INTEGRATED NUTRIENT MANAGEMENT IN FARMING SYSTEMS IN SOUTHEAST ASIA AND AUSTRALIA

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Integrated Nutrient Management in Farming Systems in Australia and Southeast Asia

Foreword

CHANGES in the economic situation of farmers and changes in farming systems has refocused attention on ways to integrate organic and inorganic nutrient sources. Increasing cropping intensity and the opening up of new lands, often with poor soils, has led to substantial declines in soil organic carbon. This decline can often be associated with declining soil chemical and physical fertility.

Recognising these changes, ACIAR funded two sequential projects on integrated nutrient management LWR2/1991/002 'Nutrient Management in Rainfed Cropping Systems' from 1992 to 1995 and LWR2/1994/048 'Carbon Dynamics, Nutrient Cycling and the Sustainability of Cropping and Pasture Systems' from 1996 to June 1999. These collaborative projects were carried out in Thailand, Philippines, Lao PDR and Australia. PN9448 also included a component in Tonga.

In LWR2/1991/002, a procedure was developed which allowed the division of soil carbon into labile (active) and non-labile forms. This technique was then used in LWR2/1994/048 to evaluate the effects of return of crop residues, and the addition of small amounts of leaf litter from leguminous trees on crop production and soil properties. The research established the benefits from the integrated use of these organic inputs and inorganic fertilisers in the farming systems in each country.

At the conclusion of LWR2/1994/048, a workshop was held in Vientiane, Lao PDR to summarise the findings from the projects and to integrate these with results from other similar projects conducted in the region.

These Proceedings from that workshop have been refereed by the editors and Dr A.R. Till, Agronomy and Soil Science, University of New England, Australia.

It is hoped that these papers and the summary of the country meetings presented here will be of benefit to the researchers, extension personnel and decision-makers, and that the information contained in these papers can be translated into actions to improve the welfare of farmers and the sustainability of farming in the region.

Anthony Whitbread
Graeme Blair

Summary of Country Meetings

DELEGATES from each participating country met and addressed 10 issues. The following represents a summary of their deliberations.

1. The importance of organic matter

Delegates from each participating country agreed that it was important to raise soil organic matter levels in order to improve chemical, biological and physical fertility. Delegates from Cambodia indicated the importance of research carried out in northeast Thailand which showed increased soil buffering capacity, nutrient availability and water holding capacity when the soil organic matter was increased. The relevance of increases in soil organic matter to most farmers was also raised. Improvements in management technologies, the use of appropriate plant species and better on-farm residue management practices are likely to improve soil organic matter. The extension group suggested that demonstrating that increases in soil organic matter do relate to improved yields will result in better on-farm adoption.

With increasing populations in Southeast Asia, an increasing supply of household waste becomes available for recycling. This material potentially provides a valuable source of organic matter for peri-urban areas

2. The importance of animals in organic matter recycling

In parts of Thailand, the use of buffalo for ploughing has been replaced by machinery. This contrasts with Cambodia where animals are still important for traction and transportation in all of the rice-growing areas except the northwest. These changes in the importance of livestock should be considered against the long-term requirements for animal products, which are anticipated to increase some 75% over the next 25 years. In systems where animals are becoming less important, the opportunity to grow in-field green manure crops is likely to be less, given the increased cropping pressure as farmers move into multiple crops in the one year. In systems such as in Cambodia, where animals remain vitally important, it seems unlikely that green manures would be grown specifically for crop production but rather they would be grown for high protein leguminous feeds to enhance animal nutrition. Increasing the use of forage in farming systems was seen as one way of improving the on-farm recycling of residues and potentially improving soil fertility and cash flow.

3. Risks of pre- and post-green manure crops

Delegates from all countries considered pre- and post- rice cropping to be a risky practice. In Thailand, cowpea or mung bean varieties better adapted to variable moisture conditions may be acceptable. In the rainfed lowlands of Laos, the problem of water control was seen as a major restriction. In this system, the need for phosphorus on the green manure crop was seen as a risky enterprise for farmers should the crop fail. Growing green manure after rice in the irrigated areas of Laos may be a possibility provided it does not interfere with the sowing time for the next crop. In Cambodia, the consequence of growing a pre-rice green manure was to potentially delay the transplanting of the rice crop. The labour availability in Cambodia to grow the green manure crop, the potential to tie up nutrients and the potential toxic effects soon after incorporation were seen as disincentives to grow pre-rice green manure. The balance of quality and quantity of green manures was seen as an important issue. Ideally, green manures, which had a breakdown rate and nutrient release rate similar to that of crop requirement, was seen as advantageous. Improving on-farm water storage, land levelling and a better choice of legume species were seen as improvements which are needed.

4. Balance between quantity and quality of crop residues and the interaction with soil type

The difficulty in handling large amounts of pre-rice biomass was highlighted by all delegates. With current yields in the sandy soils of northeast Thailand, incorporation of straw or green manure was not seen as a problem. However, as yields increase, specialised machinery was likely to be needed to be able to incorporate larger quantities of residues. In Laos, the problem of controlling animals in the dry season in the rainfed lowland system was seen as a difficulty. When high quality green manure crops pre- or post-rice are grown, not only is lack of labour for incorporation seen as a problem, but fencing to exclude animals was also deemed essential. In Cambodia, the increased cultivation required to incorporate green manures was seen to lead to increased breakdown rates more on sandy soils than on clay soils. The potential advantages from the green manure crop could therefore be undone by the increased cultivation required to incorporate them. The large straw resource available, particularly in irrigated areas, was seen to be a problem because of its high C to N ratio. The potential immobilisation of N in the following crop was seen to be a disadvantage. The complicated issue of the need for a sustainable farming system to balance between residue type, quality and quantity, tillage system and soil type was also considered.

5. Crop intensification and the opportunities for residue reuse

Given the relatively low production in northeast Thailand, the use of on-farm residues from rice stubble and rice husks, together with on-farm leguminous trees, was seen as a distinct possibility to enhance productivity. The use of off-farm organic resources was seen to be unrealistic, except in profitable areas or areas close to intensive chicken production. In areas of Laos where animal numbers are low, opportunities for the reuse of on-farm organic resources was seen to be limited. This was particularly so if animals were sent to forest areas during the dry season where it was not possible to collect the manure. In Cambodia, industrialisation and its effects on labour availability was seen as a considerable constraint to the on-farm use of organic nutrient sources. The delegates from Cambodia pointed out that when a particular nutrient, such as phosphorus, is required, the recycling of organic nutrients is unlikely to have a major benefit in increasing productivity unless additional inorganic phosphate resources are brought in from outside. Often the use of residues obtained off-farm will be opportunistic, depending on availability. The use of peri-urban wastes may be important in areas where this resource is available, but overall, increases in agricultural production will require more than this resource.

6. Benefits of recycling of nutrients from organic residue

Data from research in Laos have indicated a higher grain yield per kilogram of N returned in green manures than would be anticipated from an inorganic source. It was considered that this apparent increased efficiency in the N utilisation could be due to a combination of increased biological activity and the fresh application of nutrients when the organic matter is incorporated into the soil. Although the total amount of nutrient returned in the green manure is generally small compared to crop requirement, the timing of its availability was seen to be a major advantage. The effects on soil physical fertility, which enhance root growth and increase the access to native soil nutrients was also seen to be a contributing factor to the increased response to the green manure crop.

7. Usefulness of the carbon management index (CMI)

The lack of a fixed desirable value for CMI was seen as a disadvantage of this system. It was generally felt the CMI would be useful to the policy makers who are attempting to change broad-scale farming practices. Given the limited availability of soil testing facilities throughout the region, its usefulness to farmers was likely to be limited. The CMI was seen to be particularly useful in designing farming systems but there was a feeling that more definition of what was required in particular soil and environments for both stability and productivity was needed. The Cambodian delegates raised the question about needing established relationships between the CMI and other indicators or measures of stability. The CMI cannot directly predict yield increases because yield is influenced by many other factors for example, available soil nutrients, soil water and climatic influences.

8. Future requirements for research and extension

Delegates from Thailand felt that there was a greater need for research on integrated nutrient management rather than on inorganic fertilisers or extension. This contrasted with the views of delegates from Laos and Cambodia who felt that there was now good data throughout the region on integrated nutrient management but this needed to be extended to farmers. It was considered that there was a great deal of unpublished information available to allow a better assessment of the value and management of organic materials in the cropping systems of the region. It was felt that a reassessment of this data, through short-term, masters and PhD level training programs, together with a small amount of focused research, would enhance the value of the research already conducted.

The extension group felt that much of the research was unavailable to extension workers, and was often not relevant to specific farming areas. The variability in soil types, even within a village, made the package technologies difficult to implement. Improving the contact between extension workers, farmers and researchers was deemed necessary so that research topics were addressing the appropriate problems. These problems could be partly solved by informal release of research findings in the form of newsletters, or more formal mechanisms such as the formation of joint research and extension committees.

Delegates from IBSRAM and UNE felt that improving the use of existing data sets and knowledge, especially between regions, was needed. From this knowledge, surrogates and simple indicators of various soil properties (i.e., colour charts, soil identification) could be developed and would be more useful for extension activities. It was also proposed that a research proposal be developed with the purpose of collating regional data, training scientists and extending research findings to extension services.

9. Inter-regional linkages

All delegates felt that there would be considerable advances from increased inter-regional linkage. It was felt that such linkages should concentrate on the science associated with integrated nutrient management to enable policy to be clearly formulated. Such linkages would enhance the limited national capacity for research and extension which was characteristic of many countries of the region. It was stressed that such linkages would require coordination from a centre within the region.

10. Other research and adoption opportunities

Integrated trials across the region on phosphorus requirements were seen as advantages. Given the general similarities of climate and soils in parts of each country, such inter-regional coordinated research was seen to be beneficial. In Thailand, the greater use of industrial and city wastes were seen as an important research opportunity. In Cambodia, efforts to improve the reliability of fertiliser quality was seen to be an important research opportunity. District or regional nutrient balance studies were seen as important both to make farmers aware of the loss of nutrients from their farm and to policy makers in them assisting farmers with nutrient applications. Research to investigate the possibility of reducing nutrient exports to urban areas was seen to be useful. The incorporation of perennial crops into farming systems was seen as a way in which better integrated nutrient management could be obtained.

The development of a database which would collate integrated nutrient management data for rice-based systems was seen by delegates from PPI as essential. This simple database would be used by extension services as a decision support system.

Managing Residues and Fertilisers to Enhance the Sustainability of Wheat Cropping Systems in Australia

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Abstract

The continuous cultivation and cropping of many Australian soils, which previously supported native vegetation, has resulted in substantial losses in soil organic matter (SOM). Field trials consisting of legume/wheat rotations were established at Warialda, NSW, Australia, to investigate the effect of crop residue and fertiliser management on wheat yield, nutrient balances, carbon and soil structure. Wheat yields were significantly lowered in the first year following a lucerne or soybean legume phase. Wheat grain production was increased from 6% to 19% with fertiliser application and from 3% to 9% with the retention of wheat stubble. After five wheat and two legume/fallow crops, nutrient balances showed N balances of up to –303 kg/ha on the treatments where wheat stubble was not retained and bare fallow leys were used. The balance of nutrients such as K, which are contained in larger proportions in stubble, were found to be up to –362 kg/ha on the wheat residue removed treatments and up to +29 kg/ha on the residue retained treatments. The greatest improvements in SOM were associated with two lucerne rotations which increased total carbon sequestration to 41 t/ha as compared to 31 t/ha on the fallow treatments.

MANY Australian soils used for cropping are fragile and highly degraded. Farming practices such as the removal of crop residues, poor management of leys and excessive tillage, are common and unsustainable. The cultivation of soil which has previously supported native vegetation and/or pastures, generally leads to a decline in SOM and C levels (Dalal and Mayer 1986), lower biological activity (Gupta et al. 1994) and deteriorating soil structure (Chan et al. 1992).

Soils under natural grasslands have a large total C pool, containing residues of different ages and qualities and consequently contain sub-pools of fast, medium and slow turnover rates. In cropped land, cultivation increases the breakdown rate of residues yielding C pools are that are generally much smaller than under natural grasslands and the C remaining is more resistant to decay. In addition, the major carbon additions occur in discrete events such as when cereal stubble is incorporated into soil. Legume rotations, often used to improve soil fertility and to provide forage to animals, introduce a highly decomposable OM source and the benefit depends on amount of C returned and amount of cultivation.

A field trial was conducted at the University of New England's Douglas McMaster research station in northwest NSW to examine the effects of legume ley crops, management of the legume residue, management of wheat residue and fertiliser on wheat yields. The aim of this experiment was to investigate:

- the effects of management systems on the level and nature of SOM;
- the changes in soil nutrient status and soil physical properties that result from changes in organic matter;
- the nutrient dynamics of these systems; and
- the subsequent effect on production.

Materials and Methods

The trial was established in 1992 on a moderately degraded Red Earth soil (Paleustaf) which had previously been cropped in a cereal-legume rotation. In phase 1 of the experiment, three legume systems (lucerne, chickpea and medic) and a fallow were established with no fertiliser during the 1992 winter

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cropping season on an exisiting wheat field. The lucerne system was established on an adjacent existing lucerne field. The residue from these systems was either removed, returned or grazed. On these same sites, wheat (cv. Janz) was grown during 1993, 1994 and 1995, with two fertiliser treatments [0 (–F) or 25:7:27 kg N:P:S/ha(+F)] and two wheat residue management treatments [removed (–R), returned (+R)].

For phase 2 of the experiment, three legume (soybean, medic, lucerne) or fallow treatments were replanted during the winter of 1996 (8 and 8.8 kg P and S/ha, respectively) with the residue from these systems being removed, returned or burnt. Wheat was again grown during 1997 and 1998 with two fertiliser treatments [Low (12.5:11.4:10 kg N:P:S/ha) and High (25:23:20 kg N:P:S/ha)] and wheat straw removed or returned.

The yields of the legume crops and wheat crops were measured at harvest and straw and grain samples were collected for nutrient analysis. Soil samples (0–10 cm) were collected from all plots prior to sowing. The more labile soil organic carbon (C_L) was measured by oxidation with 333 mM $KMnO_4$ (Blair et al. 1995). Total C (C_T) was measured in an automatic nitrogen and carbon analyser mass spectrometer system (ANCA-MS). Non-labile C (C_{NL}) was calculated as C_T-C_L. Since the continuity of C supply depends on both the total pool size and the lability (an estimate of turnover rate), both are taken into account in the soil of interest, and in an uncultivated reference soil, to derive a Carbon Management Index (CMI) (Blair et al. 1995). Changes in C_T, between a reference site and the cropped site a Carbon Pool Index (CPI) was calculated as follows:

$$CPI = \frac{C_{T_{cropped}}}{C_{T_{reference}}}$$

On the basis of changes in the proportion of C_L in the soil, a Lability Index (LI) was also determined as follows:

$$LI = \frac{L_{cropped}}{L_{reference}}$$

These two indices were used to calculate a Carbon Management Index (Blair et al. 1995):

$$CMI = CPI \times LI \times 100$$

The reference sample was collected from a nearby uncultivated, uncleared area which was covered by native vegetation. Following harvest in 1998, soil samples were collected to 60 cm depth and divided into 0–10, 10–30 and 30–60 cm intervals. These were analysed for C, available P (Colwell 1965) and available S (Blair et al. 1991).

Results

Wheat yields

The impact of the initial 1992 pre-wheat legume/fallow phase on grain yields was limited to a decrease in wheat grain yield following the lucerne phase and was restricted to the first season of wheat. The main impacts on grain production during the first wheat phase were due to fertiliser, which increased grain yields by 6.4, 7.8 and 19.4% in 1993, 1994 and 1995, and wheat stubble retention which increased grain yields by 8.0 and 9.4% in 1994 and 1995 (Table 1). The second legume phase resulted in wheat grain yields of 3488 and 3454 kg/ha following the medic and fallow phases and significantly lower yields of 2376 and 2754 kg/ha following the lucerne and soybean phases, respectively. There was no effect of previous stubble management on grain yields in 1997 and 1998; however, the high application of fertiliser significantly increased yields in 1997 but not in 1998.

Table 1. Fertiliser (1993–95 –F, +F: 1997–98 Low, High) and wheat stubble effects on wheat grain yield (t/ha).

	Wheat grain yield (t/ha)				
	1993	1994	1995	1997	1998
– F/Low	3.3 b^{A}	2.0 b	2.2 b	2.9 b	2.2 a
+ F/High	3.5 a	2.2 a	2.6 a	3.1 a	2.1 a
– Wheat stubble	–	2.0 b	2.3 b	2.9 a^{B}	2.1 a
+ Wheat stubble	–	2.1 a	2.5 a	3.0 a^{B}	2.2 a

[A] Means followed by the same letter within columns are not significantly different according to DMRT at $P \leq 0.05$

[B] Stubble in the first wheat crop in Phase 2 refers to the wheat stubble from crops in Phase 1

Nutrient balances

Nutrient balances, determined by the difference between the inputs (fertiliser and legume residues) and outputs (grain and stubble), were calculated up until after harvest in 1998 and are presented in Figure 1 for the lucerne and fallow treatments. The nutrient balance does not take into account the amount of N that may have been fixed during the crop growth, the nutrients contained in decomposing root material or soil nutrient changes. Fertiliser and residue management were the primary determinants of the nutrient balance. Approximately 80% of the N is contained in the grain so export of N is high resulting in negative N balances. In contrast, approximately 80% of the potassium (K) is contained in the stubble and the management of crop residue largely influences the K balance. The removal or burning of wheat stubble results in large amounts of K being exported and possible K deficiencies. Sulfur shows a pattern similar to K; however, due to the higher S applications in the first wheat phase (1993–1995), the F+ has a more positive balance. This resulted in no change in the plant available soil S pool in the topsoil. However, at 30–60 cm depth, available S increased from 2.9 to 5.1 µg/g with higher inorganic fertiliser application (the critical value for KCl-40 S is 6.5 µg/g). This highlights the highly mobile nature of this nutrient especially in light textured soils.

Soil carbon

Legume phase 1993

The decrease in C as a result of farming activities was apparent in the losses in C of up to 79% and 73% in the C_L and C_T fractions (Table 2). The reduction in C_L was proportionally greater than the reduction in C_T since the C_L represents the fraction of carbon which is more easily oxidised and lost. The existing lucerne ley resulted in a minor non-significant improvement in the carbon concentration. However, when it was continued through 1993, the increase in labile C improved the CMI from 22 in the previous year to 33 after the 1993 lucerne phase. The lucerne phase during 1992 resulted in an increase in C_T, L and the CMI (Table 1); however, the chickpea, medic or fallow phase produced no significant changes in C pools.

Table 2. The change in carbon (mg/g) and in the Carbon Management Index (CMI) from the uncropped reference and the 1992 lucerne or wheat until after the 1993 legume/fallow phase.

Year	Treatment	Labile C	Non-Labile C	Total C	Lability	CMI
		mg/g				
1992	Reference	5.3	19.9	25.2	0.27	100
	Lucerne	1.2	6.3	7.6	0.20	22
	Wheat	1.1	5.5	6.7	0.21	20
1993	Lucerne	1.7	5.7	7.4	0.30	33
	Chickpea	1.1	5.0	6.1	0.22	19
	Medic	1.2	5.0	6.2	0.23	21
	Fallow	1.1	5.3	6.4	0.21	19

Phase 1. 1993–1996

Following the legume/fallow rotations, the management of wheat stubble became the critical determinant of C. In 1996 after the two seasons of wheat stubble incorporation and surface retention of the 1995 wheat residues, C_L was significantly higher on the returned than on the stubble removed treatments. C_T tended to be lower on both treatments than in the previous season but this was not significant. The higher C_L in the residue retained treatments resulted in an increase in the CMI to 27 (Table 3).

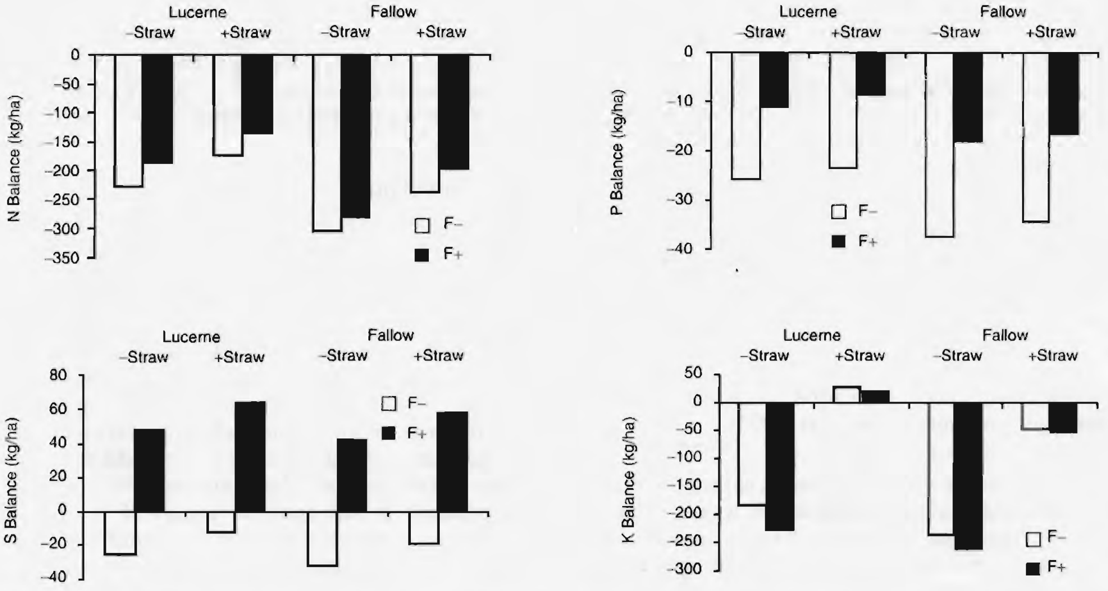

Figure 1. The N, P, S and K balance of the lucerne and fallow treatments in 1998 after five wheat crops and two legume or fallow phases.

Table 3. The change in carbon (mg/g) and in the Carbon Management Index (CMI) measured in 1995 and 1996.

Year	Stubble	C_L	C_{NL}	C_T	CMI
		mg/g			
1995	Removed	0.89c[A]	5.52 a	6.41 a	16 c
	Returned	1.01 b	5.86 a	6.87 a	18 b
1996	Removed	1.04 b	4.89 a	5.93 a	19 b
	Returned	1.38 a	5.13 a	6.51 a	27 a

[A] Means followed by the same letter within columns are not significantly different according to DMRT at $P \le 0.05$.

Legume phase 1996

The greatest improvement occurred where lucerne was planted which resulted in a C_T of 8.61 mg/g compared to a C_T of 5.85 mg/g in the fallow treatment. There was a continued loss of C from the fallow treatments, where there were no organic matter inputs during the ley phase. There was an interaction between the wheat stubble management during the 1993–1996 wheat phase and the legume or fallow phases in 1992 and 1996. The retention of wheat stubble during 1997 and 1998 slowed the loss of C from both the fallow and the lucerne treatment.

By calculating the total C sequestration to a depth of 60 cm, the magnitude of C change is highlighted (Table 4). The highest C sequestration was found where lucerne was used as the ley legume. There was a 10 t difference between the lucerne and fallow phases as C in the fallow treatment continued to be lost.

Table 4. Total C sequestration (0–60 cm) from 1992 to 1998 following the various rotations.

	Tonnes C/ha
Lucerne	41 a[A]
Chickpea	37 ab
Medic	34 bc
Fallow	31 c

[A] Means followed by the same letter are not significantly different according to DMRT at $P \le 0.05$.

Discussion

As a result of farming activities, soil carbon declined by more than 70% from the pre-clearing levels. The use of lucerne as a traditional ley phase resulted in the greatest improvement in C_T. The improvement in C_L was somewhat smaller than that in C_T. It is hypothesised that at the time of sampling, legume residues had been ploughed in and good soil moisture resulted in high rates of microbial decomposition, especially of the labile carbon compounds.

The retention of wheat stubble has resulted in significantly higher C_L and improvements in the CMI following the wheat phase in 1996. During the 1996 legume/fallow phases, the differences in C_L disappeared; however, the improvement in soil carbon became apparent through an increase in C_T. Although longer term data are required, it appears that an improvement in soil carbon can be achieved through the retention of wheat stubble. This has longer term environmental consequences than the

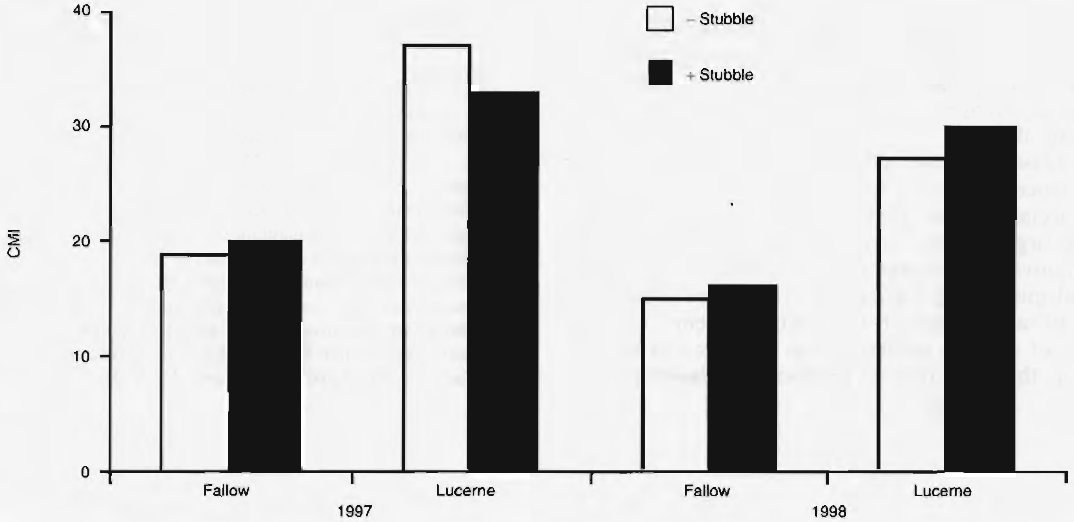

Figure 2. The effect of wheat stubble management on the Carbon Management Index (CMI) of the fallow and lucerne phases in 1997 and 1998.

alternative of using it as a substrate for ethanol production or its loss through burning.

The benefits of wheat stubble retention are apparent through the 8% and 9.4% increases in grain yields in 1994 and 1995. This benefit was not apparent in the 1997 grain yields following the 1996 fallow phase. Although carbon was somewhat higher following the lucerne phase, grain yield was significantly reduced due to lower pre-cropped stored moisture and difficulties in killing the lucerne plants during the wheat cropping season. The reduced yield in the lucerne and soybean treatments may have been partly associated with the reduced stored water in these treatments (lucerne – 259 mm water, fallow – 267 mm water 0 – 70 cm).

Residue retention has the potential to influence the amount of nutrients being returned to the soil. This is especially important for K in which approximately 80% is located in the stubble but less important for N which is mostly contained and exported in grain. Other nutrients such as P and S are also significantly influenced by stubble management. The magnitude of K export in residue removed systems is up to 133 kg/ha and soil K deficiency would develop under this form of management. In the long term, nutrient balances can be used to predict likely fertiliser requirements.

One of the most significant impacts of stubble retention was found to be on soil physical properties. Stubble retention increased hydraulic conductivity by more than 65%, increased water stable aggregates and lead to lower soil strength (Whitbread et al. 1997).

Conclusions and Research Directions for Australian Cropping Systems

Adequate SOM levels are the key to sustainable agro-ecosystems. Management practices that optimise the use of crop residues and rotations to increase SOM are likely to be sustainable farming practices, but are, however, costly to implement especially in the short term. Management decisions are largely market driven so the financial returns of improving SOM need to be quantified. Increasing C and minimising nutrient export requires a balanced fertilisation approach to farming systems, efficient use of on-farm produced crop residues and maximising the return of plant residues from ley phases.

Gaps in knowledge which require research are:

- C in cropping systems needs to be studied using measurements of labile C, total C, bulk density;
- reversing C loss will need a better understanding of the 'quality' of residue inputs, bulk soil C changes, seasonal C changes and below ground inputs of C;
- understanding C losses in high clay soils;
- delivering a clear C message to the farming community will stop misconceptions.

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The Management of Organic Residues in Sugar Cane and Cotton Cropping Systems in Australia

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Abstract

Sugar cane and cotton are crops that produce large amounts of residues when they are harvested. In both cropping systems in Australia, the past practice has been to burn the crop residues but changes in technology and environmental considerations have led increasingly to returning the crop residues to the soil. Data presented in this paper from a survey of commercial cotton farms has shown that cropping has resulted in a marked decline in both total carbon (C_T) and labile carbon (C_L) with the greatest decline in C_L. Changes in C_T and C_L in a cropped soil, relative to an uncropped reference soil, have been successfully used to calculate a Carbon Management Index (CMI) and this has been used to indicate the rate of change of the soil C status of sugar cane and cotton cropping systems. In a farming systems experiment, the inclusion of wheat in the cotton rotation was found to result in an increase in C_T, C_L, and in CMI. Sugar cane cropping also resulted in a marked decline in C_T, C_L, and CMI. Green trash management and no-till farming are two management options that can be used to reverse the decline in soil C status in sugar cane cropping systems. Measurement of soil C by mild oxidation with $KMnO_4$ has been shown to be related to active C pools in the soil. Changes in soil aggregate stability as a result of changes in soil C status are important. Regression analyses have shown that C_L is more closely related to aggregate stability than other measures of soil C.

SUGAR CANE production is a major agricultural enterprise on the tropical coast of Queensland, Australia. The sugar industry was first established in the 1800s by opening up land which was under forest or natural grass. As the industry has developed, new land, often of low quality, has been brought into production. Better varieties, better agronomy, and, in some cases, water management have led to increased yields. Concurrently, high labour costs and timeliness of harvesting have led to the introduction of mechanical harvesting. These changes have generally increased the quantity of crop residues and created options for their management.

In contrast to the sugar industry, the cotton industry in Australia is a new industry. The first commercial cotton was produced in the Gwydir Valley of NSW in the 1960s. Lack of adapted varieties, poor pest and disease management strategies and inadequate control of water resulted in lint yields of below 2500 kg/ha. Subsequently, improvements in the industry have approximately doubled these yields and because of a lack of machinery able to handle the cotton stalks after harvest, they were most commonly burnt. With the introduction of genetically-engineered cotton, and the appreciation of soil structural decline, there has been a marked increase in incorporation of cotton stalks and trash into the soil.

Crop residue burning has long been used as a method of residue management and as the major method of crop residue disposal in many countries (Tanaka 1978). Annual burning of residues not only reduces soil organic matter (SOM), but can also reduce microbial activity and, consequently, lead to the immobilisation of applied N (Boerner 1982). Rasmussen et al. (1980) indicated that repeated burning decreased microbial SOM and microbial activity and Biederbeck et al. (1980) recorded a decline of 95% in the fungal population and 70% in the bacterial population in the burnt treatments at one location.

Modern sugar cane harvesting equipment returns the green cane tops to the field after harvest and, in Australia, this has largely replaced the traditional

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practice of burning the cane before harvest. Similarly, machinery has been developed to chop and incorporate cotton stalks after harvest. These changed practices will lead to marked changes in the flux of carbon and nutrients in the cropping systems

Materials and Methods

Soil sampling

Soil samples were collected from a range of cotton and sugar cane experiments and from commercial cotton farms in eastern Australia. The samples were air dried and then broken down into aggregates by rolling on a board with 4 mm side plates.

Determination of total and labile carbon

Finely ground soil samples (<0.5 mm) containing approximately 350 µg C were weighed into tin cups and analysed for total C (C_T) in an automatic nitrogen and carbon analyser mass spectrometer system (ANCA-MS). The labile carbon (C_L) was determined by the method described by Blair et al. (1995).

The measurements of C_L, C_{NL} and C_T, made on the soil samples of interest, are used in combination with similar data from a soil of an uncropped reference area to calculate a Carbon Management Index (CMI), as a measure of the relative sustainability of different agricultural systems (Blair et al. 1995).

Measurement of aggregate stability

A sample of soil was broken down to pass through a 4 mm sieve and wetted under a tension of 25 mm on a sand pad before being immersed in distilled water and sieved through a nest of five sieves of 2000, 1000, 500, 250, 125 µm size with a diameter of 100 mm. Mean weight diameter (MWD) was calculated by the formula MWD = $\sum x_i w_i$ where x_i is the mean diameter of any particular size range of aggregates separated by sieving, and w_i is the weight of aggregates in that size range as a fraction of the total dry weight of soil used.

Results and Discussion

Changes in soil C pools as a result of cropping

Sugar cane soils

In a trash management experiment at Tully, Queensland, green trash management has resulted in substantial differences in C pools compared to burning (Table 1). Sugar cane cropping has resulted in a decline in C_T in the 0–1 cm soil layer but an increase in the 1–25 cm layer compared to the uncultivated reference soil (Table 1). The method of trash management has markedly affected C_L in the 0–1 cm zone with the concentration in the green trash treatment being over 4 times that in the burnt treatment. There were no differences between treatments in the 1–25 cm soil layer. The lability of C (L) in the surface soil of the green trash treatment was some 1.7 times that in the reference soil and the burnt cane treatment. These changes in C_T and C_L are reflected in LI, CPI and hence CMI with significantly higher values in the green trash than the burnt treatment in the 0–1 cm soil layer and no significant differences between treatments in the 1–25 cm layer.

When the data in Table 1 are converted from a concentration of soil C to a mass of soil C, the differences between the management treatments become more apparent. The difficulty of such a conversion is the measurement of soil bulk density. These measurements were not made in the samples taken from the Tully experiment so assumed bulk densities have been used. Because of the identical soil cultivation practices used in the green trash and burning treatments, it has been assumed that the bulk density

Table 1. Carbon dynamics in a sugar cane cropping soil at Tully, Queensland, as affected by cane trash management. (Blair et al. 1998)

Sample	C_T	C_L	C_{NL}	L	LI	CPI	CMI
		mg/g					
			0–1 cm				
Reference	45.4	5.6	39.8	0.14	1.00	1.00	100
Green Trash	37.4a^A	7.1a	30.3a	0.24a	1.70a	0.82a	137a
Burnt	13.6b	1.6b	12.1b	0.14b	0.97b	0.30c	28bc
			1–25 cm				
Reference	9.0	0.7	8.3	0.09	1.00	1.00	100
Green Trash	12.1b	0.9b	11.2b	0.08c	0.92b	0.74b	65b
Burnt	10.9b	1.0b	9.9b	0.10c	1.17b	0.66b	80b

^{A} Numbers within a parameter followed by the same letter are not significantly different at $p<0.05$ according to DMRT.

does not vary between treatments, but that it varies with depth (1.2 g/cc for 0–1 cm and 1.4 g/cc for 1–25 cm depth).

Cultivation, irrespective of trash management treatment, resulted in a reduction of C_T present in the 0–1 cm soil layer (Table 2). Conversely, the mass of C_T present in the 1–25 cm layer was higher where sugar cane had been grown than in the reference site. This resulted in an overall higher mass of soil C in the 0–25 cm layer in the cropped than in the reference site. Of this total, a greater amount of C derived from C4 plants (sugar cane) was present at both depths in the green trash treatment than in the burnt treatment.

Table 2. The effect of management of sugar cane trash at Tully, Queensland, on soil C.

Depth (cm)	Treatment	C_T (t/ha)	C derived from C4 plants (t/ha)	C_L (t/ha)
0–1	Reference	5.45	0	0.67
	Green trash	4.49	3.49	0.85
	Burnt	1.63	0.78	1.45
1–25	Reference	30.24	0	2.35
	Green trash	40.66	26.02	3.02
	Burnt	36.62	16.85	3.36
0–25	Reference	35.69	0	3.02
	Green trash	45.14	29.51	3.88
	Burnt	38.26	17.63	4.81

In contrast to C_T, there is a higher amount of C_L in the cropped treatment at each depth than in the reference soil. There was a higher amount of C_L in the burnt than in the green trash treatment at each depth.

In a trash management experiment being conducted at the Bureau of Sugar Experiment Stations at Mackay, Queensland, the no-till treatment had significantly higher C_T and C_L than the cultivated treatment in the 0 to 10 cm soil layer. These changes resulted in a significantly higher CMI in the no till compared to the cultivated treatment (Table 3).

Table 3. Effect of cultivation on C fractions in the 0–10 cm soil layer of soil in a sugar cane trash management experiment at Mackay, Queensland (Blair 1998).

	No–till	Cultivated
C_T (mg/g)	12.46a^{A}	10.22b
CPI	0.37a	0.31b
C_L(mg/g)	1.99a	1.68b
C_{NL}(mg/g)	10.47a	8.54b
L	0.2a	0.2a
LI	0.98a	0.99a
CMI	35.4a	29.9b

[A] Numbers within a parameter followed by the same letter are not significantly different at $p < 0.05$ according to DMRT.

In another trash management experiment being conducted at Ayr, Queensland, the C_T concentration in the cropped soils was again lower than in the uncropped reference soil. The loss of C_T from the 0–25 cm soil layer, assuming a bulk density of 1.2 g/cc, amounted to 27.5 t/ha and 25.9 t/ha in the green trash and burnt treatments, respectively. This equates to a loss of 46.6% and 43.9% of soil C. Cane burning resulted in the lowest C_T but the difference between this and the green trash treatment was only significant in the 0–1 cm layer. A similar result was found with C_L.

Cotton soils

Soils from a series of cotton experiments and from commercial cotton farms in Eastern Australia have been studied. In a survey of the effect of cotton cropping on soil chemical and physical fertility, 14 uncropped (reference) and 22 cropped soils were collected from a wide variety of soil types ranging from red brown earths with low clay contents (20%) to heavy cracking clay soils (68% clay). The 22 cropped soils had an average of 56% lower C_L concentration and 41% lower C_T concentration than their corresponding reference soil. Syers and Craswell (1995) suggested such a decline was due to increases in decomposition rate by shattering of macro-aggregates, mixing of surface soil and increases in the intensity and number of wetting and drying cycles. Cropping has caused the labile carbon to decline more than total carbon which is similar to the findings of Blair et al. (1995).

In an experiment conducted at Warren in New South Wales on a Vertisol soil (Entic Chromustert), a series of seven rotations containing cotton are included in a farming systems experiment. The experiment commenced in 1993 and the results of soil analyses on samples collected after 2 years are shown in Table 4.

A significant increase in C_L was recorded in the CFP rotation, a significant increase in C_T in the CWLLF rotation and significant increases in both C_T and C_L in the three rotations which included wheat (Table 4). These increases in C_L resulted in significant increases in CMI.

The effects of cotton stalk management were examined in an experiment conducted over three years at the Australian Cotton Research Institute, Narrabri. Samples were collected in 1991 and again in 1994 and were analysed for C_T, C_L $^{13}\delta C$, N_T, light fraction carbon and polysaccharides. The experiment consisted of a split-plot with residue management as the main plot and nitrogen as the sub-plot. Results are shown in Table 5.

Table 4. Changes in C under 2 years of different cotton rotations at Warren, NSW. Original C concentration 1993 CT = 6.15 mg/g, CL = 0.84 mg/g. (Conteh 1998).

Rotation	ΔC_T(mg/g)	ΔC_L(mg/g)	ΔCMI
Continuous Cotton (CC)	0.11	0.02	3
Cotton-long fallow (CLF)	–0.45	–0.07	–9
Cotton-field peas (CFP)	0.33	0.14*[C]	18*
Cotton — low input wheat[A] (CWlo)	1.61**	0.20*	23**
Cotton — high input wheat[B] (CWhi)	0.84*	0.14*	17*
Cotton-wheat-lablab (CWLL)	1.12**	0.20*	24**
Cotton-wheat-lablab-fertiliser (CWLLF)	1.00*	0.07	8

[A] 40 kg seed/ha, 17 kg N/ha, [B] 106 kg seed/ha, 120 kg N/ha

[C]* Change significant at $p<0.05$%, ** Change significant at $p<0.01$%

Table 5. Trash Management Effects on N, C and polysaccharides in a cotton experiment conducted at Narrabri, NSW, Australia (Conteh 1998).

Trash management		N_T	C_T	C_L	Polysaccharides (mg C/g)	
		%	---------- mg/g	----------	Total	Labile
Retained	1991	1.09a[A]	10.05 b	1.13 b	1.28 b	0.11 b.
	1994	1.11a	11.11 a	1.67 a	1.66 a	0.14 a
Burnt	1991	1.07a	9.67 b	1.07 b	1.24 b	0.10 b
	1994	1.09a	10.08 b	1.01 b	1.20 b	0.10 b
Retained	Change	+0.02 m[B]	+1.06 m	+0.54 m	+0.38 m	+0.03 m
Burnt	Change	+0.02 m	+0.41 n	–0.06 n	–0.04 n	0.00 n

[A] Numbers within a column for each year followed by the same letter are not significantly different at $p<0.05$ according to DMRT.

[B] Numbers within a column for change data followed by the same letter are not significantly different at $p<0.05$ according to DMRT.

There was no significant change in N_T over the three-year period in either the trash retained or trash burnt treatment. Both C_T and C_L increased significantly through time in the trash retained treatment but not in the trash burnt treatment. In addition to these changes in carbon, a significant increase in total and labile polysaccharides was measured in the trash retained treatment and again no significant change occurred in the trash burnt treatment. The changes in both C_T and C_L resulted in significant changes in the CPI and LI resulting in marked differences in the CMI at the end of the experiment. In the trash-retained treatment, the CMI increased to 141 and, by contrast, declined to 94 in the burnt treatment.

Distribution and Losses of Carbon Fractions in Different Aggregate Sizes

The loss of organic carbon from soil aggregates has been reported by Conteh et al. (1998) (Table 6). This study showed that both C_T and C_L concentrations were higher in smaller aggregates (<250 μm) than in the larger aggregates (>250 μm). Baldock et al. (1989) similarly showed that both organic carbon and carbohydrate contents increased with decreasing aggregate size. These findings contrast with those of Gupta and Germida (1988) and Elliott et al. (1991) who found no clear trend in carbon concentration between aggregate size fractions and Haynes and Swift (1990) and Camberdella and Elliott (1993) who found that organic carbon content decreased with decreasing size of aggregates.

The relative losses of both C_T and C_L due to cultivation are higher in the larger aggregates than in the smaller aggregates. These differences in rates of loss of C_T and C_L between aggregate sizes suggest a higher degree of protection of the organic matter in the smaller aggregates than in the larger aggregates. This can be seen from the fact that even though the labile carbon content increases as aggregate size decreases, losses of both C_T and C_L decrease as aggregate size decreases. This agrees with the conclusion of Skjemstad et al. (1996) that the major mechanism responsible for the relative stability of organic matter in soil is a physical association with the inorganic components, rather than an inherent chemical or biochemical inertness.

Table 6. Average concentration (mg/g) and relative losses of carbon in micro- (<250 mm) and macro- (>250 mm) aggregates in five soils from cotton growing areas of Queensland and New South Wales, Australia.

Cropping history	Aggregate size			
	<250 μm		>250 μm	
	C_T	C_L	C_T	C_L
Reference (mg C/g)	22.0	4.3	19.3	3.7
Cropped (mg C/g)	12.4	1.8	10.0	1.2
% loss	43.6	58.1	48.1	67.6

From the results of this study, it appears that the mechanisms responsible for the loss of organic carbon in soil are first a change in chemical structure, the breakdown of which can be inhibited by physical protection. The results obtained in this study also agree with the report of Elliott (1986) who fractionated soil organic matter into decomposable and recalcitrant fractions on the basis of its location within aggregates of different sizes. He demonstrated that organic matter associated with macro-aggregates (>250 μm) was more readily mineralised than that associated with micro-aggregates (<250 μm) and was the primary source of nutrients lost during cultivation.

Relationship Between Measured Carbon Fractions and Other Measures of Soil C

Conteh et al. (1998) has examined the relationship between carbon measured by $KMnO_4$ oxidation (C_L) and more traditional measures of soil carbon (Table 7). Neither C_L or C_{NL} were found to be related to humic acid. By contrast, C_L correlated strongly to fulvic acid whereas C_{NL} was more related to the humic fraction. Both C_L and C_{NL} were related to total polysaccharides but only C_L was related to the labile polysaccharides. C_L was also related to microbial carbon whereas C_{NL} was not.

Table 7. Relationship (r^2) between CL CNL and other measures of soil C (Conteh et al. 1998).

Component	C_L	C_{NL}
Humic acid (HA)	0.19	0.02
Fulvic acid (FA)	0.91**	0.56
Humin	0.54	0.96**
Microbial biomass C	0.59*	0.45
Total polysaccharides	0.71*	0.63*
Labile polysaccharides	0.84**.	0.40
Non-labile polysaccharides	0.68*	0.64*

* Change significant at $p<0.05\%$
** Change significant at $p<0.01\%$

An indication of the size of various C pools in a grey clay soil from the Gwydir Valley in northwest NSW, Australia, is shown in Table 8. The concentration of C_L is some 10 times that of the microbial biomass in this soil. Although the concentration of C_L and total polysaccharides are similar in this soil, this condition does not occur frequently.

Table 8. Size of a range of C pools in the 0–20 cm horizon a grey clay soil from the Gwydir Valley in NSW, Australia. (Conteh 1998).

Component	Uncropped	Cropped
C_T (mg/g)	22.4	9.4
C_L (mg/g)	3.6	1.3
Humic acid (mg C/g)	2.7	1.9
Fulvic acid (mg C/g)	8.4	4.0
Total polysaccharides (mg C/g)	3.0	1.2
Labile polysaccharides (mg C/g)	0.25	0.10
Light fraction (mg/g)	15.1	6.9
Light fraction –C (mgC/g)	6.9	1.1
Light fraction –C_L (mgC)	2.5	0.2
Microbial biomass (mg/g)	0.23	0.12

Relationship Between Carbon Pools and Aggregate Stability

Blair et al. (1997) has examined the relationship between various carbon pools and aggregate stability. In a survey of soils from the cotton growing areas of eastern Australia, they found that C_L was more closely related to mean weight diameter of aggregates following tension wetting than was C_T (Table 9) in soils with <52% clay. No significant relationships were found between aggregate stability and C_{NL}, less labile C ($C_{LL} = C_{Walkley\text{-}Black} - C_L$) or intractable C ($C_I = C_T - C_{LL}$). When soils with >52% clay were included in the relationship, no correlations were found, presumably because that in high clay soils, materials such as calcium are more important in binding aggregates than organic compounds.

Table 9. Linear relationships (Y = a+bX) between aggregate stability (Y), expressed as mean weight diameter (MWD) measured following tension wetting, and C fractions (X) in 20 soils collected throughout the cotton growing areas of eastern Australia (Blair et al. 1997).

X	r^2
C_L	0.61 **
C_T	0.46 *
C_{NL}	0.41 ns
C_{LL}	0.43 ns
C_I	0.05 ns

* Change significant at $p<0.05\%$
** Change significant at $p<0.01\%$

Research and Extension Needs

There is a need to conduct a systematic survey of the C status of sugar cane growing soils, in much the same way as has been done for cotton. This will inform the industry of the consequences of different management practices on soil C and provide information on ways to rehabilitate soil C concentrations through agronomic practices.

The farming systems experiments commenced by the Cooperative Research Centre for Sustainable Cotton Production need to continue to provide long-term data on the effects of rotations on soil chemical and physical fertility.

The inclusion of a labile C test and the derivation of a CMI should become a standard part of a routine soil testing procedure in both the cotton and sugar cane industries. This will allow producers to track changes in soil C status in the same way as they do for plant nutrients.

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Soil Fertility Decline in Lao PDR and the Potential of Pre-Rice Green Manures to Improve the Sustainability of Rice Production Systems

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Abstract

Rice is the staple diet in Laos and accounts for 98% of the land area farmed in the wet season. The loss of soil fertility due to unsustainable farming practices results in poor yields and inefficient nutrient use. Surveys in Champasak province of southern Laos revealed the low use of inorganic fertilisers, some recycling of on-farm organic materials and losses of 19–78% in labile C (C_L) and 38–87% of total C (C_T). The use of *Sesbania rostrata* has been proposed as a possible pre-rice legume crop which can tolerate flooded conditions and provide a source of N to a subsequent rice crop. Field trials in the Champasak and Savannakhet provinces of Laos have shown the importance of the application of P fertiliser on both the growth of *S. rostrata* and rice yields. Total biomass of *S. rostrata* was maximised at 4.88 t/ha with the application of 19.4 kg P/ha at the Savannakhet site. This increased rice yield from 1.1 t/ha with no P applied to *S. rostrata* to 3.0 t/ha. The application of 12.9 kg of P/ha to *S. rostrata* resulted in a significantly higher rice grain yield of 2.63 t/ha than the same application to rice grown with no previous *S. rostrata* crop which had a grain yield of 1.9 t/ha. Total P uptake in grain increased from 1.31 kg/ha where no P was applied to 7.10 kg/ha where 12.9 kg P/ha was applied to both the *S. rostrata* and the rice phases. A number of other pre-rice green manure legumes were evaluated during 1991–1997. During some years, yields were high, while in other seasons the crops failed. On the basis of both yield and the least variation between years, *Sesbania aculeata* and *Aeschynomene afraspera* were the most promising green manure species in Vientiane Province.

RICE IS THE SINGLE most important crop in the Lao PDR. The area planted to rice in 1998 approximated 650 000 ha and wet season rice cultivation accounted for about 98% of the rice area and more than 97% of the production. Rice yields in the rainfed lowland environment are reported in the range 2–3 t/ha. However, individual yields can be as low as 1 t/ha. Approximately 85% of the rainfed lowland rice area is in the central and southern agricultural regions, mainly in those provinces adjacent to the Mekong River. Seven major rice producing plains are recognised—Vientiane Plain (Vientiane Province and Vientiane Municipality), Borikhamxay, Sebang-Faay (Khammouane and Savannakhet), Sebang-Hiang (Savannakhet Province), Sedone (Saravane Province), Champasak and Attapu. The topography of this area is comprised mainly of a system of ancient low-level terraces with an elevation of about 200 m above sea level. These plains are the focus of the Lao government's efforts to raise the level of rice self-sufficiency.

Rainfall in most provinces along the Mekong River Valley ranges from about 1500 to 2200 mm, with about 75% being received in the period May to October. Alfisols, Acrisols, Cambisols, Luvisols and Arenosols are the soils throughout much of the rice producing area adjacent to the Mekong River and these are derived mainly from old alluvial deposits and, in some provinces (Saravane and Savannakhet), sandstone materials. They are usually highly

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weathered, moderately acid, loams, sandy loams and loamy sands. They typically have a topsoil sand content exceeding 65% (and occasionally more than 80%), and a clay content sometimes as little as 5%. Low organic matter content, low CEC and low percentage base saturation are usual. Their low water retention capacity makes them very drought prone. Recent research within the National Rice Research Program has shown many of them to be acutely deficient in P and N, but capable of giving substantial yield improvements with appropriate nutrient inputs. Parts of the Champasak and Khammouane provinces have shown responses to K.

Apart from family labour, inputs into the system in many areas are minimal. Organic fertiliser, in the form of farmyard manure (FYM), is usually applied to seedbed rice. Despite the generally infertile soils, and demonstrated high potential yield responses to combined inputs of P and N throughout much of the area, application rates of both organic and inorganic fertiliser in transplanted rice are low. For households using inorganic fertilisers, application rates generally do not exceed about 10–15 kg/ha N and 6–8 kg/ha P and often the rates applied are insufficient to give any meaningful yield response. Currently, the cost of inorganic fertilisers is often beyond the means of the average cash poor farmer in Laos and alternative forms of improving soil fertility are being evaluated.

The use of green manures such as *S. rostrata* have been investigated by many workers for their potential to supply nitrogen and soil organic matter to a rice system. Previous work from Thailand has indicated the potential increase in green manure biomass production when small applications of nutrients, especially P, are made. Experiments were conducted at three sites in Laos to evaluate the benefits of P application to *S. rostrata* and to a subsequent rice crop.

Materials and Methods

Farm survey

A survey of farmers in the Phonethong district of the Champasak Province was undertaken during mid-March 1997. This survey was undertaken in five villages in a transect from Pakse to the Chongmek border crossing in the Phonethong district. The farmers surveyed were previously chosen by staff of the Phone Ngam Research and Seed Multiplication Center on the basis of being representative farmers of the area. Each farmer was asked a series of questions regarding farming practices, crop yields, fertiliser and residue management practices. Soil samples were collected from areas of the farm; some samples were collected near to the house, where crop yields were generally higher, while other paddies further from the house, which were more representative of the entire farm, were also sampled. Soil from an uncultivated area was also collected and used as the reference soil.

S. rostrata studies

The purpose of these studies was to determine (1) the responsiveness of *S. rostrata* to P and (2) the effect of P applications to *S. rostrata* on the following rice crop. Similar experiments were conducted in three provinces: Vientiane, Savannakhet, and Champasak. The eight treatments applied are given in Table 2. *S. rostrata* was incorporated between 60 and 65 days after sowing. Nitrogen (30 kg/ha as urea) was applied to rice in all treatments 45 DAT.

S. rostrata biomass yield measurements were taken before incorporation and rice grain yields at maturity. However, all samples were not saved for nutrient analysis; therefore, it was not possible to develop a complete nutrient budget for each site. In Champasak, the *S. rostrata* was analysed but not the rice. In Savannakhet, only the rice samples taken at maturity were analysed. No samples were analysed from the Vientiane site.

Soil samples were collected prior to land preparation, at 55 days after planting *S. rostrata* and after the rice harvest. Soil samples were analysed for available phosphorus (Colwell 1965) and carbon. Total carbon (C_T) was measured in an automatic nitrogen and carbon analyser mass spectrometer system (ANCA-MS), consisting of a Dumas-type dynamic flash catalytic combustion sample preparation system (Carlo Erba NA1500), with the evolved gases separated and analysed by mass spectrometry (Europa Scientific Tracermass Stable Isotope Analyser). The more labile soil organic carbon (C_L) was measured by oxidation with 333 mM $KMnO_4$ (Blair et al. 1995). A Carbon Management Index (CMI) was calculated from changes in C_T and C_L relative to the C_T and C_L values obtained from the soil samples collected prior to land preparation (Blair et al. 1995).

The potential of other pre-rice green manure crops

These studies have evaluated a number of green manure (GM) crops for early wet season pre-rice cultivation and measured the benefits to the following rice crop through the input of organic N. The experiments were conducted at the National Agricultural Research Center (NARC) in Vientiane Municipality and at the Phone Ngam Research and Seed Multiplication Center in Champasak province. Due to seedling establishment problems, yields of the green manures grown at the Champasak sites were very low so only the data from the Vientiane site are reported here.

Results and Discussion

Farm surveys and identification of soil samples for the data in Table 1

The following is a summary of the information collected during the farm survey.

Site 1: Phonesung Village GPS position 15°.07.146 N 105°38.885E

Farm size: 3.1 ha.

Area cleared for at least 280 years.

Labour: 4 adults.

Supports 12 people.

Yields:

1996 5.4 t/3.1 ha 1.7 t/ha;
1995 5.0 t/3.1 ha 1.6 t/ha;
1994 4.2 t/3.1 ha 1.4 t/ha.

Only local variety of rice grown.

Residue management: Rice straw is grazed by buffalo and no straw is left by the next season. Buffalo move to the forest when all feed has been eaten.

Fertiliser management: Some organic fertiliser is applied to approximately one third of the farm, although most is applied to the nursery.

Constraints to production: Drought and flood 1996, insects, hoppers, mites.

General comments: Raising cows produces more revenue than growing rice. If supplied with credit, a farmer would purchase cows. He could only grow GM or a cash crop if irrigation were available.

Soil samples: 1A–close to house where some organic manure is applied;
1B-normal paddy soil.

Site 2: Nong Hao Kok Village GPS 15°.08.645N 105° 36.820E Elevation 110 m.

Farm size: 4.5 ha, 2.5 ha farmed only.

Area cleared for at least 200 years.

Labour: 6 adults.

Supports 2 families (11 people).

Yields:

1996 3.5 t/2.5 ha 1.4 t/ha;
1995 3.5 t/2.5 ha 1.4 t/ha;
1994 2.2 t/2.5 ha 0.9 t/ha.

Rice is predominantly grown, half local variety and half improved (RD6 and RD8).

Some vegetables, beans, chilli, and cucumber are also grown.

Residue management: Rice straw is grazed by buffalo but some straw is left by the next season.

Fertiliser management: 100 kg of 16:20:0 (N:P:K) applied over the 2.5 ha in 1995 and 1996. Dung from 1 buffalo applied to seedbed.

Constraints to production: Soil fertility, generally not drought or flood.

General comments: If the farmer had more money, he would buy fertiliser. He would attempt planting Sesbania or other tree type legumes, e.g. Sieow or Acacia.

Soil samples: 2A–close to house where some organic manure is applied,
2B–normal paddy soil.

Table 1. Carbon fractions, total N and available S for soils collected during the survey.

Sample	C_L	C_{NL}	C_T	CMI	N_T	Available P	Available S
		mg/g			%	µg/g	
Reference	1.33	10.07	11.40	100	0.109	6.85	3.3
1A	0.56	4.74	5.30	41	0.051	4.7	3.9
1B	0.61	2.09	2.70	52	0.026	0.8	0.5
2A	1.08	5.92	7.00	85	0.067	0.8	3.9
2B	0.66	4.94	5.60	50	0.054	0.0	1.6
3A	0.58	3.22	3.80	46	0.036	2.6	2.2
3B	1.08	10.82	11.90	79	0.113	11.4	3.0
4A	0.69	2.71	3.40	58	0.032	5.2	1.1
4B	0.67	3.43	4.10	53	0.039	3.6	1.3
5A	0.73	3.07	3.80	60	0.036	4.0	3.4
5B	0.29	1.11	1.40	25	0.014	3.9	2.9
Mean A	0.83	5.45	6.28	65	0.060	5.2	3.1
Mean B	0.56	2.96	3.52	45	0.033	2.2	1.7

Available P — Colwell (1965). Available S (KCl-40S) — Blair et al. (1991).

Site 3: Navieng Village GPS 15°.09.364N 105° 34.685E Elevation 90 m.

Farm size: 3.4 ha.

Area cleared for at least 100 years.

Labour: Supports 3 families (15 people).

Yields:

1996 4.3 t/3.42 ha 1.3 t/ha;
1995 7.2 t/3.42 ha 2.1 t/ha;
1994 7.2 t/3.42 ha 2.1 t/ha.

Local rice varieties are predominantly grown. A mixture of early, and late maturing varieties are grown to compensate for erratic rainfall. Early maturing varieties are grown on higher terraces. Cash crops are grown for consumption by the family.

Residue management: Rice straw is grazed by his 10 buffalo which are tied up in one paddy each day. Some straw is left by the next season. He needs more buffalo manure to improve fertility.

Fertiliser management: Applies fertiliser to areas of the paddy which have the poorest growth. Buys 2 × 50 kg bags of fertiliser each year (16:20:0) (US$8/bag). Buffalo tied up in the paddy and dung left there. By the time he cultivates next season, dung is very hard to plough in.

Constraints to production: Soil fertility is the greatest constraint. Also drought at transplanting, erratic rainfall and weeds were also cited as problems.

General comments: If the farmer had access to credit, he would buy a pump for irrigation, grow vegetables and have more livestock.

Soil samples: 3A–more than 100 years of cultivation;
3B-soil recently cleared and cultivated for 1 season.

Site 4: Vang Thao Village GPS 15°.08.227N 105° 30.159E Elevation 104 m.

Farm size: 7.6 ha.

Labour: 6 people.

Supports 3 families (16 people).

Yields:

1996 6.0 t/7.6 ha 0.79 t/ha;
1995 6.0 t/7.6 ha 0.79 t/ha;
1994 6.0 t/7.6 ha 0.79 t/ha.

Early maturing local rice and RD6 are predominately grown.

Residue management: Rice straw is grazed by buffalo but very little straw is left by the next season. Buffalo are tethered at night, limiting dung transfer to the paddy.

Fertiliser management: 100 kg of chemical fertiliser applied to the seedbed.

Constraints to production: Soil fertility, lack of labour, drought at transplanting

General comments: Seeding 25 × 25 cm seed spacing, 5–6 plants/hill. Would plant cash crop or GM but labour is a big constraint.

Samples: 4A–Close to house where there are good yields;
4B–further away from the house where there are poor yields.

Site 5: KM 12 Village GPS 15°.05.571N 105° 40.474E Elevation 65 m.

Farm size: 4 ha.

Labour: 6 people.

Supports 9 people.

Farmed for more than 100 years.

Yields:

1996 3.6 t/4 ha 0.9 t/ha;
1995 4.8 t/4 ha 1.2 t/ha;
1994 3.0 t/4 ha 0.8 t/ha
(Gall Midge infestation).

Early maturing local rice variety and RD6 are predominantly grown.

Residue management: Rice straw is grazed by buffalo but very little straw is left by the next season.

Fertiliser management: Some chemical fertiliser use.

1996 3 bags of 16:20:0 over 4 ha, 1995 2 × 50 kg bags of 16:20:0 over 4 ha.

Constraints to production: Soil fertility, drought, especially at the end of the season, and insects.

General comments: Some potential for GM. The idea of growing Acacia sounded interesting to the farmer. There is insufficent water after rice to grow crops and any cash crops grown are used for the family.

Soil samples: 5A–Close to house where there are good yields;
5B–further away from the house, representative of farm.

The survey results show the lower concentration of soil N and C, available P and available S present in the soils that have been cleared and cropped compared to the forest reference site (Table 1). The data also show the differences in soil C and nutrient status within the farms. In all the parameters measured, there is a lower soil concentration in the areas distant from the house than those near the house which receive additional inputs of organic wastes etc. Using critical levels of 35 μg/g for available P and 6.5 μg/g for available S, it can be seen how deficient these farms are in these two nutrients.

The general features of the farms surveyed are the low rice yields, cash and labour limitations and the importance of animals for manure. On those farms where inorganic fertiliser is used, it is applied at extremely low rates. The average application rates used on the three farms where inorganic fertiliser was used amounted to only 5.7 kg N/ha and 7.1 kg P/ha. The data collected suggest that the opportunities for growing green manure crops before or after rice would be limited by unfavorable moisture conditions, interference from animals, the need to grow supplementary food crops and labour shortages. Given these limitation of growing green manure crops in situ, the next likely senario would be to grow leguminous trees in a lot where they could be protected from unsupervised grazing. If this were done, it is likely that the herbage produced would be fed to ruminant animals to supplement the poor diet that they have. In the long term, this would benefit rice production through the production of better quality manure, better animals that could be used to prepare the land better for sowing, to generate cash to purchase inorganic fertiliser and to provide fuelwood.

S. rostrata studies

Vientiane, Phonehong district

S. rostrata biomass yields were lower in the Vientiane site than at the other two sites (Table 2). The highest yields were 1.29 t/ha in the treatment which received 25.8 kg P/ha. There was a linear response of *S. rostrata* biomass dry weight to P input, suggesting that higher P inputs may have resulted in greater yields.

Rice yields were all below 2.8 t/ha. While there are some statistically significant results, the results were not consistent. Based on the comparison of treatments 1 and 6, rice did not respond to P presumably because of the overriding N deficiency This is in contrast to the *S. rostrata* which demonstrated a clear response to P, presumably because of the supply on N through fixation.

Table 2. Phosphate fertilisation effects on *S. rostrata* (GM) biomass dry weight and subsequent rice yields (14% moisture) in Vientiane, Savannakhet and Champasak provinces during the 1996 wet season.

	P applied to		Vientiane		Savannakhet		Champasak	
	S. rostrata	Rice	*S. rostrata*	Rice	*S. rostrata*	Rice	*S. rostrata*	Rice
	(kg P/ha)		t/ha					
1	0	0	0.40	2.04 b[A]	0.32	1.11 d	1.10	1.80 bc
2	6.5	0	0.61	2.32 ab	2.64	2.50 b	2.32	2.21 abc
3	12.9	0	1.15	2.79 a	3.91	2.63 ab	2.19	2.44 ab
4	19.4	0	0.90	2.43 ab	4.88	2.99 a	2.83	2.67 a
5	25.8	0	1.29	2.62 a	3.92	2.72 ab	3.49	2.62 a
6	0	12.9	0.57	2.32 ab	0.31	1.90 c	0.71	1.63 c
7	6.5	12.9	0.69	2.66 a	1.97	2.90 a	2.27	2.20 abc
8	12.9	12.9	0.93	2.34 ab	3.04	2.74 ab	2.79	2.23 abc

[A] Means followed by the same letter within columns are not significantly different according to DMRT at $P \leq 0.05$.

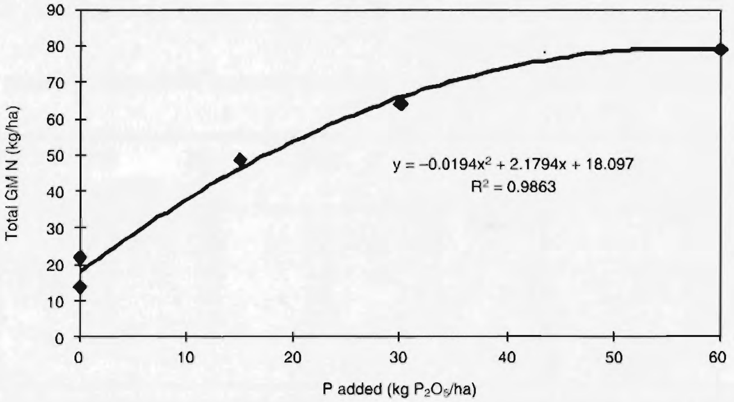

Figure 1. Total N in *S. rostrata* in relation to the amount of P fertiliser added calculated from treatments 1, 5, 6, 7 and 8.

Champasak Phonethong district

S. rostrata biomass yields demonstrated a linear response to P within the range of P rates examined (Table 3). Dry weight biomass production increased from 0.71 t/ha in the control to 3.49 t/ha with the addition of 25.8 kg P/ha. Nitrogen inputs in the biomass increased with increasing P inputs (Figure 1). Total *S. rostrata* biomass N increased by approximately 50 kg N/ha with the addition of 25.8 kg P/ha.

Rice did not respond to fertiliser P applications made directly to the rice in contrast to *S. rostrata*. However, there was a significant rice yield response to increasing P inputs to the *S. rostrata*, most likely due to increased N-fixation by *S. rostrata* (Figure 1).

Savannakhet, Champhone district

S. rostrata dry weight biomass yields increased from 0.31 t/ha with no P applied to 4.88 t/ha with the application of 19.4 kg P/ha (Table 2). There was no further increase from the addition of 25.8 kg P/ha.

When no P was applied to either the *S. rostrata* or rice, rice yields were 1.11 t/ha. Additions of 12.9 kg P/ha to rice when 6.5 kg P/ha or less was added to *S. rostrata* (treatments 6 and 7) resulted in a significant increase in rice yields. Rice yields were 0.73 t/ha greater when 12.9 kg P/ha was applied to the GM rather than to the rice. This increase in rice yield is most likely due to improved N nutrition in rice resulting from greater N-fixation by *S. rostrata* rather than improved P nutrition in the rice since total rice P uptake between the two treatments was almost identical, averaging 5.28 kg P/ha. This provides good evidence that at least some of the P applied to the GM crop is available to the following rice crop.

Other potential green manure crops

From 1991 to 1993, the potential of *S. rostrata*, Sun hemp (*Crotalaria juncea*), mung bean (*Vigna radiata*), blackbean, and cowpea (*Vigna unguiculata*) was assessed. The studies continued in 1994 through 1997 but *C. juncea* and *V. unguiculata* were replaced by two other potential GM crops, *S. aculeata* and *Aeschynomene afraspera*.

In 1997, the final year of the study, climatic conditions were favorable for all legumes, although early season drought limited their productivity. Legume biomass GM ranged from 1.2 t/ha (*S. rostrata*) to 2.5 t/ha (*S. aculeta*), although these differences were not statistically significant due to high variability in the experiment (Table 3). Average GM dry weight biomass was 1.8 t/ha.

Between 1991 and 1993, *C. juncea* and *V. unguiculata* performed poorly under saturated soil conditions and these were replaced with *S. aculeata* and *A. afrespera*. Of the two grain legumes which were kept in the experiment (on account of being more tolerant of saturated soil conditions), black bean generally performed better than mung bean. Relative to *S. rostrata*, black bean performed better than *S. rostrata* in all years except 1992 and 1994. In 1994, both grain legumes did poorly due to saturated soil conditions. *A. aferaspera* was included in the experiment in 1994 as it is reported to have a similar yield potential to *S. rostrata* as well as being less likely to act as a host for the *Meloidogyne graminicola*, the root-knot nematode of rice. In 1994, *A. aferaspera* performed poorly due to poor stand establishment and 1994 should not be used as a basis for evaluating it. Between 1995 and 1997, *A. aferaspera* and *S. aculeata* performed as well or better than *S. rostrata* and are suited to saturated soil conditions.

Nitrogen inputs varied from year to year and were dependent on biomass production and biomass N concentration. Average GM yields for all years were 2.3 t/ha and assuming a N concentration of 3.3% this represents an N input of approximately 76 kg N/ha. Rice yields were usually higher following a GM crop. Yields in these and other experiments suggest that GM in this environment provides N equivalent to 30 to 60 kg N/ha. Therefore, GM N is generally

Table 3. Dry matter yield (t/ha) of various green manures grown in Vientiane Municipality between 1991 and 1997 wet seasons.

	1991	1992	1993	1994	1995	1996	1997	Means	Standard deviation
S. aculeata				3.7	1.8	3.1	2.5	2.9	0.8
A. afraspera				0.7	1.8	6.6	1.8	3.0	2.6
S. rostrata	1.8	2.4	4.9	0.7	2.3	3.7	1.3	2.6	1.4
C. juncea	1.7	4.3	2.4	2.3	1.7	2.8	1.2	2.5	1.0
Cowpea	1.2	1.6	2.7	0.9	2.9	4.4	2.2	2.3	1.2
V. radiata	2.6	0.2	3.5					2.1	1.7
Black bean	0.9	0.6	1.2					0.9	0.3

NOTE: Dry weights for 1991 and 1992 were calculated using the average moisture concentration of each green manure from 1993 to 1997. Rainfall for the months of May and June are given above the corresponding year.

insufficient to meet the total N requirement of rice and it has been found in other GM studies that rice yields are further increased if 30 kg N/ha fertiliser N is applied at 50 DAT.

Conclusions

In all the parameters measured in the survey, there was a lower soil C and nutrient status in the areas distant from the house than those near the house which receive additional inputs of organic wastes etc. Using critical levels of 35 µg/g for available P and 6.5 µg/g for available S, it can be seen how deficient these farms are in these two nutrients.

In the *S. rostrata* study, the yield varied widely between sites with the lowest yield being recorded in Vientiane (up to 1.29 t/ha) and the highest in Savannakhet (4.88 t/ha). At each site there was a clear response of *S. rostrata* to P fertiliser additions with the greatest response being in Savannakhet. The P requirement for optimal *S. rostrata* productivity was greater than 25.8 kg P/ha in Vientiane and Champasak and 19.4 kg P/ha in Savannakhet. Nitrogen analysis of *S. rostrata* tissue from the Champasak site demonstrated that improving the P nutrition of the GM increased N-fixation and total biomass N, thereby improving the N nutrition for the following rice crop.

In all cases, rice yields were below 3 t/ha. In the Vientiane and Champasak provinces rice productivity was not limited by P fertility. This is in stark contrast to the response of *S. rostrata* to improved P fertility and demonstrates that GMs are much more susceptible to P deficiencies than rice. It was not possible to determine whether or not P applied to the *S. rostrata* was available to the following rice crop at these sites since only yield data were available and there was not a rice yield response to P. At the Savannakhet site, where P was limiting to rice, nutrient analysis of the rice crop provided strong evidence that P applied to a GM is available to the subsequent rice crop.

At the Savannakhet site, rice P uptake ranged from 1.74 to 10.19 kg P/ha. This represents approximately 29% of the fertiliser P applied to each treatment and highlights the need to understand the long-term fate and residual benefits of applied P.

The adoption of *S. rostrata* as a green manure crop by farmers has been limited for several reasons. The planting density for dense stands of *S. rostrata* is high and requires large quantities of seed. In addition, the uncertainty of wet season opening rains makes planting risky. Green manure crops require extra labour for planting, weeding and incorporation of large amounts of biomass. The use of green manure technologies is most likely suitable to specific areas where labour is available, and P is less limiting.

Research Recommendations

1. Evaluation of pre and post rice legume crop areas most suited to those technologies.
2. Evaluation of the potential of on-farm residue recycling, e.g. not burning rice straw, incorporation of straw and husk, efficient use of manure and household wastes.
3. Evaluate slow breakdown leaf and organic material for improving soil organic matter and rice yields, e.g. the Ubon study with locally grow trees on bunds.
4. Further investigation of the effects of green manure management on soil organic matter, i.e. setting up of an on-station long-term residue management experiment.
5. Working with farming systems groups to diversify farm production, i.e. not growing rice alone, but other crops such as forage, cash crops, trees. These studies need to address the problem of fencing.
6. Enough technical data exist on the use of *S. rostrata* as a green manure, i.e. P requirement, residual value, N fixation. If on-farm use is to be achieved, then a farming systems approach to solve the problems of seed production, biomass incorporation and adoption by farmers is needed.

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Sesbania rostrata as a Green Manure and Phosphorus Management for Lowland Rice Production in Lao PDR

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Abstract

The use of *Sesbania rostrata* has been proposed as a possible pre-rice legume crop which can tolerate flooded conditions and provide a source of N to a subsequent rice crop. The primary objective of this experiment was to identify the role of pre-rice green manure *S. rostrata* in supplying nutrients to the following rice crop and also their effect on longer term soil fertility. As available P can be very low in these soils, the optimal P requirement of *S. rostrata* and its residual value to rice was determined over three seasons. The experiment was conducted in Champone district of Savannakhet Province (SVK) and in Phonethong district of Champasak Province (CMK), Southern Laos, during 1997 and 1998. Both soils had less that 10% clay to 40 cm and were predominantly of sandy loam texture. At both sites, there was a significant *S. rostrata* biomass yield response to P which reached a maximum at a P application rate of 19.4 kg P/ha. There was a strong linear relationship between rice yield and the amount of N returned in the *S. rostrata* (slope 0.93 kg grain/kg N at CMK and 45 kg grain/kg N at SVK). Such high slopes suggest N is not solely responsible for this increase in yield. The rice yield at the SVK site responded significantly to P applications during the rice phase, while at the CMK site there was no response. The efficiency of P recovery decreased from about 120 kg grain/kg P when P was applied only to the *S. rostrata* crop or in a split to the *S. rostrata* and rice crop to less than 77 kg grain/kg P when only applied to the rice crop. The yield of rice was highly correlated with the time since the last P application. A linear relationship was determined which predicts a yield decline of 69 kg grain/month since P was last applied. Applying fertiliser P in smaller regular applications, rather than large infrequent applications was found to stabilise yield and increase the efficiency of P use.

RICE IS THE SINGLE most important crop in the Lao PDR, accounting for more than 88% of the cropped land area. Rainfed lowland cultivation accounts for about 70% of the total rice area and in 1997, 78% of production. National policy aims at achieving a greater level of rice self-sufficiency by the year 2000, by increasing the productivity of the rainfed lowland environment to account for approximately 90% of total production. Rice yields in the rainfed lowland environment are reported in the range 2–3 t/ha. However, yields as low as 1 t/ha are not uncommon.

Lao government policy is to encourage the use of organic fertiliser inputs in all rice-growing environments. This reflects recognition of the limited purchasing power of the smallholders, and a desire to restrict fertiliser imports that involve the use of limited foreign exchange.

The use of *Sesbania rostrata* has been proposed as a possible pre-rice legume crop which can tolerate flooded conditions and provide a source of N to a subsequent rice crop. Field trials reported by Lathvilyavong et al. (1998) showed that the application of P to *S. rostrata* was essential for adequate biomass and N production.

In the lowland rainfed environments, crop residues are potentially an important source of carbon and nutrients which are, in many cases, poorly managed. During harvest, grain and panicle straw is removed to a central position for threshing.

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Depending on the rice variety and farmer practice, panicle straw may represent 40–60% of the total straw produced. The rice straw remaining in the paddy is an important food source for buffalo during the following dry season. Some is grazed in situ in the paddy, and some rice straw is put in hay sheds or haystacks and fed to animals throughout the year.

The practice of burning rice stubble is quite common and straw may be burned in the field or wherever straw or rice hulls are piled. A common explanation for straw being burnt in the paddies is the accidental starting of fires due to people smoking cigarettes, or fires that spread from neighbouring areas. By the end of the dry season, little plant cover remains in the paddies and the buffalo manure is very dry and prone to losses through wind or floating away when the rains come.

The primary objective of this experiment was to identify the role of pre-rice green manure *S. rostrata* in supplying nutrients to the following rice crop and also their effect on longer term soil fertility. As available P can be very low in these soils, the optimal P requirement of *S. rostrata* and its residual value to rice was determined over a number of seasons.

Materials and Methods

The experiment was conducted in Champone district of Savannakhet Province (SVK) and in Phonethong district of Champasak Province (CMK), Southern Laos, during 1997 and 1998. Both soils had less that 10% clay to 40 cm and were predominantly of sandy loam texture (Table 1). At CMK, more than 74% of the sand was fine sand while at the SVK site, there was a mixture of fine and coarse sand fractions. The pH was acid, becoming slightly more alkaline at depth and the cation exchange capacity (CEC) was low.

The experiments were initiated in 1997 with the planting of *S. rostrata* with different rates of P applied (Table 2). The effect of *S. rostrata* as a green manure was assessed by growing a wet season (WS) rice crop immediately following this phase. Additional treatments (6–10) were also included to assess the effect of the timing of P application on this rice phase and P recycling. A dry season (DS) rice crop was grown at SVK only in the 1997–1998 season with irrigation, and a fresh application of P was applied to Treatments 1 and 9 to determine the residual value of the initial P fertiliser applied. These treatments were applied to a wet season rice crop grown at CMK during the 1998

Table 1. Initial soil properties at the Savannakhet and Champasak experimental sites.

Site	Depth (cm)	pH (H_2O)	CEC (cmol/g)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
SVK	0–10	5.4	3.8	49	33	12	7
	10–20	5.6	3.4	47	36	10	7
	20–40	6.1	5.4	45	40	7	8
CMP	0–10	5.4	3.3	6	83	6	5
	10–20	5.6	3.4	7	77	8	9
	20–40	6.0	3.5	5	74	12	10

Table 2. The P applications (kg P/ha), as triple superphosphate, to the Savannakhet and Champasak experiments during 1997 and 1998.

Treatment No.	Both sites		SVK DS 1997–98	CMK WS 1998	SVK WS 1998
	GM	Rice	Rice	Rice	Rice
1	0	0	12.9	12.9	12.9
2	6.5	0	0	0	0
3	12.9	0	0	0	12.9
4	19.4	0	0	0	6.5
5	25.8	0	0	0	0
6	0	12.9	0	0	12.9
7	0	25.8	0	0	0
8	6.5	6.5	0	0	12.9
9	12.9	12.9	0	0	0
10	6.5	6.5	12.9	12.9	0

wet season. In the 1998 wet season at SVK, P was added to the treatments to make the final P additions over the whole experiment to 25.8 kg P, excluding the control treatment.

The experiment was arranged as a randomised complete block design with 10 treatments and 3 replications (30 plots). Plot size was 4 × 5 m and bunds (25 cm wide × 25 cm tall) separated each plot. Land preparation was done using a buffalo and a single-tyned plough. P as triple superphosphate (Table 2) and the seeds of *S. rostrata* (50 kg/ha) were uniformly broadcast onto all plots and soil was raked over. At 55 days after sowing, the *S. rostrata* was sub-sampled, cut to ground level, weighed and incorporated into each plot.

Following incorporation, the soil was prepared for transplanting by raking soil to break up clods. P fertiliser was applied to treatments 6, 7, 8, 9 and 10. A basal application of 30 kg K/ha as KCl was applied to all plots and 25-day-old rice seedlings (RD10 at SVK and TDK1 at CMK) were transplanted into all plots at 3 plants/hill at 20 × 20 cm spacing. Any missing hills were replaced 7 days after treatment (DAT). To control insect pests, Furidan was applied at 25 and 45 DAT at a rate of 33 kg/ha to all treatments. At 35 DAT, 30 kg N/ha as urea was topdressed onto all plots.

At maturity, 10 representative hills from each plot were selected, cut at ground level and collected for analyses. After removing border rows, the remainder of the plot was harvested by hand. During harvest, the rice is generally cut at approximately 30 cm above the soil surface (depending on the variety), bundled and removed for threshing. The grain and panicle straw were then separated by threshing and weighed.

In the 1997–1998 dry season (SVK only) and the 1998 wet season (SVK and CMK), P was applied at transplanting according to Table 2 and 25-day-old seedlings of RD10 were transplanted into all plots. An application of 20 kg N/ha and 23 kg S/ha as ammonium sulfate ($(NH_4)_2SO_4$), 30 kg K/ha as KCl was made to all plots prior to transplanting and 30 kg N/ha as urea was topdressed to all plots at 35 and 50 DAT. The mature rice crop was sub-sampled and harvested as in the 1997 wet season experiment.

Soil samples were collected before land preparation, at 55 days after planting *S. rostrata* and after the rice harvest and analysed for available phosphorus (Colwell 1965) and carbon. Total carbon (C_T) was measured in an automatic nitrogen and carbon analyser mass spectrometer system (ANCA-MS), consisting of a Dumas-type dynamic flash catalytic combustion sample preparation system (Carlo Erba NA1500), with the evolved gases separated and analysed by mass spectrometry (Europa Scientific Tracermass Stable Isotope Analyser). The more labile soil organic carbon (C_L) in the whole soil samples and each particle size fraction was measured by oxidation with 333 mM $KMnO_4$ (Blair et al. 1995). A Carbon Management Index (CMI) was calculated from changes in C_T and C_L relative to the C_T and C_L values obtained from the soil samples collected prior to land preparation (Blair et al. 1995).

Subsamples of *S. rostrata*, rice grain and stubble were dried at 40 °C and ground to <2 mm. An ARL3560 Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) was used to measure phosphorus (P), sulfur (S), and potassium (K) and other macro and micro-nutrients after the plant material had been prepared using the sealed container digest procedure of Anderson and Henderson (1986). Total nitrogen (N) in the plant material was determined using an autoanalyser following a sulfuric acid/perchloric digestion procedure.

The apparent recovery of P was calculated by:

Apparent recovery of P = (Total P content of grain + straw in treatment – Total P content of grain + straw in control)/(Total fertiliser P applied).

The P balance at the beginning of the season was calculated by the difference between fertiliser P applied and P removed in grain and panicle straw.

Results and Discussion

Response of *S. rostrata* to P

Due to exceptionally dry seasonal conditions and slow germination, total biomass production of the *S. rostrata* was generally less than 1600 kg/ha (Figure 1), which is somewhat lower than reported elsewhere in the region (Lao-IRRI 1997). At both sites, there was a significant *S. rostrata* biomass yield response to P which reached a maximum at a P application rate of 19.4 kg P/ha. At the CMK site, biomass production was almost 400 kg/ha even where no P was applied.

At SVK, the N content of the aboveground biomass of *S. rostrata* increased as biomass production increased from 1.3 kg N/ha where no P fertiliser was applied to 30 kg N/ha at the higher P application rates. At CMK, N content of the biomass ranged from 7 to 36 kg N/ha at the zero and maximum P application rates respectively.

The 1997 rice crop wet season

There was a strong linear relationship between rice yield and the amount of N returned in the *S. rostrata*. This was especially so at the CMK site ($R^2 = 0.83$). The rice yield is clearly responding to the N inputs from N fixation in the green manure phase (Figure 2). The response of rice yield to kg N applied

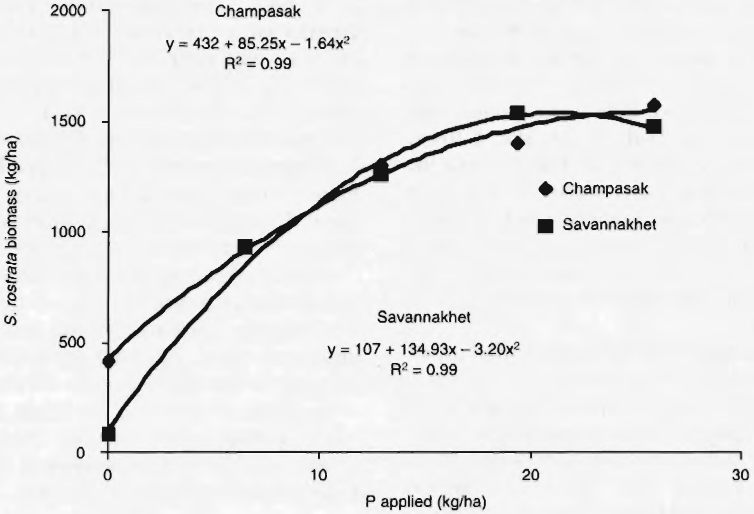

Figure 1. The yield response of *S. rostrata* to P applied at sowing.

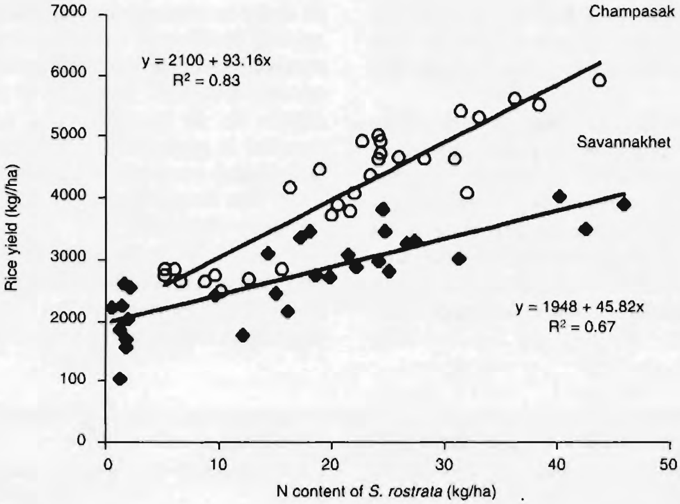

Figure 2. The relationship between grain yield and N content of the *S. rostrata* biomass.

far exceeds published values of approximately 20 kg grain/kg N applied as inorganic fertiliser. The most likely explanation is that the P applied to the *S. rostrata* is efficiently recycling through the green manure and is essentially a fresh P application. There may have also been the additional benefits to soil structure, but under a flooded rice paddy soil structure is relatively unimportant.

Although there was a yield response in rice to the N added in the *S. rostrata* at both sites the slope of the response function was lower as Savannakhet than at Champasak. More N would be expected to be lost by leaching from the coarser texture of the soil at Savannakhet than at Champasak and this is the most likely reason for the lower slope of the N response function at Savannakhet. The response of rice to P applications differed between sites, indicating a difference in inherent soil fertility at the sites.

At the SVK site, the yield of the rice on the control treatment, which received no P, was significantly lower than the treatments where P was only applied to the rice phase (Table 3). A split application of 12.9 kg P/ha to both the *S. rostrata* and rice phases resulted in rice grain yields equal to rice yields produced when 19.4 or 25.8 kg P/ha were applied only to the *S. rostrata* phase. At the CMK site, a lower split application rate of only 6.5 kg P/ha to both the *S. rostrata* and rice phases resulted in rice grain yields equal to the other treatments which received split application rates of 12.9 kg P/ha. The highest rice grain yield at the CMK site was achieved where 19.4 or 25.8 kg P/ha was applied only to the GM phase.

The apparent recovery of P followed a similar pattern for both treatments. The apparent recovery of P was significantly influenced by the timing of P fertiliser application (Table 3). A single application of P was more efficiently used when applied to the green manure phase or equally split and applied to the green manure and the rice phase. The highest recoveries were associated with these treatments at the CMK site and were the result of better rice yields and higher P uptake. The lowest apparent recoveries were found where 12.9 or 25.8 kg P/ha was applied to only the wet season rice phase (Table 3). The recoveries on these treatments were very similar for both sites.

P efficiency can also be calculated in terms of kg grain response/kg P applied. When P was applied to the GM or split equally between the GM and the rice the response in terms of grain yield/kg P applied was higher at CMK than SVK, presumably because of the better retention of N in the soil at this site. Extremely low grain responses/kg P applied were recorded at CMK when all of the P was applied to the rice crop.

At both sites, the highest grain response/kg P applied was when 6.5 kg P/ha was applied to the GM crop. At application rates of 12.9 or 25.8 kg P/ha, highest grain responses/kg P applied were when all of the P was applied to the GM crop or split equally between the GM crop and the rice (Table 3).

Apparent recovery of P = (Total P uptake in treatment – Total P uptake in control)/(Total P applied). Total P uptake calculated from total P uptake in grain + total P uptake in rice straw.

Available soil P measured after harvest showed that at the SVK site, fertiliser P application did not significantly increase soil P levels. Available P decreased from 7.8 µg/g at 0–10 cm to 5.0 and 3.5 µg/g in the 10–20 and 20–40 cm depths.

Available P levels at the CMK site were significantly higher where 25.8 kg P/ha was applied to *S. rostrata* (11 µg/g) compared to an average of 6 µg/g for all the other treatments.

The response of rice to P in the 1997/98 irrigated dry season rice crop at Savannakhet

In order to evaluate the residual value of previously applied fertiliser P, the yield of treatments which had received earlier P applications were compared to the treatment which received a fresh P application (Table 4). At the SVK site, a fresh P application resulted in grain yield significantly higher that those which had received the same P rate to an earlier crop. The longer the period since the P application, the lower the yield.

Due to a loss of a replicate at the CMK field site and large variation between the remaining two replicates, rice yields at the CMK site did not show significant responses to fresh P applications.

Table 3. The response of the 1997 wet season grain yield (kg/ha) and apparent recovery of P to applications of P (kg P/ha) to a pre-rice *S. rostrata* green manure crop and directly to rice at transplanting.

	Savannakhet (SVK)					Champasak (CMK)		
Treatment No.	P applied in 1996 (kg/ha)		Grain yield	Apparent recovery of P	kg grain/kg P applied	Grain yield	Apparent recovery of P	kg grain/kg P applied
	GM	Rice	(kg/ha)	(%)		(kg/ha)	(%)	
1	0	0	1440 d	—	—	2649 d	—	—
2	6.5	0	2207 c	31 a	118	4265 c	42 ab	249
3	12.9	0	2971 b	31 a	118	4519 bc	41 ab	145
8	6.5	6.5	2938 b	34 a	115	4629 abc	50 ab	152
10	6.5	6.5	3044 b	29 ab	123	4129 c	33 b	114
6	0	12.9	2298 c	17 bc	67	2682 d	12 c	3
4	19.4	0	3343 a	31 a	98	5310 ab	46 ab	137
5	25.8	0	3423 a	28 ab	77	5351 a	42 ab	105
9	12.9	12.9	3404 a	27 ab	76	4583 abc	32 b	75
7	0	25.8	2204 c	11 c	30	2811 d	12 c	6

Table 4. Grain yield in the 1997/98 dry season rice crop.

Time of P application			SVK
GM	Previous rice	Current rice	Rice (kg/ha)
0	0	12.9	3725 a
0	12.9	0	2972 b
12.9	0	0	2364 b

The P balance as determined by the removal of P in grain and panicle straw varied depending on the yield and P concentration of the previous WS crop. When all treatments, excluding the two treatments which received fresh P, were included in a regression analysis, a linear relationship between grain yield and P balance at transplanting was found (Figure 3).

The treatment which received a fresh application of 12.9 kg P/ha, and had received no previous P application, was highly P responsive and produced 924 kg grain more than predicted by the linear relationship. At low soil P levels, the rice crop is therefore highly responsive to fresh P applications. The treatment which had received a P application in the previous season and a fresh P application at transplanting, was much closer to the yield level predicted by the linear relationship derived in Figure 3. Therefore at higher soil P levels, a fresh application of P did not increase the availability of P or rice yields.

The 1998 wet season rice crop in Savannakhet

In the final rice phase during the wet season 1998, P was added to all the treatments, excluding the control, to make the final P additions over the whole experiment to 25.8 kg P. The yield of all treatments which received fresh applications of 12.9 kg P were significantly higher than the other treatments which received no P application or treatment which received a fresh application of only 6.5 kg P/ha (Table 5).

Available P measured after the wet season 1998 harvest was found to be significantly higher in the 0–10 cm depth on the treatments which had received the most recent application of P (Table 5). Available P levels were in the extremely low range (generally less than 2.5 µg/g) and declined with depth. Available P was <1.0 µg/g in the 10–20 and 20–40 cm depths. The critical value, or the soil test value where the application of P is likely to increase yield, used in Australia for Colwell P is 35 µg/g.

As in the two previous rice crops, grain yield was also highly correlated with the P balance at transplanting (Figure 4).

The yield of rice was highly correlated with the time since the last P application. A linear relationship was determined which predicts the yield based on the period since last P application (Figure 5).

If the same relationship was applied to the data in Table 4, a similar linear relationship (slope = –78.95 $R^2 = 0.89$) was calculated. These relationships are important for predicting the decline in the residual value of P.

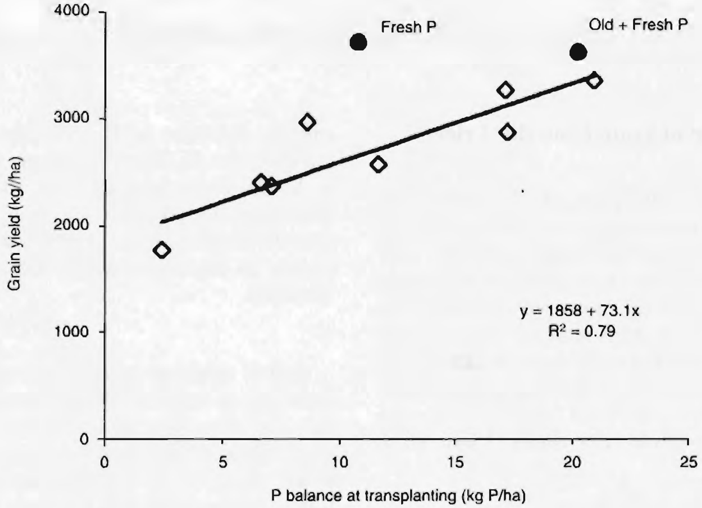

Figure 3. The relationship between P balance at transplanting and grain yield at final harvest, dry season 1997–98 in Savannakhet. (Fresh P treatments represented by closed circles and are not included in the regression analysis).

Table 5. Rice grain yield (kg/ha) in the 1998 wet season rice crop and available soil P (0–10 cm) after harvest at Savannakhet.

WS97	WS97	DS97/98	WS98	Grain yield	Available P (µg/g)
GM	Rice	Rice	Rice	WS98	0–10 cm
0	0	12.9	12.9	2581 a	2.4 a
6.5	0	0	0	988 c	1.0 bc
12.9	0	0	12.9	2578 a	2.1 a
19.4	0	0	6.5	2039 b	2.5 a
25.8	0	0	0	1703 b	1.0 bc
0	12.9	0	12.9	2661 a	1.5 ab
0	25.8	0	0	1797 b	2.2 a
6.5	6.5	0	12.9	2648 a	0.1 c
12.9	12.9	0	0	1703 b	0.0 c
6.5	6.5	12.9	0	1848 b	0.1 c

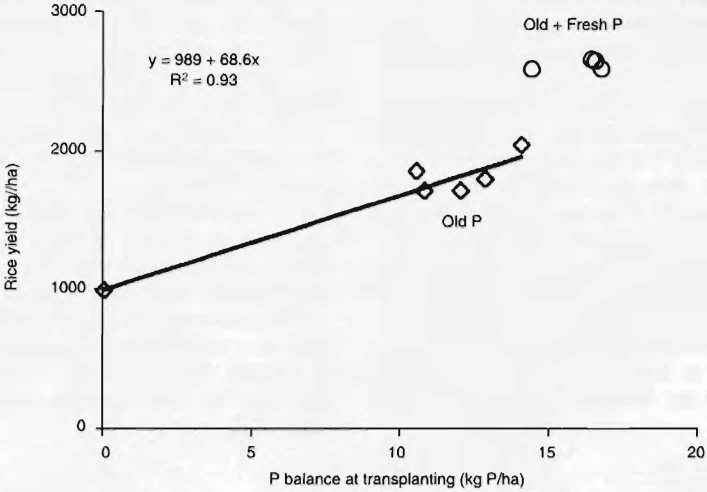

Figure 4. The relationship between P balance at transplanting and grain yield at final harvest in the wet season 1998 at Savannakhet.

The total production of grain from the 3 rice crops

By the final rice phase all treatments, excluding the control, had received the same total P application. The cummulative grain yield of all treatments was similar excluding the control treatment which was significantly lower (data not presented). The standard deviation across the 3 seasons indicates the variability of the yields between seasons. The most stable yields were produced in the treatments where the applications of P were split between seasons, rather than applied in single large doses (Table 6).

Soil carbon

Pre-trial soil samples taken at 3 intervals in the soil profile show the generally low level of C in this soil and the decrease in C down the profile (Table 7). Lability (L= C_L/C_{NL}), however, was slightly higher in the 20–40 cm layer than the 10–20 cm layer which may indicate possible leaching of labile C compounds. Naklang et al. (1999) also found increases in lability at depth in a sandy soil in nearby northeast Thailand.

Soil C analyses were performed on soil samples collected at intervals throughout the trial to investigate the dynamics of C and the possible influence that the green manure phase may have had on soil C levels. Analysis of soil samples (0–10 cm) collected following the 1997 WS rice crop (i.e. after the green manure and rice phase) showed a small but non significant increase in C_T and C_L. (Table 8).

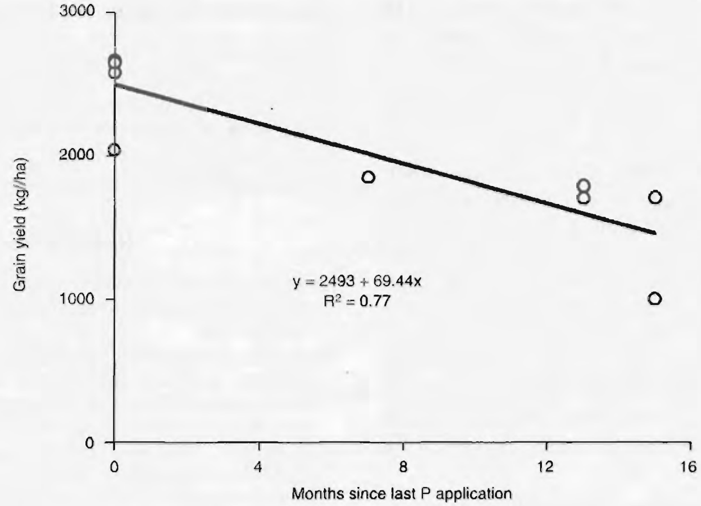

Figure 5. The rice as a function of the period since the last fertiliser P application. The regression analysis is based on all treatment data excluding the control and the treatment which received 6.5 kg/ha in the 1998 wet season.

Table 6. The total P applied, P removed, the P balance, the grain produced from 3 seasons of rice production and the standard deviation (SD).

WS 97 *S. rostrata*	WS 97 Rice	DS 97/98 Rice	WS 98 Rice	Total yield	Standard deviation
		kg P/ha			kg/ha
6.5	6.5	0	12.9	7989 a	268
0	0	12.9	12.9	7747 a	1142
25.8	0	0	0	8389 a	950

Table 7. The C content of pre-trial soil samples at 3 depths.

	C_T	C_{NL}	C_L	L
Depth		mg/g		
0–10	2.96	2.26	0.70	0.31
10–20	1.63	1.34	0.29	0.22
20–40	1.52	1.22	0.30	0.25

Table 8. C parameters following the 1997 wet season.

WS97	C_T	C_L	L	CMI
GM	mg/g			
0	3.52	0.77	0.29	108
6.5	3.55	0.80	0.29	113
12.9	3.84	0.85	0.29	119
19.4	3.29	0.73	0.29	103
25.8	4.42	0.86	0.25	117

The increases in soil C are not related to green manure management and do not reflect biomass inputs. They are, however, due to inputs of P across the experiment which improves rice yields. All straw that remained after harvest was incorporated during this trial and this, combined with the rice roots, increased soil C levels.

The range in C_T from 3.29 to 5.68 mg/g and in C_L from 0.60 to 1.24 mg/g measured after harvest in 1998 were related to the cummulative grain yield from all three seasons. The strongest relationship was found between C_T and the total grain yield ($R^2 = 0.71$) and C_L and total grain yield ($R^2 = 0.48$). At the low C levels in these soils, any increases in organic matter inputs such as rice stubble and roots has resulted in a detectable change in C.

Conclusions

S. rostrata can supply some of the N requirement for a following rice crop depending on the amount of biomass it produces. On P deficient soils the growth of *S. rostrata*, and similarly for many legumes, is highly dependent on adequate P fertiliser application. The P requirement for adequate growth of the green manure often exceeds the rice requirement for P. Fertiliser P applied to a green manure phase is more efficiently used by the following rice crop than when P is applied directly to the rice. Fertiliser P in this experiment was found to be most efficiently used if applied to a GM or in split applications. The likely mechanisms involved in improving P use efficiency are a combination of the improvement in soil physical conditions and the re-release of P and N in an available form from the highly decomposable *S. rostrata* residues. Significant management problems will likely limit the adoption of this technology by farmers as experienced in other neighbouring countries

Knowledge of the residual value of P is an important management tool when making fertiliser decisions. The highest residual value of P is in the bag. Once applied some is lost, removed or transformed into various less available chemical forms. P which was recycled through the green manure plant was most efficiently used due to the additional N provided through N fixation. Fresh P applications of P were found to increase rice yield when compared to similar or higher amounts already present in the soil from earlier applications. Applications of P on each crop is better than larger infrequent applications decreases risk and stabilises yields.

Future research needs for P management in Laos

Longer term residual P studies needed in key areas of Laos on soil types representative of the main cropping areas. Investigation of the availability of phosphate rock in Laos or neighbouring countries is needed. If significant reserves exist, the agronomic effectiveness should be determined.

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The Potential of On-farm Residues for Improving Rainfed Lowland Rice Productivity in the Lao PDR

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Abstract

Rainfed lowland rice is grown on approximately 70% of the total rice area farmed in the Lao PDR. Lowland rice soils are generally highly weathered, sandy, and acid with low organic matter contents. The objectives of this paper are to discuss the impact of on-farm residues for improving N-use efficiency and for maintaining soil fertility in rainfed lowland rice systems. An experiment was conducted at two sites in the Lao PDR to measure the effect of on-farm residues (farmyard manure at 2.6 and 5.2 t/ha and rice husks at 1.3 t/ha) on urea-N-use efficiency. The yield response to 60 kg N/ha alone, averaged across both sites, was 1.2 t/ha. At both sites, application of residues alone increased rice yields by 0.2 to 0.9 t/ha. At one site, the benefit of N plus residue was additive (no significant interaction) while at the other site there was no response to the residue. Another experiment was conducted to improve green manure (GM) N-use efficiency using rice straw. In this study, two GM crops were used: *Sesbania rostrata* and *Aeschynomene afraspera*. The N-recovery efficiency (NRE) was lowest (29%) for *A. afraspera* without rice straw; however, with the addition of rice straw, NRE improved to 50%. The NRE for *S. rostrata* with or without straw was 45%. The difference in response to rice straw was most likely due to a lower C:N ratio in *A. afraspera*. While the initial benefits of applying on-farm residues may be small, the long-term effects on soil fertility maintenance can be significant. Approximately 80% to 90% of crop K, Ca, and Mn remain in the straw at harvest. Removal of large amounts of straw from the system could lead to deficiencies of these elements. The application of fertilisers containing only N and P will exacerbate this problem. In Lao PDR, straw is often grazed or fed to livestock. Although we would not advocate stopping this practice (livestock account for about 50% of cash income), we would suggest managing livestock and straw so that manure could be collected and used more efficiently. Further work in this area needs to be conducted at the farming-systems level.

RICE IS the single most important crop in the Lao PDR, with a 60% share of total agricultural production (UNDP 1998). Approximately 70% of the total rice area (646 000 ha) is in the rainfed lowland ecosystem. More than 80% of lowland rice is grown on six plains adjacent to the Mekong River. The remaining 20% is grown in valleys, primarily in the mountainous north.

Lowland rice soils on the six main plains are generally weathered and infertile: 80% have organic matter contents of less than 2%, 68% are coarse textured (sands, loamy sands, and sandy loams), and 87% have a pH of less than 5.5 (H_2O). In contrast, lowland rice soils in the mountainous regions are more fertile: 66% of the soils have organic matter contents of greater than 2%, 80% are loams or clay loams, and only 48% have a pH of less than 5.5.

Results from 37 on-farm NPK omission trials conducted throughout the Lao PDR indicate that N and P are the primary nutrients that limit rice productivity (Linquist et al. 1998). At 80% of the sites tested in the central and southern regions, there was a response to P, and P was the most limiting nutrient (no response to other nutrients unless P was applied first) at 30% of the sites. In the north, P deficiencies occurred at 33% of the sites. The response to inorganic fertilisers was generally

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favourable. On average, and relative to a no-fertiliser control the application of 60:13:17 kg/ha of NPK increased yields by 1.5 t/ha in the southern and central regions and by 0.8 t/ha in the north.

Maximising nutrient-use efficiency is imperative for farmers because of the high risk of crop failure or poor crop performance caused by drought or flooding in this environment. Data from Thailand indicate that, on some sandy soils, responses to inorganic fertilisers have been small to nonexistent without additions of organic amendments (Willet 1995; Ragland and Boonpuckdee 1988). In the Lao PDR there has normally been a relatively good response to inorganic fertiliser; however, it may be possible to improve the efficiency of inorganic fertilisers with the combined use of organic amendments. In this paper, results from several experiments conducted in the Lao PDR which examine the potential of on-farm residues to improve N-use efficiency, are presented and discussed. The role of on-farm residues in maintaining the soil nutrient balance will then be discussed.

Materials and Methods

Experiment 1

The objectives of this experiment were to quantify the effects of on-farm residues on rice productivity and to assess whether urea-N-use efficiency is improved when used in combination with residues. The experiment was conducted in Vientiane and Saravan provinces during the 1998 wet season. Soils at both sites were coarse textured and low in organic matter.

The experimental design was a split-plot with three replications. Main-plot treatments were 0 and 60 kg N/ha and the four subplots were residue treatments (none, farmyard manure (FYM at two rates), and rice husks). On a dry weight basis, the FYM was applied at 2.6 and 5.2 t/ha and rice husks at 1.3 t/ha. The source of residues was the same for both sites. Nitrogen fertiliser (urea) was applied in three equal splits: basal, active tillering, and panicle initiation. A basal application of P, K, and S was made to all plots at a rate of 13, 66, and 30 kg/ha using triple-superphosphate and potassium sulfate.

Bunds were made around each plot (3 × 6 m) following land preparation and just before transplanting. Basal fertilisers and residues were applied just before transplanting and incorporated with a hoe. Thirty-day-old rice seedlings (TDK-1, a medium-maturing glutinous variety) were transplanted at a hill spacing of 20 × 20 cm and 4 to 6 seedlings per hill. Grain weight was determined at crop maturity and adjusted to 14% moisture.

Experiment 2

The objective of this experiment was to examine the effects of combining rice straw with green manure (GM) to improve GM-N-use efficiency. The experiment was conducted in Vientiane Municipality during the 1997 wet season on a deep sandy soil.

The experiment was a randomised complete block design with nine treatments replicated three times. There were five residue treatments: *Sesbania rostrata* and *Aeschynomene afraspera* (both with and without straw) and straw alone. In all straw treatments, straw was applied at a rate of 1.3 t/ha. The four remaining treatments were N rates ranging from 0 to 90 kg urea-N/ha, applied in three equal splits at transplanting and 35 and 55 days after transplanting.

The field was tilled in late April and bunds made around each plot (3 × 6 m). In the GM plots, a seedbed was prepared and *S. rostrata* and *A. afraspera* seeds were sown at a rate of 120 and 69 kg/ha, respectively, then P applied at a rate of 19 kg/ha. Both the seeds and P were raked into the surface soil. Because of low rainfall, rice transplanting was delayed so the GM crop was grown for 79 days rather than the recommended 55 to 60 days. At 79 days, 10 representative plants from each GM plot were sampled for determination of moisture content, dry weight, and nutrient content of above-ground biomass. In each GM plot, the GM was cut at ground level and fresh weight determined; it was then cut into 10 cm to 20 cm lengths and evenly distributed across the plot it originated from. Rice straw was added to the appropriate plots and all residues were incorporated.

One week after residue incorporation, 30-day-old seedlings (PN-1, an early maturing glutinous variety) were transplanted with hills at 20 × 20 cm spacing and three seedlings per hill. At maturity, rice yields were determined in each plot and a sample was taken for nutrient analysis.

Results

Experiment 1

In Vientiane, yields without N were 2.1 t/ha, but increased by 0.9 t/ha in response to 60 kg N/ha (Figure 1). The agronomic efficiency of applied N (AE = yield increase in response to N/N applied) was 15 kg/kg. There was a significant yield response to all residues in Vientiane. Averaged across both N levels, yield increased by 0.9, 0.6, and 0.4 t/ha in response to 5.2 and 2.6 t/ha of FYM and to rice husks, respectively (yield increase ranged from 15% to 35%). The interaction between N and residue

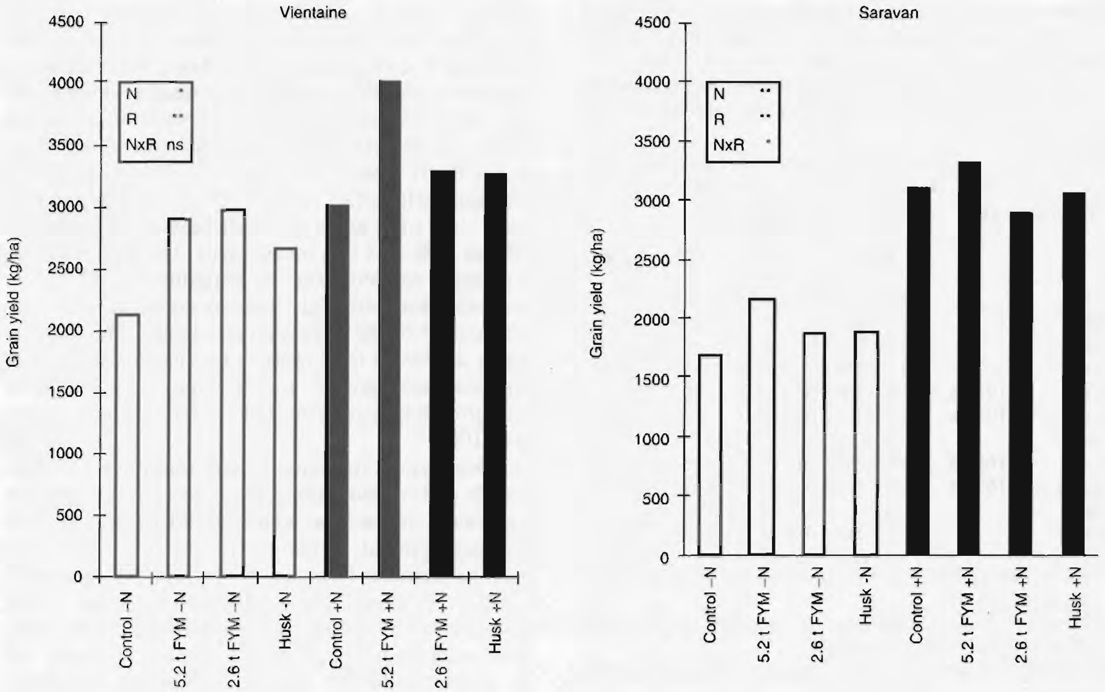

Figure 1. Rice grain yield response to the application of inorganic N (60 kg N/ha) and residue (rice husks and farmyard manure (FYM)). * and ** indicate a significant difference at P = 0.05 and 0.01, respectively.

treatment was not significant, suggesting that the application of residues did not improve N-use efficiency but rather the benefits from the residues were additive.

At the Saravan site, yields increased by 1.4 t/ha in response to urea-N alone (an AE of 23 kg grain/kg). There was a significant yield response to residues and the interaction between N and residue treatments was significant. In the treatments that did not receive N, yields increased by about 0.2 t/ha in response to rice husks and 2.6 t FYM/ha and by 0.5 t/ha in response to 5.2 t FYM/ha (an increase in yield of 12% to 28%). Where fertiliser N was added, there was no significant effect of residues on rice yields.

Experiment 2

Above-ground dry weight of *S. rostrata* and *A. afraspera* was 1.9 and 1.6 t/ha, respectively (Table 1). Lack of rain following seeding resulted in poor stand establishment and low biomass production despite a relatively long growing period of 79 days, but these yields are typical for the Lao PDR (Changphengsay et al., these Proceedings). The N concentration of *S. rostrata* (1.86%) was lower than that of *A. afraspera* (2.13%), but the total N contribution from each was about 35 kg N/ha.

The rice grain yield response to urea-N was linear for urea-N rates between 0 and 90 kg N/ha. Maximum yields of 3.7 t/ha were obtained in response to 90 kg urea-N/ha. The AE of urea-N averaged 27 kg/kg across all N rates. Nitrogen-recovery efficiency (NRE = (N uptake–N uptake in control)/N applied * 100) for urea-N averaged 37% across N rates.

Sesbania rostrata and *A. afraspera* alone increased rice yields by 1.3 and 0.6 t/ha, respectively, which was roughly equivalent to 30 to 60 kg urea-N/ha. Adding rice straw to *A. afraspera* increased rice yields by 0.7 t/ha but had no effect when applied to *S. rostrata*. The NRE of *S. rostrata*-N without straw was 46% compared with only 29% for *A. afraspera*-N. Adding rice straw to *A. afraspera*, however, increased the NRE of *A. afraspera*-N to 50% but had no effect on the NRE of *S. rostrata*-N. Applying straw alone increased yields by 0.45 t/ha, although this was not significant, and the NRE was over 100%.

Table 1. The effect of different organic N sources [*S. rostrata* (S.r.), *A. aferaspera* (A.a.), and rice straw] on rice yields (14% moisture), N uptake, N recovery efficiency, and agronomic efficiency. Within columns, means followed by the same letter do not differ significantly at the 0.05 probability level.

Treatment	GM yield	Total N Added	Rice yield	N uptake	NRE ++	AE +++
	kg/ha				%	kg/kg
0 N		0	1749 e	17.9		
30 N		30	2854 bc	30.0	40.4	36.8
60 N		60	3074 b	37.6	32.9	22.1
90 N		90	3664 a	51.6	37.4	21.3
S.r.	1916 a	35.6	3093 b	34.3	46.0	37.8
S.r. + straw+	1916 a	42.7	3017 b	37.0	44.6	29.7
A.a.	1626 a	34.6	2351 cd	27.8	28.6	17.4
A.a. + straw	1626 a	41.7	3029 b	38.7	49.9	30.7
Straw		7.1	2197 de	26.6	123.1	63.1

+ Straw was added at a rate of 1335 kg/ha to all straw treatments.

++ Nitrogen-recovery efficiency = increase in N uptake relative to the control/N applied.

+++ Agronomic efficiency of applied N = increase in yield relative to control/N applied.

Discussion

Immediate benefits of residues for rice productivity

Although all soils in these studies were coarse textured (sands, loamy sands, and sandy loams), the response to urea-N was good. The AE of urea-N ranged from 15 to 27 kg/kg and, where NRE estimates were possible, the NRE averaged 37%. Similarly, Linquist et al. (1998) reported that, with the application of 60 kg N/ha on average (22 sites in central and southern Lao PDR), yields increased by 1.2 t/ha, which corresponds to an AE of 20 kg/kg. These data are in contrast to those of Willet (1995) and Ragland and Boonpuckdee (1988), who reported that on some sandy soils in northeast Thailand there was no response to inorganic fertilisers without also applying organic amendments. One reason for this discrepancy may be the split applications of N that were used in these studies, although it is not clear from the northeast Thailand studies how the fertiliser was applied. On sandy soils, where N is highly susceptible to leaching and denitrification, splitting N applications has improved N-use efficiency (Prasad and De Datta 1979).

In all experiments, there was a yield benefit to applying residues alone. The yield response to rice husks was generally the lowest and averaged 0.37 t/ha across the two sites. Farmyard manure usually gave a slightly higher response (0.2 to 0.9 t/ha), although it was applied at two to four times the rate of the rice husks. The yield increase in response to residues alone, while small relative to the response to N, ranged from 17% to 34% (averaged 26%). These yield responses are higher than those reported by Supapoj et al. (1998) in northeast Thailand, where rice straw (6.25 to 18 t/ha) and rice husk (3.13 t/ha) applications increased rice yields by 10% to 15% (0.3 t/ha on average). The high NRE for rice straw applied alone in Experiment 2 (Table 1) suggests that, although these residues contain low amounts of N, the N is used efficiently. This may be partly attributed to slow N mineralisation as well as improved root growth and N acquisition. Improved root growth may have resulted in NRE values greater than 100%.

While yield responses were observed for both urea-N and residues alone, there was never a positive significant interaction, which would suggest that the residues resulted in more efficient N uptake. This may be because fertiliser N was applied as a split application. In the GM experiment, however, where GM-N is all added before transplanting, straw additions significantly improved the N recovery of *A. afraspera*-N but not *S. rostrata*-N. Similarly, Becker et al. (1994) reported that adding straw to GM residue slowed N mineralisation, reduced N losses, and improved N-use efficiency. The difference in results between the two green manures is most likely due to the higher C:N ratio of *S. rostrata*. In this study, *S. rostrata* biomass N concentration (1.86%) was lower than that of *A. afraspera* (2.13%), suggesting a higher C:N ratio. Becker et al. (1990) also found *S. rostrata* to have a higher C:N ratio than *A. afraspera*. The higher C:N ratio results in slower N mineralisation and an N supply that is more synchronous with crop demand.

Role of residues in maintaining the soil nutrient balance

Fertiliser use in the Lao PDR is low, especially in the rainfed environment where risk of drought and/or flooding is high. Results from a benchmark study conducted in southern Lao PDR, however, indicate that fertiliser use is increasing (Pandey and Sanamongkhoun 1998), as indicated by the statistic that 60% of fertiliser users have only been using fertiliser since 1995. The average application rate applied by fertiliser users was 19-8-1 kg/ha of N, P, and K, respectively. The low amount of K used reflects the limited availability (K made up only 4% of total fertiliser imports in 1996) and higher cost of K-containing fertilisers.

Currently in the Lao PDR, about half of the rice straw (depending on the variety and farmer) remains in the field following harvest. This stubble is most commonly grazed by livestock during the dry season, but it may also be burned. The panicle straw, which is removed with the grain, is moved to a central location, which depends on how the rice will be threshed. Large mechanical threshers mounted on trucks are becoming more common and, in such a case, the straw will be moved near the road. Following threshing, the straw will often be burned in the road ditch. If the panicles are to be hand threshed, the straw will be moved near the house and often the panicle straw will be stored for livestock feed. Rice husks are usually left at the rice mills, although some farmers apply rice husks to their fields. Husks may be burned before incorporation.

Straw accounts for approximately 50% of above-ground biomass and is probably the most abundant on-farm residue available. Rice husks account for about 20% of unmilled rice (Juliano and Bechtel 1985) or about 10% of above-ground biomass. Table 2 shows the percentage of some plant nutrients that remain in the straw at harvest. At least 50% of all the nutrients measured remain in the straw, with the exception of N, P, and Cu. Furthermore, 80% or more of crop K, Ca, and Mn remains in the straw at harvest. These data suggest that continual removal of rice straw could rapidly deplete soil nutrient reserves. To examine the effects of straw management on the soil N, P, and K balance, input and yield data from the Pandey and Sanamongkhoun (1998) benchmark study were used to develop a simple nutrient budget (Table 3). Straw management had little effect on the N and P balance because of the low concentration of these nutrients in straw. The positive P balance is due to the preferential use of 16-20-0 fertiliser by farmers. In contrast, straw management had a large effect on the soil K balance. Removing straw results in a K balance of −19 kg K/ha. With straw returned, however, the K was almost balanced (–4 kg K/ha). The exclusive use of N and P fertilisers, as is the common practice, will accelerate the decline in soil fertility, especially in these sandy soils with low nutrient reserves.

Table 2. Percentage of crop nutrients that remain in the straw at harvest.

Nutrient	N	P	S	K	Ca	Mg	Mn	Zn	Cu
Percent in straw	37	26	52	80	91	66	88	57	28

Data are the mean of three experiments (Experiment 2 of current study and the Champassak and Savannakhet experiments presented by Whitbread et al., these Proceedings).

While rice straw is important in maintaining the soil nutrient balance, it is also an important livestock feed during the dry season when little other forage is available. Livestock accounts for 46% of expendable cash income (Pandey and Sanamongkhoun 1998); therefore, the most valuable use of straw may be as livestock feed, the current practice of many farmers. Livestock are left to graze freely, however, and little effort is made to collect and use manure. Data from a farming systems study conducted in southern Lao PDR (Lao-IRRI 1995) indicate that only 11% of farmers used manure, with application rates varying between 35 and 1050 kg/ha and most of it being applied to nurseries.

Table 3. Calculated nutrient budget with and without the return of rice straw. Input and yield data are from a benchmark study conducted in southern Lao PDR (Pandey and Sanamongkhoun 1998). Data are only from farmers who reported using fertiliser. Yields at these input levels averaged 1500 kg/ha.

Nutrient	Inputs	Outputs	Nutrient balance (straw removed)	Nutrient balance (straw returned)
	kg/ha			
N	19.5	21.0	–2.5	+4.5
P	8.1	6.0	+2.1	+3.6
K	0.9	19.5	–18.6	–3.6

Assumptions: Grain concentration of N, P, and K is 1.0%, 0.3%, and 0.3%; straw concentration of N, P, and K is 0.4%, 0.1%, and 1.0%; harvest index is 0.5.

Table 4. Nutrient concentration of some on-farm residues.

Residue	N	P	K	S	Ca	Mg	Mn
	%	%	%	%	%	%	µg/g
Rice straw	0.4	0.05	1.0	0.09	0.38	0.17	814
Rice husks*	0.43–0.55	0.03–0.08	0.17–0.87	0.05	0.07–0.15	0.03	116–337
FYM**	0.5–1.0	0.12–0.17	0.22–0.26	na	na	na	na
Cattle dung**	0.35	0.11	0.09	na	na	na	na
Cattle urine**	0.80	0.02	0.26	na	na	na	na

* Juliano and Bechtel, 1985. ** Uexkull and Mutert, 1992. na = not available.

The average farmer has about five cows and/or buffalo (Lao-IRRI 1995). Assuming that each animal produces 1.5 t manure/year and that the farmer collects half of the manure (3.75 t), if this manure is evenly distributed over 1.5 ha, the application rate will be approximately 2.5 t/ha. Returning livestock dung to the field will have little effect on the K balance (2.5 t of manure contains about 2.3 kg K) because the K concentration is low (Table 4), but it may have a significant effect on the nutrient balance of other nutrients.

Summary and Conclusions

Improved and sustained rice productivity in cash-poor economies will require a balanced nutrient management program that includes the efficient use of inorganic fertilisers and recycling of on-farm residues. These data suggest that, at realistic residue application rates, grain yields can be increased by about 25%; however, moderate inorganic fertiliser applications can increase yields by 50% to 100%. The role of residue management in these systems will be to maintain the inherent soil fertility and return nutrients that are not available in commercially available fertilisers. Currently, farmers use primarily N- and P-containing fertilisers because K-containing fertilisers are either not available or are expensive and little on-farm residue is returned to the field. While such nutrient management practices may result in some short-term yield gains, there will be a net negative effect on soil nutrient balance, which will lower the sustainability of these systems. The situation is exacerbated by the fact that most soils are coarse textured and low in nutrient reserves. Because of the importance of livestock in these systems, in terms of generating cash and as a consumer and producer of on-farm residues, future research on residue management needs to be conducted at the farming-systems level.

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Use of Plant Residues to Sustain Soil Productivity in Rainfed Lowland Rice in Northeast Thailand

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Abstract

Two field experiments were established at the Ubon Rice Research Center on an infertile acid sandy soil (Aeric Paleaquult) of the Roi Et series to evaluate the impact of small annual applications of leaf litter, fertiliser inputs and post-harvest rice straw management on rice production, nutrient balances, and soil organic matter dynamics. The first experiment consisted of a complete factorial design with five leaf litter treatments (no leaf litter, *Cajanus cajan, Acacia auriculiformis, Samanea saman*, and *Phyllanthus taxodifolius*), two inorganic fertiliser rates (low, 25:7:7, and high, 50:14:14 kg NPK/ha, respectively), and two rice stubble managements (stubble removed and returned), with three replications. Thirty-day-old seedlings of rice (cv. KDML105) were grown. The results showed rice yields increased the most with the annual application of low rates (1500 kg/ha dry matter) of leaf litter from *Cajanus cajan, Phyllanthus taxodifolius, Acacia auriculiformis*, and *Samanae saman*. The six seasons of leaf litter application increased the total (C_T) and labile (C_L) carbon pool by 11% to 21% and 7% to 27% relative to a no-residue control, respectively. A carbon management index (CMI), which incorporates changes in labile and non-labile C (C_{NL}) pools, was found to be able to detect changes in soil C over the 6-year trial. In the second experiment, the experimental design and management is similar to that described for the first experiment. The treatment combinations included the three plant residue application (a no-residue control, *C. cajan, A. auriculiformis*) and two inorganic fertiliser rates (25, 16, 8 and 50, 16, 8 kg/ha of N, P and K) and two rice stubble managements (stubble removed and returned), with four replications. Soil samples were collected early in the wet season to determine the breakdown and possible leaching of C and N. The treatments intensively sampled were the ones on which fertiliser was applied and rice straw residues were retained. Soil samples were collected from T4, T5 and T6 (0, *C. cajan, A. auriculiformis*) at 0–10, 10–30 and 30–60 cm depth at three sampling dates. The results showed that leaching of C and N varied with the kind of plant residue added.

THAILAND is a major rice-growing country in which rice production in 1995–1996 was estimated at 22.02 million tonnes (Office of Agricultural Economics 1995). Among the four regions in Thailand, the northeast is the largest and covers about one-third of the total area of the country. The area of land used for rice production in the northeast is also the largest, at approximately 5.12 million hectares (OAE 1995), but average rice yields are the lowest of the country. Thailand's average rice grain yield is 2.2 t/ha, with an average of 1.7 t/ha in the northeast and 2.9 t/ha in the more fertile central region (OAE 1995). Infertile sandy soils and erratic rainfall are the major causes of lower yields.

The major problem with most of northeast Thailand's soil is low fertility. Soil samples down the profile to 10 cm were collected from adjacent cropped and uncropped areas in the southern part of northeast Thailand to assess the impact of long-term rice production on soil carbon (C) (ACIAR PN9448 1997). This survey revealed the large decline of 52%–85% of total soil C and 60%–83% of total soil nitrogen (N). It is clear that these changes in soil C and N after periods of cropping are associated with reduced soil fertility and low rice yields in this area.

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Soil organic matter (SOM) is considered a key factor in maintaining soil quality and is therefore crucial in determining long-term soil fertility (Wallace 1994). Much evidence indicates that the decline in crop yield with continued production in many temperate and tropical areas is correlated with declines in organic matter levels (Sanchez et al. 1987). Therefore, maintaining soil organic matter must be considered one of the goals of sustainable land management systems.

In the past, soil management to increase SOM has generally been approached via the use of green manuring and crop residue return. Application of green manure, e.g. *Sesbania rostrata*, *Aeschynomene afraspera* etc. often results in increases in crop yield. However, there was no evidence of long-term improvement of SOM and soil fertility (Herrera et al. 1989). Green manuring often produces short-term pulses of nutrients into the farming systems, resulting from extremely rapid release of C and nutrients due to the rapid breakdown of the added material. Conversely, lower quality crop residue (e.g. cereal straw) releases nutrients too slowly, and in insufficient quantities to meet microbial and crop requirements. As an alternative, the application of high quality residues which break down relatively slowly due to chemical and/or physical restrictions, could result in significant inputs of C, maintain other nutrients at suitable levels over longer periods and reduce soil nutrient losses.

To examine this hypothesis, and to assess whether the generally low rice yields and poor quality of some of northeast Thailand's soils could be improved despite the uncertain rainfall, a field experiment was conducted to investigate the impact that relatively small annual additions of organic material to a rainfed lowland rice system have on SOM and rice yields in one of the major soil types of northeast Thailand.

Material and Methods

The field experiment (R2 experiment) began in 1992 at the Ubon Rice Research Center on an infertile acid sandy soil (Aeric Paleaquult) of the Roi Et series. This field experiment was established to evaluate the impact of small annual applications of leaf litter, fertiliser inputs and post-harvest rice straw management on rice production, nutrient balances, and soil organic matter dynamics. The experiment consisted of a complete factorial design with five leaf litter treatments (no leaf litter, *C. cajan*, *A. auriculiformis*, *S. saman, and P. taxodifolius)*, two inorganic fertiliser rates (low, 25:7:7, and high, 50:14:14 kg NPK/ha, respectively), and two rice stubble managements (stubble removed and returned), with three replications.

The *A. auriculiformis*, *S. saman, and P. taxodifolius* leaves were collected from locally grown trees and dried prior to incorporation in the appropriate treatments. *C. cajan* was grown at the research station and prepared in the same way as the other leaf litters. All leaf litters and rice straw were subsampled and the decomposition rate determined using in vitro perfusion technique of Konboon et al. 1995.

Leaf litter was applied each year at 1500 kg dry weight/ha and incorporated one week before transplanting, except for *C. cajan* in 1992, which was applied at half the rate due to a shortage of material. Table 1 shows the annual average addition of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) in leaf litters. Thirty-day-old seedlings of rice (*Oryza sativa* cv. KDML105) were transplanted and P, K, and half of the N were applied at transplanting and the remainder of the N at panicle initiation.

Plants were harvested at maturity and plant samples taken for nutrient analyses. Soil samples were collected following harvest and were dried at 40 °C and ground for chemical analyses. Only results from the 0–10 cm layer are reported here.

Total C (C_T) and labile C (C_L) measurements

Sub-samples of the <2 mm sieved soil were taken and ground to <500 µm and the total C (C_T) measured in an ANCA-MS. The more labile soil organic carbon was measured by oxidation with 333 mM $KMnO_4$ (Blair et al. 1995) as described in Whitbread et al. (1999) in these Proceedings. The reference sample used was the soil collected from primary forest near to the experimental sites.

Table 1. Average annual input (kg/ha) of N, P, S, and K in the leaf litters applied at 1500 kg/ha.

Leaf litter	N	P	K	S
C. cajan	62.7	3.9	17.9	3.5
A. auriculiformis	24.5	1.5	8.1	2.0
P. taxodifolius	29.3	1.4	6.6	2.3
S. saman	26.5	1.4	8.3	2.5

An additional experiment to study the fate of nutrients and C from crop residues and fertiliser (R3 experiment) was also commenced at Ubon in 1996. The experimental design and management is similar to that described for the R2 experiment. The legume residues applied were 1.5 tonnes dry weight/ha. The treatment combinations included the 3-plant residue application (*C. cajan, A. auriculiformis* and a no-residue control), two inorganic fertiliser rates (25:16:8 and 50:16:8 kg/ha of N, P and K) and two rice stubble managements (stubble removed and returned), with four replications. Thirty-day-old seedlings of rice (cv. KDML105) were transplanted at a spacing of 25 × 25 cm and 3 seedlings per hill. Plants were harvested at maturity and plant samples taken for nutrient and yield determinations. Soil samples were collected early in the wet season to determine the breakdown and possible leaching of C and N. The treatments intensively sampled were the ones on which fertiliser was applied at higher rate and rice straw residues were retained. Soil samples were collected from the control, *C. cajan, A. auriculiformis* treatments at 0–10, 10–30 and 30–60 cm depth at three sampling dates:

Sample 1: 10/6/97. Pre-rice — Rain event 2.
Sample 2: 14/7/97. After incorporation — first rain.
Sample 3: 25/7/97. After incorporation — second rain.

These samples were analysed for C_T, C_L, and total soil nitrogen (N_T) to investigate the movement of C and N down the profile as a result of leaching. Only the results of C and nutrient leaching are described in this paper.

Results and Discussions

Decomposition of plant residues

After 32 days, the highest C release of 40% was observed from *C. cajan* followed *by S. saman* (31.6%), *P. taxodifolius* (25.4%), rice straw (18.8%) and *A. auriculiformis* (13.4%) (Figure 1). This study showed that during the first 15 days there were very large differences in the rates of decomposition with *C. cajan* the fastest and *A. auriculiformis* the slowest. From 15 to 30 days, the rates of carbon release from the residues were very much closer

Field experiment R2

Rice grain yields

In 1992, the *C. cajan* leaf litter, although applied at only half the rate of the other leaf litters, resulted in the highest grain yields of 1683 kg/ha, most likely because of the high concentration of nitrogen and the faster breakdown and nutrient release of this leaf litter.

In 1993, the *C. cajan* leaf litter, from now applied at 1500 kg/ha, still resulted in the highest yield compared to other residue treatments, but the difference was smaller than in 1992. All leaf litter treatments produced higher rice grain yields than the no-leaf litter control (Table 2). In the following three years, *C. cajan* still resulted in the highest grain yields and was closely followed by the *A. auriculiformis* and *P. taxodifolius* treatments. By 1997 and 1998, there was no significant difference in rice grain yield when compared between *C. cajan* leaf litter treatment and other residue treatments. They were, however, significantly higher than the no-residue control treatment.

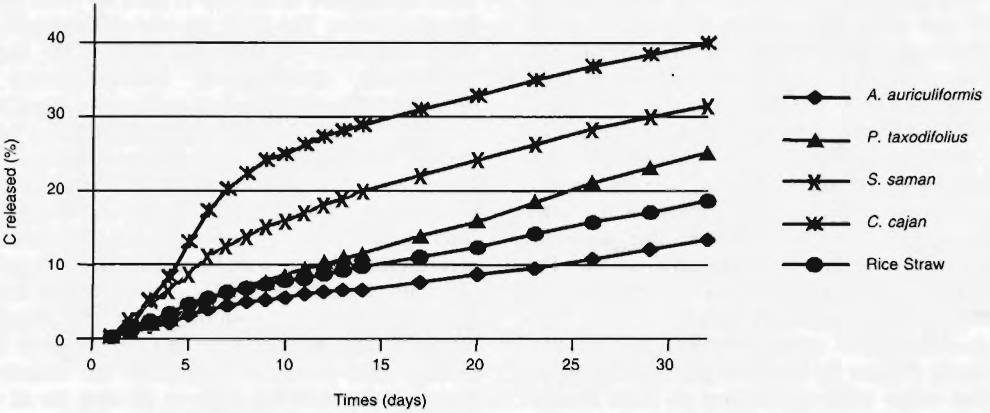

Figure 1. Decomposition of plant residues used in the experiment.

Table 2. Rice grain yield (kg/ha) of the leaf litter treatments from 1992 to 1998.

	1992	1993	1994	1995	1996	1997	1998
C. cajan	1683 a[A]	1604 a	2010 a	1637 a	2282 a	1882 a	1969 a
A. auriculiformis	1363 b	1463 ab	1597 b	1415 b	2090 b	1813 a	1916 a
P. taxodifolius	1242 b	1327 bc	1683 b	1493 b	2043 bc	1886 a	1981 a
S. saman	1194 bc	1210 cd	1631 b	1456 b	1896 c	1804 a	2121 a
No leaf litter	1012 c	1051 d	1197 c	1188 c	1545 d	1507 b	1567 b

[A] Means followed by the same letter within columns are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

In every year of the experiment, increasing fertiliser application rates led to an increase in rice grain yield. At an early stage of the experiment (1992–1994), rice grain yield increased by 22%–26% with increasing fertiliser application rate. In the latter years (1995–1998), the increment was less than 20%. Chemical fertiliser is an important nutrient source for crops during the early stages of integrated nutrient management. Differential nutrient release rates from residues can add to this nutrient supply. Residual nutrient release from plant residues can supply nutrients over the long term.

Effect of rice stubble management on rice grain yield was quite small. The only significant effect of returned stubble was observed in 1993, resulting in an increase in grain yield from 1456 to 1606 kg/ha. Apart from 1993, there was no significant effect.

In 1992, the *C. cajan* leaf litter applications produced the highest rice yields and yield gap compared to *C. cajan* leaf litter and other residue treatments. The higher the nutrient input (62.7 kg/ha) and faster decomposition rate associated with the *C. cajan* leaf litter, the more nutrients were available for the rice crop (Table 2). However, the yield gap between the *C. cajan* leaf litter treatment and other residue treatments were gradually decreased from 1993 to 1996. By 1997 and 1998, there was no difference in grain yield obtained from the four residue treatments. Moreover, application of *A. auriculiformis*, *P. taxodifolius* and *S. saman* leaf litter produced the highest grain yield in 1996, 1997 and 1998, respectively. Slow decomposable organic materials, e.g. *A. auriculiformis*, *P. taxodifolius*, gradually decomposed and gradually released nutrients for the latter rice crops—this is in addition to residual nutrients accumulated from the previous application. The grain yield results (Table 2) reflect the differences in breakdown rate and nutrient release of these residues, confirming the result from the in vitro perfusion study (Figure 1). The poor performance in the early rice crops after application of slow decomposing organic materials suggests that when using these residues to improve soil organic matter a larger amount of inorganic fertiliser would be required to compensate for the nutrients immobilised during the early stage of nutrient management. The response to different types of leaf litter in this field experiment suggests that management of residue breakdown, by choice of species, method of incorporation, and application of fertiliser, can have significant effects on the short, medium and perhaps even long-term availability of nutrients.

In the present study, applications of leaf litters also improved grain yields by at least 19% over those from the no-leaf litter control treatment. Results from this study support the findings of many workers that application of plant residues improves crop growth and yield (Ta and Faris 1990; Wonprasaid et al. 1995) because the incorporation of residues of forage or grain legume crops usually results in an increased supply of mineral N (Doughton and MacKenzie 1984; Strong et al. 1986).

Soil carbon

The reference soil, collected from an undisturbed forest area, indicated the initially large C_T and C_L pools that existed originally in this soil series (Table 3). The experimental site had been cleared in 1971 and farmed to rice for at least 20 years prior to the experiment. The 1992 pre-trial soil analyses indicated reductions of 90% and 85% in C_L and C_T, respectively, resulting in carbon lability (L) decreasing from 0.25 to 0.14 and a very low CMI of 9 (Table 3). Soil samples collected after the harvest in 1997 showed a significant improvement in C associated with the relatively small leaf litter additions. However, there were no differences between the leaf litter treatments for any of the C parameters measured. All the leaf litter treatments have significantly higher C_T and C_L concentrations than the no-leaf litter control, resulting in an improvement in the CMI. The improvement in C in all pools in the no-leaf litter treatment represents the contribution from incorporated rice straw as the data for all treatments in this Table are the means of the plus and minus straw return and fertiliser treatments.

Table 3. The effect of leaf litter addition on soil C status and carbon management index (CMI) of the 0–10 cm soil layer at Ubon, Thailand, at the beginning of the experiment (1992) and after 6 cropping seasons (1997).

		C_T	C_L	C_{NL}	L	CPI	LI	CMI
	Reference soil	23.02	4.55	18.47	0.25	1.00	1.00	100
1992	Pre trial	3.48	0.44	3.04	0.14	0.15	0.59	9
1997	No leaf litter	3.88 b[A]	0.59 b	2.79 b	0.21 a	0.15 b	0.86 a	13 b
	C. cajan	4.24 a	0.79 a	3.45 a	0.23 a	0.18 a	0.95 a	17 a
	S. saman	4.01 a	0.76 a	3.24 a	0.24 a	0.17 a	0.97 a	17 a
	P. taxodifolius	4.07 a	0.81 a	3.26 a	0.25 a	0.18 a	1.03 a	18 a
	A. auriculiformis	4.44 a	0.77 a	3.67 a	0.24 a	0.19 a	0.98 a	17 a

[A] Means followed by the same letter within columns are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

The lability, or the proportion of the C pool that is labile, increased from 0.14 in 1992 to more than 0.20 in the leaf litter treatments. Although the size of the total carbon pool was still considerably lower than that of the reference soil, there was a 15%–27% improvement above the original C_T in 1992 and an almost doubling in the C_L pool above the pre-trial concentration (Table 3).

The change of CMI over time is shown in Figure 2. The CMI at the start of the trial in 1992 was 9 and began to improve in all treatments in 1994. The initial improvement in the CMI of the no leaf litter applied treatment subsequently levelled off in 1995. The increase in C in the no leaf litter treatments is due to the inclusion of benefits of improved fertility, from residue return and fertiliser. The CMI in the four leaf litter treatments has steadily increased to approximately 20 in 1996, except for the CMI of the *S. saman* treatment, which declined sharply in 1996. This may have been due to the poor quality of the *S. saman* residues in 1996, which had been stored since 1995.

In 1997, however, the CMI in the *C. cajan, A. auriculiformis and P. taxodifolius* treatments, decreased markedly, while the CMI of the *S. saman* treatment increased.

The management of residues can affect the input of carbon and other nutrients into the system and the rate at which SOM turns over. This in turn will affect the size of the various SOM pools and, therefore, the overall supply and availability of nutrients and the general chemical, physical, and biological fertility of the soil, all of which contribute to the sustainability of the system.

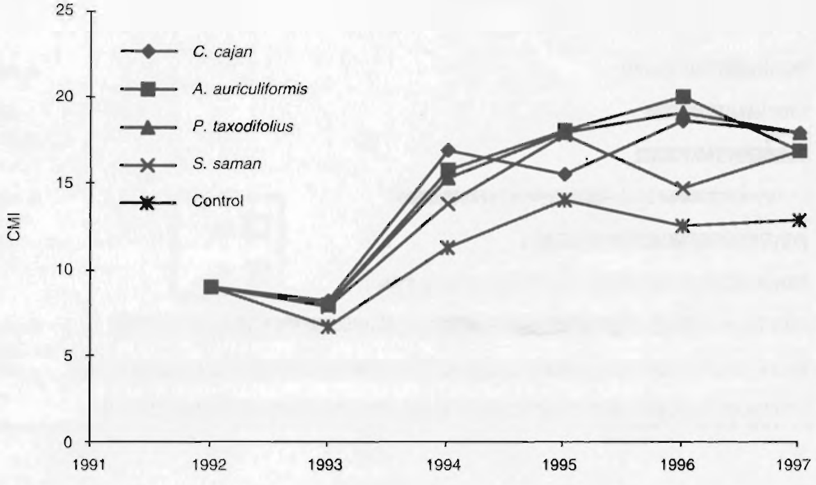

Figure. 2. Impact of leaf litter addition on the carbon management index (CMI) in an Aeric Palequult soil at Ubon Ratchathani, Thailand.

Calculation of the CMI takes into account the change in C_T pool size and its lability and gives a more definitive picture of soil C dynamics than when only a single parameter is used. It appears to be a useful measure of the relative restorative or degrading capacity of different management systems. Blair et al. (1995) found it a more useful indicator of soil C dynamics than C_T in a range of agricultural systems in Australia and Brazil.

This field experiment shows that by understanding the turnover rate of crop residues and leaf litters, the fate of the nutrients released from the organic materials, and the crop demand for nutrients, it is possible to devise systems that maximise the reuse of plant nutrients by crops.

C and N leaching experiment (R3)

There is a substantial decline in C with depth, although C_L does not decrease substantially from 10–30 cm to 30–60 cm (Figure 3). There is no significant difference in soil C between the 3 applied residues.

Over time, however, there was a significant change in C_T in the 0–10 and 10–30 cm depths and this was related to the type of residue which had been applied. Where no residue was applied, the C_T continues to decline throughout the sampling period in the 0–10 cm depth. However, at the 10–30 cm depth, the C_T initially declines but then increases in the final sampling. The *C. cajan* residue which has a fast decomposition rate follows a similar pattern. However, the *A. auriculiformis* shows a continuous increase in C_T at 0–10 cm (not significant) and a slight decrease in the 10–30 cm depth (Figure 4). There does not appear to be a simple explanation for these results but they may be due to relatively small additions of residue C compared to the total soil C in 1992.

The total C content of the soil was calculated using a bulk density of 1497 kg/m^3, which was measured at a nearby site and the measured C_T and C_L values. There was a significant interaction between the applied residue and sampling time for the total C content. However, there were no significant changes at the deeper depths or for the C_L measurement. At the first sampling date, the total C content for all three treatments started at a similar content. By the second sampling time, the C content of the no residue control treatment or where *C. cajan* was applied, C declined significantly and then recovered somewhat by the third sampling time. The total C content of the slower decomposing residue treatment of *A. auriculiformis* remained steady for the first two sampling times and increased by the third sampling.

Table 4. The total C content (t C/ha) in the 0–10 cm depth at three sampling dates.

Date	O	*C. cajan*	*A. auriculiformis*
10/6/97	7.05 a	7.36 a	6.97 a
14/7/97	6.48 b	5.85 b	6.97 a
25/7/97	6.04 b	6.82 a	7.22 a

[A] Means followed by the same letter within a sampling date are not significantly different according to Duncan's multiple range test at P≤0.05.

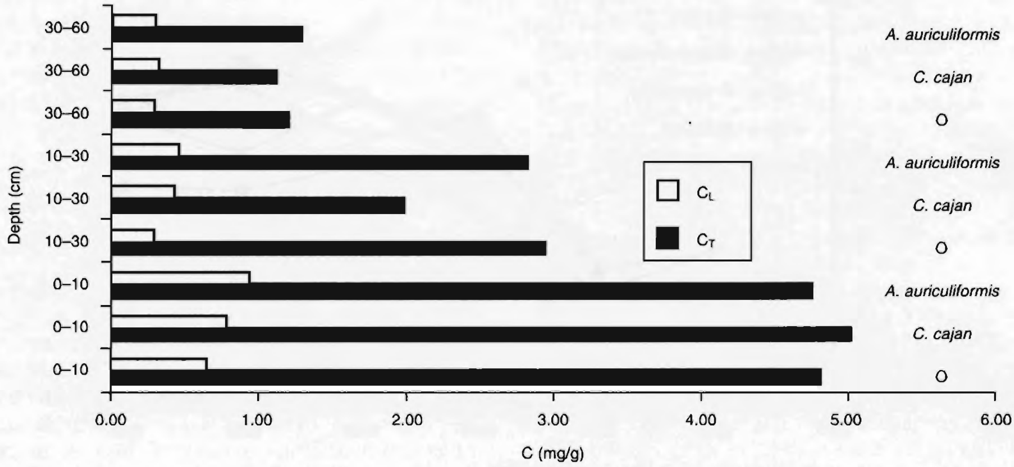

Figure 3. The C_T and C_L of the 0, *C. cajan, A. auriculiformis* treatments at the first sampling.

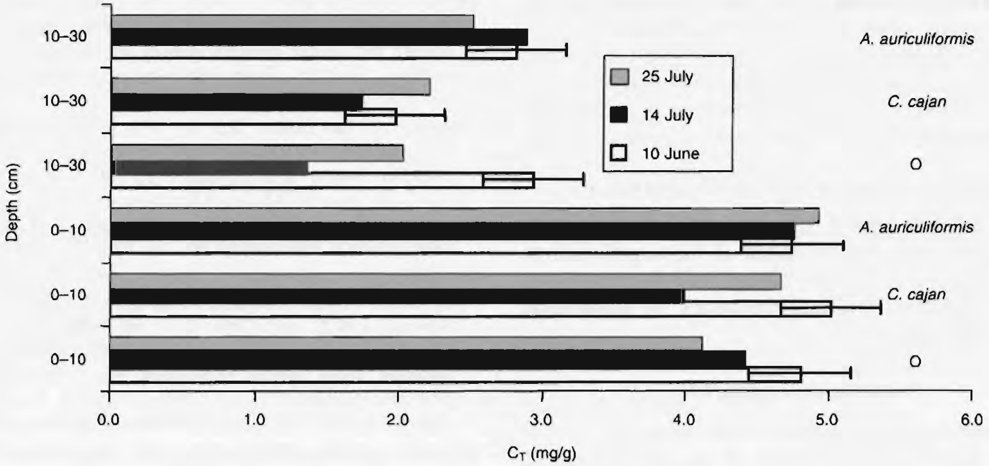

Figure 4. Total C (C_T) at 0–10 and 10–30 cm depths at the three sampling periods.

A similar pattern emerged for N_T. In the O residue treatment, N_T decreased from 0.042% to 0.037% over the sampling period. The N_T remained relatively steady for the *A. auriculiformis* treatment but on the *C. cajan* treatment N_T decreased from 0.043% at sampling 1 to 0.038% at sampling 2 and again increased to 0.043% by the final sampling.

Conclusion

The development of efficient residue management systems for improving soil organic matter and restoring soil fertility levels requires an understanding of plant growth rates, and thus of course demand for nutrients, such as N and S, and an understanding of the current nutrient status of the soil and the likely risk of leaching. Optimising the supply of organic nutrients to crops requires synchronising the soils' nutrient mineralisation rate with the crops' nutrient needs. Improved matching of supply and demand would result in less excess mineral nutrients in the soil and, therefore, reduced opportunity for losses. The nutrient supply may be synchronised with plant nutrient uptake by manipulating plant demand, for example, the planting date or crop growth duration may be controlled (McGill and Myers 1987). Alternatively, nutrient release and nutrient use efficiency may be manipulated by controlling the quality of organic inputs such as crop residues and green manures (Francis et al. 1994). Thus, an organic material of the right quality may release nutrients at approximately the same rate as required by the crop.

Future Research Directions

Field experiments

The results of the study on C and N leaching need to be clarified. Similar evaluations of the effects of different management systems on the leaching of C and nutrients need to be undertaken in field experiments. Where the use of radioactively-labelled residues is safe and permitted, this is the preferred methodology due to its high precision and accuracy. In areas where this is not possible, the use of ^{13}C, ^{15}N and ^{34}S stable isotope labelled residue is an attractive alternative. Priority should be given to developing economical systems for production of large quantities of evenly labelled residues and leaf litters. Natural abundance techniques (for ^{13}C, ^{15}N and even ^{34}S) will continue to be useful, but with reduced accuracy compared to the use of labelled/enriched residues.

On-farm trials

The results of this field experiment showed the impact that the addition of small amounts of leaf litter and crop residues can have on crop production. There is a need to now take the study to farmers' fields to ascertain its practicality on-farm.

The trees used in this field experiment, e.g. *A. auriculiformis, S. saman, P. taxodifolius*, were shown to be effective in improving soil productivity. The productivity of these and similar trees should be further evaluated in farmers' fields. A practical system for their production, either on rice bunds or in an agro-forestry system, needs to be developed.

Collaboration among the associated organisations, e.g. Department of Agriculture, Department of Agricultural Extension, Department of Land Development and non-government organisations (NGOs), in addition to technical supports from the Department of Forestry is needed to ensure success of these studies.

Modification of the current field experiment

As seen in Figure 2, the CMI started to reach a plateau in 1995. Modification of the experiment to include increased residue application rates, other residue species and their frequency of application should be considered.

Acknowledgments

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The Management of Pre and Post-Legume Crops, Fertilisers and Plant Residues on Rice Yields and Soil Carbon in a Flooded Rice Cropping System

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Abstract

A field experiment began in 1992 at the Ubon Rice Research Center, in northeast Thailand, on an infertile acid sandy soil (*Aeric Paleaquult*). The objective of this study was to evaluate the effect of legume residues, lower quality rice straw, and inorganic fertiliser, on soil fertility, soil carbon and the growth of rice. The inclusion of cowpea (*Vigna unguiculata*) within the rice system was also evaluated for its potential to produce seed and biomass for incorporation. The treatments were in a complete factorial design consisting of three rice cropping systems (rice alone, rice with cowpea and rice followed by cowpea), two leaf litter rates (0 and 750 kg/ha of raintree (*Samanae saman*) leaves, two fertiliser rates (18:14:13 and 50:14:13 kg/ha NPK) and two crop residue treatments (rice stubble removed and returned), with three replications. Generally, the application of the higher fertiliser rate resulted in 14%–39% increases in rice yields but no effect on the growth of cowpea. Annual additions of raintree leaf litter improved rice yield from 1994 and cowpea yields from 1996 indicating a buildup in soil fertility. The Carbon Management Index (CMI) reflected this improvement in soil fertility by increasing from 12 in 1992 to 29 in 1996. The retention of rice straw, however, did not impact on rice yield until 1998 (six seasons of rice straw retention) and was critical for the success of the cowpea sown after harvest. This was almost definitely related to the mulching effect of the straw reducing soil water loss and protection of the cowpea seedlings. Raintree additions also positively influenced cowpea yields sown after rice in later years of the trial. The benefit, in terms of cash and biomass, that mung beans or cowpea may provide when included in the traditional rice system, depends almost entirely on seasonal conditions. As these legumes are sensitive to waterlogging, good early season rains reduce legume growth. The success of legumes sown following the rice crop depends on stored water in the profile and the occurrence of late season rains. The variable environment in northeast Thailand makes the inclusion of legume crops in the rice system a risky option.

THAILAND is a rice-growing country in which 70% of the total population are rice farmers. Thailand presently produces rice in excess of its local consumption and is thus a major exporter of milled rice. Total rice production of the country in 1991–1992 was estimated at 20.4 million tonnes (OEA 1992).

Thailand is divided into four regions: north, northeast, central and south. The northeast is the largest of the four regions, covering about one third of the total land area of the country. The area of land in rice production in the northeast is also the largest, at approximately 2.7 million hectares. However, average rice yields are the lowest in the country. The average rice grain yield of Thailand is 2.2 t/ha compared to an average of 1.7 t/ha in the northeast and 3.0 t/ha in the more fertile central region. Infertile sandy soils, with some salinity problems, low use of fertilisers and erratic rainfall account for the lower yields achieved by northeast farmers.

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Large increases in rice yields have been demonstrated with applications of fertiliser, farmyard manure, rice straw, other rice residues and the use of green manuring technologies, such as *Sesbania rostrata* and *Aeschynomene afraspera* (Herrera et al. 1989). Generally, these increases are only obtained at unacceptably high costs in terms of cash outlay, the fertility of other regions or labour. A combination of relatively low cost technologies is required to produce increases in yield and result in long term restoration and subsequent maintenance of the soil resource base. Careful management of residue quality and quantity, combined with the judicious use of inorganic fertilisers, allows management of organic matter and nutrient dynamics to produce systems which should prove to be more sustainable.

Another constraint to rice production in the northeast is that 95% of paddy fields are in rainfed areas. The annual rainfall varies between 1000 and 2000 mm. In addition, and perhaps more critically, the distribution of rainfall varies considerably. Delays in the onset of the rainy season in May and June, dry spells in mid season (late June and July) and short flooding periods later in the season (September and October) can be significant constraints.

In the past, transplanting of rice seedlings was the normal practice, but now direct seeding is gaining in popularity because of the shortage of labour. Land preparation is usually carried out by animal power or small farm tractors, as soon as there is sufficient moisture. Some farmers apply chemical fertilisers, but a large part of the rice growing area is still cultivated without the application of any fertiliser. The cost of chemical fertilisers in Thailand is relatively high compared to other countries. Even those farmers who use fertilisers apply low amounts; common applications are in order of 40, 11 and 10 kg/ha of NPK as 16:16:8 compound fertiliser and urea.

In the face of these constraints, farmers in Thailand must combine technologies for optimal production. A system is described in this experiment that demonstrates the long-term impact of the management of different organic residue sources on soil fertility and yields.

Materials and Methods

A field experiment was commenced in 1992 at the Ubon Rice Research Center, in the northeast of Thailand, on an infertile acid sandy soil (*Aeric Paleaquult*) of the Roi Et series—a widely distributed soil used for rice production in northeast Thailand. The Roi Et series are acid (pH_{H_2O} 4.2), sandy (sand = 85.4%, silt = 10.5%, clay = 4.1%) soils derived from sandstone. The site of the experiment had been cleared in 1971 and farmed to rice for at least 20 years prior to the experiment.

This field experiment was established to evaluate the effect that small amounts of relatively high quality legume residues with different breakdown rates, lower quality rice straw, and inorganic fertiliser had on soil fertility, soil carbon and the growth of rice. The inclusion of mung bean or cowpea as a cash crop within the rice system was also evaluated for its potential to produce seed for harvest and biomass for incorporation. The treatments were in a complete factorial design consisting of three rice cropping systems [rice alone, rice with mung bean/cowpea (*Vigna radiata/Vigna unguiculata*) and rice followed by cowpea (*Vigna unguiculata* CP-4-3-2-1)], two leaf litter rates (0 and 750 kg/ha of *Samanae saman* leaves), two fertiliser rates (18, 14, 13 and 50, 14, 13 kg/ha NPK) and two crop residue treatments (rice stubble removed and returned), with 3 replications. The sowing and harvesting dates of the rice and legume crops from 1992–1998 are displayed in Table 1.

Table 1. The sowing and harvesting dates of the rice and legume crops from 1992–1998.

	1992	1993	1994	1995	1996	1997	1998
Rice							
Sowing	17 June	9 June	17 June	22 June	12 June	9 June	3 June
Flowering date	5 Oct	18 Oct	17 Oct	1 Oct	7 Oct	10 Oct	9 Oct
Harvest	11 Nov	15 Nov	15 Nov	9 Nov	11 Nov	12 Nov	4 Nov
Mung bean/cowpea with rice							
Sowing	17 June	9 June	17 June	14 May	12 June	9 June	3 June
Sampling	24 July	12 July	5 Aug	20 June	16 July	14 July	7 July
Cowpea after rice							
Sowing	13 Nov	24 Nov	18 Nov	10 Nov	18 Nov	14 Nov	10 Nov
1st Harvest	2 Feb	11 Feb	2 Feb	29 Jan	10 Feb	19 Jan	8 Feb

One week before the rice was sown, the dry leaves of rain tree were applied and incorporated into the soil. At planting in 1992 and 1993 and 1995, chemical fertiliser was applied and incorporated into the soil, at the rate of 0, 14, 13 kg NPK/ha and 32, 14, 13 kg NPK/ha for the low and high nitrogen treatments, respectively. In 1994 and 1996–1998, fertiliser was broadcast 1 month after planting instead of being incorporated. At panicle initiation, urea fertiliser was topdressed to all plots at the rate of 18 kg N/ha.

In all three rice cropping systems, rice (cv. RD15) was broadcast at the rate of 60 kg/ha onto cultivated moist soil. Where rice was planted with mung beans in 1992 or cowpea in 1993–1998, the legume seeds were broadcast together with the rice at a seeding rate of 30 kg/ha and soil was raked over the seeds. The principle behind this system is that the legume and rice grow together until the legume can no longer tolerate the anaerobic conditions. If the rains fail, the legume and rice can grow together, and both can be harvested. The stage at which the legume is flooded out will determine the benefit derived by the rice from the biomass and, more particularly, fixed nitrogen produced by the legume. From 1993–1996, cowpea (cv. CP4-3-2-1) was used instead of mung bean because it is more tolerant to flooding.

In 1995 only, the cowpea was planted alone and grown for 35 days before it was incorporated and 30 day-old rice seedlings were transplanted (Table 1).

In the rice followed by cowpea system, cowpea was planted less than 10 days after the rice was harvested (Table 1) and grew on the residual soil moisture and any late rains that fell. Soil remained untilled after harvest and the cowpea seeds were dibbled into the soil at a spacing of 20 × 40 cm. This system can produce harvestable product or just biomass, depending on the season. The cowpea crop was harvested as it matured and was separated into shell and seed. When all the plants had stopped producing seeds, the remaining biomass was weighed, and returned to its respective plot along with the shells.

Rice plants were harvested at maturity and plant samples taken for nutrient analyses of grain, threshed panicle straw, and stubble. The straw was removed from the stubble removed treatments and remained in the stubble retained treatments. Soil samples were taken from the 0–10 cm layers following harvest and prior to cultivation in the following crop, dried at 40 °C and ground for analysis.

Total C (C_T) and labile C (C_L) measurements

Subsamples of the <2 mm sieved material were taken and ground to <500 μm and the C_T measured in an automatic nitrogen and carbon analyser mass spectrometer system (ANCA-MS), consisting of a Dumas-type dynamic flash catalytic combustion sample preparation system (Carlo Erba NA1500), with the evolved gases separated and analysed by mass spectrometry (Europa Scientific Tracermass Stable Isotope Analyser). The more labile soil organic carbon was measured by oxidation with 333 mM $KMnO_4$ (Blair et al. 1995).

The C_T, and C_L measurements were used to calculate a Carbon Management Index (CMI) (Blair et al. 1995) as described in Whitbread et al. (1999) in these Proceedings. The reference sample used was the soil collected from primary forest near to the experimental sites.

Results

Carbon

Soil samples collected and analysed following harvest in 1996 reflect the influence of the various residue and fertiliser treatments over the past four seasons on C. The reference soil, collected from a nearby forested site, represents the original C levels of these soils prior to clearing and farming. The pretrial sample which is a composite of the three replicates shows the effect of more than 20 years of rice paddy cultivation on these sandy soils. C_T and C_L declined by 83% and 88% from the original reference soil resulting in a CMI of 12 (Table 2).

There was an overall increase in C on all treatments representing better management of the site and inputs of C from ungrazed weeds growing on the plots during the dry season. Inputs of C in the form of roots were an additional C source that was not measured.

By 1996, the annual input of 750 kg/ha of raintree leaf litter significantly increased the C_T, C_L, and the CMI from 25 to 29 (Table 2). The high fertiliser rate increased C_L and the CMI while the management of rice straw at harvest had no effect on any of the C parameters.

The C measured on soil samples during 1994 and 1995 were included in a repeated measures AOV with the 1996 data. There were significant increases each year in all C parameters measured and when averaged across seasons, the addition of raintree leaf litter resulted in significantly higher C. No significant interaction between year and treatment was found (data not presented).

Table 2. Effect of raintree leaf addition, fertiliser and rice straw on C dynamics.

Site/treatment	C_T	C_L	C_{NL}	L	LI	CPI	CMI
Reference	23.02	4.55	18.47	0.25	1.00	1.00	100
Pre-trial	3.92	0.56	3.36	0.17	0.68	0.17	12
– Raintree	6.89 b[A]	1.15 b	5.74 b	0.21 a	0.84 a	0.30 b	25 b
+ Raintree	7.49 a	1.33 a	6.16 a	0.22 a	0.90 a	0.32 a	29 a
Low fertiliser	7.01 a	1.17 b	5.83 a	0.21 a	0.84 a	0.30 a	25 b
High fertiliser	7.38 a	1.31 a	6.07 a	0.22 a	0.90 a	0.32 a	28 a
– Straw	7.00 a	1.22 a	5.78 a	0.22 a	0.87 a	0.30 a	26 a
+ Straw	7.38 a	1.26 a	6.11 a	0.21 a	0.86 a	0.32 a	27 a

[A] Means followed by the same letter within columns are not significantly different according to DMRT at $P \leq 0.05$.

Mung bean (1992) or cowpea (1993–1998) sown with rice

The dry matter yield of mung beans and cowpea varied enormously between the seasons and as a result of treatment effects. No grain was ever produced and only the biomass production at the sampling dates in Table 1 are reported. In 1992, due to the slightly delayed planting of this experiment and the early rain, the mung bean did not establish very well before the plots were flooded and, consequently, on most plots there was generally less than 50 kg DM/ha produced.

In 1993, mung bean was replaced by cowpea in the broadcast rice + legume system. Cowpea biomass production responded significantly to the higher fertiliser application rate which increased yield from 644 to 1124 kg DM/ha. Although not significant, rice stubble retention increased the cowpea yield from 752 to 1014 kg DM/ha.

The cowpea dry matter yields in 1994 and 1995 were unaffected by treatment imposed and varied from 48 to 905 kg DM/ha in 1994 and from 84–1354 kg DM/ha in 1995 (average of the raintree treatments in Table 3). By 1996, however, the cumulative effects of the residue treatments (raintree and rice stubble management) began to influence cowpea yields.

From 1996, cowpea biomass production increased significantly due to the annual applications of raintree leaf litter (Table 3). In 1996, grain yield increased from 1641 kg/ha where rice stubble was removed to 2044 kg/ha with four seasons of rice stubble retention. However, the same effect was not significant in 1997 and 1998.

Yield of cowpea sown following rice

Cowpea immediately following rice harvest grew on the residual soil moisture that remained from the rice crop. As rain following harvest is generally very limited, it was critical that the cowpea established quickly and was able to grow roots into the soil profile to tap the water from the drying soil profile. During 1992, the yield of grain, shell and plant biomass showed no significant effect due to the treatments imposed. By 1993, however, the retention of rice stubble became critical for maximising cowpea growth and generally resulted in more than doubling cowpea yield (Table 4).

Cowpea yield was unaffected by the fertiliser rate applied to the rice crop but the application of the raintree leaf litter significantly increased cowpea grain and shell' yield in 1995 and 1996, and shell yield only in 1997 (Table 5). The 1998 data are still being collected.

Table 3. The effect of annual applications of raintree (750 kg DM/ha) on mung bean (1992 only) or cowpea (1993–1998) dry matter yield produced when sown with rice.

Mung bean/cowpea yield (kg/ha)	1992	1993	1994	1995	1996	1997	1998
– Raintree	61 a	799 a	332 a	538 a	1503 b	380 b	337 b
+ Raintree	17 a	968 a	353 a	590 a	2182 a	509 a	461 a

[A] Means followed by the same letter within columns are not significantly different according to DMRT at $P \leq 0.05$.

Table 4. The effect of rice straw management on the grain, shell and stubble yield of cowpea sown after the rice harvest.

		Grain	Shell	Stubble
		Yield (kg/ha)		
1992	– Straw	226 a[A]	97 a	298 a
	+ Straw	236 a	103 a	479 a
1993	– Straw	205 a	109 a	538 a
	+ Straw	434 b	257 b	1022 b
1994	– Straw	185 a	109 a	96 a
	+ Straw	458 b	257 b	399 b
1995	– Straw	132 a	376 a	134 a
	+ Straw	193 b	548 b	445 b
1996	– Straw	155 a	68 a	134 a
	+ Straw	719 b	276 b	536 b
1997	– Straw	61 a	43 a	51 a
	+ Straw	267 b	166 b	138 b

[A] Means followed by the same letter within a year are not significantly different according to DMRT at $P \leq 0.05$.

Table 5. The effect of annual application of 750 kg/ha raintree leaf litter on the grain, shell and stubble yield of cowpea sown after the rice harvest in 1995, 1996 and 1997.

		Grain	Shell
1995	– Raintree	122 b	385 b
	+ Raintree	203 a	540 a
1996	– Raintree	295 b	115 b
	+ Raintree	578 a	229 a
1997	– Raintree	126 b	82 b
	+ Raintree	202 a	126 a

[A] Means followed by the same letter within plant part and year are not significantly different according to DMRT at $P \leq 0.05$.

Rice yield

The effect of the various treatment combinations on rice growth was measured annually on rice grain, panicle straw and stubble production. Across all years, the most consistent treatment effect on the yield of rice was due to the higher rate of application of fertiliser which significantly increased rice grain yield (Table 6), panicle straw and stubble yields (data not presented) each year. The percentage increase in grain yield due to the increased rate of fertiliser varied between seasons and ranged from 14% to 39%.

Table 6. The effect of fertiliser rate on rice grain yield (kg/ha).

	Grain Yield (kg/ha)		
Year	Low fertiliser	High fertiliser	Per cent increase
1992	2389 b[A]	2970 a	24
1993	1389 b	1930 a	39
1994	1497 b	2006 a	34
1995	2453 b	2795 a	14
1996	2544 b	2906 a	14
1997	2262 b	3077 a	36
1998	2045 b	2461 a	20

[A] Means followed by the same letter within a year are not significantly different according to DMRT at $P \leq 0.05$.

The annual application of a relatively small amount of raintree leaf litter (750 kg DM/ha) resulted in significant increases in grain yield in years 1994 and 1996 to 1998. These increases

Table 7. The effect of the application of raintree leaf litter on rice grain yield.

	Grain yield (kg/ha)		Per cent increase[A]	Panicle straw + stubble (kg/ha)		Per cent increase[A]
	– Raintree	+ Raintree		– Raintree	+ Raintree	
1992	2685 a	2674 a	0	4459 a	4412 a	–1
1993	1626 a	1694 a	4	4070 a	4217 a	4
1994	1615 b	1887 a	17	3805 b	4201 a	10
1995	2533 a	2716 a	7	4167 b	4647 a	12
1996	2621 b	2829 a	8	6086 b	6810 a	12
1997	2506 b	2832 a	13	6145 b	7211 a	17
1998	2101 b	2405 a	14	4716 b	5762 a	23

Means followed by the same letter within a plant part and rows are not significantly different according to DMRT ($P<0.05$).
[A] % increase = (yield of + raintree)–(yield of – raintree)/yield of – raintree.

generally becoming larger each season reflecting the cumulative benefits of annual leaf litter additions to soil fertility (Table 7). Panicle straw + stubble yields were also significantly increased by raintree leaf litter additions in every season from 1994, with the difference in yields between the no raintree treatment and the treatment with leaf litter applied becoming consistently larger each year (Table 7).

The effect of the mung bean/cowpea planted either with rice or following the rice crop varied between seasons. In 1992, early flooding induced the poor growth of the mung bean planted with the rice (Table 2) and resulted in no effect on the final rice yield (Figure 1). Biomass produced from cowpea following the harvest was also minimal (Table 4). As a result the 1993 rice yields were unaffected by the previous years legume growth. The biomass produced by the cowpea planted with rice in 1993 again resulted in no significant effect on rice yield. In 1994, the grain yield increased where cowpea was sown with rice ($P<0.01$) (Figure 1) while there was a highly significant increase ($P<0.001$) in panicle straw and stubble yields (data not presented).

In 1995, there was a significant interaction between fertiliser rate and the cowpea treatments in rice yield. The high fertiliser rate applied to the rice alone or the cowpea planted after rice systems increased grain yield (Table 8), panicle and stubble yields (data not presented) compared with the low fertiliser rate. Rice yield remained unaffected by an increase in the fertiliser rate where cowpea had been grown after the rice phase.

Table 8. The interaction between the cowpea system and the fertiliser rate on rice grain yield (kg/ha) in 1995.

	Grain yield (kg/ha)		Per cent increase
	Low fertiliser	High fertiliser	
Rice alone	2395 c	2775 ab	16
Cowpea before rice	2281 c	2950 a	29
Cowpea after rice	2684 b	2661 b	–1

[A] Means followed by the same letter within a year are not significantly different according to DMRT at $P\leq0.05$.

In 1996, the cowpea treatments, whether planted with or following the rice crop, resulted in significant increases in grain yield of almost 300 kg/ha (Figure 1) while stubble yield was also significantly increased by more than 1000 kg/ha on the cowpea following rice treatment compared with rice alone. In 1997, rice yield only significantly increased on the cowpea following rice system.

Grain and panicle straw yield in 1998 was unaffected by the cowpea treatments. However, stubble biomass significantly increased from 3715 kg/ha where rice is planted alone and 4047 kg/ha where rice is planted with mung bean to 4814 kg/ha on the cowpea planted after rice treatments.

Discussion

The response to different types and rates of legume residues in this field experiment suggests that

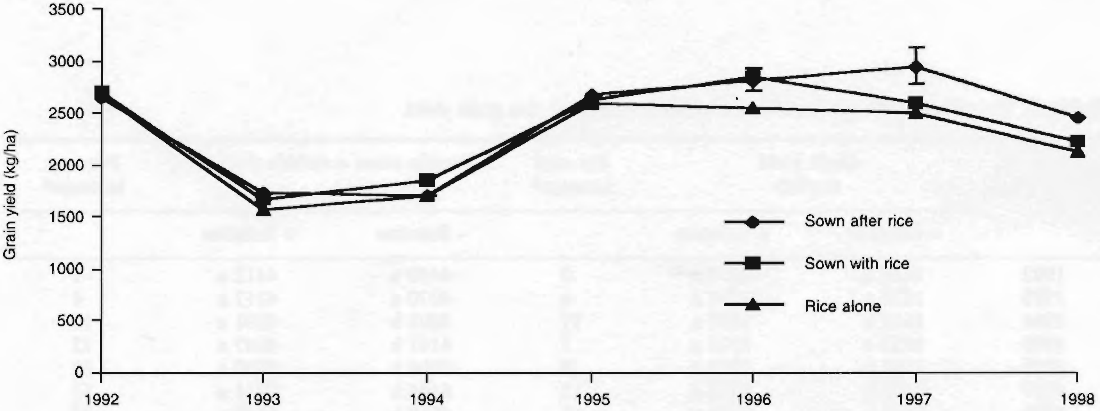

Figure 1. The yield of rice (1992–1998) on a cropping system planted with mung bean/cowpea, cowpea following the rice harvest and rice alone.

management of residue breakdown, by choice of species, method of incorporation and application of fertiliser, can have significant effects on the short, medium, and perhaps even long-term availability of nutrients. Therefore, management of residues can affect the input of carbon and other nutrients into the system and the rate at which soil organic matter turns over. This in turn will affect the amount of soil organic matter in the various soil organic matter pools and, therefore, the overall supply of nutrients, the availability of nutrients and the general chemical, physical and biological fertility of the soil.

Generally, the application of the higher fertiliser rate resulted in a positive and immediate impact on yields and C while the effect of the other residue treatments was cumulative. The addition of raintree leaf litter resulted in increases in C and rice yields later in the experiment (Tables 2 and 3) indicating a buildup in soil fertility. The retention of rice straw, however, did not impact on C or rice yield, but was critical for the success of the cowpea sown after harvest. This was almost definitely related to the mulching effect of the straw reducing soil water loss and protection of the cowpea seedlings. Raintree additions also positively influenced cowpea yields sown after rice in later years of the trial.

The benefit, in terms of cash and biomass, that mung beans or cowpea may provide when included in the traditional rice system, depends almost entirely on seasonal conditions. As these legumes are sensitive to waterlogging, good early season rains reduce legume growth. The success of legumes sown following the rice crop depends on stored water in the profile and the occurrence of late season rains. The variable environment in northeast Thailand makes the inclusion of legume crops in the rice system a risky option. If cheap seed is available and the additional labour required for planting and harvesting is kept to a minimum, the legumes may provide extra cash and/or food in some seasons. Rice yields were positively influenced by the cowpea following rice harvest system indicating some soil fertility benefits derived from the legume biomass produced. The additional soil fertility benefits, however, are fairly small and probably worthwhile only in combination with the production of a cash crop. An economic evaluation of this system will provide additional information for the decision-making process.

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Nutrient and Organic Matter Management in Cash Poor, Rice-Based Cropping Systems of Cambodia: Research and Extension Needs

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Abstract

Cambodian agriculture is in a phase of rapid development that requires more sophisticated management of nutrients and organic matter in order to increase and stabilise yields. Research indicates that there is a diverse range of soils throughout lowland rice-growing areas of Cambodia to which management must be tailored. On sandy surfaced soils, organic matter addition intensifies soil reduction and pH increases upon flooding. These changes have led to improved fertiliser use efficiency on similar soils in northeast Thailand. However, in Cambodia, field experiments have not shown a positive interaction between cow manure and inorganic fertiliser addition in terms of grain yield of rice grown on these soils. On the low activity clay soils, field experiments at some sites show a positive interaction between cow manure and inorganic fertiliser addition so that the efficiency of inorganic fertiliser use is substantially improved when applied together with cow manure. It is not clear, however, whether the effects of cow manure are operating through induced chemical changes in the soil or through the addition of potassium or other nutrients contained in the cow manure. A comparison of the soil properties of the seedbeds and mainfields on 15 farms showed that seedbed areas received about five times more cow manure and slightly more urea than mainfield areas over a period of seven years. Plant growth on the nursery areas was higher than on the mainfield areas, but total organic C and other soil properties were not different. The cost and benefits of research aimed at improving soil organic matter levels as opposed to research aimed at better management of inorganic fertilisers on sandy soils needs to be examined. Simple indicators are also needed to help local researchers and extension officers monitor changes in soil chemical and physical fertility due to different management regimes.

CAMBODIAN agriculture is entering a period of rapid development. The economy has become more open, agricultural inputs are more available and the government has a policy to increase food production to keep pace with the rapidly expanding population (FAO 1994). The need for increased food production and inability to significantly expand agricultural areas will substantially change the way farmers manage nutrients and organic matter in their soils.

For most of the country's history, farmers have subsisted on low yields which removed small amounts of nutrients from the soil. These nutrients could be replaced through natural nutrient additions (inputs through rain, soil weathering and N fixation) and the recycling of organic materials (straw, cut-and-carry green manures, cow manure and household waste). The increased quantities of nutrients removed by higher yields will have to be replaced through inorganic fertiliser additions and changes in the management of manures and crop residues. Greater biomass production, greater turnover of nutrients, and the utilisation of an unfamiliar nutrient sources (inorganic fertilisers) will all require more sophisticated management of resources by farmers than currently occurs. Importantly also, the management strategies that need to be developed and extended to farmers will vary over the country, depending on the soils, existing farming system and environment.

A varied range of soils occurs in the rice-growing areas of Cambodia. Some soils are acidic, sandy, with low levels of organic matter and weatherable minerals. Other soils are moderately fertile, with

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higher clay contents and low to moderate organic matter levels. Still other soils have relatively high organic matter levels and good soil structure but very low available nutrient levels (White et al. 1997a). All these soils present different problems for nutrient and organic matter management. Added to this complex range of soils are varied farming systems and environments. Large land holdings (2–5 ha) in the north and northwest of the country, which rely on tractor-ploughing and direct seeding, contrast with the small land holdings (<1 ha) in the south of the country, where animal-ploughing and transplanting systems are used. Similarly, the unpredictable growing conditions caused by total reliance on erratic rainfall in some areas contrasts with the wetter and more stable environments in the direct seeding rice areas (Nesbitt and Chan 1997).

Specific problems and solutions are therefore likely to arise for many individual circumstances. Generalisations should be made with caution, but extrapolation of research results from other countries is likely to speed progress in Cambodia, given the limited soil research that has been conducted. Recent advances in the understanding of the effects of fertiliser and organic matter addition to the rainfed rice soils of northeast Thailand has enabled good progress in the understanding of these processes in Cambodia (Willett 1995; Wonprasaid et al. 1995; Supapoj et al. 1998; Konboon et al. 1998). These results apply to some soils in Cambodia under some circumstances, but there are still significant areas where fundamental research is required. As a better understanding of Cambodia's soils is obtained, then collaborative research with other national and international research institutions is likely to produce substantive gains.

This paper reviews research involving nutrients and organic matter that has been conducted in Cambodia. The aim is to examine the types of responses that occur as a result of organic and inorganic nutrient addition and to compare these with research conducted elsewhere in the region. New directions for research and extension are discussed in the final section.

Rice-growing Soils in Cambodia

White et al. (1997b) described 11 soils used for rice production in Cambodia but only four will be discussed here to illustrate the range of variation that occurs (Table 1).

Sandy soils

Soils with sandy surface textures have been classified into either the Prey Khmer or Prateah Lang groups (White et al. 1997b). The Prey Khmer soil has a sandy surface horizon extending 50 cm or deeper, while the Prateah Lang soil has a shallow, sandy-textured surface horizon (usually 10 to 30 cm) over a clayey or loamy textured subsoil. These soils can be classified either as Entisols, Ultisols or Alfisols (often Plinustults or Haplusalfs) (Soil Survey Staff 1994).

The response to nutrient and organic matter management of these soils are similar in some respects to those of northeast Thailand as described by Willett (1995). The organic carbon fraction of these soils constitutes a large proportion of the cation exchange capacity (CEC). Willett (1995) summarised data (percentage organic carbon content (OC), pH, percentage clay content (clay) and CEC) from 16 soil samples from northeast Thailand by fitting the following multiple regression equation which accounted for 95.5% of the variation: $CEC = -10.5 + 0.18\ clay + 4.1\ OC + 2.0\ pH$. Similar regressions were fitted to the Prey Khmer and Prateah Lang soil types and the multiple regressions shown in Table 2 were produced.

Table 1. Chemical properties of Cambodian rice soils (modified from Sovuthy et al. 1996).

Soil parameter measured[a]	Prey Khmer	Prateah Lang	Koktrap	Bakan
pH (1:1 soil:H_2O)	5.48±0.74	5.53±0.59	5.09±0.60	5.34±0.71
Organic C (%)	0.34±0.31	0.29±0.21	1.28±0.63	0.43±0.23
Total N (%)	0.04±0.03	0.03±0.02	0.12±0.06	0.05±0.02
Olsen P (mg/kg)	1.02±0.86	0.90±0.98	3.19±1.81	1.71±2.97
CEC (cmol$^{(+)}$/kg)	1.36±1.77	2.28±2.74	7.36±6.84	4.75±4.87
Clay (%)	4.9±2.9	8.8±7.1	22.2±15.5	17.6±14.1
Silt (%)	29.9±22.48	40.4±12.3	40.6±12.8	47.4±15.3

[a] Value ± standard deviation.

Table 2. Constant and regression coefficients of the equation CEC = $b_0 + b_1$ Clay content + b_2 OC content + b_3 pH for four rice-growing soils in Cambodia.

Soil type	Constant and regression coefficients					Number of samples
	b_0	b_1	b_2	b_3	r^2	
Prey Khmer	−1.63	0.22	3.15	0.13	0.76	27
Prateah Lang	−2.18	0.24	1.30	0.33	0.56	108
Bakan	−5.24	0.24	2.56	0.82	0.69	80
Koktrap	−23.72	0.19	6.11	3.75	0.81	20

The CEC of the Thai soil samples were determined at soil pH and low ionic strength (Gillman and Sumpter 1986) which unfortunately was not the case for the Cambodian samples (ADAS 1981). OC contents of all samples were determined using the Walkley-Black method.

The regressions indicate some similarity between the sandy soils of northeast Thailand and those of Cambodia, particularly the Prey Khmer soil type. The effect of OC on CEC was larger than that of clay for both soil types since the parameters are expressed as percentages. The contribution of OC to CEC, however, was clearly greatest for the Thai soils, followed by the Prey Khmer soils and then the Prateah Lang soils.

The chemical changes in the sandy Cambodian soils upon flooding are also similar to those observed for the Thai soils (Willett 1995; Seng et al. 1999a). The pH and Eh values of the Prey Khmer soil changed rapidly upon flooding. The addition of organic matter increased soil pH and decreased its Eh significantly (Seng et al. 1999a). The kinetic pattern of pH and Eh changes in the Cambodian soil was similar to that of the Thai soil. However, the Thai soil was more strongly reduced than the Cambodian soil which could have been due to greater level organic carbon and extractable Fe in the Thai soil compared to those of the Cambodian soils (Willett and Intrawech 1988; Seng et al. 1999a).

Adding rice straw to the flooded Prey Khmer soil in a pot experiment increased plant growth, extractable P levels in the soil and P uptake by the plant (Table 3). The increased P availability and P uptake resulted from the pH and Eh changes described above and were directly related to the increased plant growth (Seng et al. 1999a). Addition of inorganic P resulted in a higher yield than when straw was applied alone. Addition of both straw and P resulted in a significant additive effect but an interaction between P and straw application did not occur (Seng et al. 1999a).

Results from field experiments examining the response of rice grown on the Prey Khmer and Prateah Lang soils to inorganic fertiliser, and organic matter additions, are variable. In general, however, rice responds well to inorganic fertiliser application and slightly less well to cow manure application but rarely is an interaction observed from adding both nutrient sources together on these soils (Table 4). Typical responses of rice to inorganic fertiliser and cow manure application that have been observed over the past 10 years of research by CIAP are presented in Table 4. The average increase in rice yield was about 100% (range: 19–175) when inorganic

Table 3. Response of shoot dry matter and P uptake at panicle initiation (PI) of lowland rice, cv. Neang Ourk to the addition of phosphorus and straw into two soils subjected to continuously flooded conditions and grown in pots.

Treatments	Koktrap soil		Prey Khmer soil	
	Shoot DM (g/pot)	Shoot P content (mg/pot)	Shoot DM (g/pot)	Shoot P content (mg/pot)
Control	11.8	9.3	30.9	33.6
+P[a]	58.7	96.1	59.6	111
+ Straw [b]	14.2	13.6	37.7	48.8
P+straw	69.6	137.3	63.0	125.2
LSD[c] (P<0.05)	0.8	4.4	1.3	3.9

[a] P applied at 45 mg/kg soil, [b] straw applied at 2 g/kg soil, [c] least significant difference.

Table 4. Rice yield responses to inorganic NPK fertilisers (InF) and cow manure at 10 locations in Cambodia. Data sources CIAP (1992), CIAP (1995), CIAP (1999), and Seng et al. (1999b).

Location	Soil type	Rice grain yield in the control treatment (t/ha) and yield response (t/ha) to additions of inorganic fertiliser, cow manure or combinations of the two forms			
		Yield of control	Inorganic fertiliser (InF)	Cow manure (CM)	InF + CM
Por Lors	Prateah Lang	0.4	0.7	0.8	1.7
Tuk Will	Prey Khmer	1.1	1.2	0.5	0.7
Koktrap	Prey Khmer	1.2	1.3	0.2	1.5
CADRI	Prateah Lang	3.7	0.7	0.4	1.5
Toul Bakha — DS 90	Bakan	2.5	1.8	–0.2	2.0
Toul Bakha — WS 90	Bakan	2.4	1.7	0.2	2.4
Ta Saang — WS 94	Bakan	2.4	0.7	0.2	0.9
Slakou — WS 94	Bakan	1.5	0.9	0.4	1.2
Toul Koktrap RS 94	Koktrap	1.2	1.3	0.1	1.5
Toul Koktrap RS 94	Koktrap	1.6	1.4	0.3	1.7

fertiliser was applied alone, 68% (range: 11–200) when cow manure was applied alone, and 168% (range: 40–425) when inorganic fertiliser and cow manure were applied together. These averages are somewhat misleading because of the very low yields of rice at Por Lors station when grown without fertiliser in 1989. The average yield increases in all trials conducted in 1993 by CIAP on the Prey Khmer and Prateah Lang soil types was 79% (range: 26–109) for inorganic fertiliser addition, 22% (range: 8–45%) for cow manure addition and 89% (range: 50–125) for concomitant inorganic fertiliser and cow manure addition (CIAP 1994).

The variable responses to inorganic fertiliser and cow manure addition are consistent with the variation commonly occurring in the rainfed rice-growing environment of Cambodia, where water supply fluctuates causing drought and flooding (Nesbitt and Chan, 1997), and the nutrient concentration of cow manure varies (Litzenberger and Ho Ton Lip 1963). The mean nutrient concentrations of the cow manure used in the experiments reported above were not determined; however, the data available on the nutrients contained in various sources of cow manure in Cambodia are listed in Table 5.

Modelled responses to nutrient addition predict similar yield increases as those detailed in Table 4 (CIAP 1998). The model is based on 78 replicated trials measuring the response of rice to varying rates of urea, TSP, KCl and $CaSO_4$ which were conducted by CIAP from 1994 to 1997. The model predicts that, under average conditions, the response to N and P is relatively flat once an initial response to low rates of fertiliser addition is obtained except for the response to N application on the Prateah Lang soil.

Table 5. The mean composition of cow manure sampled from various locations in Cambodia (taken from Litzenberger and Ho Ton Lip 1963).

Nutrient	Average	Range
Moisture (%)	59.5	13.5–76.9
Organic matter (%)	19.5	7.3–55.9
Ash (%)	21.0	11.0–38.4
N (%)	1.5	0.42–6.2
P (%)	0.20	0.04–0.16
K (%)	0.83	0.83–2.00

The model predicts also that, given the average nutrient composition of cow manure listed in Table 5, then the responses to cow manure addition in most of the experiments conducted by CIAP to date can be explained primarily by the addition of nutrients contained within the cow manure. For example, the CIAP model predicts that rice grown on the Prey Khmer soil without fertiliser will yield about 1.3 t/ha; 5 tonnes cow manure per hectare would be expected to supply about 45 kg N/ha, 2.6 kg P/ha and 24.9 kg K/ha (average of values listed in Table 5); the predicted yield of rice with this level of nutrient addition on the Prey Khmer soil is 1.9 t/ha (CIAP 1998). The predicted yield when larger quantities of nutrients are applied through the concomitant application of inorganic fertiliser and cow manure is 2.3 t/ha. The yields predicted by the model are comparable with those listed for the Prey Khmer soil in Table 4. Responses to cow manure applied alone are, however, lower than that predicted by the model. This is likely due to a lower N concentration in the cow manure used in these experiments than that derived from the average of the values in

Table 5. The average N concentration of cow manure in Table 5 is high due to very high N concentrations of cow manure from three locations.

These results contrast with the work reported on sandy soils of northeast Thailand where responses to inorganic fertiliser are absent or very small without concomitant cow manure addition (Ragland and Boonpuckdee 1987; Willett 1995). The lack of response to fertiliser on these soils has been ascribed to extremely low CEC and buffering capacity which makes it difficult to match nutrient supply to plant demand (see Willett 1995). Cow manure or straw applied with inorganic fertiliser alleviates these problems by enhancing soil reduction, and increasing soil CEC and buffering capacities which improve the retention of nutrients in the soil and the subsequent supply to plants.

Nevertheless, the flat responses to fertiliser application particularly on the Prey Khmer soil show that response to moderate or high fertiliser rates are limited. The regressions of CEC with the soil properties presented above indicate that the clay fractions of the Cambodian soils are probably less weathered than those of the Thai soils because of the greater relative contribution to CEC of the clay fraction. Possibly the inherent CEC, buffering capacity and nutrient supplying power of the Cambodian soils are sufficient to allow retention and supply of a low level of nutrients without the need for cow manure additions to increase CEC. Hence, good responses to small amounts of inorganic fertiliser occur without concomitant cow manure application. However, larger additions of cations through the application of inorganic fertilisers are likely to saturate the CEC of these soils and much of the fertiliser would likely be lost. Substantially higher rates of cow manure than applied in the Cambodian experiments conducted so far are likely to be required to improve the CEC and buffering capacity of these soils in order to achieve good responses to moderate and high rates of inorganic fertilisers.

Low activity clay soils

Soils with a weathered, loamy or clayey surface texture occupy about 20% of the rice-growing area in Cambodia and are classified within the Bakan group in the local soil classification (White et al. 1997b). The clay fraction in these soils is dominated by kaolinite, the CEC is generally very low and organic C levels are low, but higher than in the sandy soils described in Table 1. The low activity of the clay fraction is shown by the regression of soil pH, OC and percentage clay on CEC which shows that OC has a relatively larger influence on CEC than the percentage of clay in the soil (Table 2).

Responses to inorganic fertiliser and cow manure addition show a similar pattern as for the sandy soils. However, an interaction between cow manure addition and inorganic fertiliser addition may have occurred at Toul Bakha on two occasions (Table 4). Similar to the responses on the other soil types, however, increases in yield due to cow manure addition on the Bakan soil are likely to be explained primarily by the direct application of nutrients contained in the cow manure, even at the Toul Bakha site. Potassium was not applied as an inorganic fertiliser in this experiment and hence the interaction between the N and P addition and cow manure may be the result of an interaction between N, P and K applied with the cow manure. The Bakan soil type has low available K levels and responses to KCl application in the field have frequently been observed (CIAP 1998). It is important to note also that fertiliser response trials demonstrate that substantial yield increases are obtained by moderate and high inorganic fertiliser application rates on the Bakan soil type even without concomitant cow manure application.

Black clays

The Koktrap soil group has the highest level of OC of any soil group in the rainfed lowland rice-growing areas of Cambodia (Sovuthy et al. 1996). A regression of CEC with soil pH, OC and clay content shows that the OC has a very high influence on the CEC of this soil despite the high clay content (Table 2) and that relative to the other soils the CEC is highly dependant on soil pH. The buffering capacity of this soil is considerably higher than for the other soils described above and pH and redox changes upon flooding proceed at a slower rate (White and Seng 1997). In addition, the exchangeable Al level of this soils is about 3-fold that of the sandy soils, suggesting a stronger pH buffering capacity of these clay soils (Seng et al. 1999a). The use of straw in these soils was still beneficial in stimulating soil reduction and enhancing P availability to rice plants which led to increases in plant growth (Table 3).

The relatively high OC content of these soils is unusual for lowland rice soils which have experienced a long period of cultivation (Syers and Craswell 1995). Rapid declines in soil organic C levels usually follow clearing of native vegetation and cultivation. The high OC levels, therefore, suggest that these soils either contained very high levels of organic C before being used for agriculture, which have only now declined to their present levels, or that oxidation of organic matter in these soils proceeds very slowly. Available nutrient levels in this soil are also very low despite the higher OC content. High levels of Al present in this soil may hinder the further decomposition of organic matter and may be one reason for the low supply of nutrients and high OC of this soil (Seng, pers. comm.).

Yield increases of rice in response to inorganic fertiliser or cow manure additions to the Koktrap soil are similar to responses on the other soils although few experiments have been conducted. Again, no interaction between the application of CM and inorganic fertiliser has been observed (Table 4).

Long-term changes in soil properties

The research conducted in Cambodia to date has only related to the short-term (usually one season) consequences of fertiliser additions to the soil. There is scant information about the long-term changes in soil properties from yearly applications of organic or inorganic fertilisers. Given that rainfed lowland rice-growing environments are predisposed to high rates of organic matter oxidation because of the wet-dry moisture regimes, it is important to determine if it is indeed possible to increase soil organic matter levels, nutrient supply and rice yields, through regular additions of organic fertilisers over a long period. Differences between seedling nursery and mainfield areas may provide insights into long-term changes in soil properties because these areas are usually managed very differently by farmers for long periods.

Ros et al. (1998) compared the soil chemical properties of seedling nurseries with those of the mainfield of 15 farms on the Prateah Lang and Bakan soil types. On average, the seedling nurseries had been used continuously for a period of 6.9 years and they occupied 14% of the land area. The nurseries had received 9.6 t cow manure/ha and 13 kg N/ha. The main crop had received 1.5 t cow manure/ha; 19 kg N/ha; and 5 kg P/ha. Nutrients taken up by seedlings were exported (within the seedlings) to the main field at transplanting, but seedlings were also transplanted back into the old nursery area which was incorporated into the main cropped area. The nursery areas therefore received a second fertiliser addition as part of the main crop.

Shoot biomass at PI and straw yields were higher for plants harvested from the nursery area than for plants harvested from the main field (Table 6). Grain yields also tended to be higher, although, differences were not statistically significant. Shoot biomass and grain yields were significantly correlated with shoot N and grain N concentrations respectively but not P or K concentrations. Grain yields and straw dry weights were also correlated to the amount of cow manure added but not with total N applied (Ros et al. 1998).

The concentration of soil OC, total soil N, Olsen P and CEC were the same for both the nursery and the mainfield areas. Extractable and exchangeable K levels in the nursery soil, however, were lower in the mainfield than in the nursery soil.

These results indicate that long-term improvements in soil organic matter or nutrient status through the continuous application cow manure are difficult to achieve, if at all, on the Prey Khmer, Prateah lang and Bakan soil types, given the current rates of cow manure application and farming practices in Cambodia. Application of higher rates of cow manure may produce long-term increases in OC and nutrient status, as has been observed elsewhere (Supapoj et al. 1998). However, it should be noted that the rates of cow manure currently applied by Cambodian farmers are achieved by concentrating applications to the relatively small area of the nursery. Improvements in soil OC that would impact on total crop yields is likely to require a substantially higher rate of cow manure applied to a substantially larger land area than currently occurs. Clearly, there is not enough cow manure to go around.

Table 6. Crop yields and soil characteristics of nurseries and mainfields of farmers' fields on the Bakan and Prateah Lang soil types. Figure represent means ± standard deviation of 15 farms (Data from Ros et al. 1998).

Parameter	Mainfield	Nursery	P[a]
Shoot dry weight at PI (kg/ha)	19±4.6	24±6.1	0.019
Grain yield at maturity (kg/ha)	1039±444.5	1302±444.3	0.116
Straw yield at maturity (kg/ha)	1652±566.1	2078±580.2	0.052
Total Soil N (%)	0.03±0.004	0.03±0.008	0.784
Soil organic C (%)	0.22±0.051	0.25±0.076	0.169
Soil CEC (cmol$^{(+)}$/kg)	1.78±0.438	1.81±0.358	0.864
Extractable P (Olsen mg/kg)	0.44±0.226	0.56±0.266	0.208
Extractable K (cmol$^{(+)}$/kg)	0.03±0.008	0.02±0.008	0.054
Exchangeable K (cmol$^{(+)}$/kg)	0.03±0.011	0.02±0.010	0.045

[a] Probability level for the t distribution

The results of Ros et al. (1998) also indicate that the status of essential elements such as K may be declining in the nursery areas. A greater supply of N (either through inorganic N or cow manure) may have caused a greater uptake of K through higher biomass production of seedlings which in turn was be exported from the nursery area at transplanting. Potassium supplied with the cow manure may not have been sufficient to balance the K removed. This highlights the fact that organic matter, if derived from a soil deficient in a particular nutrient will contain low concentrations of that nutrient.

Studies discussed so far relate to cow manure application, which, because of its higher C/N ratio, decomposes quickly producing a small contribution to the relatively stable, slowly decomposing, soil organic matter pool (Wonprasaid et al. 1995). Other organic materials with higher C/N ratios (rice straw) or tannin contents (*Flemingia macrophylla* shoots) breakdown slowly and contribute more to this stable organic matter pool (Wonprasaid et al. 1995). Only one experiment in Cambodia has examined the effect of slowly decomposing organic materials (rice straw) on rice growth (Seng et al. 1999b). This experiment, however, aimed only to examine the short-term chemical changes in the soil and did not examine long-term soil OC changes.

Research and Extension Needs

Much of the recent research in Cambodia has concentrated on characterising soils and quantifying the response of rice to additions of organic or inorganic nutrient resources. Research has focused on this aspect of agricultural development because agricultural research capacity in the country is limited and there has been an increasing demand for this type of information as the economy has opened and agricultural inputs have become more available to farmers (Helmers 1997). Little research has thus far been conducted on understanding the processes of loss or fixation of nutrients in soils, nutrient availability and uptake by plants and the recycling of nutrients through animals, crop residues and pastures.

Research into these more fundamental processes of nutrient and organic matter management are important for Cambodia because responses of rice to nutrient and organic matter addition are different from those in neighbouring countries despite some similarities in some soil properties. Furthermore, as work expands to crops other than rice, the difference in soils and production systems are likely to become more apparent because the physical structure of soils assumes more importance. In addition, experience with green manure cropping in Cambodia has shown that technologies that are acceptable to farmers will involve small adjustments to current practices rather than the introduction of significant new practices. Hence it is important to understand the factors affecting the dynamics of nutrient and organic matter flows in soils so that a series of small and sensible adjustments in farming practice can be made that will lead to long-term improvements in soil quality and farm productivity.

As has been shown above, significant increases over the current very low yields can be achieved through simple technologies such as inorganic fertiliser addition. This has important implications for research directions. Emphasis for research on the Bakan soils should be to increase production through nutrient addition and then management of the increased biomass produced (roots, straw, stubble) to enable increases or stabilisation of soil OC levels. Research on the Prey Khmer and Prateah Lang soil types should similarly emphasise inorganic fertiliser management but also strategies for extra biomass production through growing legumes or other species in order to extend responses on these soils to higher rates of inorganic fertiliser application. Some specific recommendations for research and extension are discussed below.

There is a strong need to establish long-term trials examining the typical production systems in the country. Without these, it will not be possible to effectively manage the agricultural systems. Important aspects that need to be examined for lowland rice in Cambodia are:

1. the flows and balances of major nutrients;
2. the dynamics of organic carbon oxidation under different strategies of straw management and organic materials with different decomposition characteristics, and
3. the impact of land levelling and increased soil disturbance through mechanical cultivation of soils.

It is important to note that the emphasis of the long-term trials will vary with different soil types. In the sandy, Prey Khmer and Prateah Lang soils, trials are needed to examine the benefits of increases in the stable organic matter fraction of the soil through the use of slowly decomposing organic materials as has been shown in northeast Thailand. Factors influencing the quality of organic matter and the release of nutrients are probably more pertinent questions for investigation on the Koktrap soils.

Research is needed into methods of increasing total biomass production and incorporation of increased amounts of organic materials into the soil. As mentioned already, there is insufficient cow manure produced to significantly impact on crop production. Green manure cropping is one technology able to effectively use early season moisture to produce extra biomass which is incorporated into the soil to increase rice production (CIAP 1990; Becker et al. 1995). For various reasons, however, green manure cropping has proved inappropriate to farmers (Becker et al. 1995). New strategies are needed that make use of early season moisture.

Improved pasture production is one potential alternative. One strategy could be to establish a sparse, low quality grassy pasture each year at the beginning of the opening rains and let it grow until the soil is cultivated in preparation for the main rice crop. In some years when insufficient rain falls to establish a crop, the pasture may grow for the complete season, particularly on the upper paddies. Little use is made of this pasture except for low intensity cattle grazing. There is good scope to dramatically increase the quantity and quality of this pasture which will have benefits to animal health and production, rice yields and soil quality. Research into species composition, nutrient requirements and grazing management, however, is needed. Improving pastures would only require slight changes to the management of a resource that already exists rather than the introduction of new practices (as in green manure cropping) and hence may be easier to promote to farmers. However, free access to fallow land is usual in Cambodia regardless of ownership, hence, the common problems of improving and managing a collective resource would also need to be addressed.

The chemical dynamics of rice soils during flooding also requires further research in Cambodia. Significant changes in the pH and redox process occur when the soil is flooded and the amount and nature of organic matter in the soil, or added as an amendment, has a strong influence on the dynamics of these processes and hence influence the availability of nutrients to plants (Seng et al. 1999a). The small amount of research currently conducted on these processes needs to be expanded to a greater range of soils and organic materials.

Finally, the improved systems which are developed need to be applied and managed by provincial researchers, extension officers and farmers who have little understanding of formal agricultural science. If technologies are developed for specific soils and environments then these people must be able to identify these soils and environments in the field. Furthermore, to be effective, improved systems will need to be managed dynamically (rather than following a set of standard recommendations). Hence, the researchers, extension officers or farmers will need to recognise changes in the soil properties to determine if improvements are occurring or not. Simple indicators are required.

The agronomic soil classification of White et al. (1997a) and the Carbon Management Index of Blair et al. (1995) are two useful tools that need to be expanded. Research to improve the accuracy and applicability in the field of these tools is required and more tools need to be developed.

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The Management of Fertiliser Nutrients in Cash Poor Rice-based Systems of Southeast Asia—Examples from Vietnam

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Abstract

The present trend of land intensification in Southeast Asia's rice-based food production requires a constant increase in yield in order to maintain food security for the region's fast-growing population. During the 1990s, Vietnam has so far been the only country of Southeast Asia to meet increased food requirements, largely by increasing paddy yields from 3.2 to 4.0 t/ha between 1990 and 1998. This development was accompanied by a >150% increase in NPK fertiliser nutrient consumption during the same period, of which most was consumed in rice-based systems. The impact of fertiliser NPK, Ca, Mg, S nutrients applied with and without addition of farmyard manure (FYM) was studied during 3 years (1996–1998) at two representative sites on alluvial and degraded soils of the Red River in northern Vietnam. The results indicate that fertiliser nutrients are necessary to support large yields of spring rice and summer rice at both locations. A combination of adequate amounts of all the fertiliser nutrients tested and 10 t FYM/ha resulted in the largest yields for all the six crops tested at both sites. Such treatments supported average annual paddy yields of 12.9 and 8.8 t/ha on alluvial and degraded soils respectively. The omission of fertiliser N from such treatments resulted in average annual yield reductions of 2.8 t/paddy/ha on the alluvial soil. On the degraded soil, N and K were the most limiting nutrients and reduced annual average paddy yields by >2 t/ha when omitted from the best treatments. Next to N and K, Mg and S were the most limiting nutrients on the degraded soil tested. The results indicate that integrated plant nutrient management is required to support large annual paddy yields of 8–15 t/ha under conditions of land intensification, as presently experienced in Vietnam. Similar studies are needed in other parts of Southeast Asia to provide basic information for production oriented on-farm research and for nutrient management decision support in food crop extension.

DURING THE PAST decade of this century, Southeast Asia's population is expected to increase by more than 80 million and reach 525 million in the year 2000 (FAO 1999). Since rice area expansion is increasingly limited due to high costs of development, urbanisation and industrialisation, the harvested area of rice is expected to increase by only 3.7 million hectares between 1990 and 2000. In other words, the region will have to nourish an extra one person per hectare of rice farmland in the year 2000 compared to 1990.

This trend of land intensification requires a constant increase in output per unit rice land if Southeast Asia's food security with regard to its staple food is to be maintained. However, with the exception of Vietnam — and in part of Cambodia and Laos — rice yields have stagnated in countries of Southeast Asia during the 1990s (Table 1).

The authors have chosen examples from Vietnam to demonstrate and to discuss the impact of fertiliser nutrient application on rice yield under conditions of land intensification.

Between 1990 and 1998, Vietnam's harvested area of rice increased by 1.1 million hectares. During the same period, the production of rice in Vietnam increased by >9 million tonnes paddy and the country became a major rice exporter, although in 1998 it provided the staple food for over 78 million

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Table 1. Average rice (paddy) yields (t/ha) in Southeast Asia between 1990 and 1998 (FAO 1999).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cambodia	1.4	1.3	1.2	1.3	1.1	1.7	1.8	1.8	1.8
Indonesia	4.3	4.3	4.3	4.4	4.3	4.4	4.4	4.4	4.1
Laos	2.3	2.2	2.7	2.3	2.6	2.5	2.6	2.8	2.8
Malaysia	2.6	2.4	3.1	3.0	3.1	3.2	2.9	3.0	3.0
Myanmar	2.9	2.7	2.9	3.1	2.9	3.0	3.2	3.1	3.0
Philippines	2.8	2.8	2.9	2.9	3.0	2.9	3.0	2.9	2.9
Thailand	1.8	2.0	2.1	2.2	2.2	2.4	2.2	2.4	2.3
Vietnam	3.2	3.1	3.3	3.6	3.5	3.7	3.8	3.9	4.0
Southeast Asia	3.0	3.0	3.1	3.2	3.2	3.3	3.3	3.3	3.2

Vietnamese when compared with nearly 67 million in 1990 (Table 2).

Intensification was a major factor of this achievement and average annual paddy yields in Vietnam increased by 0.8 t/ha (compared to 0.2 t/ha in Southeast Asia) between 1990 and 1998 (Table 2).

Obviously fertiliser use contributed substantially to this development as annual NPK fertiliser nutrient consumption in Vietnam increased by >750 000 tonnes since 1990 (Table 2). It is estimated that 80% of presently consumed fertiliser N, 70% of fertiliser P and 40% of fertiliser K is applied in rice-based systems.

Assuming that in 1998 every hectare of rice received 5 t farmyard manure (FYM) in addition to NPK fertiliser, and 18 kg N, 2.6 kg P and 12.5 kg K were removed from Vietnam's rice soils per tonne paddy, the country's annual NPK nutrient input/output balance for rice would be expected to be presently positive for N and P but seriously negative for K (Table 3).

Table 3 indicates that, throughout the 1990s, about 20 kg K/ha, together with other essential nutrients such as Mg, S, Zn, etc., were mined annually from Vietnam's rice soils.

Materials and Methods

In order to study the effect of fertiliser nutrients on paddy yields, two field trials were initiated in 1996 on degraded soils and alluvial soils of the Red River in northern Vietnam. These soils can be clearly distinguished by their physico-chemical properties (Figure 1).

Alluvial soils are clays and their topsoils contain >2% organic carbon and relatively large reserves of P and K. CEC is >8 cmol/kg of which more than 80% is occupied by Ca and more than 10% by Mg. However, contents of exchangeable K are <0.2 cmol/kg and contents of available P (Olsen et al. 1954) are <20 mg/kg in topsoils of young alluvial deposits of the Red River.

By contrast, degraded soils derived from old alluvial deposits of the Red River and their topsoils contain >80% sand and silt and have small contents of organic carbon (<1.5%) and a CEC below 3 cmol/kg. Accordingly, reserves of P and K, and also the contents of exchangeable Mg and K, are small (Figure 1).

The field experiment on the alluvial soil is located at Thuong Mo commune, Dan Phuong District, Ha

Table 2. Population, harvested area, production and yield of paddy, export of rice and NPK fertiliser nutrient consumption in Vietnam, 1990 and 1998 (FAO 1999).

	Unit	1990	1998	Increase 1990–98	% Increase
Population	(M)	66.7	78.2	+ 11.5	17.2
Area harvested	(M ha)	6.0	7.1	+ 1.1	18.3
Production (paddy)	(M t)	19.0	28.2	+ 9.2	48.4
Yield (paddy)	(t/ha)	3.2	4.0	+ 0.8	25.0
Export (rice)	(M t)	1.6	3.9	+ 2.3	144.0
NPK consumption	(000 t)	483	1235	+ 752	156.0
N	(000 t)	419	930	+ 511	122.0
P	(000 t)	45	163	+ 118	262.0
K	(000 t)	19	142	+ 123	647.0
N:P:K	(N = 100)	100:11:5	100:18:15		

Table 3. Total NPK nutrient input/output balance for rice (paddy) in Vietnam, 1991 and 1998 (IFA 1992; IFA et al. 1994; FAO/RAPA 1994; FAO 1999).

	1991 Area: 6.3 M ha; Production: 19.6 M t			1998 Area: 7.1 M ha; Production: 28.2 M t		
	N	P	K	N	P	K
FYM*(Kt)	126	20	132	142	23	148
Fertiliser** (Kt)	163	10	0	446	69	57
Crop removal*** (Kt)	–353	–51	–245	–507	–73	–352
Balance (Kt)	–64	–21	–113	+81	+18	–146
Balance (kg/ha)	–10	–3	–18	+11	+3	–21

* 5 t FYM/ha (4 kg N, 0.7 kg P, 4 kg K per t FYM); ** Fertiliser recovery: N, P = 60%, K = 100%); *** 18 kg N, 2.6 kg P, 12.5 kg K per tonne paddy.

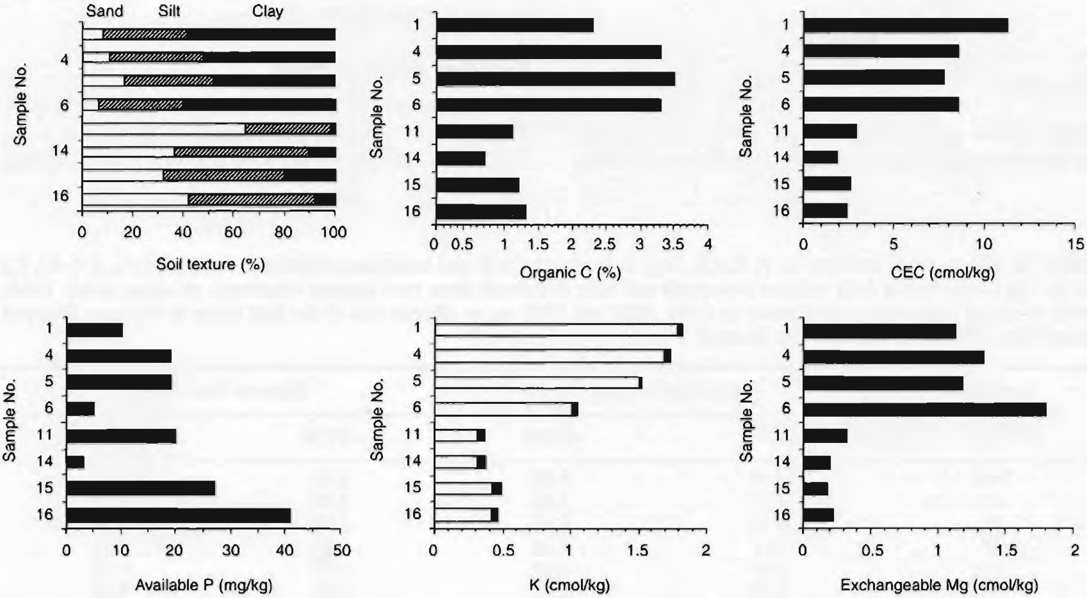

Figure 1. Selected characteristics of topsoils of alluvial (Sample numbers 1, 4, 5, 6) and degraded soils (Sample numbers 11, 14, 15, 16) of the Red River in northern Vietnam.

Tay Province. Average values for pH (KCl), organic C, total N, total P and total K in the topsoil were 5.5%, 2.2%, 0.21%, 0.04% and 1.6% respectively before the start of the experiment.

A rice-rice-maize rotation was grown in 1996, 1997 and 1998 under irrigation. Since crop production at the degraded soil site is limited to two rice crops per year, this paper will discuss the impact of fertiliser nutrients on yields of spring rice and summer rice at the alluvial and degraded sites.

The degraded soil site is located at the Ha Bac Station for Degraded Soils Improvement, Hiep Hoa District, Bac Giang Province. Average contents of organic C, total N, total P and total K in the topsoil were 0.68%, 0.07%, 0.04% and 0.08% respectively, before the start of the experiment.

A randomised complete block (RCB) design is used at both sites. Plot size is 20 m^2 at the alluvial soil site and 24 m^2 at the degraded soil site. Each treatment is replicated three times.

The 14 treatments at each site are: Full treatment (N, P, K, Ca, Mg, S) = T_1, Full –N, Full –P, Full –K, Full –Ca, Full –Mg, and Full –S ($T_2 – T_7$) and Full + treatments ($T_8 – T_{14}$) which include FYM at the rate of 10 t/ha in addition to the fertiliser nutrients applied with treatment $T_1 - T_7$. Treatments will continue until 2001.

The fertiliser nutrient rates applied on the alluvial soil are: Spring rice: Full = (kg/ha) 150 N, 52 P, 50 K, 143 Ca, 24 Mg, 33 S. Summer rice: Full = (kg/ha) 120 N, 39 P, 50 K, 143 Ca, 24 Mg, 33 S.

The fertiliser nutrient rates applied on the degraded soil are: Spring rice: Full = (kg/ha) 120 N, 39 P, 100 K, 143 Ca, 24 Mg, 33 S. Summer rice: Full = (kg/ha) 90 N, 26 P, 75 K, 143 Ca, 24 Mg, 33 S.

Nutrient sources are urea, DAP, SSP, MOP, SOP, CaO, kieserite, MgO, elemental sulfur and local FYM.

Results

Site effect

Paddy yields of spring and summer rice were larger on all treatments applied on the alluvial soil in 1996, 1997 and 1998 when compared with those on the degraded soil (Tables 4 and 5, Figures 2 and 3).

Manure effect

Paddy yields of spring rice and summer rice in 1996, 1997 and 1998 on a per crop basis were largest in treatments which included application of FYM (Full +). When compared with full fertiliser N, P, K, Ca, Mg, S treatments (Full) the addition of 10 t FYM/ha, resulted in yield increments of 12%–18% on alluvial soils and 9%–22% on degraded soils of annual accumulated (spring rice + summer rice) paddy (Tables 4 and 5). The 'Full +' treatments resulted in the largest average annual paddy yield in all 3 years: 12.9 t paddy/ha on alluvial soils and 8.8 t paddy/ha on degraded soils (Figure 2).

Fertiliser nutrient effect

The omission of N, P and K from the full fertiliser N, P, K, Ca, Mg, S nutrient treatment (Full) and from the 'Full +' treatment reduced paddy yields of spring

Table 4. Effect of full fertiliser N, P, K, Ca, Mg, S treatment (Full) and treatments without N (– N), P (–P), K (–K), Ca (–Ca), Mg (–Mg) and S (–S) without (–manure) and with additional farm yard manure (+manure) on mean paddy yields (t/ha) of spring and summer rice grown in 1996, 1997 and 1998 on an alluvial soil of the Red River in Vietnam (Nguyen Trong Thi, 1997, 1998; Nguyen Van Bo et al. 1999).

Treatment	Spring rice (t/ha)		Summer rice (t/ha)	
	–FYM	+FYM	–FYM	+FYM
Full	6.13	6.86	5.11	6.05
–N	4.78	5.40	3.49	4.70
–P	5.72	6.13	4.39	5.08
–K	5.61	6.18	4.50	5.29
–Ca	5.97	6.62	4.97	5.78
–Mg	5.90	6.64	4.99	5.82
–S	5.93	6.68	4.82	5.74

Table 5. Effect of full fertiliser N, P, K, Ca, Mg, S treatment (Full) and treatments without N (–N), P (–P), K (–K), Ca (–Ca), Mg (–Mg) and S (–S) without (–manure) and with additional farm yard manure (+manure) on mean paddy yields (t/ha) of spring and summer rice grown in 1996, 1997 and 1998 on a degraded soil of the Red River in Vietnam (Nguyen Trong Thi 1997, 1998; Nguyen Van Bo et al. 1999).

Treatment	Spring rice (t/ha)		Summer rice (t/ha)	
	–FYM	+FYM	–FYM	+FYM
Full	4.00	4.70	3.63	4.06
–N	2.93	3.48	2.82	3.20
–P	3.49	3.99	3.28	3.63
–K	3.14	3.58	2.59	3.02
–Ca	3.78	4.30	3.46	3.88
–Mg	3.41	3.95	3.01	3.36
–S	3.60	4.25	3.09	3.54

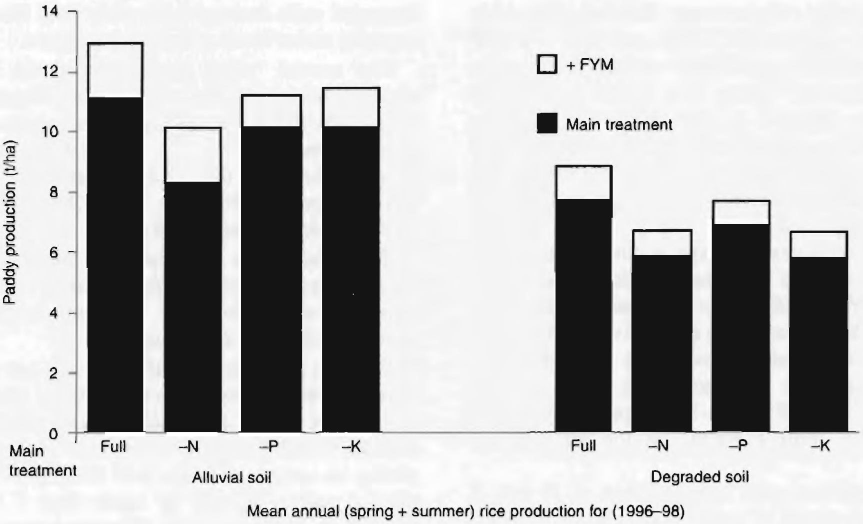

Figure 2. Effect of fertiliser nutrients with and without N, P, K and farmyard manure on average annual (1996–1998) accumulated paddy yield of spring and summer rice on alluvial and degraded soils of the Red River in Vietnam (Nguyen Trong Thi 1997, 1998; Nguyen Van Bo et al. 1999).

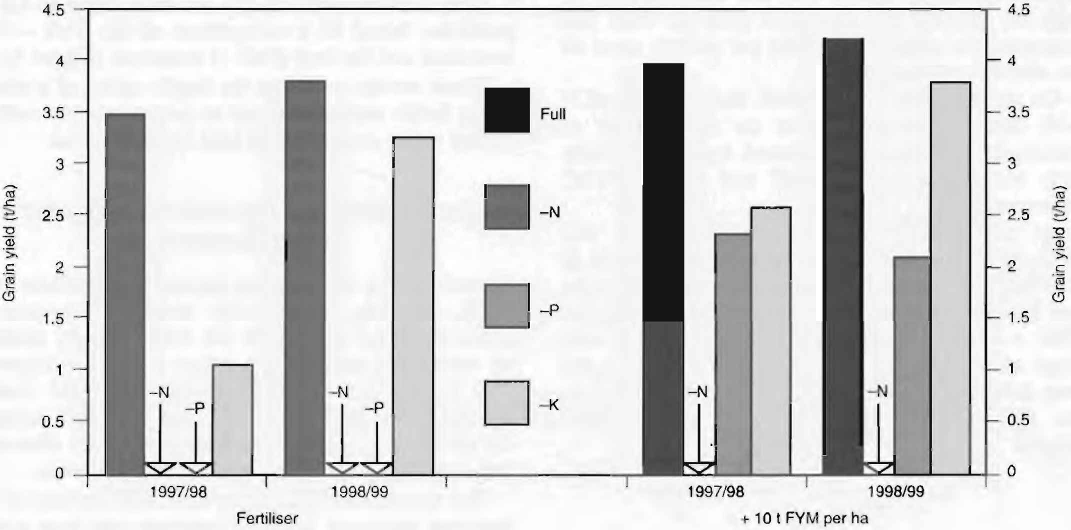

Figure 3. Effect of fertiliser nutrients with and without N, P, K and farmyard manure on grain yield of hybrid winter maize on an alluvial soil of the Red River in Vietnam 1997 – 1999 (Nguyen Trong Thi 1997, 1998; Nguyen Van Bo et al. 1999). Full = 180 N +52 P +75 K +143 Ca +24 Mg +33 S (kg/ha); arrows indicate no yield.

rice and summer rice on alluvial and degraded soils significantly in all 3 years.

The reduction of paddy yield was largest when N was omitted from the 'Full' and 'Full + FYM' treatment on the alluvial soil (Table 4, Figure 2) and when N and K respectively were omitted from the 'Full' and 'Full +' treatments on the degraded soil (Table 5).

The omission of Ca, Mg and S resulted in comparatively small reductions of paddy yields on the alluvial soil when compared with 'Full' and 'Full + FYM' treatments (Table 4).

On the degraded soil, however, the omission of Mg (–Mg) and S (–S) from the 'Full' and 'Full + FYM' treatments resulted in significant reductions in paddy yield in all 3 years. Spring rice yields in 1998 for example were reduced by 0.9 and 0.7 t paddy/ha when Mg and S were omitted from the 'Full + FYM' treatment and similar yield reductions in summer rice resulted from the omission of Mg and S in 1997 and 1998 on the degraded soil.

Based on the 3-year average accumulated annual yield the omission of N reduced paddy yield on the alluvial soil by 2.8 t/ha when compared with 'Full' and 'Full + FYM' treatments respectively (Figure 2).

Omission of P and K resulted in smaller reductions of 1 t/ha when compared with 'Full' and 1.7 and 1.5 t/ha for –P and –K, respectively, when compared with 'Full + FYM' on the alluvial soil (Figure 2).

On the degraded soil, the omission of N and K resulted in reductions of average annual paddy yields of 1.8 and 1.9 t/ha when compared with 'Full'and 2.1 and 2.2 t/ha for –N and –K, respectively, when compared with 'Full + FYM' (Figure 2).

The omission of K clearly increased the rate of unfilled grains in spring rice and summer rice on both the alluvial and degraded soils in 1998 and decreased the number of grains per panicle most on the alluvial soil in that year.

On the degraded soil in 1998, the omission of N (–N) had the largest impact on the number of panicles/m^2 which were reduced by up to nearly 30% when compared to 'Full' and 'Full + FYM' treatments.

At the alluvial soil site in 1997–1998 and 1998–1999, omission of nitrogen (– N) resulted in crop failure of the hybrid maize crop succeeding the two annual rice crops even when FYM was applied (Full + – N). The low availability of P after two crops of rice per year is seen as a major reason for crop failure of maize in the 'Full – P' treatments in the 1997–98 and 1998–99 winter crop seasons (Figure 3).

Discussion

Under conditions of rice land intensification as presently experienced in Vietnam, balanced fertilisation using a combination of N, P, K, Ca, Mg, S nutrients and farmyard manure can increase average annual paddy yields by 3 t/ha according to these 3-year experiments at representative sites on alluvial and degraded soils of the Red River in northern Vietnam.

Obviously, the higher level of native soil fertility of the alluvial soil, which derived from geologically younger deposits of the Red River can, for the present, support higher yields when compared with degraded soils derived from older Red River alluvial deposits under similar fertiliser regimes.

The annual 'yield gap' between the best treatments (Full +) on the alluvial and degraded soils, based on a 3-year average, was more than 4 t paddy/ha and this was increased to more than 6 t paddy/ha between the 'Full +' treatment on the alluvial soil and the 'Full + – N' or 'Full + – K' treatments on the degraded soil.

Thus cash poor rice farmers on degraded soils may substantially reduce their income if they cannot afford essential fertiliser nutrient inputs, as, for example, nitrogen and potassium.

Farmers on degraded soils who are not able to use farmyard manure of sufficient quality and quantity, and cannot afford essential fertiliser nutrient inputs such as N and K may see their average annual paddy yields, as compared to the best treatment (Full +) on alluvial soils, reduced by more than 7 t paddy/ha (Figure 4). The long term (30 years) annual average paddy yield at Ha Bac Station was found to be as small as 2 t/ha where neither fertiliser nor manure had been applied.

On alluvial soils, the annual 'yield gap' caused by a single fertiliser nutrient (N) can be as large as 4.6 t paddy/ha, based on a comparison of the 'Full – N' treatment and the best (Full +) treatment (Figure 4).

These results underline the fragile status of a relatively fertile soil with regard to nutrient supply sufficiency under conditions of land intensification.

Conclusions and Recommendations for Future Research

A combination of adequate amounts of fertiliser N, P, K, Ca, Mg, S nutrients and 10 t farmyard manure/ha/crop resulted in the largest paddy yields of spring and summer rice when tested in comparison to treatments with and without FYM from which single fertiliser nutrients were omitted during six rice crops in three consecutive years on alluvial and degraded soils of the Red River in Vietnam.

The results clearly indicate that combinations of a balanced supply of fertiliser nutrients and farm yard manure are required to support large annual paddy yields of 8–15 t/ha under conditions of land intensification, as presently experienced in Vietnam.

The application of 10 t FYM/ha/crop is usually insufficient to compensate for essential fertiliser nutrients in situations of limited supply from the soil and thus makes its use less efficient, and less economic, than in combinations with fertilisers which contain sufficient N, P, K, Ca, Mg and S. This applies especially to N on the alluvial soil of the Red River and to N and K (in some cases also to Mg and S) on the degraded soil of the Red River tested during 1996–1998.

The authors conclude that integrated nutrient management, the combination of fertiliser nutrient supply and recycling of nutrients in residues and manures is the most effective way to support increasing rice yields in Southeast Asia under conditions of land intensification.

Medium to long-term studies, such as the ones reported here on representative soils and in economic environments of Southeast Asia, are needed to study the effects of single plant nutrients in this respect.

A network of representative experimental sites is to be interlinked with researcher managed and farmer managed on-farm research on integrated crop management in order to study and monitor the impact of fertiliser nutrient application under realistic conditions.

An easy to use database for integrated crop management is required for rice-based systems in Southeast Asia. Such a database would allow the involvement of extension services, presently the weakest link in a chain between research and farm, to develop research-based food crop production in Southeast Asia and to monitor the role of production factors such as fertiliser nutrients in rice based systems, and their impact on yield and quality of the staple food.

Close and broad-based monitoring is essential at a time when unprecedented growth of population and food demand in Southeast Asia is changing plant nutrient resources in regional soils faster than ever before in human history.

Acknowledgments

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A Network Approach to Improving Nutrient and Organic Matter Management of Infertile Acid Soils

R.D.B. Lefroy[1] and D. Santoso[1]

Abstract

There is a great need to develop improved land management systems that increase agricultural production while maintaining the resource base so as to achieve food security and reduce poverty. The greatest need for improved land management is on the inherently marginal areas and in areas that have become marginal due to severe degradation. The challenge is to identify what sustainable land management (SLM) is feasible, where different strategies can be applied, and how particular strategies can be implemented. The IBSRAM acid soil network has been operating in Southeast Asia since 1990. During this time, the research focus has shifted from reduction in Al toxicity, through lime and organic matter management, to the current focus on improved management of phosphorus. A generic design for researcher-managed, on-farm experiments was developed and currently is in use in eight sites in Vietnam, Philippines, Indonesia, and Myanmar. These experiments aim to assess the response to P, the value of different inorganic and organic sources of P, and the interactions between these sources. Thorough characterisation of the treatments and of the socio-economic and biophysical aspects of the sites is a critical part of the network. In addition, there is a focus on improving the quality of laboratory analyses and the management and use of research data. Information gathered across this range of sites should allow greater insights into the underlying processes and thus better appreciation of the situations in which particular strategies are best suited. Supporting activities include more detailed studies to understand the underlying processes of particular strategies, the development of techniques and indicators to improve the matching of strategies to particular environments, and farmer-managed on-farm trials, to appreciate the potential for adoption and methods of extension and implementation. While further identification and development of land management strategies is important, the twin problems of matching appropriate strategies to particular situations and encouraging the implementation of improved management strategies by resource-poor farmers are seen as the most limiting steps to widespread achievement of food security and reduced poverty.

DESPITE major gains during the past four decades, the world requires still greater increases in agricultural production, particularly in developing countries. The ever increasing world population, the inadequate per capita food consumption in many parts of the world, and the dwindling reserves of quality arable land combine to exert considerable pressure on land resources (Lefroy and Craswell 1998).

Increased agricultural production relies on the implementation of sustainable land management (SLM) in different agricultural systems. Firstly, output from the highly productive agricultural systems must be maintained and made more sustainable. Secondly, management strategies that reverse land degradation must be developed and implemented where reversal is possible. Thirdly, SLM systems must be developed for the lands not currently in use, which tend to be the more marginal lands. As the reserves of good quality land decrease and the area of degraded land increases, greater agricultural production will rely on sustainable management of both

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the marginal uplands and the marginal rainfed lowlands.

There are three critical steps that must be followed in developing and implementing improved land management strategies. Firstly, a range of practical strategies must be identified. These may be selected from current local practices, from practices introduced from other areas, or from practices developed through research and adaptation of other management strategies.

Secondly, an appropriate management strategy must be selected from the suite of strategies such that the strategy matches the particular characteristics of the system. This selection must be done on the basis of biophysical, sociological, and economic characteristics, and must involve thorough appreciation of the constraints and potential of the systems.

Finally, the farming communities must implement the appropriate strategies, which may require particular extension methods, specific government policies, and the intervention of government and non-government agencies. Clearly, these are not three activities separate in both space and time, but form a continuum from research, to development, to implementation. The process of identifying what strategies are feasible will indicate some of the critical characteristics required when matching strategies to an environment. Similarly, activities in the first two stages may end up being part of the implementation process.

A Network Approach

A network approach to developing SLM strategies, such as that used in the IBSRAM *ASIALAND* Management of Acid Soils network, can assist in achieving these three critical steps – *what* strategies are feasible, *where* can different strategies be applied, and *how* can particular strategies be implemented. A network allows coverage of a wide set of biophysical and socioeconomic conditions, and thus a chance for better understanding of the underlying processes and development of methods for overcoming particular limitations. This, in turn, can lead to better matching of strategies to specific systems. In addition, a network allows improved transfer of information between countries and institutions and the sharing of knowledge and experience in research, development and implementation.

Essential to the success of this approach are the use of multidisciplinary and interdisciplinary approaches and the active participation of farmers, extensionists and researchers. One expected outcome of this approach is improved understanding of specific SLM strategies, but a second important outcome is a significant improvement in the capacity of all the collaborators, as individuals, as institutions, and as groups of institutions, to undertake quality collaborative research, development and implementation towards improved SLM.

The Constraints of Infertile Acid Soils

The first step in focussing on research and development of SLM strategies for infertile acid soils is to identify the constraints to production. Most of the marginal soils of the tropics and subtropics are marginal because of low fertility or poor water supply, or both. Many of these infertile marginal soils are infertile acid soils, particularly infertile acid upland soils. It is estimated that there are approximately 2 billion hectares of acid soils in the tropics (Von Uexkull and Mutert 1995). The acid upland soils of the tropics and subtropics are inherently infertile as a result of a wide range of nutrient deficiencies, associated low amounts of soil organic matter (SOM) and low anion and cation exchange/adsorption capacity, and a number of toxicities. Correction and proper management of these limitations can yield productive and sustainable farming systems; failure to do so exacerbates the problem through further degradation.

In many cases, nitrogen is the major nutrient limiting agricultural production in tropical cropping systems (Sanchez et al. 1997). While inorganic N fertilisers are important, particularly in the more productive cropping systems such as irrigated rice, sustainable N replenishment strategies, particularly for low to medium input systems on marginal soils, can rely on biological N_2 fixation (BNF) processes, with limited reliance on chemical fertilisers. In many systems, phosphorus is the next most limiting nutrient and, considering the impact of correct P nutrition on BNF, amendments to correct P deficiencies can become the most important input management strategy in many low input systems. Although biological supplementation and recycling are important, there is no biological approach for adding P, as with BNF for N. As such, improved P management strategies are likely to continue to rely on fertilisers (Sanchez and Cochrane 1980; Fairhurst et al. 1998).

Clearly, P and N are not the only nutrient problems. Once management strategies have been established to improve the P and N fertility of soils, the status of other nutrients may or, in time, will limit production. Consequently, an initial focus on P and N management must be expanded to an integrated plant nutrient management approach. Deficiencies of other macro and micronutrients are common on acid soils and these must be addressed. In addition, as production and offtake increase, there will be a need to balance removals, especially where nutrient reserves are low.

Similarly, once nutrient problems have been addressed in infertile soils, attention must turn to problems with the hydrologic cycle. Many limitations, such as the amount and distribution of rainfall, cannot be addressed other than in the limited cases in which irrigation is available. However, the availability of soil water can be affected by SLM strategies through the choice of crop and crop rotation, and through the management of ground cover, SOM, nutrient supply, and tillage, which in turn have considerable impact on the nutrient cycles, thus demonstrating the highly interrelated nature of carbon, nutrient and water cycles.

Focusing on Phosphorus

Deficiency of P is widespread in the tropics and subtropics. Different estimates suggest that there are approximately 2 billion hectares of soils in the tropics that are likely to respond to P (Sanchez and Cochrane 1980; Von Uexkull and Mutert 1995; Fairhurst et al. In press). It is likely that SLM strategies for improved fertility management of these marginal soils will involve adaptation of the farming systems with greater reliance on organic sources of nutrients, combined with the judicious use of inorganic fertilisers. Although much is known about phosphorus, more remains to be done. There is reasonably good understanding of the management of phosphorus with inorganic amendments, less detailed information on management with organic forms, and limited information on the interaction of organic and inorganic forms. Even with those areas where the processes are understood, there is limited capacity to match management strategies to farming systems, including crop rotations, perennial cropping systems, and livestock. Practical recommendations are required that improve the synchrony of phosphorus supply and plant demand through management of organic and inorganic amendments, and other aspects of system management.

The IBSRAM Acid Soils Network

With the critical nature of P in limiting agricultural production on marginal lands, the IBSRAM acid soils network aims to contribute to this knowledge of P nutrition through high quality applied and appropriate research. Prior to 1996, the focus of the network was on amelioration of the toxic effects of Al and low pH. The current phase of the IBSRAM acid soils network concentrates on overcoming the limitation of P on agricultural production. The objective is to contribute to the process of improving management of infertile marginal soils, with a particular focus on improved management of phosphorus in the acid upland soils of Southeast Asia.

A systematic approach is taken in the network towards the development of SLM strategies for the marginal infertile acid uplands through a core set of activities undertaken by the majority of collaborators and a number of important related initiatives with a limited number of the collaborators. The collaborators from the national agricultural research and extension systems (NARES) in SE Asia are the National Institute for Soils and Fertilisers (NISF) in Vietnam, the Bureau of Soil and Water Management (BSWM) and the Central Mindanao University (CMU) in the Philippines, the Center for Soils and Agroclimate Research (CSAR) and the University of Gadjah Mada (UGM) in Indonesia, and the Land Use Division of the Myanmar Agriculture Service (LUD-MAS). Additional activities involve a number of government institutions in Indonesia and Thailand, and limited involvement of similar institutions in most of the countries of ASEAN. Developed country research organisations involved in the network include the University of Queensland and the Queensland Departments of Natural Resources (QDNR) and Primary Industry (QDPI) in Australia, and Massey University (MU), New Zealand, with limited interaction with other international research institutions.

The network aims to establish quality analytical and experimental methodologies, develop and implement appropriate field experiments concentrating on inorganic and organic P management, and thoroughly assess the socio-economic characteristics of the farming systems and of the experimental treatments. In this approach, it is recognised that sound scientific and sociological methods and principles must be used in the interpretation of any improved crop growth that might be achieved by various treatments. In addition, the results of field experiments will be implemented and extended successfully to other sites only if the results take full consideration of the socioeconomic context. This approach helps with the *what*, *where*, and *how* components of achieving SLM.

A generic experimental design to evaluate different P management strategies was developed and adapted for the local biophysical and socioeconomic conditions. The designs were applicable to particular sites, but the similarity in designs allowed for greater interpretation of results across different socioeconomic and biophysical environments. The primary aims of the experiment were to assess the responsiveness to a chemically available P form, to assess the relative response to different inorganic and organic materials, and to assess the interactions between organic and inorganic sources.

The responsiveness to P is assessed with readily available P sources that have undergone different degrees and methods of acidification, such as triple superphosphate, single superphosphate, and SP 36 – a phosphate fertiliser produced in Indonesia, which contains 36% P_2O_5, or 16% P. The inorganic/organic combinations included these same sources plus some sources of inorganic P that are less available, in the chemical sense, such as fused magnesium phosphate, and different phosphate rocks from North Carolina, Christmas Island, and the Peoples Republic of China. The organic sources were chosen on the basis of what was available, or may become available, for transfer within or importation from outside the farming system. They included the retention of corn residue where this was not normal practice; application of chicken manure purchased from commercial chicken farms; farmyard manure, generally from on-farm sources; Tricho compost produced with the fungal agent *Trichoderma harzianum*; the cuttings of *Stylosanthes guianensis* grown under the corn; cuttings of *Tithonia diversifolia* from field edges; and for the sites in Australia, residues of *Lablab pupureus* and Rhodes grass (*Chloris gayana*). The treatments were chosen after discussions with collaborating scientists and surveys of farmers, farm suppliers, and the local agro-industries.

The inclusion of basal or treatment applications of lime depended on the pH of the soils. At sites with soils of very low pH, lime was included as a basal application, with the exception of a number of treatments without lime to assess the impact of lime. Similarly, at sites with soils of pH 5 or above, if lime was used, it was applied to a limited number of treatments, to assess the impact of adding lime. Basal lime applications were not applied to treatments with rock phosphate.

Most of the field trials are located on farmers' fields that were assessed as being representative of a major soil type and agroecosystem in the area. The experiments in Myanmar and Australia are located on research stations for reasons of access and management.

Site characterisation

An essential component of running good field experiments, particularly medium to long-term multi-site experiments, is careful characterisation of the sites. This is important for running and interpreting a good experiment, but more importantly, it allows far greater comparison of the results from different sites, and thus aids in the development of relatively site-specific management recommendations. A range of techniques was used to characterise the sites.

Firstly, the available P and P supply capacity were assessed. The network sites cover a wide range of soils in terms of the available P and P sorption characteristics. As there is particular interest in the immediate availability and the residual value of different forms or organic and inorganic P, a limited set of soils samples have been collected for measurements of P fractions using a modification of the technique of Hedley et al. (1982).

Carbon has not been a major focus of the network; however, the importance of the carbon cycle in nutrient and water supply means that there is interest in the impact on soil carbon. Improvements have been made with respect to the method for measuring total soil carbon, and it is hoped that some of the treatment differences will be revealed using measurements of labile carbon (Blair et al. 1995).

Soil analyses and glasshouse trials were used to assess the nutrient status and indicate likely basal nutrient applications. Although variability in soils is the reality with which the farmer must cope, minimising heterogeneity, or at least understanding the variability, is important in the experimental context. Site uniformity was assessed, with soil analyses and growth trials. Together these analyses and experiments improved the capacity to select the rates of treatments and basal fertilisers, and improved the potential quality of data by minimising experimental error.

In order that results can be interpreted accurately, it is essential that there are sufficient data to characterise all fertilisers and organic materials. Samples of all fertilisers and organic materials have been analysed to estimate total and, in some cases, available nutrient contents, although further analyses, using different methodologies will need to be undertaken.

Choosing analytical methods for the less available inorganic sources, and for the organic sources, presents some problems. For organic materials, information is required on the moisture content of the material as applied, the total content of inorganic elements, the content of particular organic compounds and an estimate of breakdown rate. The rate of breakdown can be estimated by measuring the particular organic compounds that affect breakdown (Tian et al. 1995; Palm and Rowland 1997) or by a more empirical approach (Lefroy et al. 1995).

Results

Results to date indicate responses to additions of P at all sites, albeit to different degrees and at different yield levels. Similarly, there have been significant differences in response to the different inorganic and organic forms and combinations of P fertilisers and organic amendments. The combinations of inorganic and organic sources have produced large differences between treatments. The less available inorganic sources (fused magnesium phosphate and rock phosphate) result in lower yields, although it appears that the relative differences are declining with time as the residual benefits accrue. As for the organic sources, the higher quality inputs, such as chicken manure and farmyard manure (FYM), are out-yielding the lower quality materials from plant residues, such as corn residue, although there is limited evidence that the impact of additions of carbon from the lower quality, slower breakdown materials may have a significant impact on crop growth at the poorer sites, particularly through improved soil physical conditions.

The challenge facing the network as the amount of data increases is to assess these significant responses in terms of the characterisation of the soil and the different fertilisers and organic amendments. With good experimental data and good characterisation, the information from all sites should aid in improving our understanding of the underlying processes controlling the dynamics of P and other nutrients.

The results of supporting biophysical studies, such as the soil P fractionation work at UQ and QDNR, the rhizosphere studies at Massey University, and sulfur work at CSAR, will further aid the identification of strategies which are biophysically sustainable.

Improved management of data is critical to this process. Increased use and, where possible, standardisation of computer-based spreadsheets/databases is essential to the network for analysis of data across years at each site, across sites, and ultimately for dissemination to the wider research and development community. Data management, analysis and interpretation needs to be improved in most national, bilateral, and multilateral research activities, particularly for research and development in the more marginal lands.

Matching Strategies to Systems Conditions

The identification of feasible SLM strategies is an important step towards the establishment of sustainable agricultural systems, but the matching of strategies to particular agroecosystems is an equally important step that has received comparatively little attention. The first part of matching strategies to systems is to gain a thorough understanding of the system. This involves appreciation of the current status of land management, production, and the resource base, and evaluation of the potential of the system, and an assessment of the reasons for a gap between the current system, in terms of production and the quality of the resource base and the potential.

Experimental results can be useful in appreciating the constraints and potential of the system and possible reasons for yield gaps, but a much broader information base is required. This involves the use of a wider range of data collection/acquisition techniques such as village resource mapping, biophysical and socioeconomic surveys of individual farms and of farming communities, the use of secondary data sources such as national statistics on yield, land use, etc., and observations and measurements, possibly associated with the surveys, on yield, available nutrients and SOM in the soil, nutrient balances, etc.

As some of these methods are fairly new to those involved in agricultural research and development, training is required, particularly in farmer participatory approaches. In addition, there is a need to improve laboratory facilities and procedures. This is critical for research purposes, and it is required for the broader-scale assessment of system characteristics for improved matching of strategies.

As improved management and interpretation of experimental data is critical, so is improved management of the broader-scale data for matching strategies to the characteristics of the agroecosystems. The increased ease with which data can be geo-referenced and with which the geo-referenced databases can be handled by non-experts has enormous potential for facilitating the matching of appropriate strategies to the characteristics of particular locations. Further developments will include the coupling of geo-referenced system characterisation, as Resource Management Domains (Dumanski and Craswell 1998), with user-friendly decision support systems for much easier and more accurate matching of strategies to locations.

As simple or sophisticated information management systems are developed, the critical question is the quality and the relevance of the data. The development or improvement of methods, followed by training, will increase the quality of data, be it laboratory, field experiment, or survey data. The relevance of the data is more of a problem. The more we understand the underlying processes, the more relevant will be the data collected to characterise locations and systems. However, if we end up with relevant measurements that are too time-consuming or expensive to collect, then the data density for characterisation will not be sufficient; which will have greatest impact in the marginal areas. For this reason, an important step in the analysis and interpretation of data is the identification or development of surrogate indicators which are good proxies for more complicated data, integrate a number of indicators, or both, and which are easily measured or observed.

Prime examples of surrogate indicators are simplified soil and plant testing methods, simplified soil classification systems based on relatively simple observations or data (colour, texture, soil depth, pH, etc.) (White et al. 1997), and the use of particular plants (weeds, crops, and other non-agricultural plants) to indicate parameters such as acidity, available nutrients, toxicities, etc.

A particularly useful and relatively simple indicator is an estimate of the nutrient balance of systems. Although the net removal of nutrients can continue without negative consequences for some time, eventually there will be a negative impact on the resource base and on productivity. Nutrient balance studies have been used in sub-Saharan Africa (Stoovogel et al. 1993) and Central America (Stoorvogel and Smaling 1998) to estimate some alarming annual losses of nutrients at the regional, farm and field levels. Crude estimates of nutrient budgets for different crops in Northeast Thailand indicate reasons for concern (Lefroy and Konboon 1998) and led to the development of a project on nutrient balance studies in Northeast Thailand (NBS-NET), which is associated with the acid soils network. NBS-NET aims to develop improved databases on nutrient balances in rainfed rice-based cropping systems and, in so doing, develop improved methodologies for calculating nutrient budgets at the field, farm and higher levels.

The nutrient balance is calculated as the inputs minus the outputs of nutrients from the system. At its simplest, this considers the input of fertilisers and output in products; however, a more complete budget is based on more components (Table 1).

Table 1. The components of nutrient input and output used to estimate nutrient budgets.

Inputs	Outputs
Fertiliser	Product
Organic materials	Residues removed
BNF	Gaseous losses
Wet and dry depositions	Leaching
Sedimentation	Runoff/Erosion

In general, the components towards the top of each column are more easily and accurately measured or estimated than those towards the bottom.

Its is hoped that a simple nutrient balance calculator can be developed from these studies. Such a calculator could be in the form of a simple set of printed look-up tables, or of a computer-based database/spreadsheet with a simple interface. To be of significant use in the marginal uplands, it would cover a range of annual and perennial tropical crop and livestock systems. To cope with data-poor situations that are encountered frequently in the marginal areas, it will be designed with a set of default values that can be modified by the user when data are available. Defaults are required for harvest indices, nutrient contents in products and residues, inputs of rain, BNF, and other depositions, and losses from erosion and leaching. Nutrient balances need to be calculated per land management unit and then be integrated for the whole farm for use in recommendations for fertility management. Summation to higher scales – district, province, country – will assist in managing the supply, importation, and manufacture of fertiliser. Once again, management of such data in geo-referenced databases provides a powerful tool for extensionists and policy-makers.

Implementation of Sustainable Land Management Strategies

Having identified the feasible strategies and matched a strategy to the social, economic, and biophysical characteristics of the situation, the problem is to implement the strategy. The level and stability of profit of a particular strategy may be a very important factor in selecting the strategy for implementation; however, the start-up cost and the availability and cost of credit may be more important considerations for implementation. Similarly, the most profitable strategy may not be selected as it does not fit in with the rest of the farming enterprise or some other social factor. For these reasons, it is critical that the farming community is involved at all stages of development and implementation of new land management systems. On-farm, farmer-managed trials are an effective way to assess strategies, to see how they match the biophysical and socioeconomic constraints, and to highlight any problems or potential solutions in the implementation stage.

Farmer trials

A series of on-farm, farmer-managed trials are underway in five provinces of Indonesia as part of the SebarFos Upland Agriculture Improvement Project. The project, which aims to increase the productivity of acid upland soils, is being conducted by a number of agencies within the Indonesian Department of Agriculture in partnership with the Potash and Phosphate Institute (PPI) and in collaboration with the IBSRAM acid soils network and several upland farming projects supported by GTZ.

In each of five provinces in Sumatra and Kalimantan, farmers are involved in on-farm trials to test the hypothesis that the application of a large amount of reactive rock phosphate (approximately 150 kg P/ha, or 1 t/ha of rock phosphate), in combination with the introduction of improved and locally adapted germplasm for whichever crop they use, and appropriate soil conservation measures, is a strategic intervention for the development of improved farming systems. The aim is to assess this strategy in terms of policy implementation, as well as agronomic and economic impact.

These trials involve comparison between current farmer practice and the *SebarFos* strategy on large areas of the farmers' fields. The initial step in implementing the improved strategy is to establish appropriate erosion and runoff control measures. The control measure that is chosen will depend on the characteristics of the site and the farming system (slope, ground cover, tillage, etc.). Commonly, this will be an alley cropping system, involving grass or legume species planted along the contours, which has the added attraction of providing forage for livestock. The next step is to improve the soil fertility with direct application of a high rate of reactive rock phosphate, which is an attractive intervention, as it is a relatively cheap source of P that is effective and has a long-term residual effect. The last step is to use improved locally adapted germplasm that can utilise the newly established fertility of the soils.

The difference between farmers' practice and the *SebarFos* treatment may be limited to differences in the application of P where farmers already are using conservation measures and responsive varieties. Monitor 'windows' are located in each treatment on some farms so that more detailed information and plant and soil samples can be collected to aid interpretation of the results.

The *SebarFos* trials in the village of Pauh Menang, in Jambi Province, show that crop yield and economic benefits have improved and indicate that an indirect effect of improved P nutrition is improved N nutrition through greater root nodulation (Table 2).

Table 2. The mean effect of improved practice on crop growth, economic benefit, and soil characteristics during the 1997/8 wet season peanut crop.

Attribute	Unit	Management		T test
		Improved practice	Farmer's practice	
Pod yield (field dry)	t/ha	1.6	1.1	**
Biomass (field dry)	t/ha	1.8	1.2	—
Economic benefit	Rp/ha	2 900 000	1 750 000	**
Soil pH		4.7	4.5	*
Root nodules (fresh weight)	g/hill	169.2	85.7	*

** * and – indicate significant differences with Student's t-test at 1%, 5% and 10%, respectively.

The residual effects of rock P resulted in significantly higher yields for subsequent crops, and evidence from earlier experiments in Lampung Province indicated residual effects for up to seven maize and soybean crops. A small area in the improved management practice treatment on some farms is receiving additional P so that the residual value of the rock P application can be assessed.

An important benefit of these trials is that they provide evidence for the importance of conducting on-farm research to enhance technology adoption. The farmers actively participated in all stages of these activities, with decisions on the crop to be planted, the application of other inputs etc., and through attachment to their farmer's group.

This on-farm research approach has resulted in spontaneous adoption of the suggested technology. The *SebarFos* farmers in Pauh Menang voluntarily formed a group and gradually expanded the group using a revolving fund scheme to include farmers willing to implement the three basic steps of improving upland farming. Through this procedure, membership of the group has grown from nine in the first season to 40 by the fourth crop (second year).

To begin with, each farmer received a stake of Rp300 000 (US\$1≈Rp5000 at this time), which consisted of 400 kg rock P, 20 kg urea, 60 kg KCl, 30 kg kieserite, and 40 kg of peanut seed—sufficient for an area of 4000 m^2. It was agreed that the loan would be repaid in six instalments after each harvest. Repayments were in the form of fertiliser or seed, except for the rock P, which was paid back in cash. The farmers decided to grow king grass along the contour lines and to establish a saving fund to be used in the case of drought, pest attack, or harvest failure, and to buy rock P.

The gradual expansion of the group resulted from the return of funds, although the more recent members were more independent as they obtained urea, KCl, kieserite, and seeds, and established hedgerows by themselves, and used the support of the group for rock P.

The improvement of productivity through these strategic interventions requires follow up to ensure that some of the profits are used to maintain soil fertility.

Integration in the farming system

The success or failure of particular strategies often depends on how well they can be integrated into the farming system. This requires balancing the cost of establishment, the time delay until profits are returned, the security or stability of profits, and how the various farm enterprises interact.

Using the example of the farming systems in the transmigrant village of Pauh Menang in Jambi province, Indonesia, we can see differences in simple economic analyses (Table 3) and the importance of considering a balance of different enterprises (Table 4). In addition, the integration of enterprises in the farming system impact upon the flow of carbon and nutrients within the farm and allow flexibility for management (Figure 1).

Table 3. Simple economic analysis of three enterprises at Pauh Menang, Jambi, Indonesia, 1996–1997.

Variable	Peanut	Oil Palm	Cattle
Cost (US$/yr)	309/ha	750/ha	171/head
Yield	3 t/ha/yr	24 t/ha/yr	300 kg/yr
Price (US$/kg)	0.29	0.056	1.43
Gross income (US$)	870	1344.00	428.7
Net income (US$)	561.42	593.93	257.15
B/C ratio	1.82	0.80	1.50

Decisions on the mix of enterprises involves consideration of the value of by-products (forage from weeds and hedgerows, FYM, etc.), while the level of input of fertilisers to the whole farm and to parts of the farm can be manipulated in response to productivity, the costs of inputs, and the price for products. These are critical considerations in matching strategies to farming systems and establishing the requirements for implementation. Consideration of the information in Tables 3 and 4 and in Figure 1, shows why the farmers of Pauh Menang have had to rely on annual cropping while establishing their perennial crops, and have altered their management of annual and perennial crops, particularly in terms of forage production, as livestock have become more important. In addition, this assessment indicates the potential for greater recycling of residues from oil palm processing and flexibility in fertiliser management for crops (both rate and enterprise) with respect to forage and crop production.

Table 4. Assessment of the positive and negative aspects of three enterprises in Pauh Menang.

Enterprise	Positive aspects	Negative aspects
Peanut	High B:C ratio Forages from residues and hedgerows Rapid returns (in one cropping season	Risk of crop failure
Oil palm	Regular income every two months Forages from weeding Relatively low upkeep (cost and time)	Long time to establish
Cattle	Low costs Provides dung and draught	Delayed returns

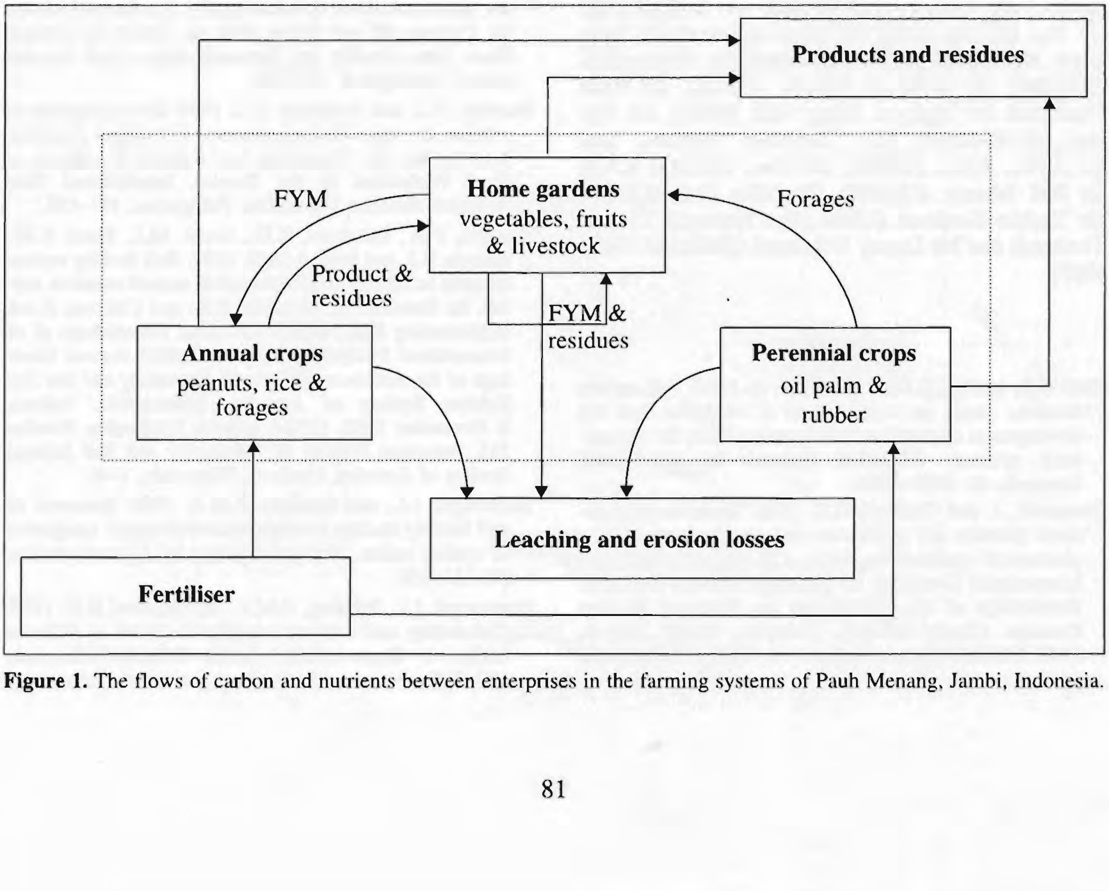

Figure 1. The flows of carbon and nutrients between enterprises in the farming systems of Pauh Menang, Jambi, Indonesia.

Conclusion

The suite of activities within, or associated with, the IBSRAM acid soils network constitute multidisciplinary approaches to a wide range of strategic and applied research. These activities should result in improved management of marginal soils through enhanced research and development capacity and communication between collaborating institutions and through direct outputs from network activities. What are the feasible land management strategies should be answered by greater appreciation of the underlying processes of different strategies. Where should particular strategies be implemented will become clearer through better understanding of the constraints of the systems and matching these with the characteristics of the feasible strategies. How particular strategies can be implemented will be aided by greater understanding of the agroecosystems and the strategies and through the involvement of the major stakeholders, the farmers, the government and non-government agencies, and the private sector, in as much of the research and development process as possible.

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Bridging the Gap Between Farmers and Researchers: The Lao Pilot Extension Project Experience

J.G. Connell[1] and K. Soysithatthha[1]

Abstract

The Pilot Extension Project (PEP) has used an off-the-shelf 'technology package' for rice production with great effect, raising yields by approximately 1 t/ha in 3 years, over 20% of the paddy area in pilot villages. While this generally applicable technology package has been an effective vehicle to train staff and mobilise extension, there is in fact no real 'bridge' between the emerging research and extension institutions, let alone farmers, in Laos. Any such bridge should provide for a flow of information in two directions: research providing research results for extension to use with farmers, and extension feeding back information to direct research. However, there are a number of factors which make this seemingly straightforward information flow a complex task. Firstly, extension needs to develop farmers' capabilities, not simply deliver 'technology packages'. Secondly, the diversity of the production environment raises questions as to the role of site specific research, and, how extension can best use the precise and careful results of research when faced with the reality of farmers' conditions. Despite this complexity, PEP believes there are a number of robust mechanisms which could be used to ensure both that research findings are used more effectively, and that farmers' issues are indeed able to contribute to the direction of research.

THE OBJECTIVE of the Pilot Extension Project is to establish a model for development of a national extension system, based on the existing Provincial and District Agriculture and Forestry Offices (PAFO and DAFO). In the past, their work has been mainly administrative, or mobilising villagers for activities such as constructing irrigation weirs and digging canals. The instances of using improved technologies to gain increases in productivity are rare. As a result, staff at both levels have few of the basic technical or communication skills for extension, or in most cases, even a concept of what is involved in extension work.

The key to the development of an extension system is capacity-building of the staff. At the same time, PEP has tried to focus not just on training of the DAFO technical staff, but on up-grading the DAFO as a unit. Eventually, this will involve changes to its structure and administrative procedures to give the necessary priority to extension work.

PEP has developed:

(a) **Working Models** for implementing extension:
  - extension methodology;
  - DAFO organisational structure adjusted for extension;
  - extension management system.

(b) **Programs** to develop staff capacity, to work according to the models:
  - for capacity-building of the DAFO and its staff;
  - developing leadership for the senior DAFO staff.

These could be applied to PAFO and DAFO throughout the country to gradually establish the basis for an extension system. Over the past 3 years, PEP has implemented these models and programs in two DAFO in each of two Southern Provinces,

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Saravan and Champassak (i.e. a total of four DAFO) and is currently in a process of presenting these models and programs and their impact to MAF for assessment.

Using a Technology Package

Given the general lack of understanding of the processes of extension by PAFO and DAFO staff, in order to carry out the Capacity-Building Program, PEP needed to find technical interventions which would (a) have a visible impact on production, and (b) would be rapidly adopted by farmers. While under no delusions that such a technology would provide long term solutions to farmers' problems, this 'quick-fix' was needed as a training mechanism, to ensure DAFO staff would see they had gained results with farmers, and could see the process of adoption begin to spread from farmer to farmer, within 1 or 2 seasons.

With rice the predominant production activity in the pilot areas, PEP used a basic 'technology package' as the main technical intervention to introduce to farmers. This consisted of the components shown in Table 1.

This technology package was the result of research conducted by the Lao National Rice Research Program, having been tested in on-farm trials in numerous locations by the Rice Research Network. It was regarded as a 'confirmed' technology, and indeed was the single main technical intervention to be promoted to farmers. Thus in 1996 when field work began in the pilot areas, PEP simply accepted this technology package for DAFO staff to use in the pilot areas.

Table 1. 'Technology Package' for improved rice production.

New materials	Improved practices
Improved rice varieties: TDK 1 PN 1 RD 10	Close spacing (20 × 20 cm)
Chemical fertiliser	Rates and timing of fertiliser application: Basal 16–20–00 × 150 kg Top dress 1# 46–00–00 × 50 kg Top dress 2# 46–00–00 × 50 kg
	Smaller seed-beds with drainage channels.

One of the characteristics of a 'technology package' is that the components interact to support each other to achieve the full potential yield. While this is true, it is also characteristic that farmers 'disassemble' technology packages! Extensionists see this as part of the adoption process.

The effects of this on this 'technology package' have been (Sipaphone et al. 1998) illustrated by a socio-economic study by Lao IRRI in Ban Oupalath, Phone Tong District Champassak.

From 1995–97, the Lao IRRI project conducted a study to assess the impact of its 'technology package' on rice yields and farmers' income. They provided seven 'collaborating farmers' with all the material inputs to apply the full technology package over 1 ha of paddy under supervision. In the two following seasons (1996 and 1997), the project surveyed the yield and practices of 66 farmers in the

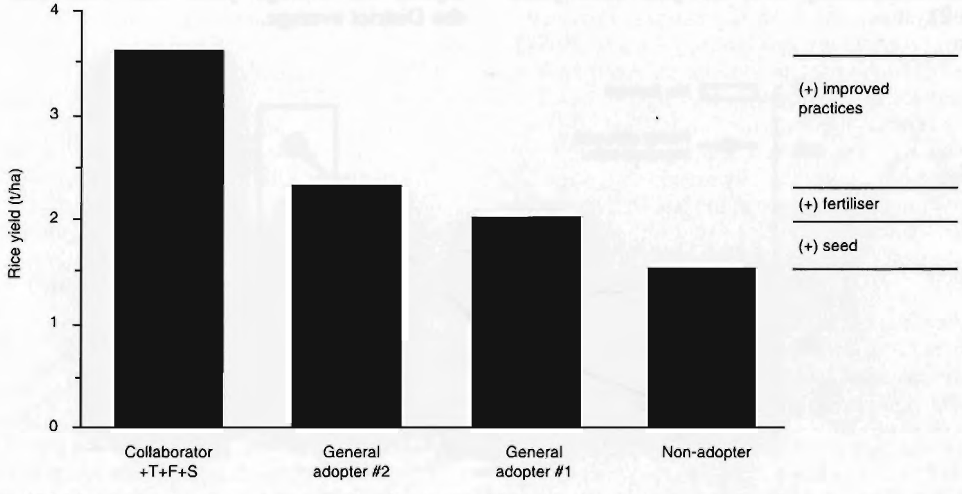


Figure 1. Yield Increases due to components of technology package.

village (56% of all farmers in the village) to assess the general adoption of the technology in village.

The results (Figure 1) showed that farmers had indeed dis-assembled the 'package' and used the components separately, or in combination.

Even with the package dis-assembled, there were significant increases in yield above the yield for traditional practices (1.5 t/ha) for each of the components of the technology package used. These were:

Improved seed (– fertiliser; – imp. practices)	+ 0.5 t/ha.
Fertiliser (– imp. practices)	+ 0.3 t/ha.
Improved practices	+ 1.3 t/ha.

From the point of view of the technology package, the survey showed clearly that farmers would gain a far greater benefit from using the full technology package over adopting only components.

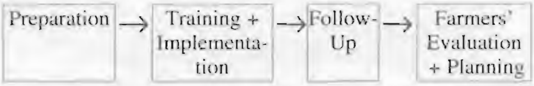
However, looking at this from an extension point of view, the data also separate the benefits of:

- the new material inputs; from
- the improved practices (i.e. 'how to use the new material inputs').

This is important as often farmers adopt the new material inputs, but not the improved practices. The new material inputs are visible and concrete. They can be quickly transferred via seed exchange; via merchants etc. The knowledge of how to use the material inputs does **not** automatically travel with them. Far more conscientious effort is needed to assist farmers to gain the improved practices.

The case of Ban Oupalath was a special one where the collaborating farmers were contracted to use the technology package and supervised by research staff. In one of the pilot DAFO, PEP working with the DAFO staff on an extensive level in 12 pilot villages has seen the use of improved seed rise dramatically over the past three years (Figure. 2).

The DAFO staff followed the 'extension methodology' introduced by PEP, which employs 4 steps for each cycle of extension:



This includes trips to farmers' fields, Farmers' Exchange Meetings and Village Evaluation Meetings, to stimulate farmers to observe and analyse their results, and to spread the results and knowledge among other farmers. Farmers' Exchange Meetings are held for representatives from villages in a 'cluster' to exchange experiences; to learn; and to stimulate each other. Village Evaluation Meetings are held within a village at the end of a season for the selected farmers to report back to the village on the new technologies they used on a trial basis. The effect of these extension activities in assisting farmers to know how to use the material inputs is clearly demonstrated (Figure 3).

In the years 1996 and 1997, the use of new material inputs throughout the District was minimal. This changed rapidly in 1998 due to greater availability of the inputs, and spill-over from PEP villages. As a result, the average rice yield for the District showed a significant rise to **2.5 t/ha**. This use of inputs, however, was without extension support, and so the increase in yield was limited, **0.7 t/ha**, very similar to the general adoption in Ban Oupalath.

However, in the 12 PEP villages which had received extension for 2–3 years, the average yield was **3.8 t/ha**. Thus here in this extension case, where extension had assisted farmers in how to use the inputs, the average yield was **+1.3 t/ha** above the District average.

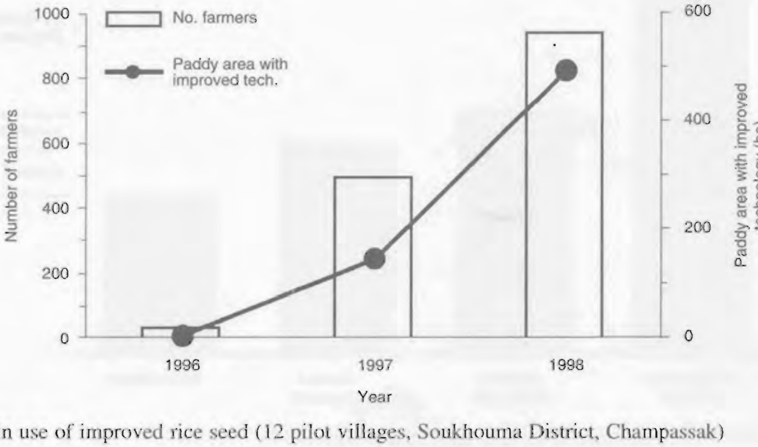


Figure 2. Increase in use of improved rice seed (12 pilot villages, Soukhouma District, Champassak)

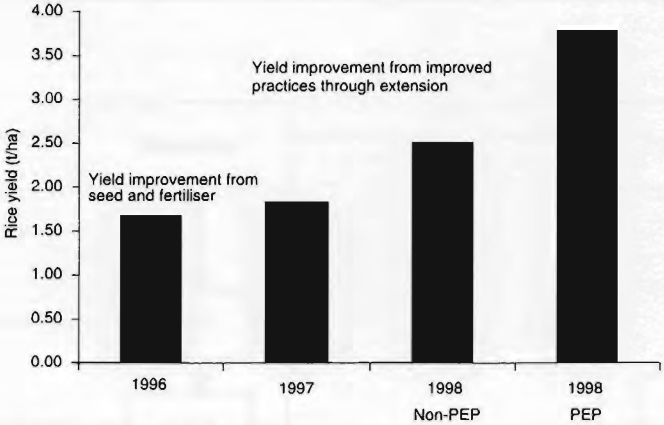


Figure 3. Effect of extension over general use of material inputs.

The DAFO staff in Soukhouma estimated that with the experience they now had, that they could achieve similar results over 50% of the paddy area of the District (i.e. 5300 ha) within 5 years. This would result in production of additional rice each year of 8957 tonnes, worth approximately 5373 million Kip (≈AUD$1.2 million). Extension would then be having a macro-economic effort on the economy of the District.

This has been a short story and one with a happy ending. The availability of a technology package which was generally applicable provided an example for PEP to train DAFO staff and demonstrate the dynamics of adoption over just a few seasons. As it was, no 'bridge' or linkage between research and extension was needed, as the technology package was well known.

The success of the 'off-the-shelf' technology package was possible as farmers' present production practices are at such a low level of intensification, so that any general technology package with improved varieties and fertiliser would provide an increase in yields. Once this general technology package or something similar has been adopted, gaining the next level of improvement in production will be far more difficult; research will need to work harder to get smaller increases, and any new technologies will have to be tailored for specific production domains. In this situation, functional linkages between research and extension will need to develop quickly.

There are two information loops for linking research and extension, (Figure 4):

1. Research needs to convey its results to extension for use with farmers;
2. Extension needs to provide information to research on problems areas which need research efforts.

Given that both research and extension are still emerging in Laos, this makes the institutional structures for this unclear. PEP as a pilot project has worked in a very limited area and has not the direct experience on the ground to have been confronted with a wide range of issues. However, there are a number of robust mechanisms which PEP does see could be put into place fairly quickly and serve to stimulate the development of a research/extension linkage.

Before we look at this it is necessary to appreciate the more complex issues that research and extension face.

Complex Issues for Extension

Extension and transfer of technology

As Lao farmers begin to move from traditional agricultural practices to more developed agriculture, they are faced with a whole range of decisions which they need to make, sometime each season. These include what crop to grow in the dry-season under their new pump irrigation scheme, how much fertiliser to purchase for the main rice crop, whether to buy from the local merchant or trust to the Agriculture Promotion Bank to deliver its subsidised fertiliser on time, and so on. Their sources of information may come from a variety of sources, including neighbours, radio, merchants and finally the DAFO staff.

These decisions are common place, yet demanding. Farmers need the ability to analyse their constraints and opportunities. Thus the broad objective of extension for farmers to be able to deal with the complex issues they deal with on a day-to-day basis, is to:

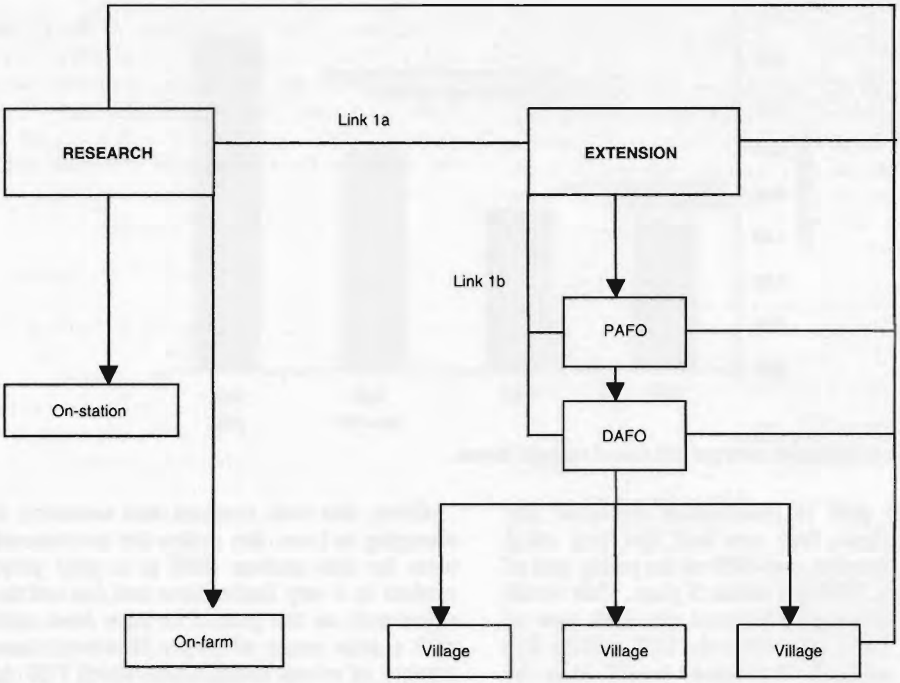


Figure 4. Typical information linkages between research, extension and farmers.

Assist farmers to have the ability to assess their problems; to learn and try new technologies; to evaluate these, and to make decisions.

Simply delivering the latest 'technology package' to farmers will not achieve this. At the same time, a common task of DAFO staff will be introducing improved technologies to farmers. More often than not, this will not be as a 'package' as part of a campaign, but in the context of assisting farmers to solve various production problems as they arise. Thus DAFO staff will need a range of technical knowledge they can call on for problem-solving, rather than simply to instruct farmers in a technical package.

Diverse production environments

Rainfed paddy is a highly diverse environment. Within a single village, there may be 2–4 different soil types which need not only different nutrient applications, but even require farmers to adjust the ways they manage the soil tillage, transplant seedling, and other operations. The rain-fed environment means that recommendations with precise times for split fertiliser application often cannot be followed if no rain falls at the time. Even worse, the threat of flood and drought can make the application of expensive inputs a risky venture.

This sort of diversity means researchers need to think clearly about what is the real meaning of any on-farm trial. An on-farm plot located 500 m away could easily have given a quite different result. When a technology package is released, it is presented as a precise set of procedures. These recommendations are not then precise, but in fact an 'average' of many different results from a number of on-farm sites. If this is the case, should farmers, faced with the particular conditions of their fields, be expected to follow this 'average' technology package precisely?

Instead of researchers trying to home in on the 'best' technology, what is needed is a range of technologies as options. Extension can then provide these to farmers as 'starting points' for farmers to try and expect them to adapt these to their particular conditions.

'Mechanisms' for Linkage Between Research/Extension/Farmers

The sort of mechanisms for linkage between research and extension and farmers can now be discussed with the two areas of complex issues in mind.

Research results → Farmers

Loop 1a: Research → Extension

This first part of the information loop, transferring research results to extension, is perhaps the expected or the most 'traditional' part of the loop. At present, the mechanisms for this are not yet clear in Laos. Given the 'complex issues' described above, the mechanisms for this need to be considered carefully and not assumed.

(i) Formal release of research results

Once research has a mature technology ready for application, this should be notified to extension. The process for ratifying and releasing new technologies is not yet clear in Laos.

Once results of research have been ratified for general release, they need to go through a further process to put them into a form where they can be used by extension. There needs to be discussion between research and extension about (a) the way results could be used and then (b) how they should be presented.

There has been one attempt at this during the past year, when staff from PEP and Lao IRRI jointly produced a pamphlet on the general technology package for rice production. Extension was able to raise difficulties farmers might face. They would have to follow certain procedures recommended, and researchers were able to advise when certain common farmer practices were just not functional. The resulting pamphlet focused on how to use the recommendations, rather than a description of the recommendations, and was in terms more readily accessible to farmers.

Proposed linkage mechanism:

Form a joint committee from research and extension to ratify confirmed research results for release;

Form teams as required to prepare results of research in an accessible form for extension.

(ii) Informal release of research results

There is a great deal of research results which do not lend themselves to an extension campaign, to be spread throughout the country. Examples of such results are: NPK omission trials, or the responsiveness of released varieties to N, etc.

These results provide extremely useful background information, which extension staff could use to explain observations in the field, or to gain incremental improvements in production in a particular environment. Yet, at present, these sort of results do not reach extension at all, except perhaps as technical papers, in English.

Proposed linkage mechanism:

Establish a newsletter aimed at the DAFO staff and Village Extension Workers (VEW). This would be published by extension, but with access to researchers, and would include news of current research; experiences for the field etc. Such a mechanism would be dynamic and stimulate thinking at all levels.

Loop 1b: Extension → Farmers

Given the two complex issues for extension, extension cannot simply be the delivery of technology packages. The diversity of the production environment precludes this (except with a few generally applicable technologies), and the need to enable farmers to be able to analyse their own situation and make decisions, demands something more dynamic.

The model for 'extension methodology' introduced by PEP firstly allows extension to respond to farmers' identification of their particular problems. Secondly, any new technology is introduced for trial by farmers, rather than being promoted.

In a very practical way, this allows farmers to select the best option for their own conditions. After 'selected farmers' in the villages in Soukhouma used two different rice varieties on a trial basis, other farmers selected the variety they thought would suite their own conditions. In some villages, TDK 1 was preferred over PN 1, and visa versa, but in each village both varieties gained acceptance by at least some farmers (Table 2).

Table 2. Farmers' selection of rice variety according to site conditions (Soukhouma, March 1997).

Village	Adoption of improved technologies		Seed requirements (kg)		
	No. farmers	Area (ha)	TDK1	PN1	total
None Yang	36	12.0	54	658	712
Done Kong	35	18.5	697	417	1114
That	96	30.0	863	885	1748
Samkha	62	33.5	1033	967	2000
Don Wy	66	18.5	69	1039	1108
None Phachao	70	32.0	145	1732	1877
Total	365	144.5	2861	5698	8559
Total as % of village	43%	24%			

These four steps follow a natural process of working and are not 'contrived' to try to be 'participatory'. Yet, at the same time, farmers are involved in decision-making at each step, which engages them in the process of looking for solutions to their own field, rather than just following instructions. In the long term, this will work toward developing farmers' capacity for, and encourage the habit of, problem identification and experimentation.

Extension Feed-back→ Research

(i) Confirmation trials

Extension staff should be able to conduct confirmation trials of research results under farmers' conditions to determine any limits to their applicability. Such trials would prevent release of technologies which break down under certain conditions. These trials would not be replicated or require data collection, but only require observation and comment by DAFO staff with checks by researchers.

Proposed linkage mechanism:

Establish procedures for confirmation trials.

(ii) Normal feed-back

General reports do presently move back from the DAFO to PAFO and then to the Ministry of Agriculture and Forestry (MAF). There is no specific process for this and no sense of purpose that such general impressions should affect research direction at present.

Reports should be requested to include: performance of introduced rice variety under various conditions of drought etc.; their unacceptability to local millers etc. The development of this change in attitude and procedures will be a slow process until extension becomes more general, and local staff begin to gain a sense that results from research can be applied in their work.

Proposed linkage mechanism:

Establish a policy that DAFO and PAFO should comment on performance of introduced technologies and identify areas problem areas where research could assist.

(iii) Farmer exchange meetings

As part of PEP's extension methodology, farmer representatives from villages within a cluster meet to exchange results and experiences on production of the season. These meetings provide research staff with an opportunity to directly hear feed-back of farmers use of introduced technologies, and to collect issues which they could direct research for in the future.

Within the PEP pilot areas, staff of Phone Ngam station have attended farmer exchange meetings over the past 2 years, as observers, but not yet with the intention to use this as a feed-back opportunity for research.

Proposed linkage mechanism:

Assign research staff to attend farmer exchange meetings and to report on key issues raised to Nation Agriculture and Forestry Institute (NAFRI).

(iv) Emergency feed-back

There will be occasions when serious problems occur which need immediate attention from research. Examples of this will be with disease or pest outbreaks. Research staff should visit problem areas to determine the conditions which have led to the outbreak. Understanding of these conditions can then be used within a research program.

Proposed linkage mechanism:

Initiate a form for reporting outbreaks of pest and disease or other problems.

Joint and Shared Activities

On-farm trials

DAFO staff have become involved in the research network to conduct on-farm trials. These staff have greatly benefited from the training and the experience. However, this occurred during a period when there was still little regular extension work being done by DAFO staff. It is clear from work in the PEP pilot Districts, that if the DAFO is to provide extension to all villages of a District, the technical staff will not have the time for the detailed work of on-farm trials.

However, on-farm trials will still require a co-operative effort between researchers and DAFO staff. The interaction required should begin with researchers discussing the purpose of any trial with DAFO staff. The DAFO staff with their detailed knowledge of the area should then assist to identify an appropriate site for the trial and introduce the researcher to prospective farmer co-operators. Following this, the researcher is responsible for conducting and monitoring the trial and any data collection.

Proposed linkage mechanism:

Establish a new protocol of responsibilities for co-operation between researchers and DAFO staff for on-farm trials.

Planning Research

Research activities must be directed to the needs of farmers. Thus, as well as providing feed-back information, extension should be directly involved in setting the priorities for research.

Over the past year, PEP has been invited as representatives for extension, to attend planning meetings with research staff. In addition, PEP has had some input to the direction of research through the various other interactions between PEP and research staff already stated. This interaction and purpose could be formalised.

Proposed linkage mechanism:
Establish a joint research/extension committee to advise on priorities for research. This committee could share the work of the committee proposed above for ratification of research results for release to extension.

Final Conclusions

The diverse production environment for the rainfed paddy areas of Laos means that research results will need to be reported either as being site specific, or as general recommendations which should be adapted by farmers to suite their own specific conditions.

The extension methodology introduced by PEP actively engages farmers in making decisions, and so should simulate the sort of local adaptation of introduced technology needed in diverse production environments.

In time, this dynamic extension approach could affect research strategies, as it would relieve researchers of the need to conduct repetitive trials, such as fertiliser trials, which farmers will always need to adapt and which can now be achieved through engaging farmers in problem solving during extension.

To ensure good linkage between research and extension, three formal mechanisms are proposed:

1. Establish a joint research/extension committee with functions of:
   - establishing priorities for research;
   - ratifying results of research for general release;
   - assignment of research/extension teams to prepare such results in forms which are readily useable by extension.
2. Establish procedures for 'confirmation trials' to be conducted by:
   - extension to validate research results over wide areas, in preparation
   - for ratification and release.
3. Institute a report bulletin which allows DAFO and PAFO personnel to:
   - quickly communicate events which need researchers to observe; and
   - assess as background information to identifying issues for research.

In addition to these formal mechanisms, two informal and dynamic mechanisms should also be established:

1. Institution of a newsletter to disseminate results of research which are currently lost to extension, and to provide a forum for discussion between researchers and extension workers and village extension workers.
2. Institute researchers' attendance at farmers exchange meetings (where these are held) to gain direct feed-back from farmers on introduced technologies and to identify issues for future research.

All of the above, except perhaps for the joint research/extension committee, could be established quickly and would ensure more effective and dynamic linkage between research and extension.

Acknowledgments

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