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journal or publication title	Journal of Integrated Field Science
volume	9
page range	59-65
year	2012-03
URL	http://hdl.handle.net/10097/54442

JIFS, 9 : 59－65 (2012) Symposium Paper

Effect of Toposequence Position on Soil Properties and Crop Yield of Paddy Rice in Northern Mountainous Region, Vietnam

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Keywords: sediments, soil fertility, spatial variability, crop performance

Received 29 November 2011; accepted December 27 2011

Abstract

In tropical mountainous regions of Northern Vietnam, intensive cultivation of upland crops enhances large nutrient losses through erosion in the upland areas. However, in the valley areas, sediment deposition can enhance soil fertility depending on the quality of the sediments, and influence the crop productivity. To access the spatial differences in soil properties and crop yield at cascade level affected by either sediment induced or farmers' fertility practice, field experiment was conducted in Cheing Khoi watershed area during the spring crop season (February to July, 2011) with two different cascades (one cascade consists of 5 different toposequence fields) wherein half of each cascade was fertilized with farmer recommendation practice.

Total nitrogen and carbon contents were significantly higher in middle field than others. Number of effective tillers, panicle length, grains per panicle, filled grain % and 1000 grain weight varied significantly due to different toposequence position. Rice yield in the middle of toposequence showed better performance than the other field positions in fertilized and unfertilized fields in both cascades. The observed grain yields for non-fertilized fields averaged over both cascades, accounted for 0.55, 0.64 and 0.47 kgm^{-2} in top, middle and bottom fields, respectively, while for fertilized fields, grain yield of 0.72, 0.79 and 0.63 kgm^{-2} were obtained. The larger toposequential differences in crop yield require different crop management practices for each toposequential position, in order to improve rice production in this watershed area.

Introduction

In Northern mountainous region of Vietnam, the topography is characterized by mountains with partly steep slopes with altitudes between 300 and 1000 m. In this region, 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 monocropping systems that have a low soil cover during their establishment phase (eg. 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 to nutrient transportation within sediments and irrigation water. During erosion events, nutrients are removed and, attached to eroded sediments, reallocating in the watershed (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).

Rice fields are located on the gently sloping land with differences 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 (Eshett et al., 1989; Posner and Crawford 1992; and Yamauchi, 1992), nitrogen (N), phosphorus (P) and potassium (K) content (Moormann et al., 1977; Eshett et al., 1989; Posner and Crawford, 1992, and Yamauchi, 1992) among the toposequence position. 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; Ruth and Lennartz, 2008).

There have been studies about spatial variability of yield, crop growth performance and soil 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. Therefore, the experiment was conducted with the objective of (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 induced by farmers' fertilization practice.

Materials and Methods

The study watershed area (2 km^2) is located in the ChiengKhoi commune (350 masl, 21˚ 7′60″N, 105˚ 40′0″E) situated in the Yen Chau district, Northwest Vietnam. The climate is characterized by tropical monsoons with very hot and rainy summers (May-October) and cool and dry winters (November-April) with average annual rainfall of 1200 mm and average annual temperature of 24˚C.

Two rice cascades (series of paddy terraces) were selected for this experiment. Cascade 1 (C-1) was 83 m long with height difference of 7 m, and cascade 2 (C-2) was 87 m long with height difference of 5 m among the toposequence position. Both cascades contained 5-6 successive paddy fields, covering a total of 0.8 ha. The uppermost field of cascades received water directly from the irrigation channel. All other fields received water from single inlet from above lying field and drain via single outlet to the lower situated field.

The experiment was laid out in a split plot design with three replications at each site. Two sets of factors included in this experiment are as follows: different toposequence position (top, middle and bottom) as the main plot and with (+F) and without (-F) fertilizer application as the subplot. The applied chemical fertilizers were 213 kg N ha^{-1}, 150 kg P ha^{-1} and 93 kg K ha^{-1}according to the local recommendations by extension service.

Soil type was Gleysols (silty loam in the different horizons). Seed of variety Nep 87 was raised in seed bed on 12 February 2011. Seedlings of 17 days old were transplanted on 28 February 2011 in the well-puddled experimental fields. Fertilizer was applied three times: basal, active tillering stage and heading stage. All other managements were the same in both cascades.

Top soil samples at 0-5 cm depth were taken before rice transplanting and after harvest for total N (TN) and total carbon (TC) content. 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 7.0 statistical software. Treatment means were compared by least significant test ($LSD_{0.05}$).

Results

Soil TN and TC contents were significantly different ($P<0.01$) among the field position (Table 1). The C-1 and C-2 contained average value of 0.25 gkg^{-1} and 0.24 gkg^{-1} TN whereas TC was 4.75 g kg^{-1} and 3.89 g kg^{-1}, respectively. When compared with different toposequence position, TN content was significantly higher at the middle field followed by bottom and the lowest was found at the top field. The same trend like TN was also found in TC content in C-1, but bottom field of NF was the highest after trans-

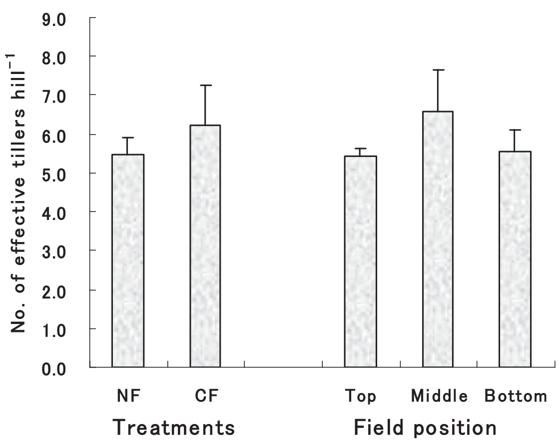
Table 1. Soil total nitrogen and carbon content after harvest of the spring crop

Cascade	Field position	Fertilizer	TN (gkg^{-1})	TC (gkg^{-1})
C-1	Top	NF	0.17	3.08
		CF	0.17	3.31
	Middle	NF	0.33	5.94
		CF	0.30	5.44
	Bottom	NF	0.28	5.52
		CF	0.29	5.22
		CV(%)	11.2	11.6
		$LSD_{(0.05)}$	0.05	1.0
C-2	Top	NF	0.18	2.55
		CF	0.17	2.42
	Middle	NF	0.25	4.48
		CF	0.32	4.27
	Bottom	NF	0.31	5.67
		CF	0.21	3.96
		CV(%)	10.9	10.8
		$LSD_{(0.05)}$	0.04	0.8

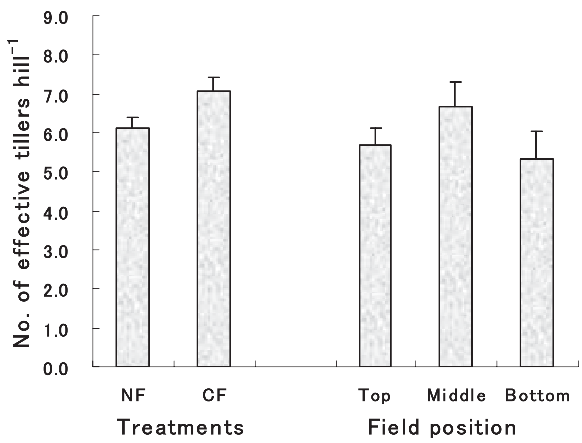
planting in C-2. There were no significant differences in TN and TC content between the two sampling times (before transplanting and after harvest) for C-1 (data not shown).

Significance differences in effective tiller per hill ($P<0.05$) were observed among the different toposequence position in both cascades (Fig. 1). For the effect of field position on average, the highest number of effective tillers per hill was found in the middle field than other fields. The lowest number of effective tillers was observed at top field (5.5) in C-1 and at bottom field (5.3) in C-2. Number of effective tillers in top and bottom fields showed no significant differences in both cascades. Significant variation in number of effective tillers per hill ($P<0.05$) was observed due to fertilization (Fig. 1). Application of fertilizer produced higher number of effective tillers with 6.2 and 7.0 in C-1 and C-2 while those in non-fertilized plots were 5.5 and 6.1, respectively.

Fertilizer treatment did not show any significant variation in respect of panicle length and filled grain proportion (Table 2). The overall mean values were



(a) Cascade 1



(b) Cascade 2

Fig. 1. Effect of fertilizer and field position on no. of effective tillers $hill^{-1}$. Error bar indicates standard deviation

Table 2. Effect of fertilizer and toposequence position yield components of spring rice in Cascade 1 and 2

		Treatment	Panicle length (cm)	Grains panicle^{-1}(no)	Filled grains%	1000-grain weight (g)
C-1	Fertilizer	NF	21.7	136.1	78.9	24.1
		CF	22.5	154.4	80.6	25.0
	CV(%)		3.9	15.6	14.7	3.7
	$LSD_{(0.05)}$		1.2	13.2	4.5	0.9
	Field position	Top	23.3	167.0	76.5	22.4
		Middle	21.5	185.8	82.7	25.3
		Bottom	20.1	95.9	80.0	24.0
	CV(%)		4.0	16.2	15.4	4.3
	$LSD_{(0.05)}$		1.4	13.2	5.5	1.12
C-2						
	Fertilizer	NF	21.5	132.1	72.4	24.2
		CF	22.1	153.7	76.8	25.3
	CV(%)		5.7	15.5	10.2	3.7
	$LSD_{(0.05)}$		0.8	16.1	4.7	0.8
	Field position	Top	23.3	129.3	68.3	25.5
		Middle	22.3	189.3	80.6	25.7
		Bottom	19.7	110.0	74.9	22.3
	CV(%)		5.7	15.7	9.4	2.7
	$LSD_{(0.05)}$		0.9	19.8	5.8	1.0

higher in fertilized part than in the non-fertilized part. Regarding the effect of different toposequence position, significant differences ($p<0.05$) in panicle length were observed with the longest in the top field (23.3 cm and 23.3 cm) followed by middle (21.5 cm and 22.1 cm) and the lowest was in the bottom field (20.1 cm and 19.7 cm) in C-1 and C-2, respectively. Filled grains proportion was the highest in middle field than other fields in both cascades.

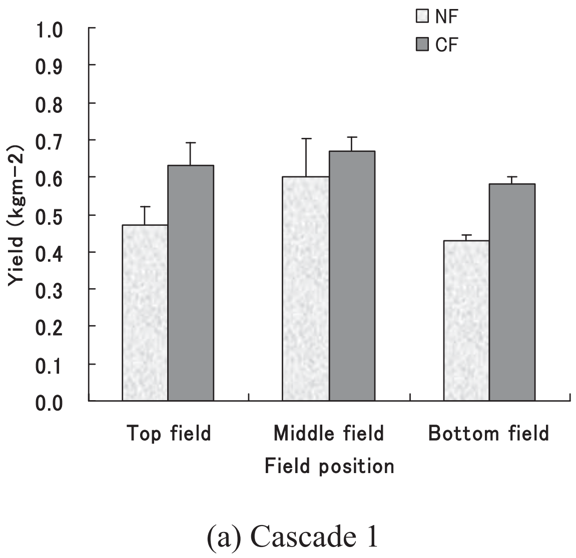
Significant differences in grains per panicle and 1000 grain weight were observed due to fertilizer ($p<0.05$) and different toposequence position ($p<0.01$, Table 2). Fertilization increased grain per panicle and 1000 grain weight than non-fertilized part in C-1 and C-2. The middle field position showed the highest value of grains per panicle and 1000 grain weight in average of both cascades 187.6 and 25.5, respectively.

The grain yield of rice differently responded to the different toposequence position of the fields and to the different fertilizer treatment (Fig. 2). A significant difference ($p<0.01$) of grain yield was observed between the fertilizer treatments with fertilizer application showing a higher value of yield (+F: 0.65 kgm^{-2}) than non-fertilizer plot (–F: 0.55 kg m^{-2}) in the average of both cascades.

The effect of different field position along the toposequence was significant as well ($p<0.01$) and the highest yield was achieved by the middle in C-1 and C-2. On average the middle field produced the highest grain yield of 0.71 kg m^{-2} followed by the first field (0.63 kg m^{-2}) and last field (0.54 kg m^{-2}). Yield differences in non-fertilized plots were observed among the different toposequence positions with the highest yield in the middle field position in both cascades. The interaction of fertilizer and different field positions was also observed where higher yields were shown in the three field positions of the fertilized plot than in the non-fertilized part.

Discussion

The result showed that there was a high degree of spatial variability related with TN and TC content among the different toposequence position in both cascades (Table 1). This indicated that different sediment sources contributed to an enrichment or depletion of soil fertility explaining spatial variability patterns on landscape level (Schmitter et al. 2010). The



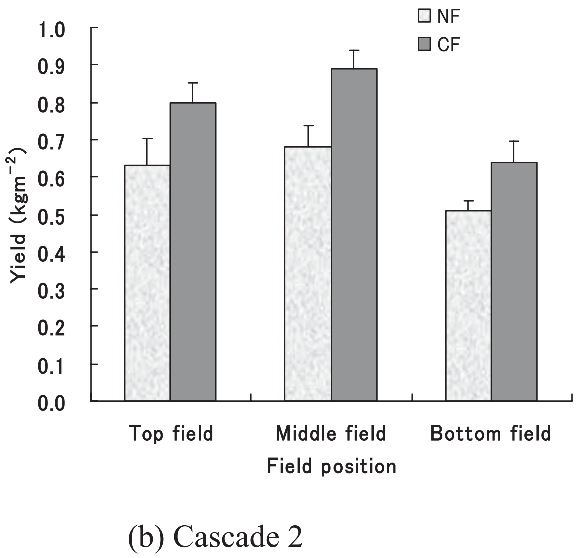


Fig. 2. Grain yield in non-fertilized and fertilized plots at different field positions. Error bar indicates standard deviation.

result showed that mostly the first field in the cascade had lower TN and TC content than the lower fields. Increases in soil TN and TC were related to the different toposequence position, which was influenced by irrigation and runoff water from the upper fields. This result was in agreement with Tsubo et al. (2007) who examined rainfed rice terraces and analyzed the downward movement of finer nutrient in soil. Spatial variation in TN and TC contents occurs due to transportation and deposition of sediment during irrigation. Our finding was in agreement with Hartel et al. (2007). They reported that the maximum distance sediment coming from irrigation water was obviously until the middle field positions while the irrigation water velocity at the bottom fields was low, and those fields mainly derived the water from rain.

This study showed that the number of effective tillers must be related to higher content of TN in both cascades (Fig. 2). Furthermore, both cascades showed generally higher number of effective tillers in the fertilized fields than in the unfertilized ones (Table 2). This corresponds to the findings of Hertel et al. (2007) in Cheing Khoi area. Hertel et al. (2007) reported significant higher number of effective tiller due to increasing N levels in soil. Significant higher grains per panicle, filled grain proportion and 1000 grain weight were the highest in the middle field but only the panicle length was the highest in the first field. All other fields, the fertilized as well, were not significantly different from each other.

In both cascades, the highest yield was observed in the middle fertilized fields (Fig. 2). Grains per panicle, effective tillers, filled grain % and 1000 grain weight were also highest in these fields. The same trend was observed in both cascades, where for example the last non-fertilized field showed the lowest yield which correlated with grain per panicle, panicle length and 1000 grain weight. Pantuwan et al. (2002) discussed that this might be due to runoff and seepage, the water availability in the paddy fields constantly changes which lead to water stress in different time scales and severities and this affects the nutrient availability. The effect of sedimentation can be seen clearly in the unfertilized part where the middle field produced the highest grain yields than other fields (Fig. 2). The fertilizer management did not mitigate this trend in this experiment. Hertel et al. (2007) reported that the middle field of the unfertilized part produced the highest grain yield, but fertilizer mitigated this effect. 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. This result was in contrast to the findings of our research, where fertilized plots produced higher yield but in non-fertilized part, there was a significant difference in grain yield among the different field position. No significant differences were found in the middle field of C-1 between the fertilized and unfertilized parts where nutritious soil particle should be settling down. The observed average grain yields for the fertilizer strips in both cascades (0.70 kg m^{-2}) were of similar magnitude as those reported by Schmitter et al. (2011) who cited an average grain yield of 0.68 kg m^{-2} in Chieng Khoi in 2011. Most of the spatial variations observed among the different toposequence position are likely to be contributing to the continuous flow, transportation and deposition of sediment during irrigation. The top field in the cascade produced higher grain yield than the bottom field. This could be due to some water inputs other than rainfall in the higher positions on the toposequence. This result was in agreement with Tsubo et al. (2006). They stated that in Chapassk Province, the grain yield was 66% higher in the top field than bottom field. This could be due to run-on of water from the catchment above the top field or irrigation water in the top field and also due to flood in the fields lower on the toposquence.

Conclusion

This study showed clearly that there were spatially differences in all measured parameters due to the effect of different toposequence position. In non-fertilized part of the cascades, the middle field produced a better growth performance than the other fields of the toposequence. The spatial variability of the non-fertilized plots represented the different sediment deposition along the fields and can be assumed that fine textured clay and nutrients and organic matter will be flushed from the irrigation channel into the field and deposited at the middle field. In fertilized plots, the spatial variability along the toposequence position might be due to different sediment deposition due to irrigation. The results point out that farmer management practice of fertilization as toposequence specific management should be no longer suitable for this area and by practicing site specific fertilizer management. Site specific managements would save money, contribute to higher yield and lead to sustainable agricultural production.

Acknowledgement

We gratefully acknowledge to the members of Center of Agricultural Research and Ecological Studies (CARES) and the Uplands Program (SFB 564) "Research for Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia." The authors would like to thank the farmers from Van Put, Chieng Khoi commune, Yen Chau district, Northwest Vietnam for their kind permission to set up experiment.

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