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Toposequential variation in soil properties and crop yield from double-cropping paddy rice in Northwest Vietnam

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To access the spatial differences in soil properties and crop yield at cascade level affected by either sediment induced or farmers' fertility practice, field experiments were conducted in Cheing Khoi watershed area during spring and summer seasons with two different cascades. The cascades had fertilized and unfertilized parts and all the measurements were conducted at the top, middle and bottom field of each part. In both rice cascades, middle and bottom fields showed high silt and clay content while sand was the dominant type in the top field. Total nitrogen (TN) and carbon (TC) contents were significantly higher in lower lying fields than top field. Seasonal average surface water NH_4 concentrations for top, middle and bottom fields were 2.7, 3.4 and 3.2 mg L^{-1} in spring and 2.8, 3.5 and 3.1 mg L^{-1} in summer, respectively. Differences were substantial in yield components parameters and grain yield depending on toposequence position. Grain yields in the middle fields of both rice cascades were higher than other field positions in both fertilized and unfertilized fields. The grain yields were significantly related with surface water NH_4 concentration, TN content, sand and silt content of soil. The larger toposequential differences in crop yield require different field specific management practices for each position in order to improve rice production in this watershed area.

Key words: Crop performance, double-cropping, paddy rice, spatial variability, toposequence.

INTRODUCTION

In Northern mountainous region of Vietnam, an important agro-ecosystem is a composite swidden agriculture which integrates annual food crops, such as maize, cassava and upland rice, and fallow in the uplands and permanent wet rice fields in valley bottoms of the catchment (Lam et al., 2005) to form a single household resource system (Rambo, 1998). More recently, traditional agriculture methods involving fallows are more and more replaced by market oriented land use annual mono-cropping systems, that have a low soil cover during their establishment phase (e.g. maize), inducing severe erosion on steep slopes. Such land use alterations have dramatic environmental effects (Wezel et al., 2002) and high precipitation will lead to accelerate soil degradation due to erosion of the steep slopes used for agriculture.

Soil erosion is considered to have serious impacts on the current productivity and sustainability of the land. Upstream erosion will lead to sedimentation and siltation of downstream water bodies and paddy fields as well as nutrient transportation within sediments and irrigation water. During erosion events, nutrients are removed and attached to eroded sediments, reallocated in the watershed

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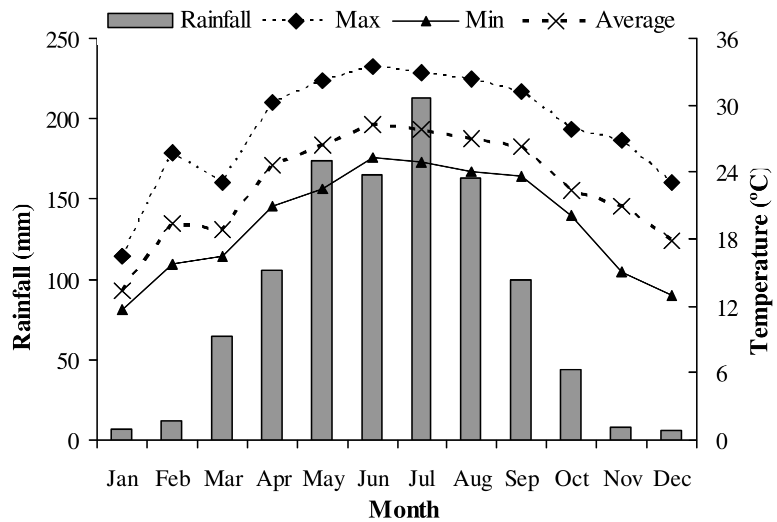

Figure 1. Monthly average rainfall and temperature of Yen Chau city recorded during the year 2011.

(Dung et al., 2008; Pansak et al., 2008). Sediment rich water will flow into the paddy fields at the upper side and flow out at the lower side so that the distribution of the sediments is unequal throughout the rice fields. The deposited sediments create patterns of spatial variability in soil fertility of downstream watershed (Gao et al., 2007; Mingzhou et al., 2007) and will influence the crop productivity of the terrace rice fields.

Rice fields are located on the gently sloping land which differs in elevation for a few meters in an undulating topography. These differences in toposequence position may lead to differentiation in soil properties and hydrological conditions (Hseu and Chen, 2001; Tsubo et al., 2006) and therefore crop yield. Topography directly affects soil-forming processes through erosion and deposition, and variation has been observed in soil texture (Yamauchi, 1992), nitrogen (N), phosphorus (P) and potassium (K) content (Moormann et al., 1977; Eshett et al., 1989; Posner and Crawford, 1992; Yamauchi, 1992) among the toposequence positions. Furthermore, organic compounds present in the water also will influence soil fertility in paddy rice fields. However, redistribution of nutrients through erosion-sedimentation processes in upland-lowland areas and its impact on soil fertility in the lowland are too often neglected (Mochizuki et al., 2006; Rüth and Lennartz, 2008).

In general, large field to field variations in soil fertility and rice growth along the toposequence are not desirable for rice production. For developing the site-specific fertilizer management strategies of crop, it is essential to know the spatial variability of soil factors and to assess their influence on the variability of crop growth and yield. Accessing spatial variation among the toposequence field positions is necessary for identifying and quantifying the limiting factors for rice growth, and addressing the spatial variability of rice yield. There have been studies about spatial variability of yield, crop growth performance and soil (Wezel et al., 2002; Homma et al., 2003, Tsubo et al., 2006; Rüth and Lennartz, 2008) but the knowledge about sediment inducing spatial variation in soil properties and crop yield among the toposequence position due to upland soil erosion is still limited.

Thus, the objectives of this study were (1) to access the sediment inducing toposequential variability of soil properties and crop yield at cascade level and (2) to distinguish between the inherent spatial variability in soil fertility induced by sediment deposits and soil fertility influenced by farmers' fertilization practices.

MATERIALS AND METHODS

The field experiments were carried out from February until November 2011, during two rice cropping seasons in the Chieng Khoi commune (350 m.a.s.l., 21° 7′60″N, 105°40′0″E), Yen Chau district, Northwest Vietnam. The studied area is located in the tropical monsoon area with very hot and rainy summers with 858 mm (May to October, 2011) and cool and dry winters with 201 mm rainfall (November to April, 2011) (Figure 1). The annual precipitation was 1059 mm in 2011. Open channel irrigation system and a lake reservoir allow for two rice cropping seasons a year; spring crop from February to June and summer crop from July to November.

Two rice cascades (Cascade 1 and 2) were selected for this experiment. The length and altitude differences were 83 and 7 m for cascade 1 and 87 and 5 m for cascade 2, respectively. Both cascades contained 5 to 6 successive paddy fields, covering a total area of 0.8 ha. The uppermost field of cascades received water directly from the irrigation channel. All other fields received water from a single inlet from above lying field and drain via single outlet to the lower situated field. At the beginning of the first crop season, sediments entering the rice fields are mainly provided through irrigation system. The irrigation water had an average concentration of 2 mg l^{-1} organic C and 1.5 mg l^{-1} total N when no rain occurred (Schmitter et al., 2010). During rainy season, additional sediments

Table 1. Physico-chemical properties of the experimental soils among the field positions before transplanting of spring rice, 2011.

Field position	Sand (%)	Silt (%)	Clay (%)	TN (g kg^{-1})	TC (g kg^{-1})	pH	EC (msm^{-1})
Cascade 1							
Top	54.0	32.6	13.4	0.17	3.2	8.1	24.2
Middle	23.3	51.9	24.8	0.32	5.6	8.0	25.3
Bottom	31.9	49.7	18.5	0.29	5.3	8.3	21.7
$LSD_{(0.05)}$	8.5	8.4	4.6	0.05	1.0	0.1	3.5
Cascade 2							
Top	58.9	34.1	7.0	0.18	2.5	8.0	25.3
Middle	25.5	43.4	31.2	0.29	4.4	8.2	23.4
Bottom	40.3	37.3	22.4	0.26	4.8	8.4	17.6
$LSD_{(0.05)}$	12.5	4.1	8.6	0.04	0.8	0.1	3.7

from upland are delivered to some of the rice fields besides the irrigation system.

The experiment was laid out in a split plot design with three replications at each site. All fields in both cascades were divided into two parts resulting in two strips per cascade. Two sets of factors included in this experiment were as follows: different toposequence positions (top, middle and bottom) as the main plot and with (+F) and without (-F) fertilizer application as the subplot. The soil type was Gleysols (silty loam in the different horizons) (UNESCO, 1974). The applied chemical fertilizers were 213 kg N ha^{-1}, 150 kg P ha^{-1} and 93 kg K ha^{-1} per rice season with split applications according to the local recommendations by extension service. The first dressing, at transplanting, contained 56% N, 100% P and 34% K of the total amount of fertilizer applied in the form of NPK and urea. Second and third dressings contained 22% N and 33% K of the total amount of fertilizer in the form of urea and Kali (K_2SO_4 – 40% K_2O) which were applied at active tillering and heading stage.

The sticky rice variety (*Oryza sativa*, Var. Nep 87) was used in both cropping season for both cascades. Seedlings of 18 days old were transplanted in the well-puddle fields. Rice seedlings were transplanted on February 28 and harvested on June 30, 2011 for the spring rice and the corresponding dates for the summer rice are July 28 and November 7, 2011, respectively. After harvesting the spring rice, all the fresh crop residues leftover were incorporated into the soil by plowing and harrowing. All management practices were followed by farmer practices in both cropping seasons. Previous to this experiment, all fields were used similarly for continuous double-cropping paddy rice for several years.

Top soil samples at 0 to 5 cm depth were taken before transplanting and after harvest for sand, silt, clay, total nitrogen (TN) and total carbon (TC) content. Soil particle analysis was done by pipette method (Gee and Bauder, 1986). (TN) and total (TC) contents were analyzed by using a NC analyzer (Sumigraph NC-80; Sumika Chemical Analysis Service Co., Japan). The soil pH was measured in the supernatant suspension of a 1 : 2.5 soil: water mixture using a portable pH meter equipped with a combined electrode (glass : Ag/AgCl, Horiba, Japan). Electrical conductivity of the soil water was measured in the supernatant suspension of a 1 : 5 soil : water mixture using EC meter (OM-51, Horiba, Japan). Water samples were collected at 10 days interval for NH_4 concentration analysis. The analysis was done by using ion selective pack test for NH_4, simplified chemical analysis (Kyoritsu Chemical-Check Lab., Corp).

Seven samples hills were collected from each plot for collection of data on plant characters and yield components. Grain yield was determined from 1 m^2 sampling area at harvest and was expressed as rough (unhulled) rice at 14% moisture content. All the data were evaluated by an analysis of variance (ANOVA) by using CropStat 7.2 statistical software. Treatment means were compared by least significant differences (LSD) at $p=0.05$.

RESULTS

Soil properties

Soil physical properties varied significantly among the field positions in both rice cascades (Table 1). Sand was the dominant particle type in the top fields containing 50.0% and 58.9% in cascade 1 and 2, respectively. The middle and bottom fields showed higher silt content in both cascades; 51.9 and 49.7% in cascade 1 and 43.4 and 37.3% in cascade 2, respectively. In cascade 1, clay content was significantly ($p<0.01$) higher in middle field but there were no statistical differences in clay content between top and bottom field. Significantly ($p<0.01$) higher clay content was found in the middle and bottom fields of cascade 2 than in the top field.

Soil TN and TC contents were significantly ($p<0.01$) different among the field positions (Table 1). In cascade 1 and 2, the average values of TN from different field positions were 0.25 and 0.24 g kg^{-1} in the top soil layer, respectively. TC content for cascade 1 and 2 were 4.75 and 3.89 g kg^{-1}, respectively. When comparing different toposequence positions, TN content was significantly ($p<0.01$) higher in the middle field with 0.32 and 0.29 g kg^{-1}, followed by bottom field with 0.29 and 0.26 g kg^{-1} and the lowest was observed in the top field with 0.17 and 0.18 g kg^{-1} in cascade 1 and 2, respectively. In both rice cascades, similar trend like TN was also found for TC content. The highest TC content was observed in the middle fields followed by bottom field and the lowest was in the top field. There were no significant differences in TN and TC content of the soil taken before transplanting and after harvest (data not shown). Soil pH ranged from

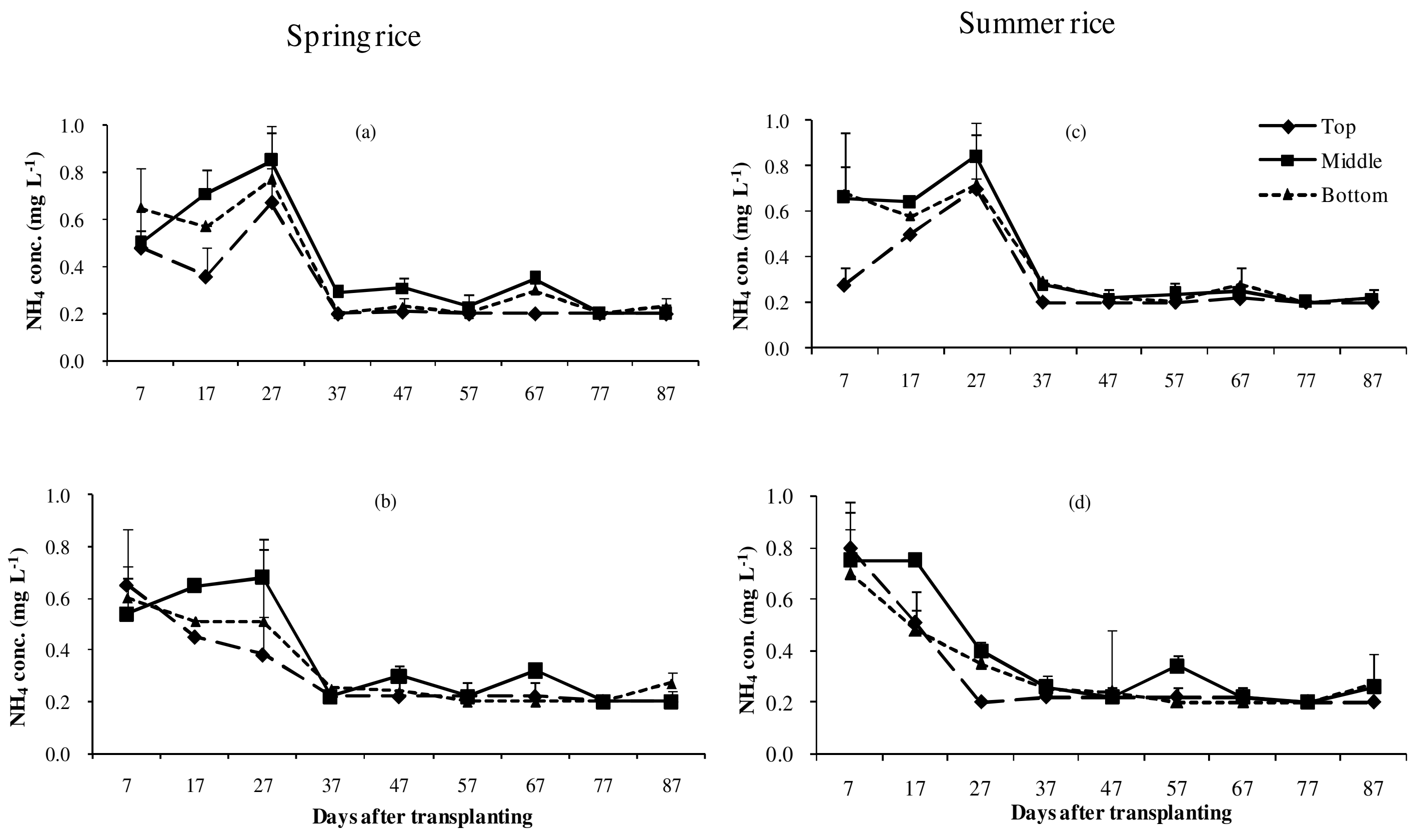

Figure 2. Seasonal variations in NH_4 concentration of surface water; (a and c -cascade 1) and (b and d – cascade 2) among the positions of toposequence rice field (bar – standard deviation).

8.0 to 8.4 in both rice cascades and significant (p<0.05) higher soil pH was found in bottom fields than the others (Table 1). Electrical conductivity (EC) value was found significantly higher in top field than bottom fields in both rice cascades (Table 1).

NH_4 concentration in surface water

Seasonal variations in NH_4 concentrations were observed among the field positions in both cascades in spring rice (Figures 2a and b) and also in summer rice (Figures 2c and d). In spring rice, the concentration of NH_4 in surface water ranged from 0.2 to 0.85 mg L^{-1} for cascade 1 and 0.2 to 0.68 mg L^{-1} for cascade 2 with the highest peaks at 27 DAT. Seasonal NH_4 concentrations for top, middle and bottom fields in average of both cascades were 2.7, 3.5 and 3.1 mg L^{-1}, respectively. In summer rice, the concentrations of NH_4 in flood water were observed in the range of 0.2 to 0.84 mg L^{-1} in cascade 1 and 0.2 to 0.8 mg L^{-1} in cascade 2 with the highest peaks occurred between 17 and 27 DAT during rice growing season. Top, middle and bottom fields contained average NH_4 concentration in surface water of 2.8, 3.5 and 3.1 mg L-1, respectively, for both rice cascades.

Number of effective tillers

Significant differences (p<0.05) in effective tiller per hill were observed among the different toposequence positions in both cascades (Table 3 and Figure 3). In spring rice, for the effect of field position on average of both cascades, number of effective tillers per hill was found the highest in the middle field than the other fields. The lowest number of effective tillers was observed at top field in cascade 1 and at bottom field in cascade 2. The fertilized part produced more effective tillers than unfertilized part in both rice cascades.

In summer rice, the middle field also showed the highest number of effective tillers in average of both cascades followed by bottom field and the lowest was found at top field. Application of fertilizer produced significantly (p<0.05) higher number of effective tillers than unfertilized part in both cascades.

Yield component parameters

In spring rice, fertilizer treatment did not show any significant variation with respect to panicle length and filled grain proportion in cascade 1 and 2 (Tables 2 and

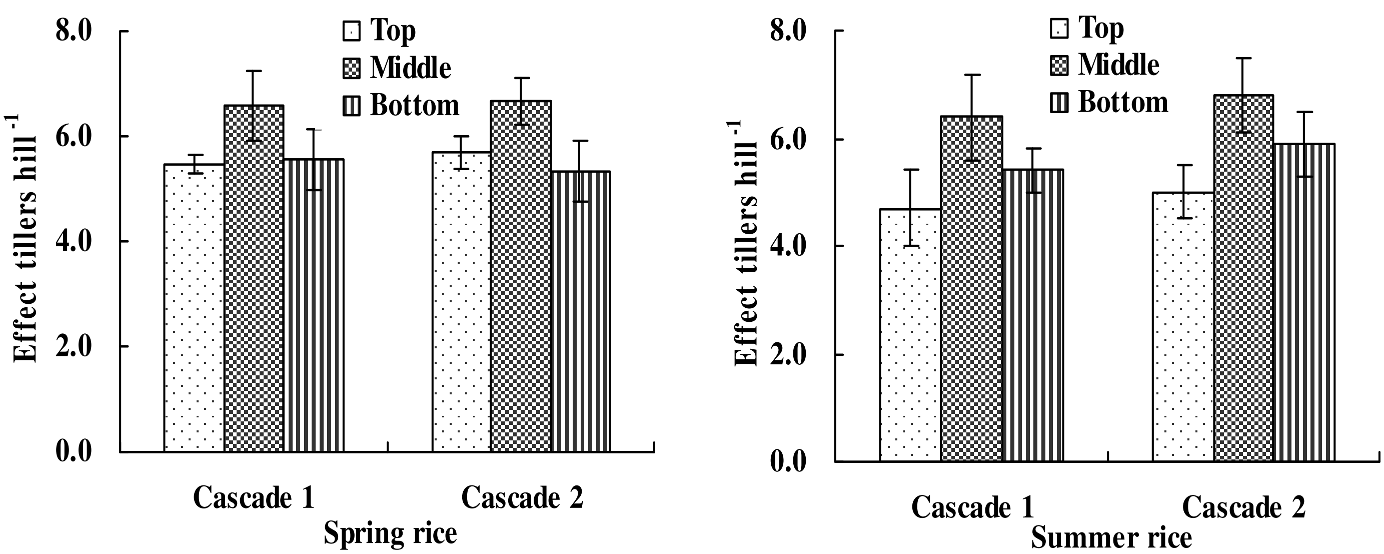

Figure 3. Number of effective tillers at different field position of cascade 1 and 2 in spring and summer rice seasons (Error bar indicates standard deviation).

3). The overall mean values were higher in fertilized part than unfertilized part. Regarding the effect of different toposequence positions, significant ($p<0.05$) differences in panicle length were observed with the longest in the top field followed by the middle and the lowest was observed in the bottom field in both cascades (Table 2). Middle field showed the highest filled grain proportion followed by the bottom field and the lowest was found in the top field in both cascades.

In summer rice season, fertilizer application did not show any significant variation in respect of filled grain proportion but showed significant ($p<0.05$) differences in panicle length in both cascades (Table 3). Among the field positions, middle field showed significantly higher value in panicle length and filled grain proportion than other fields in both cascades (Table 2). The variation in panicle length and filled grain proportion was influenced by interaction of fertilizer and field position only in cascade 2 of spring rice. In summer rice, only panicle length was significantly ($p<0.05$) influenced by fertilized and field position in both cascades.

In both rice seasons, significant ($p<0.05$) differences in grains per panicle and 1000 grain weight were observed due to fertilizer and different toposequence positions (Table 3). Fertilization increased grains per panicle and 1000 grain weight than unfertilized part in both rice seasons (Table 2). In spring rice, the middle field showed the highest value of grains per panicle and 1000 grain weight in both cascades. The variation in grain per panicle was also influenced by fertilizer and field position in cascade 2 and 1000 grain weight in cascade 1. In summer rice, the highest values of grains per panicle and 1000 grain weight were also observed in middle field followed by the bottom field and the lowest was found at the top field in both cascades. There were no interaction effect of fertilizer and field position on grain per panicle and 1000 grain weight in summer rice in both cascades.

Spatial variability in grain yield

The grain yield of rice differently responded to the different toposequence positions of the fields and to the different fertilizer treatments (Figure 4 and Table 3). Grain yield was also influenced by interaction of fertilizer and field position in both rice cascades except in summer rice of cascade 1 (Table 3). In spring rice, a significant ($p<0.05$) difference of grain yield was observed between the fertilizer treatments in both rice cascades with fertilizer application showing a higher value of grain yield (+F: 644.3 g m^{-2}) than unfertilized plot (–F: 483.3 m^{-2}) in the average of cascade 1 and 2. In summer rice, significantly ($p<0.05$) higher grain yield was observed in fertilized part (+F: 599.8) than unfertilized part (-F: 480.8) in the average of both cascades.

Significant ($p<0.05$) yield differences were observed among the toposequence positions in both cascades of spring rice (Table 3) and the highest yields were observed in the middle field in both cascades. The middle field produced the highest grain yield of 644.8 g m^{-2} followed by the first field; 518.2 g m^{-2} and the lowest value 512.1 g m^{-2} was found in the last field during spring rice season. The obtained grain yields for spring rice in cascade 1 and 2 were significantly ($p<0.01$) and positively related with TN content in the soil by a simple linear regression model (Figure 5). Grain yields were also found to be negatively related ($p<0.05$) with sand content in cascade 2 but not related in cascade 1 (Figure 6). Observed grain yields in spring rice season were significantly ($p<0.05$) related with silt content only in

Table 2. Effect of fertilizer and toposequence position on yield components of spring and summer rice.

Parameter	Spring rice				Summer rice			
	Panicle length (cm)	Grains panicle^{-1}	Filled grain %	1000- grain wt (g)	Panicle length (cm)	Grains panicle^{-1}	Filled grain %	1000-grain wt (g)
Cascade 1								
Treatment								
-F	21.7	136.1	78.9	24.1	18.9	80.5	76.2	24.2
+F	22.5	154.4	80.6	25.0	20.3	101.0	77.6	25.4
$Lsd_{(0.05)}$	1.2	13.2	4.5	0.8	0.6	12.1	6.7	1.0
Position								
Top	23.3	167.0	76.5	22.4	19.3	77.9	76.2	23.6
Middle	21.5	185.8	82.7	25.3	20.4	101.8	77.9	25.8
Bottom	20.1	95.9	80.0	24.0	19.9	92.4	77.4	24.9
$Lsd_{(0.05)}$	1.4	13.2	5.5	1.12	0.8	14.0	12.1	0.1
Cascade 2								
Treatment								
-F	21.5	132.1	72.4	24.2	19.2	86.0	72.8	24.0
+F	22.1	153.7	76.8	25.3	20.4	90.9	76.8	25.5
$Lsd_{(0.05)}$	0.8	16.1	4.7	0.8	0.7	10.8	6.0	0.2
Position								
Top	23.3	129.3	68.3	25.5	19.9	85.5	67.1	24.0
Middle	22.3	189.3	80.6	25.7	20.4	107.7	77.7	25.6
Bottom	19.7	110.0	74.9	22.3	19.1	95.6	73.3	25.1
$Lsd_{(0.05)}$	0.9	19.8	5.8	1.0	0.8	13.2	12.1	0.2

-F and +F stand for unfertilized and fertilized part, respectively.

cascade 2 (Figure 7). In spring rice, grain yields were significantly ($p<0.05$, $r=0.812$) correlated with NH_4 concentration in surface water in both rice cascades.

In summer rice, the highest value 559.2 g m^{-2} of grain yield was also observed in middle field followed by the bottom field; 517.7 g m^{-2} and the last was in the top field; 400.2 g m^{-2} in average of both cascades. The obtained grain yields for summer rice in both cascades were significantly ($p<0.01$) and positively related with TN content (Figure 5) and negatively ($p<0.01$) related with sand fraction by a simple linear regression model (Figure 6). Observed grain yields in summer rice season were significantly ($p<0.01$) related with silt content in both cascades (Figure 7). According to spearman rank order correlation analysis, grain yields were significantly ($p<0.05$, $r=0.88$) related with average concentration of NH_4 in surface water for both rice cascades in summer rice.

DISCUSSION

Influence of toposequence position on soil properties

There were substantial differences in soil texture among the different toposequence positions (Table 1). The downward movement of finer nutrient rich soil material along with irrigation and runoff water from upland were deposited to the

Table 3. Results of the ANOVA test for growth and yield components of rice during spring and summer rice growing period in 2011.

	Effective tiller no.	Panicle length	Grain panicle^{-1}	Filled grain (%)	1000 grain weight	Grain yield
Cascade 1						
Spring						
Fertilizer (F)	**	ns	*	ns	*	*
Field position(FP)	**	**	**	ns	**	**
F x FP	*	ns	ns	*	*	*
Summer						
Fertilizer (F)	*	**	**	ns	**	**
Field position(FP)	*	*	*	*	**	**
F x FP	ns	*	ns	ns	ns	ns
Cascade 2						
Spring						
Fertilizer (F)	*	ns	*	ns	*	*
Field position(FP)	**	**	**	**	**	**
F x FP	**	**	*	ns	ns	*
Summer						
Fertilizer (F)	*	**	*	ns	*	**
Field position(FP)	**	*	**	*	**	**
F x FP	*	*	ns	ns	ns	*

Ns, Not significant, ** and * indicate significant at 0.01 and 0.05 levels, respectively.

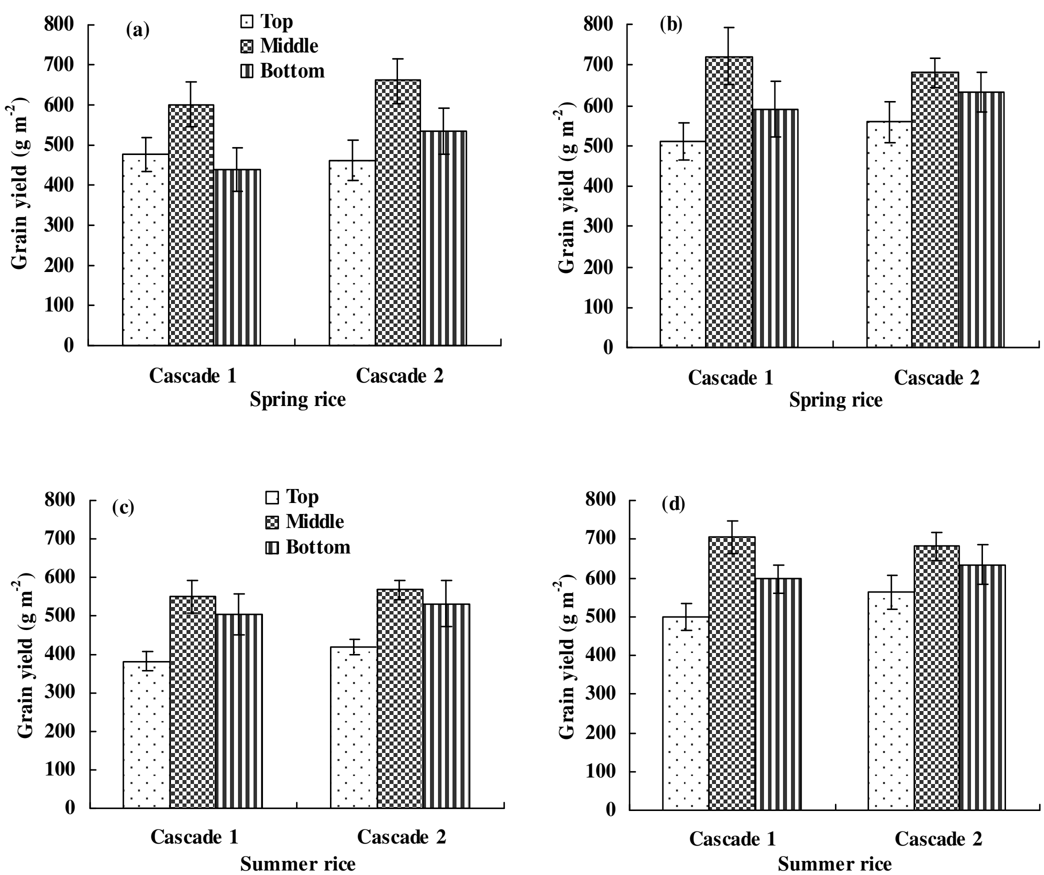

Figure 4. Grain yield in non-fertilized (a and c) and fertilized plots (b and d) at different toposequence positions of cascade 1 and 2 in spring and summer rice seasons (Error bar indicates standard deviation).

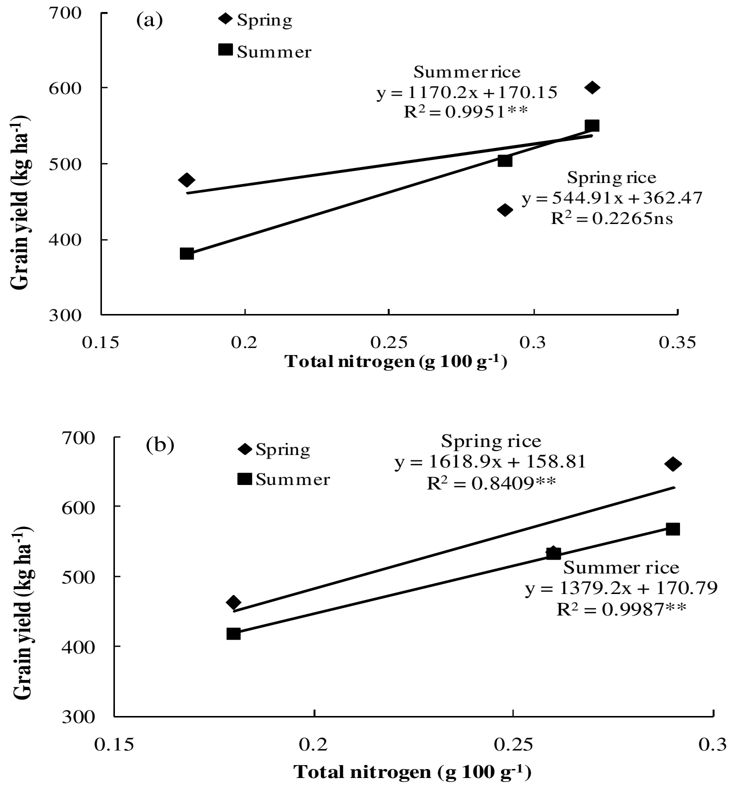

Figure 5. Relationship between grain yield and total nitrogen content of soil (a) Cascade 1 and (b) Cascade 2.

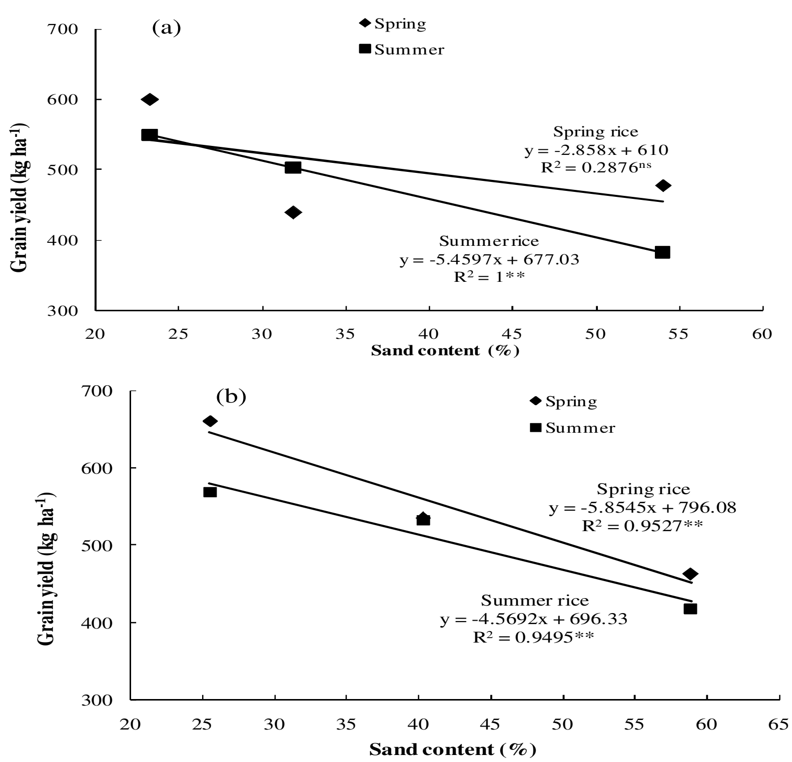

Figure 6. Relationship between grain yield and sand content (a) Cascade 1 and (b) Cascade 2.

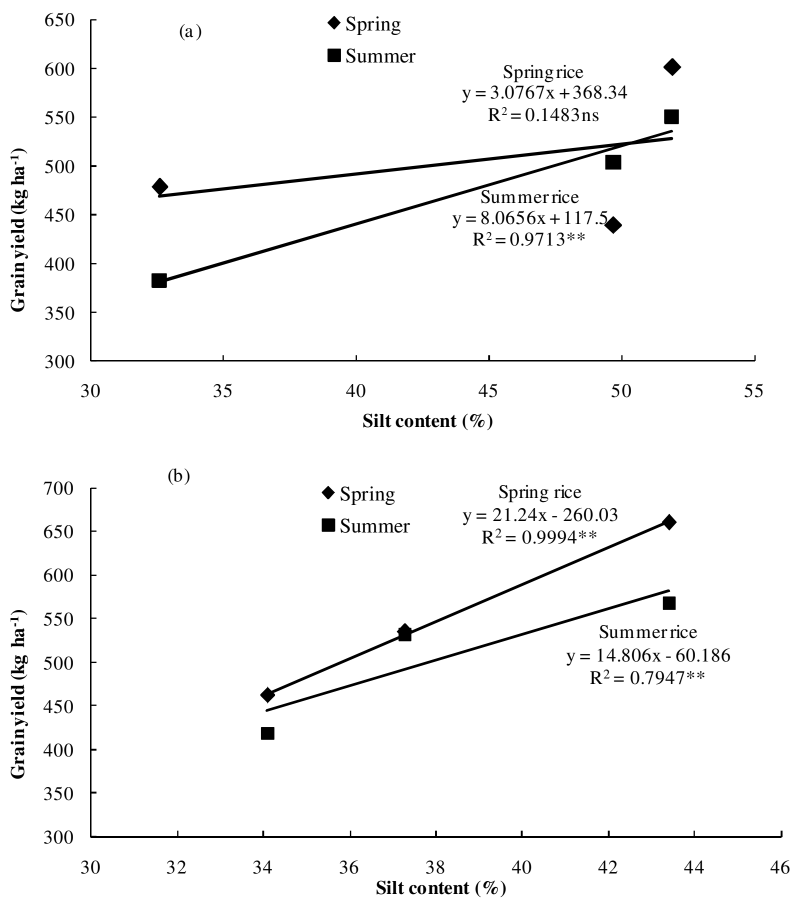

Figure 7. Relationship between grain yield and silt content (a) Cascade 1 and (b) Cascade 2.

lower lying fields of the cascades (Schmitter et al., 2010). Therefore, silt and clay contents were higher in the middle and bottom fields than top field. The increasing trend in clay content from top to bottom along the toposequence was also observed by Eshett et al. (1989) in Nigeria and Posner and Crawford (1992) in Senegal and Boling et al. (2008) in Thailand and Indonesia.

TN and TC content also varied among the different toposequence positions (Table 1). The first field in the cascade had lower TN and TC content with higher sand fraction than the lower fields. Increase in soil TN and TC were related to the different toposequence positions, which were influenced by the distance from the irrigation channel and possibility of material transportation between fields due to runoff water from the upper fields. Tsubo et al. (2007) also reported the downward movement of finer nutrient in soil in rainfed rice terraces. Increase in TN and TC in the middle and bottom fields were related to increase in clay and silt fraction in these fields. The results of analysis of NH_4 concentration in surface water showed that the middle and bottom fields of both rice cascades were higher in concentration than top fields (Figure 2). This indicates transportation of organic rich sediment material from the irrigation channel (Poch et al., 2006). In irrigated rice fields, irrigation water has been identified as a considerable source of additional particulate N and organic C to be transported into irrigated fields depending on its origin (King et al., 2009). Besides irrigation water, runoff water from the surrounding steep slopes could be identified as an additional pathway of sediment delivery into the paddy fields influencing strongly the SOC content and textural changes of the paddy soil (Schmitter et al., 2010).

Influence of management and toposequence position on yield and yield component parameters

Cascade irrigation water can lead to an enrichment or depletion of soil fertility, which can explain the spatial variability patterns in landscape level (Schmitter et al., 2010). This study showed that the number of effective tillers was related to higher content of TN in both cascades (Figure 3). Furthermore, both cascades showed generally higher number of effective tillers in the fertilized fields than in the unfertilized ones. This corresponds to the findings of Salahuddin et al. (2009) in Mymensingh, Bangladesh. They reported that the number of effective tillers increased with increasing N levels in soil. Significant higher grains per panicle, proportion of filled grain and 1000 grain weight were observed in the middle field which might be related to higher silt and clay content, TN and TC content and NH_4 concentration in surface water of the middle field in both rice seasons. Only the panicle length was the highest in the first field in spring rice.

The spatial variation in grain yield observed in both cascades showed a clear difference depending on the different topsequence positions within each season (Figure 4). In both rice cascades, the grain yield increased along the cascade with increasing distance from the irrigation channel, which resembled the distribution of soil particles, and TN and TC content within the cascade. Schmitter et al. (2011) stated that the increase in grain yield towards the bottom fields of toposequence was related to an increase in soil organic C and decrease in sand content in Chieng Khoi area. Rice performance increased when finer nutrient rich sediments were deposited (Schmitter et al. 2011). In this experiment, the higher grain yield in middle fields were significantly related with the higher NH_4 concentration in surface water in both rice seasons. Mochizuki et al. (2006) also pointed out that the incorporation of SOC enriched sediments in lowland rice paddy fields had positive effect on grain yield. For both rice seasons, the TN and TC content and sand fraction significantly affected the obtained rice yields with higher yield at the lower situated rice fields containing higher silt, clay, TN and TC content.

Seasonal differences

In both cascades, among the toposequence positions, the highest yield was observed in the middle fertilized fields in spring and summer rice seasons (Figure 4). Grains per panicle, effective tillers, proportion of filled grain and 1000 grain weight were also highest in the middle field. Grain yield was higher at bottom field than top field position in fertilized part of both cascades and unfertilized part of cascade 2 in spring rice. However, that was not the case at cascade 1 of unfertilized part in spring rice. This might be due to flood damage in the fields lower on the toposequence of cascade 1 which was located next to the river. Schmitter et al. (2010) pointed out that cascade 1 was affected by flooding during typhoons and discussed that flooding events in relation to sediment deposits altered the linear trend of soil fertility changes along a cascade.

In summer rice, higher grain yield was observed in bottom field than top field position in all parts of both cascades. The increase in grain yield in the bottom fields in both rice seasons might be related to an increase in TN and TC content and a decrease in sand content. Schmitter et al. (2011) reported that the grain yield increase along the cascade with increasing distance from irrigation channel resembled the soil fertility pattern observed in the top soil (that is, an increase in SOC and decrease in sand content in this watershed area). A similar spatial variability of grain yield has been reported by Homma et al. (2003), Rüth and Lennartz (2008) and Haefele and Konboon (2009) who observed increasing grain yields due to deposition of nutrient rich fine sediments at the end of a toposequence.

Influence of fertilization

The effect of sedimentation can be seen clearly in the unfertilized part where the middle field produced the highest grain yields than other fields in both crop seasons (Figure 4). Application of the recommended amount of fertilizers increased yields over unfertilized plots but fertilizer management did not mitigate spatial variation trend that middle field also produced the highest yield in both spring and summer rice. Mochizuki et al. (2006) reported that combining chemical fertilizer with the incorporation of the sediment soil into the paddy soil increased the grain yield significantly, while without fertilizer the sediments had no effect on yield. This result was in contrast to the findings of our research, where fertilized plots produced higher yield, but still showed the effect of toposequence positions. The study by Schmitter et al. (2011) showed that an average, the fertilized fields yielded continuously more than the fields without fertilizer in Chieng Khoi area. In unfertilized part, there was a significant difference in grain yield among toposequence positions which showed the significant influence of sediment deposition from the upland to the lowland rice fields. Grain yield increased in lower lying fields when finer nutrient rich sediments were deposited depending on quality and quantity of the sediments and the deposition pathways.

Conclusion

This study showed clearly that the spatial variations in soil properties and crop production in the cascades could be linked to sediment deposition onto the top soil. The downward movement and deposition of sediment along the toposequence positions created spatial variability patterns and influenced the crop productivity. Although recommended types of fertilizer management practice increase grain yield over unfertilized parts, toposequence specific management practice such as the same amount of fertilization in all toposequence positions should not be practiced in this watershed area. The results highlighted that spatial variations in soil properties and crop yields required field specific and field adapted management practices for each position rather than toposequence specific management practice for sustainable land use in this watershed area.

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