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Land Evaluation for Soybean (*Glycine max* L. Merrill) Production Based on Kriging Soil and Climate Parameters for the Kakamega District, Kenya

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Abstract: The purpose of this study was to produce soil and climate characteristic maps from random sample point data and demonstrate their potential in land suitability evaluation for soybean (*Glycine max* L. Merrill) production in Kakamega District, Kenya. Crop requirements were sourced from literature and adapted to local conditions. Soil data were generated from soil samples collected from 76 geo-referenced sites randomly distributed throughout the District. Climate data was obtained from the Almanac Characterization Tool and records of Kakamega Research Station for the two seasons evaluated. The sample points were used to obtain continuous surface maps of individual characteristics using ordinary kriging method in GIS. They were reclassified into suitability classes using the crop requirements and overlaid to produce the final land suitability based on the most limiting factor. Very suitable, moderate and marginally suitable land is 3, 38 and 39%, during long rains and 1, 40 and 39% during short rains respectively. Unsuitable land owing to soil pH is 2% in both seasons while valleys, escarpments and forests account for 18% of the land. Comparison of the results with those obtained by averaging data from sample points representing soil units revealed that kriging produced better evaluation results.

Key words: Suitability classification maps, kriging, soybean, Kenya

INTRODUCTION

Land evaluators inform land-use planners and farmers about the suitability of land for use and its management requirements through conducting a land suitability evaluation. Traditionally, land evaluation was based on soil survey data. The data interpretation methods range from quantitative to qualitative (Van Diepen *et al.*, 1991).

Quantitative methods may specify the farm inputs and outputs of land-use or involve computer simulation models of crop growth and yield that require a lot of data (Van Lanen and Wopereis, 1992). Qualitative evaluation methods are those which give land suitability in general physical terms, produce quick results and are attractive when the data available are insufficient for quantitative land evaluation (Wandahwa and Van Ranst, 1996). They rate land suitability according to classes such as those developed by FAO (1976) which expresses suitability in descriptive terms: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable with (N1) or without (N2) possibilities for land improvement.

The data used for land evaluation is derived from soil survey maps and reports that range in degree of detail

from small to large scales. Muchena and Kiome (1995) report that soil resource inventory in East Africa is inadequate for land use planning and there is need to accelerate systematic soil surveys at larger scales for this purpose. However, there is a perceived failure of soil survey to deliver relevant and timely information at affordable cost (Basher, 1997).

Conventional soil survey has traditionally produced maps characterized by a modal soil profile pit representing a soil unit on which suitability evaluations are based (Kimaro *et al.*, 2003). The soil units define the boundaries of a natural body of soils occupying a certain land area that can be delineated on a soil map and showing a set of properties differentiating it from other soil units (Buringh, 1979). They can be simple map units defined as delineations containing a very low percentage of dissimilar soils and conforming to the definition of a single soil type or compound map units referring to delineations with a higher percentage of dissimilar soils (Taylor and Pohlen, 1970; Siderius, 1980). Analysis of soil maps shows that there can be considerable uncertainty in map unit composition with consequent spatial variability in soil properties and land assessment results within map units (Webb and Lilburne, 2005).

An alternative procedure in soil mapping is to focus on point observations from which individual characteristic or single factor maps are derived through interpolation to produce a continuous surface (Cook and Coles, 1997; Ceballos-Silva and Lopez-Blanco, 2003a). Points for interpolation must be geo-referenced, as a prerequisite for management of this spatial information. Ordinary kriging is one of several geostatistical optimal interpolation techniques useful in mapping soil resources (Bekele *et al.*, 2003). The technique utilizes information about the spatial autocorrelation in the vicinity of each sample point to provide optimal interpolation between the individual points into continuous surfaces (Stein and Ettema, 2003).

The purpose of this study was to produce land characteristic maps through kriging random sample point data and demonstrate their potential in suitability evaluation for soybean (*Glycine max* L. Merrill) production in Kakamega District, Kenya. Soybean was used as a case study crop because of its increasing importance among cropping systems as a means of alleviating soil fertility, poor nutrition and poverty in the District.

MATERIALS AND METHODS

The physical environment of the study area: The study was conducted in Kakamega District, western Kenya during the month of April 2001. The District lies between latitudes 0°15' and 1°N and longitudes 34°20' and 35°E in the western part of Kenya. It covers approximately 1,486 km². The altitude ranges from 1,250 m above sea level (asl) in the southwest to 2,000 m asl in the east. Two distinct physiographic units evident are the southern hilly belt and the slightly undulating peneplain, stretching from the north to the central and eastern parts. A prominent feature on the eastern border is the Nandi escarpment whose main scarp rises from a general elevation of 1,700 to 2,000 m asl within one kilometer.

Annual rainfall in the District varies between 1,000 and 2,400 mm per annum and is received as heavy afternoon showers with occasional thunderstorms. About 500 to 1,100 mm is received during the first rains (March through June) and 450 to 850 mm during the second rains (August through November) (FURP, 1987). Minimum, maximum and mean temperatures range from 11 to 16, 24 to 31 and 17 to 23°C, respectively.

The District contains a wide range of soils (Fig. 1 and Table 1). Most are well-drained and vary in texture from clay, to sandy loam. Heavy rainfall makes these soils

Table 1: Groupings of soil units shown in Fig. 1, number of sample points per unit, their area and slope classes

Soil unit code ¹	Unit names (FAO, 1974)	Sample points	Area (ha)	Slope (%)
UhB3	Cambisol and Ferralsols	2	1434	5-16
UhB5	Rhodic Ferralsols	1	2435	5-16
UhD1	Orthic Acrisols	15	19991	5-16
UhD2	Nito-rhodic Ferralsols	1	135	5-16
UhDC	Acrisols and Ferralsols	2	15225	5-16
UhG2	Ferralsol-humic Acrisols	4	5797	5-16
UhG5	Humic Acrisols	6	5787	5-16
UhI2	Luvic Phaeozems	5	6829	5-16
UhV1	Dystro-mollic Nitisols	2	1845	5-16
UmD2	Orthic Ferralsols	1	728	2-8
UmD3	Rhodic Ferralsols	4	3011	2-8
UmF1	Cambisols and Phaeozems	1	1042	2-8
UmG2	Ferralsol-orthic Acrisols	1	2246	2-8 ⁱ
UmG3	Chromic Acrisols	13	17532	2-8
UmG5	Humic Acrisols	16	28017	2-8
UmG7	Rankers and Cambisols	8	9870	2-8
UmU2	Ferralsols and Cambisols	1	920	2-8
UIG3	Acrisols and Lithosols	1	1779	2-8
UIGC1	Acrisols and Cambisols	4	7548	2-8
UIX1	Rhodic Ferralsols	1	2878	2-8
BXC2	Gleysols, planosols etc	1	201	0-5
FUC	Ferralsols, Acrisols etc	1	1334	2-16
HGC	Regosols, Rankers, etc	1	456	16-30
HU1	Humic Cambisols	1	648	16-30
MU2	Lithosols and Regosols	-	2660	>30
VXC	Gleysols, Vertisols etc	-	8232	-

The first soil unit letter represents physiographic position as follows: M: mountains and major scarps; H: hills and minor scarps; F: footslopes; Uh: upland (upper middle level); Um: uplands (lower middle level); Ul: uplands (lower level); B: bottomlands; V: valleys

Table 2: Climatic requirements for soybean production in Kakamega District (adapted from Sys *et al.*, 1993)

Climatic characteristics	Suitability class, ratings and range of values				
	S1 S2 S3 N				
	1	2	3	4	5
Precipitation of growing cycle (mm)	500-750	750-1100	1100-1600	1600-1900	>1900
Precipitation of 1st month (mm)	85-200	200-275	275-400	400-475	>475
Precipitation of 2nd month (mm)	140-200	200-275	275-400	400-475	>475
Precipitation of 3rd month (mm)	140-200	200-275	275-400	400-475	>475
Precipitation of 4th month (mm)	85-200	200-275	275-400	400-475	>475
Mean temp. of growing cycle (°C)	22-25	22-20	20-18	18-15	<15
Mean min. temp. of growing cycle (°C)	16-18	16-12	12-9	9-7	<7
Relative humidity (%) (2nd month)	50-80	50-42	42-36	36-30	<30
Relative humidity (%) (4th month)	30-60	30-24	24-20	<20	
Sunshine ratio (2nd month)	0.5-0.6	0.5-0.35	<0.35		
Sunshine ratio (4th month)	>0.7	0.7-0.5	<0.5		

Classes S1, S2, S3 and N represent highly, moderately, marginally and not suitable land respectively. Rating 1 represents optimal values above or below which suitability for some characteristics reduces hence the two rows

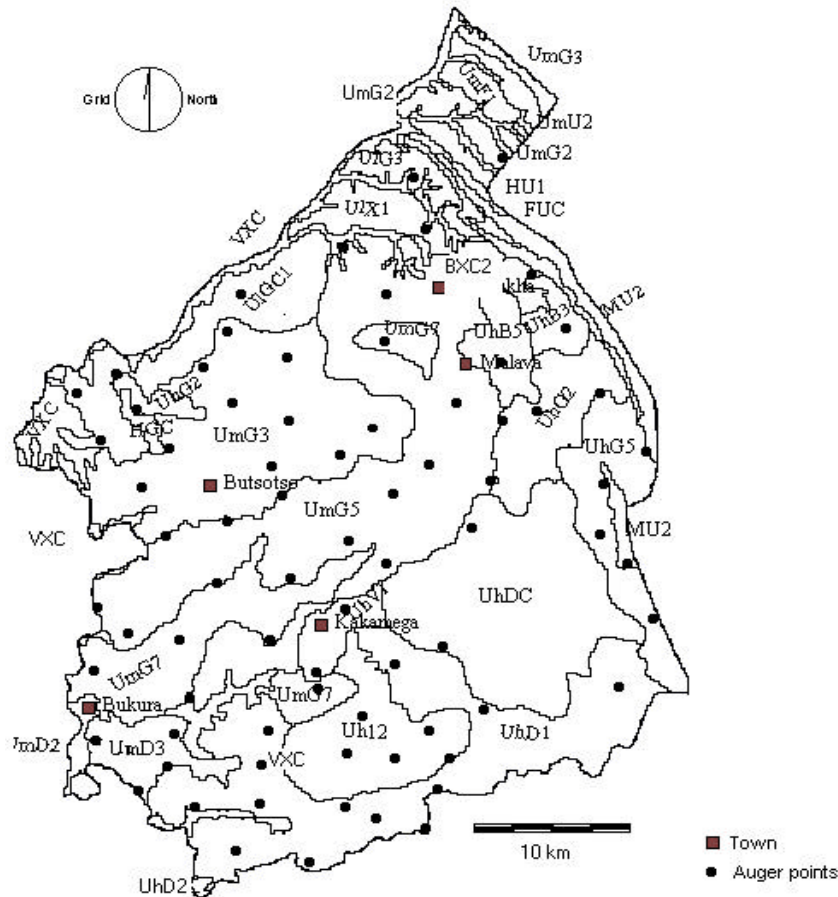


Fig. 1: Soil unit (adapted from FURP, 1987) and soil sample points for this study

vulnerable to erosion hence reducing farm productivity. Seventy percent of the soils are low in fertility due to intensive weathering, leaching and continuous use without proper conservation measures (GOK, 1997-2001).

Ecological requirements for soybean: The growth cycle of soybean is around 120 days in length and coincides with the period of each of the rain seasons in the study area (Fig. 2). Water availability for soybean development is critical during the periods of germination and pod filling (Hinson and Hartwig, 1982; Farias, 1994) that correspond to the first and third months of growing cycle, respectively.

During germination, an excess or deficit affects the number of plants per area. Moisture deficit is more detrimental to yield at pod filling than at any other growth stage. When deficits occur in the first stages of development, soybeans recover better than other crops as they can tolerate short periods of moisture stress due to a deep root system and a relatively long flowering period

(Farias, 1994). The damage caused to the plant by a dry spell will depend on the evaporation rate, duration of water deficit, the crop development stage and the type of soil. For maximum yields, 500 to 750 mm of water is required during the growing season (Langer and Hill, 1991), but dry weather is required for maturation therefore excess rainfall presents some limitation (Sys *et al.*, 1993).

Slight drainage impedance reduces yields through leaf senescence and decreases net photosynthesis. Soybean grows on both sandy and heavy textured soils with a wide pH range between 5.2 and 8.2. The crop has a medium erosion hazard and does not grow well in saline soils. Table 2 and 3 adapted from Sys *et al.* (1993) show respectively, the climate and soil requirements for soybean production in Kakamega District that were used for evaluation.

Soils and landscape data: The Fertilizer Use Recommendation Project report (FURP, 1987) contains a soil map of the study area (Fig. 1). The map was prepared

Table 3: Soil and landscape requirements for soybean production in Kakamega District (adapted from Sys *et al.*, 1993)

Land / Soil characteristics	Suitability class, ratings and range of values					
	S1	S2	S3	N1	N2	
	1	2	3	4	5	6
Topography (t)						
Slope (%)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding ^a	F0	-	-	F1	-	F2+
Drainage ^b	g	m	I	PA	PD	PND
Physical soil characteristics (s)						
Texture/structure ^c	C<60s, SiC, Co, SiL, CL, Si, SiCL	C<60v, C>60s, SC, L, SCL	C>60v, SL, LS, LfS	LcS, fSS	-	Cm, SiCm
Coarse fragment (Vol. %)	0-3	3-15	15-35	35-55	-	>55
Soil depth (cm)	>100	100-75	75-50	50-20	-	<20
CaCO ₃ (%)	0-6	6-15	15-20	20-25	-	>25
Gypsum (%)	0-0.1	0.1-0.2	0.2-1	1-2	-	>2
Soil fertility characteristics (f)						
Apparent CEC (cmol (+)/ kg soil)	>24	24-16	<16			
Base saturation (%)	>50	50-35	35-20	<20		
Sum of basic cations (cmol (+)/ kg soil)	>5	5-3.5	3.5-2	<2		
pH water	6.0-7.0	6.0-5.6	5.5-5.4	5.4-5.2	-	<5.2
Organic carbon (%)	>2	7.0-7.5	7.5-7.8	7.8-8.2	-	>8.2
Salinity and alkalinity (n)		2-1.2	1.2-0.8	< 0.8		
Ece ^d (dS / m)	0-5	5-6	6-7	7-8	8-10	>10
ESP ^e (%)	0-8	8-15	15-20	20-25	-	>25

^a F0, F1 and F2+ indicate none, occasional and seasonal including permanent excess surface water, respectively.

^b g, good; m, moderate; I, Imperfectly drained; PA, Poor and Aeris; PD, Poor but Drainable; PND, Poor but Not Drainable.

^c Cm, massive clay; SiCm, massive silty clay; C>60v, fine clay vertical structure; C>60s, fine clay blocky structure; C<60v, clay vertical structure; C<60s, clay blocky structure; SiC, Silty Clay, blocky structure; Co, Clay, oxisol structure; SiCL, Silty Clay Loam; CL, Clay Loam; Si, Silt; SiL, Silt Loam; SC, Sandy Clay; L, Loam; SCL, Sandy Clay Loam; SL, Sandy Loam; LfS, Loam fine sand; LcS, Loam coarse Sand; fS, fine Sand; S, Sand.

^d Electrical conductivity.

^e Exchangeable sodium percentage

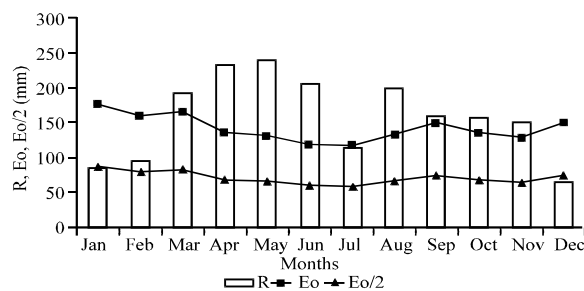


Fig. 2: Monthly rainfall (R), potential evaporation (Eo) and half the potential evaporation (Eo/2) distribution for Kakamega District

using background information from the Reconnaissance Soil Map of the Lake Basin Development Authority at scale 1: 250,000 (Andriessse and van der Pouw, 1985) and the Exploratory Soil Map of Kenya at scale 1: 1,000,000 (Sombroek *et al.*, 1982). The soil units are physiographic and descriptive in nature without any soil characteristic data. In order to retain the physiographic approach that facilitates use of soil mapping unit in land evaluation, slope classes (Table 1) of the physiographic units were used for evaluation of landscape suitability.

Soil characteristic data were obtained from samples collected at 0 to 30 cm and 30 to 60 cm depths for 76 geographically referenced points shown in Fig. 1. The sites were geographically referenced using a portable Global Positioning System (GPS). Soil depth was determined by augering to 100 cm or impervious layer. Soil drainage and flooding conditions were recorded at the sites. The collected soil samples were air-dried and the content of coarse fragments determined according to Gee and Bauder (1986), soil texture and organic carbon according to Okalebo *et al.* (2002), Cation Exchange Capacity (CEC) and basic cations (Ca, Mg, K, Na) as described in Sparks (1996), soil reaction (pH) and electrical conductivity according to Anderson and Ingram (1993). The sum of basic cations, base saturation, exchangeable sodium percentage and apparent cation exchange capacity were calculated. The values for the two depths sampled were averaged to provide the final value for evaluation (Sys *et al.*, 1991).

Climatic data: Meteorological data are required for land evaluation. These were available for Kakamega Research Station. Six other stations in the District record rainfall

data. These records were found insufficient for climatic suitability evaluation of the whole District. Therefore, the Almanac Characterization Tool (ACT) was used to obtain monthly rainfall and temperature data for the 76 sites randomly located throughout the District where soil samples were collected, ACT contains interpolated long term rainfall records for Africa and is used as a resource base for rainfall and temperature data at any referenced location (Corbett *et al.*, 2001).

Figure 2 derived from monthly data of Kakamega Agricultural Research Station over ten years (1990-1999) shows the District has two growth periods referred to as long rains' season occurring between March and June and short rains' season between August and November. Both seasons were evaluated for suitability of growing soybean. Data used in the evaluation were precipitation, mean and minimum temperatures.

Data analysis: A qualitative evaluation method (FAO, 1976) was used to select Land Characteristics (LCs) that present different suitability levels to soybean production in the District. Rain-fed production of soybean under a low level of management by small-scale farmers was the Land Utilization Type (LUT) considered for evaluation. Low level of management refers to the situation where farmers prepare land using either a hand hoe or oxen driven implements. No fertilizer or manure is used and crop yields depend on inherent soil fertility.

Evaluation of the climate for suitability to grow soybean requires that relative humidity and sunshine ration be considered (Table 2). Records from the KARI station show that relative humidity and sunshine ratio are not a problem in the study area. Land characteristics presenting different suitability ratings shown in Table 2 and 3 for the 76 sites were chosen to create maps using IDRISI32 (Eastman, 2000) Geographic Information System (GIS).

Maps showing coverage of landscape units, rivers, roads, towns, administrative boundaries and sampled points were digitized using PC Arc/Info (1992). Vector files for these features were created and exported as UNGEN files to IDRISI32. The files were imported and stored in IDRISI32 as digital maps for further analysis.

Sampled points were given identifiers in the digital map. Data base in which the 76 points had the relevant values of land characteristics were created and assigned to the sample points using point identifiers in the digital map. Surface analysis was performed on the resulting maps in a three step procedure.

First, the maps were analyzed for spatial dependence in the spatial dependence modeler and semivariograms created. Models were then fitted to the semivariograms in

the model-fitting module. Finally, these models were used to produce continuous surfaces of the characteristics using the ordinary kriging method. The continuous surfaces of the kriged maps were smoothed and reclassified based on suitability classes shown in Table 2 and 3. To evaluate the landscape, soil units in Fig. 1 were assigned their respective slope classes shown in Table 1 and reclassified according to slope classes shown in Table 3.

Climate suitability maps for both seasons were obtained by overlaying rainfall and temperature maps and then choosing the most limiting attribute layer to assign the final suitability. This accounted for the climate requirements of soybean. Overlaying maps of soil characteristics and landscape produced soils and landscape suitability map that accounted for the soils and landscape requirements of soybean. The climatic suitability maps for both seasons were overlaid with the soils and landscape map resulting in land suitability maps for both seasons.

RESULTS

Figure 3 shows evaluation maps of single land characteristics derived through ordinary kriging of sample point data and reclassifying into suitability levels. In the long rains season, mean temperature of the growing cycle (Fig. 3a) was the only climate characteristic found to present different levels of suitability to soybean

Table 4: Climatic suitability for soybean cultivation during the long and short rains seasons

Climatic suitability class	Long rains		Short rains	
	Area (ha)	(%)	Area (ha)	(%)
S1 (High)	115,898	78.0	13,971	9.4
S2 (Moderate)	30,648	20.6	134,489	90.5
S3 (Marginal)	2034	1.4	120	0.1
N (Unsuitable)	-	-	-	-
Total	148580	100	148,580	100

Table 5: Land suitability for soybean in the long and short rains seasons based on kriged values of sample points and average values of sample points per soil unit

Suitability	Long rains				Short rains			
	Kriged		Averaged		Kriged		Averaged	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
S1 (High)	4230	3	3739	2.5	2219	1	1394	0.9
S2 (moderate)	57366	38	112015	75	59877	40	115124	77.5
S3 (Marginal)	58142	39	6709	4.5	57642	39	5945	3.6
N (Unsuitable)	2725	2	0	0	2725	2	0	0
Valleys	8232	6	8232	6	8232	6	8232	6
Escarpments	2660	2	2660	2	2660	2	2660	2
Forests	15225	10	15225	10	15225	10	15225	10
Total	148580	100	148580	100	148580	100	148580	100

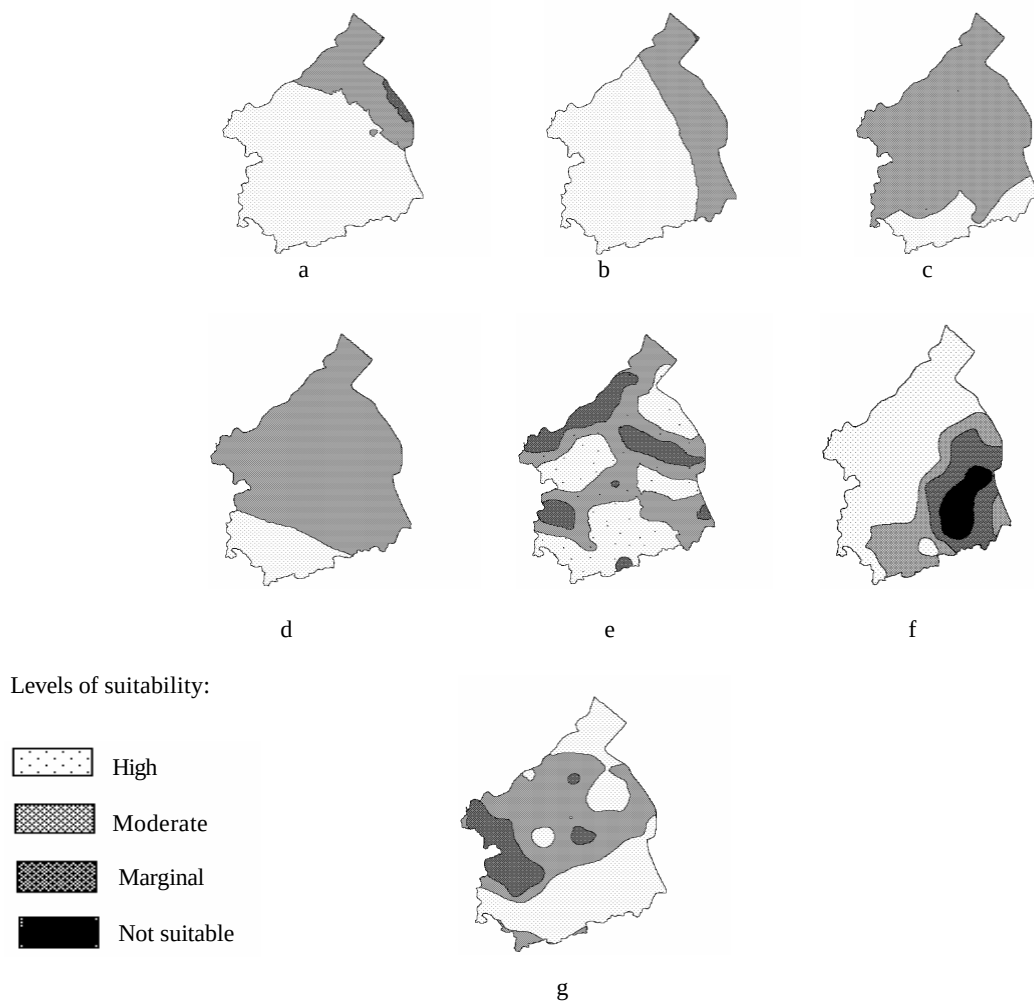


Fig. 3: Maps of climate and soil characteristics showing different suitability areas for soybean production
a = Mean temperature of growing cycle (long rains); b = Mean temperature of growing cycle (short rains);
c = Precipitation of 2nd month (short rains); d = Precipitation of 3rd month (short rains); e = Soil depth; f = Soil
pH; g = Soil organic carbon

production in the District. It was therefore used to evaluate amounts of land presenting different climatic suitability levels during this season. In the short rains season, mean temperature of the growing cycle (Fig. 3b) as well as precipitation of the 2nd month (Fig. 3c) and 3rd month (Fig. 3d) presented different suitability levels. These maps were overlaid to evaluate amounts of land with different climatic suitability levels in the short rains season.

Soil depth, soil pH and organic carbon (Fig. 3e, f and g, respectively) were soil characteristics presenting different suitability levels to soybean production. They were overlaid with the landscape and climatic suitability

maps of long and short rains seasons to give the land suitability maps for the respective seasons.

Table 4 shows results of climatic suitability evaluation for both long and short rains seasons. During the long rains season, 78% of the land is very suitable for soybean cultivation because of adequate temperatures and rainfall. Moderate and marginal land is 20.6 and 1.4% due to mean temperature of the growing cycle below 20 and 18°C, respectively. The low temperatures are associated with the high altitude of the Nandi escarpment. In the short rains season, 9.4% of the land is very suitable while moderate and marginal land is 90.5 and 0.1%, respectively. The significant reduction in very suitable

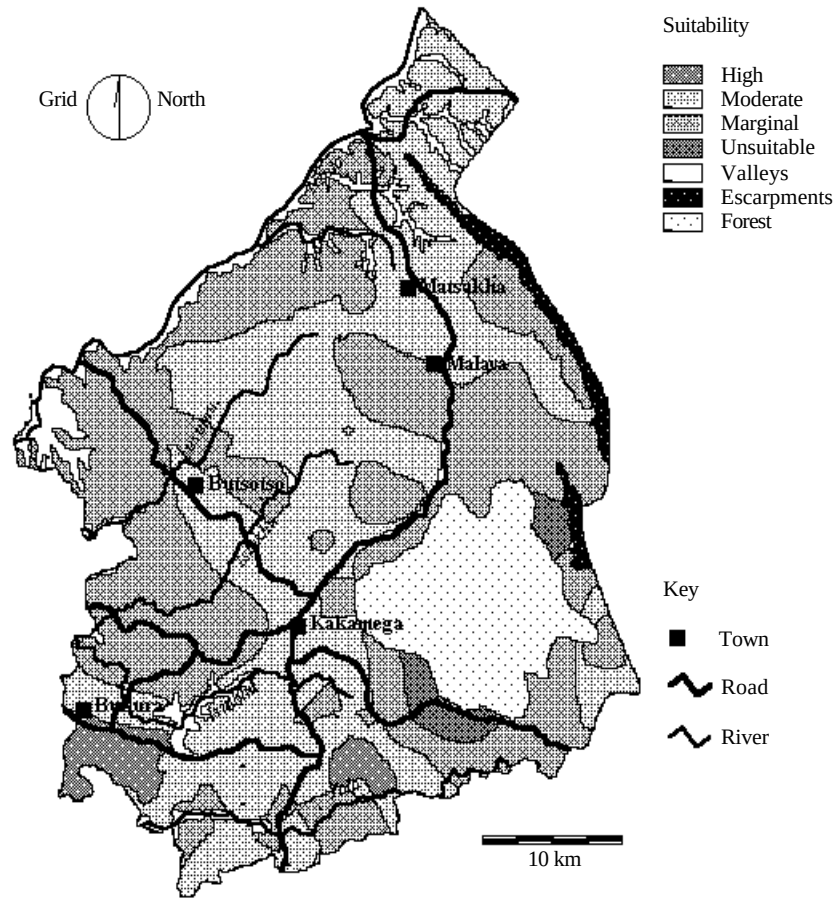


Fig. 4: Land suitability map for soybean production during the long rains season in Kakamega District

land from 78% in the long rains season to 9.4% in the short rains season is due to low amounts of precipitation (<115 mm) in October and November (Fig. 3c and 3d).

Figure 4 shows the land suitability map for the long rains season while Table 5 shows the area of land presenting various suitability levels in both seasons when evaluation is based on kriged characteristic maps and soil units. The soil units were evaluated based on average values of land characteristics from a number of sample points within a soil unit (Fig. 1 and Table 1). The total number of sample points for all the soil units was more than 76 because some fell on boundaries of two soil units and were therefore used for evaluating both units.

In the study area, 18% of the land is accounted for by valleys, escarpments and forests. Based on kriged individual land characteristic maps, very suitable land during the long rains is 3%, while moderate and marginal is 38 and 39%, respectively. In the short rains, the distribution is 1, 40 and 39%, respectively. Unsuitable land in both seasons is 2%. When evaluation was based

on soil units, the distribution was 2.5, 75 and 4.5% respectively in the long rains while in the short rains it was 0.9, 77.5 and 3.6%, respectively. No land was found unsuitable to soybean cultivation in both seasons in this case. Individual kriged characteristic maps revealed that limitations due to shallow soils, low pH and organic carbon affect 75% of the land. This reduces the amount of land that is very suitable during the long rains season from 78% due to climate to 3% when soils are included.

DISCUSSION

Land evaluation is traditionally based on conventional soil survey information i.e., the plan-view maps and written pedon and map descriptions. The plan-view maps show the distribution of soils and users of this information must glean the written descriptions in a separate location (Douglas *et al.*, 2005). Plan-view maps of the study area available did not have accompanying written descriptions. By randomly

sampling geo-referenced points and utilizing ordinary kriging techniques in GIS, it was possible to create continuous surface maps for individual soil characteristics and use them to produce land evaluation maps for soybean production in the study area. Interpolation techniques have been used before to map soil potassium in a field experiment (Bekele *et al.*, 2003). The techniques have been used to create factor maps for evaluation of suitable areas for crops even when detailed soil survey information was available (Ceballos-Silva and Lopez-Blanco, 2003a, b). Probably as a means to capture the inherent variability of soil characteristics within soil units arising from soil surveys.

When evaluation was based on average values of sample points within soil units, more land (>75%) was classified as moderate in both seasons due to the large sizes of the soil units. No land was classified as unsuitable yet sample point data showed sites that are classified as such due to limitations of soil pH. The variations in soil characteristics were therefore captured when interpolation technique was used.

The 76 sample points in this study seem far too few upon which to base analysis of an area covering about 1,486 km² compared to 1124 to 1128 sample points used by Ceballos-Silva and Lopez-Blanco (2003a, b) in their studies covering an area of about 3,026 km². Of course additional sites would improve the precision of evaluation results but this would also increase costs and timeframe within which they are required. Besides, 50 to 100 sample points have been suggested (Jongman *et al.*, 1987; Stein, 1994, 1995) as sufficient to create a semivariogram with reasonable degree of confidence. A semivariogram is a curve that traces local differences in the value of a variable when plotted against a distance axis.

Despite the limited sample points, individual factor maps created showed different degrees of suitability at different locations. The maps can be used to detect areas with attributes that require different soil management practices to improve crop production e.g. limitations brought about by soil depth, pH and organic carbon. The results also showed that suitability distribution of land during the long and short rains does not differ much. However, use of individual factor maps to address soil related problems would increase highly suitable land by reclaiming much of the 78% that has good climate in the long rains. Farmers should therefore be encouraged to utilize the long rains season to incorporate soybean in their cropping systems while at the same time practicing soil management strategies that increase soil organic carbon and pH. This study demonstrates the potential of using land characteristic maps derived by kriging geo-referenced random sample point data for land evaluation without a conventional soil survey. We suggest further research that compares land assessment

results based on such maps produced by different sample point intensities with those obtained using conventional soil survey data in terms of their precision and use for modeling agricultural systems.

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