TECHNICAL REPORT

Spatial variability of N, P, and K in rice field in Sawah Sempadan, Malaysia

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Abstract

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The variability of soil chemical properties such as total N, available P, and exchangeable K were examined on a 1.2 ha rice (*Oryza sativa*) field. The soil (n = 72) samples were systematically taken from individual fields in Sawah Sempadan in thirty-six locations at two depths (0-20 and 20-30 cm). The Differential Global Positioning System (DGPS) was used for locating the sample position. Geostatistical techniques were used to analyze the soil chemical properties variability of the samples that assist in site-specific management of the field. Results showed that areas of similarity were much greater for the soil chemical properties measured at the depth of (0-20 cm) than that of the second lower (20- 30 cm). The ranges of the semivariogram for total N, available P, and exchangeable K were 12, and 13 m (0-20 cm), 12 and 38 m (20-30 cm), respectively. Point kriging calculated from the semivariogram was employed for spatial distribution map. The results suggested that soil chemical properties measured may be spatially dependent even within the small.

Key words : geostatistics, spatial variability, semivariogram, point kriging, DGPS

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The understanding of the distribution of soil chemical properties particularly total nitrogen (N), available phosphorus (P), and exchangeable potassium (K) are important for refining farm management practices and for assessing the impact of agriculture on environment. The variability of soil properties within fields is often described by a classical method, which assumes that variation is randomly distributed within mapping units. Soil variability is the outcome of many processes acting and interacting across a continuum of spatial and temporal scales and is inherently scale dependent (Parkin, 1993). In addition, soil properties frequently exhibit spatial dependency. Soil properties tend to be more similar in samples that are progressively closer to each other. However, this depends on the spatial dependence of the soil properties. Therefore, parametric statistics are inadequate for analysis of spatially dependent variables because they assume that measured observations are independent in spite of their distribution in space (Hamlett *et al*., 1986).

Geostatistics provide a tool for improving sampling design by utilizing the spatial dependence of soil properties within a sampling region and useful to illustrate spatial inter-relationship of collected data and it reduces error, biasness and increases accuracy of data for Kriging (Myers, 1997). Geostatistical analyses have been used to estimate spatial variability of soil physical properties (Viera *et al*., 1981; Lascano and Hatfield, 1992), soil biochemical properties (Bonmati *et al*., 1991; Sutherland *et al*., 1991), and soil microbiological process (Aiken *et al*., 1991; Rochette *et al*., 1991). Values for soil properties are predicted for the majority of locations in the region where the values are not actually measured (Burgess and Webster, 1980). The variability of soil properties within fields is often described by classical statistical methods, which assume that variation is randomly distributed within mapping units. Soil variability is the outcome of many processes acting and interacting across a continuum of spatial and temporal scales and is inherently scale-dependent (Parkin, 1993).

The objective of this study was to describe the field scale spatial variability of total N, available P and exchangeable K in Sawah Sempadan rice field in Sabak Bernam, Selangor, Malaysia.

Materials and Methods

This study was conducted in the Sawah Sempadan rice plantation area, field No. 2162 located on a flat coastal plain in the Northwest Selangor Agriculture Development (PBLS). It is in the districts of Kuala Selangor and Sabak Bernam at latitude $3^{0}\ 35^{''}\ 45$ and longitude $101^{0}\ 05^{''}\ 52$. The size of the field was 1.2 ha with rectangular in shape. The soil texture was clay loam, while the texture of surface layers ranged from clay loam to clay. The soil is defined as Jawa series and was classified as clayey, mixed isohyperthermic sulfic tropaquept (USDA, 1975). Rice was cultivated two times per year and different types of fertilizers added to the soil during the season. The approximate mixture of N, P and K (30 kg of urea, 30 kg of CIPR and 20 kg of MOP per ha) is used to apply during tillering (after 5 days of sowing), 30 kg and 40 kg of urea per ha were applied during panicle formation 9after about 45 days of sowing) and during grain formation (after 70 days of sowing). The fertilizer was uniformly broadcasted over the field.

Sampling design

The best soil sampling design to quantify spatial variability is somewhat difficult to determine because measured variability and sample spacing were dependent on each other. However, the grid sampling was selected for this study because grid sampling reduces a large degree of uncertainty (uneven or clustered appearance). The plot was subdivided into subplot A and B, and a total of 18 sampling points were chosen for each subplot as shown in Figure 1. The grid size was 12.5 m × 22.0 m. Since, the length of the plot is 200 m and the width is 60 m. Each sub plot A and B divided into three sub-subplots A1, A2, and A3 and B1, B2 and B3.

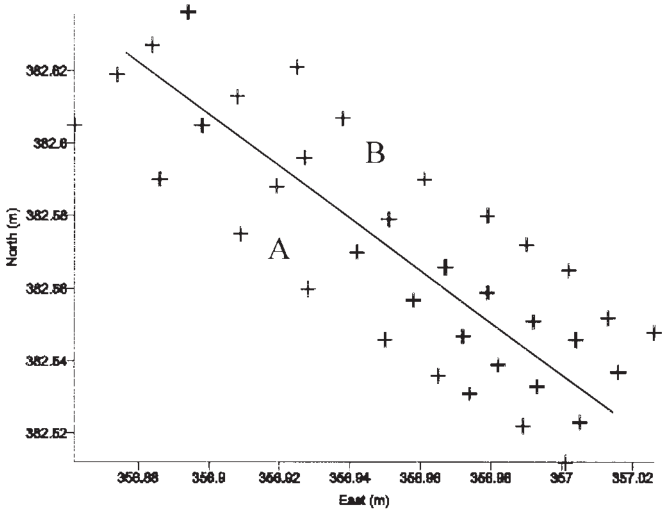

Figure 1. The sampling grid of the Sawah Sempadan rice field

Soil collection and chemical analysis

The soil samples collected before planting on March 2001.Thirty-six sampling points were taken using the DGPS unit. It is employed to precisely locate the sample with an error of ±1m. At each point, the values were recorded by the DGPS and then converted to the x and y coordinates. From each sub-subplot such as A1, six points soil samples with two depths (0-20 cm and 20-30 cm) taken from each point, the distance on the width direction is 12.5 m and in the length direction is 22.0 m. The A composite soil sample was taken for each location at two depths (0-20 cm and 20-30 cm) using a stainless steel soil auger (i.d.= 2.5 cm) (SFAUS, 1988). Three soil cores from each depth were taken and mixed together to obtain 1 sample at each point. The soil samples were packed into plastic bags, then the soil samples were air-dried and ground to pass through a 2-mm sieve, and analyzed for total N, available P, and exchangeable K. Total N was determined by the sulfuric-salicylic acid digestion method (Bremner and Mulvaney, 1982). Exchangeable K was determined by the neutral ammonium acetate extraction method (Schollenberger and Simon, 1945), which available P was determined by the NH_4F-HCl extraction method (Bray and Kurtz, 1945).

Geostatistical analysis

A geostatistical analysis of the data was performed for determining the spatial structure of total N, exchangeable K and available P at the two depths separately within the study plot using geostatistics software (GS+, Gamma Design Software, St. Plainwell, MI, version 5.0.3 Beta). The GS+ has a number of models that can be fitted to estimate semivariogram by using non-linear square procedure. The spherical model used in this study was shown below:

$$\gamma(h) = C_o + C\left\{\frac{3/h|}{2r} - \frac{1}{2}\left(\frac{h}{r}\right)^3\right\} \quad \text{for} \quad 0 < |h| \le r$$

$$\gamma(h) = C_o + C \qquad \text{for } |h| > r \qquad (1)$$

$$\gamma(0) = 0 \,,$$

Where $\gamma(h)$ is the semivariance and C_o is the nugget variance which is defined as the semivariance at X=0. The maximum semivariance was defined as the sill ($C_o + C$) , and r is the range of spatial correlation (Vauclin *et al.*, 1983). The nugget to sill ratio was used to qualitatively define spatial dependence values. The values less than 25% have strong spatial dependence, the values between 25% and 75% considered as moderate spatial dependence, and the values greater than 75% have weak spatial dependence. It was selected over linear and exponential models based on more favorable weighted residual mean squares, and visual fit to the data at short lags. The contour maps were developed using the Surfer software (Golden Software, Inc.; Golden CO).

The kriged or spatial maps for total N available P and exchangeable K were constructed by using point kriging method to estimate the values at unsampled locations and then clustering them in 3-5 ranges with equal contours intervals. The ranges for soil nutrients were five classes according to DOA (1997).

Results and Discussion

Spatial variability for total Nitrogen, available P, and exchangeable K

Measured values of soil fertility parameters appeared to be strongly variable between each other as shown in Table 1. The median for total N is 0.44 and 0.24 % for the surface and sub-soil layers, respectively, for the available P is 54.1 and 17.7 mg/kg for the surface and sub-soil layers, respectively and for the exchangeable K is 48.8 and 57.4 mg/kg for the surface and sub-soil layers, respectively. The rang for total N, available P and exchangeable K for the surface are 0.51 %, 58 mg/kg and 93 mg/kg, respectively and for sub-soil layer are 0.49 %, 56 mg/kg and 107 mg/kg, respectively. The co-efficient of variation (CV %) for total N variation was low when compared with available P and exchangeable K for both surface and sub-soil layers. The co-efficient of variations of Total N, available P and exchangeable K for the surface layer are 29%, 39% and 48, respectively and for the sub-layer are 42%, 63% and 65%, respectively. The mean values of total N, available P, and exchangeable K were found to be 0.42 and 0.29 % for N, 50.6 and 25.0 mg/kg for P and 21.3 and 60.75 mg/kg for K for the top- and sub-soil layers, respectively. However, Tisdale *et al* (1985) reported that harvesting of grain removed a greater amount of total N and P with much smaller portions of K that absorbed by plants. This variation may be due to the effect of fertilizer addition during the rice growing season and addition of different amount of fertilizer during the growing season.

The semivariogram of the total N, available P, and exchangeable K is shown in Table 2. The nugget (C_o) varied among the two soil layers with the values of 0.0002% and 0.0004 % for total N, 13.0 and 109.8 mg/kg for available P and for the exchangeable K was 61.0 and 127.0 mg/kg, for top- and sub-soil layers, respectively. The range of the semivariogram is the distance (*h*) at which γ attains the maximum value (sill). Often the sill ($C_o + C$) is approximately equal to the sample variance (Journel and Huijbregts, 1978). The values of the sill variance for all nutrients varied between 0.01724 and 0.01636 % for total N, 229 and 260 mg/kg for available P and 47 and 1075 mg/kg

Table 1. Statistical overview of some top- and sub-soil soil parameters measured on the parameters on the study area

Parameter	Depth	Unit	Range	Mean Standard-deviation	Variance	Median	Mean	CV %
N	0-20	%	0.51	0.13	0.0174	0.44	0.42	29
	20-30	%	0.49	0.12	0.0157	0.24	0.29	42
P	0-20	mg/kg	58	15.26	233.04	54.14	50.6	39
	20-30	mg/kg	56	16.01	256.404	17.74	25.01	63
K	0-20	mg/kg	93	456.07	14.8	48.8	21.35	48
	20-30	mg/kg	107	31.91	1018.70	57.4	60.75	65

Table 2. Characteristic of calculated semivariogram of spatial soil fertility

Parameter	Depth	Model	Range (A_o)	Nugget variance	Sill variance	Ratio nugget/sill	Spatial dependence level
	---cm---		----m----			%	
N	0-20	spherical	12	0.00002	0.01724	98	Weak
	20-30	spherical	13	0.00043	0.01636	97	Weak
P	0-20	spherical	12	13.00000	229.2000	94	Weak
	20-30	spherical	38	109.8000	260.0000	59	Moderate
K	0-20	spherical	31	61.000000	477.6000	72	Moderate
	20-30	spherical	32	127.00000	1075.000	88	Moderate

for exchangeable K for top-and sub-soil layers, respectively. The range expressed as distance, and can be interpreted as the diameter of the zone of influence, which represents the average maximum distance over which a soil property of the two samples is related. At a distance less than the range, measured properties of two samples become more alike with decreasing distance between them. Thus, the range provides estimate areas of similarity. The range varied between 12 and 13 m for total N, 12 and 38 m for available P and 31 and 32 m for exchangeable K for both surface and sub-soil layers, respectively. The results showed high nugget effects were found for all the parameters studied, indicating a high variability of the respective parameter between the sampling points (Webster and Oliver, 1990). For all parameters smaller sampling should be recommended on this field.

The zone of influence represented by range and the effective range for total N, available P, and exchangeable are shown in Table 2. Calculation of the effective range was derived from semivariogram, which was represented by the A_0. The total N, available P, and exchangeable K of the surface was zone of influence greater than the sub-soil layer. This is expected due to the effect of fertilizer addition during the rice-growing season. Similar studies on agricultural land (Ruhling *et al.*, 1997; Dampney *et al.*, 1997) have all indicated that soil nutrient status may have a high spatial variance. The results Table 2 indicates that the variability may even be higher on rice plantation.

Interpolation by point kriging

Point kriging values in Figure 2 for total N demonstrated the spatial pattern of the concentration of the total N along the field for the top- and sub-layer are A and B, respectively. For the top layer map, moderate N has covered the left side of the field with respect to the good concentration at the top north and at the bottom of the field, also low concentration at the middle and at the top left corner. For the sub-layer, low N concentration has covered most of the area of the field from top to middle part; also moderate N covered the bottom part of the field. So, the top soil might contain high organic matter which could hold nutrients more than the sub soil as reported by Anon (1997) and Michael (1987). Prasad and Power (1997) found that N content is generally higher in the top soil layer of any soil since most organic residues are deposited on the soil surface.

The spatial pattern maps for top- and sub-soil layers of available P are shown in Figure 3 (A and B, for the top and sub layer, respectively). For the top layer, very good range was found covering most of the area with good P concentration in the middle part which extended to the bottom part, also some small areas in the middle and bottom has moderate P. for the sub layer, the maximum area

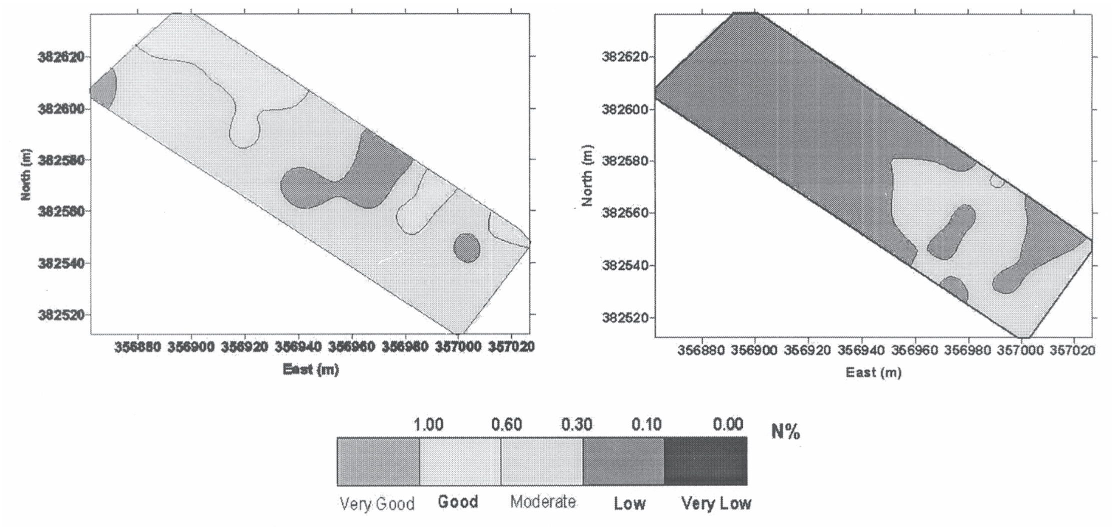

Figure 2. Kringing map showing distribution of the total N

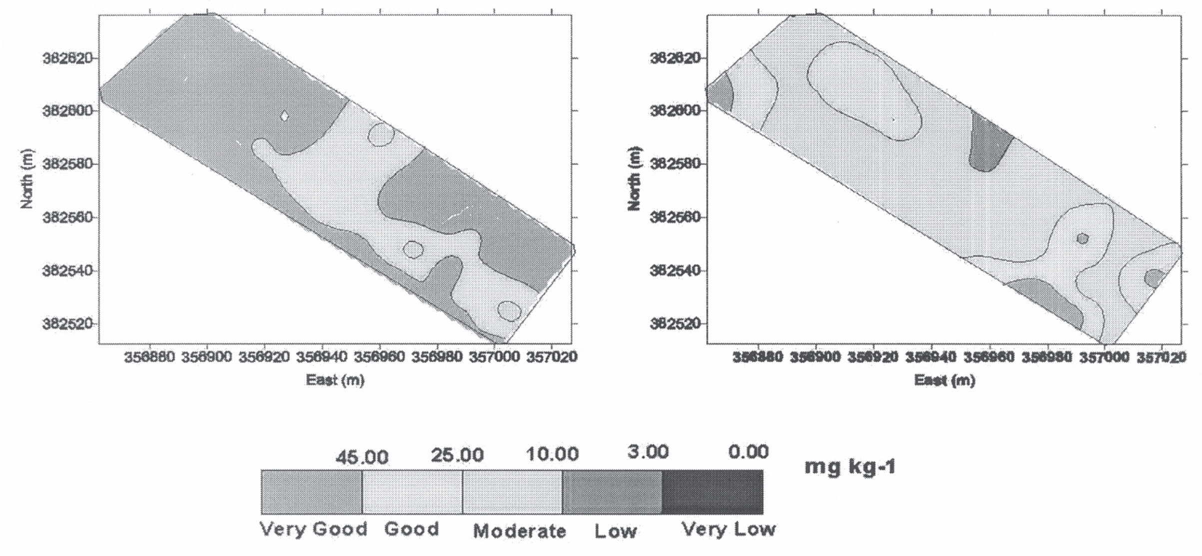

Figure 3. Kringing map showing distribution of the Available P

was under moderate P. Good and very good soil P in the top left corner and at some parts at the bottom of the field. The spatial pattern of the exchangeable K maps for the top and sub soil layer are shown in Figure 4 (A and B), the spatial pattern of the top layer, K is low in both left corners of the field, moderate K at the right side to the middle part, and good K in some parts at the right side of the field. The spatial pattern for the sub soil layer varied between low, moderate and good without consistency across the entire field. The existence of K above the moderate range might be due to paddy plant residues which is left by combine harvester in the field and later burnt or chopped in

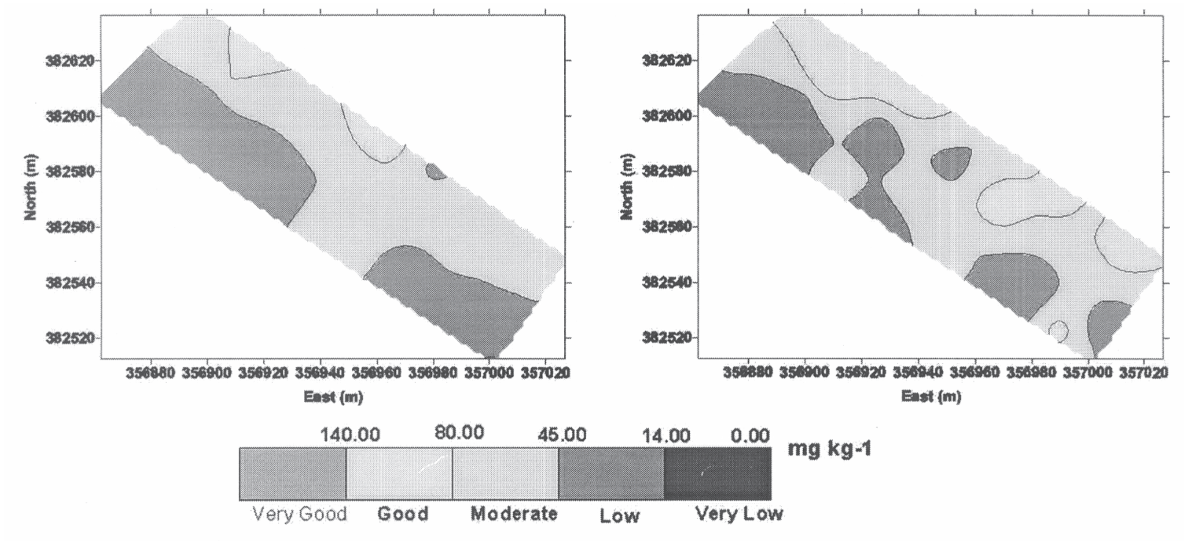

Figure 4. Kringing map showing distribution of the Exchangeable K

tillage operation. Sistani *et al.* (1998) reported rice crop residues (straw and hulls) are rich in Si and K which have beneficial effects on rice plant growth.

Soil nutrients seem to have a much smaller range and may vary within a short time period; therefore, a higher sampling density is required to characterize the spatial variance. Information on soil nutrients status and others, such as soil maps, remote sensing maps, and existing soil nutrients maps may be reducing the soil sampling density.

Conclusion

Soil total N available P and exchangeable K were spatially varied within the study field and the maximum range was reach at 38 m for the available P for the sub-soil layer. The kriged maps showed that different ranges of N-P-K existed from both sides of the field to the middle part. The soil chemical properties commonly have spatial dependence and that understanding such structure may provide new insights into soil behavior for the land management. Geostatistical techniques offer methods for the estimation of soil chemical properties and their associated variability. The pattern of spatial variability in the form of kriging map may improve the decision for field management practices, such as fertilizer recommendation rates. Also knowledge of the variability in space and time of soil fertility such as total N, available P and exchangeable K is one of the most important keys in further development of site-specific management. Measuring this variation according to present sampling methods is not always economically viable, so other sampling methods or techniques and other tools are needed.

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References

Aiken, R.M., Jawson, M.D., Grahammer, K. and Polymenopoulos, A.D. 1991. Positional, spatially correlated and random components of variability in carbon dioxide flux. J. Environ. Qual. 20:301-308.

Bonmati, M., Ceccanti, B. and Nanniperi, P. 1991. Spatial variability of phosphate, urease, protease, organic carbon and total nitrogen in soil. Soil Bio. Biochem. 23: 391-396.

Bray, R. H. and Kurtz, L. T. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

Bremner, J.M., and Mulvaney, C.S. 1982. Total N. **In** Page, A. L., Miller, R. H. and Keeny, D. R. (eds). Methods of Soil Analysis, Part 2, 2nd Ed., American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin, USA. pp, 595-624.

Burgess, T.M. and Webster, R. 1980b. Optimal and isarithmic mapping of soil properties. 1: The semivariogram and punctual kriging. J. Soil Sci. 31: 315-331.

Burgess, T.M., and Webster, R. 1980. Optimal interpolation and isarithmic mapping of soil properties. 1. The semivariogram and punctual kriging. J. Soil Sci. 31:315-331.

Dampney, P. M. R., Goodlass, A., Ridling, A.E. and Fromnet, M.A. 1997. Fertilization for sustainable plant production and soil fertility. CIEC and FAL Germany. p.155.

DOA. 1997. Rating for chemical properties of soil in Peninsular Malaysia. Soil Management Division, Department of Agriculture (DOA), Malaysia.

Hamlett, J.M., Horton, R. and Cressie, N.A.C. 1986. Resistant and exploratory techniques for use in semivariogram analysis. Soil. Sci. Soc. Am. J. 50:868-875.

Journel, A.G. and Hujibregts, C.H. 1978. Mining Geostatistics. AC-Academic Press, New York.

Lascano, R.J. and Hatfield, J.L. 1992. Spatial variability of evaporation along two transects of Abare soil. Soil Sci. Soc. Am. J. 56:341-346.

Myers, J.C. 1997. GeoStatistical error management quantifying uncertainity for environmental sampling and mapping. Van Nortrand Reinhold-division of international; Thomson publishing inc., U.S.A.

Parkin, T.B. 1993. Spatial variability of microbial process in soil a review. J. Environ. Qual. 22:409-41.

Rochette, P., Desjardins, R.L. and Pattey, E. 1991. Spatial temporal variability of soil respiration in agricultural fields. Comm. J. Soil. Sci. 71:189-196.

Ruhling, S., Haneklaus., and Schnug, E. 1997. Fertilization for sustainable plant production and soil fertility. CIEC and FAL, Germany. p.178.

SFASU. 1988. Procedure for taking soil samples. Miscellaneous Extension Publication. Stephen F. Austin State Univ. Soil Test Lab, Nacogdoches, Texas.

Schollenberger, C. J and Simon, R. H. 1945. Determination of exchangeable capacity and exchangeable bases in soil-ammonium acetate method. Soil Sci. Res. 14:161-168.

Sistani, K. R., Reddy, M. L., Savantand, N. K., Kanyika, W. 1998. An integrated nutrient management system for sustainable rice production. Proc. Of 4th Int. conference on agriculture, 19-22 july, St. Pauls, MN,USA.

Sutherland, R. A., VanKessel, C. and Pennock, D. J. 1991. Spatial Variability of Nitrogen-15 natural abundance. Soil Sci. Am. J. 55:1339-1347.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. 1985. Soil fertility and fertilizers-5th edition. Macmillan publishing Co., New York, U.S.A.

Vauclin, M., Vieira, S. R., Vachaud, G. and Nielsen, D. R. 1983. The use of cokriging with limited field soil observations. Soil Sci. Soc. Am. J. 47: 175-184.

Vieira, S.R., Nelsen, D.R. and Biggar, J.W. 1981. Spatial variability of field-measured infiltration rate. Soil. Sci. Soc. Am. J. 45:1040-1048.

Webster, R. and Oliver, M. A. Statistical methods in Soil and land resources survey (Oxford University Press, 1990), p.316.