Spatially Variable Soil Fertility in Intensive Cropping Areas of North Vietnam and Its Implications for Fertilizer Needs

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A soil survey on more than 100,000 ha of degraded soil with intensive rice and maize cultivation in North Vietnam revealed potential multiple nutrient stresses at large scale and offered improvements of site-specific nutrient management strategies for delivery.

Nearly 60% of the rice area in Asia is irrigated, where rice is often grown in monoculture with two or even three crops per year or in rotation with maize, wheat, or other crops. Farm sizes are small, ranging from 0.3 ha in North Vietnam to 4 ha or more in the Central Plain of Thailand (Moya et al., 2004). Field sizes are even smaller since farmers often have more than one parcel.

Conditions are similar in the favorable rainfed areas where cereal production dominates, but crop diversification is emerging. Thus, there is large field-to-field variability in terms of crops, cropping practices, fertilizer use, and soil fertility status, particularly in the topsoil layer. And there is the more permanent variability in soil properties in relation to the parent material affecting soil nutrient supplies and other factors of relevance for crop production. Consequently, significant spatial variability in crop nutrient needs can be expected, here defined as a crop's demand for the external supply of inorganic fertilizer nutrients to achieve high and sustainable yield. With this paper, we hope to contribute to the discussion on how to deal with the spatial variability of crop nutrients needs in the calculation of site-specific fertilizer recommendations using a case study with small-scale rice farming in North Vietnam as an example.

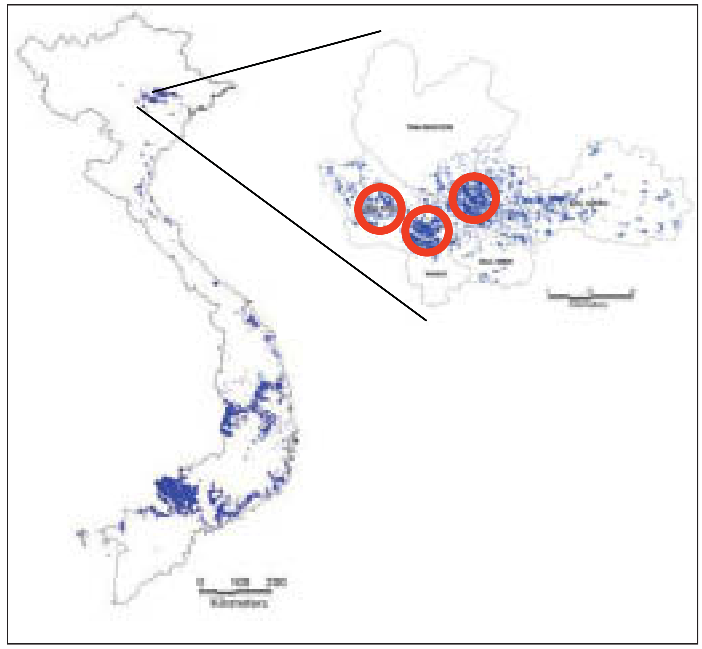

Figure 1. Location of degraded soils (blue) and study sites (red circles) near Hanoi in the Red River Delta of Vietnam.

Soil Survey and Descriptive Statistics

The main objective of the soil survey in the presented case study was to assess the spatial variability of soil properties that are expected to affect the i) general soil fertility for rice and maize production, and ii) the soil indigenous supply of specific nutrients in an area with suspected multiple nutrient stress. The gray degraded soils in the lowlands of the Red River Delta (RRD) in Vietnam were chosen as a study site because they represent one of the most intensely cultivated agricultural areas in the world (**Figure 1**).

Farmer applying fertilizer dissolved in water to a maize crop in North Vietnam.

Degraded soils of light or gray color cover about 3 million ha in Vietnam with 132,000 ha in the RRD. In the Vietnamese soil classification, degraded soils are generally characterized as low in soil fertility because of their parent material and nutrient losses caused by leaching and intensive cropping. Still, grain production in a typical rice-rice-maize rotation can reach 18 t/ha annually in the lowlands of the RRD because of excellent crop care, water availability, and significant inputs of up to 10 t/ha organic manure combined with adequate use of inorganic fertilizer. Rice and maize are planted and harvested by hand. Farm sizes range from 0.1 to 0.6 ha, but farmers own several fields of typically 200 to 1,000 m^2 in different locations. Large field-to-field variability in management practices is expected and thus, a large part of the total soil variability is likely to occur over short distances of about 20 to 100 m, which was taken into account when designing the sampling strategy.

Abbreviations and notes for this article: M ha = million hectares; Fe = iron; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; C = carbon; CEC = cation exchange capacity.

The study area covered about 103,000 ha of degraded soil in the provinces of Vinh Phuc, Bac Giang, and Hanoi, which is about 78% of the total area with degraded soils in the RRD. Existing information included soil maps of different scale and area coverage from the years 1962 to 1979 and information on selected soil profiles (Bo et al., 2002). Soils derived from old to ancient alluvium, in parts including ferralitic material. Earlier on-farm research at selected sites in Vinh Phuc indicated low soil pH and multiple nutrient stresses, including N, P, K, Mg and possibly Ca deficiencies (Son et al., 2004).

A multi-scale sampling strategy and geostatistical interpolation techniques were used to produce detailed thematic maps of soil properties in the study area. A base set of soil samples was collected in a 1 km x 1 km grid (100 ha) following the square grid cells of a 1:25,000 topographic map. To resolve short-distance variability and model semi-variograms for quantifying the spatial variation structures in each area, additional soil samples were taken along ten transects in each province. Each transect had five sampling locations in a geometric distance progression of 0 (transect origin), 100, 200, 400, and 800 m. Transects were laid out within major soil types of each study area and went in different directions depending on the actual landscape features.

Three soil cores (0 to 30 cm or 0 to 40 cm, diameter about 3 cm) were collected from each of five individual fields that were within a radius of 50 m around the sampling location, resulting in a total of 15 soil cores per location. This approach resulted in a size of spatial support of about 1 ha (100 m x 100 m) per sampling location. The combining of samples from several fields would reduce the potentially large field to field variability at each site. This resulted in better shaped variograms needed for kriging, and it minimized problems that may result from sampling error (wrong depth) or extreme values that might be found in a single field. Soil cores were split into two equal depths and combined into one composite sample per depth. Only results from the upper 0 to 15 or 20 cm soil layer are presented here for soil samples collected at 1,014 locations. Soil parameters were analyzed at the Analytical Service Laboratory (ASL) of the International Rice Research Institute (IRRI).

Table 1 presents the descriptive statistics of elevation and the 10 analyzed soil parameters across the three study sites. The investigated degraded soils had moderate levels of organic matter (median organic C of 10.2 g/kg), which is likely related to the typically high input of farmyard manure. In 75% of all soil samples, soil pH (1:1 KCl) was 5.2 or less. Liming is generally recommended particularly for maize at a soil pH <5.3. Soils are generally low to very low in clay (median 10%), CEC (median 4.1 $cmol_c/kg$), and exchangeable K and Mg (median 0.08 and 0.3 $cmol_c/kg$, respectively). Exchangeable Ca was above the critical 1.0 $cmol_c/kg$ in almost all soil samples (median 3.2 $cmol_c/kg$). The (Ca+Mg):K ratio was moderate (median 44), but low Mg levels and the wide Ca:Mg ratio (median 10.4) indicate a likely Mg deficiency considering that the Ca:Mg ratio should be about 4:1 for high rice yields. Bray-2 P levels were moderate to high ranging from 28 to 155 g/kg soil (10th and 90th percentile, respectively) with uncertain yield responses to fertilizer P application. We conclude from the descriptive statistics of this survey that yield responses to fertilizer K and Mg application are very likely in the entire study area. There is no evidence suggesting a need for variable fertilizer K and Mg rates in the sampled area. In contrast, recommendations for liming and fertilizer P application will have to consider the spatial variability of soil properties as pH and Bray-2 P assume a wider range of values including a significant portion of soil samples with pH below critical levels.

Integration of Spatial Variability in Estimating Nutrient Needs

Correlation analysis indicated only weak relationships between soil parameters that are easily estimated in the field like elevation or soil texture and soil parameters potentially related to the soil nutrient status like organic matter or exchangeable bases. It was therefore decided to map relevant soil parameters individually. The spatial distribution of pH is depicted in **Figure 2**. Soil pH was generally lower in the higher elevated

Table 1. Descriptive statistics of elevation and soil parameters in the 0 to 15 or 0 to 20 cm soil layer across all three study sites with degraded soil, North Vietnam (n=1014).

			Percentiles								
		Minimum	10%	25%	Median	75%	90%	Maximum	Mean	SD	Critical values
Elevation	m	0.7	7.4	9.4	12.0	14.8	18.6	50.8	13.1	6.1	
pH (KCl)		3.4	4.1	4.4	4.8	5.2	5.6	7.5	4.8	0.6	5.3 (maize)
OC	g/kg	1.4	6.4	8.0	10.2	12.4	14.7	36.2	10.4	3.6	
Bray-2 P	mg/kg	1.1	28	43	67	102	154.7	648	86	76	12-20
Exch. Ca	$cmol_c/kg$	0.06	1.68	2.30	3.23	4.17	5.25	18.5	3.44	1.81	1.00
Exch. K	$cmol_c/kg$	0.01	0.04	0.06	0.08	0.12	0.17	0.64	0.10	0.07	0.15-0.45
Exch. Mg	$cmol_c/kg$	0.03	0.13	0.20	0.31	0.46	0.72	3.00	0.38	0.31	1.0-3.0
CEC	$cmol_c/kg$	1.01	2.57	3.23	4.11	5.24	6.81	15.40	4.49	1.87	
Clay	%	3	5	8	10	15	23	49	13	7	
Silt	%	5	33	45	53	61	68	83	52	13	
Sand	%	-	18	24	34	44	57	82	35	15	

OC = organic carbon; CEC = cation exchange capacity. Critical values indicating likely yield responses of rice to P, Ca, K, or Mg application were based on Dobermann and Fairhurst (2000). A pH of less than 5.3 is generally considered critical for maize.

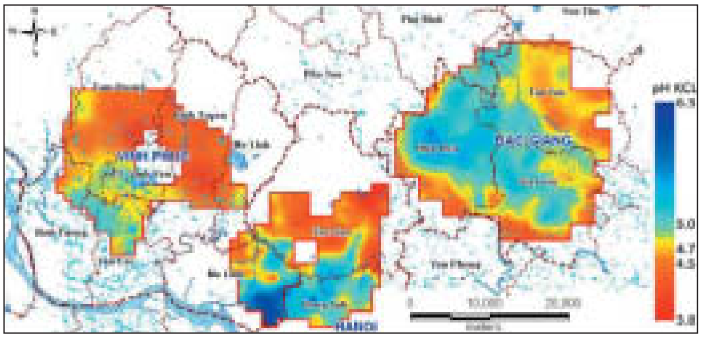

Figure 2. Soil pH (KCl) in degraded soil of North Vietnam. Interpolation by kriging.

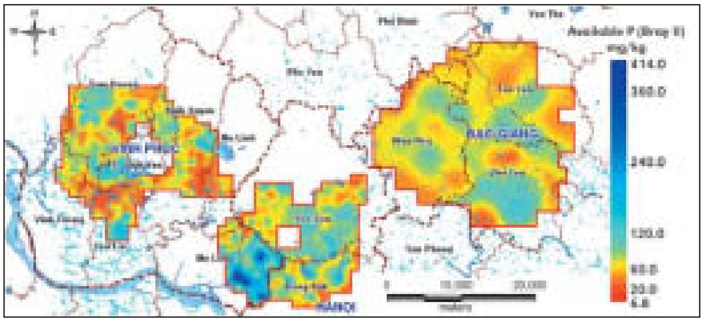

Figure 3. Available soil P (Bray-2, mg/kg soil) in degraded soils of North Vietnam. Interpolation by kriging.

areas of Vinh Phuc and Hanoi, but not in Bac Giang. There was no such correlation with other measured properties for Bray-2 P (**Figure 3**). However, there were larger continuous areas with low (red), medium (yellow), and high (blue) soil Bray-2 P levels. Interestingly, levels of both soil pH and Bray-2 P were high in the most southern part close to the city of Hanoi and near the river where crop diversification is greatest and vegetable production is common (the middle study area). Levels of Bray-2 P in this study were generally high suggesting only isolated "hot spots" with expected P deficiencies. However, studies on degraded soils in Vinh Phuc have shown rice yield responses of 0.5 to 1.5 t/ha to fertilizer P application despite high levels of Olsen-P (Son et al., 2004).

In a next step, site-specific recommendations for liming and fertilizer P application must be developed based on two or three distinct classes for pH and soil P status, respectively. In order to facilitate decision-making by farmers, there is merit in evaluating in the representative areas of the respective domains whether quantitative assessments of soil P status (such as Bray-2 P levels and yield response to P) can be associated with simple to use field-level guidelines such as historical use of fertilizer P.

Farmer with village children in North Vietnam.

Based on the presented spatial analysis of soil properties, improvements of existing site-specific nutrient management (SSNM) recommendations for farmer participatory evaluation on degraded soils in North Vietnam would thus include: i) possible adjustments of basal fertilizer N management strategies depending on organic matter, use of manure, and/or soil texture, ii) fertilizer P rates with site-specific adjustments based on a few Bray-2 P classes or historical use of fertilizer P, iii) fertilizer K rates with blanket adjustment for generally low levels of exchangeable K and with flexibility in topdressing K such as at panicle initiation in rice, iv) blanket fertilizer Mg application with use of Mg addition plots to assess whether the benefits of Mg application are associated with the farmers' use of organic inputs or other management practices, v) site-specific lime application (none, medium, high) in particular to maize based on a few pH classes (Witt et al., 2007). While N, P, and K management strategies could be combined into one SSNM practice for evaluation by farmers, the effect of Mg and lime application on yield should be evaluated in two separate addition plots embedded in the standard SSNM practice. Findings should be carefully extrapolated to degraded soils outside the study area.

Planning the survey of degraded soils in Vinh Phuc are Dr. Dobermann (left), Mr. Buy Tan Yen, and Dr. Tran Thuc Son.

Conclusions

More systematic research on the spatial variability in crop nutrient needs in small-scale rice, maize, and wheat farming in Asia is probably needed to improve the SSNM recommendations currently under development. The reliance on existing soil maps in the delineation of borderlines for fertilizer recommendations can be problematic, because maps are often old and soil classifications were not developed for agronomic purposes (Oberthür et al., 1996). New surveys and soil analysis are costly and probably only justified where multiple nutrient-stresses of unknown magnitude and spatial variability are expected, where large areas are affected, and where large scale variability in crop nutrient needs is likely to be controlled by more stable soil properties. Spatial analysis assists in the identification of most relevant soil parameters which would be useful for the development of improved survey strategies for comparable areas in a region. Soil surveys are probably not an economic tool to address short-distance variability in soil properties in Asia's rice-based systems because field-to-field variation in soil nutrient status can change quickly depending on management practices and because crop nutrient needs are not only governed by soil properties. Adequate survey strategies and classification approaches used in precision agriculture will have to be further explored to provide robust evidence that an expected variation in crop nutrient needs is manageable at an appropriate scale. Results could further contribute to the development of simplified soil classification systems for agronomic purposes (White et al., 1997; Sanchez et al., 2003) that can be provided to farmers in the form of a few simple guidelines for their use in the local adaptation and evaluation of SSNM. BC

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Conversion Factors for U.S. System and Metric Units

Because of the diverse readership of *Better Crops with Plant Food*, units of measure are given in U.S. system standards in some articles and in metric units in others…depending on the method commonly used in the region where the information originates. For example, an article reporting on corn yields in Illinois would use units of pounds per acre (lb/A) for fertilizer rates and bushels (bu) for yields; an article on rice production in Southeast Asia would use kilograms (kg), hectares (ha), and other metric units.

Several factors are available to quickly convert units from either system to units more familiar to individual readers. Following are some examples which will be useful in relation to various articles in this issue of *Better Crops with Plant Food*.

To convert Col. 1 into Col. 2, multiply by:	Column 1	Column 2	To convert Col. 2 into Col. 1, multiply by:
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
	Area		
2.471	hectare, ha	acre, A	0.405
	Volume		
1.057	liter, L	quart (liquid), qt	0.946
	Mass		
1.102	tonne[1] (metric, 1,000 kg)	short ton (U.S. 2,000 lb)	0.9072
0.035	gram, g	ounce	28.35
	Yield or Rate		
0.446	tonne/ha	ton/A	2.242
0.891	kg/ha	lb/A	1.12
0.159	kg/ha	bu/A, corn (grain)	62.7
0.149	kg/ha	bu/A, wheat or soybeans	67.2

[1]The spelling as "tonne" indicates metric ton (1,000 kg). Spelling as "ton" indicates the U.S. short ton (2,000 lb). When used as a unit of measure, tonne or ton may be abbreviated, as in 9 t/ha. A metric expression assumes t=tonne; a U.S. expression assumes t=ton.

Other Useful Conversion Factors

Phosphorus (P) x 2.29 = P_2O_5 — P_2O_5 x 0.437 = P

Potassium (K) x 1.2 = K_2O — K_2O x 0.830 = K

parts per million (ppm) x 2 = pounds per acre (lb/A)

Corn (maize) grain — bu/A x 0.062 = t/ha

Wheat or Soybeans — bu/A x 0.0674 = t/ha