

Comparison of Fuzzy logic and Boolean methods in mapping nitrogen and phosphorus nutrients

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Abstract

One of the approaches for increasing of yield and reduction of rice production costs is precision agriculture. Complete and correct determination of nutrition status of paddy soils is necessary in precise agriculture. To compare fuzzy and Boolean methods and mapping of nutrition status of nitrogen and phosphorus, 370 compound samples were collected from 306 ha of paddy soils of Rice Research Institute in Rasht County from plots with the dimension of 50 × 100 m. Total nitrogen and available phosphorus contents were measured. Results showed that interpolation and mapping by fuzzy logic was more accurate and correct in comparison with Boolean method and had greater distinguishing power to indicate deficiency of nutrients. Evaluation of dependency of paddy soils using of fuzzy function and Boolean method, showed that the southwest of study area have nitrogen and phosphorus deficiency and the other parts have minor limitation for these elements.

Keywords: Fuzzy logic, mapping, nutrients, precision agriculture.

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Introduction

Determination of homogeneous management zones is an appropriate tool used in precision agriculture that improves crop management and reduce the destructive effects of environmental (Franzen et al., 2002; Khosla et al., 2002). Administrative regions in precision agriculture shows similar characteristics and soil conditions in landscape and spatial similarity of them leads to the same potential crop yield, inputs efficiency, and environmental effects (Schepers et al., 2004). Due to a lot of changes within the farm and dynamic nature of soil nutrients, a traditional soil map does not offer enough information. One common method of soil fertility evaluation is Boolean method (Heuvelink and Burrough, 1993; McBratney and Odeh, 1997). However, using appropriate methods such as fuzzy set causes less data loss at different stages of analysis (Burrough et al., 1992). Fuzzy set for the first time Zadeh (1965) introduced the fuzzy system as a possible method for the expression of uncertainty in the processes or uncertain vague of experts knowledge (Freissinet et al., 1998). Based on Zadeh comments, fuzzy logic theory is an effective way for recreation of the relations between accuracy and math class ambiguity and lack of precision in the real world (Zadeh, 1965).

Fuzzy Logic philosophy is creation of a network in which mathematical concepts in uncertain decisions is being studied accurately. This logic can be used especially when that sufficient data to determine the uncertainty through the use of standard statistics (e.g. mean, standard deviation and distribution type) is not present (Martin-Clouaire et al., 2000). Today in Soil Science, the fuzzy logic theory has broad applications that include: numerical classification of soil and mapping, land evaluation, modelling and simulation of soil physical processes, fuzzy spatial statistics of soil, soil quality indicators, and measurements for fuzzy defined

soil phenomena (McBratney and Pringle, 1997). Reyniers et al. (2006) used from fuzzy logic changes of yield potential changes in relation to characteristics of loamy soils of Central Belgium. Fuzzy set led the field into 5 regions with different yield potential. This information caused to accurate management and optimized performance in the field. Amini et al. (2005) used from a combination of fuzzy classification and spatial prediction for assessment of soil pollution for 225 samples in Isfahan. Concentrations of heavy metals based on the optimal number of classes and Fuzzy c-mean method were grouped into 4 classes and the results showed that fuzzy classification is a proper method for grouping of soil contamination data.

Related researches

In a case study, Sicat et al. (2005) used fuzzy model of farmer's knowledge and GIS to evaluate of fertility of agricultural lands. The results of their study showed that the usefulness of fuzzy model for determining land suitability classes and optimal land use. Ping and Dobermann (2003) evaluated the spatial variation of rice yield in relation to soil properties in paddy lands using fuzzy logic and classical statistics and indicated that the relative advantages of the fuzzy logic and emphasized on the necessity of further research about interpolation method. This study was carried out with the aim of comparison of Boolean and fuzzy logic method for diagnosis of real requirement of paddy lands to nitrogen and phosphorus fertilizers.

Material and Methods

Study area and sampling

The study area was 306 ha of paddy fields in Rice Research Institute, located in Rasht city. This field stands in the rice cultivation area of Gilan province in north of Iran.

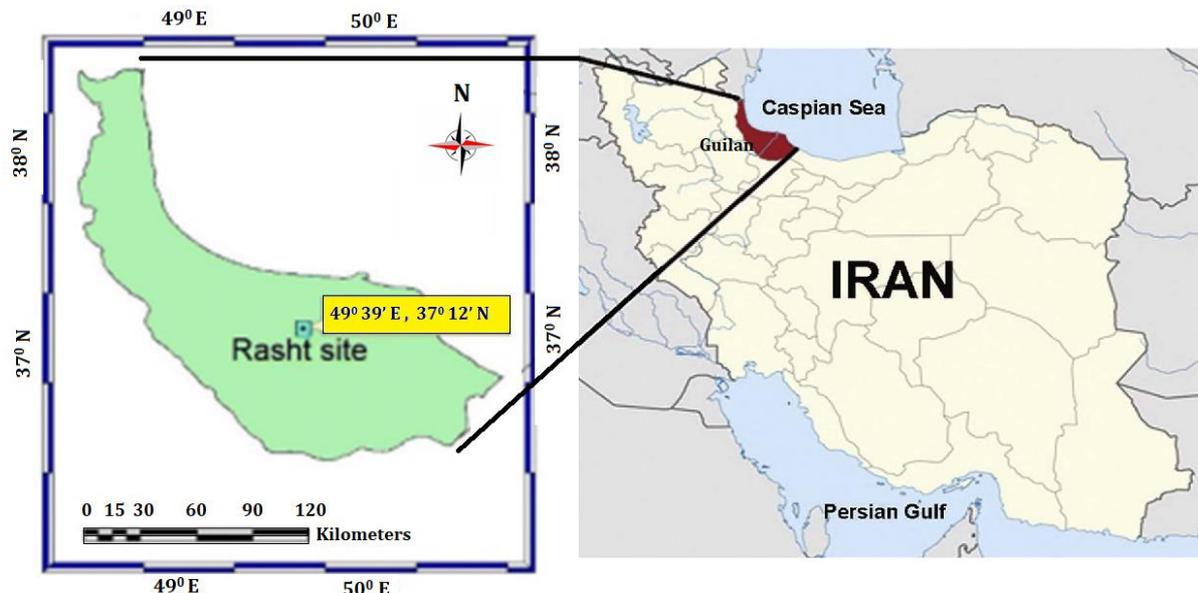


Figure 1. Rice cultivation area of Gilan province in north of Iran.

Gilan province with the 238,000 ha paddy farms has the second rank of rice cultivation area in Iran (37% of total) (Khodabande and GhasempourAlamdari, 2005). This region has a humid climate with average annual rainfall of 1200 mm. 370 soil samples were collected from the plots with the dimensions of 50 × 100 m. Sampling procedure was a compound 9 points that the first sample were collected from the centre of the plot and the rest with a radius between 15 and 25 m from around it, then mixed with equal weight and transferred to the laboratory. After air drying the samples were passed through 2 mm sieve. The main soil taxonomy class of study field was xeralf according to US Taxonomy (Soil Survey Staff, 2014). The characteristics of study field were measured in former researches and the average of them is presented in Table 1. Because of high potassium content of Gilan province (as soils, no potassium fertilizers usually used by farmers, therefore, nitrogen and phosphorous were studied in this research.

Table 1. Mean soil characteristics of paddy fields of Rice Research Institute

Soil Depth (cm)	Electrical conductivity (dS.m ⁻¹)	pH	OC (%)	Total nitrogen (%)	Available phosphorus (mg.kg ⁻¹)	Available potassium (mg.kg ⁻¹)	Sand (%)	Silt (%)	Clay (%)	Soil texture
0-30	1.2	7.4	1.9	0.187	26.7	224	10	42	48	Silt-Clay

Chemical analysis

Total nitrogen was measured by Kjeldal method (Boltz and Howell, 1978) and available phosphorus extracted by Olsen method and measured with spectrophotometer (Murphy and Riley, 1988).

Descriptive statistics

Statistical parameters related to the position distribution (mean, median, mode), frequency distribution parameters (variance, standard deviation and range) and the distribution parameters (skewness, traction coefficient of variation) were calculated. Assessment for normal distribution of data done using Histogram test and skewness significance test by the SPSS software version 11.5 (Lund Research Ltd, 2018).

Boolean and Fuzzy logic theory

In Boolean method, for converting of input variables to a set of explicit values membership function, membership for conditions of deficiency or severe limitation Class (relationships 1 and 2) and conditions of adequacy or without limitation Class (relationships 3 and 4), were defined as follows:

$$\text{if } Z \leq b_1 \text{ } BMF_z = 1 \quad (1)$$

$$\text{if } Z > b_1 \text{ } BMF_z = 0 \quad (2)$$

$$\text{if } Z < b_2 \text{ } BMF_z = 0 \quad (3)$$

$$\text{if } Z \geq b_2 \text{ } BMF_z = 1 \quad (4)$$

Where: Z ; variable, b_1 ; critical level lower than that in the plant is accompanied by severe shortages b_2 ; critical upper limit that the plant doesn't face to any restrictions and BMF_z ; membership of Boolean function.

In fuzzy logic, for converting the value of each variables to the fuzzy membership function, use from a continuous range from 0 to 1; 1 indicates full membership, and 0, indicating non-membership. Fuzzy membership function for the class of deficiency or severe limitation (relationships 5 and 6) and adequacy class or conditions without limitation (relationships 7 and 8) were defined as follows:

$$\text{if } Z < (b_1 - d) \text{ } FMF_z = 1 \quad (5)$$

$$\text{if } Z \geq (b_1 - d) \text{ } FMF_z = \frac{1}{1 + \left(\frac{Z - b_1 + d}{d} \right)^\rho} \quad (6)$$

$$\text{if } Z > (b_2 + d) \text{ } FMF_z = 1 \quad (7)$$

$$\text{if } Z \leq (b_2 + d) \text{ } FMF_z = \frac{1}{1 + \left(\frac{Z - b_2 - d}{d} \right)^\rho} \quad (8)$$

where: Z ; variable, FMF_z ; fuzzy membership function, b_1 ; critical level that the plant shows severely deficiency in the values lower than it, b_2 ; critical upper limit that the plant doesn't not faced with restrictions, d ; width of transitional range ρ ; indicate curve slope is based on the desired element behaviour in the study area, is determined by plant nutrition specialist.

To determine the upper and lower critical level of nutrient table 2 was used. b_1 ; lower critical level of nitrogen and phosphorus concentrations, which in the amounts less than it the plant has a severe shortage of these 2 elements in paddy lands and yields loss is the possible. b_2 ; critical upper limit (adequacy), which in higher nitrogen and phosphorus concentrations than it the plant doesn't faced to any restrictions in these nutrients uptake and, if other production factors likely to be optimized, high performance is archived.

Table 2. Critical level of nitrogen and phosphorus for rice in paddy soils

Soil properties	b1	b2	d
Total Nitrogen %	0.1	0.2	0.02
Available Phosphorus (mg. kg ⁻¹)	6.0	12.0	2.0

Statistical analysis

In this research, GS + 5.1 software was used for semi-variogram and representation of Boolean and fuzzy membership functions. For the representation of spatial distribution of fuzzy membership functions and Boolean by kriging first fitting and selection of varogram model were done. Fitted models, a model which remains the lowest sum of squares (RSS) and the highest coefficient explained (R^2) was selected as the best model for fitting of experimental values on semi-variance of practical values. To realize the spatial power structure (dependency) of each variable, the ratio of item variance (C0) to the total variance (C0 + C) were used. The ration of item variance to the threshold of a piece showed the share of piece variance from the total variance. This ratio helps us to compare the relative effect of piece variance between the different characteristics (Trangmar et al., 1985). the value of less than 25% of this ratio shows that the variable has a strong spatial dependency, 25 to 75% indicates the average spatial dependency and the values more than 75% considered as a weak spatial dependency (Sun et al., 2003).

Results and Discussion

Frequency distributions of the studied variables were shown in Table 3. Skewness of soil nitrogen and phosphorus was not significant at 5% level and their mean (0.16 and 7.0) is close to median (0.16 and 6.6) therefore the distribution of them is normal because the mean and median are approximately equal (Hasani Pak, 1997). If only random factors were affective in creating of differences, the distribution of values is normal or close to it (Rezaee, 1995).

Table 3. Statistical distribution of the studied properties

Properties	mean	min	max	median	mode	Var	S.D	skewness	kurtosis	C.V%
N%	0.16	0.07	0.28	0.16	0.17	0.00089	0.02981	0.336 ^{ns}	0.467	18.1%
P (mg. kg ⁻¹)	7.00	0.40	19.20	6.6	5.60	9.93232	3.15156	0.728 ^{ns}	1.020	44.6%

ns: insignificant at 5% level[‡]

Division of properties based on coefficient of variation (CV) and grouping based on Dahiya et al. (1985) and Wilding and Deres (1983) were shown in the Table 4. Parameter of coefficient of variation (CV) was dimensionless and can be use to compare of variation of a variable among the sampling units of 2 or more statistical populations with heterogeneous or incongruous observations between different properties of a sampling unit that have different observation size (Rezaee, 1995; McBratney and Odeh, 1997).

Table 4. Grouping properties based on coefficient variation (CV %)

Properties	Classification of Dahiya et al.			Classification of Wilding and Deres		
	high variation	medium variation	low variation	high variation	medium variation	low variation
	CV>75	75CV<<15	75CV<	CV>35	35CV<<15	15CV<
N %		*			*	
P (mg. kg ⁻¹)		*		*		

With considering the grouping based on Dahiya et al. (1985) nitrogen and phosphorus has changes were moderate, while Wilding and Deres (1983) grouping resulted that phosphorus was had an extremely deficit. Coefficient of variation of more than 30% shows substantial variations of soil, more dissimilarity between the data and the requirement of more sample collection from the study population (Schöning et al., 2006). Boolean and fuzzy membership functions of nitrogen deficiency and sufficiency conditions are shown in the figures of 1 to 2. According to Figure 2a, the fuzzy membership function, number of examples with a concentration of less than 0.1% had a full dependence to severe limitation class, but samples with higher N 0.1 to close 0.2% had also relative dependence to deficiency class (severe restriction), but Boolean method was very rigid and samples with more than 0.1% N showed without dependence to severe restriction class (Figure 2a). Fuzzy membership function in the class of without nitrogen limitation. Figure 3a showed that samples with higher N 0.2% with complete dependence to adequacy class (without limitation and high fertility) are almost rare. While Boolean membership function, considered samples with less than 0.2% N without dependence on the class of without limitation (Figure 3b).

Fuzzy membership function for phosphorus in deficiency conditions (severe limitation) was shown in Figure 4a. Number of samples in class with severe limitations was very high and samples with the phosphorus concentrations of more than 6 mg kg⁻¹ had also the relative dependence on severe limitations class. However, in severe limitations class of membership Boolean function this dependence did not exist (Figure 3b). Fuzzy membership function for class of without limitation phosphorus (Figure 5) showed that the number of samples in the class of high fertility and low limitation was very low. These results showed that the studied soils had more limitation for phosphorus than nitrogen.

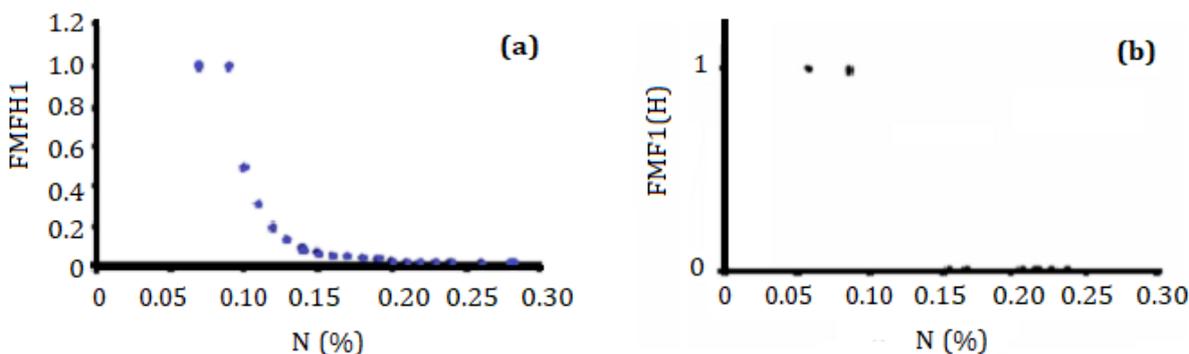


Figure 2. Fuzzy membership function (a) and Boolean membership function (b) of severe N limitation

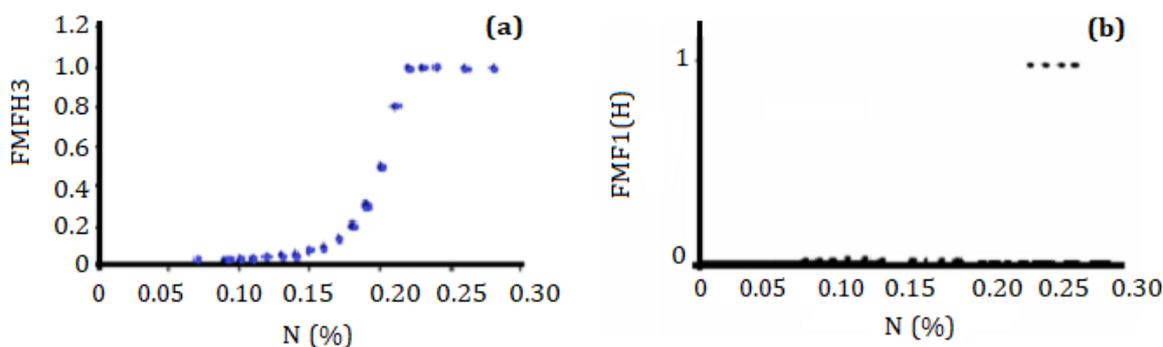


Figure 3. Fuzzy membership function (a) and Boolean membership function (b) of without N limitation

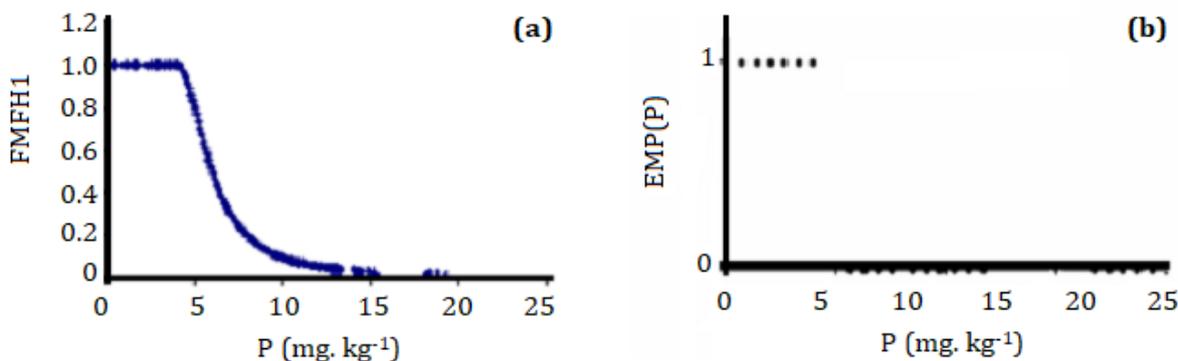


Figure 4. Fuzzy membership function (a) and Boolean membership function (b) of severe limitation of P

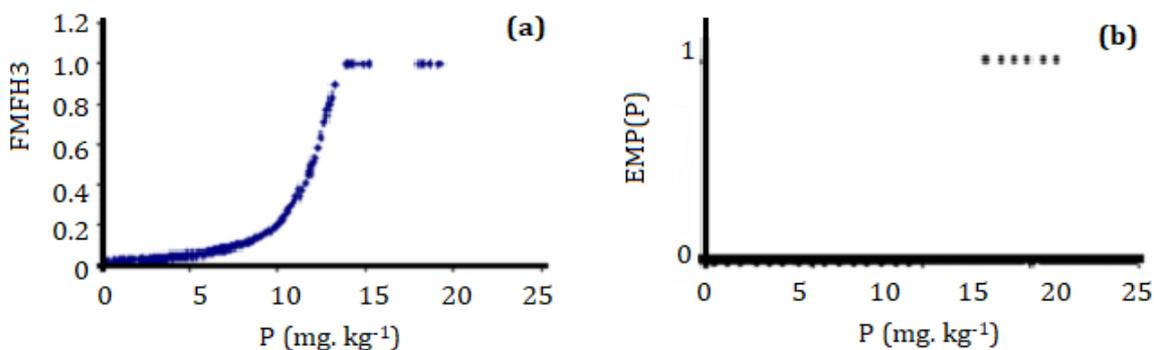


Figure 5. Fuzzy membership function (a) and Boolean membership function (b) of without limitation of P

The best fitted model of variogram for the data on membership functions of nitrogen and phosphorus, along with the spatial structure parameters of these variables were shown in the Table 5. Fuzzy membership functions and Boolean of N in severe limitation class followed from spherical variogram model and fuzzy membership functions and Boolean phosphorus in both classes (severe limitation or low fertility) (Figure 6) and adequacy (without limitation or high fertility) (Figure 7) also followed from spherical variogram model. Spherical variogram model shows a specific spatial dependence of a variable in a distinct range.

Table 5. Model of parameters estimated of N and P

Properties	Method	Class	Model	C ₀	C ₀ +C	A ₀	R ²	RSS	$\frac{C_0}{C_0+C} \times 100$
N	Boolean	low fertility	spherical	0.00750	0.01430	1000	0.094	7.284×10 ⁻⁴	52.4
		high fertility	linear	0.12382	-	-	0.052	9.499×10 ⁻³	-
	Fuzzy	low fertility	spherical	0.00329	0.01132	1400	0.379	4.199×10 ⁻⁴	29.0
		high fertility	spherical	0.03900	0.06590	300	0.088	5.185×10 ⁻³	59.1
P	Boolean	low fertility	spherical	0.17000	0.26500	1000	0.399	0.0161	64.1
		high fertility	spherical	0.05020	0.06500	1100	0.193	0.0360	77.2
	Fuzzy	low fertility	spherical	0.07278	0.15877	2222	0.634	0.0111	45.9
		high fertility	spherical	0.03100	0.04210	1000	0.189	8.418×10 ⁻³	73.6

Note. C₀: Piece variance, C₀ + C: Threshold, A₀: Effective range, R²: Coefficient of determination, RSS: Residual sum of square

Effective ranges of nitrogen and phosphorus membership function were variable and fuzzy membership function for class of without nitrogen limitation was the lowest. This range indicates the magnitude of spatial dependence. Although, inherent soil forming factors have the greatest effect on the amount of effective range, but reduction of nitrogen effective range is further under the control of management factors such as differences in the amount of fertilizer applied and land leveling program (Sun et al., 2003), in addition, the effective range was used to determine of neighborhood radii in kriging.

Fuzzy membership function of N in severe restriction class followed from the spherical model. Range of its dependence was high (1400 m) and had the medium spatial structure (29.0). Fuzzy membership function of phosphorus in both classes of severe restriction and without limitation followed from spherical model, but the extent and power dependency in the class of severe limitation were similar to the class of without limitations. Range of dependence for phosphorus in severe limitation class was high (2222 m) which indicates high range of spatial dependence and the spatial similarity of the study farm to the class of deficiency or severe restriction.

Parts of the paddy lands in of the southwest of study farm with the N fuzzy membership function between 0.2 to 0.6 had the highest values. But in other parts, there was no serious problem of nitrogen. Boolean method didn't able to detect severe limitation range in the Southwest and all of the studied paddy lands have dependence of more than 50% to the severe limitations class for nitrogen. Dobermann and Oberthür (1997) believed that nitrogen management is the key factor in control of yield throughout the study region. Representation of spatial membership distribution function of nitrogen in the class of without limitation showed that the central parts of the studied land with the fuzzy membership function of 0.6 to 1 and the Boolean membership function 0.5 to 1, had optimum status for nitrogen and had no limitation for supplying of plant nitrogen. But Boolean membership function unlike to fuzzy membership function could not separate the other parts of the land and determine the degree of their dependency to the class of without limitations (Figures 7).

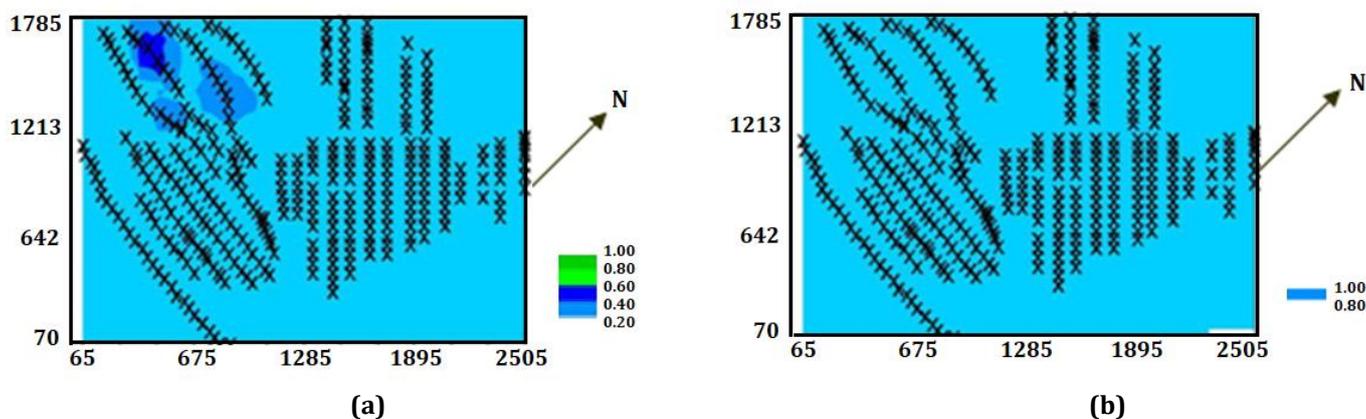


Figure 6. Map of fuzzy (a) and Map of Boolean (b) nitrogen severe limitations class

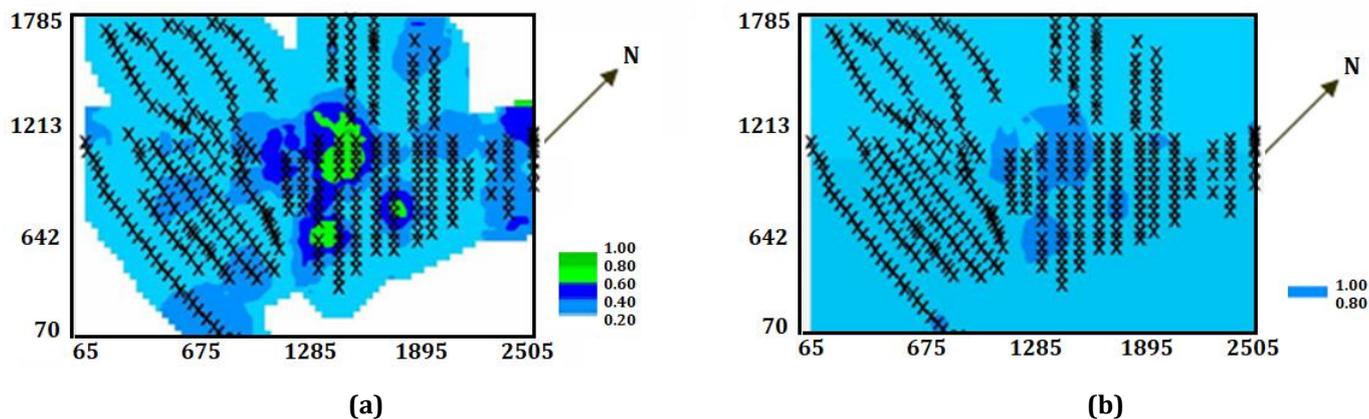


Figure 7. Map of fuzzy (a) and Map of Boolean (b) nitrogen without limitations class

North, south, south west and some parts of the centre of study field, with the fuzzy membership function of 0.6 to 0.8 and 0.8 to 1, had the most dependency to severe limitation class, and these had phosphorus shortage (Figure 8a). Spatial distribution of Boolean membership function also showed that these areas have limitations but with the lower resolution and considered the other parts of field without dependency on the class of severe limitation (Figure 8b). Only very small areas in north-central of studied paddy lands with fuzzy membership function of 0.6 to 0.8 had a dependence on middle limitation class for phosphorus (Figure 9). Except to very small area in centre and north of land with the Boolean membership function of 0.5 to 1 had minimum dependence on the class of without limitation. But the land separation ability of this function was weaker. Deficiency of P in the most of paddy-lands is partly related to the lack of phosphorus application for a long time, therefore, a suitable phosphorus fertilizer consumption is recommended for the almost all of the study area, especially to the parts belonging to class of severe restrictions and if the achievement of the yield more than 5-6 t/ha is considered the consumption of nitrogen and potassium should be considered.

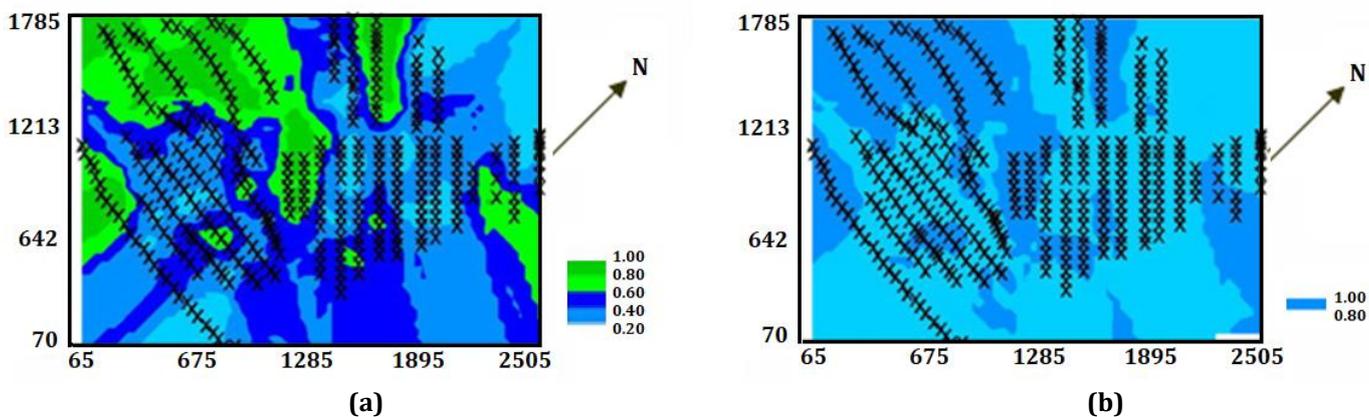


Figure 8. Map of fuzzy (a) and Map of Boolean (b) phosphorus severe limitations class

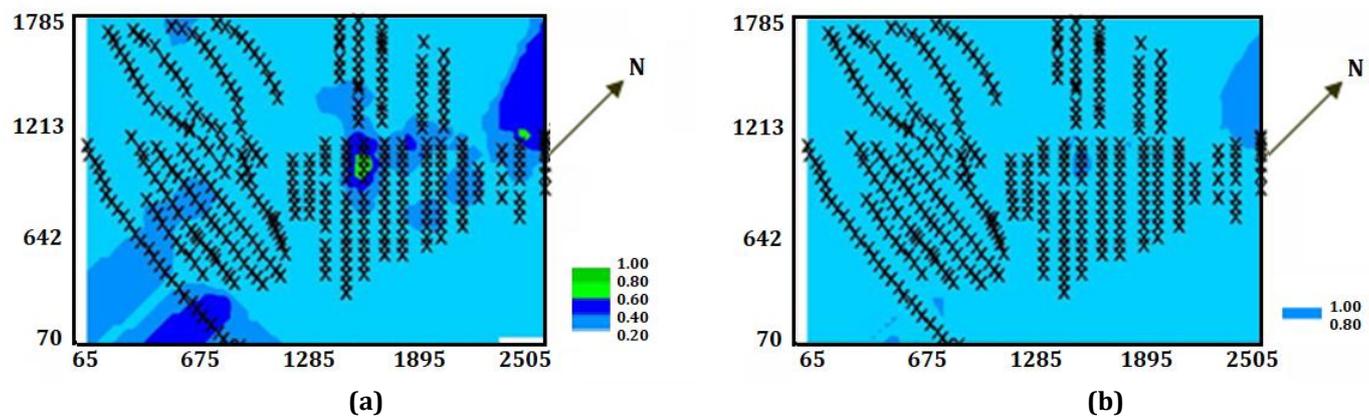


Figure 9. Map of fuzzy (a) and Map of Boolean (b) phosphorus without limitations class

Fuzzy system was better in mapping of soil fertility for plant’s nutrients and its prediction was also more accurate compare to the Boolean method. The efficiency of this method for phosphorous was superior to the nitrogen.

Conclusion

Preparation of soil fertility maps with fuzzy system improves precision and accuracy. Distinguishing of nutrient deficiencies using fuzzy logic much better than regular approaches; so that, severe nitrogen deficiency in some part of study farm was distinguished in fuzzy system, but not with Boolean method.

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