



Article Best Crop Rotation Selection with GIS-AHP Technique Using Soil Nutrient Variability

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Abstract: Crop selections and rotations are very important in optimising land and labour productivities, enhancing higher cropping intensities, producing better crop yield. A land suitability analysis system based on the analytical hierarchy process (AHP) technique coupled with the Geographic Information System (GIS) software environment can be a unique tool for better crop selection. The AHP-GIS technique was used in land suitability analysis in crop rotation decisions, for rice-jute (Kharif season) and potato-lentil (Rabi season) crops in the Hooghly District, West Bengal, India. The study area covering 291 ha was classified based on eight major soil nutrient levels with 70 randomly selected plots for soil sampling and analysis. The soil nutrient variability was examined with descriptive statistics followed by best semivariogram-based model selection for kriging interpolation in the 'R' software environment. The pairwise comparison matrix based ranking of parameters and giving weights was carried out considering the importance of each parameter for specific crops. The total area, being under the major rice-potato belt, could be classified from the suitability view point to the 'highly suitable' (S_1) class occupying 29.2%, and 'not suitable' (N)class; 4.5% for rice, about 6.5% of land is 'highly suitable' (S_1), 'and nearly 2.1% area is 'not suitable' (N) for jute; and 21.3% is 'highly suitable' (S_1) for potato and 12.4% for lentil crops. The yield maps showed nearly 75% and 90% of the area for rice and potato crops, respectively, gave sound crop yield. Furthermore, the GIS platform was used for crop rotation analysis to spread multiple seasons ensuring better crop management in long run. Overall, 25% of the rice crop area for jute in Kharif and 8% of potato crop area for lentil in the *Rabi* season were recommended as replacements.

Keywords: land suitability; rice and potato; semivariogram; kriging interpolation; pairwise comparison

1. Introduction

Achieving agricultural sustainability has been given the highest priority in both developed and developing nations. It can be attained through studying cropping system analysis (CSA), which is defined as the cropping pattern and its management to derive maximum benefits from the given resources under specific environmental conditions. West Bengal produced 16.2 million tons of rice, which is highest among the Indian states [1]. However, the growth rate of rice production in the state was 6.39% during 1980–1981 to 1990–1991, slowing down to 1.47% during 1991–1992 to 2000–2001, and more recently the growth rate turned negative at -0.25% [2]. In the other hand, the potato production was enhanced by 22% in 2016–2017 which causes low market price [3]. Additionally, the profit margin was continuously reduced with a high cost of "*Jalandhar*" based seed producing low export-quality potatoes [4]. Overall, the farmers are stressed with low profit margins from their farmland. So, there is an immediate need for a land suitability study to decide the best crop rotation for farmland in the region.

A cropping pattern is a spatial phenomenon [5,6] and refers to the sequence and arrangements of crops in an area at a particular space and time [7,8]. Crop rotation, growing one crop after another on the same piece of land at different timings (seasons) without impairing the soil fertility, should be practised. In crop rotation, the succeeding crops are of a different genus, species, subspecies or variety than previous crop for optimum utilization of resources.

Timely information about the present cropping pattern and its effects are pre-requisites to devise an ideal cropping pattern within an agroecological region. The Food and Agriculture Organization (FAO) [5] proposed land evaluation in terms of two broad classes, 'suitable' (S) and 'not suitable' (N). These two classes can further segregate into four suitability groups, such as: highly suitable, moderate suitable, marginal suitable and not suitable.

The Geographic Information System (GIS) is used as a decision support tool for the land suitability analysis for various developmental activities [9,10]. Land-use suitability mapping and analysis have been carried out with GIS for spatial planning and management [11–13]. Land-use suitability analysis is a multi-criteria evaluation, which aims at identifying the most appropriate spatial pattern for future land use [14], according to specific requirements, preferences, or predictors of some activity [15–18]. GIS is sometimes handicapped in ranking the parameters for suitability analysis.

The analytical hierarchy process (AHP) technique proposed by Saaty [19] is very suitable for ranking the individual parameter in terms of their importance and validated the rankings. AHP can be integrated with GIS applications and used for agricultural land suitability analysis [20–22]. It is one of the promising methods used for the agricultural land suitability analysis based on individual criteria through quantitative analysis [23,24]. In AHP, pairwise comparison matrix is used to rank and estimate the overall weight of individual criteria or parameter. Integration of AHP and GIS helps in developing a better decision support system by creating suitability maps [25–27] for agricultural crops. GIS-assisted land suitability analysis along with AHP was carried out for wheat and barley crop in Ethiopia [28]. The final output map showed that 83.21% (1945.17 ha) was moderately suitable and 16.79% (392.52 ha) marginally suitable for wheat crops, and, 86.14% (2013.61 ha) moderately suitable and 13.86% (324.08 ha) marginally suitable for barley crops. Similar suitability studies have been carried out using the AHP-GIS technique for, rice crop in Bangladesh [29], various vegetable crops in Java, Indonesia [30], Sorghum crop in Ethiopia [31], and for cotton in Maharashtra, India [32], etc.

In this study, we explored the major crop rotations/systems for *Kharif* (summer) and *Rabi* (winter) seasons by carrying out agricultural land-use suitability assessment for rice-jute and potato-lentil crops using AHP-GIS techniques in West Bengal, India. The soil samples data were tested for statistical validity and yields maps were also compared with respective suitability distribution maps before recommending the best crop rotation.

2. Methodology

2.1. Study Area

This study was carried out in *Tarakeswar* block, *Hooghly* district located around 70 kilometres from Kolkata, the state capital of West Bengal, India. The geographical location of the district is within $22^{\circ}39'32''$ to $23^{\circ}01'20''$ N latitude and $87^{\circ}39'32''$ to $88^{\circ}30'15''$ E longitude. The total area of *Hooghly* district is around 3149 km² (Figure 1). The underlying parent material within the study area consists primarily of quaternary alluvial deposits. Alluvial soils, formed by the *Damodar-Hooghly* river as accumulated sediments, are deposited in the region. The study area lies at an elevation of approximately 0 to 40 m (MSL). However, the area is formed by flat plains with remarkable topographical homogeneity. The climate in the region is transitional between the CWg₃ (warm temperate rainy climate monsoon type with dry winters) and AW₁ (tropical Savannah types) types, and the average minimum and maximum temperature is around 15–20 °C and 28–35 °C, respectively. The average annual rainfall of the district varies from 1200 mm to 1700 mm with the major soil type of naranyanapara silty clay loam-cultivated. The area represents an "ustic" soil moisture and "hyperthermic" soil temperature

regime. Predominance of fertile soils, land and adequate water resources are the key factors facilitating intensive agriculture in the study area [33].



Figure 1. Study area location in West Bengal, India.

The important *Kharif* crops are rice, jute, sesame etc. and *Rabi* crops are potato, mustard, pulse (lentil) and different types of vegetables. *Boro* paddy (transplanted rice) is also widely cultivated in irrigated areas. The *Kana Nadi* (*Kana* River) drainage stream of *Hooghly* River and deep tube wells etc. supply the required water for irrigation in the study area. Five revenue villages, *Aligori, Bajitpur, Basudebpur, Jothsombhu and Kolaikundu* of *Tarkeswar* block, *Hooghly* district, West Bengal, India, were selected for study. The open series map sheet no. F45K1 (79B/1) developed by Survey of India, 2011 was used for creating base map. The scale of the map was 1:50,000 in the Universal Transverse Mercator (UTM) projection system with World Geodetic System -1984 (WGS-84) datum. The study area is situated in Zone 45 of UTM system between 2528500 to 2530600 Northing and 604500 to 606500 Easting. The base map was created by digitizing the aforementioned topographical map in Arc GIS 10.1 (ESRI, Redlands, CA, USA) software environment. Around nine ground control points (GCPs) were collected using eTrex 20 Global Positioning System (GPS) Receiver (Garmin Ltd., Olathe, KS, USA) for registration of the base map. The features such as, study area boundary, road network including railway track, canal network and ponds etc. have been mapped (Figure 2). The railway track present in the study area connects *Howrah* and *Tarakeswar city*. The total study area is around 291 hectares.



Figure 2. Study area map.

2.2. Soil Sampling and Analysis

Soil samples were collected from the study area along with the GPS coordinate point of the *Rabi* season. Randomly identified 70 plots were selected for soil sample, and crop yield information collection located in the five villages. The soil samples, with a depth of 20 centimetres, were collected at the end of the *Rabi* season of India during May 2015 [34]. The soil samples were dried, cursed and passed through a 2 millimetres sieved screen. Soil chemical characteristics, such as soil texture, pH, organic carbon, available phosphorus, total nitrogen and total potassium etc., were used along with other parameters to carry out the land suitability study for rice and wheat crop in West Bengal [35]. The availability of zinc and level of electric conductivity were found to be important for rice-wheat crop rotation [36,37]. The samples under went laboratory analysis for selected parameters, such as: pH, soil texture, EC, organic Carbon, available N, P, K and Zn, following standard laboratory soil analysis procedures [38,39]. Soil texture of soil samples was determined by estimating percentage of sand, silt and clay according to the United States Department of Agriculture (USDA) system using Hydrometer technique [40] followed by textural triangle diagram. The readings of the nutrients were expressed in parts per million (PPM) scale.

2.3. Statistical Analysis

Statistical analysis shows the trend and discrepancy in the collected soil nutrient data. Descriptive statistics are important and useful to visualize what the data are showing especially if there is a lot of it. It enables us to present the data in a more meaningful way, which allows simpler interpretation of the data [41]. The descriptive statistics for this study, including minimum, maximum, means, coefficient of variation of physico-chemical properties of soil samples, were evaluated in 'R' software (Opensource software developed in University of Auckland, New Zealand) environment.

2.4. Semivariograms Analysis

The semivariogram is a statistic that assesses the average decrease in similarity between two random variables as the distance between the variables increases, leading to some applications in exploratory data analysis [42]. For stochastic studies, the semivariogram is preferred over co-variance as it does not require knowledge of the mean of the random functions for its estimation [43]. In semivariograms analysis, the choice of the number of basic models appears to be secondary, although it greatly influences the resulting interpretation of the co-regionalization variogram analysis in the

'R' software environment. When using linear co-regionalization analysis in a descriptive way, results are acceptable only if they are consistent with any prior physical knowledge or with a new physical interpretation without references to the statistical models that are used [44]. In semivariogram, range is the distance beyond which spatial dependence between soil samples ceases to exist and it can be used as indicator of the appropriate cell size for a field survey in site-specific management [45]. Thus it can be an effective criterion for the evaluation of sampling design and the mapping of soil properties. The value of the nugget varied widely for soil properties. Lower values of the nugget effect (C_0) indicate low errors in measurements. In general, a nugget/sill ratio < 25% indicates strong spatial dependency is moderate [46]. The log-transformed selected soil parameters content residuals are correlated, since the corresponding cross-variograms have fairly large sills, particularly when residuals from the same horizons are considered. These restrictions mean that the selected models do not fit the sample variograms very accurately for all cases, although the overall fits are satisfactory for the analysis.

2.5. Interpolation Analyses for Suitability

In the present study, ordinary kriging (OK) interpolation method was applied for predicting the spatial distribution of soil nutrient suitability for the crops. 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 [47]; kriging uses a semivariogram technique to determine the spatial correlation between two points in that weightings change according to the spatial arrangement of the samples. The root mean squared error (RMSE) values can be estimated using the following Equation (1):

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

where:

 $\hat{z}(s_i)$ —the predicted value, $z(s_i)$ —the observed (known) value, n—the number of values in the dataset [48].

2.6. Weightage Analysis in Analytical Hierarchy Process (AHP)

The suitability level of individual parameters for the crops were mapped in the Arc GIS software environment using suitability range of the parameter for the specific crop (i.e. rice, jute, potato and lentil; Table 1). Being a biological entity, the opinions of 10 experts, in the field of agronomy and soil science related to agriculture in general, were sorted for ranking the relative importance of crop nutrients for a particular crop. In this investigation, the evaluation criteria were selected considering the crop requirements in the local conditions. In this MCA (multi-criteria analysis), the factors were selected based on inputs from local experts and reviews of existing literature [49,50]. Such an approach produced valuable information on the relative importance of the factors under evaluation and could be a useful precedent for future studies of crop suitability. Specific efforts were made to gain agreement among the experts on final ranking of the parameters. Utilizing the ranking parameters and AHP guidelines, the pairwise comparison matrices for four crops, two in each season (Kharif and *Rabi* seasons) were estimated. Using this process to standardize the criterion maps, first a pairwise comparison matrix for each parameters and suitability classes (i.e. S₁-Highly suitable, S₂-Moderate suitable, S_3 -Marginal suitable, and N-Not suitable) were prepared. The eigenvector weightage of each parameter was calculated using the technique [51]. Random inconsistency index (RI) was also taken [19] for eight parameters (Table 2). The principal eigenvalue (λ_{max}) and consistency index $(CI = \lambda_{max}/n - 1)$ were estimated then the consistency ratio (CR = CI/RI) was calculated, to validate the weightage [52] and can be used further for land suitability estimation.

Soil Parameters	Unit	Сгор Туре	Highly Suitable (S ₁)	Moderate Suitable (S ₂)	Marginal Suitable (S ₃)	Not Suitable (N)
Soil pH	Reaction	rice jute potato lentil	6–7.5 6.5–7.5 6–7 6.0–7.5	7.5–8; 4.5–6 5.0–6.5 5.0–6.0; 7.0–7.5 7.5–8.0; 5.5–6	8-8.5; 4-4.5 4.5-5.0 4.5-5;7.5-8.0 8-8.5;4.5-5.5	>8.5; <4.0 <4.5 <4.5; >8.0 >8.5; <4.5
Available nitrogen (N)	ppm	rice jute potato lentil	>30 >45 >55 >7.5	20–30 30–45 35–55 5.0–7.5	10–20 15–30 20–35 2.5–5.0	<10 <15 <20 <2.5
Available phosphorous (P)	ppm	rice jute potato lentil	>50 >8 >11 >11	25–50 5–8 8–11 8–11	10–25 2–5 5–8 5–8	<10 <2 <5 <5
Available potassium (K)	ppm	rice jute potato lentil	>60 >30 >55 >5	45–60 20–30 35–55 10–15	30–45 10–20 15–35 5–10	<30 <10 <15 <5
Organic carbon (OC)	%	rice jute potato lentil	>1.0 >1.0 >0.7 >1.5	0.66–1.0 0.66–1.0 0.5–0.7 1.0–1.5	0.33–0.66 0.33–0.66 0.3–0.5 0.5-1.0	<0.33 <0.33 <0.3 <0.5
Electrical conductivity (EC)	(dS/m)	rice jute potato lentil	0.0-3.0 <1.0 <4 0-1.0	$3.0-4.0 \\ 1.0-2.0 \\ 4-6 \\ 1.0-1.5$	4.0-5.0 2.0-5.0 6-8 1.5-2.0	>5.0 >5.0 >8 >2.0
Available zinc (Zn)	ppm	rice jute potato lentil	>1.5 >3 >1.2 >1.0	1.0–1.5 2–3 0.8–1.2 0.8–1.0	0.5–1.0 1–2 0.4–0.8 0.5–0.8	<0.5 <1 <0.4 <0.5
		rice	Clay, silty clay, silty clay loam	Sandy clay, loam, silt loam, clay loam	Sandy clay loam, sandy loams, silt	Loamy sands, sands
Soil texture		jute	Loam, silty loam, sandy clay loam	Silty clay, silty clay loam, clay	Sandy loam, clay >60%	Sand
(ST)	Class	potato	Sandy loams, sandy clay loam	Sandy Clay, silt clay loam, silt loam, clay loam	Clay, silt	Fine sand, loamy sand
		lentil	Loam, silty loam, sandy clay loam	Silty clay, silty clay loam, clay	Sandy loam, clay >60%	Sand

Table 1. Suitability range for individual soil parameters for the crops.

Table 2.	Values of random	i inconsistency	v index (RI)) for $n = 15$.

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.56	1.59
Source: [52].															

2.7. Yield Mapping

Yield mapping was carried out to have a sound observation on distribution of crop yield in the study area. Maps were developed for both rice and potato crops grown in the *Kharif* and *Rabi* seasons, respectively. The areas giving low yield can be allot for alternative crops such as jute and lentil crops. The maps had four yield classes in line with four classes of suitability distribution maps.

3. Results and Discussion

3.1. Soil Sample Analysis

The study area is located on the deltaic plain formed as alluvial deposits carried by the *Damodar* river in *Hooghly*. Alluvial land and its soils often show spatial variations in their properties over short distances. The seventy samples were analyzed for eight parameters and verified statistically. 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 content between 11% and 65%. The mean values for organic carbon was around 0.5%. As for macronutrients, available P, K and Zn levels showed high level variation among the plots. Available N varied between 10 ppm and 55 ppm with average value of 28 ppm. Mulla and McBratney [59] reported that when the coefficient of variation (CV) is lower than 15%, variability is classified as low; while 15% to 35%, classified as moderate; and above 35%, classified as high. 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 (Table 3). The N, P and K have numerical high maximum values in terms of ppm.

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

	pН	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	0.36	2.23	1.07	-0.06	-0.25	-0.42	-1.7	0.30
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	231.6	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. in samples; 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 $>1, 0 \rightarrow$ application of logarithmic change.

For better interpolation with the kriging technique, it is required to select the best semivariogram models from five models, such as: spherical, exponential, linear, Gaussian and rational quadratic [60]. Exponential models were fitted to the experimental semivariograms for the pH, EC, OC, K, Zn, Sand, Silt and Clay, whereas N and P values best suited to the Gaussian model (Figure 3, Table 4). The Gaussian model is generally used for large range of data (i.e. Phosphorous ranges from 35 to 230 ppm) for interpolation operation [61]. Comparing range values, highest value was observed for EC (1088.9 m) and lowest for P (53.589 m). Nuggets were highest for available potassium (K) and lowest for soil organic carbon (OC).



Figure 3. System comparison of variograms and cross-variograms for soil pH, EC, OC, N, P, K, Zn, sand, silt and clay in the study area.

n (Co	6	6 6		DSD	6 D	Estimated Error				
Parameters	Model	0	C_1	$C_0 + C_1$	\mathbf{A}_{0}	(%)	SD	MSE	ASE	RMSE	RMSSE	
Log pH	Exponential	0.064	0.086	0.149	459	42.54	М	-0.01	0.32	0.34	1.05	
LogEC(ds/m)	Exponential	0.043	0.065	0.107	1088.9	39.68	Μ	-0.001	0.24	0.27	1.12	
OC (%)	Exponential	0.006	0.018	0.024	542.4	24.99	S	-0.005	0.11	0.12	1.09	
N (ppm)	Gaussian	66.147	16.636	82.783	804.0	79.90	W	-0.002	9.08	10.07	1.10	
P (ppm)	Gaussian	4.939	4939.8	4944.73	53.58	0.099	S	-0.10	106.9	79.57	0.92	
K (ppm)	Exponential	442.1	770.1	1212.33	578.5	36.47	Μ	-0.05	30.79	29.35	1.02	
Zn (ppm)	Exponential	0.118	0.396	0.514	734.5	22.98	S	0.04	0.48	0.47	0.98	
Sand (%)	Exponential	20.79	170.7	191.553	846.6	10.85	S	-0.01	7.65	7.80	1.02	
Silt (%)	Exponential	7.405	24.83	32.238	633.2	22.97	S	-0.003	4.23	3.99	0.98	
Clay (%)	Exponential	16.53	72.87	89.413	931.4	18.49	S	-0.02	6.07	5.71	1.08	

Table 4. Summary of semivariogram parameters of best-fitted theoretical model to predict spatial variability of soil nutrient parameters and cross-validation statistics (n = 70).

Note: $C_0 = nugget effect; C_1 = partial sill; C_0 + C_1 = sill; A_0 = Range (m); degree of spatial dependence (DSD) = <math>C_0/(C_0 + C_1)$ DSD; S = strong DSD (<25%); M=moderate DSD (>25 to <75%); W = weak DSD (>75%). SD: Spatial dependence; ASE: Average standard error; RMS: Root mean squared error; MSE: Mean standard error; RMSSE: Root-mean-square standardized error.

According to this classification, OC, P, Zn, sand, silt and clay showed a strong spatial dependence; pH, EC and K exhibited moderate spatial dependence, and only N showed weak degree spatial dependence of (Table 4). Cross-validation was used to estimate the best models to give the most accurate predictions of the unknown values in the study area. It was shown that the error terms ME (mean error) and MSE (mean standard error) were close to zero for EC, OC, N and silt. However, soil texture type was used instead of sand, silt or clay % values for interpolation analysis.

3.2. AHP Weightage Estimation

Some studies [62] have utilized the effect of individual parameters on crop yield, to define their importance on crop production. However, the impact of a single parameter on the crop yield is minimal and the regression curves are very insignificant. Hence, the technique of ranking parameters with regression co-efficient was not followed [63]. Ranking was carried out based on the opinion of experts from relevant specializations.

3.3. Kharif Crop Suitability Analysis

Rice and jute are the major crops during *Kharif* season in the study area. The pairwise comparison matrix table gave highest weightage value to soil texture (ST) and lowest weightage value of available zinc (Zn) for the rice crop (Table 5), where as for jute, pH was given highest weightage value and available potassium (K) was given lowest weightage value (Table 6).

Table 5. Pair wise comparison matrix and eigenvector of criteria in analytical hierarchy process (AHP) for rice crop (n = 8).

	ST	pН	EC	OC	Ν	Р	К	Zn	Weightage
ST	1	2	3	3	5	7	7	9	0.311
pН	0.5	1	2	2	5	7	7	8	0.227
EC	0.333	0.5	1	2	4	6	6	7	0.171
OC	0.333	0.5	0.5	1	3	4	4	6	0.122
Ν	0.2	0.2	0.25	0.333	1	3	3	5	0.07
Р	0.142	0.142	0.167	0.25	0.333	1	2	4	0.043
Κ	0.142	0.142	0.167	0.25	0.333	0.5	1	4	0.037
Zn	0.111	0.125	0.142	0.167	0.2	0.25	0.25	1	0.019

Note: consistency index $(\lambda_{max}) = 8.75$, Random inconsistency index (RI) = 1.41, consistency index (CI) = 0.11; consistency ratio (CR) = 0.08 (<0.10). ST—soil texture, OC—organic carbon, N—available nitrogen, P—available phosphorous, K—available potassium, Zn—zinc level, n—no. of parameters.

3.3.1. Rice

Rice is a major staple food for the rural population in West Bengal, India. It is mainly cultivated by small farmers with farm holdings of less than 1 hectare during the *Kharif* season. The rice suitability map of the study area (Figure 4) showed that nearly 29.2% of the area is 'highly suitable' (S_1), 51.2% area is 'marginal suitable' (S_3) and nearly 13% of area is 'not suitable' (N), (Figure 4). Nearly, 85.5% of the farms also found sound for suitable rice, as the study area is a major rice-growing zone in the region.

The unsuitable area, where soils have some rice growth limitations, such as the presence of acidic soil (pH value < 5.5). The soil may be treated with lime or different soil strengthening material for growing rice profitably. However, these areas may be allotted alternative crops. For better assessment of rice yield, various advanced techniques may be used, such as, aerial photography, image processing [64], low altitude remote sensing [65] and satellite-based remote sensing etc.

	pН	ST	Ν	Zn	OC	EC	Р	K	Weightage
pН	1	2	3	4	5	5	6	7	0.317
ST	0.5	1	2	3	4	4	5	6	0.218
Ν	0.333	0.5	1	2	4	4	5	5	0.165
Zn	0.25	0.333	0.5	1	2	2	4	5	0.105
OC	0.2	0.25	0.25	0.5	1	1	3	5	0.072
EC	0.2	0.25	0.25	0.5	1	1	2	3	0.06
Р	0.167	0.2	0.2	0.25	0.333	0.5	1	2	0.037
Κ	0.142	0.167	0.2	0.2	0.2	0.333	0.5	1	0.026

Table 6. Pair wise comparison matrix and eigenvector of criteria in AHP for jute crop (n = 8).

Note: $\lambda_{max} = 8.53$, RI = 1.41, CI = 0.08; CR = 0.05 (<0.10). ST—soil texture, OC—organic carbon, N—available nitrogen, P—available phosphorous, K—available potassium, Zn—zinc level, n—no. of parameters.

3.3.2. Jute

Jute is an important major deep rooted cash crop grown under irrigated conditions in the study area. About 6.5% and 56% of total farm areas are classified as 'highly suitable' (S₁), and 'moderate suitable' (S₂) groups, respectively. Nearly 2.1% of the area is found under 'not suitable' (N) class for jute crop. So, nearly 62% of the land area was classified under suitable range (Figure 4) may replace rice area giving low yield. The major limitations for crop growth reported for these soils were low organic matter and nitrogen content and acidic pH.

3.4. Rabi Crop Suitability Analysis

Potato and lentil are the major crops during *Rabi* season in the study area. The pairwise comparison matrix table gave highest weightage value of available potassium (K) and lowest weightage value of available zinc (Zn) for potato crops (Table 7), whereas for lentils, soil texture (ST) was given highest weightage value and available nitrogen (N) was given lowest weightage values (Table 8).

	К	ST	Ν	pН	OC	EC	Р	Zn	Weightage
K	1	2	3	4	5	6	7	8	0.326
ST	0.5	1	2	3	4	4	6	6	0.217
Ν	0.333	0.5	1	2	3	3	5	6	0.15
pН	0.25	0.333	0.5	1	3	3	5	5	0.119
ŌĊ	0.2	0.25	0.333	0.333	1	2	4	4	0.075
EC	0.167	0.25	0.333	0.333	0.5	1	3	3	0.056
Р	0.142	0.167	0.2	0.2	0.25	0.333	1	2	0.032
Zn	0.125	0.167	0.167	0.2	0.25	0.333	0.5	1	0.025

Table 7. Pair wise comparison matrix and eigenvector of criteria in AHP for potato crop (n = 8).

Note: $\lambda_{max} = 8.60$, RI = 1.41, CI = 0.09; CR = 0.06 (<0.10). ST—soil texture, OC—organic carbon, N—available nitrogen, P—available phosphorous, K—available potassium, Zn—zinc level, n—no. of parameters.



(a)

(b)

Figure 4. Kharif crops suitability distribution maps; (a) rice, (b) jute.

	ST	pН	Zn	EC	OC	Р	K	Ν	Weightage
ST	1	2	3	5	6	7	8	8	0.345
pН	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
Р	0.142	0.2	0.25	0.333	0.5	1	2	3	0.046
Κ	0.125	0.142	0.2	0.2	0.25	0.5	1	3	0.033
Ν	0.125	0.125	0.142	0.167	0.2	0.333	0.333	1	0.021

Note: $\lambda_{max} = 8.53$, RI = 1.41, CI = 0.08; CR = 0.05 (<0.10). ST—soil texture, OC—organic carbon, N—available nitrogen, P—available phosphorous, K—available potassium, Zn—zinc level, n—no. of parameters.

3.4.1. Potato

During the field visit, potato was found to be one of the dominant crops in the study area during the *Rabi* season. Under irrigation conditions, potato gives sound yield in the study area. The land suitability study divided the farms into four classes (Figure 5). Nearly 21.3% area is under the 'highly suitable' (S₁) class and 67.3% under the 'moderately suitable' class (S₂), (Table 9). The first two suitable classes occupy a total area of 88.6% (256 ha), which proves the dominance of the crop in the study area. High EC, low pH and organic carbon are the major limitations of this area, which can be improved by adopting specific management practices.

3.4.2. Lentil

Lentil is an important pulse crop grown in the *Rabi season* in West Bengal. Lentil suitability distribution map (Figure 5) revealed that 12.4% of the total area is 'highly suitable' (S_1), for the crop, whereas 54.6% was 'moderately suitable' (S_2), (Table 9). Nearly 30% area was under 'marginal suitable' (S_3) class and 3% were under 'not suitable' (N) class. Together, the two categories 'highly suitable' and 'moderately suitable' make up 67% of the total area. The analysis also depicted that physical and environmental conditions of the study area were mostly suited to potato cultivation.



Figure 5. Rabi season crops suitability distribution maps; (a) potato, (b) lentil.

3.5. Crop Yield Mapping and Validation

Yield distribution map for currently grown crops, such as rice and potato, were developed with the yield information collected for each plot during the soil sample collection. In terms of crop yield, nearly 75% and 90% area found sound for growing rice and potato crops, respectively, in the study area (Figure 6). It may be one of the major reasons of farmers' inclination towards rice-potato crop rotation system in the region. These maps were compared with the suitability distribution map of the corresponding crops.



Figure 6. Yield distribution map of study area; (a) rice crop, (b) potato crop.

Comparing the rice yield map with rice suitability distribution map, showed the area under the highly suitable class (Figure 4a) produced highest crop yield (Figure 6a) in the range of 5 ton/ha or higher. Additionally, some areas under marginal suitable class give moderate crop yield along with the area distributed under the moderately suitable class. For potato crops, majority of the study area was classified as moderate suitable, which gave moderate crop yield in a range of 15 to 20 ton/ha. These yield maps validated the suitability distribution map developed based on various soil nutrient parameters using the AHP-GIS technique.

3.6. Crop Rotations

The pattern of crops or sequence in which the crops are cultivated on a piece of land over a fixed period of a year defines a cropping pattern. Analysis by AHP-GIS techniques reflected that rice and jute are two major crops in the *Kharif* season and rice is currently preferred throughout the study area. Similarly, potato and lentil are the two major crops during the *Rabi* season and potato is mostly concentrated throughout the study area as well as the region. Crop rotation, the sequential planting of crops, indicates that the *Tarakeswar* block has the major crop rotations of rice/jute and potato/lentil (Table 9). Consequently, the results obtained from the study indicated that the use of AHP in the GIS software environment could provide a superior database and guide map for decision makers for precision agriculture adoption through crop rotation.

Table 9. Land suitability distribution for *Kharif* and *Rabi* season crops.

Class	Description	Kharif (%	6 of Area)	Rabi (% of Area)		
	Description	Rice	Jute	Potato	Lentil	
S ₁	Highly suitable	29.2	6.5	21.3	12.4	
S_2	Moderate suitable	15.1	56.0	67.3	54.6	
S_3	Marginal suitable	51.2	35.4	11.3	30.0	
N	Not suitable	4.5	2.1	0.1	3.0	

3.7. Crop Recommendation

Using the 'Map Query' tool in Arc GIS 10.1, analysis was carried out to find the suitable crop for areas classified as 'unsuitable' for rice crops. Using the application, jute crop was recommended for the area, earn-marked as 'unsuitable' for rice crop but classified as 'suitable' for jute crop (Figure 7). Nearly 25% of the area classified as unsuitable for rice crop can be grown jute with great success (Table 10). Therefore, for the *Kharif* season crop rotational practice, we recommended the rice area (25% or around 74 ha) be allotted to jute crop as an alternative providing better economic benefit.



Figure 7. Crop recommendation based on suitable area distribution analysis; (**a**) jute in rice area, (**b**) lentil in potato area.

Sl. No.	Description	Area (ha)	(% of Area)	Current Crop	Recommended Crop
			Kharif crop		
Ι	Highly suitable	217	75	Rice	Rice
II	Not suitable	74	25	Rice	Jute
			Rabi crop		
III	Highly suitable	267	92	Potato	Potato
IV	Not suitable	24	8	Potato	Lentil

Table 10. Crop recommendation based on suitability analysis.

Similarly, the area unsuitable for potato crop but classified as suitable for lentil crop were recommended for growing lentil in *Rabi* season (Figure 7). The amount of area recommended for the potato crop and for lentil crop was 92% and 8%, respectively (Table 7). So, in the *Rabi* season, the lentil crop was suggested as an alternative for growing with better crop yield and profit margin in 8% of the area found unsuitable for the potato crop.

Therefore, it can be strongly recommended that the crop land suitability classes must be considered for allocation land to new alternative crops, using GIS-AHP techniques.

4. Discussion

The study area is the leading producer of potato as well as rice being located in the fertile *Hooghly* river basin of West Bengal. The majority of the farms in the study area are following rice-potato crop rotation for a long time. However, due to low crop yield (rice crop) and reduced profit margin (potato crop) for the farmers, land suitability evaluation for the best crop rotation is required for the study area and its surrounding region. Low price of potato during harvesting time along with unavailability of cold storage has drastically reduced the return to the farmers. Also, traditional rice varieties with the age-old cropping system have substantially reduced the crop yield and profit.

Land suitability evaluation is a powerful tool to support decision-making in land-use planning; it deals with the assessment of the response of land when used for specified purposes. The AHP-GIS technique has been used to find the best suited crop for a piece of land. As farmers are growing nearly 2–3 crops per year, it is required to select the best crop combination using this technique. Two set of crops (rice-jute for *Kharif* and potato-lentil crop for *Rabi*) were evaluated for suitability in 70 farm plots in *Hooghly*, West Bengal, India. Descriptive statistical models gave preliminary but vital information on data values, their variation and presence of outliers. Overall, the availability of organic carbon in the range of 0.5% is low for growing crops. A semivariogram model depicts the spatial autocorrelation of the data values by range, sill and nuggets of a fitted model. Among the semivariogram models, exponential models were fitted well for the pH, EC, OC, K, Zn, sand, silt and clay and Gaussian models for N and P parameters for the study area. Cross-validation was used to estimate and select best suited semivariogram models to give the most accurate predictions of the unknown values through kriging interpolation in the study area.

The yield map showed nearly 75% of rice and 95% of potato growing areas gave good crop yield. This may be the reason why farmers are still following rice-potato crop rotation. Land suitability evaluation was carried out using the AHP-based weighting for the nutrients for the crops such as rice, jute, potato and lentil. The area classified as suitable (under highly suitable and moderately suitable) class with AHP (Figures 4 and 5), gave sound yield (Figure 6) for both rice and potato crops in the study area. This validated the suitability of the AHP-GIS technique for land suitability analysis. The suitability distribution map showed jute was suitable for 62% (180 ha) and lentil for 67% (195 ha) of the study area. Therefore, we have alternative crops for (both *Kharif* and *Rabi* seasons) to replace the traditional crops.

Although the majority of the area found suitable for rice-potato crop rotation pattern, the areas which are unsuitable for rice may be dedicated for jute crop (*Kharif* season) and potato area for lentil

crop (*Rabi* season) as an alternative in the region. The area recommended for jute and lentil were selected using the "Map Query" application in the Arc GIS software environment. Similar study by Mustafa et al. [66] carried out for various *Kharif* crops in Agra, U.P., India, to map suitable areas for crops such as cotton, rice, maize and sorghum etc. and *Rabi* crops such as mustard, wheat etc. However, the best crop rotation was not suggested. Marraccini et al. [67] used the land suitability technique to introduce new crops in northern France ensuring better profit to the farmers. A similar strategy can be used to allocate new crops in areas unsuitable for currently raised crops or varieties.

On the basis of the above discussions and findings, the study explored a simple but effective way to use AHP-GIS for land suitability crop mapping and major crop rotation identification by analyzing the crop dynamics in a spatial and quantitative way.

5. Conclusions

The present study introduces a method for analyzing the cropping systems for main crops and alternative crops. Two season crop rotational maps were derived using a GIS overlay technique with an AHP decision support system. The land suitability evaluation based on various soil nutrients, derived from the GIS overlay technique with AHP, computed that only 29.2% of the study area is 'highly suitable' for rice, and 67.3% area is 'moderate suitable' for potato. Additionally, 62% and 67% area is found suitable for jute and lentil, respectively. The yield maps showed nearly 75% and 90% of the area for rice and potato crops, respectively, gave sound crop yields. The 'moderate' to 'marginal' suitability class of (S_2 – S_3) was mostly found all over the plain, for irrigated rice, potato, jute and lentil cultivation.

GIS-AHP based land suitability can be extended to select alternative crops. The study recommended 25% unsuitable rice area for jute crops in *Kharif* and 8% unsuitable potato area for lentils as *Rabi* crop cultivation.

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