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Biological N_2 fixation and residual N benefit of pre-rice leguminous crops and green manures

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Abstract

Rice yields in soils of low soil organic matter may benefit from preceding leguminous green manure crops. A pre-rice crop experiment, including groundnut (*Arachis hypogaea*), mungbean (*Vigna radiata*), *Sesbania* (*Sesbania rostrata*), and a mixture of *Sesbania* and multipurpose cowpea (*Vigna unguiculata*) was conducted on a characteristic sandy soil of North East Thailand. The *Sesbania*-cowpea intercrop gave a similar total plant biomass as the *Sesbania* green manure alone (7 t ha^{-1}) but with the advantage to yield an edible product. The direct economic yield of cowpea was 1.3 t ha^{-1} green beans and greater than that achieved with groundnut or mungbean. The *Sesbania*-cowpea combination also proved to enhance rice yields by 0.8 t ha^{-1}. The benefits in rice production were similar to the *Sesbania* green manure alone but surpassed the yields with the other grain crops or urea fertilizer of 30–60 kg N ha^{-1}. *Sesbania* dry matter production increased with increasing planting density. The resulting variation in plant quality, e.g. lignin, however, was low. Rice responses to treatments were more related to the total residue N yields than to changes in plant quality.

Apart from mungbean (25%) the pre-rice leguminous crops were able to obtain a considerable (>39%) proportion of their N from N_2 fixation. The green manure *Sesbania* however fixed a larger proportion (79–89%) of its N than the grain crops (25–62%). This led not only to high amounts of N_2 fixed by *Sesbania* but together with a N harvest index of zero yielded a large systems N benefit. With grain legumes this benefit was moderated by the N export in harvestable products. In the case of mungbean this may even result in effective soil N mining. Residue N use efficiency varied between 19–29% and was similar to that obtained from a single application of chemical N fertilizer (17–28%).

For the farmer the *Sesbania*-cowpea intercrop option seems thus the most promising one not only regarding rice yield benefits but also in terms of soil fertility enhancement and generation of edible products.

Keywords: Cropping-systems, N_2-fixation, cover cropping, green manure, residual N benefit, Thailand

Introduction

Asian rice production systems have been intensified in the last decades. As farmers are looking for multiple benefits from their investment, green manure systems will have to provide additional benefits besides soil fertility improvements, e.g. food, fodder, fuel or comercial products (Garrity & Becker, 1994). Despite substantial research in past years on the effectiveness of green manures (e.g. Becker *et al.*, 1990), adoption of green manure technologies has been slow. Short duration pre-rice grain legumes provide one option to enhance the value of the pre-rice crop (Toomsan *et al.*, 1995). However, because of the limited time window before the rice crop and the risk of flooding, grain legume productivity and hence also residual benefit is often limited. Intercropping a short duration food legume, e.g. multipurpose cowpea, with a fast growing green manure may provide not only an edible product but also a large biomass and hence ensure a large residual effect. The use of a multipurpose cowpea as compared to a grain legume has the advantage that if copious rains arrive early and fields get flooded green beans can already be harvested. Hence we compared both green manures and food legumes or combinations for their suitability as soil fertility-enhancing pre-rice crops.

Many green manure crops such as *Sesbania* decompose quickly and release N rapidly (McDonagh *et al.*, 1995). Thus N release is often not in synchrony with rice N demand (Becker & Ladha, 1997). Plant residue decomposition and N release are governed by environmental constraints, decomposer community as well as by their quality characteristics. Vityakon *et al.* (2000) and Becker *et al.* (1997) successfully manipulated N release from pre-rice green manures by mixing with high C : N ratio rice straw. The (lignin+polyphenol) : N ratio is now considered a widely applicable index related to N release from plant residues (Handayanto *et al.*, 1995). Plant photosynthate partitioning and plant structural attributes are strongly affected by shading and intra and interspecific plant competition. Higher seed rates may not only increase growth of pre-rice *Sesbania* (Pradhan & Garrity, 1994), but may also delay development of woodiness (Yadvinder-Singh *et al.*, 1994). Here we tried to manipulate plant quality attributes of *Sesbania* (*Sesbania rostrata*) by altering the planting density.

From this perspective we conducted a lowland rice experiment with the following objectives: i) to measure N_2 fixation in grain legumes and green manures (^{15}N dilution technique), ii) to test the effect of plant density on plant quality and its consequent effect on the efficiency of nutrient cycling, and iii) to test the residual N benefit of legume crops and green manures in lowland farming systems which occupy over 60% of the farmland in North East Thailand. The underlying hypotheses were that i) green manures and grain legumes in crop rotation systems are able to sustain higher rice yields than those achieved in rice monocrops, ii) legumes differ in their N_2 fixation capacity, leaf retention and N harvest index and may therefore vary in their residual N value, iii) increasing plant density leads to the development of smaller plants with less woody stems so increasing N cycling efficiency and iv) combining a green manure with a food crop gives similar rice yield benefits but includes a harvestable product which gives more incentive for farmers to adopt the technique.

Materials and methods

Pre-rice crops

A pre-rice grain legume and green manure experiment was established at the North East Regional Agricultural Extension Centre (Tha Phra), 20 km south from Khon Kaen University. The experiment was established on a characteristic sandy soil (Roi Et Series; isohyperthermic Aeric Paleaquult) of North East Thailand with (0–15 cm): 0.48% organic matter, 0.041% total N, pH 5.3 (1:2.5 H_2O), CEC 4.5 cmol(+) kg^{-1}, 0.59 Ca and 0.11 K cmol kg^{-1}, 17 mg P kg^{-1}, 0.05 dS m^{-1}, 79% sand and 10% clay. The experimental treatments comprised of three densities of *Sesbania* (*Sesbania rostrata*) as well as single densities of mungbean (*Vigna radiata*), short duration groundnut (*Arachis hypogaea*), *Sesbania* intercropped with multipurpose cowpea (*Vigna unguiculata* cv. KVC-7) and natural fallow. The pre-rice crops were planted during May 17–18, 1995 and harvested by replicate between August 14–24, 1995.

The experiment was layed out in a randomized block design with four replications. Plot size was 6.5 × 8 m and harvested area was 5 × 3 m. *Sesbania* planting densities were: low density 25 × 25 cm, normal density 25 × 10 cm and high density 10 × 10 cm. In mixture with cowpea, *Sesbania* was planted at 50 × 5 cm. The grain legume crops were planted at 50 × 20 cm (groundnut 2 plants $hill^{-1}$, others 1 plant $hill^{-1}$) and rice at 25 × 25 cm (5 plants $hill^{-1}$). In the fallow treatments native seed germination was allowed to occur. Cowpea and groundnut were inoculated with a mixture of strains THA 201 & 205, mungbean with strains THA 301 & 302 obtained from the Department of Agriculture and *Sesbania* with a solution of crushed *Sesbania* root nodules. Recommended fertilizer rates (except for N) were applied prior to sowing i.e. 25 kg P and 30 kg K ha^{-1} for green manures and grain legumes.

Leaf fall in crops and rice were collected weekly in border parts (3 subsamples/plot of 1×1 m). At final harvest grain, pods, stover and accumulated litter material were separated, fresh weight taken and subsampled. Subsamples were dried at 65 °C, ground and analyzed for total N (Kjeldahl).

N_2 fixation measurements

^{15}N subplots were established in leguminous plots. The size of the subplots was 2 × 2 m for grain legumes, 2 × 1.2 m for *Sesbania* and 2 × 1.5 m for *Sesbania*-cowpea intercrop. 10 kg N ha^{-1} with 10 atom $\%^{15}N$ was applied in solution mixed with glucose to give a C:N ratio of 10:1 in order to immobilize the ^{15}N more rapidly into the soil microbial biomass (Giller & Witty, 1987), and incorporated to 15 cm depth 14 days prior to sowing. Harvest area excluded a 25 cm border. Plant materials were harvested and subsampled as above and analyzed for ^{15}N enrichment using a Europa Scientific 20–20 mass spectrometer coupled to a C/N analyzer. The proportion of N derived from the atmosphere was calculated as (McAuliffe *et al.*, 1958):

$$\%N\,from\;N_2 fixation = [1 - \frac{atom\%^{15}N_{excess}\,fixing\;legume}{atom\%^{15}N_{excess}\;non\text{-}fixing\;control}]x\;100 \qquad (1)$$

As non-fixing control plants non-nodulating groundnuts (obtained originally from ICRISAT, Hyderabad, India; plants were checked for absence of nodules at harvest) and rice (*Oryza sativa*) were used. N_2 fixation estimates were not significantly affected by non-fixing control species and hence only data with non-nodulating groundnut are presented.

Legume residue management

The leguminous pre-rice green manures and residues of grain legumes were chopped to 10 cm and incorporated to 15 cm after yield estimates and subsampling for analysis (see above). For comparison of residue N recovery of different green manures and grain legumes, labelled material from the N_2 fixation plots were applied in separate subplots of 1 × 2 m at the respective pre-rice crop production rate. A bulked sample of the stover was again subsampled and analyzed for ^{15}N and N content and C (dry combustion), acid detergent fibre and lignin (Van Soest & Wine, 1967) and total extractable polyphenols (Anderson & Ingram, 1993). The recovery of the legume stover added in the rice was then calculated as follows:

$$\%N\ recovery = \left[\frac{atom\%^{15}N_{excess}\ catch\ crop\ x\ N\ yield\ catch\ crop}{atom\%^{15}N_{excess}\ residue\ x\ residue\ N\ added}\right] x\ 100 \qquad (2)$$

Rice crop

After pre-rice crops rice cultivar R.D.6 (glutinous rice) was planted (September 5–7, 1995). Two weeks after rice transplanting three N fertilizer (ammonium sulphate) treatments, e.g. 0, 30 and 60 kg N ha^{-1}, were imposed in fallow plots. These were randomly pairwise mixed in one plot. So actual plot size for these treatments was 3 × 4 m. A metal sheet to 40 cm depth was inserted to avoid N contamination between these neighbouring plots. Labelled ammonium sulphate fertilizer at 10 at%^{15}N was applied in 1 × 1 m^2 sub-plots and fertilizer N recovery estimated as above. Basal fertilizer was applied at recommended rates of 25 kg P and 30 kg K ha^{-1}. Weeding and pest controls were done when necessary for both pre-rice crops and rice crops.

Results

Pre-rice green manures and grain legumes

Pre-rice crops established slowly due to drought stress after emergence. However, high dry matter yields of up to 7.6 t ha^{-1} were obtained with *Sesbania* (Table 1). The combination of *Sesbania* with multipurpose cowpea gave a similar total plant biomass as the *Sesbania* green manure alone but with the advantage of an edible product. The economic yield (green beans) of cowpea was in fact greater than that achieved with the other grain legume crops. Mungbean performed rather poorly both

Table 1. Dry matter and N yields of pre-rice crops at Tha Phra, 1995.

Pre-rice crop	Dry weight (kg ha^{-1})				Nitrogen yields (kg ha^{-1})		
	Economic yield	Fallen leaves	Stover	Total biomass	Grain/ Pod[2]	Stover	Total[3]
Sesbania low density	0	nd	5604	5604	0	105	105
Sesbania medium density	0	nd	7036	7036	0	143	143
Sesbania high density	0	nd	7642	7642	0	126	126
Sesbania-cowpea	1309	169	6552	8030	39	135	177
Mungbean	790[1]	806	473	2249	30	4	45
Groundnut	718	67	4734	5519	19	56	75
Non-nod groundnut	180	0	3045	3225	3	28	31
Rice	0	0	3333	3333	0	28	28
Fallow-N0	0	nd	1519	1519	0	14	14
Fallow-N30	0	nd	1397	1397	0	13	13
Fallow-N60	0	nd	1516	1516	0	15	15
CV%	38	62	23	20	41	16	23
SED	160	91	596	570	3	11	10

[1] without shell (181 kg ha^{-1})
[2] including shell N
[3] including fallen leaves where determined
nd = not determined

Table 2. Nitrogen harvest index and biological N_2 fixation of pre-rice green manures and crops at Tha Phra, 1995.

Pre-rice crop	N harvest index (%)	Atom% ^{15}N excess	N_2 fixed (%)	Amount of N_2 fixed (kg N ha^{-1})	Net benefit from N_2 fixation[1] (kg N ha^{-1})
Sesbania low density	0	0.0991	79	82	+82
Sesbania medium density	0	0.0522	89	126	+126
Sesbania high density	0	0.0754	84	105	+105
Sesbania-cowpea	22	(0.058/ 0.295)[2]	69 (88/39)	140 (97/43)	+101
Mungbean	67	0.3392	25	10	–20
Groundnut	25	0.1837	62	46	+25
Non-nod groudnut	10	0.4837	0	0	–3
Rice	0	0.5040	0	0	0
CV (%)			24	29	
SED	nd		11.7	17.3	nd

[1] N benefit = amount of N_2 fixed – N exported in produce (including shell N)
[2] values in brackets for sesbania and cowpea respectively
nd = not determined

in total yield and grain yield. Also groundnut pod yield was at 718 kg ha^{-1} rather low but stover yields of 5 t ha^{-1} promised a good residual benefit potential. The dry matter yield of the fallow was inferior to all other treatments.

The large *Sesbania* dry matter yields achieved, resulted in a large N accumulation of 105–143 kg N ha^{-1} which was only surpassed by the *Sesbania*–cowpea mixture that yielded 177 kg N ha^{-1} (Table 1) Among the crops which yield an edible fraction, mungbean had lowest total N yields. The non-fixing crops rice and non-nod groundnut had very similar low N yields of about 30 kg N ha^{-1}, which was about twice the N yield in the fallow treatments. The higher N yield in rice and non-nod groundnut compared to fallow is probably mainly due to the faster and more dense establishment of the planted crops and therefore a higher soil-N utilization.

Mungbean had the highest nitrogen harvest index while those of groundnut and *Sesbania*-cowpea intercrop were similar (Table 3). Mungbean was the poorest N$_2$ fixer under lowland conditions (Table 3). Mungbean fixed only 25% of the total N taken up leading to a negative N balance of –20 kg N ha^{-1}. *Sesbania* fixed a large proportion of its N (79–89%) resulting in 82–126 kg N ha^{-1} being fixed. The highest N$_2$ fixation (140 kg N ha^{-1}) was obtained when *Sesbania* was intercropped with cowpea. This combination not only resulted in a highly positive N balance (+101 kg N ha^{-1}) but also produced an economic yield of 1.3 t ha^{-1}.

The pre-rice green manures not only resulted in different amounts of stover returned to the field but also varied widely in their chemical quality attributes (Table 3). *Sesbania* residues had the lowest C:N ratio and highest soluble N concentration. However, the variations in fibre (ADF, lignin) between the different sowing densities with *Sesbania* were much less than expected.

Response of rice to previous cropping history

The pre-rice green manuring treatments resulted in a significant increase in rice grain yield of up to 865 kg ha^{-1} (Table 4). This residual benefit was greatest in the

Table 3. Chemical characteristics of returned bulk stover of pre-rice green manures and crops, 1995.

Pre-rice crop	C:N ratio	Total N (%)	Soluble N (mg N g^{-1})	ADF[1] (%)	Lignin (%)	TEP[1] (%)
Sesbania low	21	1.88	6.3	49	8.3	0.6
Sesbania medium	20	2.05	3.9	51	9.4	0.4
Sesbania high density	24	1.65	5.0	50	8.4	0.5
Sesbania-cowpea	18	2.01	7.4	47	8.3	0.7
	(17/29)	(2.3/1.4)	(8.3/7.4)	(45/48)	(8.6/6.6)	(0.7/0.6)
Mungbean	39	1.01	1.5	51	7.7	0.6
Groundnut	30	1.29	2.5	44	5.8	0.9
Non-nod groundnut	36	1.08	1.9	42	6.6	1.0
Rice	46	0.84	1.8	39	2.5	0.6
Fallow	nd	0.98	nd	nd	nd	nd

[1] ADF = acid detergent fibre; TEP = total extractable polyphenols (Folin-Ciocalteau)
nd = not determined

Table 4. Rice dry matter and N yields after pre-rice green manuring at Tha Phra, 1995.

Pre-rice crop	Dry matter yields (kg ha^{-1})				Nitrogen accumulation (kg N ha^{-1})		
	Seed	Stover+ Stubble	Total	Seed yield increase[1]	Seed	Stover+ Stubble	Total
Sesbania low density	2659	4425	7083	865	29	26	50
Sesbania medium density	2653	4786	7439	859	30	32	63
Sesbania high density	2377	4580	6957	583	27	32	59
Sesbania-cowpea	2609	3767	6375	815	29	21	51
Mungbean	1897	2162	4259	103	19	12	31
Groundnut	2413	3666	6079	625	27	21	48
Non-nod groundnut	2177	2670	4846	383	24	14	35
Rice	2119	2681	4800	325	21	10	27
Fallow-N0	1794	2154	3918	0	17	15	38
Fallow-N30	2355	3034	5389	561	25	16	41
Fallow-N60	2212	3364	6576	41	26	26	51
CV (%)	11	18	12		12	23	12
SED	180	440	478		2.2	3.5	4.2

[1] yield increase over fallow N0

Sesbania treatments. There was however, no effect of increasing *Sesbania* planting density on rice yield. Field observations showed that with the highest *Sesbania* planting density some lodging of the rice after incorporation of the residues was apparent suggesting excess of available N in this treatment. The pre-rice treatment with *Sesbania*-cowpea resulted in the same yield benefit as the *Sesbania* alone treatments. Mungbean did not improve subsequent rice yields. Pre-rice *Sesbania*, *Sesbania*-cowpea and groundnut increased rice grain production more than N fertilizer additions of 30 or 60 kg N ha^{-1}. For unknown reasons there was no N fertilizer response above 30 kg N ha^{-1}.

Nitrogen accumulation in rice was also significantly affected by the pre-rice crop. Again, highest N yields were obtained in the *Sesbania* treatments (Table 4). The comparison with the N fertilizer treatments suggested that *Sesbania* residual N benefits were in excess of 60 kg N ha^{-1} fertilizer equivalents. Although rice took up more N at the higher fertilizer N application rate compared to the 30 kg N ha^{-1} treatment, this N was not translocated to seeds suggesting limiting factors other than N (Table 4). About 17–58% of the residue N applied was recovered by rice (Table 5). A similar fertilizer use efficiency was observed with recoveries between 17–28%. ^{15}N recovery measurement agreed well with N balance estimates ($R^2 = 0.87$). There was only a poor relationship ($R^2 = 0.2$ for the (lignin+polyphenol):N ratio) between residue quality attributes and the proportion of residue N recovered. The amount of residue N recovered by rice however, was well related to the amount of N applied and the relationship improved when considering residue quality attributes as well.

Table 5. Recovery of nitrogen from pre-rice green manures, crop residues or fertilizers at Tha Phra, 1995.

Pre-rice crop	Nitrogen recovery			
	Residue-N			Soil-N[2]
	^{15}N method		N difference method[1]	
	(%)	(kg N ha^{-1})	(kg N ha^{-1})	(kg N ha^{-1})
Sesbania low density	29	34	27	21
Sesbania medium density	27	39	35	24
Sesbania high density	24	35	32	24
Sesbania-cowpea	16	26	23	24
Mungbean	58	1(5)[3]	4	26
Groundnut	19	11	21	37
Non-nod groundnut	17	5	12	35
Rice	17	4	7	31
Fallow-N0	–	0	0	27
Fallow-N30	17	5	14	36
Fallow-N60	28	17	24	34
CV (%)	49	42		
SED	7.7	5.5	nd	

[1] calculated as rice N yield treatment – N yield fallow N0
[2] calculated as total rice N yield – residue N recovered
[3] including fallen leaves

Discussion

The current experiment demonstrated that combining a green manure, e.g. *Sesbania,* with a food legume, e.g. cowpea can result in similar total plant biomass as with the *Sesbania* green manure alone. The selected cowpea seems particularly suited for this system as the economic yield was greater than that achieved with the other grain legume crops. The green bean yield of multipurpose cowpea of 1.3 t ha^{-1} obtained in this experiment compares well with the 1 t ha^{-1} found by McDonagh *et al.* (1995) in a similar system. They observed that the economic yield of cowpea in mixture with *Sesbania* was reduced only by 35% compared with pure cowpea stands. An alternative legume option to combine with *Sesbania* could be stakeless yard-long bean with similar yield potential (McDonagh *et al.*, 1995). The *Sesbania*-cowpea intercrop also proved able to enhance rice yields greatly. The benefits in rice production were similar to the *Sesbania* green manure alone but surpassed the yields with fertilizer.

Sesbania dry matter production increased with increasing plant density, a fact that had also been observed by Palaniappan and Budhar (1994). The resulting variation in plant quality, e.g. lignin or ADF, however was less than expected. Thus the hypothesis that woodiness of *Sesbania* decreases in a denser stand (Yadvinder-Singh *et al.*, 1994) was not confirmed. Our results however, agree with observations of

Dempsey (1975) that increasing planting density resulted in smaller plants with a higher fibre yield per unit area but we did not observe greater fibre contents (hemp) or better quality of strong fibres (kenaf) as did he. Shoot lignin in our experiment was relatively low at 8–9%. McDonagh *et al.* (1995) found shoot lignin concentrations to be higher than those observed here probably as a results of older plant material used. One practical constraint with high yielding woody green manures is the difficulty in incorporation of the material particularly when using animal draft powered tillage implements (Palaniappan & Budhar, 1994). The bulky material is sometimes slashed by hand or specific machine powered tools are used but in all cases additional labour is required and this needs to be taken into account when assessing the suitability of green manures (Whitmore *et al.*, 2000).

Apart from mungbean, the pre-rice leguminous crops were able to obtain a considerable (>39%) proportion of their N from N_2 fixation. The green manure *Sesbania* however fixed a larger proportion (79–89%) of its N than the food crops (25–62%). This led not only to high amounts of N_2 fixed by *Sesbania* but also to a high systems N benefit as no N is exported (zero N harvest index). With grain legumes this benefit is moderated by the N export in harvestable products, and resulted in the case of mungbean even to a potential soil N mining (Table 3). This relationship between harvest index, nitrogen fixation and soil N mining has been explored by Giller and Cadisch (1995) who suggested that with a N harvest index of 67% for mungbean an equivalent proportion of N derived from fixation would be necessary to avoid soil N mining. The mungbean pre-rice crop also did not improve subsequent rice yields. This was likely due to its low N_2 fixation potential and low residue N returns as the % recovery was above average. In a previous pre-rice crop study Toomsan *et al.* (1995) observed larger N_2 fixation potentials for groundnut (160–200 kg N ha^{-1}) than in this study due to the longer growth period (106–119 days compared to 90 days here). It appeared that the time window for grain crops like groundnut and mungbean to produce large amounts of grain in these pre-rice systems is often relatively short. This is further evidence that a green bean crop, e.g. multipurpose cowpea, combined with a green manure is a more favourable option. Green beans are ready for harvest earlier and continue to yield. This system is thus better buffered against early flood risks.

Residue N use efficiency was similar to single application fertilizer use efficiency. The residue N recoveries reported here are in good agreement with results obtained by McDonagh *et al.* (1995) who observed 22%, 15% and 10% recoveries for *Sesbania* alone, *Sesbania*-cowpea and groundnut respectively. Manguiat *et al.* (1997) reported slightly lower *Sesbania* residue recoveries of between 9–25% presumably due to poorer soil fertility. McDonagh *et al.* (1995) observed that with *Sesbania* 80% of its N had been released within 20 days. Part of the residue N which has not been taken up by the rice crop may still be present in the soil as either undecomposed material or incorporated in the microbial biomass or soil organic matter. There is a large potential for N losses in these rice based systems (Vityakon *et al.*, 2000) and hence scope for improved N use efficiency that needs further investigation. Although plant quality attributes affected N recovery in this experiment or can improve N synchrony between N release and rice N demand (Vityakon *et al.*, 2000) the largest impact on rice performance was the choice of the pre-rice crop and the resulting large differences in the amount of residue N returns. McDonagh *et al.* (1995) and Manguiat *et al.* (1997) stressed that high N_2 fixation and stover residue production of pre-rice crops depends on adequate supply of basal fertilizer (e.g. P, K, lime) and water.

The residual benefits of *Sesbania* in rice production surpassed the yields obtained with fertilizer. This effect was also observed by Manguiat *et al.* (1997). However, their findings that rice took up a greater amount of soil N with *Sesbania* residues than with fertilizer was not supported in this study; on the contrary, soil N uptake was less. Fertilizer use efficiency was, however, similar between the studies. The effect of residues on rice grain yield could be attributed solely to a N effect as residue treatments fall well within the predicted fertilizer N response path, e.g. there was no evidence of additional physical or other improvements in the duration of this experiment. The linear relationship between rice N uptake and rice grain yield over all residue treatments compared to the lack of a similar relationship over fertilizer N levels also suggests that N release from residues is probably in better synchrony with rice N demand than a single dose of fertilizer. However, at both the highest *Sesbania* residue level and highest fertilizer N treatments there was initially an excess of plant available N that resulted in increased stover production only. While it is recommended to split fertilizer applications to improve grain filling, splitting *Sesbania* residues is not feasible, but residue management could be complimented with late fertilizer applications where necessary. Mixtures of residues that differ in quality could be applied, however, as shown by Vityakon *et al.* (2000).

The current study suggests that for farmers the option *Sesbania*-cowpea intercrop is the most promising one not only for rice yield benefits but also in terms of soil fertility and generation of edible products and income generation (Whitmore *et al.*, 2000).

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