On-farm residue effects on rainfed lowland rice productivity in Laos

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Abstract

Rice is the most important crop in Laos, accounting for almost 70% of the total calorie supply. Low yields (typically 1.5 to 2.0 t ha^{-1}) and high risk (due to drought and/or flooding) characterize the rainfed lowland rice environment. Improving and sustaining rice yields on these coarse textured soils requires an increase in nutrient inputs. Currently, on-farm residues such as farmyard manure (FYM), rice straw and husks are poorly utilized. Two field experiments were initiated in 1999 to test effects of applying on-farm residues with commercial fertilizers on nutrient-use efficiency. The experiment was conducted for two years Saravane and three years in Champassak. The experiments were set up in a split plot design with minus and plus fertilizer (60, 13 and 18 kg ha-1of N, P and K, respectively) as main plot treatments and residues (none or 2 t ha^{-1} dry weight of FYM, rice straw or rice husks) as sub-plot treatments. This rate of residue provided 40, 5 and 30 (FYM); 5, 1 and 6 (rice husks); and 14, 1 and 27 (straw) kg ha-1of N, P and K, respectively.

Rice yields when neither fertilizers nor residues were applied ranged from 1.1 to 1.6 t ha^{-1} across sites and years. In response to fertilizer alone rice yields in Saravane increased on average by 2.0 t ha^{-1} (150%) in both years. In Champassak, yields increased by 1.5 t ha^{-1} (126%) in the first two years but only by 0.7 t ha^{-1} (43%) in the third year.

When residues were applied alone, yields increased by 0.6 t ha^{-1} (48%) in Champassak in the first two years and 1.2 t ha^{-1} (78%) in the third year. In Saravane, yields increased on average by 0.95 t ha^{-1} (68%) in both years. There was no difference in rice yield response to the different residues when they were applied alone, despite a large difference in N, P, and K concentration of the residues.

In the first two years, at both sites, there was little to no yield benefit of applying residues if commercial fertilizer was already applied. However, in the third year at the Champassak site, there was a response to residues when fertilizers were applied. This response been have been the result of a decline in soil fertility when only fertilizer was used. This is supported by the fact that in the fertilizer only treatment, both yield and response to fertilizer declined in the third year. This decline may be due to the depletion of micronutrients and carbon. While commercial fertilizers can maintain N, P and K balances, other nutrients, such as micronutrients may become depleted with continuous cropping and removal of residues. Recycling on-farm residues returns much of these nutrients back into the soil system, helping to maintain soil fertility. Based on these results, the most productive and sustainable practice is to apply residues with commercial fertilizers. Applying residues alone is sustainable but may not be as

productive, however, more research is required to determine the long-term impacts of each practice.

Keywords: lowland rice, residue management, fertilizer management, nutrient-use efficiency

Introduction

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. Lowland rice soils on these 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) (Soil Survey and Land Classification Center, Lao PDR, 1997).

Maximizing nutrient-use efficiency in these rainfed systems is imperative for resource poor farmers. High inputs are not the solution for improved and sustained productivity, due to the high risk of crop failure. Fertilizer use by rainfed lowland rice farmers is recent and farmers apply commercial fertilizers at low rates (Pandey and Sanamongkhoun, 1998). There is generally good responses to applied fertilizers at these low to moderate rates (Linquist *et al.*, 1998). Reports from across the border in NE Thailand, however, indicate that on some sandy soils, there is little to no response to fertilizer unless combined with organic amendments (Willet, 1995; Ragland and Boonpuckdee, 1988). Despite good responses to fertilizer alone in Laos, two experiments were initiated in southern Laos to examine the potential of on-farm residues to improve fertilizer-use efficiency and maintain soil fertility.

Materials and Methods

An experiment was initiated in 1999 at two sites in southern Laos (Champassak and Saravane) to evaluate the effect of using on-farm residues and inorganic fertilizers alone or in combination with each other. The soil in Champassak was a sandy loam and in Saravane a silty loam (Table 1). Soils at both sites were relatively infertile, although, the Saravane soil was more fertile than the Champassak. The experiment was set up as a split-plot design with minus or plus fertilizer (60, 13 and 18 kg $ha^{-1}$of N, P and K, respectively) as main plot treatments and residues (none or 2 t ha^{-1} of FYM, rice straw or rice husks: on a dry weight basis) as sub-plot treatments. Plot size was 16 m^2 (4 x 4 m). The residues used for both sites and years were the same. The nutrient concentration and amount of N, P and K added in each residue treatment is shown in Table 2.

Table 1 Soil properties for both locations of the on-farm residue experiments.

Location	Soil Texture	Organic C	Kheldahl N	Olsen P	Avail K
		%	%	mg kg^{-1}	cmol kg^{-1}
Saravane	Silty loam	0.231	0.028	1.1	0.085
Champassak	Sandy loam	0.086	0.010	1.1	0.039

Table 2 N, P and K concentrations of residues and the amount of N, P and K applied in each treatment when applied at a rate of 2 t ha^{-1}.

Nutrient	Manure	Rice hulls	Straw
		Nutrient concentration (%)	
N	2.00	0.25	0.70
P	0.27	0.04	0.07
K	1.50	0.28	1.36
	Amount of nutrient applied from residues (kg ha^{-1})		
N	40	5	14
P	5	1	1
K	30	6	27

The Saravane site was terminated after two years but the Champassak site was maintained. The varieties used in both locations were improved glutinous Lao varieties. Transplanting was done when the seedlings were about 30 days old and 4 to 6 seedlings were planted per hill. Hill density was 25 hills m^{-2}. At harvest, 7.8 m^2 was sampled from the middle of each plot to determine grain yield. From within this harvest area, 12 rice hills were sampled by cutting the rice at ground level for determination of straw yield and harvest index. This sample was ground for nutrient analysis (data not presented). All grain yield estimates are on a 14% moisture basis.

Results and Discussion

Residue and fertilizer effects on rice yields

Rice yields, when neither fertilizers or residues were applied, ranged from 1.1 to 1.6 t ha^{-1} across sites and years (Figure 1). Such yields are typical on these coarse textured, infertile soils (Linquist *et al.*, 1998)

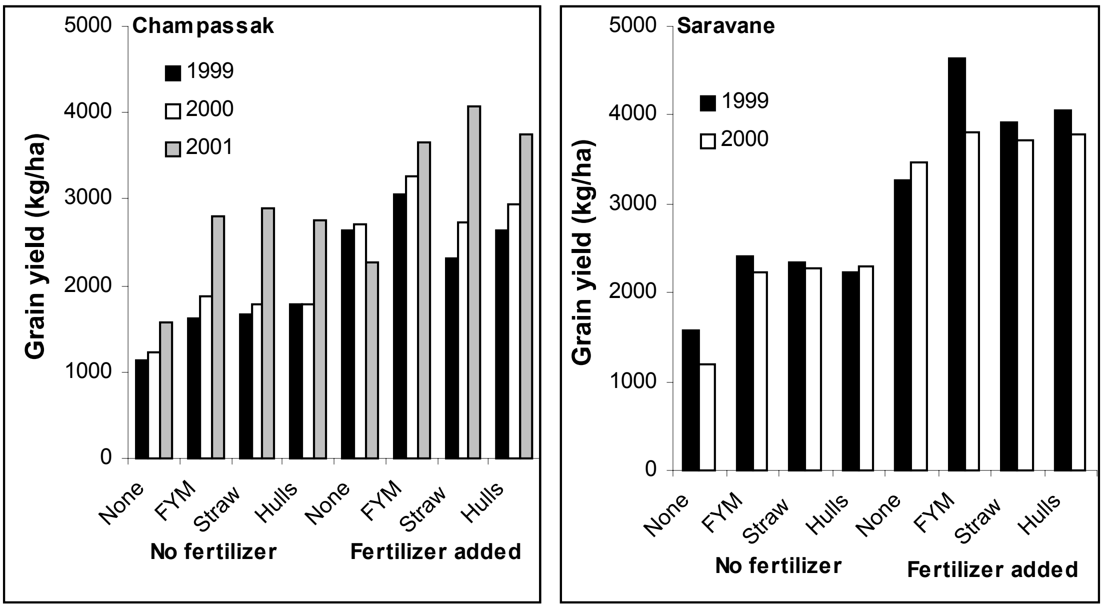


Figure 1 Rice yield response to fertilizers and residues in Champassak and Saravane during the 1999, 2000 and 2001 wet season.

Yields in the no fertilizer plots changed little during the coarse of the experiment. Despite the higher native soil fertility at the Saravane site yields were similar.

In all sites and years there was a significant response to the application of fertilizer applied alone (Table 3). In Saravane yields increased by 1.7 (107% increase) and 2.3 t ha^{-1} (192% increase) in the first and second years, respectively, in response to fertilizer. In Champassak, yields increased by 1.5 t ha^{-1} (126% increase) in the first two years, but only by 0.7 t ha^{-1} (43% increase) in the third year.

Table 3 Results of analysis of variance (Pr>F) by year and site.

Parameter	1999	2000	2001
Champassak			
Fertilizer	0.0023	0.0034	0.0020
Residue	0.0207	0.0000	0.0000
Fertilizer x Residue	0.0151	0.0014	ns
Saravane			
Fertilizer	0.0007	0.0004	-
Residue	0.0000	0.0000	-
Fertilizer x Residue	0.0101	0.0016	-

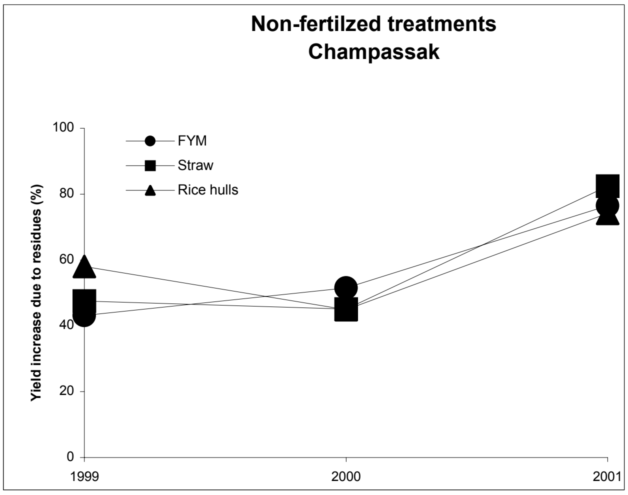
When residues were applied alone, rice yields increased by 0.6 t ha^{-1} (48% increase) in Champassak in the first two years and by 1.2 t ha^{-1} (78%) in the third year (Figures 1 and 2). In Saravane, yields increased by 0.8 t ha^{-1} (47% increase) in the first year and 1.1 t ha^{-1} (90% increase) in the second year. There were no significant differences between residues when they were applied without fertilizer (Figure 1), despite large differences in the nutrient concentration of the on-farm residues (Table 2).

The reason for this is not clear, but it suggests that other factors besides the N, P and K nutrient content of the residues are important for improving productivity. Given the good response to fertilizer, one would have expected there to be a greater yield response in the FYM treatment that contained higher amounts of N, P and K (Table 2).

When residues were applied in combination with fertilizer, there was little to no benefit of the residue in the first year or two (Figures 1 and 2). This is shown by the significant residue by fertilizer interaction in the first two years (Table 3), which indicates that the response to residues was different, when fertilizers were applied compared to when it was not applied. FYM typically performed better than the other residues when applied in combination with inorganic fertilizer.

In the third year at Champassak, the effect of the residues changed and there was no interaction between residues and fertilizer (Table 3), suggesting that the benefits of fertilizer and residue were additive. In this year the benefits of residues increased in both the non-fertilized and fertilized treatments (Figure 2). The cause of this is unclear and further research is required. However, it is interesting to note that the yield response in the "fertilizer only" treatment declined in the third year (Figure 1).

In the first two years the yield increase in response to fertilizer averaged 126% but in the third year only 43% (there was also a decline in yields compared to the first two years). The cause of this may be due to declining soil fertility.



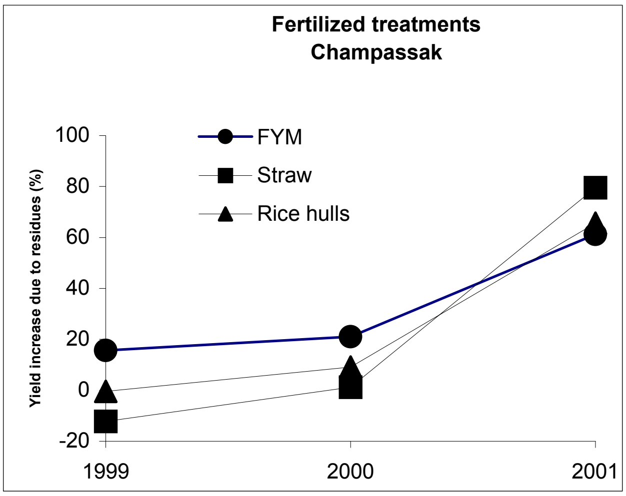


Figure 2 Rice yield increases due to residue applications for the non-fertilized and fertilized treatments in Champassak.

Applying only N, P and K fertilizers increases yields in the short term, but in the long term a greater amount of nutrients are extracted. Most inorganic fertilizers do not replenish other macronutrients and micronutrients so these become depleted with continual cropping and removal of grain and crop residues. A depletion of soil nutrients may occur rapidly in coarse textured soils. Data provided in Table 4 illustrate the importance of rice straw management in maintaining soil fertility. With the exception of N, P and Cu, over 60% of the nutrients are contained in the straw at harvest. Removing the straw removes these nutrients from the soil system. Thus straw has an important role to play in maintaining soil fertility and nutrient balance, even when fertilizers are being used.

Table 4 Macro-and micronutrients in the rice grain and straw at harvest. (data from Linquist and Pheng, 2001).

	N	P	K	S	Ca	Mg	Mn	Zn	Cu
	%	%	%	%	%	%	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$
Nutrient concentration									
Grain	0.79	0.19	0.28	0.10	0.04	0.10	103	23	39
Straw	0.32	0.04	0.79	0.10	0.39	0.17	884	25	25
Nutrient per ton of grain yield (kg t^{-1})[a]									
Grain	7.9	1.9	2.8	0.9	0.4	1.0	0.1	0.02	0.04
Straw	4.8	0.6	11.8	1.4	5.9	2.6	1.3	0.04	0.04
Total	12.6	2.4	14.7	2.4	6.3	3.6	1.4	0.06	0.08
Percent of nutrient in grain or straw at harvest									
Grain	62	76	19	41	7	28	7	38	51
Straw	38	24	81	59	93	72	93	62	49

[a]Assumes a harvest index of 0.4. Therefore, if rice grain yield is 1 t ha^{-1}, the straw yield would be 1.5 t ha^{-1}

Results from the first two years of data are in sharp contrast to those of Willet (1995) and Ragland and Boonpuckdee (1988). They reported that for some soils in NE Thailand, there was little to no response to either fertilizer or on-farm residues applied alone, but a good response if applied in combination. In the first two years of this study, there were good yield responses to both residues and fertilizer alone. However, as mentioned above, with continued use of only fertilizers, residue applications may become increasingly important. However, this will need to be evaluated further.

Residue availability

Straw accounts for approximately 60% of aboveground biomass and is probably the most abundant on-farm residue available. In Laos, about half (depends on variety and farmer) of the rice straw remains in the field following harvest. This stubble is grazed by livestock or burned during the dry season. The panicle straw and grain is moved to a central location. If large mechanical threshers mounted on trucks are used, the straw is moved near the road and following threshing, the straw is burned in the road ditch. If the panicles are to be hand threshed, the panicle straw is moved near the house and after threshing the straw is often feed to livestock.

Straw is 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 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 1,050 kg ha^{-1} and most of it being applied to nurseries. The average farmer has about five cows and/or buffaloes (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^{-1}.

Rice husks account for about 20% of unmilled rice (Juliano and Bechtel, 1985) or about 10% of aboveground biomass. Rice husks are usually left at the rice mills, although some farmers apply rice husks to their fields.

A number of studies have been conducted using very high rates of residues (i.e. Supapoj *et al.*, (1998) where up 25 t ha^{-1} of rice straw was added in NE Thailand), however, it is unlikely that farmers can acquire this amount of residue. Based on the assessment of residue usage above, the rates used in this study (2 t ha^{-1}) are realistic. Interestingly, the type of residue seems to have little short term effect and farmers should be encouraged to recycle the residues they have available.

Conclusion

The short term effects of on-farm residues and fertilizers applied alone are good, with yields increasing by approximately 50% for residues and over 100% for fertilizers. In the first couple of years, applying residues with the fertilizer did not increase fertilizer-use efficiency. In fact, if fertilizers were applied there was generally little benefit of applying residues. However, in the long term there is some indication that the combined use of residues and fertilizers are beneficial. We speculate, that the continued use of fertilizers (without residues) deplete the soil of carbon and nutrients (besides N, P and K) resulting in lower yields. Residues have an important role to play in maintaining soil fertility, as they replenish carbon and nutrients not available in most commercial fertilizers. Evaluation of the effect of residues will continue at the Champassak site.

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