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LAND SUITABILITY EVALUATION FOR EFFECTIVE LAND USE PLANNING, SUSTAINABLE AND PROFITABLE CROP PRODUCTION IN MINNA, NIGER STATE

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ABSTRACT
A 500-ha land of the commercial farm of the Federal University of Technology, Minna, Niger State was evaluated for production of maize, soybean, mango and coconut using a parametric Rabia equation method. Semi-detailed soil survey using 100 m x 100 m rigid grid method preceded the evaluation. Three mapping units designated as UCF-1 and UCF-2 and UCF-3 were delineated. In each unit, two representative profile pits were dug, described and soil samples collected following the USDA guidelines. The samples were analysed for some physical and chemical properties using standard laboratory analytical procedures. Soil reaction (pH 5.9 to 6.5) was favourable for the uptake of most nutrients, which were low to moderate. All the mapping units had potential suitability indices (PSI) of greater than 50 %, when evaluated for maize and soybean which made them moderately suitable for their production, except UCF-3 with PSI of 35 % making it marginally suitable for maize. Mapping units UCF – 1 and UCF – 2 with PSI greater than 57 % after being evaluated for mango are moderately suitable for its production. The PSI of all the mapping units was less than 50 % after evaluating them for coconut production making them only marginally for its production.

Keywords: Commercial crop production, Land suitability evaluation, Land use planning, Land use type, Sustainable land management.

INTRODUCTION
Land evaluation broadly encompasses systematic assessment of land qualities and it is critical in taking decisions about land potentials for alternative uses (Moloudi and Mahabadi, 2019; Mohammed *et al*., 2021). The objective of conducting land evaluation is to manage and improve or increase the potentials of the land for human uses in a sustainable way (Anaya-Romero *et al*., 2015). The emphasis of land suitability evaluation (LSE) for agricultural uses is to predict the potentials and limitations of a given parcel of land for production of specific crops (AbdelRahman *et al.*, 2016). The LSE process is usually based on intrinsic properties of the soils (which can be altered by human management) such as depth, drainage, texture, soil reaction (pH), electrical conductivity (EC) as conditioned by climate and topography; and provides useful information which guides decision-makers on how resources can be optimally utilized (Rabia and Terribile, 2013; Kumar *et al*., 2021). Different methods (qualitative and quantitative) of land evaluation have been developed; each having different data requirements and various qualities of estimates (Mathewos *et al*., 2018). Among them is the Rabia equation model (Rabia and Terribile, 2013), a modified version of the square root method. Rabia equation is a parametric method which takes the entire land characteristics into consideration

but placing more emphasis on the factor with highest impact. This study however, adopted the modified square roots method (Rabia equation) due to fact that several works that compared different methods of qualitative land suitability, evaluation can be concluded that the square root methods gave more reasonable results, because the land indices calculated were highly correlated with actual yield (Moloudi and Mahabadi, 2019).

Soils containing hardened iron concretions in form of gravels (pisoliths) either on the surface horizons or beneath are widespread within the basement complex rocks formation of Niger State (Lawal *et al*., 2012; Lawal *et al*., 2019). These soil types have been described as very difficult to manage due to their inherent limitations such as low fertility, shallow effective depth, easily susceptible to flooding under rainy season and could also be prone to drought within short period of water cessation (IUSS Working Group WRB, 2014). To overcome such shortcomings, conducting soil survey to generate soil information and performing land suitability evaluation are important. On this basis, a parcel of land can rationally be assigned to perform specific roles based on its potentials for optimum and sustainable productivity.

Information on soil-site suitability evaluation for the commercial farm of the Federal University of Technology, Minna is not available and this may pose a challenge for effective land use thereby impairing the productivity and sustainability of the farm. Hence, the need for conducting land suitability evaluation before embarking on any further development in the farm cannot be overemphasized. According to Okunsebor *et al*. (2021), neglecting land suitability evaluation arbitrarily pave way for allocation of crops to parts of the landscape where they are not ecologically suited, thereby leading to massive failure of agricultural projects. Therefore, the objective of this study was to evaluate the suitability of the soils of the commercial farm of the Federal University of Technology, Minna in the southern Guinea savanna of Nigeria for commercial production of maize (*Zea mays* **L.**), soybean (*Glycine max*), mango (*Mangefera indica*) and coconut (*Cocos nucifera*). This will enable profitable and sustainable productivity of the farm.

MATERIALS AND METHODS

The Study Site

The study site is located at kilometre 20, along Minna-Bida Road, Garatu village, a suburb of Minna, Niger State. It lies within the geographic boundaries of Latitude 9° 27′ 33.455″ N and Longitude 6° 25′ 1.093″ E; Latitude 9° 27′ 3.351″ N and Longitude 6° 23′ 20.208″ E; latitude 9° 28′ 41.154″ N and Longitude 6° 24′ 3.131″ E; Latitude 9° 28′ 12.630″ N and Longitude 6° 25′ 49.090″ E on elevation between 148 and 193 m above mean sea level (Figures. 1a-c). The climate of Minna is sub-humid with the rainy season usually starting in March and ending in October. Mean annual rainfall for Minna is 1200 mm with 90 % of the rains usually falls between the months of June and August. Mean daily temperature rarely falls below 22 °C with peaks of 40 °C and 36 °C in months of February-March and November-December respectively (Adeboye *et al*., 2009; Weather Spark, 2022). Minna is underlain by igneous and metamorphic rocks of the pre-Cambrian Basement Complex (Ojanuga, 2006) which weathered to dominant soil groups such as Typic Plinthustalf, Plinthic Paleustalf and Typic Plinthaqualf (Lawal, 2017). Minna is located within the southern Guinea savanna of Nigeria. Cereals (maize, sorghum and upland rice), legumes (groundnut and soybean) and tubers (yam) are the major crops grown in the area.

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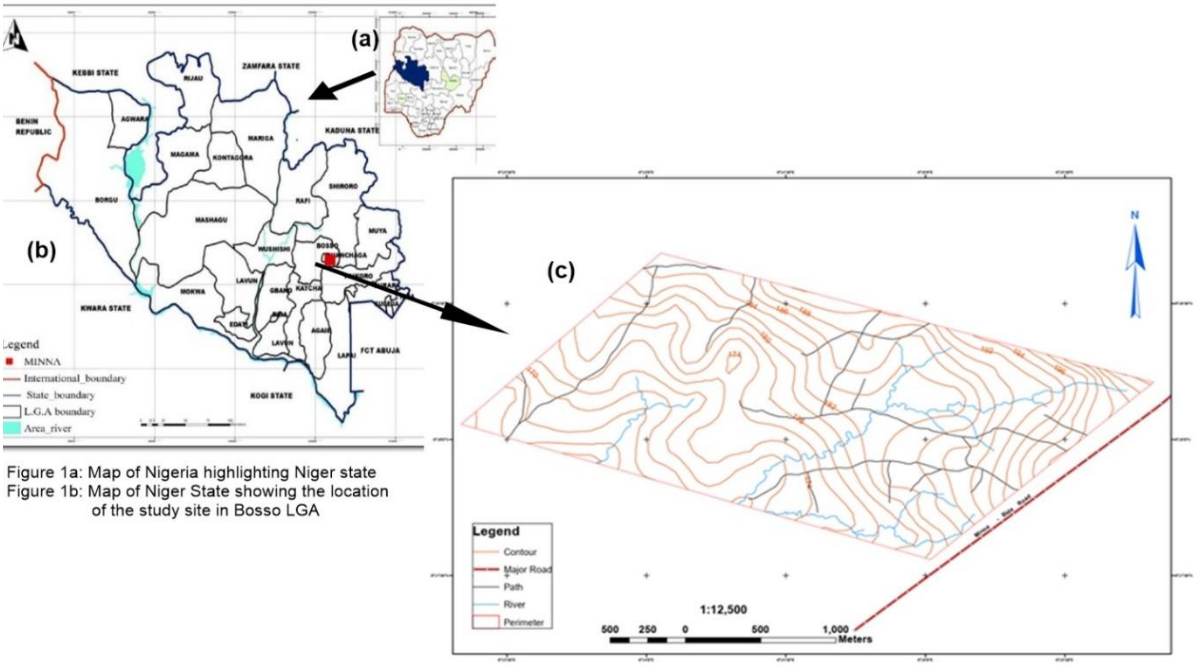

Figure 1a: Map of Nigeria highlighting Niger state
Figure 1b: Map of Niger State showing the location of the study site in Bosso LGA

Figure 1c: Contour map of the study site (500 ha) evaluated for various crops in Garatu, Minna, Niger State

Field Data and Soil Sample Collection

Five hundred hectares (500 ha) parcel of land was delineated for feasibility study. The land was surveyed at semi-detailed scale of soil survey, combining the use of a processed Google imagery of the site and a hand-held GPS device (GARMIN ex-10) to facilitate ground-truthing in delineating the major soil units and identifying representative positions for soil profiles. In each unit, two representative soil profiles were dug and described according to the USDA guidelines (Soil Science Division Staff, 2017). Soil samples were carefully collected from each identified genetic horizon for laboratory for analysis.

Laboratory Analysis

The air-dried bulked soil samples were processed and passed through a 2 mm mesh. The sieved samples were analysed according to standard laboratory procedures (IITA, 2015) for particle size distributions using the Bouyocous hydrometer method with sodium hexametaphosphate as dispersing agent. The textural classes of the soils were determined using IUSS soil textural triangle. Soil pH was determined in a 1:2.5 soil / calcium chloride using a standard pH meter and electrodes. Exchangeable acidity (H^+ and Al^{3+}) was determined by titrimetric method. Organic carbon was determined by Walkley-Black method of wet combustion involving oxidation of organic matter with potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4). Exchangeable bases, calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were extracted with 1N NH4OAC. Calcium and Mg in the soil extract were determined using atomic absorption spectrophotometer while K and Na were determined by flame photometry. Cation exchange capacity (CEC) was determined by the neutral 1N NH_4OAc saturation method. Base saturation was determined by calculation, dividing the sum of exchangeable bases by their CEC and then multiplied by 100.

Mapping and Soil Data Interpretation

Soil map of the site was digitally generated by interpolation of the geo-referenced data using SURFER 20 software for Windows (Golden Software Inc., 2021). Fertility rating of the chemical properties of the soils followed the criteria of Chude *et al*. (2011). Suitability evaluation was performed for production of maize, soybean, and mango using Rabia equation (Rabia and Terribile, 2013) as expressed in equation (1) below:

$$S_i = W_{max} \text{ x } \sqrt{\frac{A}{100} \text{X} \frac{B}{100} \text{X} \frac{C}{100} \dots \dots, \dots} \qquad \dots(1)$$

where; Si= suitability index, W_{max}= connotes the factor that has maximum weight; and A, B, C… are ratings of other factors besides the maximum. The parameters used for the evaluation includes climate, soil physical characteristics, wetness (drainage), topography, nutrient availability and nutrient retention capacity of the surface soil (Tenka and Balogun, 2019). These characteristics were matched with soil and environmental requirements recommended for maize, soybean, and mango (Sys *et al*., 1993). Final suitability for each crop was defined by applying the computed index values converted to its corresponding land suitability classes. According to suitability ranking of Sys *et al*. (1991), land suitability index from 0 to 12.5 % connotes permanently not suitable (N2), 12.5 to 25 % is currently not suitable (N1), 25 to 50 % is marginally suitable (S3), 50 to 75 % is moderately suitable (S2) and 75 to 100 % is highly suitable (S1).

RESULTS AND DISCUSSION

Land Characteristics/Quality Attributes of the Mapping Units

Results of land characteristics and soil quality attributes essential for suitability evaluation are presented in Table 1. The farm was dissected with network of gullies and creeks which collects and drains out run-off. The micro-relief of the farm had remarkable influence on soil colour pattern, particle size distribution (texture), effective soil depth, topography and drainage formed the basis for the delineation of the farm into three major mapping units (Figure 2) designated as UCF-1 (320 ha), UCF-2 (155 ha) and UCF-3 (25 ha) for ease of management.

Table 1: Land qualities/characteristics of the three soil units of the study site

Parameters		**Soil unit**	
	UCF-1	**UCF-2**	**UCF-3**
*Climatic data:			
Mean annual rainfall (mm)	1150.5	1150.5	1150.5
Mean monthly temperature (°C)	31.1	31.1	31.1
Land / soil physical properties:			
Slope (%)	2 – 3	2 – 5	< 2
Drainage	Well-drained	Well-drained	Poorly drained
Soil depth (cm)	71	25	35
Texture (surface)	Sandy loam	Sandy loam	Sandy clay loam
Nutrient availability (Topsoil):			
pH (H_2O)	6.3	6.5	5.9
Total N (g kg^{-1})	0.11	0.23	0.29
Available P (mg kg^{-1})	6	7	9
Exchangeable K (cmol kg^{-1})	0.10	0.13	0.11
Organic C (g kg^{-1})	4.72	3.68	11.53
CEC (cmol kg^{-1})	9.38	9.66	12.18
Base saturation (%)	78.36	78.11	80.74

*(Weather Spark, 2022)

Soil reaction (pH) ranged from 5.9 to 6.5 which was moderately acid in UCF-3 and slightly acid in UCF-1 and UCF-2. Lawal (2017) reported pH 6.0 to 6.3 in earlier investigations of the site and attributed the acidity status of the soils to nature of parent materials that weathered to produce them. Brady and Weil (2013) have established soil pH range of 5.5 to 7.0 as best for the availability of most nutrients for uptake of plants. Organic carbon was low in UCF-1 and UCF-2 and moderate in UCF-3. Intensive land use, poor nutrients management practices and burning of crop residues by local farmers currently working on the studied site may have contributed to low turnover of plant residues observed; hence, low to medium organic carbon content in these soils. This finding also agrees with earlier investigations on similar soils by Adeboye *et al*. (2009) and Lawal (2017) that attributed low organic C in the soil to annual cycles of burning of crop residues by farmers and erosion by run-off which removes colloids from the soils resulting low organic matter. The nature of the soils (that is, been petroplinthitic) might also be a contributory factor for the low organic carbon observed (IUSS WRB Soil Working Group, 2014), Thus, soils under assessment will respond well to use of organic matter/fertilizer as soil amendment.

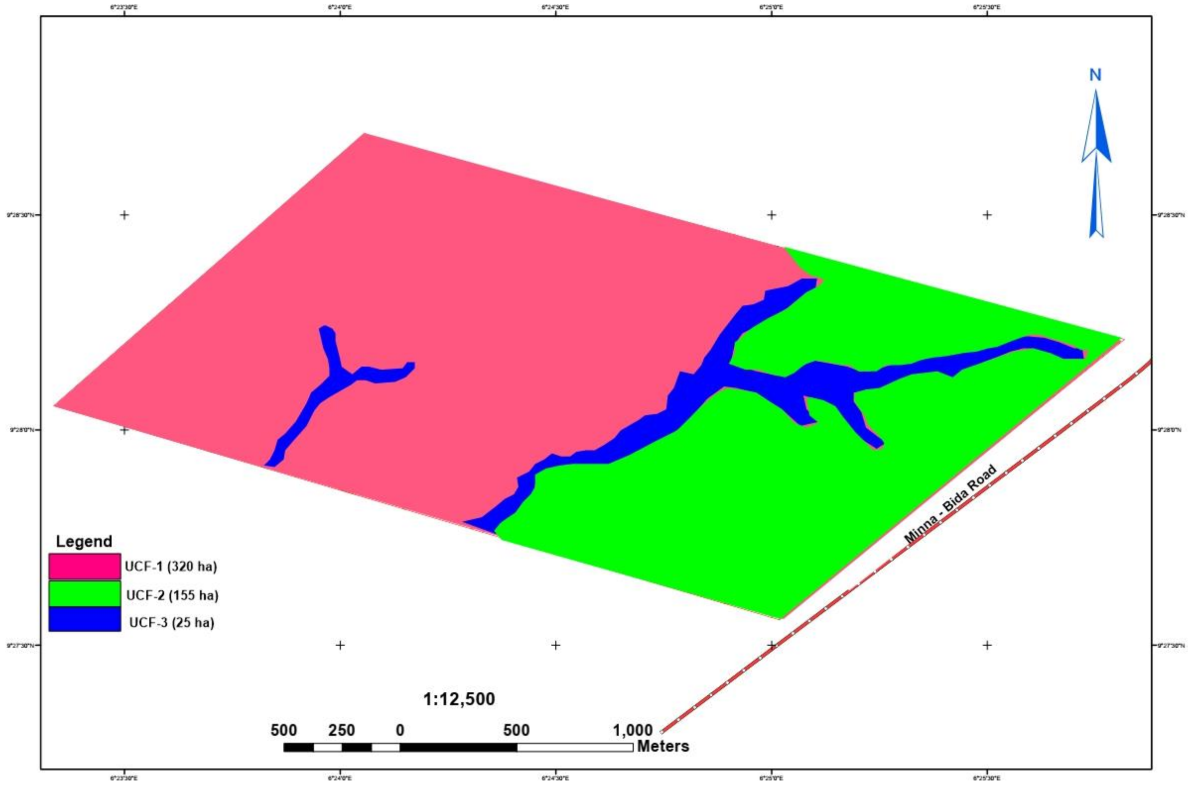

Plate 2: The soil map of the surveyed site showing the three major mapping units

The UCF-1 and UCF-2 occupy the middle and upper physiographic positions, and were characterized with dark brown (10YR4/3) graded to dark yellowish brown (10YR4/4) colour at the surface. Both were well-drained with weak medium crumb structure. The UCF-3 occupies the lower slope position and had very dark greyish brown (10YR3/2) to dark greyish brown (10YR4/2), poorly drained with moderate medium sub-angular blocky structure. Plinthic horizons and stone-line in the subsurface distinguished UCF-2 from the other two soil units. The effective soil depth varies from shallow due to high water-table in UCF-3 (mean, 35.00 cm deep) and plinthic/stone-line in UCF-2 (mean, 39.50 cm deep) to moderate in UCF-1 (mean, 70.50 cm deep). Shallow depth in UCF-2 and UCF-3 was a major limiting factor in these units. Textural classes of the surface soil ranged from sandy loam in UCF-1 and UCF-2 to sandy clay loam in UCF-3 underlain by sandy clay loam or clay.

Total nitrogen (N) was medium in UCF-1 to high in UCF-2 and UCF-3 despite the trend of low to medium organic carbon content in the soils. This implies that medium to high content of N may be linked to application of N-fertilizers by farmers to nourish their crops. Available phosphorus (P) and potassium (K) concentration were low in all mapping units; hence, the soils will respond well to application of these nutrients. Base saturation was medium in UCF-1 and UCF-2 and high in UCF-3, suggesting the dominance of basic cations in the exchange surfaces of the soil (Atoforati *et al*., 2012).

Suitability Evaluation of the Mapping Units for the Selected Crops

The assessment of the fitness of the mapping units for commercial production of maize, soybean, mango and coconut closely follow the suitability criteria laid down by the Sys *et al.* (1993) with emphasis on climatic conditions Minna and environ and soil quality as recommended by Grassano *et al*. (2011). The outcome of matching the land characteristics/ quality (Table 1) with soil and environmental requirements for optimum growth and yield of the crops under the actual and potential suitability evaluations are presented in Table 2. Evaluation also put into consideration the accessibility of the farm to market, for which all the crops ranked highly suitable (S1).

Table 2: Aggregate suitability ranking of the mapping units for selected crops according to Rabia equation

Crop	Nature of Suitability	UCF-1 S-Index	UCF-1 S-Class	UCF-2 S-Index	UCF-2 S-Class	UCF-3 S-Index	UCF-3 S-Class
Maize	Actual	16	N1fn	18	N1sfn	19	N1wsf
	Potential	66	S2n	51	S2s	35	S3n
Soybean	Actual	36	S3fn	31	S3sfn	20	N1wsf
	Potential	61	S2n	51	S2s	55	S2n
Mango	Actual	55	S2fn	38	S3sfn	34	S3wsf
	Potential	71	S2n	49	S3s	58	S2n
Coconut	Actual	43	S3cs	35	S3cs	19	N1wcs
	Potential	46	S3cs	38	S3cs	29	S3wcs

Suitability evaluation for maize

Results of actual suitability revealed that the three mapping units in the farm were currently not suitable (N1) for commercial production of maize due to severe limitations of soil fertility (particularly nitrogen) and nutrient retention (organic carbon) in UCF-1, nutrients retention in UCF-2 and wetness/drainage limitation in UCF-3. Similar results were reported by Kefas *et al*. (2020) which placed some soil units in Taraba State under currently not suitable (N1) for maize. After imposing corrective (management) measures to correct the limitation through application of mineral fertilizer, organic matter and in-field drainage, UCF-1 and UCF-2 upgraded to moderately suitable (S2) and UCF-3 to marginally suitable (S3). However, full potentials of UCF-2 and UCF-3 (both having shallow soil depth) would be realized when they are ridged to provide adequate rooting environment for maize crop.

Suitability evaluation for soybean

Results of actual suitability evaluation of the farm for soybean revealed that UCF-1 and UCF-2 were marginally suitable (S3) for commercial production of the crop while UCF-3 was currently not suitable (N1). Major limitations were low fertility (mainly P) and nutrient retention (organic matter and CEC). Also, limitations of shallow effective soil depth in UCF-2 and wetness (drainage) problem in UCF-3 affected the suitability ranking of these two mapping units for soybean. These results were in agreement with the findings of Vanger *et al.* (2021)

with exception of available phosphorus, indicate low soil organic carbon, poor drainage and low pH values as major limiting factors affecting optimum soybean production in Konshisha Local Government Area of Benue State under similar agroecological zone with the present study site. Potential suitability assessment revealed an improvement of all the units to moderately suitable (S2) upon imposition of appropriate management practices such as correction of P-deficiency which is critical in the nutrition of leguminous crop.

Suitability evaluation for mango

Actual suitability assessment for mango revealed that UCF-1 was moderately (S2) suitable while UCF-2 and UCF-3 were marginally suitable (S3). Major limitations, especially in UCF-2 and UCF-3 were soil depth (in UCF-2) and wetness of the soil (in UCF-3). After imposing corrective (management) measures to correct the limitation through application of mineral fertilizer, organic matter and in-field drainage, UCF-1 remain moderately suitable (S2) and UCF-2 also maintains marginally suitable (S3). However, UCF-3 upgraded from marginally suitable (S3) to moderately suitable (S2). By implication, UCF-1 was best for mango while UCF-2 was the least in ranking. Additional cost may be incurred in draining out water in UCF-3 to improve its productivity. Mango requires favourable temperature around 25 °C, deep and well-drained soil condition for its optimum growth and yield (Kumar *et al*., 2021). This could explain why none of mapping units scored SI despite corrective measures employed.

Suitability evaluation for coconut

Actual suitability assessment for coconut revealed that UCF-1 and UCF-2 were marginally (S3) suitable in their current status while UCF-3 was not suitable (N1). Major limitations for coconut production in the studied site were climate, soil depth and wetness. Except wetness, climate and shallow soil depth cannot be amended. Coconut have been reported performs excellently under rainfall range of 2000–3000 mm per annum (Oko-oboh *et al*., 2018; Okunsebor *et al*., 2021). After imposing corrective (management) measures to correct the limitations, UCF-1 and UCF-2 remains marginally suitable (S3) while UCF-3 upgraded from currently not suitable (N1) to marginally suitable (S3). By all indications, it is not worth investing on commercial production of coconut in the farm based on the suitability indices/classes recorded despite all corrective measures imposed.

Overall Ranking of the Mapping Units

The decision for selection of land use type was based on the scale of ranking from 1 to 5 as presented in Table 3 in which S1 = 5, S2 = 4, S3 = 3, N1 = 2 and N2 = 1. On the basis of crop selection, soybean ranked the best with 12 points out of maximum of 15 and can successfully be cultivated on 100 % of the assessed land. Soybean can be successfully cultivated on the entire 500 ha assessed. This was followed by maize (95 %) which ranked 11 points may best be suited for cultivation on UCF-1 and UCF-2 (475 ha). Mango ranked 11 points and may perform better in UCF-1 and UCF-3 (345 ha) translated to 69 % of the site assessed. Coconut ranked very low, scoring 8 out of 15 points.

Table 3: Ranking for selection of the mapping units for specified kinds of land use

LUT	Mapping units			LUT Total Ranking	Selected Mapping units	Suitable area (ha)	Suitable area (%)
	UCF-1	UCF-2	UCF-3				
Maize	4	4	3	11	UCF-1 + UCF-2	475	95
Soybean	4	4	4	12	All	500	100
Mango	4	3	4	11	UCF-1 + UCF-3	345	69
Coconut	3	3	2	8	None	0	0

Note: LUT = Land use type; UCF = University commercial farm

CONCLUSION AND RECOMMENDATIONS

The three mapping units delineated had favourable soil pH for normal growth of the crops selected. Low fertility (N, P and K) can be corrected through application of appropriate fertilizers depending on the requirements of maize and soybean. Drainage of excess water in UCF-3 and making ridges in UCF-2 may enhance the productivity of these units for cultivation of maize and soybean. Relatively, soybean showing good performance in all mapping units should be considered first in UCF-2 and UCF-3 where it had comparative advantage over maize and mango, while cultivation of maize should be restricted to UCF-1 and UCF-2. Mango should be restricted to UCF-1 and UCF-3. On the basis of the results, coconut should not be cultivated in commercial quantities as soil and environmental factors were not favourable for its production.

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