Mapping Spatial Zinc Distribution in Rupandehi District, Nepal

S.K. Rai, S.P. Pandey, Y.G. Khadka, K.B. Karki and R. Uprety
Soil Science Division, Nepal Agricultural Research Council, Khumaltar, Nepal

Abstract

Soil zinc is an important micronutrient for agriculture and for human health. The zinc content in Nepalese soils is lower than the optimum. Soil is the primary source of zinc for plants, animals, and human nutrition. This study attempted to investigate the spatial pattern of soil zinc distribution in the soils of Rupandehi District of the Terai plains of Nepal. A total of two hundred and ninety-seven samples were collected at random intersections of a 1 by 1 km square grid. The data indicated a strong variability in soil zinc content within the study area. The predicted (kriged) map showed the zinc content in the soil of the study area to be within the low to medium range (0.013-1.402 mg kg^{-1}). The study did not identify any association of available zinc in the soil with other soil factors such as pH, organic matter, and available phosphorous. This study should contribute to better understanding of the nature and extent of zinc deficiency and to the improvement and sustainability of agricultural production.

Introduction

Soils are the primary source of zinc for plants, animals, and humans. Total zinc content in the soil generally ranges between 10 and 300 ppm (Silllanpää 1982). Zinc availability, however, is greatly affected by a number of factors: mainly soil pH, organic matter, available P, and soil textural conditions. Soils with acidic conditions are less affected by zinc deficiency problems, as zinc is more available in such soils (Dvarák et al. 2003). However, zinc disorders are common in calcareous soils (Katyal 1972). More available phosphorous in the soil or a substantial level of phosphatic fertiliser application also induces soil zinc deficiency (Olsen 1972). Soil organic matter content also inactivates soil zinc and makes it deficient in rice plants (IRRI 1972; Yoshida et al. 1973). Extractable soil zinc decreases as the organic carbon content starts to increase over 0.4% (Silllanpää 1982). Zinc deficiency is also associated with soil moisture and is more common in wetland conditions than in dryland soils (Castro 1977; Randhawa et al. 1978). Zinc is more readily available in upland soils than in submerged soils. Unlike other micronutrients, the concentration of zinc decreases as the soil becomes submerged. In soils with a pH greater than 7.0 in wetland conditions, deficiency of zinc becomes common.

Zinc deficiency is the most widespread micro-nutritional disorder in food crops. Zinc problems are common in areas where lowland rice is grown, especially in soils that are near neutral to alkaline (Jaishy et al. 1989), causing considerable decrease in yield. The Terai is a major rice growing area in Nepal, and rice is grown on 32% of the total Terai area of 1,099,277 ha (MOAC 2002).

As zinc in soil and its availability are related to many other factors and other nutrients, its management requires an understanding of how other nutrients vary across the land (White et al. 1997). This study attempted to establish the spatial distribution pattern of soil nutrients and other parameters of some importance for zinc availability in the soil. Organic matter, soil pH, available phosphorous, and soil texture were studied and estimated for their spatial distribution pattern in the study area. These soil properties were also evaluated in terms of their relationship to zinc. The output of the research was intended to contribute to the improvement and sustainability of agricultural and livestock production, to improvement in the quality of the human diet, and to a better understanding of the nature and extent of plant, human, and animal zinc deficiencies.

Materials and Methods

The study area was in Rupandehi district in the Western Development Region of Nepal, which lies between 83°10' and 83°30' E and 27°20' to 27° 45' N, covering an area of approximately 133,596 ha. It has a subtropical climate with a mean annual rainfall of 1600 mm with a uni-modular structure. The mean monthly temperature varies from 8.5°C in January to 36°C in May. The altitude increases from south to north from approximately 100 to 200 masl (Harrington et al. 1989).

Soil samples collected during soil surveys in the past (Dec/Jan 1999) were used in the study. Samples were collected at random intersections of 1 by 1 km from a depth of 0-30 cm and analysed at the laboratory of the Soil Science Division, Khumaltar. Soil properties were determined using standard methods: organic matter by Walkley and Black (1934); available phosphorous by modified Olsen (1972) (USDA); zinc extracted following methods explained by Lindsay and Norvell (1978); pH by pH-meter; and texture (clay, sand, and silt %) by the hydrometric method.

Statistical analysis

Descriptive statistics were computed for sample mean, median, minimum, maximum, standard deviation, and coefficient of variation (CV). Multivariate regression analysis was performed to identify the most influential parameters that affect the available zinc content. For mapping the spatial variability of the soil properties, isotropic semi-variograms were calculated using GS+ Version 3.11.20 (Gamma Design Software 2000). The extreme outliers were excluded from the subsequent analysis and estimation. The best-fitted model with the maximum r^2 value was used in kriging for the estimation of soil properties at unknown locations (Yanai et. al. 2002). The punctual kriging interpolation method was carried out on Surfer Version 7.0 (Golden Software Inc. 1999) using the geostatistical model parameters. The spatial structure of the samples on the sampling scale was determined by the Q value as described by Yanai et al. (2002): $Q = (S-N)/S$, where S and N are the sill and nugget variance respectively. The spatial analytical work was done in ArcView 3.1 (Environmental Systems Research Institute Inc. 1999).

Results and Discussions

Descriptive statistics

The descriptive statistics for the measured soil variables over the entire study area are presented in Table 1. All the soil properties, except for soil reaction and silt, showed a great extent of variability with high coefficient of variation (CV) values (Wilding 1985; Yanai et al. 2002; Miao et al. 2000). Phosphorous exhibited the greatest spatial variability with a CV of

116% from values ranging from 0.487 to 137.62 mg kg^{-1}, followed by zinc and organic matter with CVs of 72.6 and 59.0% respectively. Soil reaction exhibited the least spatial variability (CV = 13.0%) of all the parameters tested.

Table 1: **Descriptive statistics for soil properties**

Variables	Minimum	Maximum	Mean	Median	SD	CV %	Variance	Skew
OM (%)	0.130	2.950	1.20	1.340	0.709	59.0	0.502	0.064
pH	3.600	8.000	6.02	6.100	0.781	13.0	0.610	-0.548
Clay (%)	9.000	66.000	24.99	23.000	10.768	43.1	115.960	0.893
P (mg kg^{-1})	0.487	137.620	17.05	11.549	19.789	116.0	391.600	3.006
Sand (%)	1.000	57.000	22.51	21.000	11.877	52.8	141.060	0.573
Silt (%)	24.000	79.000	52.51	53.000	8.504	16.2	72.325	-0.263
Zn (mg kg^{-1})	0.002	1.641	0.29	0.232	0.212	72.6	0.045	2.196

Zn = zinc, P = Av. phosphorous, OM = organic matter

Spatial variability of soil properties

Table 2 shows the geostatistical parameters such as nugget, sill, Q value, range, and model. Sill represents the overall variance of the sample data which was observed to be higher in P. The range indicates the limit of spatial dependence beyond which the samples become spatially independent and uncorrelated (Nayak et al. 2002). The higher value of range for pH might indicate that soil properties other than those tested might have an influence on pH. The nugget variance provides an indication of short distance variation. The variable P shows the highest nugget value, which might have caused higher CV.

Table 2: **Geostatistical parameters of the soil properties**

Variables	Nugget (Co)	Sill (Co+C)	Range Ao	Q (C/Co+c)	r^2	Model
OM (%)	0.168	0.522	10550	0.68	0.962	Sph
pH	0.172	0.769	27960	0.78	0.987	Sph
P (mg kg^{-1})	2.19	4.239	18780	0.48	0.85	Exp
Zn (mg kg^{-1})	0.009	0.035	12990	0.74	0.713	Exp

Sph = spherical, Exp = exponential

The isotropic semi-variogram for pH and OM is best fitted to a spherical model, and for zinc and P, to an exponential model. Models were selected for interpolating the soil properties over the study area based on the maximum r^2 value. The degree of spatial dependence of the soil properties varied among the properties taken into consideration. The Q value ranged from 0.48 to 0.68 for available phosphorous and organic matter, suggesting a moderately developed structure which was also confirmed by the higher nugget value (Mueller et al. 2000). Soil reaction and available zinc demonstrated a highly developed spatial structure with Q values of more than 0.74 (Yanai et al. 2002). Soil variables exhibiting strong spatial dependence may be controlled by intrinsic variability, and if there is less strong spatial dependence by extrinsic variability (Miao et al. 2000). Using the measured data and the models, estimates were computed by punctual kriging. The model used for zinc estimation seems satisfactory since the differences in mean and standard deviation between measured and estimated zinc values were not much different compared to P (Table 3 and Figure 1).

Table 3: Comparison of statistical parameters for measured and estimated zinc		
Variable	**Mean**	**Standard deviation**
Measured zinc (mg kg^{-1})	0.29	0.21
Estimated zinc (mg kg^{-1})	0.28	0.13
Measured P (mg kg^{-1})	17.05	19.79
Estimated P (mg kg^{-1})	17.50	11.22

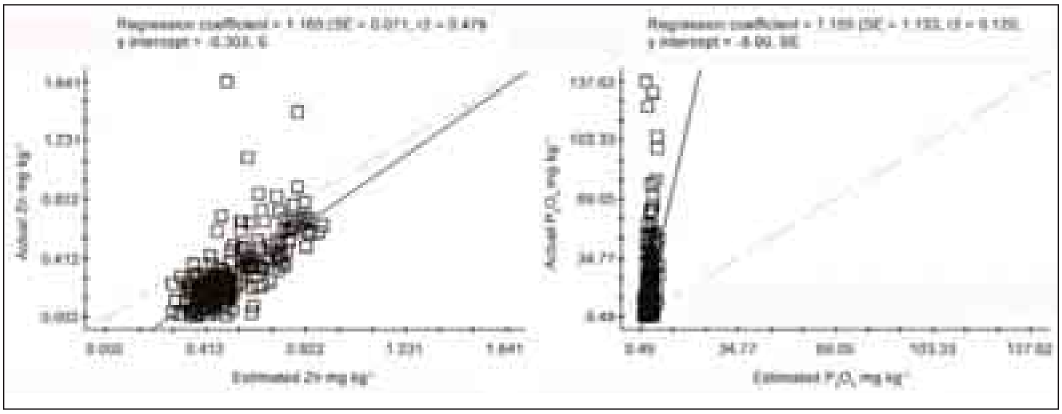

Figure 1: **Relationship of measured and predicted values of zinc and P**

The available zinc in the study area was quite low, ranging from 0.013 to 1.402 mg kg^{-1} (Table 4). Organic matter was also low. Most of the area has a slightly acidic to neutral soil reaction.

Figure 2 presents the map of the spatial distribution of the soil properties. Kriged maps showed considerable spatial variability for soil properties. Phosphorous and zinc portray a higher spatial variability than pH and organic matter.

Correlation analysis of OM, pH, P, clay, sand, and silt with zinc was not significant (Table 5) and could be attributed to experimental error and short distance variation (Kuzyakova et al. 2001).

Table 4: Area and percentage area of the soil properties with classes and ranges					
Soil Property	**Range**	**Class and range**		**Area (ha)**	**Area (%)**
Zinc[a]	0.013-1.402 mg kg^{-1}	Low	<0.17 mg kg^{-1}	23,596	17.7
		Medium	0.17 – 11.5 mg kg^{-1}	110,000	82.3
OM[b]	0.019-2.84%	Low	< 2.5%	133,264	99.8
		Medium	2.5-5.0%	332	0.2
P[b]	3.02-115.34 mg kg^{-1}	Low	<13.39 mg kg^{-1}	59,868	44.8
		Medium	13.39-24.55 mg kg^{-1}	45,536	34.1
		High	>24.55 mg kg^{-1}	28,192	21.1
pH[b]	3.7-7.7	Acidic	<5.0	15,304	11.5
		Slightly Acidic	5.0-6.0	55,740	41.7
		Neutral	6.0-7.0	59,572	44.6
		Slightly Alkaline	7.0-8.0	2,980	2.2
[a] = Lindsay and Norvell 1978; [b] = SSD 1999					

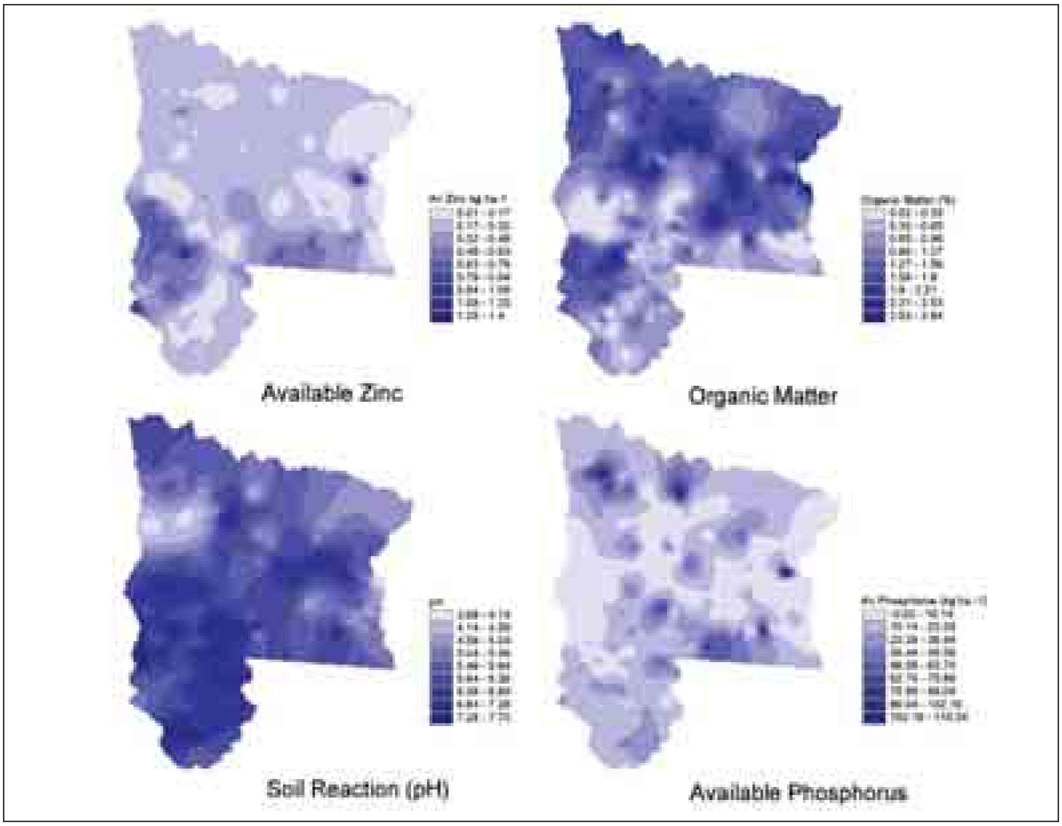

Figure 2: **Maps of soil properties**

Multivariate analysis of measured zinc, phosphorous, OM, pH, clay, silt, and sand were carried out to elucidate the factors that affect available zinc quantitatively, and the relationships among the properties investigated using stepwise multiple regression analysis. The most appropriate model obtained with the significance levels of $\alpha = 0.2$ (Gomez and Gomez 1984) was:

$$Zn = 0.07115 + 0.04627 (pH) + 0.00147 (P) - 0.00285 (Clay)$$

The r^2 value of 0.0237 indicates that the model using only soil factors explains 2% of the total variance of the measured zinc. Thus, a major part of the variation in the zinc could not be explained from the effects of the investigated factors.

Table 5: **Correlation of z inc with other soil properties**

Soil property	Zinc (mg kg^{-1})	P value
OM	-0.03	0.61
pH	0.07	0.21
P	0.09	0.12
Clay	-0.08	0.20
Sand	0.02	0.76
Silt	0.07	0.24

Conclusions

Available soil zinc and the other elements studied are generally low to medium in the soils of Rupandehi district. No specific associations were observed between zinc and other soil properties, this might be due to the low quantity of the tested soil properties. Soil properties with stronger spatial dependence make it easier to use kriging or other interpolation methods to predict soil properties at unsampled locations. Geostatistics and geographical information systems (GIS) are essential tools for analysing geo-referenced information and for advancing our understanding of spatial variability at different scales.

References

Castro, R.U. (1977) *Zinc deficiency in rice: a review of research at the International Rice Research Institute,* IRRI Research Paper Series 9. Manila: IRRI

Dvarák, P.; Tlustoš, P; Száková, J; Cerný, J; Balík, J. (2003) 'Distribution of soil fractions of zinc and its uptake by potatoes, maize, wheat and barley after soil amendment by sludge and inorganic Zn salt'. In *Plant Soil Environ.,* 49(5):203-212

Gomez, A. K.;Gomez, A.A. (1984) *Statistical procedures for agricultural research*, an International Rice Research Institute book. Singapore: Wiley-Interscience

Harrington, L.W.; Fujisak, S.; Hobbs, P.R.; Adhikary, C.; Giri, G.S; Cassaday, K. (1989) *Rice-wheat cropping systems in Rupandehi district of the Nepal Terai: Diagnostic surveys of farmers' practices and problems, and needs for further research.* Nepal:National Agricultural Research Centre (NARC), International Maize and Wheat Improvement Centre (CIMMYT), International Rice Research Institute (IRRI)

IRRI (1972) *Annual Report for 1971*. Manila: IRRI

Jaishy, S.N.; Shrestha, K.K.; Baral, K. P. (1989) *Effect of zinc on grain yield of rice*. Paper presented at the 14th Summer Crops' Workshop, NARSC, NRIP, 17-25 January 1989, Parwanipur, Nepal

Katyal, J.C. (1972). *A study of Zn equilibria in flooded soils and amelioration of Zn deficient soils of Agusan del Norte,* Terminal Report. Manila: IRRI

Kuzyakova, I.F.; Romanenkov V.A.; Kuzyakov, Y.V. (2001) 'Application of geostatistics in processing the results of soil and agrochemical studies'. In *Eurasian Soil Science*, 34(11):1219-1228 (Translated from Pochvovedenie 11:1365-1376)

Lindsay, W.L.; Norvell, W.A. (1978) 'Development of soil test for zinc, iron, manganese, and copper. In *Soil Sci. Soc. Am. J.,* 42:421-428

Miao, Y.; Robinson, C.A.; Stewart, B.A.; Evett, S.R. (2000) *Comparison of soil spatial variability in crop and rangeland,* Proceedings of the Fifth International Conference of Precision Agriculture, July 16-19, 2000. Madison: ASA-CSSA-SSSA

MOAC, (2002) *Statistical information on Nepalese agriculture 2001/2002.* Kathmandu: Agri-Business Promotion and Statistics Division, Ministry of Agriculture and Cooperatives, HMGN

Mueller, T.G.; Wells, K.L.; Thomas, G.W.; Barnhisel, R.I.; Hartsock, N.J.; Shearer, S.A.; Kumar A.; Dillon, C.R. (2000) 'Soil fertility map quality: case studies in Kentucky'. In Robert, P.C. et al. (eds) *Proc. 5th International Conference on Precision Agriculture*. Madison: ASA, CSSA and SSSA

Nayak, A.K.; Chinchmalatpure, A.R.; Khandelwal, R.M.K.; Nath, G.G.; Munshi, A.H.Y.; Tyagi, N.K. (2002) 'Geo-statistical analysis of surface and sub-surface soil salinity of the irrigation block of Sardar Sarovar Canal Command'. In *Journal of the Indian Society of Soil Science,* 50(3):283-287

Olsen, S.R. (1972) 'Micronutrient interactions'. In Mortvedt, et al., (eds) *Micronutrients in agriculture*, pp. 243-264. Madison: Soil Science Society of America

Randhawa, N.S.; Sinha, M.A.; Takkar, P.N. (1978) 'Micronutrients'. In *Soil and Rice*, pp.581-604. Manila: IRRI

Sillanpää, M. (1982) 'Micronutrients and the nutrient status of soils: a global study'. In *FAO Soil Bulletin* 48:242-250. Rome: FAO

SSD, (1999) *Annual Report 2055/56 (1998/99).* Kathmandu Soil Science Division, Nepal Agricultural Research Council, HMGN

Walkley, A.; Black, I.A. (1934) 'Estimation of soil organic carbon by the chromic acid titration method'. In *Soil Sci.,* 37:29-38

White, J.G.; Welch R.M.; Norvell, W.A. (1997) 'Soil zinc map of the USA using geostatistics and geographic information systems'. In *Soil Sci. Soc. Am. J.*, 61:185-194

Wilding, L.P. (1985). 'Spatial variability: its documentation, accommodation and implications to soil surveys'. In Nielsen D.R.; Bouma J. (eds) *Soil Spatial Variability, Proc. Workshop, SSS and SSSA*, *Las Vegas, 30 Nov-1 Dec 1984*, p. 166-189. Wageningen (Netherlands): PUDOC

Yanai, J.; Lee, C.; Umeda K. M.; Kosaki, T. (2002) *Spatial variability of soil properties and rice yield in paddies: is precision agriculture worth practicing?* Paper 284 presented at the 17th World Congress of Soil Science, 14-21 August 2002, Bangkok, Thailand