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Assessment of Physical Suitability of Soils for Vegetable Production in the Libga Irrigation Scheme, Northern Region, Ghana Using the Analytic Hierarchy Process and Weighted Overlay Analysis

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ABSTRACT

Assessing the suitability of soils for agricultural production is critical in promoting sustainable agriculture. Knowledge gained from soil suitability analysis provides the sound basis for making informed decisions about soil management and crop selection in a given area. In view of this, this study was carried out to assess the physical suitability of soils in the Libga Irrigation Scheme for the sustainable cultivation of jute mallow (*Corchorus olitorius*), tomato (*Solanum lycoperscum L.*) and cabbage (*Brassica oleracea var capitata*). Soil samples were collected at 0–30 cm and 30–60 cm depths from 50 geo-referenced points located at the nodes of a 100 m × 100 m regular grid. Particle size distribution, bulk density, total porosity, field capacity, permanent wilting point, available water capacity, saturated hydraulic conductivity, electrical conductivity and pH were determined following standard laboratory protocols at the AGSSIP Laboratory of the University for Development Studies, Nyankpala campus, Ghana. Weighting of soil properties was achieved through the analytic hierarchy process (AHP). Soil suitability maps for the selected crops were produced using weighted overlay analysis in ArcGIS (10.5). The results showed that generally about 44.3 ha (76.4 %), 44.7 ha (82.2 %) and 55.7 ha (96.0 %) of the irrigation field are moderately suitable for jute mallow, tomato and cabbage production respectively. The major limiting factors for the crops were high bulk density and acidity levels. The AHP proved to be a very useful tool for the incorporation of farmers' views into decision making about the suitability of soils for crop production.

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Introduction

Soil suitability analysis is an important strategy for promoting sustainable agriculture. It involves matching crops to soil conditions to which they are best suited (Kihoro et al., 2013). In effect, the suitability of crops to soils depends largely on a number of factors including the soil physical, chemical, hydraulic and biological properties and socioeconomic factors such as prices, markets, tastes, traditions and culture (Fadlalla and Elsheikh, 2016).

Over the years, most studies have assessed mainly the physical suitability of the land and soils for different purposes. This according to Fadlalla and Elsheikh (2016) is due to the fact that the physical attributes of the land and terrain are relatively more stable and can help farmers make and take informed decisions about the use of their lands. Physical suitability is assessed first by determining the spatial distribution of attributes through various methods including geostatistics, the ranking or rating of the soil attributes according to crop preferences using multi-criteria decision-making approaches including the analytic hierarchy process (AHP) and the production of suitability maps through various methods including weighted overlay analysis (ESRI, 2016).

The AHP, introduced by Saaty (1980), is one of the most common techniques used in multi-criteria evaluation (Quinta-Nova and Natalia, 2018). It involves the selection of the best alternative from a number of alternatives with respect to several criteria (Triantaphyllou and Mann, 1995). According to Hossain et. al. (2007), the AHP is an efficient method of addressing complex decision making issues. It is regarded as a superior weighting method due to its capacity to deal with inconsistency in the judgments and responses of respondents (Kumar et al., 2018).

Weighted overlay analysis is a technique usually implemented in a geographic information system to select suitable sites for a given use. According to Papadopoulou and Hatzichristos (2019) it requires the analysis of many different factors in raster layers with varying value scales and relative importance. The main task in overlay analysis is to assign a common scale to different and dissimilar inputs (ESRI, 2016). Three main approaches have been widely used to accomplish this task; weighted overlay, fuzzy overlay and weighted sum. Weighted overlay involves the combination of several raster layers using a common measurement scale and weighting each according to its importance (ESRI, 2016).

Over the years, several studies have assessed the suitability of soils in different land-use systems using different methods. Okiror et al. (2017) assessed the suitability of Kabangolo soils for fruit and vegetable production by comparing the levels of soil properties in the fields to crop requirements. Gyekye et al. (2020) assessed the soil and land suitability for sustainable rice production in the northern zone of Ghana using the traditional land capability rating developed by the FAO. A major limitation of these methods however has been the lack of mechanism to check the consistency of the decisions made in the ranking and rating of alternatives (Singha and Swain, 2018).

In recent years, the application of Multi-criteria decision making analysis (MCDA) using the analytic hierarchy process (AHP) and geographic information system (GIS) has increasingly been adopted in soil and land suitability analysis. Kihoro et al. (2013) used the MCE and GIS approach to assess the soil suitability of rice growing sites in the great Mwea region, Kenya. Singha and Swain (2018) used the AHP for a soil profile-based land suitability study for jute and lentil in India. Kumar et al. (2018) also evaluated soil suitability for cotton using the AHP in India. Owusu et al. (2017) applied MCDA to assess land suitability for aquifer storage and recharge in northern Ghana. Also, Nketia et al. (2018) evaluated the suitability of some soils in the Forest-Savannah Transition and Guinea Savannah Zones of Ghana for Maize production using the MCDA.

Currently, jute mallow (*Corchrus olitorius*) and roselle (*Hibiscus sabdariffa*) are the two most widely grown vegetables in the irrigation scheme (Adongo, 2015). According to Adongo (2015), the irrigation scheme produces about 3.8 t/ha - 4.2 t/ha of jute mallow and 45 t/ha – 60 t/ha of roselle per season. With the current growth in population and changes in the soil conditions of the field, there will the need to increase and diversify production to meet demand and tastes of people. Also, since intensive cultivation is noted to cause degradation of the soil, sustainability will be an issue to look at. This study was therefore conducted to assess the suitability of soils in the Libga irrigation scheme for the production of jute mallow, tomato and cabbage.

Methodology

Study Area

The study was conducted in the Libga Irrigation Scheme covering an area of about 56 hectares. The irrigation scheme is located between latitudes 9° 35' 48" and 9° 36' 12" and longitudes 0° 51' 07" and 0° 51' 25" (Figure 1). The climate of the area is characterized by a unimodal rainfall pattern with mean annual rainfall and temperatures of 1099 mm and 28.2°C respectively. The main crops grown in the irrigation scheme include rice (*Oryza sativa*), roselle (*Hibiscus sabdariffa*), jute mallow (*Corchorus olitorius*) and pepper (*Capsicum annuum*).

The topography is generally flat and the elevation is about 166 m above sea level. The geology of the area is defined by the paleozoic consolidated sedimentary rocks developed mainly from sandstone, shale and mudstone (Mensah et al., 2014). The major soil groups in this area are stagnic plinthosol and planosols. These are moderately deep and consist of imperfectly drained, pale brown/yellowish-brown, porous and very fine sandy loam or silty-clay loam topsoil, usually less than 30 cm thick, overlying hard ironpan. The layer may overlie a brown, silty clay with strong brown to reddish-yellow mottles up to a depth of 45 cm to 60 cm. Subsurface colours may vary from light yellowish-brown to light grey (Gyekye et al., 2020).

Soil Sampling and Analysis

Soil samples were collected at 0–30 cm and 30–60 cm sampling depths from 50 georeferenced points located at the nodes of a 100 m × 100 m regular grid laid over the study area (Figure 2). The coordinates of the sampling points were recorded using a handheld global positioning system (Garmin).

Soil samples were analyzed at the AGGSIP Laboratory of the University for Development Studies, Nyankpala campus, Ghana following standard laboratory protocols. Disturbed soil samples were air-dried and passed through a 2 mm sieve before analyzing for particle size distribution (PSD), soil pH and electrical conductivity (EC). Undisturbed soil samples were first saturated for 72 hours in plastic basins before the analyzing for bulk density (BD), total porosity (TP), saturated hydraulic conductivity (Ksat), soil moisture retention at field capacity (FC), soil water retention at permanent wilting point (PWP) and available water capacity (AWC).

Particle size distribution was determined using the Bouyoucos hydrometer method as described by Carter and Gregorich (2008). Bulk density was determined using the core method (Carter and Gregorich, 2008). Total porosity was calculated using (1 – bulk density/particle density) as described by Ali (2010). Saturated hydraulic conductivity was determined using the falling-head method (Carter and Gregorich, 2008). Soil moisture retention at field capacity and permanent wilting point was determined using the pressure plate apparatus (Eijkelkamp). pH in water was measured in a 1:2.5 soil-water suspension using Crison pH meter as described by Carter and Gregorich (2008). Soil electrical conductivity was also measured in a soil-water suspension (ratio of 1:2.5) using a Crison conductivity meter as described by Jackson (1962).

Geostatistical Analysis

Geostatistical analysis was performed using the geostatistical analyst tool in ArcMap® (ArcGIS 10.5). Semivariance was calculated using Equation 1 (Usowicz and Usowicz, 2004).

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=0}^{N(h)} [z(x_i + h) - z(x_i)]^2 \qquad (1)$$

Where;

γ (h) = the estimated semivariance at lag h (distance between observations), $z(x_i)$ = the value of the random variable Z at x = x_i, $z(x_i + h)$ = the value of Z at a distance h from x_i and N(h) = the number of pairs of points that are a distance h apart. Ordinary kriging was employed in the interpolation and mapping of soil properties (Equation 2).

$$Z(x_0)=\sum_{i=1}^{n} \lambda_i Z(x_i) \qquad (2)$$

Where;

Z (x_i) is the measured value at a location (i th), λ_i is the unknown weight for the measured value at the location (i th) and x_o is the estimation location. The unknown weight (λ_i) depends on the distance to the location of the prediction and the spatial relationship among measured variables (Webster and Oliver, 2007).

Weighting of Soil Attributes Using the AHP

Soil attributes were weighted according to crop preferences using the AHP as described by Kumar et al. (2018). This involved four steps. First, the criteria were defined. Then, pair-wise comparisons of the factors were conducted and a comparison matrix with weights, ranked Eigen values, and consistency measures obtained. In the following step, the paired comparisons for the alternatives under each factor were used to calculate scores and consistency measures. Finally, products of weights of the factors were added to the scores of alternatives to synthesize the ranks of alternatives. The flow chart of the suitability analysis methodology is given in Figure 3.

Pairwise Comparison

Weighting of the criteria for evaluating the suitability of soils/lands for a given objective is done by determining the degree of influence (priority vector) of each criterion using a pairwise comparison matrix (Equation 3) (Triantaphyllou and Mann, 1995).

$$A = \begin{bmatrix} 1 & a & b \\ 1/a & 1 & c \\ 1/b & 1/c & 1 \end{bmatrix} \qquad (3)$$

The priority vectors are determined by taking the ratio of the value or weight of each element in the same row to the sum of values of the elements in a corresponding column. This is done in order to normalise the weights. Then the average of the normalized weights in the same row is taken to obtain the normalized principal Eigen vectors of each criterion in the row (Triantaphyllou and Mann, 1995). The normalized principal Eigen vectors are used to determine the percentage of influence of each criterion in achieving the given objective (Kumar et al., 2018; Herzberg et al., 2019).

A very important step in pairwise comparisons is to check the consistency of the responses in the matrix. This is done by calculating the consistency index and consistency ratio given by equations 4 and 6 respectively (Siddayao et al., 2014).

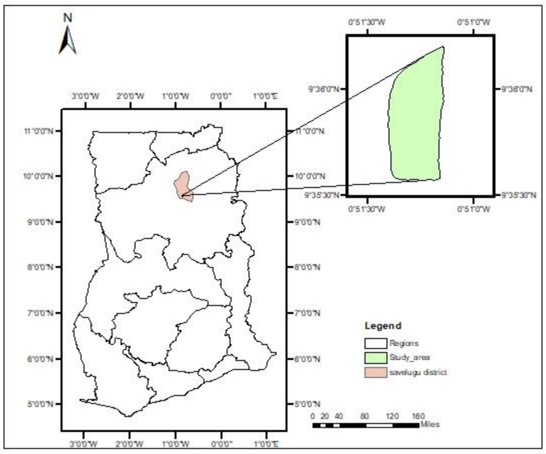

Figure 1. Study area location (Source: authors)

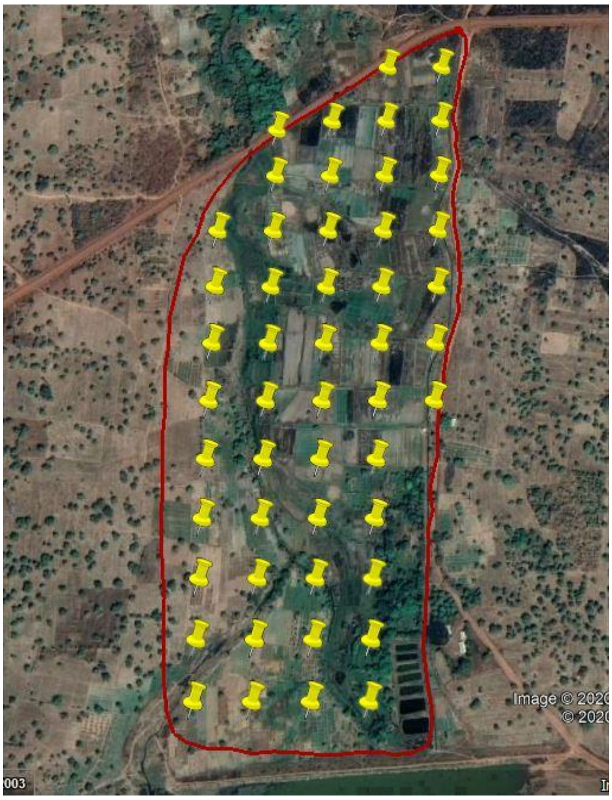

Figure 2. Sampling design and layout (Source: authors)

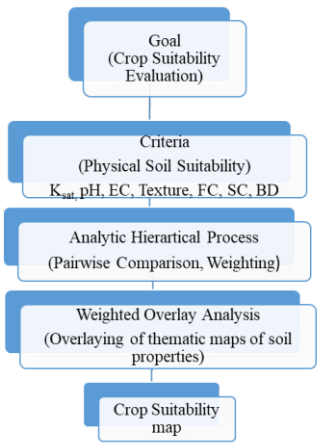

Figure 3. Flow chart of the suitability analysis methodology (Source: Authors)

$$\text{Consistency index (CI)} = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

Where λ_{max} is the largest Eigen value and n is the number of items being compared. λ_{max} is calculated using equation 5.

$$\lambda_{max} = \sum(m*n)\ldots\ldots \quad (5)$$

Where m is the sum of weights of elements in a given column and n is the principal Eigen vector of the corresponding row.

The consistency ratio is given by (Siddayao et al., 2014);

$$\text{Consistency ratio (CR)} = \frac{CI}{RI} \quad (6)$$

Where CI = consistency index, RI = random consistency index (Table 1). In Table 1, N is the number of criteria being compared. Consistency ratio smaller or equal to 0.1 is deemed as acceptable whereas a CR greater than 0.1 is unacceptable and the process need to be revise (Triantaphyllou and Mann, 1995).

Weighted Overlay Analysis

Weighted overlay was performed in AcrMap (ArcGIS 10.5) using ModelBuilder. Individual soil properties were weighted and reclassified based on four suitability classes; highly suitable, moderately suitable, marginally suitable and unsuitable using the reclassify tool of spatial analyst. (Table 5). They were then imported into ModelBuilder as layers. Using the weights of influence determined for each soil property through the AHP, the weighted overlay tool was used to produce maps of soil suitability for the crops studied. Figures 5, 6, and 7 depict the structure of the weighted overlay model for jute, tomato and cabbage respectively.

Four suitability classes were considered. These were high suitability, moderate suitability, marginal suitability and unsuitable. The most suitable value or range of values of a given soil property was assigned the highest number of 9 while the unsuitable value was assigned the lowest number, 1. This is an important step in overlay analysis which ensures that all the input rasters are brought under a common scale. In the overlay tool, the weightages of the individual soil properties generated through the AHP was assigned to their respective raster layers to produce the final output (suitability map).

Data Analysis

Geostatistical analysis was performed in ArcMap® (ArcGIS 10.5) using the geostatistical analyst tool. The spatial distribution maps were produced using Ordinary Kriging. The accuracy of the spatial distribution maps produced was evaluated through cross-validation using the mean-squared error (MSE), root mean-squared error (RMSE) and root mean-squared standardised error (RMSS) as described by Oliver and Webster (2014). Pairwise comparison was done in Microsoft Excel whiles overlay analysis was done in ArcMap (ArcGIS 10.5).

Table 1. Random Consistency Index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Siddayao et al., 2014)

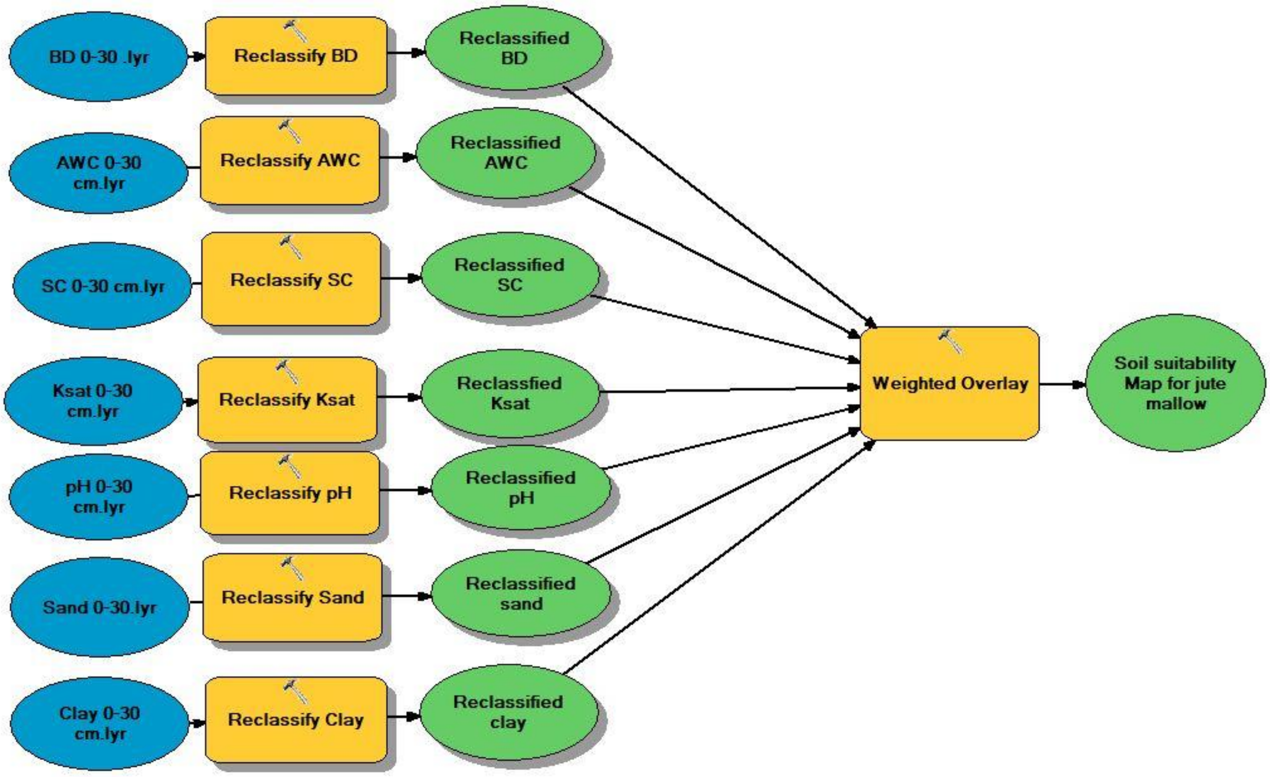

Figure 5. Structure of the weighted overlay model for soil suitability of jute mallow (Source: authors)

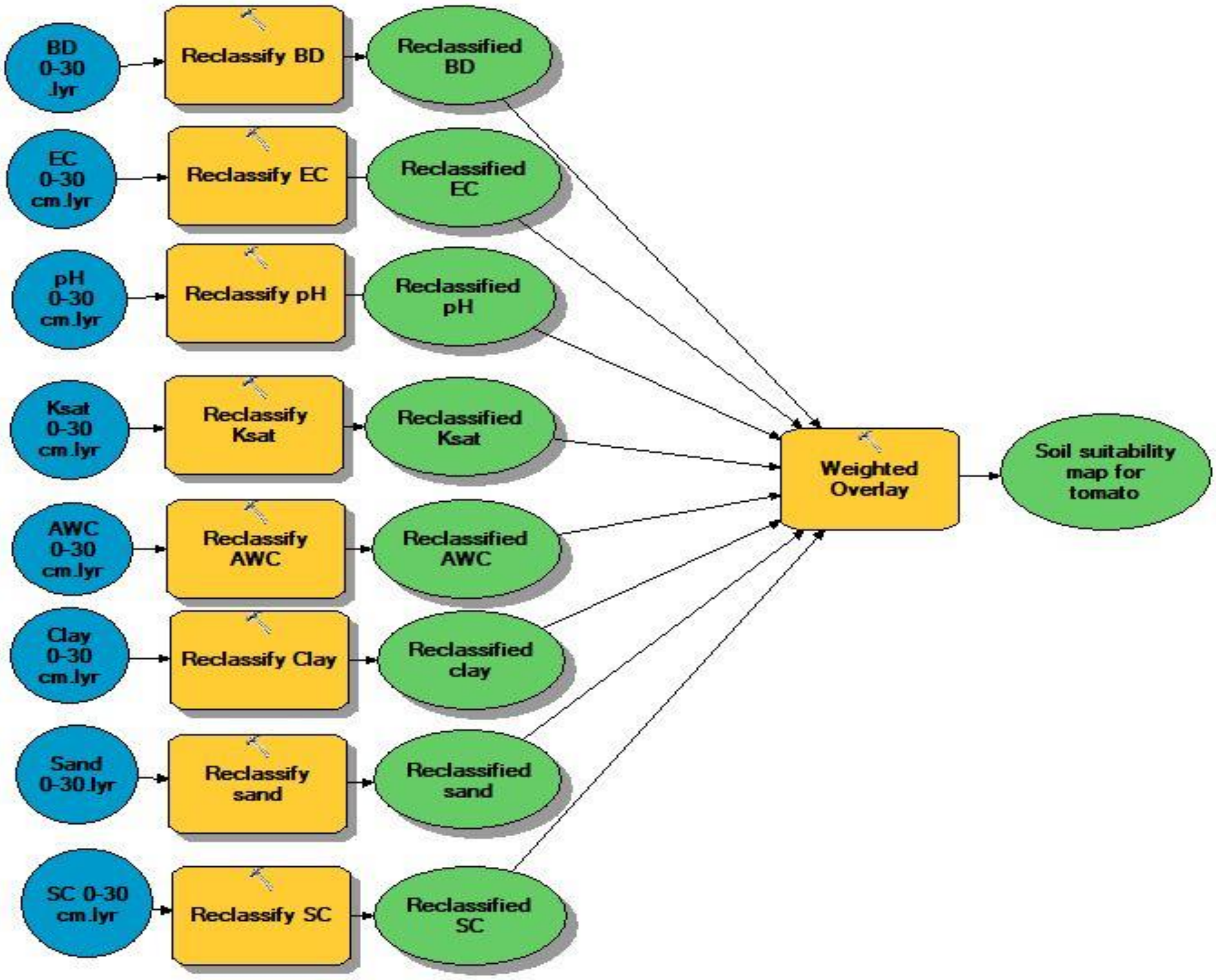

Figure 6. Structure of the weighted overlay model for soil suitability of tomato (Source: authors)

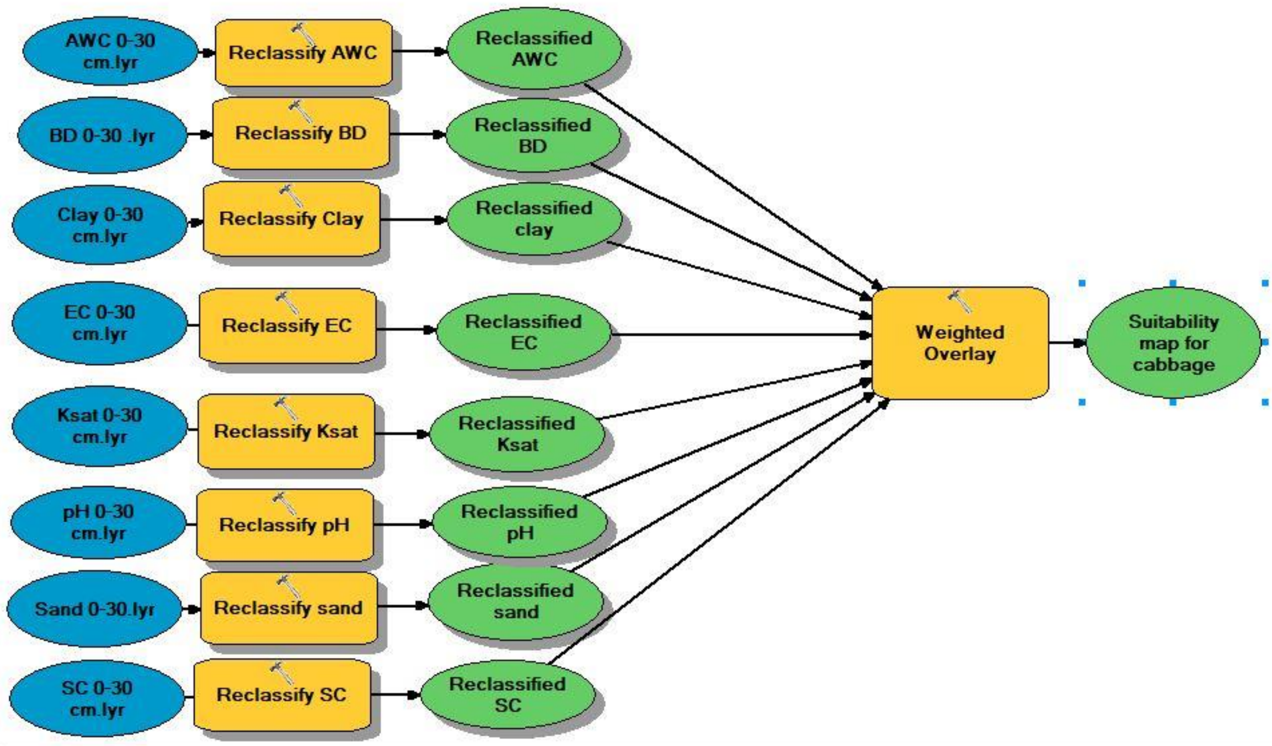

Figure 7. Structure of the weighted overlay model for soil suitability of cabbage (Source: authors)

Results and Discussion

Soil Characteristics of the Study Area

As presented in Table 2, soils in the Libga Irrigation Scheme were predominantly sandy loams with higher clay content in the subsoil layer. The BD was relatively high with mean values of 1.70 and 1.78 at the 0–30 cm and 30–60 cm respectively. Saturated hydraulic conductivity was generally low with mean values of 0.73 cm/hr and 0.58 cm/hr at the 0–30 cm and 30–60 cm respectively. The pH is slightly acidic and the EC was low with values less than 2.0 dS/m.

The results presented above indicate that the soils are generally poorly drained. This could be due to the fact that the major soil groups in this area are planosols and plinthosols. According to Gyekye et al. (2020), these are moderately deep soils which are imperfectly drained, pale brown/yellowish-brown, porous and very fine sandy loam or silty-loam topsoil, usually less than 30 cm thick, overlying hard iron pan.

Pairwise Comparisons of Soil Attributes for Tomato, Jute Mallow and Cabbage Production

As shown in Tables 2, 3 and 4, pH was ranked highest among the soil properties in terms of its influence the growth and yield of jute mallow (pH=0.37), tomato (pH=0.36) and cabbage (pH=0.36). This may be due to its influence on nutrient release and microbial activity (Foth, 1990).

Table 2. Classical statistics of the measured soil properties

Variable	Depth (cm)	Min.	Max.	Mean	Kurt.	Skew	SD	CV (%)	S-W Test (P<0.05)	
									Stat.	Prob.
Sand (%)	0–30	25.15	83.1	66.19	5.59	-1.86	9.981	15.08	0.82	<0.001
	30–60	37.8	81.45	64.37	1.89	-1.06	9.047	14.05	0.90	<0.001
Silt (%)	0–30	4.05	30.35	18.55	0.20	-0.24	5.311	28.63	0.99	0.878
	30–60	6.3	30.2	18.29	-0.67	-0.02	5.758	31.48	0.98	0.640
Clay (%)	0–30	5.3	46.9	16.12	8.76	2.63	7.341	45.55	0.69	<0.001
	30–60	7.8	34.4	18.1	1.16	0.92	5.845	32.29	0.93	0.005
BD (g cm^{-3})	0–30	1.49	1.82	1.70	-0.02	-0.74	0.076	4.43	0.93	0.005
	30–60	1.55	1.93	1.78	-0.02	-0.30	0.085	4.8	0.97	0.25
Total Porosity (cm^3/cm^3)	0–30	31.48	42.83	35.75	-0.02	0.74	2.85	7.98	0.93	0.005
	30–60	27.04	41.59	32.88	-0.02	0.30	3.22	9.79	0.97	0.25
FC (cm^3/cm^3)	0–30	17.32	52.43	23.79	27.31	4.62	4.65	19.53	0.52	<0.001
	30–60	21.55	40.20	25.68	7.46	2.39	3.20	12.45	0.77	<0.001
PWP (cm^3/cm^3)	0–30	4.75	16.57	8.73	1.75	1.05	2.30	26.31	0.94	0.010
	30–60	2.98	16.26	8.35	2.16	0.96	2.42	28.99	0.93	0.006
AWC (cm^3/cm^3)	0–30	11.6	20.33	16.53	0.13	0.00	1.78	10.74	0.98	0.595
	30–60	9.06	20.84	16.6	2.21	-1.17	2.34	14.08	0.92	0.002
Ksat (cm/hr)	0–30	0.6	1.07	0.73	1.08	1.12	0.104	14.24	0.91	<0.001
	30–60	0.40	0.84	0.58	-0.26	0.77	0.118	20.48	0.92	0.002
EC (dS/m)	0–30	0.011	0.62	0.11	3.09	2.06	0.166	154.6	0.60	<0.001
	30–60	0.011	0.49	0.06	7.46	2.81	0.103	178.7	0.51	<0.001
pH	0–30	4.44	6.20	5.23	-0.93	0.18	0.478	9.05	0.96	0.143
	30–60	4.25	6.46	5.534	-0.86	-0.21	0.570	10.30	0.97	0.214

Min.=minimum, Max.=maximum, SD=standard deviation, CV=coefficient of variation, kurt.=kurtosis, skew=skewness, S-W=Shapiro-Wilk test, FC=volumetric water content at field capacity, PWP=volumetric water content at permanent wilting point, AWC=available water content, Ksat=saturated hydraulic conductivity, EC=electrical conductivity, pH=soil reaction.

Table 2. Pairwise comparison matrix and weights of selected soil properties for jute mallow

Pairwise Comparison Table

	Ksat	AWC	Clay	Sand	pH	SC	BD
Ksat	1	0.5	0.5	2	0.25	3	1
AWC	2	1	1	3	0.33	4	2
Clay	2	1	1	3	0.33	4	2
Sand	0.5	0.33	0.33	1	0.2	2	0.5
PH	4	3	3	5	1	6	4
SC	0.33	0.25	0.25	0.5	0.167	1	0.33
BD	1	0.5	0.5	2	0.25	3	1
Total	10.83	6.58	6.58	16.5	2.527	23	10.83

Weighting

	Ksat	AWC	Clay	Sand	pH	SC	BD	Weight
Ksat	0.092	0.076	0.076	0.121	0.099	0.130	0.092	0.098
AWC	0.185	0.152	0.152	0.182	0.131	0.174	0.185	0.166
Clay	0.185	0.152	0.152	0.182	0.131	0.174	0.185	0.166
Sand	0.046	0.050	0.050	0.061	0.079	0.087	0.046	0.060
pH	0.369	0.456	0.456	0.303	0.396	0.261	0.369	0.373
SC	0.030	0.038	0.038	0.030	0.066	0.043	0.030	0.040
BD	0.092	0.076	0.076	0.121	0.099	0.130	0.092	0.098
Sum								1

PEV	CI	CR
7.146764	0.024461	0.018531

Ksat-saturated hydraulic conductivity, BD-bulk density, SC-saturation capacity, AWC-available water capacity, PEV-principal Eigen value, CI-consistency index, CR-consistency ratio (Source: authors)

Table 3. Pairwise comparison matrix and weights of selected soil properties for tomato

Pairwise Comparison Table							
	Ksat	AWC	Clay	Sand	pH	SC	BD
Ksat	1	0.5	0.5	2	0.25	3	0.5
AWC	2	1	1	3	0.33	4	1
Clay	2	1	1	3	0.33	4	1
Sand	0.5	0.33	0.33	1	0.2	2	0.33
PH	4	3	3	5	1	6	3
SC	0.33	0.25	0.25	0.5	0.167	1	0.25
BD	2	1	1	3	0.33	4	1
Total	11.83	7.08	7.08	17.5	2.607	24	7.08

Weighting								
	Ksat	AWC	Clay	Sand	pH	SC	BD	Weight
Ksat	0.085	0.071	0.071	0.114	0.096	0.125	0.071	0.090
AWC	0.169	0.141	0.141	0.171	0.127	0.167	0.141	0.151
Clay	0.169	0.141	0.141	0.171	0.127	0.167	0.141	0.151
Sand	0.042	0.047	0.047	0.057	0.077	0.083	0.047	0.057
pH	0.338	0.424	0.424	0.286	0.384	0.250	0.424	0.361
SC	0.028	0.035	0.035	0.029	0.064	0.042	0.035	0.038
BD	0.169	0.141	0.141	0.171	0.127	0.167	0.141	0.151
Sum								1

PEV	CI	CR
7.135253	0.022542	0.017077

Ksat-saturated hydraulic conductivity, BD-bulk density, SC-saturation capacity, AWC-available water capacity, PEV-principal Eigen value, CI-consistency index, CR-consistency ratio (Source: authors)

Table 4. Pairwise comparison matrix and weights of the selected soil properties for cabbage

Pairwise Comparison Table							
	Ksat	AWC	Clay	Sand	pH	SC	BD
Ksat	1	0.33	0.33	2	0.2	2	0.5
AWC	3	1	1	4	0.2	4	2
Clay	3	1	1	4	0.25	4	2
Sand	0.5	0.25	0.25	1	0.2	1	0.33
PH	5	3	3	5	1	5	3
SC	0.5	0.25	0.25	1	0.2	1	0.33
BD	2	0.5	0.5	3	0.33	3	1
Total	15	6.33	6.33	20	2.38	20	9.16

Weighting								
	Ksat	AWC	Clay	Sand	pH	SC	BD	Weight
Ksat	0.067	0.052	0.052	0.100	0.084	0.100	0.055	0.073
AWC	0.200	0.158	0.158	0.200	0.084	0.200	0.218	0.174
Clay	0.200	0.158	0.158	0.200	0.105	0.200	0.218	0.177
Sand	0.033	0.039	0.039	0.050	0.084	0.050	0.036	0.047
pH	0.333	0.474	0.474	0.250	0.420	0.250	0.328	0.361
SC	0.033	0.039	0.039	0.050	0.084	0.050	0.036	0.047
BD	0.133	0.079	0.079	0.150	0.139	0.150	0.109	0.120
Sum								1

PEV	CI	CR
7.171545	0.028591	0.019718

Ksat-saturated hydraulic conductivity, BD-bulk density, SC-saturation capacity, AWC -available water capacity, PEV-principal Eigen value, CI-consistency index, CR-consistency ratio (Source: authors)

Table 5. Percentage of area for each suitability class for jute, tomato and cabbage

	Cabbage		Tomato		Jute mallow	
Suitability Class	Area (ha)	% Area	Area (ha)	% Area	Area (ha)	% Area
Marginal	2.0	3.4	-	-	-	-
Moderate	55.7	96.0	47.7	82.2	44.3	76.4
High	0.33	0.6	10.3	17.8	13.7	23.6
Total	58.0	100.0	58.0	100.0	58.0	100.0

The principal Eigen value and Eigen vector were also calculated as proposed by Saaty (1980). The principal Eigen vector provides the relative priorities of the factors. Based on these, the consistency index (CI) and the consistency ratio (CR) were obtained to validate the weights computed for each of the soil properties (Singha and Swain, 2018). As presented in Tables 2, 3 and 4, the CR computed from the AHP for jute mallow, tomato and cabbage were 0.019, 0.017 and 0.02 respectively. Since these values are all below the 0.1 threshold for validating the AHP process, the AHP for all the crops was considered acceptable (Coulter and Coakley, 2006).

Physical Soil Suitability Maps for Jute Mallow (Corchorus olitorius), Tomato (Solanum lycoperscum) and Cabbage (Brassica oleracea var capitata)

As shown in Table 5, generally, soils in the Libga irrigation scheme are currently moderately suitable for the production of jute mallow (76.4%), tomato (82.2%) and cabbage (96.0%). The reason for this could be largely attributed to the high acidity and high bulk density observed in most parts of the field. According to Amara et al. (2016), the most suitable pH for tomato and cabbage is 6.0–7.0 and 6.0–7.5 respectively. This indicates that the pH range of 4.4–6.2 recorded in most parts of the field could have accounted for the moderate suitability of the soils for these crops. In their study, Amara et al. (2016) who also found soils in the northern semi-arid region of India to be moderately suitable for tomato and cabbage production.

As clearly displayed in Figures 8, 9 and 10, the highly suitable soils for the production of jute mallow, tomato and cabbage were observed in patches at various sections of the field. These were largely areas with relatively well drained soils characterised by relatively low bulk density (1.4–1.6) and slight acidity (5.5–6.5). This is in line with Amara et al. (2016) who contend that soil drainage is a very important suitability criterion for tomato and cabbage production. Also, according to Nethononda et al. (2014), jute mallow prefers soils with moderate pH (5.5–6.8) and low waterlogging potential indicating that areas in the field with soils having pH ranging from 4.0–5.0 could be considered not be suitable for jute mallow production. In order to improve the soils and make them suitable, soil management practices such as application of organic amendments and liming could be adopted (Rivenshield and Bassuk, 2007; Kaprath and Smyth, 2005).

Conclusion

Based on the soil properties measured, about 0.33 ha (0.6 %), 55.7 ha (96.0 %) and 2.0 ha (3.4 %) of the field is currently highly suitable, moderately suitable and marginally suitable respectively for the cultivation of cabbage whereas about 10.3 ha (17.8 %) and 44.7 ha (82.2 %) of the field is currently highly suitable and moderately suitable respectively for the cultivation of tomato. For jute mallow, it was found that about 13.7 ha (23.6 %) and 44.3 ha (76.4 %) of the field is currently highly suitable and moderately suitable respectively for its cultivation.

The major limiting soil properties in the field for most vegetables were soil pH and bulk density.

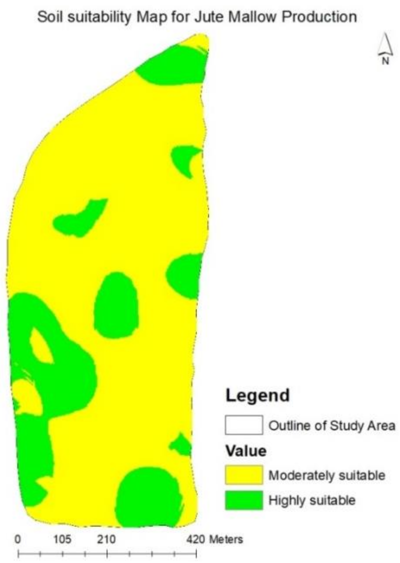

Figure 8: Soil suitability map for jute mallow in the Libga Irrigation scheme

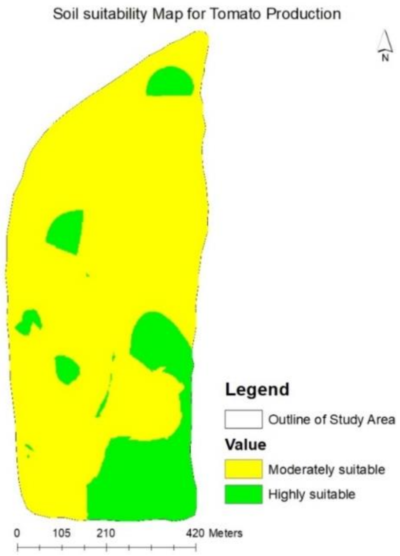

Figure 9: Soil suitability map for tomato in the Libga irrigation scheme (Source: authors)

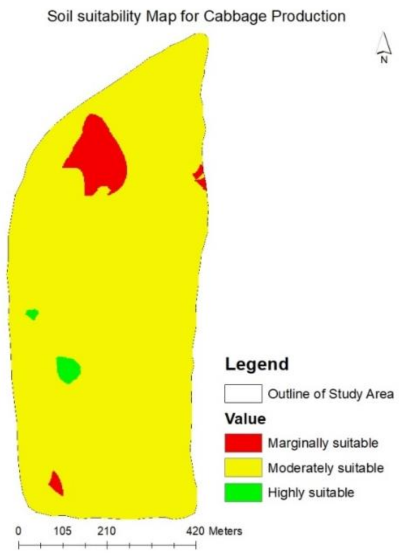

Figure 10: Soil suitability map for Cabbage in the Libga irrigation scheme (Source: authors)

The strong levels of acidity (pH ranging from 4.2 to 5.0) the soils in most parts of the field make crops such as garden eggs and pineapple which thrives well under such pH conditions to be best suited for cultivation in the field. For most vegetables such as tomatoes, cabbage, jute mallow and watermelon, the acidity levels in the field may need to be lowered for them to be profitably cultivated in the field.

The AHP proved to be a very useful tool for the incorporation of farmers' views into decision making about the suitability of soils for crop production. This is important considering the wealth of knowledge farmers have about soils in their fields.

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