg N/ha	114.9ab	69.1ab	133.1c	154.8a	84.4abc	199.2abc
Urea 150 kg N/ha	110.3ab	78.2abc	130.5bc	148.0a	110.5c	214.1bc
Starter Z 20 kg P/ha	92.9ab	57.7ab	128.6bc	133.7a	70.6ab	218.1c

The amounts of NO_3-N in the soil profile at various times are given in Table 7.6. Due to the high inherent variability at the Gatton site, no significant differences in the amounts of NO_3-N in the 0-150 cm soil depth were found at most sampling periods except after the sorghum harvest in April 2007, where lowest amount of NO_3-N was found in the control soil and the highest amount in the FLM-treated soil. Similar trends were observed for soil profile mineral N since NO_3-N and mineral N were closely correlated at all sampling periods (R^2>0.95). Because of the initial high mineral N and NO_3-N contents at this field site, no significant relationships were found between available N and either grain yield or N uptake for the first sorghum crop and the following wheat crop. Only in the second sorghum crop, sorghum N uptake was significantly correlated with the amount of NO_3-N (and mineral N) in the soil present at the sowing of the sorghum crop (Figure 7.2).

Table 7.6. Soil profile nitrate N (kg/ha. 1.5 m depth) pre-sorghum 2005, pre-wheat 2006, pre-sorghum 2005 and post-sorghum 2007 (back-transformed from log-transformed values) (Significant differences at P<0.05 level are shown by different letters).

Treatment	Pre-sorghum 2005	Pre-wheat 2006	Pre-sorghum 2006	Post-sorghum 2007
Control	390.0a	154.2a	181.0a	41.1a
FLM 10 t/ha (repeat)	458.2a	315.0a	252.9a	159.1b
FLM 20t/ha (once)	486.1a	201.6a	222.9a	88.5ab
FLM 20t/ha (repeat)	450.5a	267.7a	218.8a	167.3b
GWC 10t/ha	525.9a	161.4a	197.0a	41.6a
GWC 20t/ha	494.2a	264.5a	189.6a	59.4ab
FLM 10t/ha + GWC 10t/ha	495.9a	162.6a	174.4a	45.6a
FLM 5t/ha + GWC 15t/ha	547.9a	291.3a	280.2a	200.8b
Urea 75 kg N/ha	757.5a	342.8a	262.2a	202.3b
Urea 150 kg N/ha	560.0a	228.2a	265.8a	174.4b
Starter Z 20 kg P/ha	491.9a	293.6a	279.7a	98.5ab

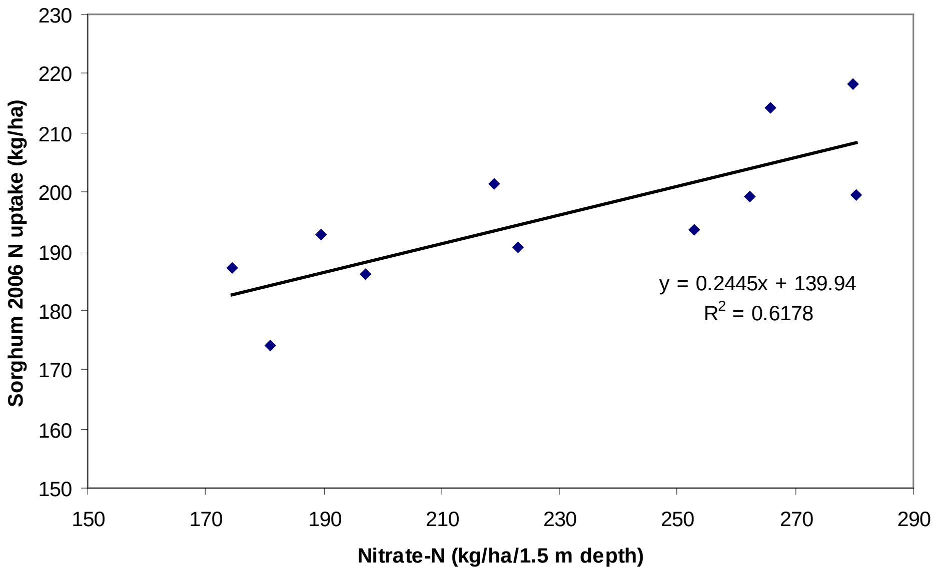

Figure 7.2. Relationship between the amount of nitrate-N in the soil profile at sowing and sorghum N uptake in the second sorghum crop.

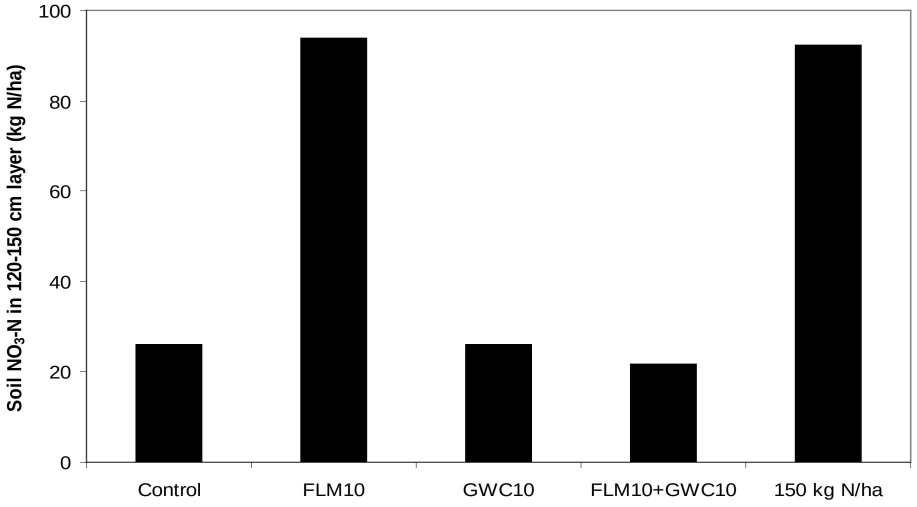

Figure 7.3. The amount of soil nitrate-N in the deepest soil layer sampled (120-150 cm) after sorghum-wheat-sorghum crops, showing the potential for nitrate leaching in the 10 t/ha FLM and 150 kg N/ha treatments

The amount of NO_3-N in the 120-150 cm depth present in soil after three crops (sorghum-wheat-sorghum) was used as an indication of the potential for nitrate leaching in the Gatton soil (Figure 7.3). Feed lot manure application at 10 t/ha showed the potential for nitrate leaching similar to that from fertiliser N application at 150 kg/ha as compared to that from green waste compost application. It appears, therefore, that a combined application of GWC and FLM (each at 10 t/ha) may be used to reduce nitrate leaching losses from soil already containing high amounts of NO_3-N or from FLM applications.

Partial N budgets prepared after three crops (sorghum-wheat-sorghum) showed that from 25 to 48% of N from FLM was utilised by the crops and/or residual available N remaining in the soil (Table 7.7). However, N utilisation from GWC was only 16-18% of the amount of N added. Application of FLM with GWC moderated N supply to crops even in soil initially containing high amounts of available N. (Tables 7.6 and 7.7).

Table 7.7. Partial N budget

Treatment	N addition kg N/ha	N uptake kg N/ha	Residual mineral N kg N/ha	Plant + soil N kg N/ha	Net plant + soil N kg N/ha	N availability (%)
Control	0	388	104	492	0	0
FLM 10 t/ha (repeat)	394	452	229	681	189	47.9
FLM 20t/ha (once)	410	412	190	602	110	26.8
FLM 20t/ha (repeat)	787	463	229	692	200	25.4
GWC 10t/ha	158	412	105	517	25.5	16.2
GWC 20t/ha	316	404	145	549	57.1	18.1
FLM 10t/ha+GWC10t/ha	552	395	110	505	13.2	2.4
FLM 5t/ha+GWC15t/ha	414	437	256	693	201	48.7
Urea 75 kg N/ha	221	438	270	709	217	98.6
Urea 150 kg N/ha	442	477	237	710	218	49.3
Starter Z 20 kg P/ha	35.5	422	161	584	91.7	nd

Sorghum grain P uptake in 2005 was lowest in the GWC applied at 20 t/ha treatment and highest where fertiliser P was applied (Table 7.8). In the following wheat crop, however, FLM applied at 20 t/ha resulted in the highest grain P uptake. Similar trends were observed for the grain P uptake by the second sorghum crop and total P uptake by all three crops. Overall, total P uptake by each sorghum crop was twice that of the wheat crop (Table 7.8), thus, emphasizing the higher P requirement for sorghum than wheat.

Table 7.8. Sorghum 2005, Wheat 2006 and Sorghum 2006 grain P content and total P content (significant differences at $P<0.05$ level are shown by different letters).

Treatment	Grain P content (kg/ha)			Total P content (kg/ha)		
	Sorghum 2005	Wheat 2006	Sorghum 2006	Sorghum 2005	Wheat 2006	Sorghum 2006
Control	18.9ab	10.2a	18.9a	31.0ab	12.7a	31.5a
FLM 10 t/ha (repeat)	20.6bc	13.2ab	28.3b	33.0ab	15.9ab	41.5b
FLM 20t/ha (once)	21.2bc	13.1ab	23.8ab	32.5ab	15.7ab	36.8ab
FLM 20t/ha (repeat)	20.9bc	15.5bc	27.5b	31.3a	17.8b	40.7b
GWC 10t/ha	19.7abc	12.7ab	23.9a	29.4ab	15.0ab	37.1ab
GWC 20t/ha	16.0a	11.5a	26.5b	27.2a	14.1ab	37.3ab
FLM 10t/ha + GWC 10t/ha	19.3abc	11.7ab	25.4b	29.5ab	14.4ab	38.3ab
FLM 5t/ha + GWC 15t/ha	22.0bc	12.7ab	23.7a	33.3ab	14.8ab	38.2ab
Urea 75 kg N/ha	20.5bc	11.3a	28.2b	35.7b	13.7ab	42.2b
Urea 150 kg N/ha	19.1abc	12.4ab	23.7a	30.9ab	16.1ab	38.8ab
Starter Z 20 kg P/ha	22.8c	11.4a	26.3b	36.3b	14.6ab	42.1b

Similar to the partial N budget, we prepared a partial P budget (Table 7.9). Phosphorus availability from FLM varied from 22% to 36%, while for GWC it varied from no increase to 10% as compared to 55% from fertiliser P application. It appears that most of the applied P was retained in the top 10 cm depth since below this depth, there was no increase in plant available P, as estimated by Colwell P (bicarbonate extractable - 16h).

Table 7.9. Partial P budget

Treatment	P added kg/ha	P uptake kg/ha	Residual Av. P kg/ha	Plant + soil P kg/ha	Net plant + soil P kg/ha	P availability %
Control	0	75.2	111	186	0	0
FLM 10 t/ha (repeat)	120	90.4	139	229	43.0	35.8
FLM 20t/ha (once)	120	85	138	223	36.1	30.1
FLM 20t/ha (repeat)	240	89.8	150	240	53.8	22.4
GWC 10t/ha	40	81.5	105	186	-0.3	0
GWC 20t/ha	80	78.6	116	195	8.2	10.3
FLM 10t/ha+GWC10t/ha	320	82.2	129	211	24.3	7.8
FLM 5t/ha+GWC15t/ha	180	86.3	135	220	34.4	19.1
Urea 75 kg N/ha	0	91.6	117	209	22.4	nd
Urea 150 kg N/ha	0	85.8	117	203	16.8	nd
Starter Z 20 kg P/ha	64	93.0	129	222	35.4	55.3

Nitrous oxide and soil properties

We measured N_2O emission rate for one year after FLM and GWC application to the second sorghum crop in December 2006 (Fig. 7.4). The N_2O emission rates generally peaked soon after rainfall events although the peak heights generally decreased throughout the year (Figure 7.4). In general, N_2O emission rates were lowest from GWC and similar to the unamended soil but highest from FLM applied at 20 t/ha and fertiliser N applied at 150 kg/ha.

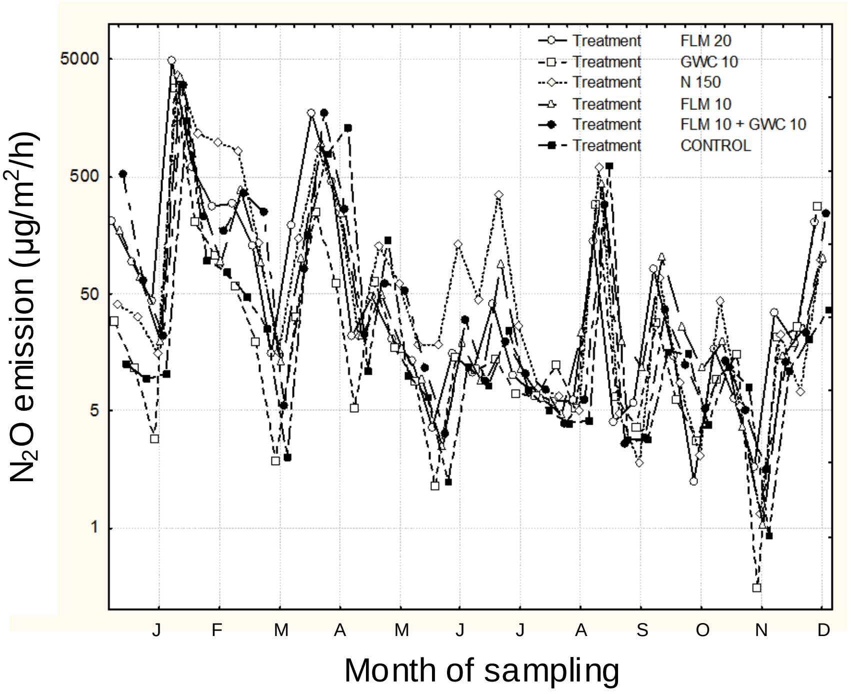

Figure 7.4 The N_2O emission rates from different treatments from December 2006 to December 2007. Sorghum crop was grown from December 2006 to April 2007 and then clean fallowed until December 2007.

Figure 7.5. Cumulative N_2O emission from the Gatton soil treated with FLM, GWC, and fertiliser N from December 2006 to December 2007. The emission factor (EF) is calculated as [100 x (N_2O-N from applied N - $N2_O$-N from control)/N applied]

The cumulative N_2O emission over one year were: Control, 3.3 kg/ha, GWC applied at 10 t/ha, 2.2 kg/ha, FLM applied at 10 t/ha and 20t/ha, 5.1 kg/ha and 5.5 kg/ha, respectively, fertiliser N applied at 150 kg N/ha, 5.0 kg/ha, and FLM + GWC applied at 10 t/ha each, 4.3 kg/ha. Thus, annual N_2O emission from the FLM applied at 20 t/ha treatment was the highest and that from the GWC applied at 10 t/ha treatment was the lowest in 2006-2007 (Figure 7.5). The N_2O emission factor ((annual N_2O emission from a treatment – annual N_2O emission from control) x 100) varied from 0.7% from fertiliser N application, 0.6% from FLM applied at 10 t/ha and only 0.22% when both FLM and GWC were applied together at 10 t/ha each. N_2O emission factor became negative when GWC was applied at 10 t/ha (-0.7%), that is, N_2O emission rate was lower in GWC treatment than the unamended soil.

The rate of N_2O emission from the Gatton soil was significantly correlated with soil temperature; it increased with increasing temperature (Figure 7.6), with a Q_{10} of about 2.2. Similarly, the rate of N_2O emission was significantly correlated with NO_3-N concentration in soil. Thus, reducing the nitrate-N concentration could reduce N_2O emission from the Gatton soil. However, no significant relationship was found between water-filled pore space (WFPS) and the rate of N_2O emission from the Gatton soil (Figure 7.6, 7.7, 7.8), possibly either due to the narrow range in WFPS measured in this study or it poorly reflected the microsite soil water relationships in this soil. Some other factors such as C availability may have also limited the effect of WFPS on N_2O emission from this soil. It also emphasizes the interactive effects of a number of biophysical factors on predicting N_2O emission from soil.

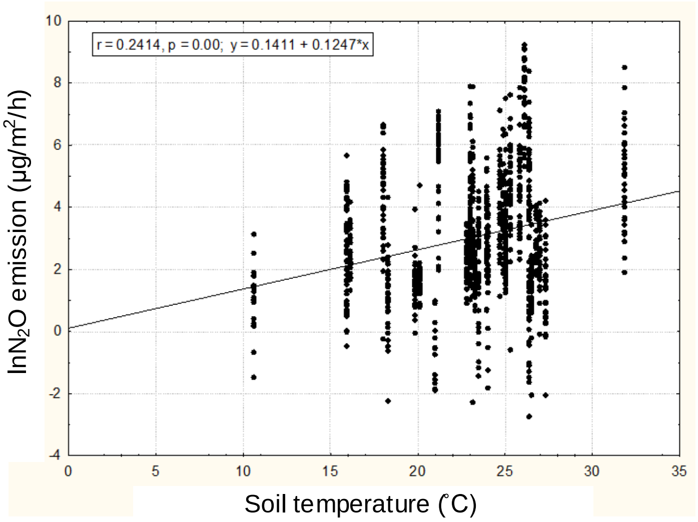

Figure 7.6. Relationship between soil temperature and N_2O (log-transformed)

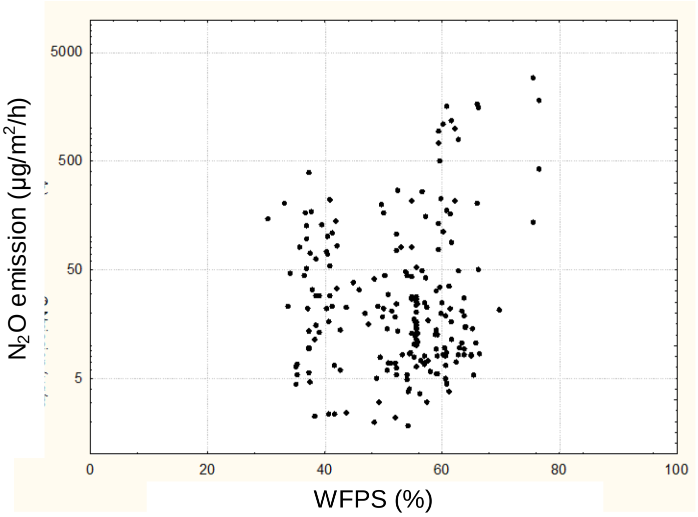

Figure 7.7. Relationship between water-filled pore space (WFPS) and N_2O (both log-transformed).

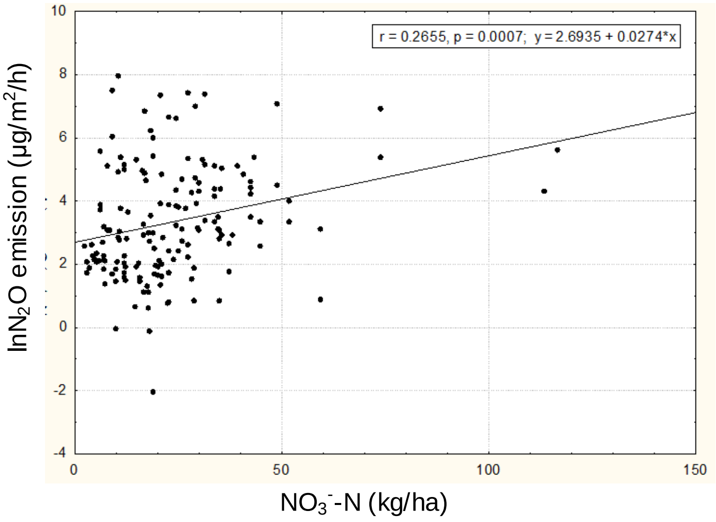

Figure 7.8. Relationship between soil nitrate-N and N_2O (log-transformed)

7.1.3 Laboratory-based mineralization / immobilization experiments

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Net mineral N produced from FLM applied at 20 t/ha increased from 30 mg N/kg soil at 16 weeks to 80 mg N/kg at 64 weeks whereas there was no net N mineralisation from GWC applied at 20 t/ha (Fig. 7.9). A combination of FLM applied at 5 t/ha and GWC applied at 15 t/ha produced intermediate N mineralisation; initial immobilisation at 16 weeks followed by net mineralisation at 32 and 64 weeks of incubation. Thus, it appears that N mineralisation from FLM can be moderated by the application of GWC. This would allow control of N supply to crops and possibly synchronised with the crop N demand. Further, mineral N available for leaching and gaseous losses through volatilisation, denitrification and N_2O emission could be minimised.

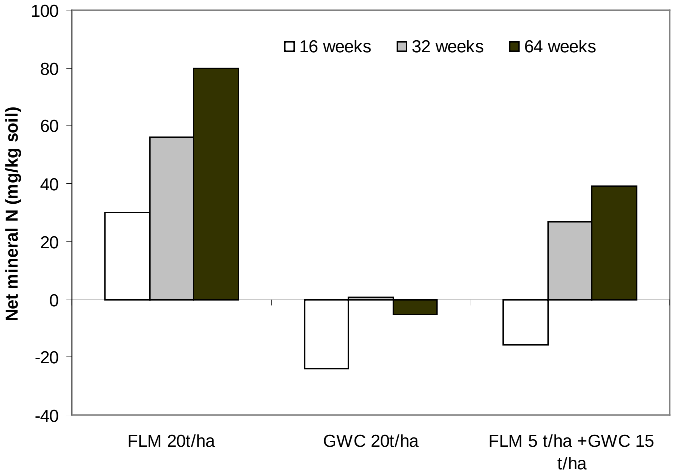

Fig. 7.9. Net N mineralisation at 16, 32 and 64 weeks of incubation from feedlot manure (FLM) and green waste compost (GWC) added to the Gatton Vertisol.

Nitrogen mineralisation over 32 weeks of incubation followed first-order kinetics (R^2>0.99). Nitrogen mineralisation potentials (N_0) varied from 180 mg N/kg soil in the unamended (control) soil to 276 mg N/kg in the soil treated with 20 t/ha of FLM (Table 7.10). The application of GWC with FLM reduced N_0 from the amended soil.

Table 7.10. Nitrogen mineralisation potentials (N_0) and N mineralisation rates (k) from organic materials added to the Gatton Vertosol and incubated for 32 weeks (first-order rate model used, Nt = Ni + N0 (1-e-kt), where N0 is the mineralisation potential, k is the mineralisation rate, Nt and Ni are N mineralised at time t (week) and initially)

Treatment	N_0 (mg/kg soil)	k (10^{-2} per week)	R^2
Control	180.4 ± 10.4	5.01 ± 0.67	0.998
FLM 10 t/ha (FLM10)	210.2 ± 17.3	5.79 ± 1.20	0.994
FLM 20t/ha (FLM20)	276.2 ± 32.0	5.34 ± 1.48	0.991
GWC 10t/ha (GWC10)	209.4 ± 23.4	2.96 ± 0.55	0.998
GWC 20t/ha (GWC 20	ns	2.19 ± 0.52	0.999
FLM 5t/ha + GWC5t/ha (FLM5GWC5)	190.9 ± 11.1	5.97 ± 0.90	0.997
FLM 5t/ha + GWC 15t/ha (FLM5GWC15)	ns	ns	

ns, regression coefficients not significant

N mineralisation rate (k) varied from 0.022/week to 0.058/week (Table 7.10), with turnover times (1/k) of 17-18 weeks for FLM to 34-45 weeks for GWC; that is, N turnover time of GWC was twice as long as that for FLM. Again, a combination or mixture of these two products could be used to regulate both the N mineralisation potentials as well as decomposition rates of FLM and GWC to control N mineralisation from the FLM and GWC.

The differences in N_0 and k between FLM and GWC were associated with the differences in the composition of these two amendments. For example, FLM had higher N concentration, lower C/N ratio, lower lignin concentration and lower lignin/N ratio than GWC; all of these characteristics have been associated with affecting N mineralisation rates from soil and organic materials.

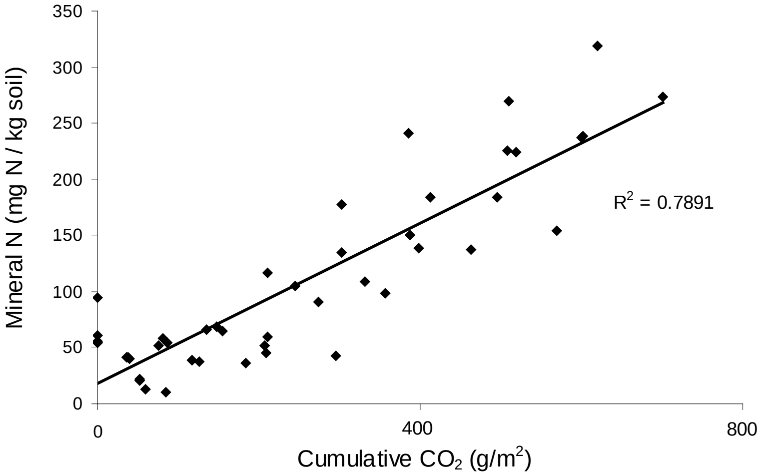

Figure 7.10. Relationship between mineral N and cumulative CO_2 produced during 32 weeks' incubation of soil amended with FLM and GWC. Regression equation of the line is: y = 0.36x + 18.2

Organic C mineralisation from soil amended with FLM and GWC, as measured by CO_2 evolution, was closely correlated with the amount of mineral N produced (Figure 7.10). For example, every 100 g/m^2 of CO_2 produced resulted in the production of 37 mg N/kg soil during the incubation period. Therefore, the amount of CO_2 evolved can be used as an approximation of N mineralised from organic amended soils.

The cumulative amount of N_2O emission from soil amended with FLM was >5 times that from GWC (Figure 7.11). In fact measured N_2O emission from GWC applied at 20 t/ha was similar to or lower than that from the unamended soil. Addition of GWC to FLM substantially reduced (<50%) N_2O emission from the Gatton soil, thus demonstrating the effectiveness of GWC in reducing N_2O emissions from FLM applications.

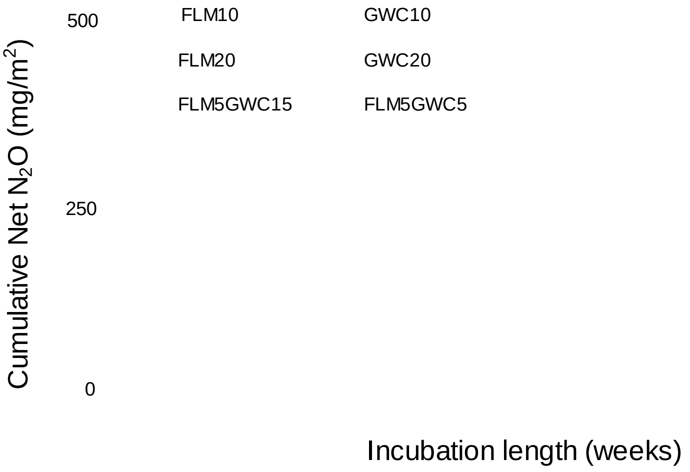

Figure 7.11. Cumulative amount of N_2O produced from Gatton soil amended with different rates and mixtures of FLM and GWC incubated at 24^{0}C at field capacity for 32 weeks.

The magnitude of these differences needs to be factored in when predicting nutrient availability for adequate crop supply and minimal environmental impact. The first-order mineralisation rate demonstrated that both the nitrogen mineralisation potential (N_0) and mineralisation rate (k) were much higher for FLM than for GWC. There are a number of variables that influence mineralisation rates such as C:N ratio in the manure and soil, soil moisture, temperature, and soil labile C and N. Since FLM had higher N concentration and lower C:N ratio than the GWC, these results confirm the observations of many workers. Addition of organic amendments of low N concentration to soil can result in net immobilisation of N as inorganic N is converted into microbial biomass.

The C:N ratio of the organic substrate is often used to predict net mineralisation or immobilisation when applied to soils (Qian and Schoenau 2001; Barbarika et al. 1985; Janssen 1996; Chadwick et al. 2000). Chadwick et al. (2000) reported that mineralisation rate was negatively correlated with C:N ratio. A general rule is that a C:N ratio of higher than 20-30 indicates an initial net immobilisation of N will occur, such as from GWC whilst a C:N ratio less than 20 will indicate net N mineralisation such as from FLM application. Moreover, GWC also had higher lignin concentration and higher lignin/N ratio than FLM. High lignin concentration in organic materials slows its decomposition (Jalota et al. 2006). Since FLM and GWC differed in N mineralisation rate, a mixture of both organic amendments could be utilised for controlling nitrate (and mineral) N availability in soil.

The application of FLM at 10 t/ha and 20 t/ha increased nitrate N availability in soil. However, crop N response in sorghum and wheat yields were rarely significant because the soil initially contained high amounts of nitrate N in the soil profile (>350 kg N/ha). The GWC treatment generally had lower nitrate N concentration than FLM. Consequently, larger amounts of nitrate-N were available for leaching and gaseous N losses from FLM than GWC. In fact, application of GWC not only reduced NO_3-N in the deep soil layer (120-150 cm depth) but also reduced N_2O losses. Thus, a mixture of FLM and GWC application to field could moderate N supply as well as reduce environmental pollution such nitrate leaching in to water bodies and N_2O emission to the atmosphere.

India

Nitrogen mineralization patterns: In the control soil, N mineralization was evident from week 1 and continued throughout the experiment at a relatively low rate (Figure 7.12). This is consistent with the relatively low organic matter content of this soil, and reflects its long history of cultivation. There were marked differences in the pattern of N mineralization from different organic material additions (Figure 7.12). Intermediate quality materials with C:N ratio of 29 to 33 (farmyard manure, soybean straw and chickpea straw) immobilized N during the first 6 weeks of incubation, followed by a release of mineral N from 8 to 16 weeks of incubation. In a comparable study, Castellanos and Pratt (1981) observed N immobilization during the first 4 weeks following application of dairy manure with a C:N ratio of 16. The addition of sufficient urea with these materials to bring the N concentration to the equivalent of 2%, thereby reducing the C:N ratio to 18 – 22, resulted in net mineralization of N from the first week onwards. Immobilization of mineral N occurred in these mixtures for 2 to 4 weeks, and thereafter there was a rapid increase in the mineral N towards the end of incubation.

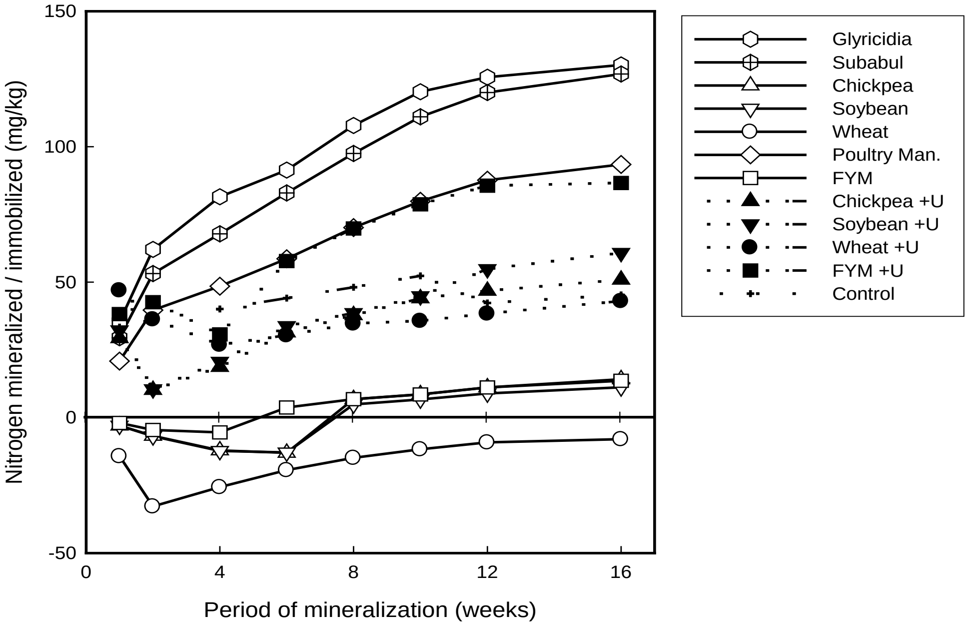

Figure 7.12. Nitrogen mineralization and immobilisation patterns of different organic materials.

Nitrogen release from good quality materials (i.e. those with a C:N ratio of 12-14 :1), such as the green manures and poultry manure, was rapid. In the case of the green manures, 47 to 59% of the total N was mineralized after 4 weeks, 68 to 78% after 8 weeks, and 89 to 95% after 16 weeks of incubation. The low lignin of the green manures and the narrow C:N ratio (Table 5.4) resulted in fast decomposition. Srinivas et al. (2006) reported that N release from green manures after 100 days ranged from 71% to 82%, while the apparent rate of N mineralization from *Sesbania aculeate* was about 2 mg N g^{-1} day^{-1} between days 0 to 7, and rose gradually to 3 mg N g^{-1} day^{-1} from day 7 to 28, and to 4 mg N g^{-1} day^{-1} from day 28 to 112 of incubation (Singh et al., 1988). Similarly, other studies have shown substantial release of N from high quality residues, particularly green manures, during incubation (Oglesby and Fowns, 1992; Constantinides and Fownes, 1994; Singh and Kumar, 1996).

Similar to green manures, the rate of N release from poultry manure was rapid, with 43% of the total N added in the poultry manure released after 4 weeks, 63% after 8 weeks, and 84% after 16 weeks of incubation. Sims (1986) reported that N release from three sources of poultry manure, incubated for 150 days at 40°C , ranged from 30% to 64%. The heterogeneity of the poultry manures was responsible for the different N mineralization patterns that Sims (1986) observed. Castellanos and Pratt (1981) observed N release of about 48% from poultry manure (C:N ratio 6.5) incubated at 23°C for 10 weeks.

Addition of poor quality materials (with a C:N ratio of 79:1), such as wheat straw, resulted in a marked decrease in mineral N due to immobilization, with the greatest rate of decrease occurring in the initial stages of incubation. The lower mineral N in the soil during the initial week of incubation is attributed to a high mineral N requirement of the microbes involved in decomposition of the wheat straw, as a result of its high C:N ratio (Tripathi and Mishra, 2001). After 4 weeks, mineralization of N started, but the mineral N released remained less than that from the untreated soil throughout the incubation period. Addition of urea N to bring the C:N ratio of the wheat straw to 22, resulted in faster mineralization of N from the wheat straw + urea mixture. In this mixture, there was net immobilization for up to 4 weeks; thereafter mineralization occurred at a more or less uniform rate until the completion of incubation. At the end of the incubation, 43% of the N added N in the wheat straw + urea mixture was mineralized, indicating that the addition of urea N offset the immobilization of N by the wheat straw. These results confirm the observation that the wider C:N ratio materials, such as wheat straw, can be utilized successfully with mineral fertilizers in integrated nutrient management, without adversely affecting crop yields.

Soybean and chickpea straws and farmyard manure with C:N ratio of 29 to 33 resulted in a marked decrease in mineral N, due to immobilization, for a period of up to 6 weeks of incubation. Among these materials, soybean straw resulted in higher immobilization of N as it had higher C:N ratio relative to other materials. In comparison, wheat straw with the highest C:N ratio of the materials tested (C:N = 79) resulting in immobilization of N throughout the incubation period. These results indicated that the C:N ratio of the residue is a key factor influencing N mineralization in organic matter amended soils. This is illustrated by the highly significant relationship between the C:N ratio and the mineralized proportion of added N. When mineralized N is expressed as a percentage of N added in the organic materials, the amount of N mineralized ranged from 95% for gliricidia to –28% for wheat residue (Table 7.11). The amounts of N mineralized were highest in green manure amended soils (89 to 95%), and poultry manure amended soils (84%).

Table 7.11. Mineralized N as a proportion of the N added in the various organic materials

Organic material	Proportion of added N mineralized (%)*
Gliricidia	95.0
Subabul	89.0
Chickpea straw	23.7
Soybean straw	20.5
Wheat straw	-28.1
Poultry manure	83.8
Farmyard manure	31.3
Chickpea straw + urea	50.9
Soybean straw + urea	60.8
Wheat straw + urea	43.0
Farmyard manure + urea	86.6
l. s. d (P = 0.05)	14.1

$$*\frac{\text{Total N mineralized in amended soil – total N mineralized in unamended soil}}{\text{Amount of N added through organic amendment}} \times 100$$

Relation of net N mineralization to the quality of organic materials: Simple correlations were calculated for the initial residue quality parameters and the percent N mineralized from organic materials at different periods of incubation, showing a strong positive correlation between total N content and the percent N mineralized at 4, 8, 12 and 16 weeks after incubation (Table 7.12). Vityakon and Dangthaisong (2005) also found the N content of residues to be the most important parameter determining N mineralization. Lignin and polyphenols had no significant relationship with the percent N mineralized. This is attributable to the low degree of variability of lignin and polyphenol concentrations among these organic materials. Further, the concentrations of polyphenols in crop residues were sufficiently low that they would not be expected to interfere with N mineralization. The low N concentration of crop residues is also responsible for the lack of relationship between lignin and polyphenol contents and N mineralization from the residues. Recous et al. (1995) suggested that when N is low in residues, the N availability controls the decomposition and N mineralization, and the biochemical quality parameters such as lignin and polyphenol are not important.

Table 7.12. Significant correlation coefficients between the proportion of N mineralized and selected quality parameters for the organic materials

Quality parameter	Weeks after incubation			
	4	8	12	16
Total N content	0.910**	0.811**	0.909**	0.912**
C : N ratio	-0.946**	-0.964**	-0.911**	-0.916**
Lignin/polyphenol	-0.783*	-0.787*	-0.750*	-0.751*
Polyphenol/N	-0.791*	-0.667*	-0.786*	-0.781*
Lignin+ polyphenol/N	-0.800**	-0.797**	-0.763*	-0.768*

* Significant at P = 0.05 ** Significant at P = 0.01

The N mineralized at 2, 4, 8, 12 and 16 weeks of incubation had significant negative relationship with C:N ratio, lignin/polyphenol, polyphenol/N and lignin+polyphenol/N ratios. The strong negative relationship between N mineralization and ratios incorporating N concentration, demonstrate the overwhelming influence of N content of different organic materials on N mineralization. Trinsoutrot et al. (2000) and Vityakon and Dangthaisong (2005) also reported that N concentration and ratios involving N concentration have an overriding influence on N mineralization. There were no discernible patterns in the relationships of different quality parameters with the percent N mineralized. It has been suggested that the index that gives the best prediction of N mineralized, varies with the time and stage of mineralization (Fox et al., 1990; Ogelsby and Fownes, 1992). Palm (1995) indicated that polyphenol/N ratio may serve as an index of short-term mineralization/immobilization patterns, whereas lignin+polyphenol/N ratio may serve as an index for long-term release patterns. However, in this study, the nature and extent of relationships of various quality parameters with N mineralized were, by and large, consistent throughout the incubation period. Furthermore, among the ratios, the highest correlation for N mineralized was with the C:N ratio (r = -0.911 to -0.930) at 2, 4, 8, 12 and 16 weeks after incubation. The relationship between N mineralized and the C:N ratio is best described by an exponential function at all stages of incubation (Figure 7.13). The exponential model at the 16 weeks after incubation is $Y = -33.93+207.3e^{-0.042x}$ ($R^2 = 0.983$) where Y = % N mineralized and X = C:N ratio. These exponential models could be used to predict the amount of N mineralized from organic materials of varying C: N ratios at different periods. Net mineralization in excess of control was found only for materials having C:N ratio <22 at 4 weeks after incubation, <23 at 8 weeks after incubation, and <25 at 16 weeks after incubation. From this study it is clear that in the case of organic manures, green manures and crop residues, the C: N ratio may be used as the index for predicting the N mineralization.

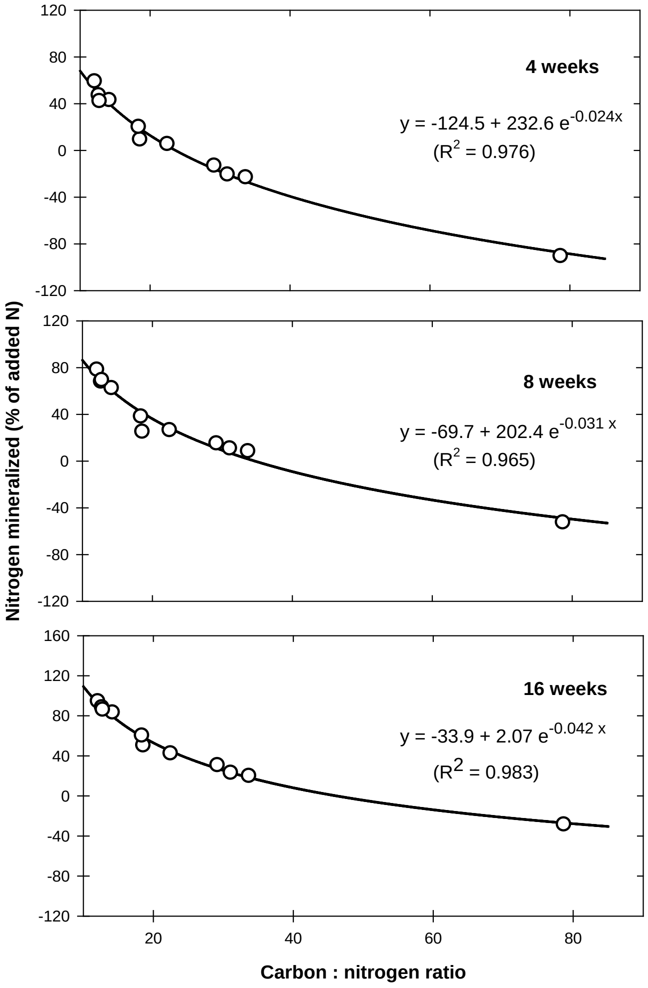

Figure 7.13 Relationship between C:N ratio of organic materials and N mineralized after 4 to 16 weeks of incubation

Nitrogen mineralization constants: The potentially mineralizable N pool (N_o) and the first order rate constant (k) are presented in the Table 7.13. The mineralizable N pool in the unamended soil was much lower than where the soil was amended with organic materials, including green manures. This suggests a high potential of these soils to mineralize N from organic residues. Similarly, Srinivas et al. (2006) showed that under aerobic conditions there was a net immobilization or mineralization as a function of the organic amendments used. Values of N_0 for unamended soils were 45 mg N/kg soil, which was lower than that of organic residue treated soils. As expected, the N_o values were markedly increased in the organic, green manure and crop residue treated soils with and without urea. The N_o values of green manure treated soils were the highest as compared to poultry manure, chickpea straw+urea, soybean straw+urea and FYM+urea treated soils. Among the organic materials added with urea, FYM+urea treated soils had higher N_o values as compared to chickpea straw+urea and soybean straw+urea treated soils. The values of N_o and k constant varied considerably, suggesting that N mineralization would vary with the type and C:N ratio of the manures.

The first rate constant (k) value for the control treatment was 1.09 mg N kg^{-1} $week^{-1}$, while those for the organic residue treated soils ranged from 0.101 to 0.261 mg N kg^{-1} $week^{-1}$ (Table 7.13). Among all the treatments, the soils treated with soybean straw+urea had the lowest k value (0.101 mg N kg^{-1} $week^{-1}$). The k values markedly decreased with the addition of green manures, poultry manure and urea plus chickpea residue, soybean residue or FYM. In general, green manure treated soils had higher k values as compared to those amended with poultry manure and chickpea straw+urea, soybean straw+urea and FYM+urea. Although substantial mineralizable N is present in soybean straw and chickpea straw, the rate of mineralization from these materials appears to be slow as reflected in lower values of first-order rate constant (k).

Table 7.13. Nitrogen mineralization constants for amended and unamended soils

Organic material	N_0	k	R^2
Gliricidia	128	0.261	0.964
Subabul	129	0.196	0.968
Poultry manure	95.7	0.186	0.958
Chickpea straw + urea	56.1	0.144	0.799
Soybean straw + urea	74.4	0.101	0.818
Farmyard manure + urea	89.8	0.197	0.845
Control	45.3	1.09	0.788

N_o = Mineralizable N pool (mg/kg); k = first-order rate constant (mg/kg/week)

Different organic manures, green manures, and crop residues used in this study varied considerably in their quality parameters and consequently in their rates of N mineralization. High quality materials such as gliricidia, subabul and poultry manure with high N content and narrow C:N ratio released N rapidly, while poor quality materials such as wheat straw immobilized N for longer periods throughout the incubation. Organic materials of intermediate quality such as farmyard manure, soybean and chickpea straws immobilized N for some time and released it later. The addition of urea N with low and intermediate quality organic materials improved the mineralization of N from these materials as compared to their sole application. The effect of lignin and polyphenol content on N mineralization was not pronounced. These results suggested that N content and C:N ratio are sound criteria for predicting N release from materials of this type. An exponential model appears to be effective for predicting N mineralization at different periods following incorporation into soil of organic materials differing in their N content and C:N ratio.

7.2 Baby trial program (India)

Soybean seed yield: In kharif (monsoon) season, the pooled data of soybean grain yield from 95 sites in 2007-2008 and 98 sites in 2009-2010 revealed that the BF through inorganic fertilizers produced 28% higher grain yield over the farmers' practice. The INM module (50% NPKS+5 t/ha FYM+Rhizobium to soybean) produced about 49% higher soybean grain yield as compared to farmers' practice. This INM module produced about 20% higher soybean grain yield as compared to BF through inorganic fertilizers alone. In the first year, the soybean grain yield ranged from 0.63 t to 2.75 t/ha in farmers' practice, from 0.75 t to 3.33 t/ha in BF and 0.85 t to 3.63 t/ha under INM (Table 7.14), with slightly lower yields produced in all treatments in the second year. During the Farmers' Day, farmers attributed the higher soybean yield under INM to the better pod bearing as compared to that of BF. Soybean crops in the INM treatment had a mean of 30 to 120 pods/plant compared to 20 to 70 pods/plant in FP.

Table 7.14. Soybean and wheat yields (t/ha) as influenced by different nutrient management options (Mean of 95 sites).

Parameter	Farmers' Practice		Balanced Fertilization (100% NPKSZn)		Integrated Nutrient Management	
2007-2008	Soybean*	Wheat**	Soybean	Wheat	Soybean	Wheat
Lowest	0.63	1.75	0.75	2.00	0.85	2.00
Highest	2.75	4.38	3.33	6.26	3.63	6.25
Mean	1.68	3.27	2.06	4.24	2.46	4.04
SD (±)	0.61	0.81	0.69	1.45	0.80	1.32
2009-2010						
Lowest	0.88	2.50	1.38	3.38	1.50	2.88
Highest	1.66	4.75	2.13	6.00	2.75	5.38
Mean	1.33	3.30	1.75	4.68	2.02	4.21
SD (±)	0.16	0.44	0.17	0.58	0.24	0.54

*Mean of 95 trials in 2007-2008 and 98 trials in 2009-2010

**Mean of 91 trials in 2007-2008 and 98 trials in 2009-2010

In the first year of baby trials, out of 95 trials, 45 trials produced more than 1.0 t/ha soybean seed under farmers' practice and these trials were well managed trials with respect to weed control, pest management etc. In the second year of baby trials, almost all farmers achieved good weed and pest control and almost all farmers achieved yields exceeding 1.0 t/ha. The soybean seed yield data from the well-managed trials in 2007-2008 are considered separately, as they provide a clearer indication of response to fertilizer treatment. The soybean grain yield from well-managed fields varied from 1.00-2.75 t/ha under farmers' practice, from 1.00-3.75 t/ha under BF and from 1.25 -3.75 t/ha under INM (Table 7.15). The mean soybean grain yield was 1.84 t/ha, 2.23 t/ha and 2.68 t/ha with the farmers' practice, BF and INM, respectively. In the well-managed fields, INM produced higher soybean yield by 46% over farmers' practice and by 20% over BF. These results clearly showed that weed and pest management practices are very important to get the full benefit from efficient nutrient management. If farmers follow recommended INM practices but do not take care of weeds and pests, they may not get good soybean response to applied fertilizers, manure, biofertilizers etc. These farmers may be best to follow their traditional fertilizer practice.

Table 7.15. Soybean seed yield (t/ha) as influenced by different balanced and integrated nutrient management in well managed fields (Sites obtained > 1.0 t/ha yield) (N = 45)

Parameter	Farmers' Practice	Balanced Fertilization	Integrated Nutrient Management
Lowest	1.00	1.00	1.25
Highest	2.75	3.75	3.75
Mean	1.84	2.23	2.68
SD (±)	0.54	0.61	0.66

Wheat grain yield: In the rabi (winter) season, wheat (variety Lok-1) was grown in the same plots with required amounts of nutrients in farmers' practice, BF and INM. In 2007-2008 four of the 95 "Baby Trials" some wheat crops could not be harvested due to severe scarcity of irrigation water. Out of 91 successful trials, 45 farmers were able to apply three to four irrigations, 12 farmers irrigated twice and the remaining 34 farmers were able to provide only one irrigation. The pooled data of 91 trials indicated that the wheat grain yield ranged from 1.75-4.37 t/ha under farmers' practice, 2.00-6.26 t/ha under BF and from 2.00-6.25 t/ha under INM, showing increases of 30% for BF and 24% for INM over those in the farmers' practice.

During the rabi (winter) season, the 91 trials were grouped into three categories viz., (i) trials receiving three to four flood irrigations, (ii) trials receiving two flood irrigations and (iii) trials receiving one flood irrigation. The wheat from the crops receiving three to four irrigations (Table 7.16) responded well to BF as well as INM. In these well-irrigated trials, wheat grain yield ranged from 3.38-4.38 t/ha with farmers' practice, from 4.75-6.25 t/ha with BF and from 4.50-6.25 t/ha with INM. Balanced fertilization produced higher wheat grain yield by 40% over the farmers' practice and by 6% over the INM.

Table 7.16. Grain yield (t/ha) of wheat that received three to four irrigations as influenced by different nutrient management options (No. of trials: 45)

Parameter	Farmers' Practice	Balanced Fertilization	Integrated Nutrient Management
Lowest	3.38	4.75	4.50
Highest	4.38	6.25	6.25
Mean	4.02	5.61	5.30
SD (±)	0.19	0.50	0.46

Wheat crops on 12 sites received only two irrigations due to non-availability of irrigation water in later stages of the growth, due to Madhya Pradesh receiving only 70% of the normal rainfall during the monsoon. In these trials, wheat grain yield ranged from 2.63-3.25 t/ha with farmers' practice, from 3.13-4.00 t/ha with BF and from 3.00-3.88 t/ha with INM. On an average, the BF and INM produced higher grain yield by 21% and 17% over the farmers' practice, respectively (Table 7.17).

Table 7.17. Grain yield (t/ha) of wheat that received two irrigations as influenced by different nutrient management options (No. of trials: 12)

Parameter	Farmers' Practice	Balanced Fertilization	Integrated nutrient management
Lowest	2.63	3.13	300
Highest	3.25	4.00	388
Mean	2.97	3.59	347
SD (±)	0.21	0.28	0.28

Thirty four farmers could only give one irrigation to their wheat crop. As expected wheat crops that only received one irrigation did not respond well to the application of more nutrients in BF and INM. The BF produced 2.67 t/ha wheat yield which was higher than farmers' practice (2.38 t/ha) but on a par with the INM (2.61 t/ha). In general, the productivity of wheat under all the three nutrient management options was very low as compared to that of wheat that received three to four irrigations (Table 7.18).

During 2009-2010,most farmers obtained good response of wheat to both BF and INM as compared to previous year baby trails (2007-08). This region received three to four good rain events during the wheat growing season (Nov 2009 – Feb 2010), ensuring good water supply at the critical stages of crop growth. These rains particularly helped the farmers who do not have sufficient irrigation facilities. Thus the 2009-2010 year provides a useful contract to the previous year trials where half of the farmers could irrigate wheat only once or thrice. The mean wheat grain yield of 98 trials showed that the integrated nutrient management produced higher grain yield by 28% over farmers' practice. Balanced fertilization (fertilizers alone) increased the wheat grain yield by 42% over the farmers' practice

Table 7.18. Grain yield (t/ha) of wheat that received 1 irrigation as influenced by different nutrient management options

Parameter	Farmers' Practice	Balanced Fertilization	Integrated nutrient management
Lowest	1.75	2.00	2.00
Highest	2.88	3.13	3.00
Mean	2.38	2.67	2.61
SD (±)	0.35	0.36	0.33

7.3 Environmental audit of feedlot manure (Australia)

Assessment of Potential Manure Production in Australia

The number of animals in lot feeding enterprises in Australia has been steadily increasing from around 400,000 in 1995 to over 900,000 in 2006 (Figure 7.14), with fluctuations from year to year depending on grain prices, cattle prices and shifting international markets. For example, record high grain prices, unexpected fluctuations in cattle feeder prices and shifting international markets, including the US re-entry into Asian markets has resulted in a decline in lot-fed cattle since mid 2006. However, significant investment is being made in the lot feeding industry despite current economic challenges which is indicative of the good production expected in the future. For example, in May 2008 a $40 million a state-of-the-art feedlot was opened near Dalby in Queensland in an already $1.3 billion feedlot industry (Press release DPI 20/5/08).

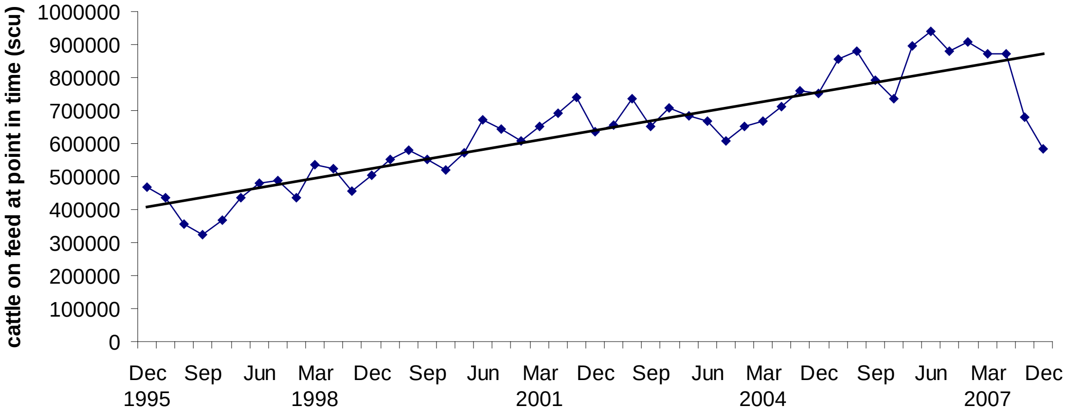

Figure 7.14. Cattle numbers in feedlots from December 1995 to December 2007, Australia. (Australian Lot Feeders Association, 1995 -2008)

Manure production from feed lot animals is estimated from the number of animals and manure produced from each animal, taken as 1.25 t/animal/year .Thus, manure produced has increased over the last decade in Australia, including Queensland, as manure production is directly proportional to cattle number on feed (Figure 7.15).

Based on the FLM nutrient composition which is estimated at 2.5% N, 0.8% P and 2.5% K, it is estimated that annual production of 1 million t of manure (30% $H_2 0$) and its application will provide 17,500 t N, 5,600 t P, and 17,500 t K annually to Australian soils. Responsible management of this quantity of nutrients is imperative in order to minimise environmental impact from leaching and gaseous losses, eutrophication, and other adverse environmental effects (including N_2O emission) and maximise the efficient use of a valuable nutrient source.

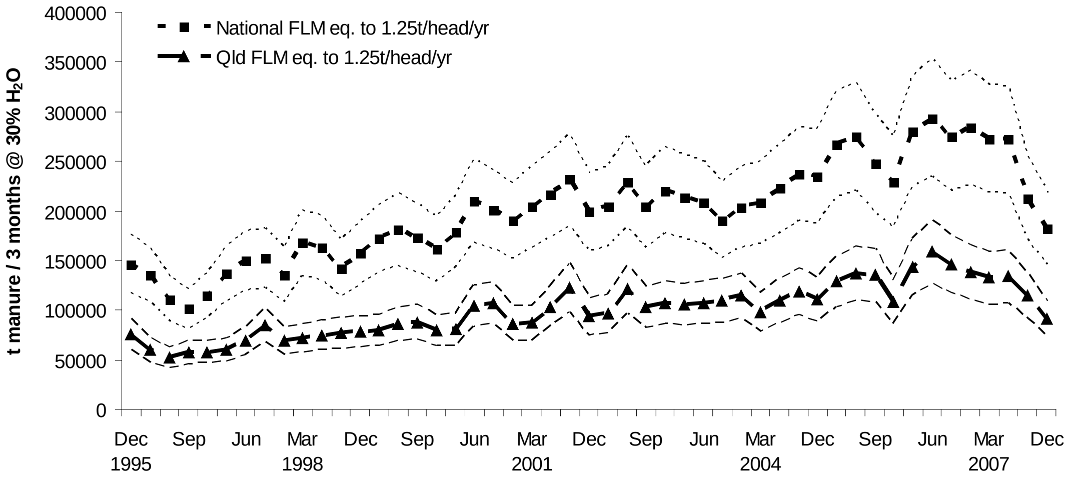

Figure 7.15. Feedlot manure production for Queensland and Australia as predicted from ALFA quarterly feedlot survey. Fine lines bounding the bold predicted trend lines indicate upper and lower limit of calculated prediction error.

A typical cost benefit analysis of FLM use on the Eastern Darling Downs of Queensland is described below. Excluding the benefit of un-costed micronutrients and organic C, it is shown that there is an equivalent of $98/t value in FLM at the fertiliser costs, without taking into account the crop nutrient use efficiency in either the FLM or fertiliser. Further, since, N, P and K are 30-33% available to a crop; its value is about $30/t to crops (Table 7.20), excluding the residual nutrient effects and no negative environmental impact.

Currently, the total cost of $25/t of FLM is estimated as the sum of $9/t at the feed lot, transport cost of $10/t up to 100 km distance, and spreading cost of $6/t in the field. This makes the cost of FLM only slightly lower than that of N, P and K contained in fertiliser. However, crop nutrient use efficiency of fertiliser is usually 50% for N, 50% for P and 30% for K. Thus, as a comparison of utilising fertiliser equivalent nutrient available from FLM, its value exceeds its cost of $25/t by 2-3 fold (Table 7.20).

Table 7.20. Value of N, P and K in FLM and fertiliser equivalent value

Nutrient	(%)	Economic value[A] ($/t FLM 70% DM)	FLM nutrient value to crop[B] ($/t)	Actual feriliser nutrient cost to crop[C] ($/kg)	Fertiliser equivalent FLM value[D] ($/t)
N	2.5	37.60	12.41	4.30	24.82
P	0.8	31.35	9.41	11.20	22.40
K	2.5	28.85	8.66	5.50	28.87
Total		97.80	30.48		76.09

[A] Based on fertiliser nutrient costs: $2.15/kg of N, $5.60/kg of P, and $1.65/kg of K (ex. Brisbane, excluding transportation cost to the farm).

[B] Table 7.7 mean value of all FLM treatments, 33% for N and Table 7.9 mean value for all FYM treatments and 30% for P. For K, about 30% is assumed to be plant available, remaining subjected to sorption and leaching loss.

[C] Fertiliser nutrient cost/nutrient use efficiency from A and B above

[D] Nutrient available from fertiliser are 50% for N, 50% for P and assumed to be 30% for K

Nutrient Budgeting: It has been practice in the past to apply manure at a rate that will supply adequate N. To supply 150 kg N/ha from FLM will require a rate of 18 t/ha, assuming that FLM contains 2.5% N (Table 5.4) and that 33% of the N in FLM is available to the crop. This amount (18 t) of manure will also contain 140 kg P, an amount in excess of the crop's need of 15-40 kg P/ha, assuming immediate availability at application. However, efficiency of crop’s P use rarely exceeds 30%, and therefore, P application to soil may be in the range of 50 to 133 kg P/ha. Therefore, an application of up to 20 t/ha to a Vertisol may not result in a risk to contributing to P pollution to water bodies. Dissolved P release from FLM applied to soil is inversely proportional to the sorption capacity and P saturation of the soil, indicating that soil chemistry rather than P mineralisation determines the potential for pollution of P from FLM amended soils.

On the other hand, for a soil having low P retention capacity and high P utilisation efficiency by a crop, then a crop P requirement of up to 40 kg/ha would result in a 5 t/ha application of FLM with an additional requirement of 25 kg/ha of N fertiliser. In practice, however, there is a significant period required for mineralisation and hence manure must be applied many months before sowing such that the available nutrients can supply the initial crop requirements and mineralisation will “slow release” nutrients during the crop growth. Until recently, application rates this low were unheard of primarily due to the technology requiring high output rates to achieve an even coverage. Additionally, the opportunity cost of applying 5 t/ha every year is higher than to apply 2-4 years worth of FLM in one spreading operation. Also, a benefit of larger and less frequent application will also reduce soil compaction.

Mapping Feedlot Location and Feeding Intensity: The majority of feedlots lie in the Northern and Southern grain belts of Eastern Australia. According to ALFA, there is an increase in feedlot establishment in the Southern states, a change from the past when feedlots appeared almost exclusively in Southern Queensland and Northern New South Wales (Australian Lot Feeders Association; Quarterly Report, 2008)

It is of clear benefit being close to cattle feed production areas (grain cropping), and feeder cattle grazing areas, particularly with the significant rise in transport costs. Consequently, it is likely that cropping and grazing areas are going to be in closest proximity to feedlots and hence be the most cost effective utilisation of the FLM.

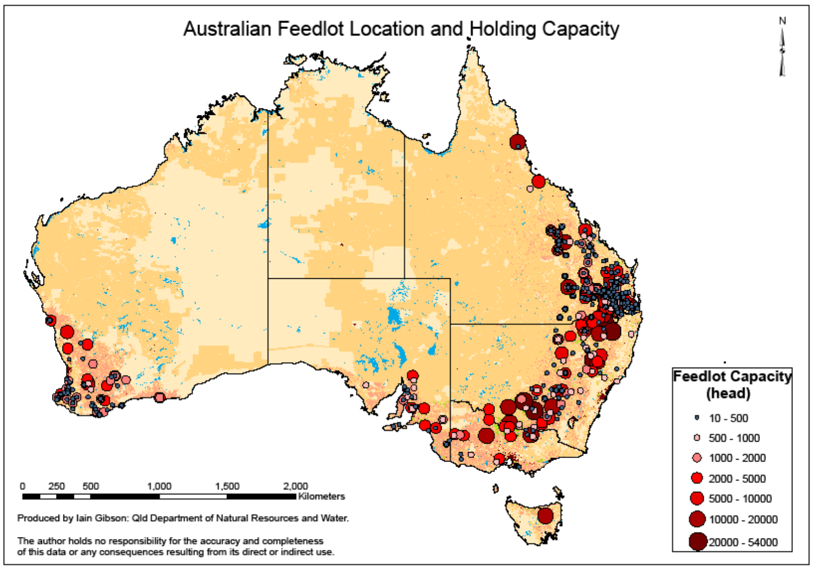

Figure 7.16. Feedlot location and feeding capacity (scu). Feedlots mapped at same location are based on locality address only and hence it is likely that there would be some distance between them.

In order to examine this further, a GIS model (geographical information system) was developed using the feedlot data as described above. Individual feedlots were weighted according to their registered capacity (SCU, Standard Cattle Units).

Modelling Safe Manure Use – Australia: In order to quantify the potential for manure use across Australia and Queensland, feedlots were spatially mapped and a 50 and 100 km radius marked around them (Figure 7.17), to represent transport distance feasible for FLM transportation to field. The 100 km radius was taken as the current maximum transport distance determined by phone survey of FLM transport companies, indicating that farmers may perceive it becoming not economical or feasible to use >100 km distance from feed lots.

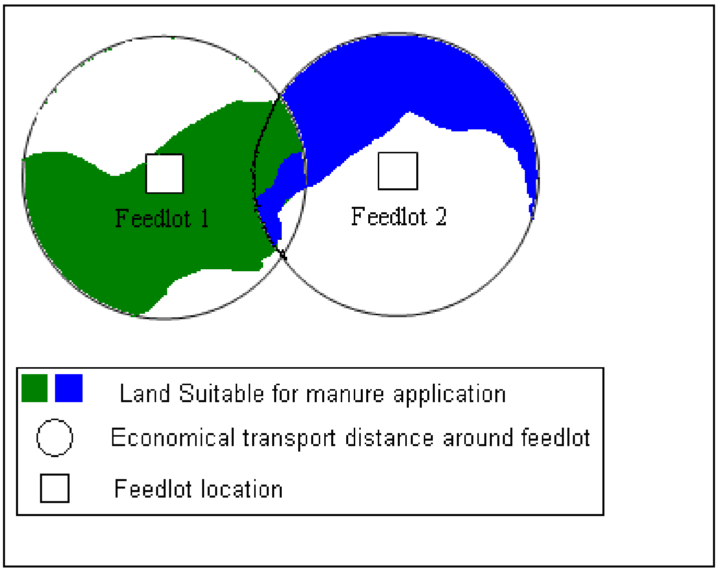

Figure 7.17. Representation of Model for suitable land use application of feedlot manure

Nationwide land use mapping data (Bureau of Rural Sciences -Catchment Scale Land Use of Australia: release 2006) was laid over the viable feedlot transport areas. Land use types that were identified as being suitable for manure use were retained for calculation of FLM application area (Table 7.21). As shown in Figure 7.17, it is often the case that economical feedlot transport distances overlap with adjacent feedlots. In this case, the area within the overlap that was deemed suitable for FLM use was proportionally divided between the number of feedlots sharing that area according to the weighting assigned to the feedlot based on its capacity. In Figure 7.17, there are two feed lots of equal size, as shown by the green and blue sections denoting the split of suitable land between the feedlots. It is acknowledged that feedlots do not operate at full capacity all the time and it was assumed that feedlots would de-stock proportionally to their maximum capacity.

Table 7.21. Selected Land use types for manure application	
Land Use Description	Suitable
Cropping	Yes
Estuary/coastal waters	No
Grazing modified pastures	No
Grazing natural vegetation	No
Irrigated cropping	Yes
Irrigated modified pastures	Yes
Irrigated perennial horticulture	Yes
Irrigated seasonal horticulture	Yes
Lake	No
Managed resource protection	No
Marsh/wetland	No
Mining	No
Nature conservation	No
Other minimal use	No
Perennial horticulture	Yes
Plantation forestry	Yes
Production forestry	No
Reservoir/dam	No
Residential	No
River	No
Seasonal horticulture	Yes
Transport and communication	No

It was not possible to obtain exact locality data for each feedlot and as such the postal address was used as a reference point and cross referenced to locality data as provided in the Australian Gazeteer (Geographical Sciences Australia). It was deemed that given the large areas that were to surround each feedlot (100 km radius) that such approximations could be acceptable. However acknowledgement is made that some misrepresentation will be made using this assumption with the error becoming increasingly significant as the radius around the feedlot is decreased because the FLM application radius is inversely proportional to the probability of error.

Using a GIS program (Arcmap 9.1 ESRI), it was possible to determine the land use on an area basis inside each circle and hence determine the maximum potential area of land to which the manure produced at each feedlot could be applied. The area of suitable land in the overlapping area was split evenly between the two feedlots as indicated in Figure 7.18 by the blue and green areas. In practice it would be necessary to look at soil type, slope, farming practices etc, but it was deemed acceptable to assume that the majority of grain cropping soils would be of reasonable low slope for manure application.

Generic suitable land use types were selected and are shown in Table 7.21. It is accepted that this may over-estimate suitable land as some pastures could be unsuitable for application due to slope, vegetation etc.

Low model outputs of potential FLM rates may be impossible practically due to the majority of spreaders in use having a minimum spreading ability of 10 t/ha. Hence, when less than 10 t/ha applications are called for according to crop requirement and mineralisation rate, it can be expected that incorrect management could call for concern as to the destination of these nutrients.

Whilst the theoretical transport limit should be reached when transport costs outweigh nutrient benefits from FLM application. In practice it is observed that buyers will rarely transport manure more that 100 km and most often less than 50 km due to the ‘perceived manure value’ of FLM.

Upon determining the suitable land use areas available to each feedlot the quantity of manure needed to be applied over that area on an annual basis was calculated assuming 1.25 tonne manure / standard cattle unit / year. This quantity of manure was then divided by the land area in hectares and a rate was produced. This rate was mapped as an indicator of potentially high applications of manure as shown in Figure7.18.

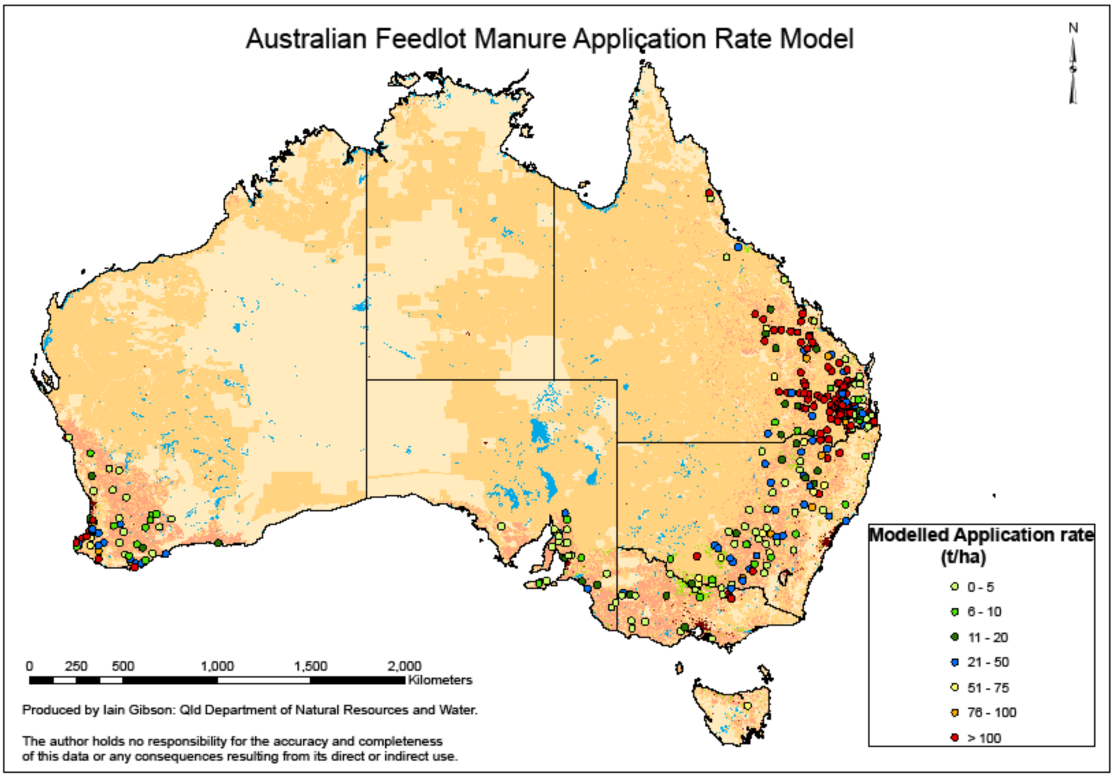

Figure 7.18. Model outputs of potential manure application rates based on available suitable land use and maximum feedlot stocking rates.

Discussion: As manure is generally priced below market value of equivalent inorganic fertiliser it can be often inefficiently used through over-application. Placing a full dollar value on manure nutrients is somewhat misleading as it is only worth the cost of the fertiliser that is being saved on a particular cropping system, and must account for transport, spreading costs and likely time period of nutrient availability.

Nutrient availability is of upmost importance for the producer and surrounding stakeholders, as it is a very significant indicator of likely nutrient leaching. Manure with highly available N is likely to be a pollution hazard before total plant uptake or sorption can occur. A sound understanding of the nutrient content of manure as well as the likely release rate is fundamental to ensuring that sufficient nutrients are available for crop growth without over-supply leading to environmental pollution.

Eghball (2002), and Sharpley and Moyer (2000) report up to 70% of P is available at the time of application. It is discussed that unlike N and S, P is not held in amino acids and complex proteins in such a large proportion. Dissolved P release from incubated manure and soil, was also shown to be inversely proportional to the sorption capacity and P saturation of the soil indicating that soil chemistry rather than P mineralisation can determine availability in manure amended soils.

In many systems large initial rates of FLM application are required in order to ensure that the first season of cropping benefits from some supply of N (long N mineralisation period). This supply is minimal due to the high immobilisation N rates that occur immediately following application (Bar-Tal 2004)

Australia's possible production of 1 million tonnes of manure has the potential to greatly increase crop production but conversely it also has great potential to contribute to pollution of ground water, surface water and greenhouse gas emissions. An understanding of how C, N and other key elements interact in decomposing manure and contribute to gas emissions is critical in minimising undesirable effects. It is estimated that manure contributes 1.17 kt N / year in the form of N_2O with a CO_2 equivalent of 0.54 Mt / year CO_2 in Australia (Dalal et al. 2003).

It is possible that after the first year of FLM application, N_2O emissions may decrease since Ginting et al. (2003) found that 4 years after applying manure and compost to soil there was a residual effects of compost and manure resulting in 20 to 40% higher soil microbial biomass C and 42 to 74% higher potentially mineralizable N compared with synthetic fertiliser treatments.

System losses are likely through applying FLM to soils at rates higher than that which ensures that N can be contained in the profile either through sorption or remaining organically bound. This is not desirable due to the negative effects associated with NO_3 in ground water and the loss of a valuable plant nutrient.

Modelling Safe Manure Use: The majority of heavy FLM application rates as determined by the model are located on the Darling Downs (Figure 7.18). This is to be expected due to the high density of feedlots located in this area. This map is by no means a definitive answer to where safe utilisation of feedlot manure is occurring or otherwise, but rather it identifies areas that may be of risk to over application and indicates a need for further intensive research, monitoring and modelling to occur in these areas.

The application rate of nutrients to land should be based on the sum of its removal in harvested products, nutrient use efficiency, sorption to soil, and acceptable system losses. When rates are at or below the requirements of these nutrient sinks, then this can be considered environmentally sound or safe application rates due to minimal losses occurring through runoff and leaching. The application rate must be calculated using the most available nutrient, otherwise higher rates than would be considered sustainable are applied. A loss not covered by this process is gaseous losses of C (CH_4 and CO_2) and N (N_2O, NO_X, and N_2) which in the current climate is becoming increasingly important.

Conclusions and future directions: Feedlot manure application to soil provides significant amounts of N and P to the crops. We found that up to 48% of N and 36% of P contained in FLM applied at 10-20 t/ha to sorghum and wheat crops grown on a Vertisol was either taken up by the crop and/or accumulated as NO_3-N in the soil profile. On the other hand, application of GWC at similar rates to a Vertisol initially immobilised or retained N and P in the soil, and even after 3 crops, only up to 18% of N and <10% of P was either taken up by the crop and/or to a less extent accumulated as NO_3-N in the soil profile. However, due to their differential N and P release characteristics of FLM and GWC, an appropriate mixture of these two amendments could be used as a management tool for their efficient utilisation and environmentally safe application to soils.

We found that GWC application at 10 t/ha reduced N_2O emissions below those from an unamended soil while annual emission rate from FLM approached that from fertiliser N application. A mixture of FLM + GWC applied at 10 t/ha reduced N_2O by almost 50% by reducing the amount of NO_3-N in the soil.

An environmental audit of FLM indicated that a number of variables determine the rate and geographical area of FLM utilisation for grain cropping and grazing enterprises. It is increasingly apparent that improved technology of even spread of FLM has already resulted in FLM application rates of 10-20 t/ha. While, on most soils low in NO_3-N, environmental impacts are likely to be small, on high NO_3-N soil, such as the Gatton field site even a modest rate of 10 t/ha to alternate crops could result in potential NO_3-N leaching and significant N_2O emissions from soil. A GIS map of Queensland and Australia was prepared taking into consideration the soil type, slope, nature of industry, cost of manure, transportation and spreading costs and distance from the nearest feed lot. As found in the previous ACIAR project, farmer’s perception of FLM benefits rarely matched fertiliser nutrient replacement costs alone. Distance from the feedlots was a major consideration.

From the field and laboratory studies, it was apparent that further research is required to fine tune the N and P release rates to meet crop N and P demands by using FLM and GWC in various proportions. This will have both effective nutrient utilisation as well as reduce environmental impact resulting from NO_3-N leaching to water bodies and N_2O emission to the atmosphere.

7.4 Compost pit mass balance

Mass balance of FYM: During the 9 month study period, it was determined that 3581 kg cattle dung, 1093 kg cattle shed wastes (straw mixed with urine), 14 kg vegetable wastes, 544 kg ash and 124 kg household wastes were put into the FYM pit (Table 7.22). Cattle dung was the main component of the FYM (66.9%) followed by cattle shed wastes (20.4%). At the end, 3400 kg FYM (output) was produced from the 5356 kg (input) organic materials that were put into the pit. These results showed that about 63.5% of the organic materials were recovered in the form of FYM. The remaining 36.5% of the organic materials were lost through decomposition.

Table 7.22. Mass balance of FYM in a compost pit

Material	Dry weight (kg)	% of total
Cattle dung	3581	66.9
Cattle shed wastes (straw + urine)	1093	20.4
Vegetable wastes	14	0.3
Ash	544	10.2
Household wastes	124	2.3
Total	5356	
Dry FYM (9 months period) (kg)	3400	
% recovery of materials as FYM	63.5	

Mass balance of nitrogen: The average N concentration of cattle dung, cattle shed wastes, vegetable wastes, ash and household wastes was 1.1%, 0.79%, 1.63%, 0.16% and 0.48%, respectively (Table 7.23). Cattle dung contributed the highest amount of N (79.4%) input in the FYM. Total N inputs into the FYM pit through these materials were 39.6 kg, 8.6 kg, 0.2 kg, 0.8 kg and 0.6 kg, respectively. Nitrogen output in the dry FYM was 29.9 kg against the input of 49.9 kg. About 59.9% of N was recovered in the FYM and remaining 40% N was lost during FYM production.

Table 7.23. Nitrogen mass balance of FYM in a compost pit

Material	Mean N concentration (%)	N input (kg)	% of total input
Cattle dung	1.10±0.08	39.64	79.4
Cattle shed wastes (Straw)	0.79±0.07	8.6	17.23
Vegetable wastes	1.63±0.06	0.23	0.46
Ash	0.16±0.05	0.82	1.64
Household wastes	0.48±0.12	0.62	1.24
Total N input (kg)		49.91	
N output in Dry FYM (kg) (0.88% N)		29.92	
% recovery of N in FYM		59.9	
% N loss		40.1	

Mass balance of phosphorus: The average P concentration of cattle dung, cattle shed wastes, vegetable wastes, ash and household wastes was 0.22%, 0.07%, 0.19%, 0.16% and 0.079%, respectively (Table 7.24). Cattle dung contributed the highest amount of P (89.3%) input in the FYM. Total P inputs into the FYM pit through these materials were 7.9 kg, 0.73 kg, 0.03 kg, 0.09 kg and 0.098 kg, respectively. Dry FYM contained 0.2% P. Phosphorus output in the dry FYM was 6.8 kg against the input of 8.8 kg, indicating that

77.2% of P was recovered in the FYM and remaining 22.8% P was lost during FYM production.

Table 7.24. Phosphorus mass balance of FYM in a compost pit

Material	Mean P concentration (%)	P input (kg)	% of total input
Cattle dung	0.22±0.03	7.87	89.33
Cattle shed wastes (Straw)	0.071±0.02	0.73	8.29
Vegetable wastes	0.19±0.09	0.027	0.31
Ash	0.16±0.08	0.086	0.98
Household wastes	0.079±0.09	0.098	1.11
Total P input (kg)		8.81	
P output in Dry FYM (kg) (0.2%P)		6.8	
% recovery of P in FYM		77.2	
% P loss		22.8	

Mass balance of potassium: The average K concentration of cattle dung, cattle shed wastes, vegetable wastes, ash and household wastes was 0.96%, 1.22%, 1.19%, 2.55% and 1.37%, respectively (Table 7.25). As with N and P, cattle dung contributed the highest amount of K (53.7%) input in the FYM followed by cattle shed wastes (21%). Total K inputs into the FYM pit through these materials were 34.4 kg, 13.6 kg, 0.66 kg, 13.6 kg and 1.7 kg, respectively. The K concentration in the FYM was 1.2%. Potassium output in the dry FYM was 41 kg against the input of 64 kg. About 63.7% of K was recovered in the FYM and remaining 36.2% K was lost during FYM production. Run off from the FYM pits during monsoon season may be responsible for the large loss of K from the FYM.

Table 7.25. Potassium mass balance of FYM in a compost pit

Material	Mean K concentration (%)	K input (kg)	% of total input
Cattle dung	0.96±0.12	34.4	53.74
Cattle shed wastes (Straw)	1.22±0.09	13.6	21.24
Vegetable wastes	1.19±0.10	0.66	1.03
Ash	2.55±0.30	13.63	21.29
Household wastes	1.37±0.2	1.72	2.69
Total K input		64.01	
K output in Dry FYM (kg) (1.2%K)		40.8	
% recovery of K in FYM		63.74	
% K loss		36.26	

Mass balance of carbon: The average C concentration of cattle dung, cattle shed wastes, vegetable wastes, ash and household wastes was 40%, 47%, 49%, 4.6% and 26.7%, respectively (Table 7.26). Cattle dung contributed the highest amount of C (71.2%) input in the FYM followed by cattle shed wastes (26%). Total C inputs into the FYM pit through these materials were 1432 kg, 514 kg, 7 kg, 25 kg and 33 kg, respectively. The C concentration in the FYM was 26%. Carbon output in the dry FYM was 884 kg against the input of 2011 kg. As expected, about 44% of C was recovered in the FYM and the remaining 56% C was lost through decomposition.

Table 7.26. Carbon mass balance of FYM in a compost pit

Material	Mean C concentration (%)	C input (kg)	% of total input
Cattle dung	40±4.2	1432	71.2
Cattle shed wastes (Straw)	47±4.7	513.7	25.5
Vegetable wastes	49±5.1	6.9	0.34
Ash	4.6±0.6	25.0	1.24
House hold wastes	26.7±2.4	33.1	1.65
Total C input (kg)		2010.7	
C output in Dry FYM (kg)		884	
% recovery of C in FYM		44	
% C loss		56	

Conclusions: Simple mass balance studies showed that the major component of the FYM was cattle dung followed by the cattle shed wastes. A considerable proportion of the nutrients, particularly N and K, were lost during the preparation of FYM. The similarity of N loss (40%) and K loss (36%) implies a common mechanism - leaching. This is currently being confirmed using mixed-bed resin traps. The P leached from the compost will largely be adsorbed to the soil under the pit, and is likely to be recovered and returned to the field through the practice of digging up soil from under compost. In contrast, N, and to a lesser extent K, leaching from the compost is mobile and will move to ground or surface water, and is thus lost to the farmer (and potentially to the farming system). Consequently, there is scope to improve the quality of FYM by reducing the losses from FYM pits by introducing simple and farmer-friendly modifications such as hybrid pit (between heap and deep pit) , thatched roofs etc in the farmer's practice of FYM production. These practices need further investigation.

7.5 Evaluation of broad bed and furrow cultivation

The results of the BBF trials showed that the integration of BBF with balanced fertilization produced 38% higher soybean yield at site 1, 46% higher yield at site 2 and 48% higher yield at site 3 as compared to integration of farmers' practice of land configuration with balanced fertilization (Figure 7.19) (Plate 1 and 2). The pooled data of three sites indicated that the integration of BBF with balanced fertilization produced 44% higher soybean yield over the integration of farmers' practice of land configuration with balanced fertilization.

Table 7.19 Soybean seed yield (t/ha) achieved using flat field or broad bed and furrow cultivation and balanced fertilizaton

	Broad Bed and Furrow	Flat Field
Site 1	2.36	1.71
Site 2	2.22	1.52
Site 3	2.07	1.40

Plate 1. Soybean crop stand at 20 DAS on broad beds and excess water flowing through furrows into the nearby pond.

Plate 2. Soybean crop stand at 35 DAS in broad bed and furrow (BBF) and flat (FP) treatments

While this is a good result, it is important to note that the area only received about 70% of normal monsoon rainfall. This suggests that the yields on flat fields would be lower in a normal year, thus the effectiveness of the BBF approach must be established in a wetter year. Nevertheless, the BBF approach has attracted the attention of the many farmers in the region. Broad beds formed during the kharif season became almost flattened by the time of harvest of soybean. The wheat crop was grown on normal flat land in rabi season.

8 Impacts

The project has moved from its initial phase of entirely experimental work primarily on crop nutrition, to an interim phase where the research is being sustained and more effort is being made to craft the initial INM results into practices acceptable to farmers. Thus the primary impacts at this time are in terms of the science performed, and the impact on the researchers. It is noteworthy also that steps have been taken to involve BAIF community workers and leading farmers who, along with the researchers, have addressed the issue of ensuring uptake by farmers.

8.1 Scientific impacts – now and in 5 years

Omission trials conducted on farmers fields showed that significant yield increases were obtained in response to P, S and Zn application (N was not tested, as it is recognized as being deficient). This simple experimental approach, when employed on farmer's fields provided an effective assessment of the deficient nutrients (confirming soil test assessments), and also provided a very effective introduction to the farming community of the nature of scientific experiments. The treatments are sufficiently simple that the farming community can readily understand the intention of the experiment, and the results sufficiently clear that farmers can see treatment differences. This approach will be used more extensively by IISS in their research, and will be further evaluated by BAIF as an extension tool.

8.2 Capacity impacts – now and in 5 years

The research groups participating in the project were leaders within their fields at the initiation of the project. Nevertheless, the project has provided excellent learning opportunities, and all researchers have developed. The interaction with farmers, and with BAIF, has provided the opportunity to better understand the farmer's perspectives and the constraints to production as they understand them. This has enabled the research team to better interpret the results of our research and to present the results to the farmers in ways that they can use.

While the project has not aimed to develop novel experimental techniques, the implementation of nutrient omission trials as a large scale farmers-field based activity is certainly unusual, proving effective in terms of both scientific outputs and extension values of the activity. A similar dual benefit has been achieved through the use of "Baby trials". From a research perspective, the baby trials confirmed the earlier experimental results across a much wider range of environments. They also extended our understanding of the constraints on the system by well illustrating the interaction between yield expectation and appropriate fertilizer application rates; where yield was constrained by poor management or lack of irrigation, the benefit of higher fertilizer application rates was reduced.

The award of a John Allwright Fellowship to Mr Monoranjan Mohanty has provided the opportunity for the project to deliver a crop simulation modelling capacity to the IISS. It is anticipated that Mohanty's modelling skills will be of value across a wide range of projects being undertaken by IISS.

At the end of the first year of the project, it was clear that a good working relationship had already developed between scientists at the IISS and the Australian team. This relationship has further strengthened. A good measure of this is the uninhibited discussions which now take place amongst the group – differences of viewpoint / interpretation are now strongly argued, rather than avoided, and the quality of the research plans being developed reflects this more robust interaction.

The relationship between BAIF and IISS has developed well, with both institutions recognising each others' strengths, and beginning to exploit these strengths to the project's benefit. The IISS, in particular, has benefited through the development of a much more sophisticated pattern of engagement with farmers.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The experimental results for the INM practices developed within this project have produced soybean yield increases of ≈ 30% over the farmers practice treatment, with an increase in economic return for this crop of ≈ 40%. For the entire crop cycle (soybean + wheat) the increase in economic return is ≈ 30%. It should be noted that these returns are from relatively small scale trials conducted on the leading farmers' fields, and may not be representative of the gains which will be achieved by other farmers. This concern is well demonstrated by the broad range of yield and fertilizer responses obtained by farmers in the baby trial program. The appropriate advice to provide farmers will be based on their yield expectations, with farmers who have a low management input needing lower nutrient inputs than high management input farmers. Nutrient requirement for the wheat crop is also strongly determined by the availability of irrigation water. The economic implications of fertilizer and management input will be better assessed following detailed analysis of the baby trial program results. It should be noted that the price of fertilizer in India is increasing rapidly (in parallel with world fertilizer prices), while the value of the farm produce is controlled. Thus, the data from the experimental program will need to be reinterpreted repeatedly as the relative value of inputs and outputs alter.

The assessment of economic return achieved through the use of FYM does not explicitly consider the additional costs which would accrue to the community if an alternative waste disposal practice had to be introduced to replace the current practice of composting followed by use on agricultural land. While this practice is clearly not a result of the current project, the improvements in INM achieved by the current project will help to sustain the use of farmyard manure as agricultural production intensifies.

Preliminary results from BBF experiments have shown substantial increases in yield on areas of land which are severely impacted by inundation during the monsoon. Unfortunately, rainfall received during the 2007 monsoon was well below average, and the results obtained from the last year's field experiments may not well represent typical years. We are continuing to investigate this practice. In contrast to the researcher’s conservative view of the value of BBF, farmer's perceive this as a potentially highly useful practice. Several farmers in the Rajgarh area indicated their interest in attempting to use BBF after the 2006 monsoon season. During the 2007 monsoon, BBF trials were conducted on fields which are frequently slightly waterlogged during the monsoon, and hence not currently used for soybean production. The success of these trials has encouraged other farmers, and several are now considering purchasing BBF plough/planters. Approximately 25% of the land area cultivated for wheat is too wet during the monsoon for soybean production. At this time, we are unable to fully assess whether the BBF system can make any of this land useable during the monsoon, but the results to date are certainly promising.

8.3.2 Social impacts

The social scientist appointed to the project, and the BAIF workers, have directed considerable effort to understanding the role of women in the farming system, and in particular in the process of making decisions about farming practice. We hope to identify areas where women can make a difference to the farming outcomes because of their particular skills. One such area identified is the use of Rhizobial cultures to ensure effective nodulation of the soybean crop. We consider that women are in a better position to care for the culture to ensure that it is viable, and would be easily able to manage inoculation of the seed prior to planting.

8.3.3 Environmental impacts

The work in India aims to enhance, and hence perpetuate the use of, an inherently environmentally friendly agricultural practice; the return of organic wastes to agricultural land, partly offsetting the need for industrially produced fertilizers, and in particular carbon expensive, nitrogen. This environmental gain through a reduction in fertilizer use is further enhanced by increasing soybean yields, and hence the amount of N fixed by the soybean crop.

Unfortunately, leaching of nutrients (especially N and K) from compost pits appears to be substantial thereby contaminating groundwater. A mass balance study of two compost pits in 2006 showed loss of 40% of the N added in waste materials to the pit. While this loss may have been the result of leaching or gaseous loss (either through volatilization of ammonium or denitrification of nitrate), the loss of a comparable amount of potassium (36%), which can only be lost through leaching, implies that nitrogen loss may also largely be the result of leaching. Sampling of groundwater in villages showed elevated concentrations of nitrate, which rose during the wet season to concentrations in excess of the WHO drinking water guideline of 10 mg nitrate/L. More detailed investigation of the loss pathways from compost pits is currently in progress, including an assessment of a NADEP style system. It should be noted that while the groundwater nitrate concentration exceeds the drinking water guideline, the validity of this threshold value is widely questioned. Furthermore, farmers rightly note that they have been using the same practices and drinking the groundwater for many years without apparent harm. They viewed an appropriate response to be the more widespread use of reverse osmosis units to clean drinking water, rather than a change in waste management practice. From their perspective, change in farm yard manure pit management would be driven by nutrient retention concerns rather than the implications for human health.

In Australia, the finding from preliminary laboratory studies, that emission of nitrous oxide from soil can be reduced through the addition of green waste compost, was somewhat unexpected, as it could be argued that the addition of an energy source for the microbial population would increase microbial respiration, increasing the risk of denitrification. Clearly, the effect of nitrogen immobilization by the high C:N material outweighs this effect. A subsequent, opportunistic and limited assessment of emissions from field sites has confirmed that compost addition does not increase nitrous oxide emissions. More broadly, the use of high C:N organic wastes as soil amendments may represent a useful tool for the manipulation of soil nitrogen in highly productive systems, providing a means of manipulating nitrogen availability to better correspond with plant uptake demands. A PhD student has been recruited to work on this area, and we have gained the support of Queensland Department of Primary Industries to run field trials.

8.4 Communication and dissemination activities

The key communication activity initiated during 2006 and completed in 2007 was the conduct of a baby trial program. During the initial two years of the project, omission and INM trials were used to optimize crop nutrient inputs. The farmers, who participated in these trials and many of their neighbours, reported that they were pleased with the results, and would be using the higher fertilization rates more extensively in the future. The use of the baby trial program was expected to provide an excellent means of extending and refining the fertilization practices proposed. It should be noted that by increasing the fertilizer input to the crop, farmers are increasing their debt, and the risk associated with the crop. While the results produced by the research trials are understood by the farmers, they are not necessarily seen as applicable to their farms. This is attributable, in part, to the conduct of trials on the fields of larger and more capable farmers. Many other farmers do not have the same yield expectations as these large farmers, and do not immediately see the experimental results as applicable to them. By increasing the number of sites used, and by increasing the diversity of farm types hosting the trials, the beneficial results of increased fertilizer inputs will be confirmed in the minds of both researchers and farmers. (Or, if the initial experiments were misleading, we will avoid these incorrect higher rates of application being promoted as the “recommended rate”).

During the baby trial program, neighbouring farmers were encouraged to learn about the trial, and to consider the results in the context of their own farm, in this way extending the engagement of the farming community beyond the farmers actually hosting trials. In a subsequent farmer’s field day, farmers noted the value of increasing N and P fertilizer rates, the use of Zn and S fertilizers, and the value in the use of rhizobium inoculum.

9 Conclusions and recommendations

9.1 Conclusions

Farmers in Australia and India well recognise the nutrient value of animal manure, but they also recognise the difficulty inherent in meeting crop nutrient demand with manure alone. In Australia, the problem of excessive nutrient supply through high application rates has largely been addressed through the development of improved manure spreading equipment, while the nutrient release data from this project will guide manure to inorganic substitution.

Crop yields in the soybean / wheat producing area of northern India are typically limited by nutrient supply. Farmers routinely use N and P fertilizer, but at rates lower than the economic optimum. Furthermore, the use of high analysis fertilizer (as this is what is readily available in the marketplace) has reduced the input of S, and S deficiency now commonly limits yield. A marginal deficiency of Zn is widespread, but, while micronutrient fertilizers are available in the marketplace, they are not routinely used by farmers.

The traditional practice of applying large applications of farm yard manure (around 20 t/ha), limits the area of land which can be treated in any year. This study has shown that smaller applications (5 t/ha) can have substantial yield benefits when combined with inorganic fertilization, and this nutrient management regime (integrated nutrient management) is attractive to farmers both from an economic and cultural perspective.

Sufficient endogenous rhizobia are present in the soils of the soybean / wheat, that soybean crops nodulate without inoculation. However, inoculation with selected, high N fixing, strains does increase yield. This is viewed as an area where women may have a much greater role. Effective inoculation requires timely seed treatment with viable rhizobia culture. Women, as the housekeepers, are aware of the need for careful food storage, and this knowledge is readily transferable to the handling of rhizobium seed treatment cultures.

Nutrient loss from manure pits by leaching is substantial. While the P leached from the compost may be recovered through the practice of taking soil from under the compost to the field, N and K are more mobile and may be lost. Much of this loss could be overcome through the use of above ground composting, especially if covered.

Nutrient release from high quality Australian feedlot FYM can be regulated by applying to field with greenwaste compost. Also, greenwaste compost substantially reduces N loss from FYM not only through reduced leaching of mineral N but also by reducing N_2O emissions. Hence it provides management option to reduce groundwater pollution and mitigate or abate greenhouse gas emissions to atmosphere.

9.2 Recommendations

Synchrony of nitrogen supply and crop nitrogen demand. While significant progress has been made in developing the synchrony of nitrogen release from FYM of different nitrogen release characteristics, that in low quality FYM by using synthetic and mineral fertilisers and high quality FYM by using greenwaste compost, further work is required, including modelling, to refine these nutrient supply systems to optimise crop yields and nutrient use efficiency as well as minimise adverse environmental impacts.

Compost pit operation. The mass balance of compost pits indicates that considerable nutrient is lost from traditional compost pits. Improved composting procedures have been developed and promoted to farmers by various groups, but the improved approaches have not been widely adopted. Our observations are that the improved composting approaches require much more management than the simple pit system operated by farmers. The improved composting pits are typically small, and one of the main advantages stated is that the compost is produced quickly. Thus the small pits would need to be emptied frequently. However, speed of composting does not appear to confer an advantage in the agronomic system used for soybean / wheat production where compost is only applied to the fields once per year - before the soybean crop. Farmers may be more willing to adopt a relatively low input improved composting system, where the compost is protected from leaching, but large pits are used which are only emptied once per year.

Broad bed and furrow. The preliminary work undertaken within this project has indicated that on seasonally waterlogged land, considerable soybean yield increases can be obtained through the use of broad bed and furrow cultivation. Further work is required to verify the broadbed abd furrow practice over a wide region and a number of seasons of different total rainfall and rainfall distribution during growth of soybean crop.

10 References

10.1 References cited in report

Acharya, C.L., Tomar, K.P., Subba Rao, A., Ganguly, T.K., Singh, M.V., Rao, D.L.N., Rao, C.S., Rupa, T.R. (1998). Integrated Plant Nutrient Supply System for Sustainable Productivity. Bulletin No. 2. Pp.1-211. Indian Institute of Soil Science, Bhopal, M.P., India.

ALFA 2007. Australian Lot Feeders Association; Quarterly Reports. http://www.farmonline.com.au/farmmags/alfalotfeeding/publication.aspx; Rural Press. Australia (Viewed April 2008)

Allen DE, Dalal RC, Rennenberg H, Meyer RL, Reeves S, Schmidt S (2007) Spatial and temporal variation of nitrous oxide and methane flux between subtropical mangrove sediments and the atmosphere. Soil Biology and Biochemistry 39: 622-631.

Barbarika Jr. A, Sikora LJ, Colacicco D (1985) Factors affecting the mineralization of nitrogen in sewage sludge applied to soils. Soil Science Society of America Journal 49, 1403-1406.

Bar-Tal A, Beraud J, Keinan A, Rosenberg R, Rosen V, Fine P, Yermiyahu U, Zohar D (2004) Nitrogen, phosphorus, and potassium uptake by wheat and their distribution in soil following successive, annual compost applications. Journal of Environmental Quality 33, 1855-1865.

Bremner, J.M. Mulvaney, C.S. (1982) Nitrogen – total. In 'Methods of Soil Analysis'.(Ed AL Page, RH Miller, and DR.Keeney) (American Society of Agronomy- American Society of Soil Science, Madison, WI) pp. 595.

Castellanos J.Z., Pratt, P.F. (1981) Mineralization of manure nitrogen – Correlation with laboratory indexes. Soil Science Society of America Journal 45:354.

Chesnin L, Yien CH (1951) Turbidimetric determination of available sulphate. Soil Science Society of America Proceedings 15, 149.

Constantinides, M., Fownes, J.H. (1994) Nitrogen mineralization from leaves and litter of tropical plants: Relationship to nitrogen, lignin and soluble polyphenol concentrations. Soil Biology and Biochemistry 26, 49.

Dalal, R.C., Acharya, C.L., Reddy, K.S., Redding, M., Sharma, A.K., Ritchie, J., Eisner, R., Kumar, N., Casey, K., Skerman, A., Thomas, G. (2002). Survey of potential of manure for meeting crop nutrient needs with integrated nutrient management in Madhya Pradesh, India. Final Report ACIAR Project LWR2/1998/136. pp. 1-61 Department of Natural Resources and Mines, Brisbane.

Dalal RC, Wang W, Robertson GP, Parton WJ (2003) Nitrous oxide emission from Australian agricultural lands and mitigation options: a review. Australian Journal of Soil Research 41, 165-195.

Deosthali, V., Akmanchi, A. Salunke, C. (2005) Soybean agriculture in India, a spatial analysis. Transcripts of the Institute of Indian Geographers. 27, 13.

Eghball B (2000) Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Science Society of America Journal 64, 2024-2030.

Fox, R.H., Myers, R.J.K., Vallis, I. (1990) The nitrogen mineralization rate of legumes as influenced by their polyphenol, lignin and nitrogen contents. Plant and Soil 129, 251.

Ginting D, Kessavalou A, Eghball B, Doran JW (2003) Greenhouse gas emissions and soil indicators four years after manure and compost applications. Journal of Environmental Quality 32, 23-32

Government of Madhya Pradesh (2000). Agricultural Statistics 2000. pp. 1-3. Department of Agriculture, Madhya Pradesh. Bhopal.

Hanway JJ, Hiedel H (1952) Soil analysis methods as used in Iowa State College Soil testing Laboratory. Iowa Agriculture 57, 1-13.

Jackson ML (1973) "Soil chemical analysis' (Prentice Hall: New Delhi, India).

Jalota R, Dalal R, Harms B, Page K, Mathers N, Wang W (2006) Effects of litter and fine root composition on their decomposition in a rhodic paleustalf under different land uses. Communications in Soil Science and Plant Analysis 37, 1859-1875.

Janssen BH (1996) Nitrogen mineralization in relation to C:N ratio and decomposability of organic materials. Plant and Soil 181, 39-45.

Lindsay WL, Norwell WA (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal 42, 421-428.

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular of the United States Department of Agriculture, 939, Washington DC.

Oglesby, K.A. Fownes, J.H. (1992) Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. Plant and Soil 143, 127.

Palm, C.A. (1995) Contribution of trees to nutrient requirements of intercropped plants. Agroforestry Systems 30, 105.

Qian P, Schoenau JJ (2002) Availability of nitrogen in solid manure amendments with different C:N ratios. Canadian Journal of Soil Science 82, 219-225.

Recous, S., Rabin, D., Darwis, D., Mary, B. (1995) Soil inorganic N availability: Effect on maize residue decomposition. Soil Biology and Biochemistry 27, 1529.

Sharpley A, Moyer B (2000) Erratum: Phosphorus forms in manure and compost and their release during simulated rainfall (Journal of Environmental Quality (2000) 29 (1462-1469)). Journal of Environmental Quality 29, 2053.

Sims, J.T. (1986) Nitrogen transformations in a poultry manure amended soil: temperature and moisture effects. Journal of Environmental Quality 14:59.

Singh Y, Singh, B., Maskina, M.S. Meelu, O.P. (1988) Effect of organic manures, crop residues and green manure (Sesbania aculeate) on nitrogen and phosphorus transformations in a sandy loam at field capacity and under waterlogged conditions. Biology and Fertility of Soils. 6, 183.

Singh, J.P. Kumar, V. (1996) Nitrogen mineralization of legume residues in soils in relation to their chemical composition. Journal of the Indian Society Soil Science. 44, 219.

Srinivas, K, Singh, H.P., Vanaja, M., Sreenivasa Raju, A. Sharma, K.L. (2006) Effect of chemical composition of plant residues on nitrogen mineralization. Journal of the Indian Society of Soil Science 54, 300.

Tandon, H.L.S. (1990). Integrated Nutrient Management for sustainable dryland agriculture. Sustainable Agricultural Issues, Perspectives and prospects in Semi-arid tropics. Vol 1. 202-225.

Tandon, H.L.S. (1997). Organic resources: an assessment of potential supplies, their contribution to agricultural productivity and policy issues for Indian agriculture from 2000 to 2025. In Plant Nutrient Needs, Supplies, Efficiency and Policy Issues: 2000-2025 (eds.

J.S. Kanwar and J.C. Katyal), pp. 15-28. National Academy of Agricultural Sciences, New Delhi, India.

Tripathi, K. P. and Mishra, B. (2001) Kinetics of N mineralization during rice straw decomposition in the soils. Journal of the Indian Society of Soil Science. 49, 56.

Subbiah BV, Asija GL (1956) A rapid procedure for the determination of available nitrogen in soils. Current Science. 25, 259-260.

Vityakon, P. Dangthaisong, N. (2005) Environmental influences on nitrogen transformation of different quality tree litter under submerged and aerobic conditions. Agroforestry Systems. 63, 225.

Walkley, A. Black, I.A. (1934) An examination of the Degtijareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37, 29.

Williams CH, Steinbergs A (1959) Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. Australian Journal of Agricultural Research 10, 342-352.

10.2 List of publications produced by project

Dalal RC, Gibson IR, Menzies NW (2009) Nitrous oxide emission from feedlot manure and green waste compost applied to Vertosols. Biology and Fertility of Soils 45, 809-819.

Dalal RC, Gibson I, Allen DE, Menzies NW (2010) Green waste compost reduces nitrous oxide emissions from feedlot manure applied to soil. Agriculture Ecosystems & Environment 136, 273-281.

Mohanty M, Reddy KS, Probert ME, Dalal RC, Rao AS, Menzies NW (2010) Modelling N mineralization from green manure and farmyard manure from a laboratory incubation study. Ecological Modelling (in press).

Muhammad W, Vaughan SM, Dalal RC, Menzies NW (2010) Crop residues and fertilizer nitrogen influence residue decomposition and nitrous oxide emission from a Vertisol. Biology and Ferility of Soils (in press).

Sammi Reddy, K., Mohanty, M., Rao, D.L.N., Singh, M., Dalal, R.C. and Menzies, N. (2008). Nitrogen mineralization in a Vertisol from organic manures, green manures and crop residues in relation to their quality. Agrochimica 52: 377-388.

Mohanty M, Probert ME, Reddy KS, Dalal RC, Rao AS, Menzies NW (2010) Modelling N mineralization from green manure and farmyard manure from a laboratory incubation study In 'Proceedings of the 19th World Congress of Soil Science. Soil solutions for a changing world'. Brisbane, Australia. (Ed. B Gilkes) pp. 24-27. (International Union of Soil Science)

Mohanty M, Probert ME, Reddy KS, Dalal RC, Rao AS, Menzies NW (2010) Modelling N mineralization from high C:N rice and wheat crop residues In 'Proceedings of the 19th World Congress of Soil Science. Soil solutions for a changing world'. Brisbane, Australia. (Ed. B Gilkes) pp. 28-31. (International Union of Soil Science)

Reddy KS, Mohanty M, Rao DLN, Rao AS, Blamey FPC, Dalal RC, Dixit SK, Pandey M, Menzies NW (2010) Development of farmers' participatory intergrated nutrient management technology using the Mother-Baby trial approach In 'Proceedings of the 19th

World Congress of Soil Science. Soil solutions for a changing world'. Brisbane, Australia. (Ed. B Gilkes) pp. 87-90. (International Union of Soil Science)

Reddy KS, Blamey FPC, Dalal RC, Mohanty M, Singh M, Rao AS, Pandey M, Menzies NW (2010) Leaching losses of nutrients from farmyard manure pits in Central India In 'Proceedings of the 19th World Congress of Soil Science. Soil solutions for a changing world'. Brisbane, Australia. (Ed. B Gilkes) pp. 202-205. (International Union of Soil Science)

Vaughan SM, Dalal RC, Harper SM, Menzies NW (2010) Reduction in soil nitrogen losses from a Vertisol with organic wast amendments under subtropical conditions In 'Proceedings of the 19th World Congress of Soil Science. Soil solutions for a changing world'. Brisbane, Australia. (Ed. B Gilkes) pp. 243-246. (International Union of Soil Science)

Sammi Reddy, K. and Pandey, M. (2007). Nutrient input, output and balance of farmyard manure production by farmers through conventional method. Paper presented at 72nd Annual Convention of the Indian Society of Soil Science held at BAU, Ranchi during November 2-5, 2007.

Sammi Reddy, K., Rao, D. L. N. Muneshwar Singh, Mohanty, M., Subba Rao, A., Dixit, S. K. Pandey, M and Geeta Singh (2007) Enhancing productivity of soybean – wheat system by balanced and integrated nutrient management on black soils of Madhya Pradesh. ICAR-ACIAR Project Bulletin No. 1, Indian Institute of Soil Science, Bhopal, PP. 17.

Sammi Reddy, K., Rao, D. L. N. Muneshwar Singh, Mohanty, M., Subba Rao, A., Dixit, S. K. Pandey, M and Geeta Singh (2007) Madhya Pradesh Kee Kali Mitti Par Santhulith Aur Samanvith Poshak Prabandh Dwara Soyabean – Gehu Pranali Kee Utpadak Ko Badawa. ICAR-ACIAR Project Bulletin No. 1, Indian Institute of Soil Science, Bhopal, PP. 17.

Sammi Reddy, K. Mohanty, M. and Pandey, M. (2006) Nitrogen mineralization characteristics of green manures, organic manures and crop residues in relation to their quality. Paper presented at 71st Annual Convention of Indian Society of Soil Science (ISSS) at Orissa University of Agriculture and Technology, Bhubaneshwar during November 10 – 13, 2006.

Sammi Reddy, K. and Neal Menzies (2007) Improved nutrient management for soybean-wheat systems. ACIAR South Asia Newsletter, July 2007, P 4-5.

11 Appendixes

11.1 Appendix 1 heading

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