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Soil Nutrient Based Land Suitability Analysis for Lentil Crop in Tarakeswar, Hooghly, West Bengal

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ABSTRACT

Background: Land suitability assessment can inform decisions on land uses suitable for maximizing crop yield while making best use, but not impairing the ability of natural resources such as soil to support development. We assessed the suitability of lentil to be produce in 300 ha land of *Tarakeswar* block of Hooghly district West Bengal.

Methods: Suitability criteria included eight criterion, such as: soil texture (ST), electrical conductivity (EC), organic carbon (OC), available nitrogen(N), available phosphorous (P), available potassium(K) and available zinc (Zn). We modified and used a novel set of techniques to assess suitability: Analytical Hierarchy Process (AHP) pairwise comparison matrixand Geographic Information System (GIS) software.

Result: The exponential model generated by Ordinary Kriging was used to estimate the lentil land use suitability. Suitability distribution of deep layer found nearly 42% area under suitability class, *i.e.* S_{1-2} which may be used for growing the crop profitably.

Key words: AHP, GIS, Land suitability, Lentil, Soil profile.

INTRODUCTION

Pulses are indispensable sources of dietary protein and also contribute to the recycling of atmospheric nitrogen through the active participation of *Rhizobium* sp. Lentil (*Lens culinaris* M.) is one of the important *rabi* legume crop in India. Lentil is one of the oldest known food crops. The lentil is a slender, semi-erect, annual legume crop (Yadav *et al.,* 2007). It is mainly cultivated as a sole crop just after the harvesting of *Aman (Kh rif)* paddy on residual soil moisture (Ali *et al.,* 2012). Lentil is one of the most nutritious (25% protein) legume and ranks next only to chickpea in India. Lentil occupies nearly 1.8M ha area giving an annual production of 1.1 million tonnes with a productivity of 611 $kgha^{-1}$ (FAOSTAT, 2014). However, variability in weather and infestation of pest and diseases and unscientific soil nutrient management *etc*. delayed sowing of lentil leading to lower crop yield.

Sustainable utilization of soil and land resources demands a fundamental understanding of the potential and quality of the land to support different activities. Land suitability assessment can help to develop strategies for planning the development of productivity of lentil (Bagherzadeh *et al.,* 2016). Land suitability assessment informs planning decisions for future farming patterns in order to improve yield ensuring food security (Singha and Swain, 2016; McDowell *et al.*, 2018; Savalia and Gundalia, 2010). Several approaches have continuously been developed and tested to conduct land suitability assessment fulfilling specific criteria for a particular crop or land (FAO, 1979; Thilagam and Sivasamy, 2013).

Wali *et al*. (2016) determined different land suitability classes for saffron cultivation using Analytical Hierarchy Process (AHP) and Geographic Information System (GIS). The final suitability result showed for Khost Province, 1.5, 4.5, 8.6 and 85.4% areas were highly suitable, moderately suitable, marginally suitable and not suitable, respectively for growing the crop. Chowdhury (2013) used GIS based land suitability study technique for finding best suited land for growing chickpea and lentil in Bangldesh. They successfully mapped the suitable area for both the crop for all the districts of Bangladesh. The suitability assessment study for lentil crop used sixteen suitability parameters, including soil types, climatic conditions, soil moisture content, nutrient characters, topography data with fuzzy-set model with analytical hierarchy process (AHP) and Multi-Criteria Decision Making (MCDM) in GIS software environment were used to develop final suitability map for lentil crop, found nearly 61% of total area highly suitable cultivable area located for West Bengal state, India (Singh *et al*., 2017). Efficient use of soil could be described as the adoption of the suitable combination of climate and soil for selecting the crop obtaining reasonable yield while sustaining the ecology and soil fertility (Nalina *et al*., 2016; Sahu *et al*., 2015; Bhaskar *et al*., 2015).

Lentil tap root may grow to a depth of 35 cm, while the

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majority of the roots will usually be found in the top 18cm of the soil profile (Sell and Aakre, 2019).

The objective of the study is to determine the soil nutrient suitability based on soil profile for adopting lentil crop in Tarakeswar block, Hooghly district of West Bengal by integrating AHP ranking model in GIS software environment.

MATERIALS AND METHODS

Study area

Hooghly district is one of the agriculturally prosperous districts of the state of West Bengal, India. The total population is 55,20,389 (as per census 2011), with density of 1753/ sq. km. The district is a completely flat land with elevation below 200 meters. Geologically, the area comes under Quaternary formation with recent alluvium. The climate of the study area is tropical and humid. The temperature normally varies from 24-40°C during summer and from 7–26°C during winter (Fig 1).

The research was conducted in the Tarakeswar block of Hooghly District. This study region covers an area of 291 hectares and is situated at 22° 48′ 00″ N and 88° 04′ 00″ E in UTM system for zone 45 WGS-1984 datum with population of 179,148 in 2011 census. The base map of the study area is in the scale of 1:50,000 developed by Survey of India, 2011 with Sheet no. F45K1(79B/1). Nine ground control points (GCPs) were supplied using eTrex 20 GPS Receiver (Garmin Ltd., Olathe, Kansas, USA) for image digitization in Arc GIS 10.1 (ESRI, Redlands, California,USA) software environment. According to agro-climatic zoning, Tarakeswar is part of the Gangetic alluvial zone with clay loam type of soil and is very fertile (Bhowmik *et al*., 2014). Though, crop production of this region is dominated by rice and potato, lentil is the only legume crop with the best current market price in the study area. Demands for consuming legume crops are sound in order to motivate rural farmers towards this crop cultivation.

Sample data collection and preparation

Field studies were carried out to identify the reality of the physiographic farm units and soils interpretation. Soil sampling points were identified by coordinate point recorded from GPS receivers. Initial sampling was conducted by auger and investigated further if changes as outlined by Soil survey Staff (2012) warranted description of the site as a different soil layer. A total of seventy observation points for two soil layers (0- 20cm top layer; 20- 40cm deep layer) were used to check the accuracy of land use suitability status. Soil samples were collected from two soil layers, air dried, crushed, sieved through <2mm screen. These samples were analyzed using standard methods (Soil Survey Staff, 2014).

In this study, eight main parameters were selected for lentil land suitability classes after an extensive literature review (Table 1).

Selection of the effective criteria for land use suitability

Analytical hierarchy process (AHP) technique is one of the most advanced MCDM techniques used in GIS-based

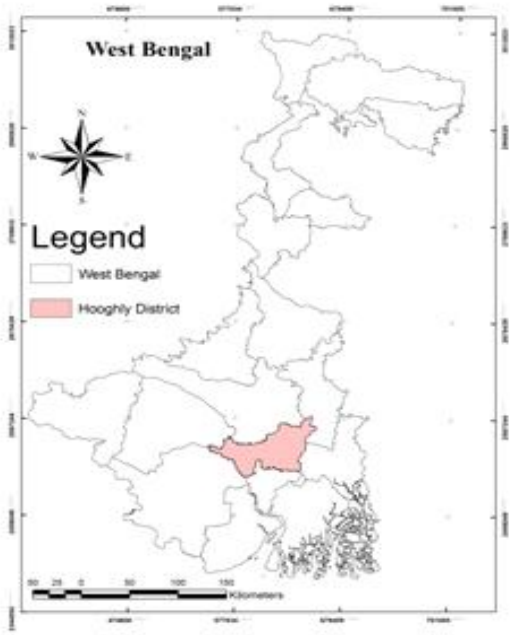


Fig 1: Location of the study area.

Table 1: Suitability range of parameters for lentil crop.

Parameters	Unit	Highly suitable (S_1)	Moderate suitable (S_2)	Marginal suitable (S_3)	Not suitable (N)
Soil pH	Reaction	6.0-7.5	7.5-8.0	8.0 – 8.5	>8.5
			5.5- 6.0	4.5- 5.5	<4.5
Organic carbon (OC)	%	>1.5	1.0-1.5	0.5-1.0	< 0.5
Electrical conductivity (EC)	(dS/m)	0-1.0	1.0-1.5	1.5-2.0	> 2.0
Available nitrogen (N)	ppm	>7.5	5.0-7.5	2.5-5.0	<2.5
Available phosphorous (P)	ppm	> 11	8-11	5-8	<5
Available potassium (K)	ppm	>5	10-15	5-10	<5
Available zinc (Zn)	ppm	>1.0	0.8-1.0	0.5-0.8	<0.5
Soil texture (ST)	Class	Loam, silty loam, sandy clay loam	Silty clay, silty clay loam,clay	Sandy loam, clay >60%	Sand

Source: Sys *et al*. (1991; 1993); NBSS and LUP (1990); FRG-BARC (2012).

suitability procedures (Din and Yunusova, 2016) because of its appropriateness for making decisions on the basis of multiple factors ranked according experts' preferences. In the current study, the pairwise comparisons of the various criteria were organized into a square matrix. The diagonal elements of the matrix were scored 1 (Table 2). Weightings were derived by expert opinion according to a questionnaire of twenty experts in the field of agronomy, soil science, general agriculture and KVK specialist *etc*. and analyzed using MATLAB 2016b software to reach final weights. In this analysis, if the consistency ratio was lower than 0.1 in node and factors matrices. This degree of consistency of the pair-wise comparison matrices is considered acceptable (Saaty and Vargas, 2013).

The consistency of the matrix of order n was evaluated. If this consistency index failed to reach a threshold level, the answers from the comparisons were re-examined. The consistency index, CI, was calculated as per Equation (1):

$$CI = \frac{(\lambda_{max} - n)}{n-1} \quad \ldots (1)$$

Where,

λ_{max} = largest or principal eigenvalue of the matrix;

n = order of the matrix.

This CI can be compared to that of a random matrix, RI, such that the ratio, CI/RI, is the consistency ratio, CR. As a general rule, a value of CR $\leq$ 0.1 should be maintained for the matrix to be consistent. In other words, the results for all RIs for the single and general hierarchies were lower than 0.1. Homogeneity of indicators within each group, a smaller number of factors in the group and better understanding of the decision problem improves the consistency index (Saaty 1993).

Interpolation analyses for suitability

In the present study, five main interpolation methods, namely Inverse Distance Weighing (IDW), Empirical Bayesian kriging (EBK), Radial Basis Function (RBF), Local Polynomial Interpolation (LPI) and ordinary kriging (OK) were employed for predicting the spatial distribution of soil nutrient suitability for lentil. Kriging is a geostatistical technique similar to IDW which employs a linear combination of weightings at known points to estimate the value at an unknown point. Bayesian kriging allows uncertainty in the model parameters to be reflected in the widths of the prediction intervals, thus providing a more reliable prediction of the parameter of interest (Diggle and Ribeiro, 2002); where local polynomial interpolation is sensitive to the neighborhood distance and a small searching neighborhood may create empty areas in the prediction surface. Kriging uses a semivariogram method to determine the spatial correlation between two points in that weighing change according to the spatial arrangement of the samples Webster and Oliver, 2001). In contrast to other estimation procedures, kriging provides a measure of the uncertainty of the estimation. The Root Mean Square Error (RMSE) method was used to compare the interpolation techniques. The lowest RMSE indicates the most accurate prediction, with estimates determined by using the following formula (2):

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} [\hat{z}(s_i) - z(s_i)]^2}{n}} \quad (2)$$

Where

$\hat{z}(s_i)$- the predicted value.

$z(s_i)$- the observed (known) value.

n - the number of values in the dataset (Webster and Oliver, 2001).

RESULTS AND DISCUSSION

Soil physico-chemical properties

Alluvial land and its soils often show spatial variations in their properties over short distances. The descriptive statistics for this study are presented in Table 3. The pH values of the soil samples ranged between 4.11 and 6.33 and electrical conductivity ranged from 0.10 dS m^{-1} to 1.73 dS m^{-1}. The soil texture class widely varied from sandy loam to clay, with clay content ranging 22% and 63% and sand between 11% and 65%. The mean values for organic matter is 0.5%. As for macronutrients, available P, K and Zn levels showed high variation. Available N varied between 10 ppm (parts per

Table 2: Fundamental scale of absolute numbers used in questionnaire.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activity contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	Experience and judgment strongly favour one activity over another
5	Strong importance	
6	Strong plus	An activity is favoured very strongly over another; its dominance demonstrated in practice
7	Very strong	Demonstrated importance
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate value	Used to represent a compromise between the priorities listed above

Source: Saaty, 1980.

Table 3: Descriptive statistical analysis of physical and chemical properties of soil samples (n=70).

Indices	pH	log pH	EC (ds/m)	Log EC (ds/m)	OC (%)	N (ppm)	P (ppm)	K (ppm)	Zn (ppm)	Sand (%)	Silt (%)	Clay (%)
Mean	4.87	1.57	0.56	-0.70	0.54	27.9	197.1	76.93	2.23	42.64	18.2	39.2
SD	0.57	0.11	0.31	0.53	0.18	8.72	60.8	29.64	0.62	13.75	5.57	9.48
Skewness	1.14	0.92	1.66	-0.40	0.01	0.96	-1.64	0.58	0.42	-0.59	0.27	0.77
Kurtosis	0.40	2.94	3.92	4.07	.36	2.23	1.07	-.06	-.25	-.42	-1.7	.30
Minimum	4.11	1.41	0.10	-2.30	0.13	10.04	35.07	25.90	1.16	11.7	10.0	22.3
Maximum	6.33	1.84	1.73	0.54	0.95	55.2	231.63	150.73	3.88	66.4	28.7	63.6
CV (%)	11.69		54.37		33.1	31.3	30.84	38.5	28.0	32.2	30.7	24.2

Note: EC-electrical conductivity; OC- organic carbon; N- Available nitrogen; P- available phosphorous; K- Available potassium; Zn- Zinc level; n- No. of sample; SD- standard deviation; *CV (coefficient of variation): <15 = low variation, 15-35 = moderate variation, >35 = high variation; **Skewness:<|-+0.5| = normal distribution, 0.5–1.0 = application of character changing for dataset and >1,0 → application of Logarithmic change.

Table 4: Cross-validation according to interpolation methods.

Soil parameters	Cross validation result of RMSE				
	IDW	EBK	RBF	LPI	OK
pH	0.355	0.322	0.359	0.343	0.340
EC(ds/m)	0.300	0.269	0.283	0.262	0.273
OC(%)	0.124	0.119	0.120	0.116	0.123
N(ppm)	10.807	9.121	10.196	9.342	10.076
P(ppm)	66.717	61.06	63.817	61.369	79.573
K(ppm)	30.802	28.036	29.086	27.750	29.358
Zn(ppm)	0.444	0.446	0.449	0.454	0.473
Sand(%)	7.577	7.623	7.640	7.930	7.806
Silt(%)	4.017	3.797	3.912	3.688	3.995
Clay(%)	5.375	5.434	5.193	5.570	5.714

Note: RMSE- root mean square error, IDW-inverse distance weighting,EBK- Empirical Bayesian kriging, LPI- local polynomial interpolation, RBF-radial basis function and OK-ordinary kriging.

million) and 55 ppm with average value of 28 ppm. In the current study, pH, content had low CV; OC, N, Zn, sand, silt and clay had moderate CVs, whereas the EC and P content had a high level of CVs.

Interpolation analysis for lentil land use suitability was used to identify the best predictive model among the five different interpolation models. The variogram or function of each interpolation method yielding the best results was determined. The exponential model generated by Ordinary Kriging was used to estimate the lentil land use suitability at unsampled locations. According to this cross validation result (Table 4) in LPI technique is more accurate for lowest RMSE showed in EC (0.262), OC (0.116), K (27.750) and Silt (3.688); IDW better resulted for least RMSE of Zn (0.444) and sand (7.577), (Table 5). Overall, output result of the analysis represented that LPI and EBK are the more accurate compared to IDW, RBF and OK giving smaller RMSE value, may be used for estimating the lentil land use suitability parameters at unsampled locations (Durdevic *et al*., 2019).

AHP weightage estimation for lentil

The assignment of the score for each soil sample comprised of three main steps. Firstly, the ranks of the parameter were decided as per the recommendations by the local experts. Secondly, AHP technique was performed to generate the evaluation scores or eigenvector. Principal eigenvalue (λ_{max}) and Consistency Index (CI) were estimated at 8.57 and 0.08, respectively. Consistency ratio (CR) was estimated and found to be 0.06 (<0.10, within the limit). So, the weightage estimated are valid and can be used further for lentil land suitability estimation. Whereas, for lentil Soil texture (0.345) was assigned highest weightage value and available nitrogen (N) (0.021) lowest weightage value (Table 5).

These results are consistent with natural and artificial factors for land use suitability and soil texture received the highest value because lentil cultivation requires soil with high water retention capacity which stems from the high clay fraction. pH content received the second weightage value due to its influence on the biological and physico-chemical properties of soils, including the development of soil acidity, aggregation and supply of nutrient elements and effects on cation exchange capacity. On the other hand, this parameter can be affected by soil and lentil cultivation practices.

Suitability analysis

As lentil crop is deep rooted, the soil suitability study for both top and deep layer are important to select the best crop for a particular field. Suitability distribution maps for individual soil parameters for the crop for both the layers were developed in GIS environment (Fig 2) based on individual suitability range. Combined suitability distribution map for lentil using the AHP weightage after validation was also developed for both the layers (Fig 3). Even during deep ploughing the deep soil layer may come up and contribute to the shallow rooted multiple crops such as rice and potato *etc* in crop rotation.

Top layer

Lentil suitability distribution map was developed for top layer using AHP weightage in GIS environment (Fig 3). The analysis revealed that around 12.4% of total crop area is in (S1)-'highly suitable' zone, 54.6% area is in (S2)-'moderately suitable' zone (Table 6). A substantial portion (30%) of the

Table 5: Contribution weight of soil parameters to lentil land suitability estimation by the AHP technique (n=8).

	ST	pH	Zn	EC	OC	P	K	N	Weightage
ST	1	2	3	5	6	7	8	8	0.345
pH	0.5	1	2	3	3	5	7	8	0.218
Zn	0.333	0.5	1	2	3	4	5	7	0.153
EC	0.2	0.333	0.5	1	2	3	5	6	0.107
OC	0.167	0.333	0.333	0.5	1	2	4	5	0.077
P	0.142	0.2	0.25	0.333	0.5	1	2	3	0.046
K	0.125	0.142	0.2	0.2	0.25	0.5	1	3	0.033
N	0.125	0.125	0.142	0.167	0.2	0.333	0.333	1	0.021

Note: CR=0.06 (<0.10), ST- soil texture, OC- organic carbon, N- available nitrogen, P- available phosphorous, K- available potassium, Zn -zinc level, n-number of parameters.

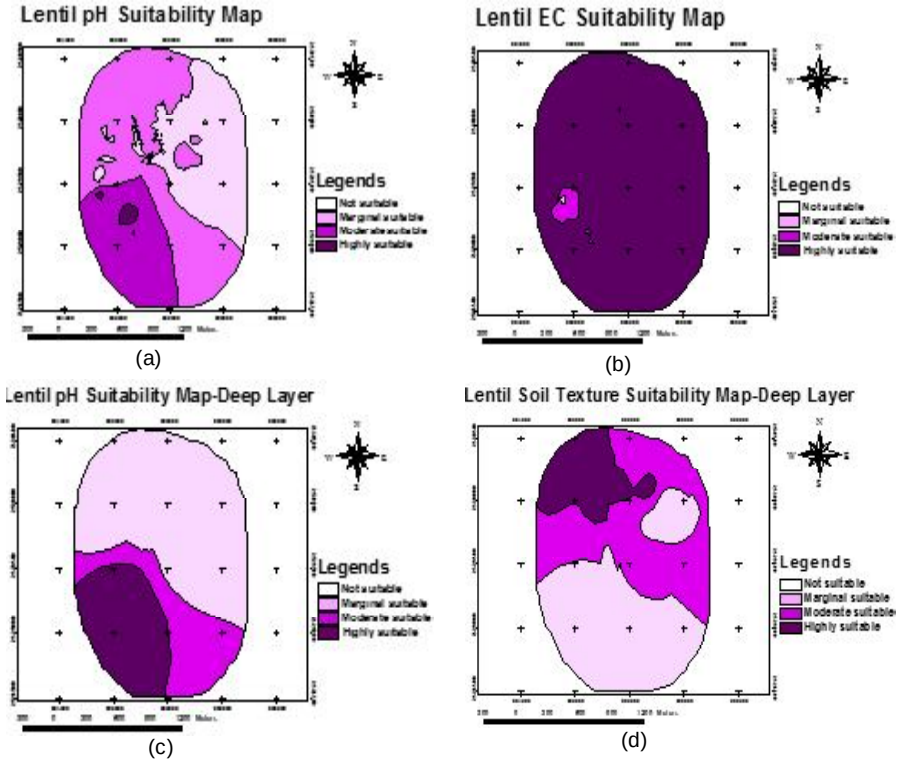


Fig 2: Sample parameters suitability distribution for lentil; a) pH suitability- top layer, b) EC suitability- top layer, c) pH suitability- deep layer, d) Soil texture- deep layer.

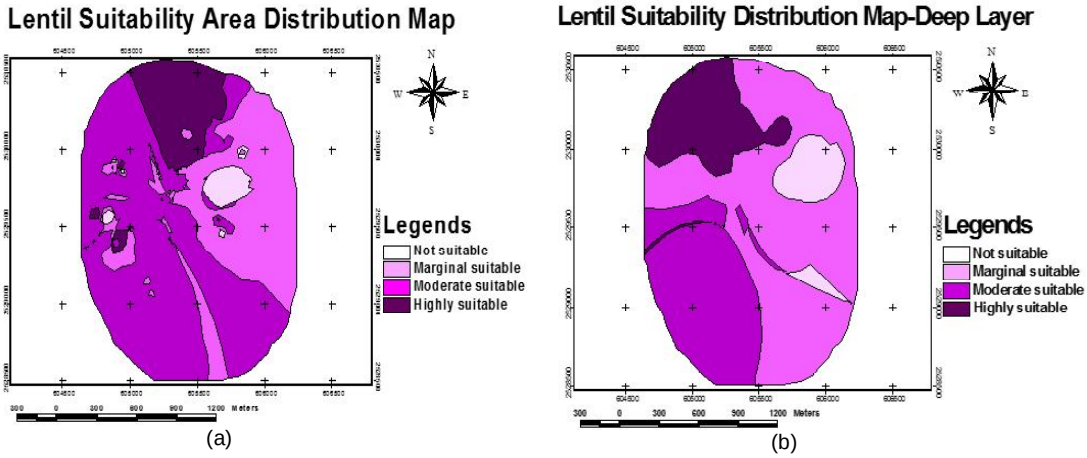


Fig 3: Land suitability distribution map for lentil crop; a) top layer b) deep layer.

Table 6: Land suitability distribution for lentil crop in different soil layers.

Class Description	S_1 Highly suitable (% of Area)	S_2 Moderate suitable (% of Area)	S_3 Marginal suitable (% of Area)	N Not suitable (% of Area)
Top layer	12.4	54.6	30.0	3.0
Deep layer	15.8	26.8	50.2	7.2

area is under 'marginal suitable' zone and lowly 3% area is under (N)-'not suitable' zone. Together, the two categories 'highly suitable' and 'moderate suitable' make up 67% of the total area, which may be dedicated for lentil crop, if potato is not profitable in those area for real market price condition as *rabi* crop.

Deep layer

Suitability map for lentil crop in the deep soil layer is also carried out using the AHP weightage in GIS environment (Fig 3). The analysis showed that 15.8%, 26.8%, 50.2% and 7.2% of lands (Table 6) are classified as S_1-S_2-S_3 and N suitability classes, respectively, for lentil crop. Area under (S_3)-'marginal suitability' is enhanced drastically showing low level of nutrient availability in the deep soil layer.

AHP is helpful in assigning the relative weights of the criteria and validating them. GIS is used to identifying study locations, geographic data manipulating and map processing and final presentation of land suitability maps.

Looking at the suitability distribution of deep layer nearly 42% area come under suitability class, *i.e*. S_{1-2} may be used for growing the crop profitably. Lentil crop may also be recommended based on higher sale value of lentil compared to other legume crops (White *et al*., 2006). The legumes crops will enhance soil fertility through nitrogen fixation, which may be introduced as alternative crop in *rabi* season. Additionally, multiple seasons may provide better results for selecting suitable land for the crop.

CONCLUSION

The land suitability analysis was carried out for an area of the 300 ha for lentil production located in the Tarakeswar block of Hooghly district, West Bengal. Across farm plots, the most important factors limiting lentil production were ST, EC, OC, N, P, K and Zn. The AHP technique showed good potential to determine criteria weights with different relative importance, based on expert opinion, while the integration of GIS with an AHP pairewise comparison matrix technique provided a realistic assessment of productivity, independent of agricultural practice (*e.g*. fertilizer applications). Soil profile based study gave a new insight towards carrying out land suitability studies for tap root crops, like lentil. Farmers throughout the study area had conflicting opinions on yield reduction in their fields, particularly during *rabi* season. The situation reinforces the need for detailed soil survey and mapping studies in areas with alluvial soils.

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