Nutrient Budget Considerations for Rice in Lao PDR

Pheng Sengxua[1] and Bruce Linquist[2]

[1]National Agriculture and Forestry Research Institute, Vientiane, Lao PDR
[2]Lao-IRRI Project

ABSTRACT

Developing efficient and balanced nutrient recommendations is important to ensure sustainable crop production systems. Rice, the primary crop grown in Lao PDR and the focus of this paper, is grown in three ecosystems: rainfed uplands, rainfed lowlands, and irrigated lowlands. Fertilizer consumption in LaoPDR is the lowest in Asia. Nitrogen and P account for 95 percent of the nutrients imported and K only 5 percent. Based on nutrient budgets (accounting for fertilizer and irrigation nutrient inputs and losses due to grain harvest and current residue management practices), the K balance is negative in all rice systems. In the irrigated environment, where higher amounts of N and P are applied and two crops of rice are grown each year, it is likely that K deficiency will become increasingly common. The N balance is positive only in the irrigated environment; however, if one accounts for losses due to denitrification, leaching, etc., it is most likely to be balanced or negative in these production systems. Phosphorus tends to be over applied in the lowland rice systems due to farmers' preference for 16-20-0 fertilizer. Since P is not readily lost in the lowland systems it is probable that P will build up in these soils under current management practices.

INTRODUCTION

With the increasing use of fertilizers in farming systems of Lao PDR it is important to develop sound policies with regard to fertilizer imports, use and balanced nutrient recommendations for various farming systems. Developing nutrient budgets for cropping systems helps us to understand where nutrient imbalances exist and can be instrumental in developing balanced recommendations.This paper focuses on the rice system, as this is the most important crop in Lao PDR. Further, this paper discusses the current trends in fertilizer consumption in Lao PDR and in which farming systems it is being applied. Rice farming systems are then discussed in detail by examining the potential nutrient inputs and losses in the system. Finally, based on the authors' assumptions, a nutrient budget is developed for each of the main rice systems.

FERTILIZER CONSUMPTION IN LAO PDR

Fertilizer consumption for Lao PDR is the lowest in Asia (IRRI, 1995) but it is increasing with approximately 10,000 tonnes being imported in 1998 (Figure 1). These figures are at best rough estimates as there is considerable unregulated cross-border trade between Lao PDR and its neighbors. There is no inorganic fertilizer production in Lao PDR so all such fertilizers are imported. Lao PDR imports primarily three fertilizers namely, urea, 16-20-0, and 15-15-15 (Table 1).

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In 1996 and 1999 these fertilizers comprised approximately 92 percent of total fertilizer imports. Of all the nutrients imported in fertilizers (the average of 1996 and 1999), N constituted 72 %, P 23 %, and K 5 % (Table 2).

Table 1. Fertilizer imports in 1996 and 1999 to Lao PDR.

% of total imports		
Fertilizer	1996	1999
Urea	31	11
16-20-0	56	62
15-15-15	10	13
Total	97	86

Source: Dept. of Agriculture, MAF.

Table 2. Nutrient imports in 1996 and 1999 to Lao PDR.

% of total imports		
Nutrient	1996	1999
N	77	67
P	19	27
K	4	6

Source: Dept. of Agriculture, MAF.

RICE

Rice accounts for 87 percent of the cultivated area and 60 percent of total agricultural production (UNDP, 1999); it provides 67 percent of total calorie intake (IRRI, 1995). Rice is grown in three ecosystems: rainfed uplands (using slash and burn), rainfed lowlands, and irrigated lowlands. During the 2000 wet season, the lowland rice area (irrigated and rainfed) accounted for 475,600 ha and 152,000 ha were cultivated in the uplands (Department of Agriculture, MAF). Most of the lowland rice (77 percent) was grown on the six main plains located in southern and central Laos. Lowland wet-season rice can be classified broadly into rainfed or irrigated rice. Wet-season irrigated rice can receive supplemental irrigation during the wet season. During the 2000 wet season, approximately 280,000 ha of the lowland rice area (almost 60 percent) had access to supplemental irrigation water.

One of the most striking features of rice production in Lao PDR during the latter half of the 1990s was the rapid expansion of the irrigated area. Through 1995 the irrigated area was approximately 13,000 ha. Between 1995 and 2000, the irrigated area increased by almost 600 percent to 91,800 ha.

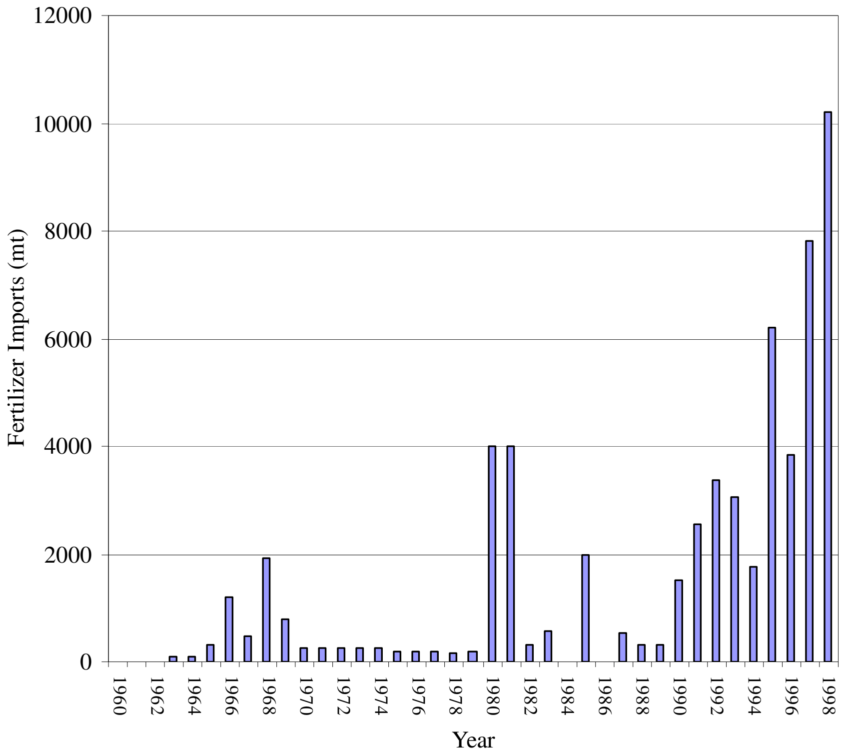

Figure 1. Fertilizer imports to Lao PDR between 1961 and 1998. (Source: FAO 1998: www.fao.org).

NUTRIENT INPUTS

Nutrient inputs include nutrients in rainfall, irrigation water, crop residues, and fertilizers. Nitrogen (N) and S inputs from rainfall were collected during a two-year period (1999 to 2000) from seven locations in Lao PDR. The rainwater contained very little N. In all cases less than 1 kg N ha^{-1} was deposited annually in rainfall (Table 3). Sulfur was supplied in the rainwater at a rate of 5 kg ha^{-1} yr^{-1}. This is slightly higher than the figure reported for Northeast Thailand which receives about 4 kg S ha^{-1} yr^{-1} via rainfall (Blair, 1990). Irrigation water can be a major source of plant nutrients. The amount of nutrients supplied by the water depends on the concentration of nutrients in the water and the amount of water used. The amount of irrigation water applied depends on the soil type, season and crop water requirement. Consequently, during the dry season, more irrigation water is applied than during the wet season. Soils with high hydraulic conductivity (usually sandy soils) require more water than soils with low hydraulic conductivity. Soils in southern and central Lao PDR, where most of the lowland rice is grown, are usually coarse-textured (Linquist et al., 1998). Irrigation water was sampled during the dry season from 12 irrigation schemes in Lao PDR. Table 4 presents the amount of nutrients added per hectare assuming a cumulative irrigation application depth of 1,000 mm of water. The quantity of N and P is either low or not detectable in most irrigation water. Potassium (K) and S are also generally low and highly variable. It is interesting to note that Sayaboury (Phiang District) where K deficiencies are most frequently observed, K concentrations in irrigation water are the lowest. Other nutrients such as Ca and Mg are relatively high.

Table 3. Annual nitrogen and sulfur inputs from rainfall water.*

	Nitrogen	**Sulfur**
	kg ha^{-1}	
Vientiane Municipality	0.18	5.27
Vientiane	0.23	5.58
Savannakhet	0.48	5.67
Champassak	0.17	6.58
Sayaboury	0.19	4.93
Luang Prabang	0.21	4.64
Luang Namtha	0.28	5.49
Mean	**0.25**	**5.45**

Data collected from March 1999 to February 2001.

Table 4. Nutrient inputs from irrigation water. (kg ha^{-1} assuming a cumulative irrigation application depth of 1,000 mm of water).

Province	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Mn**	**B**	**Fe**	**Cu**	**Zn**	**Na**	**Al**
Vientiane	0	0.06	14.2	0.0	53	9	0.57	0.07	0.41	0.02	0.13	5	0.00
Vientiane	0	0.22	14.6	0.3	87	20	0.33	0.10	0.74	0.07	0.05	15	0.01
Vientiane	0	0.20	12.8	0.5	90	17	0.17	0.07	0.46	0.01	0.03	8	0.00
Vientiane	0	0.47	11.1	12.7	168	32	0.02	0.18	0.11	0.00	0.02	65	0.09
Savannakhet	0	0.17	12.6	7.8	40	33	0.12	0.25	3.81	0.06	0.08	529	8.43
Saravane	0	2.05	25.1	3.9	88	63	0.14	0.12	0.55	0.03	0.13	67	0.57
Champassak	0	0.24	10.6	2.0	83	48	0.07	0.06	1.21	0.02	0.05	37	2.27
Champassak	0	0.29	18.0	58.9	349	60	0.02	0.27	0.23	0.04	0.01	110	0.21
Sekong	0	0.54	14.6	4.6	78	48	0.24	0.11	0.38	0.05	0.13	48	0.55
Sayabouli	0	0.11	5.3	9.2	337	31	0.03	0.07	0.47	0.02	0.01	38	0.98
Sayabouli	0	0.22	6.0	6.1	331	35	0.03	0.06	0.35	0.02	0.02	41	0.34
L. Prabang	0	0.34	20.5	11.4	583	63	0.04	0.31	0.28	0.04	0.03	76	0.27

Inputs from fertilizer vary between ecosystems, seasons, regions, and farmers. Little to no fertilizer is applied to upland rice systems. This is partially due to the high risk of crop production in this environment, the difficulty of carrying fertilizers to remote areas on small footpaths, and the limited availability of fertilizers in areas where upland rice is grown.

In the lowland systems, more fertilizer is applied to the irrigated dry season rice crop, although fertilizer use is increasing in the wet season in both the irrigated and rainfed lowland systems. A survey of rainfed lowland rice farmers conducted in Champassak and Saravane in 1996 suggested that the amount of fertilizer used is low (Pandey and Sanamongkhoun, 1998). Of those farmers using fertilizer on average only 27 kg of nutrients (N, P, and K) were applied per hectare. There are no data on fertilizer use in the irrigated environment, but based on informal interviews about four bags (each weighing 50 kg) are applied per hectare on average, or about 70 kg of nutrients per hectare.

Other potentially major inputs are those from on-farm residues such as straw, rice husks, and manure, which are by-products of the rice farming system. Residues are discussed separately below as these may be considered inputs or as a loss depending on how they are managed.

Nutrient Losses

Nutrient losses from the soil may be caused by crop removal, leaching, runoff, erosion, and/or losses to the atmosphere as ions are converted to gases. Runoff and erosion are important considerations for upland rice systems but are of less importance in the lowland rice systems. Roder et al., (1995) reported annual soil losses of 0.3 to 29 mt ha^{-1} from upland rice systems. This was accompanied by a loss of up to 71 kg N ha^{-1} and 30 kg P ha^{-1}. Soil losses vary considerably due to the effects of slope, soil physical properties, and above ground biomass.

In the lowlands where rice is grown under flooded conditions, N is highly susceptible to leaching and gaseous N losses (through denitrification and NH_3 volatilization) (Schnier, 1995). Nitrogen losses are difficult to quantify, however the efficiency of N fertilizer is generally low in flooded rice systems, with normally less than 40 % of applied N being taken up by the crop (Schnier, 1995). NH_3 volatilization is not expected to be a major problem in soils with a low pH such as those in much of Lao PDR. Denitrification is potentially a major problem especially in rainfed lowland rice systems where it is common for soils to cycle between flooded (anaerobic) and aerobic states (Wade et al., 1998). Leaching is a potential problem in sandy soils that have high water percolation rates and low nutrient retention capacity. Such soils are prevalent in the lowland rice systems of southern and central Lao PDR.

Phosphate and K are primarily lost via soil erosion and runoff, but leaching losses are possible, especially in sandy soils when high amounts of these nutrients are applied or when heaps of straw are burned leaving ash that is high in P and K. Linquist et al., (2000) reported that if soil P is not applied at excessive levels, residual P remains in the soil and is as available to rice in the following year as freshly applied P. However, they also reported that under conditions where high levels of P are applied, P may be susceptible to leaching in coarse-textured soils.

A major loss of nutrients results from the removal of rice grain and straw at harvest. Table 5 provides the approximate amount of various nutrients in the rice plant at harvest. Nitrogen and K are taken up in the largest quantities (13–15 kg per tonne of grain yield). Phosphorus is taken up in much smaller quantities, averaging about 2.5 kg per tonne of grain yield. At harvest, most of the N and P is in the grain with relatively little being found in the straw. Therefore harvested grain removes most of these nutrients. The straw contains 50 percent or more of the other nutrients, thus indicating the importance of straw management on soil fertility, which will be discussed in more detail in the following section.

Table 5. Macro- and micronutrients in the rice grain and straw at harvest.

	N	P	K	S	Ca	Mg	Mn	Zn	Cu
	Nutrient concentration								
	%	%	%	%	%	%	*u*g/g	*u*g/g	*u*g/g
Grain	0.79	0.19	0.28	0.10	0.04	0.10	103.12	22.81	38.75
Straw	0.32	0.04	0.79	0.10	0.39	0.17	883.90	25.24	24.62
	Nutrients per tonne of grain yield (kg mt^{-1})*								
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 nutrients 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

* Assumes a harvest index of 0.4. Therefore, if rice grain yield is 1 mt/ha, the straw yield would be 1.5 mt/ha.

RESIDUE MANAGEMENT EFFECTS ON NUTRIENT BUDGETS

On-farm residue (straw, rice husks, and manure) management can have a significant impact on nutrient balance and soil fertility. Generally, current residue management practices for lowland rice systems in Lao PDR can be described as follows. At harvest, farmers cut off the panicle, leaving about half (depending on the variety and the farmer) of the rice straw in the field. Usually, this straw stubble is grazed by livestock during the dry season, but it may also be burned. The straw panicles, which are removed with the grain, are 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 cases, the straw will be moved near the road. Following threshing, the straw is usually burned in the ditch beside the road. If the panicles are to be hand-threshed, the straw is moved near the house, where it will be threshed. In this case, the straw panicles are often stored for livestock feed. There is a tradeoff between the amount of straw potentially available and the number of ruminant livestock. Although rice straw may be important for soil fertility, it is also an important livestock feed during the dry season when other forage is in scant supply. Livestock accounts for a significant portion of expendable cash income (50 percent in southern Lao PDR, Pandey and Sanamongkhoun, 1998). Therefore, the most valuable use of straw may be as livestock feed. Livestock graze freely and little effort is made to collect and use manure. Data from southern Lao PDR indicates that only 11 percent of farmers use manure, with application rates (mostly to nurseries) varying from 35 to 1,050 kg ha^{-1} (Lao–IRRI, 1995). Removing the rice husk and bran is usually done at a rice mill. The cost of milling is the bran removal from the rice. The mill owner retains the rice bran in loo of cash payment and sells the bran for animal feed. The rice husks are usually left at the mill, although some farmers return the husks to their fields.

In upland rice systems, some farmers strip the rice from the panicle without removing the panicle, thus leaving all the straw spread uniformly across the field. Most farmers, however, cut the panicle and move the panicles to a central area in the upland field for threshing. The panicle straw remains in a large heap following threshing. During the dry season animals are allowed to graze in these areas. Following a fallow period of several years, fallow vegetation is cut and burned in preparation for planting.

The amount of residue available annually can be estimated relatively accurately for straw and rice husks. Straw accounts for approximately 60 percent of aboveground biomass and is the most abundant on-farm residue. Rice husks account for about 20 percent of unmilled rice. Therefore, if farm grain yields average 3.5 mt ha^{-1}, there will be 5.3 mt ha^{-1} of straw (assuming a harvest index of 0.4) and about 0.7 mt ha^{-1} of rice husks. Accurate estimates of the amount of available manure are much more difficult to estimate. Lowland rice farmers have on average five cows or buffaloes (Lao–IRRI, 1995). Assuming that each animal produces 1.5 mt manure yr^{-1}, 7.5 mt of manure are produced per farm. In the uplands, there are fewer large animals and typically they are allowed to graze freely during the dry season.

Table 6 provides the nutrient concentrations of some residues. The nutrient concentration estimates for plant residues are relatively accurate, whereas nutrient concentrations of animal wastes can vary widely.

Table 6. Nutrient concentrations of some on-farm residues.

	N	**P**	**K**	**S**	**Ca**	**Mg**	**Mn**
Residue	**%**	**%**	**%**	**%**	**%**	**%**	**$\mu g\ g^{-1}$**
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.

Table 7. Nutrient balance for lowland irrigated and rainfed systems and upland rice systems in Laos (for assumptions used, see text).

Ecosystem	**Inputs kg ha^{-1}**			**Losses kg ha^{-1}**			**Balance kg ha^{-1}**		
	N	P	K	N	P	K	N	P	K
Upland	0	0	0	16.3	3.4	15	-16.3	-3.4	-15.2
Rainfed lowland	18.5	8.1	0.9	29.8	5.9	34.4	-11.3	2.2	-33.5
Irrigated lowland	78	8.6	0	44.5	7.7	30.5	33.6	0.9	-30.5

Straw management, in particular, has a major effect on the nutrient balance because many nutrients are present in larger quantities in the straw than in the grain. Table 5 shows the percentage of other nutrients that are in the straw compared with the grain. With the exception of N, P, and Cu, more than 50 percent of the nutrients are in the straw at harvest. Therefore, removing the grain removes most of the N and P, but straw management has a greater effect on the nutrient balance of the other nutrients. Potassium (K) is of critical concern because of the amount required by the crop. If straw is continually removed from the field, K deficiencies are likely to occur. This process is accelerated if farmers apply N and P without K, as N and P inputs will initially increase yields. However, this also results in greater K uptake, which will lead to K deficiencies in the long term. The process is further accelerated in the irrigated rice system, in which farmers apply more nutrients (N and P) and crop twice a year.

Nutrient Budgets

Nutrient budgets were developed for the each of the main rice systems in Lao PDR using the following assumptions. In the upland system, rice yields are 1.5 mt ha^{-1}, the harvest index is 0.35, there are no fertilizer inputs and all the grain and half of the straw is removed. In the rainfed lowlands, yields are 2.4 mt ha^{-1} and the harvest index is 0.4. Fertilizer inputs were based on data from Pandey and Sanmongkhoung, (1998), namely 18.5, 8.1, and 0.9 kg ha^{-1} for N, P, and K, respectively. In addition, all the grain and straw is removed. In the irrigated environment, yields are 3.5 mt ha^{-1}, the harvest index is 0.4 and the fertilizer inputs are 78, 8.6, and 0 kg ha^{-1} for N, P, and K, respectively. In addition, all the grain and half of the straw is removed and the remaining stubble is burned resulting in loss of all the N but the P and K remain in the ash. The grain and straw nutrient concentrations were in each case based on data in Table 5. There was no estimate of losses apart from those removed by the crop. As indicated above, N losses are usually quite high with up to 50 percent of the N being lost.

In the upland system, all nutrient balances are negative because only nutrient losses via crop removal are accounted for and no fertilizers are applied (Table 7). Despite the fact that they are negative, the negative balances are quite small due to the low yields in these systems. Small inputs during the fallow period from N fixation, rainwater, and leaf deposition from trees with deep root systems may be able to make up for these losses. However, due to rising populations that are leading to shorter fallow periods, rice yields are declining (Fujisaka, 1991; Roder et al., 1997). Furthermore, the nutrient balance did not account for losses due to erosion, which can be significant (Roder et al., 1995).

In the rainfed lowland system, N and K are both negative suggesting a non-sustainable system. Potassium is of special concern as almost 34 kg of K ha^{-1} are removed annually (Table 7). In coarse-textured soils, which are prevalent in Lao PDR, K deficiencies are likely to increase especially with the increased use of N and P fertilizers which have improved yields (and K uptake) in the short term. The P balance is positive, as farmers tend to over apply 16-20-0 because it is the cheapest fertilizer available. Research examining the fate of residual P in these soils, indicates that at the application rates typically applied by farmers, P remains in the soil and is available (Linquist et al., 2000). Under current management practices, it is likely that there will be a buildup of soil P. In the irrigated rice system, N and P are both positive (Table 7). If 50 percent of the N is accounted for by leaching, denitrification, etc, then the actual N balance is close to zero. The major concern for the irrigated environment is K. Assuming two crops of rice are grown annually, there will be a net removal of over 60 kg K ha^{-1}.

Table 4 indicates that an average of 14 kg K ha^{-1} is applied in the irrigation water during the dry season (assuming a cumulative irrigation application depth of 1,000 mm of water). Assuming half of this amount is applied during the wet season, a total of 21 kg K ha^{-1} is applied annually in irrigation water. This still represents a negative balance of about 40 kg K ha^{-1}.

Given the low nutrient reserves in these primarily coarse-textured soils, K deficiencies are likely to become a problem in the irrigated systems. Potassium deficiencies are not yet a major problem with about 30 percent of soils responding to K inputs (Linquist et al., 1998). However, given the current nutrient and residue management practices and the recent increase in irrigation area and fertilizer use, K deficiencies are likely to become a greater problem. In the irrigated environment this process is accelerated.

To evaluate the effect of not applying K in irrigated systems, an experiment was initiated at 17 sites during the 1999 dry season. There were three treatments with only one replication per site. The treatments were; a control with no fertilizer and 16-20-0 or 15-15-15 as a basal fertilizer. In the two treatments that received fertilizer, N was applied at a rate of 90 kg N ha^{-1} in both cases. The N was equally split between an application at transplanting and at 30 and 50 DAT. The compound fertilizer supplied all the N in the first application, while urea was the N source for the two topdressings. The total P and K for each treatment was 16 and 0 kg ha^{-1}, respectively for the 16-20-0 compound fertilizer; and 13 and 25 kg ha^{-1} for the 15-15-15 compound fertilizer. These plots (50 m^2 each) were maintained for four seasons to examine the long-term effects of each fertilizer management strategy.

Across all sites and seasons there was a significant response to both fertilizer treatments. Yields in the no fertilizer control averaged 1.9 mt ha^{-1} as compared to 3.5 mt ha^{-1} for the with fertilizer treatments. In the first season, the K containing fertilizer (15-15-15) produced higher yields than the 16-20-0 fertilizer at only 13 percent of the sites (Figure 2). However, after four seasons, this had increased to 40 percent of the sites. Examining the yield trends, yields remained relatively stable averaging 3.5 mt ha^{-1} across all four seasons when 15-15-15 was applied. However, in the 16-20-0 plots, yields during the first three seasons averaged 3.6 mt ha^{-1} but in the last season yields dropped to 3.1 mha^{-1}. In all cases where farmers were questioned on their straw management practices, the straw remaining after harvest was either burned or grazed by livestock. These data highlight that K deficiencies will become more prevalent if farmers apply only N and P containing fertilizers and remove straw, supporting similar reports by Doberman et al., (1998).

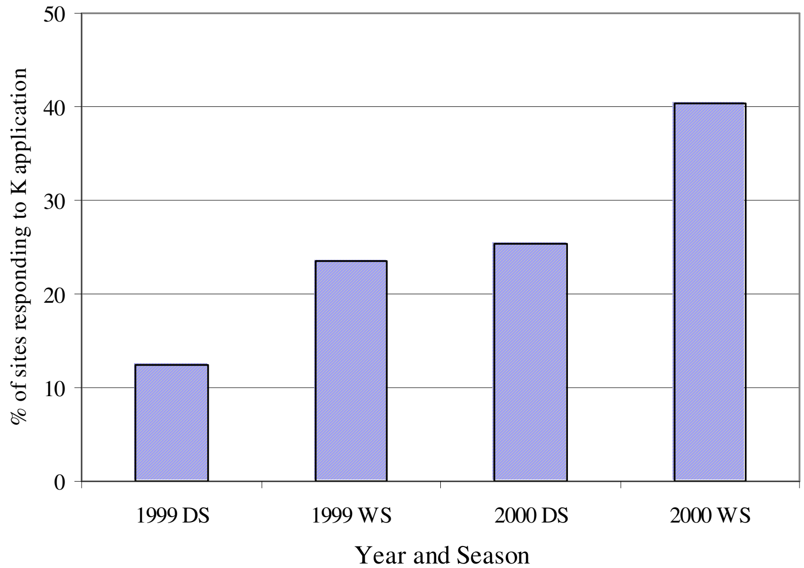

Figure 2. Results after 4 seasons comparing the use of 16-20-0 and 15-15-15 as a basal fertilizer for rice. Graph presents the percentage of sites in which the 15-15-15 fertilizer produced yields which were at least 0.4 mt ha^{-1} greater than those from 16-20-0 fertilizer. (DS = Dry Season; WS = Wet Season)

SUMMARY

National statistics on fertilizer imports suggest the probability of negative K balances in farming systems as the primary imported fertilizer nutrients are N and P. Furthermore, fertilizer and straw management practices by rice farmers indicate negative balances for K in all rice systems. With the increase in irrigation area (allowing for double cropping) and rising N and P inputs, the potential for negative K and other nutrient balances is exacerbated. Irrigation water can provide some of the required K but unless K is added or straw management practices are changed so that more of the straw K is returned to the field, K deficiencies are likely to increase especially on these coarse-textured soils.

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