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Nutrient Requirements of Rainfed Lowland Rice in Cambodia

Vang Seng*, Chhay Ros1, R.W. Bell2, P.F. White3 and Hin Sarith1

Abstract

In most rainfed lowlands of Cambodia, soils used for rice cultivation are low in available nitrogen (N), phosphorus (P) and potassium (K), and have low organic matter content and low cation-exchange capacity. Over the last 4 years, areas cultivated to rice have increased substantially from about 1.9 to 2.1 million hectares, of which rainfed lowlands comprise about 88%. The average rice yield increased from about 1.2 to 1.8 t ha⁻¹, even though nutrient deficiency remains a serious constraint for lowland rice production. The paper reviews current understanding of the nutrient requirements of rain fed lowland rice in Cambodia. Field and greenhouse trials have classified widespread N and P responses and, on sandy soils, K and sulfur responses. Recommended fertilizer rates (in kg ha⁻¹) for rice vary for the different nutrients: for N, from 20 to 120, for P, from 4 to 15, and for K, from 0 to 33. Recommendations are made for each soil type identified in the Cambodian Agronomic Soil Classification system. The need for further work on nutrient requirements of rice and other agricultural crops is also discussed.

The total area cultivated to rice in Cambodia has substantially increased from about 1.9 million hectares in 1995 to 2.1 million ha in 1999 (MAFF 1999). Wet-season, rainfed lowland rice covers about 88% of the total rice area. Demand for fertilizers for rice cultivation has gradually increased. For example, in 1994, total consumption of fertilizers was 80 000 t, increasing to 87 000 t by 1995, indicating a 9% rise in demand (CNP and SCI 1996). The increase was primarily attributed to an increase in cultivated areas and higher application rates on improved rice varieties. Despite increased fertilizer demand and use of improved rice varieties, the national average rice yield was only 1.5 t ha⁻¹ (Nesbitt 1997), which is still low, compared with 2–3 t ha⁻¹ obtained by other rice-producing countries in South-East Asia (Pandey 1997). Most lowland soils of potential use for rice cultivation in Cambodia are low in available nitrogen (N), phosphorus (P), potassium (K), and have low organic matter contents and low cation-exchange capacity (CEC) (White et al. 1997a). Hence, nutrient deficiencies represent a major constraint to rice production at present.

Common problems of rainfed lowland rice cultivation in the diverse soil types of Cambodia include varied soil-water regimes, low nutrient availability and the interactions between these two factors (Fischer 1998; Wade et al. 1998). For example, the availability of N and P in soil varies strongly in relation to soil-water content (Kirk et al. 1990; De Datta 1995). This means that the complex problems in the rainfed lowlands cannot be solved without better understanding site-specific nutrient management. In response to this need, the Cambodian Agronomic Soil Classification (CASC) system was

KEYWORDS: Rainfed lowlands, Soil types, Fertilizer recommendations, Nutrient requirements, Nitrogen, Phosphorus, Potassium, Rice
developed to provide better understanding of soil types. It forms the basis on which fertilizer rates and strategies for rainfed lowland rice production are recommended (White et al. 2000).

This paper reviews the work on nutrient research and management for rainfed lowland rice-based farming in Cambodia. Selected examples are presented to illustrate key elements of the integrated nutrient management strategy being developed in Cambodia. Some sections of this paper are summarized from White et al. (1998).

Soil Classification

The CASC system is used in soil and nutrient management in Cambodia to infer information about the soils' properties by using easily observable surrogate characters such as soil colour and texture, and stone contents, thus allowing management to be tailored accordingly. The CASC has also been used on a broad scale for applied agronomic programs in Cambodia (principally on-farm trials) but, where possible, soil chemical analysis has been used in specific research experiments.

Discussion in this paper is based on the soil groups as described in the CASC system (White et al. 1997b). Chemical properties of the soil groups are given in Table 1, but where available, soil properties from specific experiments are also provided in the text.

Cambodian soils can be broadly divided into three groups: (1) the Prey Khmer and Prateah Lang groups, which are soils with potential for low to moderate yields (White et al. 1997b). These have low nutrient reserves, low levels of organic matter and low cation-exchange capacities. Maintaining an adequate supply of nutrients for high rice yields on these soils is difficult and farmers' experience is that response to fertilizer applications is variable. (2) The potential of the Bakan, Koktrap and Toul Samroung soils is considered as higher (White et al. 1997b). These soils have relatively low levels of nutrient reserves but have higher levels of organic matter, CEC and clay. These soils are therefore more robust, responding to fertilizers more readily. (3) On the high-potential Krakor soils, farmers can produce as much as 10 t ha\(^{-1}\) with dry-season rice and moderately high N fertilizer rates.

The decision to base much of the applied agronomic research and extension of fertility management in Cambodia on the CASC was made for both sound scientific and pragmatic reasons. The alternative would have been soil analysis and diagnosis, using chemical tests. However, for anything other than a limited research program, soil analysis and diagnosis are unworkable in the current Cambodian context. The country has no operating laboratory that can provide reliable soil analysis. Neither have soil tests been calibrated for the country's soils, environments and farming systems, and limited expertise exists for interpreting test results.

The CASC was established to improve soil and nutrient management by improving communication about soil resources and by providing a usable tool to help agronomists, extension agents and farmers make decisions. Surrogate characters often help in

Table 1. Chemical properties of major rice soils in Cambodia.

<table>
<thead>
<tr>
<th>Soil type(^a)</th>
<th>pH(^b)</th>
<th>EC(^c) (dS m(^{-1}))</th>
<th>Olsen P (mg kg(^{-1}))</th>
<th>Total N (g kg(^{-1}))</th>
<th>Organic C</th>
<th>Exchangeable cation [cmol(+) kg(^{-1})]</th>
<th>CEC(^d) [cmol(+) kg(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prey Khmer (Psammments)</td>
<td>5.6</td>
<td>0.03</td>
<td>1.3</td>
<td>0.5</td>
<td>4.7</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Prateah Lang (Plinthustalfs)</td>
<td>4.0</td>
<td>0.07</td>
<td>0.4</td>
<td>0.3</td>
<td>2.9</td>
<td>0.03</td>
<td>0.13</td>
</tr>
<tr>
<td>Bakan (Alisol/Ultisol)</td>
<td>5.8</td>
<td>0.05</td>
<td>1.0</td>
<td>0.6</td>
<td>6.6</td>
<td>0.07</td>
<td>0.26</td>
</tr>
<tr>
<td>Koktrap (Kandic Plinthaquault)</td>
<td>4.0</td>
<td>0.06</td>
<td>2.6</td>
<td>1.1</td>
<td>10.9</td>
<td>0.06</td>
<td>0.42</td>
</tr>
<tr>
<td>Toul Samroung (Vertisol/Alfisol)</td>
<td>5.5</td>
<td>0.08</td>
<td>3.1</td>
<td>0.9</td>
<td>8.8</td>
<td>0.16</td>
<td>0.39</td>
</tr>
<tr>
<td>Krakor (Entisol/Inceptisol)</td>
<td>5.9</td>
<td>0.30</td>
<td>4.6</td>
<td>1.0</td>
<td>9.1</td>
<td>0.19</td>
<td>0.53</td>
</tr>
</tbody>
</table>

\(^a\)Local name as classified by White et al. (1997b). Names in parentheses refer to the Key to Soil Taxonomy by the Soil Survey Staff (1994).

\(^b\):1, soil to water, except for values in italics, which were obtained from 1:5, soil to CaCl\(_2\).

\(^c\)EC = electrical conductivity; dS = decisiemen.

\(^d\)CEC = cation-exchange capacity.
accurately predicting soil chemical properties. Indeed, elsewhere, farmers' soil classifications, which are similarly based on surrogate characters in the field, allow delicate management of those soils with which farmers have first-hand experience (Bellon and Taylor 1993). Their classifications are highly and positively correlated with laboratory chemical and physical indicators of soil quality (Sandor and Furbee 1996; Talawar 1996). A clear relationship has also been observed between land quality, as assessed by the farmer, and variety selection (Bellon and Taylor 1993).

Currently, more than 2000 copies of the Khmer-language version of the soil manual have been distributed and are used to identify soils for rice production. In 1999, seven training courses on integrated nutrient management and the use of soil manual were provided to more than 250 researchers and technical staff, extension workers and fertilizer dealers from various non-governmental and governmental organizations (CIAP 1999).

Local agronomists who use the CASC can separate soil variations sufficiently to classify a given soil and thus identify the interaction of soil type with fertilizer rates and varieties (White et al. 2000). With the CASC, agronomists can also adequately predict differences in grain yields of rice grown on the different soils in on-farm trials (CIAP 1998; White et al. 2000).

The CASC can be applied beyond Cambodia and, when combined with other management tools, is still relevant even where sophisticated soil analytical facilities are available. The philosophy, application and accuracy of the CASC are described by Doberman and White (1999), Oberthiir et al. (2000a, b) and White et al. (2000).

Diagnosing Nutrient Disorders

Through nutrient omission and field trials on fertilizer response, the major deficiencies in Cambodian lowland soils for rice cultivation have been identified (Lor et al. 1996). Deficiencies of N, P, K and sulfur (S) were identified in pot experiments and confirmed in field trials. Many soils exhibit multiple deficiencies so that factorial field trials were needed to examine interactions between the elements. In pot experiments, responses to boron (B) and magnesium (Mg) were obtained in some soils, but have yet to be demonstrated in the field.

Responses to nitrogen, potassium and sulfur

Rice is highly variable in its response to fertilizer application, depending on soil type. In Koktrap soil, the highest yield was obtained when all nutrients (N, P, K and S) were applied together (Figure 1). When N, P or S were omitted the grain yield was decreased to 1-1.5 t ha⁻¹. On this site omitting K appeared to increase yield for reasons that are not clear (NPKS-3 and NPKS-4, Figure 1b). When the nutrients were applied singularly, only a small or sometimes negative response to fertilizer resulted, especially for N or K alone (Figures 1a, b), and rice leaves became bronzed. An adequate supply of N, P and S must therefore be maintained to realize the full benefits of fertilizer application on this soil.

On Prateah Lang soils, rice grain yield increased with K fertilizer application but the effect was additive to that of N and P fertilizer application (Table 2). That is, grain yield increased overall by 12% with the addition of K at 33 kg ha⁻¹, regardless of the N and P application rates.

Table 2. The effect of potassium (K) fertilizer on grain yield of the rice cultivar Santepheap 1 with various levels of nitrogen (N) and phosphorus (P) fertilizer applications.

<table>
<thead>
<tr>
<th>N-P ratea</th>
<th>K rate (kg ha⁻¹)</th>
<th>Grain yield (t ha⁻¹)b</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK soil</td>
<td>Pl. soil</td>
<td>BK soil</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>33</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>1</td>
<td>33</td>
<td>1.8</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>1.5</td>
</tr>
</tbody>
</table>

F probabilities

NP 0.116 <0.001 <0.001 0.018 0.481
K 0.444 0.008 0.006 0.038 0.833
NP × K 0.733 0.681 0.987 0.843 0.977

*aMultiple of recommended fertilizer rate for each soil as shown in Table 3. bSoils: PK = Prey Khmer; PL = Prateah Lang; BK = Bakan; KT = Koktrap; TS = Toul Samrong.

Rice cultivated in Bakan and Koktrap soils, which generally contain relatively low levels of N, P and K (Table 1), also responded to additions of N, P and K fertilizers, similarly to rice in Prateah Lang soil (Table 2). In contrast, the response of rice to additions of N, P and K in Prey Khmer soil was low, probably because of climatic factors, since the Prey Khmer soil experienced a mid-season loss of soil-water saturation, followed by heavy rain (CIAP 1998), resulting in high losses of nutrients through run-off and leaching from the deep sandy textured profile and low-CEC soil.

Grain yields in heavy textured soils that were relatively rich in K (Table 2) were decreased to 1-1.5 t ha⁻¹. On this site omitting K appeared to increase yield for reasons that are not clear (NPKS-3 and NPKS-4, Figure 1b). When the nutrients were applied singularly, only a small or sometimes negative response to fertilizer resulted, especially for N or K alone (Figures 1a, b), and rice leaves became bronzed. An adequate supply of N, P and S must therefore be maintained to realize the full benefits of fertilizer application on this soil.

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Bakan), whose exchangeable K ranged from 0.02 to 0.07 cmol(+)/kg (Table 1).

With long-term use of N and P fertilizers to correct deficiencies of these elements, the soil reserves of K are likely to become depleted and K fertilizer may be needed in the future, even on the Toul Samroung soils.

Response to phosphorus

In Cambodia, more than three fifths of the soils used for rice production are deficient in P (Pheav et al. 1996), limiting rice yields over much of the country. Cambodia relies entirely on imported compound chemical fertilizers (e.g. di-ammonium phosphate or DAP, 16-20-0 and 15-15-15) for rice production. The expense obliges farmers to apply only small amounts of P for rice cultivation.

Local phosphate rock ores, which could supply much of the demand for P fertilizer, has only just been introduced into the local market, but with little support from research on the quantity and suitability of rock phosphate as a P fertilizer. However, previous research showed that high-grade rock phosphate was likely to be as effective as imported triple super phosphate (TSP) for rainfed lowland rice production in Cambodia, producing yields ranging from 1.5 to 2.5 t ha⁻¹ when rock phosphate was applied at 5–10 kg P ha⁻¹ (White et al. 1999). However, the response of rice to P fertilizer additions varies between soil types. Some soils (e.g. Koktrap and Prateah Lang) are acidic, with low available P and exchangeable Ca levels. They remain acidic, even after several weeks of flooding (White and Seng 1997). These factors favour rock phosphate dissolution, thus increasing the availability of P for rice (Hammond et al. 1986). In other soils (e.g. Prateah Lang), sulfur deficiency restricts the response of rice to P additions (Lor et al. 1996).

Low soil fertility, together with fluctuations in the soil-water regime during crop growth, causes rice to respond inconsistently to applied P fertilizers (White and Seng 1997). In acidic Koktrap clay soil and under flooded conditions, grain yield responds strongly to P addition alone, but the curve levels off after adding P at 20 kg ha⁻¹ or more (Figure 1). In contrast, in the sandy Prateah Lang soil, grain yield did not respond to P additions alone, with yields of about 1.4 t ha⁻¹ under flooded conditions (Figure 2). Loss of soil-water saturation decreased rice yield from 1.4 to 0.7 t ha⁻¹, but not because of water stress in rice plants. Instead, loss of soil-water saturation oxidizes the soil, enabling phosphates to react with iron oxides. This, in turn, reduces P availability and thus restricts P uptake by rice plants.
between shoot dry-matter weights and plant P uptake remained close under different soil-water regimes with two soil types and under greenhouse conditions (Figure 3). The relationships suggested that changes in soil-water regimes, which affect soil redox potential, influenced rice growth by controlling P availability (Seng et al. 1999).

Figure 2. Modelled response of rice grain yield to P fertilizer application with combined nitrogen (N) and straw (ST) additions to (a) flooded and (b) non-flooded sandy Prateah Lang soils of south-east Cambodia. The levels of N added were in kg ha\(^{-1}\), and of straw in t ha\(^{-1}\) (from Seng 2000).

**Fertilizer Recommendations**

Fertilizer application, together with the use of modern varieties, irrigation and other improved management practices, has been increasing food production in South-East Asia over the past 25 years. However, financial or crop losses and environmental damage may result if fertilizers are applied incorrectly. Careful consideration must be given to several factors when the rate and timing of fertilizer are being decided. Farmers implicitly consider some of these factors, such as risk associated with erratic rainfall, when deciding on fertilizer use.

In Cambodia, current work is focused on the best use of fertilizer for particular soil types at the appropriate rates, according to the CASC (Table 3). These rates are also formulated from local knowledge and experience and from the results of fertilizer trials conducted by the Cambodia-IRRI-Australia Project during 1992–1997 (CIAP 1998).

On the Prey Khmer, Prateah Lang and Bakan soil types, fertilizers should be broadcast into soil that has been flooded for at least a week. Farmyard manure (FYM) and inorganic fertilizer applications are also recommended. If FYM is to be applied, inorganic fertilizers should be broadcast several days after the FYM is applied. Where possible, the field should be drained before transplanting and the initial fertilizer broadcast and thoroughly incorporated into the wet soil. Further fertilizer applications should also be broadcast into wet soil.

At present, however, few data exist to permit soil-specific predictions of the fertilizer requirements and response for rice production in Cambodia. Careful detailed research is still needed to determine how farmers would adjust recommended fertilizer rates and timing to take into account drought or submergence events.

No specific type of fertilizer or combination of fertilizers is currently recommended. Urea, DAP and KCI have been used as examples here, based simply
Table 3. Recommended rates of nutrients for rainfed rice on major soil types of Cambodia.

<table>
<thead>
<tr>
<th>Soil typea</th>
<th>Recommended rate of nutrients (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Prey Khmer (Psammments)</td>
<td>28</td>
</tr>
<tr>
<td>Prey prateah Lang (Plinthustalfs)</td>
<td>50</td>
</tr>
<tr>
<td>Bakan (Alfisol/Ultisol)</td>
<td>75</td>
</tr>
<tr>
<td>Kokrap (Kandic Plinthaquult)</td>
<td>73</td>
</tr>
<tr>
<td>Toul Samroung (Vertisol/Alfisol)</td>
<td>98</td>
</tr>
<tr>
<td>Krakor (Entisol/Inceptisol)</td>
<td>120</td>
</tr>
</tbody>
</table>

*Local names as classified by White et al. (1997b); names in parentheses refer to the Key to Soil Taxonomy by the Soil Survey Staff (1994).


For the rice nursery, research in Cambodia has so far shown large benefits from applying fertilizers (Ros 1998). Farmers apply higher rates of fertilizer and manures to the seedling nursery than to the main fields (Ros et al. 1998). Such applications increase seedling vigour, which then increases subsequent rice yields by 5%-10%, regardless of whether the main fields were treated with fertilizers. Cow manure at 3.0 t ha⁻¹ and inorganic fertilizer (N at 50 and P at 22 kg ha⁻¹) are recommended for increasing seedling vigour (CIAP 1998). Other low-cost strategies suggested by Ros et al. (2000) for increasing seedling vigour include coating seeds in rock P powder and selecting seeds with high P concentration for nursery planting.

The Cambodian farmers' strategy of applying more fertilizer to the nursery is an efficient use of nutrients because applications to seedlings already transplanted to the main fields do not adequately improve their vigour. Currently, manure and inorganic fertilizer are recommended for application to seedbeds in all soils, except the Kbal Po and Krakor groups (White et al. 1997b).

**Recommended Work on Agricultural Soils in Cambodia**

**Variety × soil type interactions**

Cultivar response to fertilizer varies between soil types, although, in unfertilized plots within each soil type, no significant differences in grain yield occur between farmer and recommended varieties (Figure 4). In the infertile sandy soils of the Prey Khmer group (Figure 4a), rice grain yields were lower than those obtained from the more fertile soils of the Prey prateah Lang or Bakan groups (Figures 4b, c). Adding fertilizer substantially increases grain yield of recommended varieties growing in the Prey Khmer (from 1.8 to 2.9 t ha⁻¹), Prey prateah Lang (2.5 to 3.0 t ha⁻¹) and Bakan (2.3 to 3.3 t ha⁻¹) soil groups. Under these conditions, farmer varieties on the Prey Khmer and Bakan soil groups show similar yields, but levels are much lower than those of the recommended varieties. In contrast, in the Prey prateah Lang soil group, grain yield of farmer varieties decreased by 0.2 t ha⁻¹ when 1.5 times the recommended rate of fertilizer was applied. The greater response of recommended varieties to the recommended fertilizer rate, compared with farmer varieties, indicated that joint strategies of improved cultivars and nutrient management are needed to create significant impacts on crop yield.

Soils used for rice production in Cambodia vary largely in their physical and chemical properties. Not surprisingly, some rice varieties released by the Cambodia–IRRI–Australia Project (CIAP) are well adapted to some soils, but not to others, indicating that it is important to know how new varieties perform on different soils so that appropriate recommendations for varieties can be made.

**Long-term nutrient management**

Because farmers will continue to increase their inputs of inorganic fertilizers, and because the balance of nutrients entering and exiting Cambodian agricultural systems is unknown, long-term monitoring systems should be developed. Nutrient movement, particularly P and K nutrient retention in soils, and nutrient cycling through cropping, pasture or fallow rotations can therefore be monitored.

Simulation modelling shows that soil-specific fertilizer recommendations result in increased yields and more efficient fertilizer use than does the old recommended rate for all soils (N at 64 and P at 23 kg ha⁻¹). Yields increase by 0.2-0.5 t ha⁻¹ when higher rates of fertilizer are applied to responsive soils and lower rates to unresponsive soils (Prey Khmer and Prateah Lang). Such rates result in savings of N at rates between 14 and 36 kg and of P at 7 and 16 kg ha⁻¹ (Ros et al. in press). Further scope exists for developing site-specific nutrient management.

Improved management of the consequences of loss of soil-water saturation for rice growth may depend on the sensitivity of a given rice variety according to development stage. In the rainfed lowlands, loss of soil-water saturation can occur at any stage. Maximum tillering and panicle initiation, which are important for grain yield development in

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on cost. Other fertilizers, combined to apply the same recommended rate of nutrients, would probably produce similar responses.
rice, may also be sensitive periods of loss of soil-water saturation (Fukai and Cooper 1996). Identifying critical stages for loss of soil-water saturation will help in the management of nutrients for rainfed lowland rice because it will indicate the growth phases when the crops most need irrigation to maintain soil saturation. Alternatively, preventing or minimizing yield losses to short periods of loss of soil-water saturation may be feasible with straw or organic-matter additions (Seng et al. 1999).

**Problem soils**

In South-East Cambodia, thousands of hectares of soils are strongly acidic and many thousands of hectares of soils adjacent to coastal areas are also affected by sea salt, making rice cultivation risky. Research is needed to provide management recommendations for increasing the arable potential of these soils.

**Rice bronzing**

In Cambodia, rice bronzing occurs sporadically each year, especially on Koktrap, Prateah Lang and Bakan soil groups. Although loss of grain yields caused by this problem has not been confirmed, the disorder appears to be similar to that described for rice in Japan and Nigeria (Yamauchi 1989). In Cambodia, anecdotal evidence suggests that the problem is more prevalent and more severe with the increased use of inorganic N and P fertilizers, but no K fertilizer. Removal of rice-straw from the field limits the return of K in soils receiving none or low rates of applied K. Breeding for resistant cultivars may be the most effective strategy for the long-term alleviation of this disorder.

**Soil classification for agricultural crops**

The realization of Cambodia's agricultural potential is hampered by several inherent soil problems, compounded by limited soil information, not only for rice but also for other crops. Although a rice soil map is available and the current classification system for rice soils appears to be useful for other crops, further effort is needed to obtain soil information and maps of arable land that are both more complete and more sophisticated.

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