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ASSESSMENT OF SOIL FERTILITY QUALITY IN PADDY CULTIVATED AREA (CASE STUDY: SOUTHERN HALF OF FOUMANAT PLAIN IN NORTH OF IRAN)

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ABSTRACT

Delsouz Khaki B, Honarjoo N, Davatgar N, Jalalian A, Torabi Gol Sefidi H (2016) Assessment of soil fertility quality in paddy cultivated area (Case study: southern half of foumanat plain in north of Iran). *J. Soil Nature* 9(2), 1-10.

Improving crop productivity and resource use efficiency is necessary to ensure food security and environmental quality. For producing a high-quality soil fertility map the fuzzy technique in geographic information systems (GIS) was used to optimize nutrient input rates. Two soil fertility qualities were considered: Inherent soil fertility potential (the thickness of plow layer, clay content, CEC, organic C, EC and pH) and nutrient availability (soil nutrient-supplying capacity for N, P and K). The descriptive statistics were calculated for each property in SPSS 17.0. The semi-variance calculations and semi-variogram model fitting were performed using GS+ version 5.1 software for geostatistics analysis. Based on R^2 and residual sums of squares (RSS), soil N, K, OC, CEC, EC and pH were modeled best with spherical relationship, in addition P and clay with exponential relationship. Then ordinary kriging procedure was used for mapping in Arc GIS 9.3. The cross-validation analysis was conducted by using mean of error (ME) and root mean of squared error (RMSE). Results showed that most of the investigated area had a moderate inherent fertility potential and were in low class of nutrient availability for intensive rice production. Due to their lower inherent potential and nutrient content, most of the study area in the western parts may not be suitable for further intensification of rice production. Especially low available K seems to be the major constraint to high rice yield. Further yield increases will require improved adjustment of P fertilizer rates according to the soil P status. According to the results, better nutrient management practices based on soil nutrients status to optimize the required inputs are necessary.

***Key words**: soil, fertility, quality, paddy*

INTRODUCTION

Rice (*Oryza sativa* L.) is an important food crop for a large proportion of the world's population (Fageria *et al.* 2003). It is also considered as a strategic crop in north of Iran and second staple food after wheat in the country (Khush 1993). While nutrient management for paddy fields in Iran is based on typical and uniform recommendations for large regions. This results in over-application of fertilizers in areas with high nutrient levels and under-application of those, in areas with low nutrient levels (Davatgar *et al.* 2012). On the other hand, site-specific management for rice production needs a high-quality soil fertility map to optimize the required inputs leading to efficient productivity (Salehi *et al.* 2013).

Soil fertility deals with nutrient status and ability of soil to supply nutrients for optimum plant growth. However, the optimum nutrient status alone will not ensure soil productivity (Sumner 2000). Soil productivity is defined as the capability of the soil for producing a quantified plant production by considering field and laboratory diagnostic techniques (Davatgar *et al.* 2012).

Soils are highly variable partially due to the combined effects of physical, chemical and biological processes that operate with different intensities and scales (Goovaerts 1998). The spatial variability of soil properties is influenced by both intrinsic (soil formation factors, such as soil parent materials) and extrinsic (agricultural management practices, such as fertilization) factors (Cambardella *et al.* 1994).

Due to their low spatial resolution, focus on pedological characterization, lack of quantitative data, large between-farm variabilities in crop management and dynamic changes in many soil nutrients, existing soil maps in the developing countries of Asia often do not provide sufficient information for agronomic purposes (Oberthür *et al.* 1996). Fuzzy set theory is developed by Lotfi Zadeh (1965). Fuzzy model is one of the best models used to provide different kinds of soil maps (Cassel-Gintz *et al.* 1997). Fuzzy systems provide a rich and meaningful improvement, or extension of conventional logic (McBratney and Odeh, 1997). Past research showed that fuzzy methods produce contiguous areas and reject less information at all stages of the analyses. They are much better methods for classification of continuous variation. Joint fuzzy membership functions (JFMF) can be used to combine sets of different soil properties into more general indices of soil quality (Burrough *et al.* 1992). Use of fuzzy mapping technique that account for the various sources of uncertainty in a spatial land classification procedure are of particular interest for large floodplains (Dobermann and Oberthur, 1997).

Dobermann and Oberthur (1997) produced the soil fertility map for irrigated rice land in the Philippines by using fuzzy system. They showed a combination of fuzzy membership functions with Monte Carlo simulation to produce maps of membership values for three soil fertility classes and two multivariate soil fertility qualities. Kweon (2012) reported that from comparison of the productivity map with the map generated by a fuzzy c-means clustering algorithm (FCM map), agreement between the productivity and yield exhibited generally higher in overall accuracy and Kappa coefficient than the agreement between FCM map and yield.

The objectives of the study were: (1) to indicate the spatial variability of the soil nutrients and inherent fertility potential properties of a paddy cultivated area in Southern Half of Foumanat Plain in north of Iran, (2) to identify areas suffering from specific soil limitations to rice growth.

MATERIALS AND METHODS

Site description, soil sampling and measurements

This study was conducted on an area of 24,000 ha paddy fields located in southern half of Foumanat plain. The region is located in a flat alluvial soils of two cities (Fouman and Shaft) of Guilan province, in north of Iran (49°15'40" to 49°28'5" east longitude and 37°7'48" to 37°15'56" north latitude). An overview of the boundary of the study area is given in Figure 1. Sampling points were scattered in paddy cultivated area, except somewhere due to existence of a road and urban area. The region is sub-humid with mean annual temperature of 20.5°C and mean annual precipitation of about 1200 mm. The soil texture ranges from silty loam to clay. The soil is classified as alfisol and inceptisol (Soil Survey Staff, 2003). Full irrigation has been provided for more than 20 years and the land use of the study area is mainly rice paddy fields. Hashemi cultivar, a high quality and semi dwarf rice (*Oryza sativa*), is cultivated in irrigated lowland paddy fields of the study area. Land preparation (includes plowing, puddling and harrowing) was performed 7 to 30 days before transplanting annually in early spring. The study area was fertilized with 60 kg N ha^{-1} as urea. Although, some farmers use 45 kg P ha^{-1} as triple super phosphate. However, a few farmers use 100 kg K ha^{-1} as potassium sulfate. Soil samples were taken before fertilizing and planting the fields. Because more than 90% of total root length of irrigated rice is located within the topmost 0-20 cm soil (De Datta *et al.* 1988), thickness of the plow layer (A_p horizon) measured and was papered and soil samples were collected from each puddled top soil horizon of 119 points. The location coordinates of each sampling site were recorded using global positioning systems (GPS). Soil samples were taken in plastic bags, air-dried and ground to pass through a 2-mm sieve before chemical and physical analysis. The electrical conductivity (EC) was determined from the saturation soil paste extract by EC meter device. Particle size analysis for soil texture was determined by hydrometer method. Soil pH was measured in 1:1 (W/W) soil/water suspension, organic C (OC, Walkley and Black, 1934), cation exchange capacity (CEC, Na-Oac method, pH 8.2), total nitrogen (TN, Kjeldahl), available phosphorous (AP, Olsen, 1954), available potassium (AK, NH_4OAC method, pH 7).

Descriptive statistics

The descriptive statistics including mean, standard deviation (SD), minimum, median, maximum, coefficient of variation (CV), skewness and kurtosis were calculated for each properties in SPSS 17.0 (SPSS Inc., Chicago IL). Distribution of these properties was tested for normality using the skewness and kurtosis significance test (Sendecor and Cochran, 1980).

Geostatitics analysis

Skewed properties were transformed using natural logarithm to a normal distribution before using geostatistical analysis; then, the data was back transformed using a weighted back transformation technique. The semi-variance calculations and semi-variogram model fitting were performed using the geostatistical software GS+ version 5.1 for windows (Gamma design, Inc., 2000), restricting to half of the maximum lag distance (Journel and Huijbregts, 1987). Variogram models of spherical, exponential, linear and linear to sill and Gaussian were fitted to the empirical semi-variance. Selection of semi-variogram models was made based on the coefficient of determination (R^2) and residual sums of squares (RSS). Using Arc GIS 9.3, the fitted models were then used in an ordinary kriging procedure to estimate different properties at non-measured points as interpolated values for mapping. The cross-validation analysis was conducted for evaluating kriging interpolation bias and accuracy. In cross-validation analysis; each point measured in a spatial domain is individually removed from the domain and estimated via kriging, though it were never there (Schepers *et al*. 2004). In this way, a comparison was made for estimated vs. actual values for each sample location in the domain by using of the mean of error (ME) and root mean of squared error (RMSE) statistics.

Fuzzy membership function

A fuzzy membership function (FMF) converts attribute values Z to fuzzy membership function values (FMFz) on a continuous scale ranging from 0 to 1, with 1 representing full membership and 0 no membership to the set. Dobermann and Oberthur (1997) defined three categories for each soil property:
Class 1, low fertile, severe constraint to nutrient uptake and high rice yield ($Z < b_l$),
Class 2, medium fertile, possible constraint to nutrient uptake and high rice yield ($b_1 < Z < b_2$),
Class 3, high fertile, no constraint to nutrient uptake and high rice yield ($Z > b_2$).

They used a sigmoid FMF, which in its symmetrical form can be written as:

$$FMFz = \frac{1}{(1 + (\frac{Z - b_1 - d}{d})^{p})} \qquad \text{for } Z < (b_1 + d)$$

$$FMF_z = 1 \qquad \text{for } (b_1 + d) \leq Z \leq (b_2 - d)$$

$$FMFz = \frac{1}{(1 + (\frac{Z - b_2 + d}{d})^{p})} \qquad \text{for } Z > (b_2 - d) \tag{1}$$

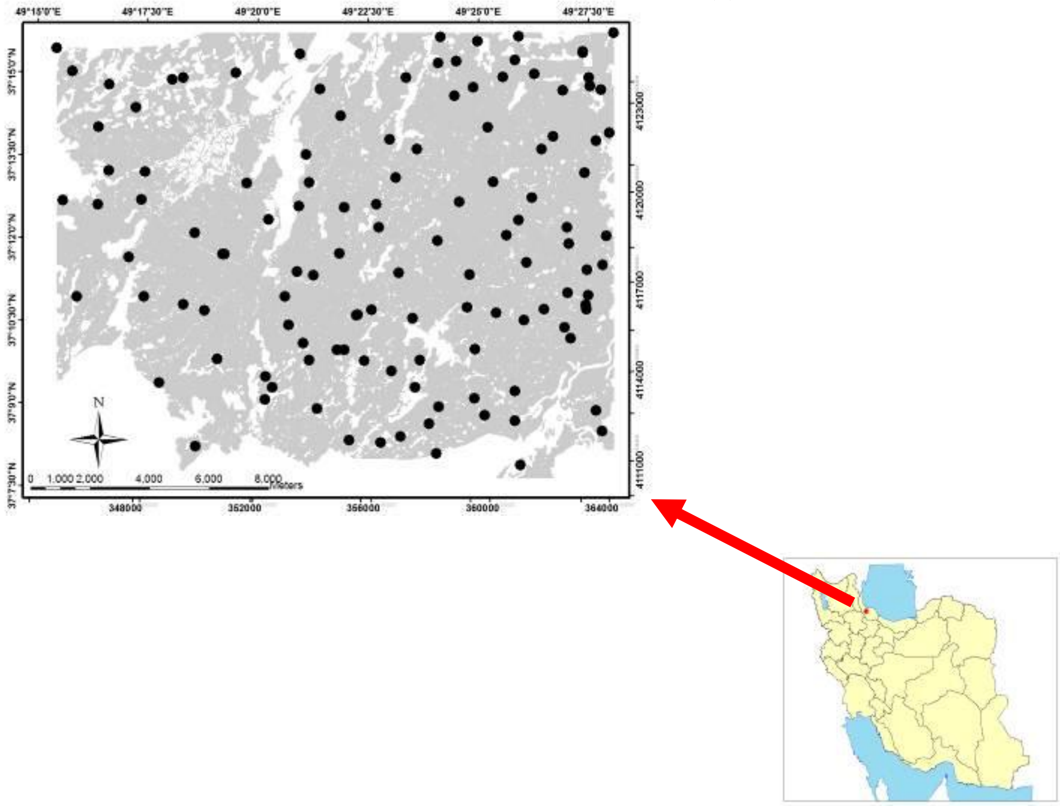


Fig. 1. Location of the study area and spatial distribution of sampling points in paddy fields of southern half of Foumanat plain in north of Iran

Where, b_l and b_2 are the lower and upper class limits, d is the dispersion value, p is the power value (determining curve slope). Because the objective of our study was mapping the potential for high fertile class, in this study, was considered to class 3 so we used just the third equal for soil properties thus instead of b_2, it shown as b in Table 1. The b values were determined by expert knowledge procedure.

Table 1. Definitional criteria for membership model and d values

Soil properties	b	d
Depth of A_p horizon (cm)	20	2.5
Clay content (%)	35	3
Organic C (g kg^{-1})	2	0.2
CEC (cmol kg^{-1})	20	2
Total-N (%)	0.2	0.02
Available P (ppm)	12	2
Available K (ppm)	160	12
pH of paste	7	0.6
EC (dS m^{-1})	2	0.2

Mapping of multivariate soil qualities

Joint fuzzy membership functions (JFMF) can be used to combine sets of different soil properties into more general indices of soil quality (Burrough *et al.* 1992). As Dobermann and Oberthur (1997), we considered mapping of two soil fertility qualities with a little change in soil properties.

(1) Inherent soil fertility potential: General physical and physico-chemical soil conditions, which are mainly influenced by the soil type. Suitable indicators of the inherent potential are, for example thickness of the plow layer (A_p), clay content (Clay), CEC, organic C (OC), EC and pH. Changes of such soil properties occur only slowly, but intensive rice production may affect some of them.

Model 1: All stable soil properties are favorable for intensive rice cropping (high inherent potential, $A_p \geq 20$ and Clay ≥ 35 and OC ≥ 2 and CEC ≥ 20, EC ≤ 2 and pH = 6 − 7).

$$\text{JMF IPhigh} = \text{MIN}(\text{FMF}_{Ap}, \text{FMF}_{Clay}, \text{FMF}_{OC}, \text{FMF}_{CEC}, \text{FMF}_{EC}, \text{FMF}_{pH}) \quad (2)$$

Where FMF_{Ap}, FMF_{Clay} , FMF_{OC}, FMF_{CEC}, FMF_{EC}, FMF_{pH} are the recalculated FMF values for Ap, Clay, OC, CEC, EC pH by using Eq. (1), respectively.

(2) Nutrient availability: Soil nutrient supplying capacity for N, P and K. These elements were selected and measured as readily available fractions. They are very dynamic and much affected by management practices.

Model 2: Inherent soil supply of all nutrients is adequate for rice yields (medium-high nutrient availability, N ≥ 0.2 and P ≥ 12 and K ≥ 160)

$$\text{JMF NA high} = \text{MIN}(\text{FMF}_N, \text{FMF}_p, \text{FMF}_K) \quad (3)$$

Where FMF_N, FMF_p and FMF_K are the recalculated FMF values for N (total nitrogen), P (available phosphorous) and K (available potassium) by using Eq. (1), respectively.

In model 1 (Eq. (2)), for example, all conditions have to be fulfilled until a soil matches the requirements of an inherently very productive soil.

According to model 1 and model 2 the two JMFs were calculated for each sample, then using the JMF values, the two soil fertility quality maps were produced using IDW method in GIS(9.3) then classified into four class: very low(JMF<0.25), low(JMF: 0.26-0.50), moderate(JMF: 0.51-0.75) and high(JMF>0.76).

RESULTS AND DISCUSSION

Exploratory analysis of data

Descriptive statistics for soil properties were given in Table 2. The soil was acid to slightly alkaline, with pH ranging from 5.5 to 7.5. The mean organic carbon (OC) was 2.48%. According to the study by Doberman and Fairhurst (2000), the mean soil OC content in this area was high for rice growth. The mean soil N and P were considered sufficient for rice growth, with a value of 0.23% and 15.64 mg kg^{-1}, respectively. The mean K content was low and would not meet the need for rice growth. Thickness of the plow layer (A_p) was mostly in the range of 10 to 22 cm due to the plow layer has created by the farmers, it is much affected by management practices). The restriction to root growth is possible in shallow plow layer less than 15 cm. Moreover, soil volume available for nutrient uptake is limited for this condition. The high value for co-efficient of variation (CV) of available P and K showed that fertilization, land use pattern and soil management practices are heterogeneous. The values of CV in soil nutrient elements were larger than inherent soil fertility potential properties (except EC). This indicated that soil nutrients in the study area had considerable spatial variability that can satisfy preconditions for soil nutrient management zones and suggested that variable rate fertilization management may be helpful to improve rice production in the study area.

Table 2. Descriptive statistics of soil properties in the study area

Soil properties	Min	Mean	SD	Max	CV (%)	Skewness	Kurtosis
Inherent soil fertility potential properties							
pH	5.49	6.63	0.52	7.53	7.92	-0.13 ns	-1.17 ns
OC (%)	1.0	2.48	0.72	4.5	28.96	0.43 ns	-0.47 ns
CEC (c mol kg^{-1})	10	29.46	7.16	47	24.29	0.002 ns	0.35
EC (dS m^{-1})	0.12	1.27	0.51	2.71	40.51	0.44 ns	-0.11 ns
Clay (%)	6	39.88	9.78	56	24.52	-0.50 ns	0.05 ns
A_p (cm)	10	15.98	2.36	22	14.77	-0.22 *	0.62*
Nutrient availability properties							
N (%)	0.11	0.23	0.06	0.4	25.86	0.52*	-0.19 ns
P (mg kg^{-1})	2	15.64	12.90	72	82.49	2.16*	5.20*
K (mg kg^{-1})	55	139.23	54.66	350	39.26	1.09*	1.30*

OC: organic carbon; CEC: cation exchange capacity; A_p: top soil depth; N: total nitrogen; P: available phosphorous; K: available potassium. ns: non significant; *: significant at probably level of 0.01.

Spatial variability analysis

The soil properties such as N, P, K and soil depth showed significant skewed properties. These properties were log-transformed before using geostatistical analysis. The results of semivariogram analysis were e shown in Table 3 and Figure 2. Soil N, K, OC, CEC, EC and pH were modeled best with spherical models, whereas P and clay with exponential model. According to Cambardella *et al.* (1994), the ratio of nugget to sill can be used to denote spatial dependence of soil variables. A ratio <25% indicated strong spatial dependence, between 25% and 75 indicated moderate spatial dependence, and >75% indicated weak spatial dependence. However, unknown spatial dependency of the variable could exist at a lower scale even if a high nugget/sill percentage was obtained (Wu *et al.* 2008). The criterion proposed by Cambardella *et al.* (1994) may have some inherited limitations (Weindorf and Zhu, 2010). For instance, the range effect of a semivariogram was not considered in this criterion. Values of this ratio for all of studied soil properties ranging from 35 to 70%, indicating that the spatial dependence of properties were moderate (except about A_p which didn't match with any of used model so for the criterion we use IDW method). The nugget/sill ratio of pH, OC, TN and AK was nearly similar. The moderate spatial dependent imprinted by a combination of intrinsic (soil-forming processes) and extrinsic factors (soil fertilization and cultivation practices). These combined factors for the soil properties might be attributed to the leaching of soil nutrients, parent material with low exchangeable K, land leveling and non uniform fertilization of the study area (Davatgar *et al.* 2012). The distribution maps of soil N, P, K, ECE, EC, clay and OC are shown in Figure 3. Soil N was high in the most parts of the study area. Soil P was moderate in paddy soils located in east and north-west of the study area. Soil K was moderate in about half of the area. The distribution of N was similar to distribution pattern of OC. It seems that with increasing in the value of OC, the indigenous N supply is increased. The moderate level of N in west part of the study area mostly occurred on low level of clay content (coarser-textured soils). The N leaching is usually increased with decreasing in clay content (Davatgar *et al.* 2012).

Soil fertility constraints to intensive rice cropping

About 38.66% of all samples analyzed had minimum values (JMF) due to AK (available potassium). Thickness of the plow layer caused 19.33% of minimum values. Both Total N and CEC resulted 1.68% of minimum values. Organic C and Clay content were the reason of the minimum values in just 3.36% of all sample points. The proportion of EC, pH and P in minimum values were 4.2%, 7.56% and 23.53%, respectively. Thus the most limitations among inherent potential factors caused by thickness of top soil and in case of nutrient availability factors by K.

Inherent potential and nutrient availability

About 92% of the sample points had inadequate soil supply of one or more nutrients and about 8% of the points had not any limitation for inherent potential factors as well as about 8% of points had not any limitation for nutrient availability factors. The average membership values for Inherent potential and nutrient availability were 0.6 and 0.35 respectively.

Most of the investigated area had a moderate inherent fertility potential and were in low class of nutrient availability for intensive rice production (Figure 4). Due to their lower inherent potential and nutrient content, most of the study area in the western parts may not be suitable for further intensification of rice production in this status.

Almost all the land had limitations due to moderate soil status of one or more nutrients but because the study area is part of the most productive rice land in the country, the need for better nutrient management practices is clear. It should be noted the two soil quality maps produced in view of class 3.

Table 3. Semi-variogram models for soil nutrients and inherent fertility potential properties in the study area

Variable	Model	Nugget C_0	Sill C0+C	Nugget/sill (%)	Range (m)Ao	R2	RSS
pH	Spherical	0.2	0.31	65	5500	0.822	2.096×10^{-3}
OC (%)	Spherical	0.32	0.52	62	3500	0.817	5.35×10^{-3}
CEC (c mol kg^{-1})	Spherical	18	52	35	3500	0.862	0.119
EC (dS m^{-1})	Spherical	0.2	0.275	73	7450	0.914	6.9×10^{-4}
Clay (%)	Exponential	28	78	36	1200	0.838	0.215
N (%)	Spherical	0.038	0.065	59	1700	0.639	1.29×10^{-4}
P (mg kg^{-1})	Exponential	0.25	0.46	54	1300	0.798	0.0116
K (mg kg^{-1})	Spherical	0.10510	0.1510	70	6200	0.860	3.3×10^{-4}

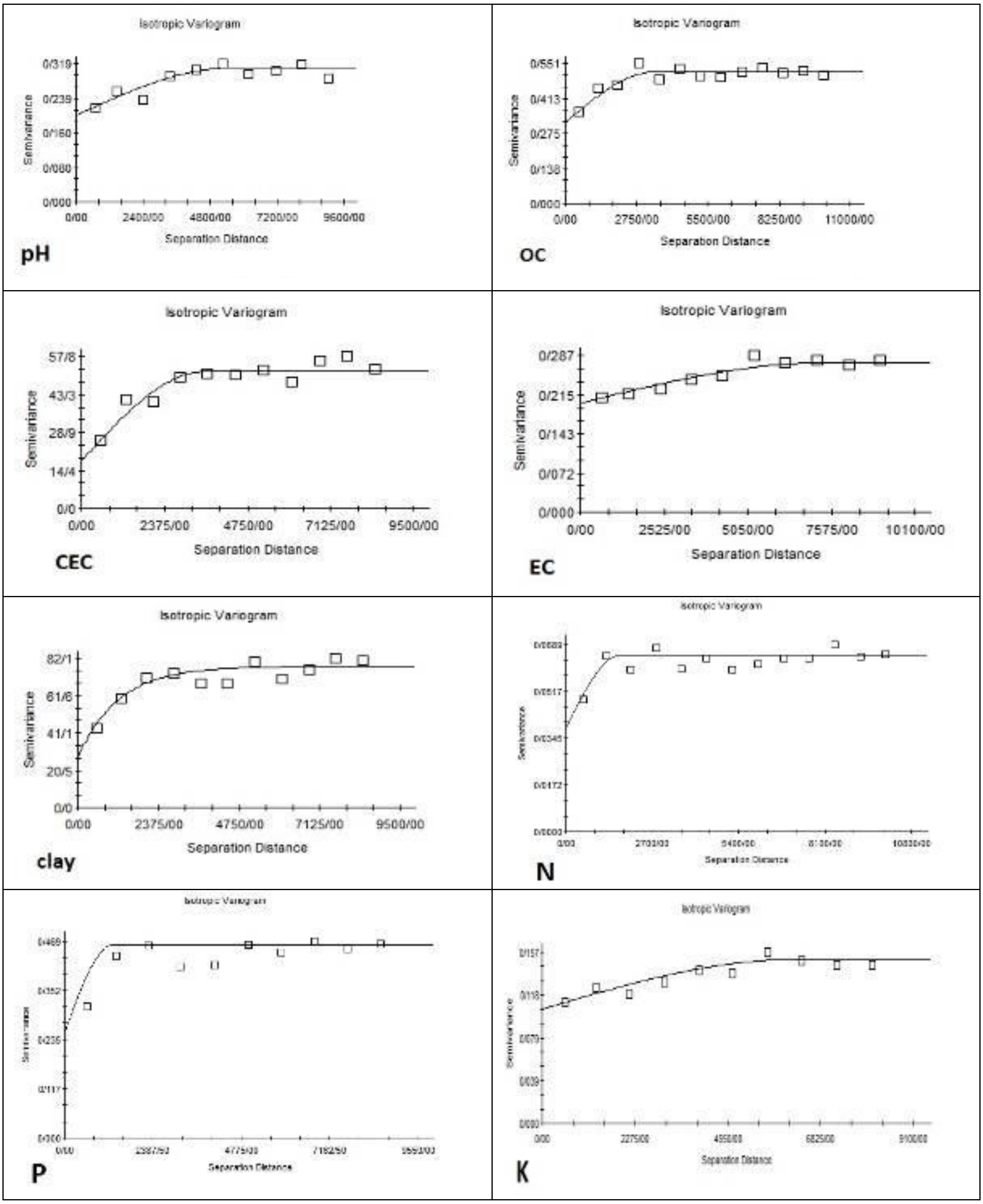
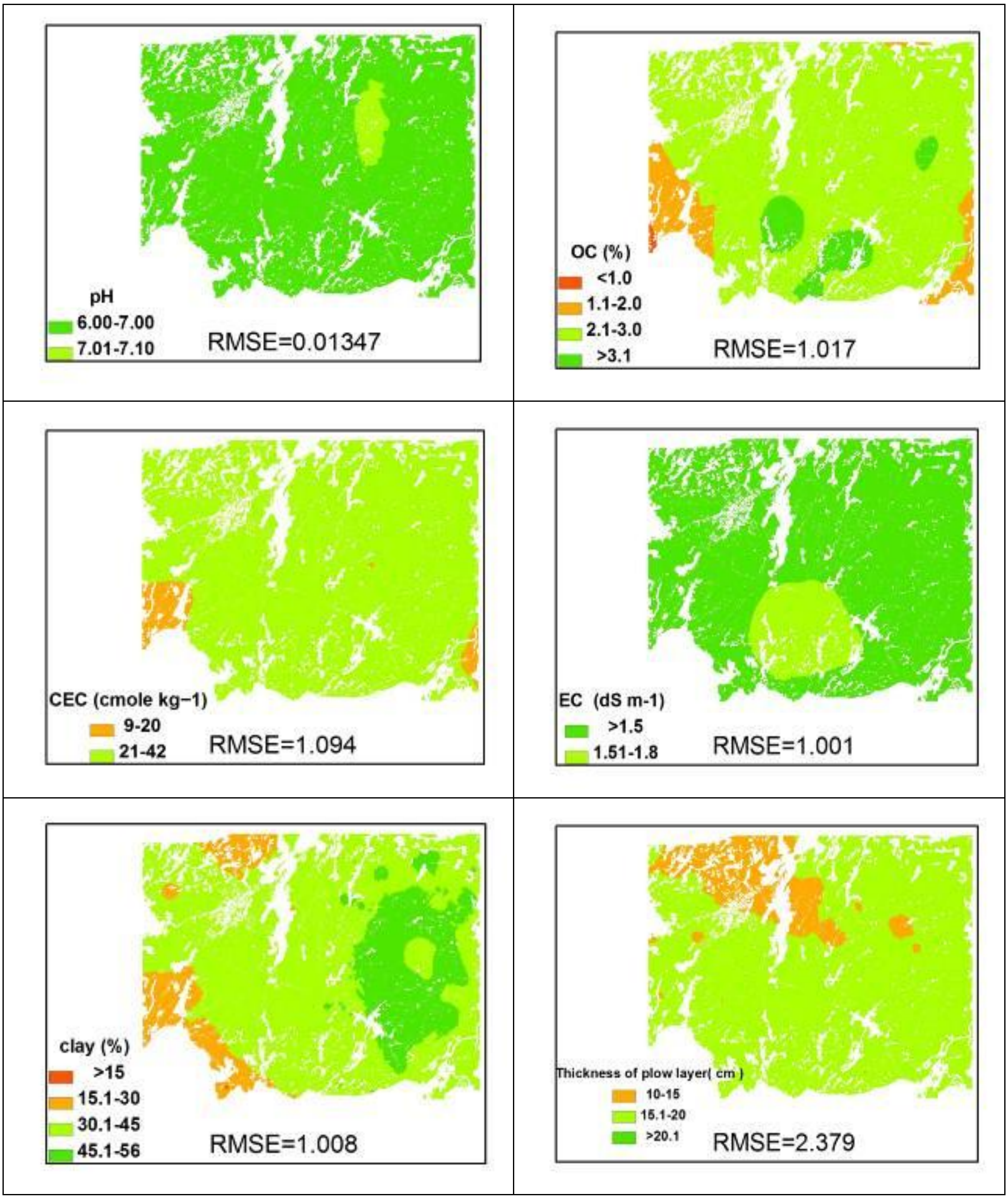


Fig. 2. Semivariogram of soil properties in the study area, experimental semivariance (□) and the fitted semivarigram models (lines)


pH
6.00-7.00
7.01-7.10
RMSE=0.01347
OC (%)
<1.0
1.1-2.0
2.1-3.0
>3.1
RMSE=1.017
CEC (cmole kg−1)
9-20
21-42
RMSE=1.094
EC (dS m-1)
>1.5
1.51-1.8
RMSE=1.001
clay (%)
>15
15.1-30
30.1-45
45.1-56
RMSE=1.008
Thickness of plow layer(cm)
10-15
15.1-20
>20.1
RMSE=2.379

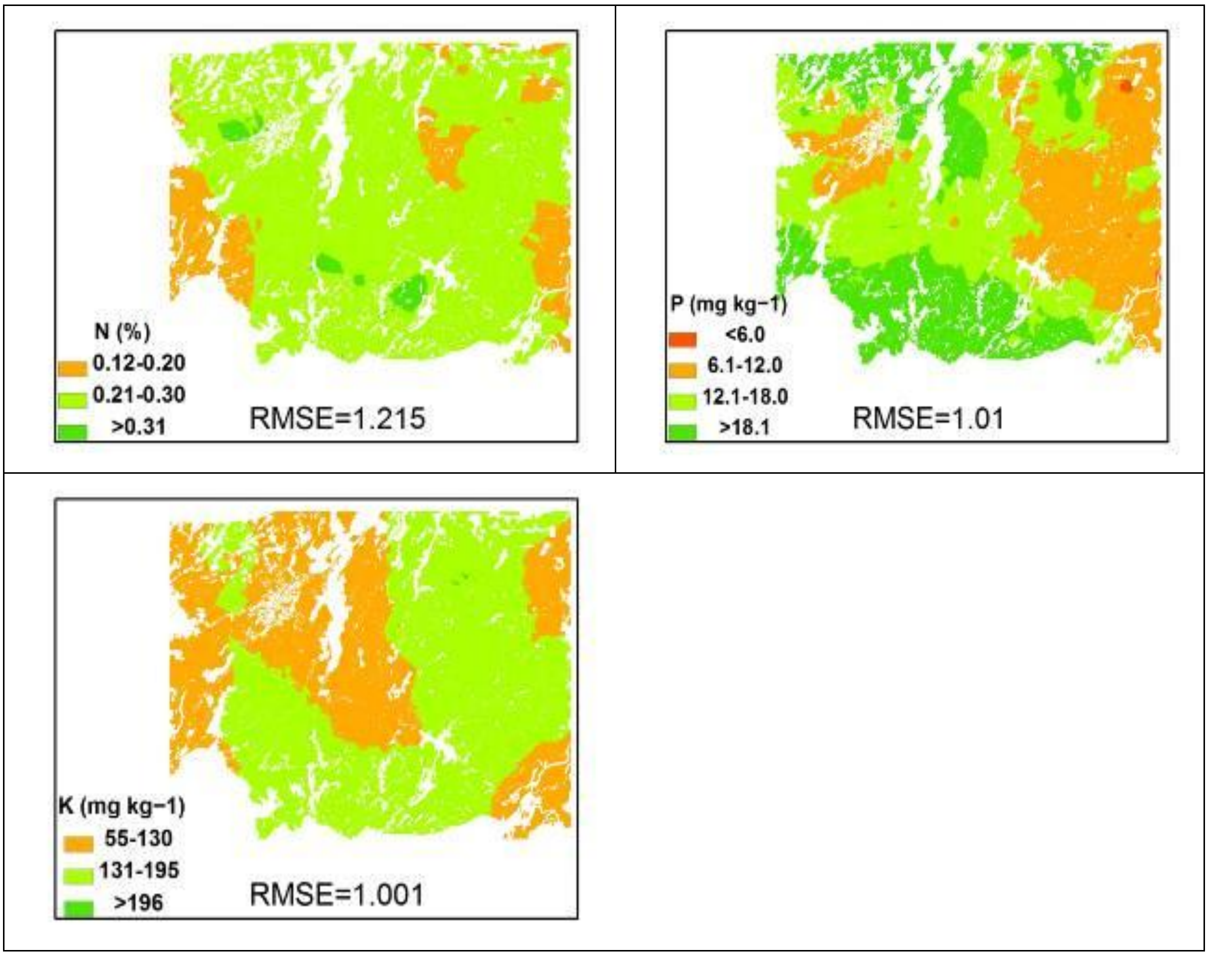


Fig. 3. Spatial variability of soil nutrients and inherent fertility potential properties in the study area

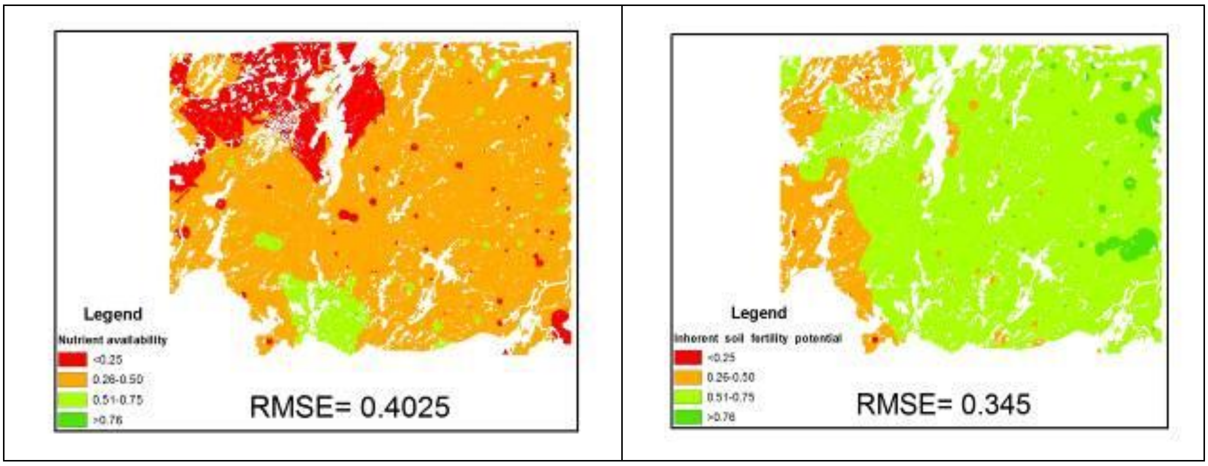


Fig. 4. Spatial variability of soil nutrients and inherent fertility potential (Fuzzy maps) in the study area

CONCLUSION

Nutrients were major yield-limiting factors in many farms of the study area. Of the soil fertility indicators measured in this case study, low available K seems to be the major constraint to high rice yields. This is because of lower soil K-supplying power and insufficient application of mineral K fertilizer. Farmers generally applied insufficient amounts of fertilizer K to maintain a positive K balance. Therefore, K management is critical for keeping rice yield at high level. In case of P management, further yield increases will require improved adjustment of P fertilizer rates according to the soil P status. Thus Monitoring soil fertility at regional scales is necessary to assess changes in the resource base over time.

The fuzzy methodology used in the study is one efficient way to account for the uncertainties associated with such activities, but approaches such as dynamic adjustment of fuzzy membership functions based on objective criteria should receive further attention. High-quality soil fertility map can potentially enable the decision makers to apply the site-specific management on input requirements in paddy cultivation.

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REFERENCES

Burrough PA, MacMillan RA, Van Deursen WPA (1992) Fuzzy classification methods for determining land suitability from soil profile observations and topography. *J. Soil Sci*. 43, 193-210.

Cambardella CA, Moorman TB, Novak JM, Parkin TB, Karlen DL, Turco RF, Konopka AE (1994) Field-scale variability of soil properties in central Iowa soil. Soil Science Society of America Journal. 58, 1501-1511.

Cassel-Gintz MA, Lüdeke MK, Petschel-Held G, Reusswig F, Plöchl M, Lammel G, Schellnhuber HJ (1997) Fuzzy logic based global assessment of the marginality of agricultural land use. Climate Res. 63(8), 135-150.

Davatgar N, Neishabouri MR, Sepaskhah AR (2012) Delineation of site specific nutrient management zones for a paddy cultivated area based on soil fertility using fuzzy clustering. Geoderma. 173, 111-118.

De Datta SK, Buresh RJ, Samson MI, Wang KR (1988) Nitrogen use efficiency and nitrogen-15 balances in broadcast-seeded flooded and transplanted rice. *Soil Sci. Soc. Am. J*. 52, 849-855.

Doberman A, Fairhurst TH (2000) Rice: Nutrient Disorders & Nutrient Management. International Rice Research Institute, Philippines.

Dobermann A, Oberthür T (1997) Fuzzy mapping of soil fertility—a case study on irrigated rice land in the Phillipines. Geoderma. 77, 317-339.

Fageria NK, Slaton NA, Baligar VC (2003) Nutrient management for improving lowland rice productivity and sustainability. Advances in Agronomy. 80**,** 63-152.

Gamma design Inc (2000) GS+ User's Manual for Windows. Gamma design software, plainwell, Michigan, USA.

Goovaerts P (1998) Geostatistical tools for characterizing the spatial variability of microbiologycal and physico-chemical soil properties. Biology and Fertility of Soils. 27, 315–334.

Journel AG, Huijbregts CJ (1987) Mining Geostatistics. Academic Press, London.

Khush GS (1993) Varietal Needs for Different Environments and Breeding Strategies. In: New Frontiers in Rice Research, Muralidharan, K. and E.A.

Kweon G (2012) Delineation of site-specific productivity zones using soil properties and topographic attributes with a fuzzy logic system. Biosyst Eng. 112(4), 261-277.

Lotfi Zadeh LH (1965) Fuzzy sets. Infor Control. 8, 338–353.

McBratney AB, Odeh IOA (1997) Application of fuzzy sets in soil science: fuzzy logic, fuzzy measurement and fuzzy decisions. Geoderma. 77, 85-113.

Oberthür T, Dobermann A, Aylward M (2000) Using auxiliary information to adjust fuzzy membership functions for improved mapping of soil quality. Geoderma. 14, 431- 454.

Olsen SR (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United states department of agriculture, Washington.

Salehi N, Ghajar Sepanlou M , Jafari Gorzin B (2013) An evaluation of Soil fertility using soil organic carbon, potassium, phosphorus and salinity factors for rice cultivation by fuzzy logic and AHP techniques. *International Journal of Agriculture and Crop Sciences.* 5(19), 2233-2241.

Schepers AR, Shanaham JF, Liebig MA, Schepers JS, Johnson SH, Luchiari JA (2004) Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. *Agronomy Journal.* 96, 195-203.

Sendecor GW, Cochran WG (1980) Statistical Methods. Iowa State Univ. Press, Ames.

Soil Survey Staff (2003) Keys to soil taxonomy. 9th ed. USDA-NRCS, Washington, DC.

Sumner ME (2000) Handbook of Soil Science. CRC press.

Walkley A, Black IA (1934) An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 37(1), 29-38.

Weindorf DC, Zhu Y (2010) Spatial variability of soil properties at Capulin Vlcano, New Mexico, USA: Implications for sampling strategy. Pedosphere. 20(2), 185-197.

Wu C, Wu J, Luo Y, Zhang H, Teng Y (2008) Statistical and geostatistical characterization of heavy metal concentrations in a contaminated area taking into account soil map units. Geoderma. 144, 171-179.