Spatial Variations in Water Availability, Soil Fertility and Grain Yield in Rainfed Lowland Rice: A Case Study from Savannakhet Province, Lao PDR

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Abstract: Rice is the single most important food crop in Laos. Savannakhet province, the largest area of rainfed lowland rice of any single province in the country was selected for the present case study to quantify the spatial distribution of two major limiting factors, water availability and soil fertility, and rice productivity in rainfed lowlands. Field water availability, fertilizer application and other crop management practices, and grain yield information were collected from over 100 farmers to provide basic information relating to rainfed lowland rice productivity and potential bio-physical constraints in this province over two rice cropping seasons. Poor soil fertility is identified as a major yield constraint with yield responding strongly to fertilizer application rate. The results also show that rainfall distribution pattern, soil type and position of rice fields on a sloping land, affect paddy water availability, and this in turn influences sowing time and is also expected to have effect on grain yield. To improve the productivity of rainfed lowland rice, combination of appropriate crop phenology, increased fertilizer use that is matched with water availability, and an understanding of soil water condition for the rice growing environment, is required. In a long term increasing soil fertility is required, and a significant improvement in rice productivity cannot be achieved by improved water availability alone, in a situation where the majority of paddy soils have low levels of fertility.

Key words: Drought, Grain yield, Oryza sativa, Soil nutrient, Toposequence, Water level.

In the Mekong region, it is widely recognized that there can be large variations in grain yield among rainfed lowland rice (Oryza sativa L.) fields within relatively small areas, this variability reflecting a combination of differences in water availability, soil fertility and fertilizer inputs (Anbumozhi et al., 1998; Wade et al., 1999; Homma et al., 2003; Inthapanya et al., 2000; Tsubo et al., 2006, 2007; Boling et al., 2008). Ouk et al. (2006) reported significant variability in water availability around flowering time in the rainfed lowland environment, with water stress often being associated with reduced yield. Similar findings have also been reported by Jongdee et al. (2005), who cited drought as the most severe constraint to productivity in the rainfed lowland ecosystem in the region. An analysis of the production constraint is crucial to bringing about improvements in the productivity of rainfed lowland rice. For example, if the crop growth cycle does not fit within the available potential growing period, or if the crop water requirements are not met, particularly during critical phases of growth such as the flowering period, significant reductions in yield will result. In addition, to maximise fertilizer use efficiency in the rainfed lowland rice ecosystem, potential sources of indigenous nutrient supply (inherent available nutrient), particularly for nitrogen (N), phosphorus (P) and potassium (K), from the soil needs to be fully evaluated and quantified. A full understanding of these constraints, together with other potential constraints such as toposequence position, a paddy position on a sloping land, is therefore important for both the characterization of rainfed lowland rice ecosystem and the related development of appropriate management strategies for maximising crop yield potential in such ecosystems. The upper and lower paddies in a toposequence are often classified as drought and submergence-prone environments, respectively (Jongdee et al., 2005).

Lao PDR is one of the rice-growing countries in the Mekong region. The rainfed lowland areas account for over 80% of rice grain production in the country (Schiller et al., 2001). In the central and southern regions, drought
and low inherent soil fertility, particular low soil N and P levels, are often cited as the factors most limiting yields for rainfed lowland rice (Inthapanya et al., 1996; Linquist and Sengxua, 2001). Savannakhet province in the lower central agricultural region has the largest area of lowland rice in the country, accounting for 23% of the lowland rice area (632,850 ha) in 2007. The predominant lowland rice soils occupying more than 50% of the rice lands are in the Acrisols soils group, which are characterized by highly weathered soils with a low content of primary minerals, and a low base saturation (< 50%) (SSLCC, 1996). Drought is classified according to the time of its occurrence, with early-season drought usually occurring in the period from mid-June to mid-July, while late-season drought occurs in the period from late-September to October and is associated with the retreat of the wet-season rains (Fukai et al., 1998), but no systematic study of a spatial and in-season variation in paddy water availability has been conducted for rainfed lowland rice at a province level in Laos or other countries in the region.

The objectives of this study were to quantify the spatial distribution of water availability, soil fertility, farmer’s crop management practices and grain yield and to identify constraints and possible solutions to increase productivity of rainfed lowland rice in Savannakhet province, Laos. The rainfed lowlands in the province suffer chronic drought and soil infertility problems and were therefore selected for the present case-study. Analyses were conducted on the rainfall pattern relative to time-of-sowing, standing water level in the period after transplanting to maturity, and date of water disappearance relative to flowering time for different toposequence positions across the province. In addition, soil fertility data available across the province was utilized, together with information on fertilizer application rates, to determine grain yield responses to nutrient availability.

Materials and Methods

1. Study area

The study focused on rainfed lowland rice areas in Savannakhet province, an area between 15°50′–17°10′ North and 104°40′–106°50′ East (Fig. 1). The central and western parts of the province consist of a wide floodplain
adjacent to the Mekong River, and a mix of sloping lands (gentle undulating to mountainous) in the eastern part of the province (Wisniewski et al., 2005). Most of the land used for growing rice, is located in the central part of the province and the south-western and north-western corners of the province (see Table 3 for soil areas for different districts). The eastern part of the province [Vilabouri (10 - district number in Fig. 1), Xepon (12) and Nong (13)] is covered by deciduous dipterocarp forest, with limited areas of rice and cash crop cultivation. Generally, the rice fields in the province are laid out on flat or almost flat land, with slopes ranging from 0–8%.

2. Soil datasets

The Soil Survey and Land Classification Centre (SSLCC) of Laos collected a total of 339 soil sample profiles throughout Savannakhet province and analysed them for soil physical and chemical properties (Phommachak and Vonghachak, 1996). The original soil samples were taken mainly from the agricultural land at a density of about 50–100 ha per soil pit. Each district had between 1–40 soil pits with an average of 26 samples, the actual number depending on the proposed use of the land and district’s agricultural land areas. Each land map unit was then given a value for soil type, soil depth, soil texture, slope, and assessed topsoil fertility. However there is no information available on which part of toposequence the samples were taken. The dominant topsoil texture types are coarse-textured–sand (4.5%), sandy loam (38%), and loamy sand (41%) while the clay loam and loam texture groups account for less than 20% out of the total areas of the province. In the subsoil layer below 20 cm soil depth, sandy loam and clay loam soil textures accounted for 36% and 31% of the areas, respectively. The soil depth also varies greatly among soil types, with deep (more than 100 cm) soils being the predominant category, covering about 78% of the province, whereas shallow and thin soils account for less than 6%.

Soil data was used to determine topsoil nutrient condition (the inherent and available nutrient content) of the study area. The potential indigenous soil nutrient supplies of N, P, and K (INS, IPS and IKS) for each site were estimated from soil chemical properties [soil pH(H2O), organic carbon (OC g kg⁻¹), total available phosphorus (TAP mg kg⁻¹) and exchangeable potassium (EK mmol kg⁻¹)] using empirical equations proposed by Janssen et al. (1990) to the form: INS=ƒN*6.8OC; IPS=ƒP*0.35OC+0.5TAP; and IKS=ƒK*400EK/(2+0.9OC) where ƒN, ƒP and ƒK are correction factors related to soil pH(H2O); ƒN=0.25(pH-3); ƒP =1−0.5(pH-6)²; and ƒK=0.625(3.4−0.4pH). The equations can be valid for rainfed lowland rice fields in our study area, as they have been successfully employed in a study quantifying INS, IPS and IKS of paddy soils in tropical and subtropical Asia (Witt et al., 1999). Moreover, based on soil analytical data [organic matter content (%), base saturation (%), available phosphorus (ppm), total cation exchange capacity (CEC me 100g soil⁻¹) and available exchangeable potassium (K2O mg 100g soil⁻¹)], a soil fertility index was developed for rice fields. For each parameter, a soil can receive between one and three points (Table 1) and their sum gives an overall indication of the fertility level. Each parameter was equally weighed for calculation of the soil fertility index. The soils of Laos have been grouped into three soil fertility levels (SSLCC, 1996)-low, medium and high, based on whether the soil fertility index is less than or equal to 7 points, between 8–12 points, and equal to or greater than 13 points, respectively.

3. Rainfall data

The province is characterized as a monsoonal climate, with the southwest monsoons being associated with distinct wet (May-October) and dry (November-April) seasons. Mean annual rainfall decreases from the southern (1800 mm) and northeastern (1900 mm) parts of the province to the northwestern corner of the province where the rainfall is lowest (1300 mm). The mean monthly rainfall for the period from 1985 to 2008 for the provincial capital of Savannakhet (16º33'N, 104º45'E) adjacent to the Mekong River in the west of the province, and Seno (16º49'N, 105º00'E) meteorological station in Outhumphone (4) district is shown in Table 2. Almost 90% of annual rainfall is received during the wet season. August is usually the month of highest rainfall, with Savannakhet City receiving an average of 345 mm (with a range of 103 to 565 mm), and Seno an average of 340 mm (with a range of 119 to 555 mm) over the 24 year period. For spatial analysis of rainfall in this study, daily rainfall data for 2007 was

| Point | OM (%) | BS (%) | P (ppm) | CEC (me 100g soil⁻¹) | K₂O (mg 100g soil⁻¹) |
|-------|--------|--------|---------|----------------------|---------------------|
| 1     | <2     | <50    | <10     | <10                  | <4                  |
| 2     | 2–4    | 50–75  | 10–25   | 10–20                | 4–12                |
| 3     | >4     | >75    | >25     | >20                  | >12                 |

OM- organic matter content; BS - base saturation; P - available phosphorus; CEC - total cation exchange capacity; and K₂O - available exchangeable potassium.

Note that each parameter was equally weighted for calculation of soil fertility index.

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obtained from the 2 main provincial meteorological stations (Savannakhet City and Seno), and 11 hydrological stations spread throughout the province, while daily rainfall data for 2008 for the period July to September was collected using rain gauges at 13 locations in 7 districts where the field soil water levels were also recorded, and they were also used to calculate mean for the year.

4. Measurements of field water level

Standing water level above or below the soil surface was measured in 2008 for three different toposequence positions in 48 farmer’s fields scattered across the main lowland rice growing areas in 7 districts [Khanthabouri (2), Outhomphone (4), Xaibouli (1), Atsaphanthong (7), Songkhone (3), Champhone (5) and Xonbouri (8)]. The number of farms in each district varied from 3 to 11, depending on the total rice growing area. The soils information for each field site for the 48 farms where water level measurements were taken, was obtained by interpolation of soils information obtained from the original survey sites (339 soil profile samples) for the entire province; the spatial interpolation techniques in GIS (Surfer®), namely variography and krigging (Goovaerts, 1997) were employed to generate soil surface. Three toposequence positions within each farm were then selected. Based on the Digital Elevation Map (DEM) for Savannakhet province produced by the Mekong River Commission (MRC) with a horizontal grid spacing of 50 m by 50 m, the difference in elevation of the top position to the bottom position in the toposequence was generally up to 10 m, with the top positions being between 0.5 to 1 km horizontally away from the bottom positions. Perforated PVC tubes with a diameter of 100 to 150 mm and a length of 350 mm (and 5 mm diameter holes in the bottom 100 mm) (Tsubo et al., 2005), were placed in each toposequence position, with a total of 144 PVC tubes being installed across all the farm sites. The level of the standing water above or below the soil surface in the fields was determined weekly from 1 July to 30 September 2008, with the lowest level of measureable water being 250 mm below the soil surface. When water level was below 250 mm, it was assumed to be 250 mm for the estimation of average water level.

5. Farm survey

Rice yield data were collected by interviewing 53 and 48 farm owners in 2007 and 2008, respectively. These farmers interviewed in 2008 were different from those in 2007, and hence 101 farmers were interviewed as a whole. The 53 farms in 2007 represented all 13 districts in the province. The number of sites in each district varied from 1 to 12 farms, depending on the size of rice growing area. The 48 farms surveyed in 2008, were the same as those for which field water levels were determined for the three toposequence positions. In majority of cases, farmers planted several varieties in their fields, and the yield data provided was based on average yields rather than the yields for individual varieties or individual paddies in a toposequence position. Information on the area planted, rice variety, dates of sowing, transplanting, and flowering, as well as fertilizer application management (both inorganic and organic fertilizers) was also collected from each farmer collaborator.

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Table 2. Monthly rainfall of long-term mean at Savannakhet and Seno towns, and mean of a number of sites across the province as well as for Savannakhet and Seno towns in 2007 and 2008 in Savannakhet province, Laos.

| Month | Long term | 2007 | 2008 |
|-------|-----------|------|------|
|       | Savannakhet | Seno | Mean | Savannakhet | Seno | Mean | Savannakhet | Seno |
| January | 4 | 4 | 0 | 0 | 0 | 0 | 2 | 0 |
| February | 23 | 22 | 10 | 21 | 19 | 0 | 0 | 0 |
| March | 44 | 35 | 39 | 15 | 61 | 45 | 13 | 17 |
| April | 77 | 66 | 43 | 7 | 26 | 33 | 61 | 48 |
| May | 203 | 180 | 181 | 206 | 245 | 265 | 400 | 264 |
| June | 290 | 224 | 221 | 258 | 313 | 266 | 263 | 291 |
| July | 260 | 272 | 129 | 189 | 125 | 190 | 182 | 185 |
| August | 345 | 340 | 284 | 284 | 371 | 243 | 138 | 221 |
| September | 208 | 220 | 178 | 145 | 162 | 293 | 330 | 243 |
| October | 88 | 80 | 318 | 316 | 346 | 72 | 100 | 70 |
| November | 8 | 3 | 9 | 0 | 2 | 44 | 47 | 88 |
| December | 3 | 2 | 0 | 0 | 0 | 9 | 20 | 20 |
| Annual | 1491 | 1447 | 1412 | 1442 | 1670 | 1461 | 1566 | 1548 |

a: 24 years from 1985 to 2008.
b: 2 meteorological & 11 hydrological stations.
c: 2 meteorological & 11 hydrological stations plus 13 measured sites.
involved in the two wet-seasons. The majority of farmers grew a combination of both improved (IV) and traditional (TV) varieties. In the 2007 wet-season, 58% of varieties grown were IV and 42% TV, while in the 2008 season the proportion of IV increased to 66%. Among the varieties, the IV such as TDK1 (photoperiod insensitive), RD10 (sensitive), RD6 (sensitive), and some TV (all sensitive) were preferred by most farmers across two cropping seasons (see Fig. 2a). Almost 90% of varieties grown by farmers in the study sites were glutinous varieties (the remaining being non-glutinous). The farmers classified the varieties into three maturity groups - early, medium and late maturity varieties, based on the number of days from sowing to maturity. The flowering date was recorded for a total of 34 genotypes grown in 13 districts for 2007 and 2008. The range in days-to flowering among genotypes in the three maturity groups was 87−105, 98 −117, and 104−138 days, for the early, medium, and late maturity groups, respectively.

Results  
1. Soil fertility  
Figure 1 shows that the rice soils in the province were mostly classified as low soil fertility based on attributes, organic matter, total CEC, base saturation, total available P, and K2O. The estimated indigenous levels of key nutrients in the 53 farmer’s fields surveyed in the 2007 wet-season ranged from 8.2 to 56.4 kg ha⁻¹ of N, 0.6 to 43.6 kg ha⁻¹ of P, and 38.6 to 140.5 kg ha⁻¹ of K, while for the 48 fields monitored in 2008 the corresponding figures were 7.4 to 69.6 kg N ha⁻¹, 0.6 to 42.4 kg P ha⁻¹, and 38.7 to 140.5 kg K ha⁻¹. Average INS was lowest in Songkhone (3) district (19.3 kg N ha⁻¹), whereas the rice soils in Champhone (5) and Xepon (12) districts averaged 42.8 kg N ha⁻¹ and 56.4 kg N ha⁻¹, respectively (Table 3). Average IPS was lowest at sites in Kanthabouni (2) district (3.1 kg P ha⁻¹), while the lowest average IKS was in Xepon (12) district (39 kg K ha⁻¹).

2. Crop management  
(1) Varieties  
More than 30 varieties were planted over 101 farms

(2) Fertilizer application  
When two seasons are combined, about 40% of farmers

Table 3. Yield of rainfed lowland rice (kg ha⁻¹) by districts within Savannakhet province, Lao PDR. Values in brackets are sample numbers. Indigenous levels of key nutrients were averaged from the single year’s district’s average values. Yield level was determined by participating farmers.
used chemical fertilizer only while about 30% used both chemical and farm manure (Fig. 2b). On the other hand, about 20% did not apply any. While most farmers used chemical fertilizer, the rate of N and P was low; most applying less than 30 kg N ha$^{-1}$ and 40 kg P$_{2}$O$_{5}$ ha$^{-1}$. (Figs. 2c, 2d). The most common chemical fertilizers used were 46−20−00% and 16−20−00%.

(3) Sowing date and flowering date

Based on the farm management data collected in 2007 and 2008 farmers in Savannakhet sow seed between late April and mid June (Fig. 2e). The time of sowing is affected by rainfall patterns. Most farmers used transplanting method for crop establishment with seedling age commonly between 26 and 40 days for the two years (Fig. 2f).

In the majority of study sites, farmers planted a combination of improved and traditional varieties, this being reflected in considerable variability in flowering time. In 2007, the early maturity genotypes flowered mainly between 2 September and 15 October, while the medium and late maturity groups flowered between 10 September and 25 October, and 12 to 26 October, respectively. The flowering date for plantings in 2008 was earlier than for 2007 for all three maturities groups; 21 August to 15 October; 13 August to 25 October; 7−13 October, for the early, medium and late genotype groups, respectively.
Fig. 3. Sowing date in 2007 and 2008 for wet season rice in Savannakhet province, Laos.

Table 4. Soil clay content, mean dates of flowering and water disappearance from rice fields, total rainfall and mean water level from 1 July to 30 September for three different toposequence positions of rice fields for each of 7 districts of Savannakhet province, Laos for the 2008 wet season.

| District         | Soil clay (%) | Flowering date | Water disappearance date | Rainfall (mm) | Mean water level (mm) |
|------------------|---------------|----------------|--------------------------|---------------|-----------------------|
|                  | Topsoil | Subsoil | Top | Middle | Bottom | Top | Middle | Bottom | Top | Middle | Bottom |
| Xaibouri (1)     | 18      | 28      | 22 Sep | 22 Sep | 22 Sep | 26 Sep | 3 Oct | 5 Oct | 309 | −24      | 86 | 117          |
| Khanthbouri (2)  | 12      | 24      | 25 Aug | 25 Aug | 25 Aug | 20 Sep | 1 Oct | 11 Oct | 238 | −50      | 27 | 92           |
| Songkhone (3)    | 11      | 24      | 22 Sep | 20 Sep | 21 Sep | 3 Oct | 7 Oct | 11 Oct | 413 | 60       | 70 | 89           |
| Outhomphone (4)  | 6       | 7       | 8 Sep  | 13 Sep | 24 Sep | 2 Sep  | 19 Sep | 5 Oct | 270 | −126     | −39 | 59           |
| Champone (5)     | 9       | 15      | 11 Sep | 12 Sep | 12 Sep | 29 Sep | 4 Oct | 4 Oct | 385 | 54       | 93 | 85           |
| Atsaphanthong (7)| 8       | 15      | 1 Sep  | 1 Sep  | 25 Sep | 19 Sep | 2 Oct | 26 Sep | 284 | −65      | −29 | 2            |
| Xonbouri (8)     | 9       | 23      | 3 Oct  | 9 Oct  | 10 Oct | 4 Oct  | 4 Oct | 6 Oct | 525 | 0        | 47 | 107          |
3. Rainfall distribution and sowing time

The 2007 and 2008 rainfall records show considerable variation in monthly rainfall distribution between years and locations (Table 2). However, total annual rainfall did not differ greatly between Savannakhet City and Seno where long term averages are available. Peak rainfall in 2007 was recorded in October, with a mean recording of 318 mm over all stations, and similar rainfalls were obtained in Savannakhet and Seno. Registrations in September 2007 were generally well below average. In 2008 peak recordings were in September, with a provincial average of 293 mm. High rainfall areas in September 2008, about the time of flowering, were distributed in the south and south west, to the central districts, which received averaged recordings for the month of more than 380 mm. The lowest rainfall areas for the same period were mainly in the west, which received less than 290 mm.

In 2007, more than 60% of the sites surveyed were sown in June. Early sowing (1−20 May) took place mostly in the northern districts, and in some locations in the central and southern parts of the province (Fig. 3). In some parts of Outhomphone (4) and Xonbouri (7) districts in the central part of the province, sowing was delayed to after 10 July. In 2008, sowing was earlier and by 20 May, for almost all districts in the central part of the province. Late sowing (after 20 June) took place in the western edge adjacent to the Mekong River. In the well known drought-prone area in Outhomphone (4) district, where soils have a clay content of less than 7% (see Table 4), early sowing (before 10 May) was possible in the wet year of 2008, while in 2007 it took place after 10 June. In 2008, this district recorded 48 mm of rain in April, almost double that recorded in the same month in 2007 (26 mm). A similar impact of early April rainfall in 2008 facilitating early sowing (May) was recorded in Champhone (5) and Atsaphangthong (7) districts.

4. Field water level

The mean field water level for the 3 months period from 1 July to 30 September which approximately corresponded to transplanting to maturity over the 7 districts for the top toposequence positions was −28 mm, ranging between −222 mm and 118 mm (Fig. 4). The overall mean water level for the middle position was 27 mm varying from −184 to 211 mm, while for the bottom position the mean level was 59 mm, with a range of between −167 mm and 174 mm. It was noted that fields in the northern districts had lower field water levels for all positions than fields in the centre and southern districts. A low level of standing water or the water level being below the soil surface was most evident in top and middle toposequence positions for rice fields in Atsaphanthong (7) and Outhomphone (4) districts. The mean water level from 1 July to 30 September averaged over 7 sites in

Fig. 4. Mean field water level (mm) from 1 July to 30 September 2008 in lowland rice fields at three toposequence positions in 7 districts of Savannakhet province, Laos.
Atsapangthong (7) district was −65 mm, −29 mm, and 2 mm for the top, middle, and bottom positions, respectively, and the average water level over 6 sites in Outhomphone (4) district was −126 mm, −39 mm and 59 mm for the same positions. The overall mean date of water disappearance (defined as the date when water was last observed above the soil surface and after which there was no standing water present until the end of the cropping season) averaged over all sites in 7 districts was 24 September, 2 October and 5 October, for the top, middle, and bottom positions, respectively. It was noted that, for almost all fields across all toposequence positions, water disappeared after flowering (Table 4). However at the top toposequence position of Outhomphone (4), standing water disappeared on average 6 days before flowering.

In addition to the effects of toposequence position described earlier, rainfall and soil clay content also had some effect on the level of standing water, with rainfall generally having a larger influence [correlation coefficient significant for top (r = 0.34) and low (r = 0.33) toposequence position] on the variation in standing water level than clay content (only significant with r = 0.30 for the low toposequence position).

**5. Grain yield and fertilizer effect**

Grain yield for a total of 101 fields over the 2007 and 2008 cropping seasons varied greatly from field-to-field, ranging from 780 to 4800 kg ha⁻¹ with the overall mean grain yield being 1987 and 2175 kg ha⁻¹ for 2007 and 2008, respectively (Table 3). The highest mean yield in 2008 of over 3800 kg ha⁻¹ was recorded for the district of Xaibouri (1), while the lowest yield of less than 1700 kg ha⁻¹ was recorded in the districts of Khanthabouri (2) and Outhomphone (4). These two districts also had below average yields in 2007, particularly Outhomphone district. The yield level across farms in 2008 was not associated with the mean water level in the year.

The indigenous soil N and P nutrient supply had a strong correlation with rice yield in years 2007, with r = 0.75* (n = 13) and r = 0.76* (n = 13) for N and P, respectively. A poor relationship was found for K (r = 0.13 ns, n = 13). In 2008, the correlations between indigenous nutrient supply and grain yield was not significant for all three nutrients (N & P) (Fig. 5), while the application of P₂O₅ and N fertilizers show large increase in grain yield for both years (2007 and 2008) (Fig. 6). The effect of other variable such as relative water level around flowering time, toposequence position, rainfall and soil clay content was not included in the regression due to insignificant contribution it made to the coefficient of determination. Therefore, only indigenous soil N and P, fertilizer application of P₂O₅, and N were
selected for explaining rice yield variation in this two cropping seasons. The following equation describes the relationship.

\[
Yield = 1201 + 35.4 \text{IPS} + 10.9 \text{INS} + 27.2 P_{\text{applied}} - 3.4 N_{\text{applied}} \quad (R^2 = 0.49)
\]

where \( P_{\text{applied}} \) and \( N_{\text{applied}} \) denote \( P \) and \( N \) supplies from fertilizer. The result of multiple regression analysis on indigenous nutrient supply from soil and the amount of \( P \) and \( N \) fertilizer applied (kg ha\(^{-1}\)) explained 49% of the variation of rice yield.

The regression for fertilizer application (\( GY = 1641 + 23.09N \) for 2007; \( GY = 1715 + 15.17N \) for 2008; \( GY = 1631 + 27.16P_{2O5} \) for 2007; \( GY = 1648 + 32.93 P_{2O5} \) for 2008) shows that the yield increase in response to the application of 50 kg N ha\(^{-1}\) and 30 kg \( P_{2O5} \) ha\(^{-1}\) was around 1050 and 730 kg ha\(^{-1}\) for 2007 and 2008, respectively. The effect of indigenous soil nutrient supply plus fertilizer application rate on grain yield shows that the correlation coefficients were similar to those obtained for chemical fertilizer when used alone.

**Discussion**

The variability of field water condition over the 144 study sites was caused by factors such as the rainfall distribution pattern, soil texture type and toposequence position of the field sites. Sites in the south of the province such as those in Songkhone (3) and Xonburi districts (8) had a longer growing period with water from paddy fields disappearing later (late September to mid October), than for sites in the central and northwestern part of the province. This corresponded with a general trend of declining rainfall from the south to the north of the province (Inthavong, 2009). The early disappearance of water or the absence of standing water mostly occurred in sites where the soil had a low clay content such as in Oouthomphone (4) district, and for fields in the top toposequence position, from which there is a high downward water loss rate (percolation rate) and a greater lateral flow of water to fields lower in the toposequence. The effects of soil type and toposequence position on field water availability are clearly evident from the field observation data, confirming previous findings in the Mekong region (Homma et al., 2003; Tsubo et al., 2006, 2007). In the present work, the clay content effect on water level was rather small, and this may be associated with the fact that the actual soils information for the three toposequence positions at each site was not available, and mean clay content across different toposequence positions was estimated from the soils map produced earlier.

Water availability was generally favourable in 2008, but some areas did have low levels of standing water, the latter probably reflecting low October rainfall registration. The September rainfall in 2008 was above the long term (1985 – 2008) average, and much higher than in 2007. Field water levels in September of 2007 were probably lower than in 2008, with potential to have a significant

![Figure 6](image_url)
effect on grain yield as this period coincided with flowering time of most rice crops. Overall grain yield was lower in 2007 than 2008. Wade et al. (1999) when characterizing the variability in the physical environment and rice production in the rainfed lowland rice ecosystem, reported that topography, soil texture and soil fertility can all have a large effect on the hydrology of rice paddies, grain yield and resulting choice of cultivars.

This study also has revealed that the annual variation in early-season rainfall had a large influence on the spatial variation in field water availability, which contributed to the year-to-year variation in time of sowing and therefore transplanting. Field data showed that early sowing date in early to mid May was possible only in some rice fields in the central and southern parts of the province for the 2007 wet season, whereas early sowing was possible for almost all areas in the central parts of the province in the 2008 wet season. This was associated with the higher late April-May rainfall in 2008 than in 2007. Fields with a high soil clay content were also associated with a delay in sowing when rainfall is inadequate at the beginning of the wet-season. For example, in the heavy textured soils of rice fields in Khanthabouri (2) district adjacent to the Mekong river to the north extreme corner of the province (see Table 4) sowing date was delayed to mid or late June in the 2008 season. The sowing date results suggest that generally the annual variation in the onset of the wet-season influences the sowing date of rainfed lowland rice crops. This is supported by a study on soil water balance in lowland rice fields in Savannakhet province (Inthavong, 2009). The simulation study has shown that the start of growing period (SGP) is correlated with April rainfall; the more rainfall, the earlier SGP. Hence the early-season rainfall is a determinant of the timing of sowing in the study region.

The association between the quality of crop management and the supply of indigenous soil nutrients has been described by Dobermann et al. (2003). They found that mean INS decreased from 57 to 51 kg N ha\(^{-1}\) with high to low management quality, with both IPS (16 to 12 kg P ha\(^{-1}\)) and IKS (86 to 73 kg K ha\(^{-1}\)) showing declines of similar magnitude. The indigenous supply of N and P in most fields in the present study was much lower than the above levels, reflecting the generally low fertility levels of lowland soils in the province (see Table 3).

The results reported in this study support earlier findings (Linquist and Sengxua, 2001), that N and P are generally very deficient in most paddy soils in the central and southern provinces of Laos, while K supply is a less yield limiting factor at current yield levels. The yield increase in response to the application of fertilizer (e.g. 50 kg N ha\(^{-1}\) and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\)) of between 730 and 1050 kg ha\(^{-1}\) is similar to that reported earlier by Inthapanya et al. (2000) that grain yield improved up to 930 kg ha\(^{-1}\) in the province, in response to the application of 60-13-16 N-P-K kg ha\(^{-1}\). Therefore, in addition to matching crop phenology such as sowing time, time-to-flowering or using varieties well suited to field water conditions, the application of appropriate rates of N and P\(_2\)O\(_5\) is needed to improve rainfed lowland rice productivity in the province. In one area of particular interest will be to consider separate fertilizer requirements for different toposequence positions. Unfortunately we were not able to obtain yield from different toposequence positions separately, and this has limited the interpretation of the effect of fertilizer application in this study. Top positions are more likely to have water stress problems while the low position to flood problems, and the fertilizer application may accompany more risks. While Boling et al. (2008) did not find the toposequence position effect on fertilizer responsiveness in Ubon Ratchathani, Northeast Thailand, this may be related to their inconsistent effect of toposequence position on chemical and physical characteristics.

Farmers are reluctant to apply high rates of fertilizer and the rates found in the present study are well below the recommended rates (Linquist and Sengxua, 2001). This may be related to drought and flood risks mentioned above as well as socio-economic factors, such as availability of fertilizer at right time and at reasonable price. Risks of drought and flooding may be quantified using models that estimate water balance in lowlands. It is important to recognize variation in fertilizer requirement and risks associated with fertilizer application. Thus, site-specific fertilizer recommendations are required that take toposequence and the field-specific indigenous nutrient supply into account, as proposed by Haefele and Konboon (2009) for Northeast Thailand.

In the long term, it would be advisable to improve soil fertility in addition to appropriate application of chemical fertilizer. Crop rotation and integration of livestock enterprises in rice-based lowlands may achieve such goals. The experience obtained in Northeast Thailand encourages this concept of breaking mono-cropping of rice in rainfed lowlands. (Homma et al., 2008, 2009)

References

Anbumozi, V., Yamaji, E. and Tabuchi, T. 1998. Rice crop growth and yield as influenced by changes in ponding water depth, water regime and fertigation level. *Agric. Water Manage.* 37: 241-253.

Boling, A.A., Tuong, T.P., Suganda, H., Konboon, Y., Harnpichitvitaya, D., Bouman, B.A.M. and Franco, D.T. 2008. The effect of toposequence position on soil properties, hydrology, and yield of rainfed lowland rice in Southeast Asia. *Field Crops Res.* 106: 22-33.

Dobermann, A., Witt, C., Abdulrachman, S., Gines, H.C., Nagarajan, R., Son, T.T., Tan, P.S., Wang, G.H., Chien, N.V., Thoa, V.T.K., Phung, C.V., Stalin, P., Muthukrishnan, P., Ravi, V., Babu, M., Simbahan, G.C. and Adviento, M.A.A. 2003. Soil fertility and indigenous nutrient supply in irrigated rice domains of Asia. *Agron. J.* 95: 913-923.

Fukai, S., Sittisuang, P. and Chanphengsay, M. 1998. Increasing...
Inthavong et al. — Field Water Availability, Soil Fertility and Grain Yield in Rainfed Lowland Rice

production of rainfed lowland rice in drought prone environments. 

Goovaerts, P. 1997. Geostatistics for Natural Resources Evaluation. Oxford University Press, New York.

Haefele, S.M. and Konboon, Y. 2009. Nutrient management for rainfed lowland rice in northeast Thailand. Field Crops Res. 114: 374-385.

Homma, K., Horie, T., Shiraiwa, T., Supapoj, N., Matsumoto, N. and Kabaki, N. 2003. Toposequential variation in soil fertility and rice productivity of rainfed lowland paddy fields in mini-watershed (Nong) in Northern Thailand. Plant Prod. Sci. 6: 147-153.

Homma, K., Mochizuki, A., Watatsu, E., Horie, T., Shiraiwa, T., Supapoj, N. and Thongthai, C. 2008. Relay-intercropping of Stylosanthes guianensis in rainfed lowland rice ecosystem in Northeast Thailand. Plant Prod. Sci. 11: 385-392.

Inthapanya, P., Sipaseuth, Sihathep, V., Chanphengsay, M. and Fukai, S. 1996. Drought problems and genotype requirements for rainfed lowland rice in Lao PDR. In S. Fukai, M. Cooper and J. Salisbury eds, Breeding Strategies for Rainfed Lowland Rice in Drought-prone Environments. ACIAR proceedings 77: 74-81.

Inthapanya, P., Sipaseuth, Sihathep, V., Siyavong, P., Sipaseuth and Chanphengsay, M. 2006. Toposequential effects on water balance and productivity in rainfed lowland rice ecosystem in southern Laos. Field Crops Res. 97: 209-220.

Ouk, M., Kang, S., Thun, V., Sakhan, S., Then, R., Pin, C., Pruch, P., Ith, Y., Fukai, S., Fisher, K.S., Basnayake, J. and Tsobo, M. 2006. Rainfed lowland rice (Oryza sativa L.) performance under contrasting water availabilities in Cambodia. Cambodian J. Agric. 7: 1-11.

Phommachak, T. and Yongmachak, S. 1996. Soil map of Savannakhet Province, Lao PDR. Soil Survey and Land Classification Center, Vientiane. 80p.

SSLCC. 1996. Soil physical and chemical properties analysis for Soil of Lao PDR. Soil Survey and Land Classification Center (SSLCC), Vientiane.

Schiller, J.M., Linquist, B., Douangsilta, K., Inthapanya, P., Douang Boupha, B., Inthavong, S. and Sengxua, P. 2001. Constraints to Rice Production Systems in Laos. In S. Fukai and J. Basnayake eds., Increased Lowland Rice Production in the Mekong Region. ACIAR Proceedings 101: 3-19.

Linquist, B. and Sengxua, P. 2001. Nutrient Management in Rainfed Lowland Rice in the Lao PDR. International Rice Research Institute, Los Banos (Philippines). 88p.

Ouk, M., Kang, S., Thun, V., Sakhan, S., Then, R., Pin, C., Pruch, P., Ith, Y., Fukai, S., Fisher, K.S., Basnayake, J. and Tsobo, M. 2006. Rainfed lowland rice (Oryza sativa L.) performance under contrasting water availabilities in Cambodia. Cambodian J. Agric. 7: 1-11.