Evaluation of Suitability of Some Soils in the Forest-Savanna Transition and the Guinea Savanna Zones of Ghana for Maize Production

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Abstract

Suitability of four soils located in the Forest-Savanna Transition zone and four others located in the Guinea Savanna zone of Ghana were evaluated for maize production using Soil Quality Index (SQI), Decision Support System for Agrotechnology Transfer (DSSAT) yield simulations and the Multi-Criteria Analysis (MCA). Wenchi (Ferric Dystric Leptosol), Ejura (Haplic Lixisol), Damongo (Dystric Nitisol) and Lima series (Eutric Gleysol) were located in the Forest-Savanna Transition agro-ecological zone whereas Kpelesawgu (Eutric Plinthosol), Varempere (Ferric Luvisol), Mimi (Haplic Lixisol) and Kupela (Eutric Gleysol) series were located in the Guinea Savanna agro-ecological zone. The study sites in the Forest-Savanna Transition zone were located in the Brong-Ahafo region whereas those in the Guinea Savanna zone were in the Northern region of Ghana. Properties used for the SQI rating included bulk density, pH, organic carbon, total nitrogen, available phosphorus, texture and water holding capacity. For the DSSAT, 1980 – 2010 weather variability impacts in addition to soil and management effects were used. The MCA evaluation included factors such as price, input and labour costs, distance to market, soil erosion and conservation factors. The three approaches gave different rankings of the soils for maize production. The SQI results rated the soils in the order: Wenchi > Damongo > Mimi > Ejura > Kupela > Lima > Varempere > Kpelesawgu. From the DSSAT simulations, the order was Varempere > Kpelesawgu > Damongo > Ejura > Kupela > Mimi > Lima > Wenchi. From the MCA, the rankings under different soil management options was in the order: Damongo > Mimi > Ejura > Wenchi > Lima > Varempere > Kupela > Kpelesawgu. Whereas both the SQI and the MCA ranked Kpelesawgu series as the least suitable for maize production, the DSSAT ranked it as the second most suitable. From the results, the soils in the Forest-Savanna Transition zone were more suitable for maize production than those in the Guinea Savannah zone. The soils with negligible gravel content could generally be considered as more suitable for intensive maize production. Although the SQI and the DSSAT yield simulations gave less desirable outcomes than the MCA simulations, they should be considered as useful basis for evaluating and designing the MCA criteria.

Introduction

Maize (*Zea mays*) is a major staple food crop in Ghana and accounts for about 1.8 million metric tons (Mt) of food consumed annually (Index Mundi, 2015). Although traditionally grown mainly in the southern zones of Ghana, maize cultivation has now spread to many locations including the Forest-Savanna Transition and the Guinea Savanna zones of the country. Maize yields are significantly higher than those of millet and sorghum (Obeng-Bio, 2010). For example, the Ministry of Food and Agriculture (2013) reported 1.7 Mt per ha of maize which was higher than the yields reported for millet and sorghum that year. In the past, decisions regarding where to locate intensive crop (maize) production had been based on land or soil suitability classification methods (Burrough *et al.*, 1992). The capability of a soil to produce food sustainably is fundamental for the survival of mankind (Mueller *et al.*, 2010) and a prerequisite for optimum land resource utilization (Mann *et al.*, 1977). However, not all soils have this capability. It is therefore necessary to assess the potential capabilities of soils regarding their properties and the management practices required for sustainable crop production.

Several land suitability ratings have been published (FAO, 1976; FAO, 1982; Landon, 2014; Qiu, *et al.*, 2014; Romano *et al.*, 2015; Zhang *et al.*, 2015). The most common is the FAO (1976) Land Suitability Rating which basically assesses the suitability of a soil for a given crop using soil properties such as pH, fertility and some morphological characteristics. From soil properties, a composite Soil Quality Index (SQI) (Mukherjee & Lal, 2014) can be determined and correlated with crop yield. With the support of the FAO, soil suitability maps have been developed for many crops in Ghana (Boateng *et al.*, 2005). Recently, climate change and climate variability have been reported to affect agricultural productivity in Ghana and could result in food insecurity (Atengdem *et al.*, 2013). There is therefore the need to also address the issues of climate change and climate variability in crop productivity assessments.

Impacts of climate change and climate variability on crop production cannot be derived from soil suitability rating alone. Thus, additional methods of assessment are necessary. Crop models offer the possibility to simulate crop productivity across different ecological zones given soil, management and long-term weather information (Naab *et al.*, 2004). In Ghana, crop models such as the DSSAT and Agricultural Production Systems Simulator (APSIM) have been evaluated and validated for several locations (Adiku *et al.*, 1998; Naab *et al.*, 2004; MacCarthy *et al.*, 2012). These tools are therefore available for the assessment of maize yield variability and stability and thus could be used for agricultural planning. Even if a location has good soil quality rating and yield stability, an investor would require additional information such as nearness to market, cost of labour and other inputs, soil conservation practices, among others to determine economic viability of a cropping venture. Thus, the overall evaluation and selection of intensive maize production sites must consider these additional factors, beyond soil and weather attributes. Appropriate tools are therefore required for such evaluations. The Multi-Criteria Analysis (MCA) provides tools for complex problems solving (Janssen, 2001; Mysiak *et al.*, 2005). Adiku *et al.* (1998), Atsivor *et al.* (2001) and Rose & Adiku (2001) also employed the MCA to compare the productivity of sole maize and maize-cowpea on some soils of Ghana. The objective of this study was, therefore, to evaluate the level of suitability of eight soil series in the Forest-Savanna Transition and the Guinea Savanna agro-ecological zones of Ghana for maize production using the SQI, DSSAT yield simulations and MCA procedures.

Materials and methods

Study areas

The study areas (Fig. 1) were in the Forest-Savanna Transition and the Guinea Savanna agro-ecological zones of Ghana located in the Brong Ahafo and the Northern Regions respectively. Eight soil series were studied, of which four namely Lima series (Eutric Gleysol), Ejura series (Haplic Lixisol), Damongo series (Dystric Nitisol) and Wenchi series (Ferric Dystric Leptosol) were located in the Forest-Savanna Transition agro-ecological zone and the other four; Varempere series (Ferric Luvisol), Kupela series (Eutric Gleysol), Mimi series (Haplic Lixisol) and Kpelesawgu series (Eutric Plinthosol), were located in the Guinea Savanna agro-ecological zone (Table 1). The eight soils were dominant in the major agricultural lands in the two agro-ecological zones. They were classified by the Soil Research Institute (1999) according the FAO/UNESCO classification system (1990).

The rainfall pattern in the Forest-Savanna Transition Zone is characterized by a main rainy season, which starts from April and continues till the second week of July. Within

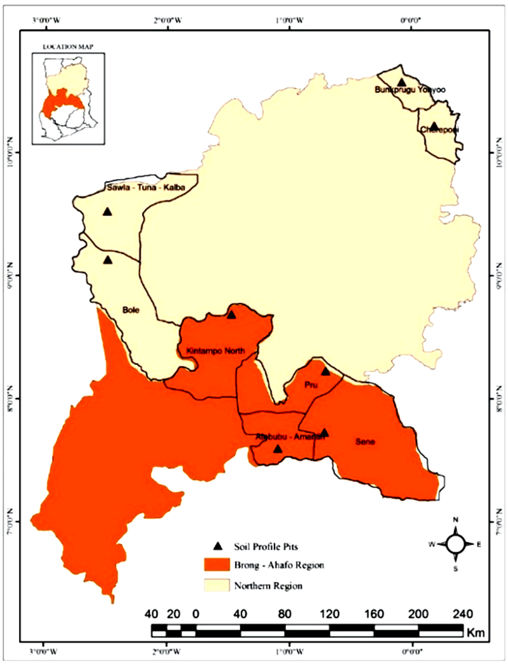

Figure 1. Location of Study Areas

this period, over three quarters of the total annual rainfall may be recorded. The minor rainy season occurs in September to October followed by a long dry season from November to the end of March or early April. The total annual rainfall varies from 1100 to 1400 mm. Temperatures in the zone range from 17 to 33 ºC with the lowest recorded in August and the highest in December, January and February.

The Guinea Savanna zone is characterized by well-defined wet and dry seasons of about equal durations with mean annual rainfall between 900 – 1100 mm. Monthly rainfalls increase gradually from March until a maximum is reached in August to September. The mean monthly temperatures are high throughout the year ranging from 25 ºC to more than 33 ºC. Relative humidity ranges from 75% in the rainy season to 35% in the dry and hot periods. The vegetation of the study area was predominately tall grasses with scattered trees and shrubs.

The study sites were predominantly nearly level to gentle slope with slope gradient of about 0.5 – 5%. The underlying geology of the study areas consist of sedimentary rocks,

TABLE 1

Location of sites and soil series

Region	Districts	Communities	Soil Series
Brong Ahafo	Pru	Kwayasi Yeji	Wenchi
(Forest-Savanna Transition)	Sene	Shafa-Wiase Zongo	Damongo
	Atebubu	Lailai	Ejura
	Kintampo North	Alhassan Kura	Lima
Northern	Bunkpurugu Yunyoo	Nannik	Mimi
(Guinea Savanna)	Chereponi	Naturi	Kpelesawgu
	Bole	Gbogdaa	Kupela
	Sawla-Tuna-Kalba	Nahari	Varempere

mainly sandstone, clay shale and mudstone of early Carboniferous age (Junner, 1946). The geological formations over which the soils were developed include coarse and fine grained Voltaian and/or feldspathic sandstones, granite, Voltaian clay, shales and mudstone (Junner, 1946). Ejura and Damongo series (Agyili, 2003) and Mimi series (Adu, 1995) were developed in-situ from Voltaian sandstone. Kpelesawgu series was also developed in-situ from clay shales and mudstone (Adu, 1995). Varempere series (Adu and Asiamah, 2003) and Wenchi series (Agyili, 2003) were sedentarily developed from granite, Voltaian sandstone, clay shales and mudstones and both soils were also strongly influenced by plinthitization. Lima series was developed from alluvial deposits on clay shales and mudstones (Agyili, 2003) whereas Kupela series was derived from alluvial deposits on granite (Adu and Asiamah, 2003).

Atengdem *et al.*, (2013) reported that farmers in the study areas were engaged in crop production, poultry and livestock as their main source of livelihood. Food crops such as maize, millet, sorghum, cowpea and yam were the main crops cultivated in the study area located in the Northern region (Guinea Savanna zone) whilst maize, cowpea and yam were mainly cultivated in the area located in the Brong Ahafo region (Forest Savanna Transition zone).

Soil quality rating

The indicators we used in the soil quality rating and evaluation included percentage gravel content, particle size distribution (Bouyoucos, 1962), bulk density (Black & Hartge, 1986), pH (Mclean, 1982), total nitrogen (Bremner & Mulvaney, 1982), organic carbon (Walkley & Black, 1934), available phosphorus (Bray I; Bray & Kurtz, 1945) of soil samples taken from the profiles of the eight soils. The soil quality index (SQI) for each soil series was determined according to the procedure of Mukherjee & Lal (2014). For this, several soil indicators, thresholds, interpretation for crop growth and scores were derived (Equations 1 – 4). In addition to physico-chemical and morphological properties, water holding capacity (WHC) estimated by pedo-transfer function (Ritchie *et al*, 1999) was also used. The data are presented in Table 2. For each property, published values were used and rated

TABLE 2

Measured Soil Properties and Calculated Soil Quality Index (SQI)

Soil Series	Depth	pHw	BD	OC	TN	Sand	Silt	Clay	Text.	Avail. P	WHC	SQI*
	(cm)	1:1	(Mg/m^3)	-------------------		%		-----------------		(mg/kg)	(mm/m)	
Wenchi	29	6.46	1.61	1.53	0.13	46.50	7.25	46.25	C	5.90	37.20	49.39
Damongo	159	6.09	1.58	0.27	0.05	47.69	14.88	37.43	SC	1.71	99.75	47.63
Ejura	140	6.16	1.71	0.23	0.05	64.51	15.34	20.15	SCL	1.80	97.50	42.11
Lima	125	7.07	1.69	0.31	0.06	61.42	13.88	24.70	SCL	2.17	52.40	36.62
Mimi	165	5.95	1.49	0.20	0.04	65.13	17.46	17.41	SL	1.95	78.60	44.61
Kpelesawgu	115	7.05	1.56	0.72	0.09	50.49	12.67	36.84	SC	1.78	12.00	33.84
Kupela	122	7.05	1.67	0.53	0.09	66.54	7.04	26.42	SCL	0.88	47.60	36.71
Varempere	102	6.65	1.59	0.25	0.05	73.28	11.25	15.47	SL	2.99	24.40	36.40

BD = bulk density, OC = organic carbon; TN = total nitrogen; Avail. P = available phosphorus; C: clay; SC: sandy clay; SCL: sandy clay loam; SL: sandy loam, Text = Texture (USDA); WHC = water holding capacity; *estimated

TABLE 3
Soil indicators, thresholds, interpretations and scores

Indicators	Range	Interpretation	Score
pH	5.5 - 7.2	Slightly acidic to neutral: Optimum for plant growth	2
	>7.2 <8.0	Slightly to moderately alkaline: Preferred by some plants, possible P and some metal deficiencies	1
EC (μS cm^{-1})	<200	low salt level	0
	200 - 500	Optimum salt level for plants	1
	>500	High salt level, adverse effect likely	0
BD (Mg m^{-3})	<1.0	High organic soil, supports plant roots	2
	1.0 – 1.5	Adverse effects unlikely	1
	>1.5	Adverse effects likely	0
N (%)	0.2 - 0.3	Moderate limitation	1
	>0.3	Slight to no limitation	2
SOC (%)	2 - 3	Moderate limitation	1
	>3.0	Slight to no limitation	2
AWC (%)	<20	Water-stress to plants	0
	20 - 50	Moderate water availability	1
	>50	Good water capacity for plants	2

BD = bulk density, OC = organic carbon; TN = total nitrogen; Avail. P = available phosphorus; C: clay; SC: sandy clay; SCL: sandy clay loam; SL: sandy loam, Text = Texture (USDA); WHC = water holding capacity; *estimated

accordingly. The rating scheme of Mukherjee & Lal (2014) was followed (Table 3). In order to minimize subjectivity in assigning rating values of measured properties to the soils, equations were derived based on limits and then applied. The functions for the soils properties are as follows:

$$\text{pH score} = 0.0086 \times \text{pH}^4 - 0.22 \times \text{pH}^3 + 1.79 \times \text{pH}^2 - 4.89 \times \text{pH} + 2.76 \quad (R^2 = 0.972; 1)$$

$$\text{SOC score} = -0.33 \times \text{SOC}^2 + 0.56 \times \text{SOC} - 0.097 \quad (R^2 = 0.992; 2)$$

$$\text{totN score} = -6.24 \times \text{totN}^2 + 8.48 \times \text{totN} - 0.83 \quad (R^2 = 0.984; 3)$$

$$\text{Avail.P score} = -0.0023 \times \text{Avail. P}^2 + 0.10 \times \text{Avail.P} - 0.0013 \quad (R^2 = 0.998; 4)$$

Bulk density is considered to affect maize growth due to mechanical impedance to root growth. For this, two values were determined. The first was the texture dependent critical bulk density (CBD; Eqn. 5) above which plant growth begins to be impaired and the second was the growth limiting bulk density (GLBD; Eqn. 6) below which growth stops (Pierce *et. al*., 1983).

$$\text{CBD} = 0.0175 \times \%\ \text{Sand} + 0.0168 \times \%\ \text{Silt} + 0.0122 \times \%\ \text{Clay} \quad (5)$$

$$\text{GLBD} = 0.0192 \times \%\ \text{Sand} + 0.0182 \times \%\ \text{Silt} + 0.0124 \times \%\ \text{Clay} \quad (6)$$

Using the average textural data for all the soils, the CBD and GLBD were determined and used to derive the BD score (Eqn. 7) as follows:

$$\text{BD score} = \min(8.51 \times \text{BD}^2 - 33.2 \times \text{BD} + 32.36) \quad (R^2 = 0.9862; 7)$$

where 'min' selects the lowest of the terms in the parenthesis. For WHC, plant extractable water was first determined from texture, organic carbon, coarse fragments percentage using pedo-transfer functions of Ritchie et al., (1999) and then converted to WHC (Eqn. 8) by multiplying with soil depth.

$$\text{WHC score} = -0.0001 \times \text{WHC}^2 + 0.029 \times \text{WHC} \quad (R^2 = 0.9784; 8)$$

The ranges of score weightings were not the same for all properties. Bulk density and available P had a zero to unity (0 – 1) scale while the others had zero to two (0 – 2). For the pH, the lowest score was "1" (Table 3).

Simulation of maize yield using DSSAT

The DSSAT crop model (Jones *et al.*, 2003) was used to simulate maize growth for each soil series. The measured soil data (Table 2) were used as inputs into the model and determined for the period 1980 to 2010. Two management conditions were simulated: (i) low-input farmer practice with no fertilizer addition (T1) and (ii) fertilizer application at the recommended rate of 120 kg N ha^{-1} using NPK (60 – 40 – 40; T2; SRID, 2011). The potential maize yield for each location was simulated (Table 4) by assuming a nitrogen application rate of 120 kg ha^{-1}. The long-term weather (daily temperature, rainfall and solar radiation) data (30 years: 1980 to 2010) for the various locations were obtained from the Ghana Meteorological Agency. The simulated yields for each location were subjected to statistics and coefficient of variation (CV) was used as a measure of yield stability.

Multi-criteria analysis

The Janssen (2001) version of the MCA tool was used in this study. The various soil series were considered as alternative locations for maize production and these were compared under 8 different criteria, namely: (1) revenue (price x yield, with the yield being the DSSAT simulated mean yield and the price adjusted for inflation price using the consumer price index; Adam & Tweneboah, 2008), (2) fertilizer cost (amount x price; GOG, 2015), (3) SQI-score, (4) labour cost, (5) Modified clay ratio (MCR, soil erodibility), (6) conservation practice, (7) Fournier index and (8) distance to market rating. Entries for soil erosion parameters namely the erosivity, soil erodibility and erosion control practices by farmers on the various soil series formed other inputs of the MCA. Rainfall erosivity was calculated according to the Fournier (1960) index (FI) as:

$$\mathrm{FI} = \frac{p^2}{\mathrm{P}} \qquad (9)$$

where *p* is the peak month rainfall (mm) and P is the annual mean rainfall. Soil erodibilty was calculated as the Modified Clay Ratio (Isikwue *et al.*, 2012):

$$\mathrm{MCR} = \frac{(\%\ \mathrm{Sand} + \%\ \mathrm{Silt})}{(\%\ \mathrm{Clay} + \%\ \mathrm{SOC})} \qquad (10)$$

Soil erosion control was based on the types of conservation practices implemented by

TABLE 4

Simulated maize yields for the various soil series

Region	Soil Series	Unfertilized (T1)	Fertilized (T2)	Mean Yield	SD	CV (%)
		---------------kg ha^{-1}	-----------------			
Brong Ahafo	Wenchi		29	29.5	0.71	0.02
(Forest-Savanna Transition)	Damongo	1,293	3,155	2,224	1,316.63	0.59
	Ejura	1,778	3,573	2,675.5	1,269.26	0.47
	Lima	3,707	4,095	3,901	274.36	0.07
	Mimi	2,712	4,038	3,375	937.62	0.28
Northern	Kpelesawgu	481	2,541	1,511	1,456.64	0.96
(Guinea Savanna)	Kupela	2,701	4,082	3,391.5	976.51	0.29
	Varempere	58	1,491	774.5	1,013.28	1.31

farmers. Practices such as residue retention and ridging were scored higher than bare and clean tillage. Data on the distance to market were calculated by the use of ArcMap software (ESRI, 2001). All the criteria were assumed to have equal weighting and the entries are summarized in an "Effects" Table (Table 5). To arrive at an overall score for each soil series, entries of each row were normalized by using their corresponding mean. The normalized values for each soil series were then summed and ranked relative to the scores of the other soil series.

Results and discussion

Soil suitability classification

The soils were generally sandy except Wenchi series which was clayey. Most of the soils were deep with depths ranging from 100 to 165 cm. On the other hand, Wenchi series was very shallow with a depth of 29 cm (Table 2). Kpelesawgu and Varempere series from the Guinea Savanna zone recorded gravel contents of 87.67% and 61.72% respectively (Table 5). Wenchi series from the Forest-Savanna Transition zone had a gravel content of 81.02%. The other soils, Kupela and Mimi series (Guinea Savanna zone) and Ejura (Forest-Savanna Transition zone) showed negligible gravel content. The bulk density of the soils ranged from 1.49 Mg m^{-3} (Mimi series) to 1.71 Mg m^{-3} (Ejura series). Table 2 shows that the pH of the soils ranged from 5.95 (slightly acidic) to 7.07 (neutral).

The pH levels fell within the range 5.5–7.2 which had a score of 2 (Tables 3). This range of pH was suitable for the growth of most plants. The levels of organic carbon and total nitrogen in the soils were low. Although the soils were generally sandy, they recorded a varied water holding capacity which ranged from the highest of 99.75 mm m^{-1} in Damongo series in the Forest-Savanna Transition zone to the lowest of 12.00 mm m^{-1} in the

TABLE 5

DEFINITE Problem Definition Alternative Effects for each Soil Series

Effects	---------------Guinea Savanna			----------------------	-------------Forest-Savanna Transition			----------
	Kpelesawgu	Varempere	Kupela	Mimi	Ejura	Damongo	Wenchi	Lima
R	720	744	720	1360	3120	1980	600	1440
FC	-363.76	-363.76	-363.76	-363.76	-363.76	-363.76	-363.76	-363.76
SQI-score	33.84	36.40	36.71	44.61	42.11	47.63	49.39	36.62
LC	-677.75	-677.75	-677.75	-677.75	-717.75	-717.75	-717.75	-717.75
MCR	-0.71	-0.26	-0.33	-0.15	-0.75	-0.39	-0.98	-0.55
CP	-10	10	-10	30	10	10	30	20
FI	174.79	141.86	141.86	174.79	178.94	178.94	178.94	144.8
DM	0.003	0.0004	0.0044	0.003	0.0016	0.04	0.01	0.0016
GC	87.67	61.72	NG	NG	NG	NG	81.02	NG

Units of measure; (-) indicate cost; (+) indicate benefits, R = Revenue (Yield x price), FC = Fertilizer cost (amount x price) GH¢ ha^{-1}, LC = Labour cost (GH¢ ha^{-1}), MCR = soil erodibility, CP = Conservation practice, FI = Fournier Index, DM = Distance to Market rating (1/d^2), GC = Gravel content (%), NG = negligible

Kpelesawgu series from the Guinea-Savanna zone. The soils had low moisture content,< 50% threshold (Wallace, 2000) at the time of observation. The SQI for the soils varied, ranging from 33.84 to 49.39 (Table 2). Wenchi series had the highest score of 49.39 while Kpelesawgu had the least score of 33.84. The major limitations of Kpelesawgu series seemed to be its poor water holding capacity (Table 2) and sandy texture. Consequently, the soil quickly dried up at the onset of the dry season. Wenchi series also showed properties similar to those of Kpelesawgu series but the presence of an underlying hardpan contributed to its relatively higher score for WHC. The SQI ranking of the soils for their suitability for maize production was Wenchi > Damongo > Mimi > Ejura > Kupela > Lima > Varempere > Kpelesawgu.

DSSAT maize yield simulations

Simulation outputs in Table 4 indicate that apart from Wenchi series, the soils would support high maize production if appropriate management interventions are adopted. Generally, T2 showed increased yield in all the soil series with CV ranging from 0.07% (Lima series) to 1.31% (Varempere series) even at very low to low WHC and SOC. The mean yield ranged from a lowest of 29.5 kg ha^{-1} (CV = 0.02%) for Wenchi series to 3,901 kg ha^{-1} (CV = 0.07%) for Lima series (Table 4). Both Wenchi and Lima series were located in the Forest-Savanna Transition zone. From the Guinea Savanna zone, Varempere series recorded the lowest mean yield (774.5 kg ha^{-1}; CV = 1.31%) whilst the highest of 3,391.5 kg ha^{-1} (CV = 0.29%) was observed for Kupela series. Under unfertilized conditions (T1), Wenchi, Kpelesawgu and Varempere series showed lower yields of maize than the 1.7 t/ha reported by the Ministry of Food and Agriculture (MoFA) (2013). However, under fertilized conditions (T2), all the soils except Wenchi and Varempere series showed higher yields than that reported by MoFA.

Multi-criteria evaluation

To make an appropriate soil management decision in crop production, there would be multiple factors to be considered including those that may affect the returns a farmer would obtain from yield. For instance, while a farmer's interest may be to increase income from harvest, an agronomist would rather focus on factors that may enhance soil productivity. Thus, to successfully combine these defined set of criteria (Table 5),

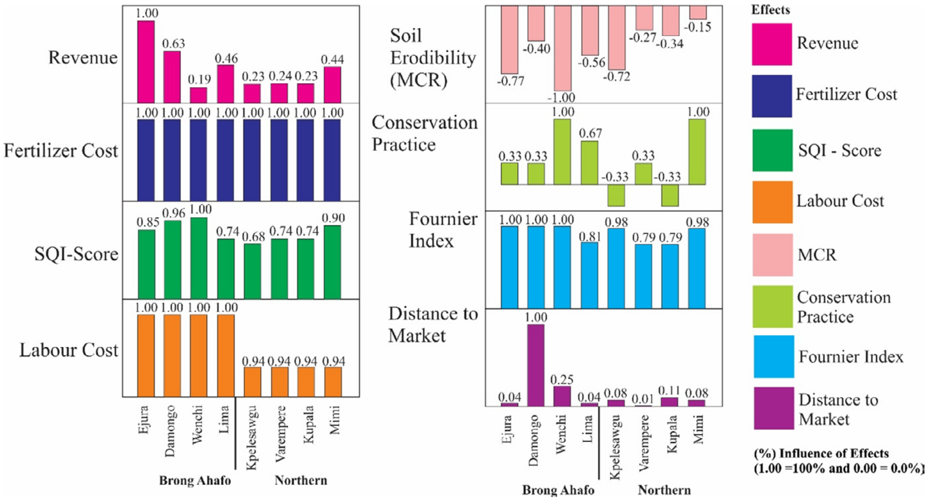

Figure 2. Criteria scores for the different soils

alternative soil management strategies were evaluated with the MCA (Fig. 2). As shown in Table 5, fertilizer cost, soil erodibility, labour cost and conservation practices were all considered as cost to the farmer because they affect crop performance and yield. On the contrary, revenue, SQI-score, Fournier index and distance to market were considered as *benefits* to farmers. Ejura series recorded the highest revenue (i.e. GH¢ 3,120.00) while Wenchi series recorded the lowest of GH¢600.00 (Table 5). The negligible gravel content of Ejura series and its proximity to market contributed greatly to its ranking with the highest revenue. On the contrary, the high gravel content of Wenchi series and the fact that it was the second farthest away from the market contributed to it having the lowest revenue.

Due to availability of subsidy, fertilizer cost was considered to be the same (GH¢ 363.76) for all the soil series.

However, labour cost was location specific and ranged from GH¢ 717.75 in the Forest-Savanna Transition zone to GH¢ 677.75 in the Guinea Savanna zone. Wenchi series recorded the highest soil erodibility value (-0.98) while Mimi series had the lowest (-0.15). Conservation practices particularly, residue retention were highly prevalent on Wenchi and Mimi series (CP value = 30). On the other hand, conservation practices were rare on Kpelesawgu and Kupela series hence a score of "-10" was recorded. Varempere series was the nearest to the market center with a score of 0.0004. The other soils were in the order: Lima = Ejura > Kpelesawgu = Mimi > Kupela > Wenchi > Damongo in terms of their nearness to a market centre.

Figure 3 shows the MCA outcomes and the overall ranking of each criterion in relation to each soil series. The MCA results generally ranked the soils of the Forest-Savanna Transition agro-ecological zone higher than those of the Guinea Savanna agro-ecological zone.

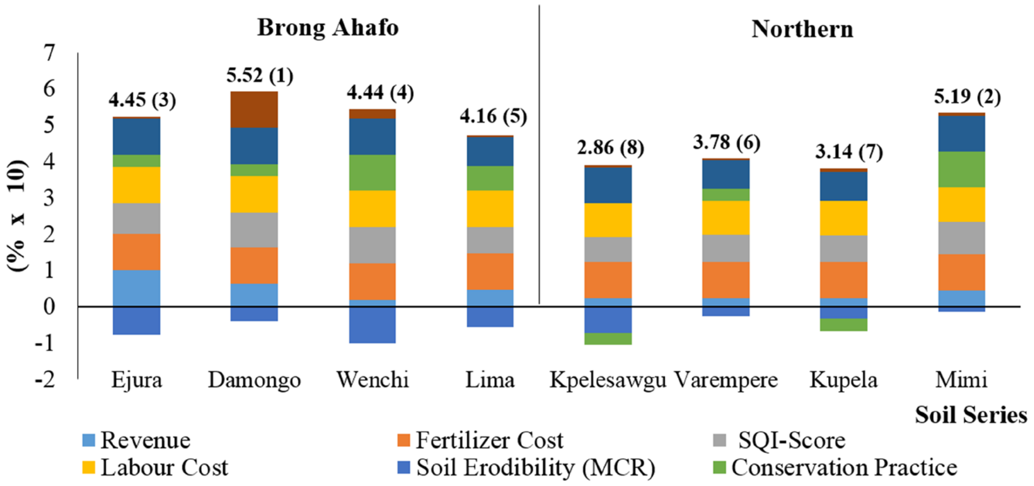

Figure 3. Ranked soil alternatives

The generally flat terrain of the Guinea Savanna agro-ecological zone might have partly contributed to the lower MCA values of the soils in that zone. The terrain of the Forest-Savanna Transition zone was, on the contrary, mostly undulating. Conservation practices were rated higher in the Forest-Transition agro-ecological zone than in the Guinea Savanna agro-ecological zone. The difference in the level of conservation practices was also partly influenced by more intensive livestock grazing in the Guinea Savanna agro-ecological zone (Antwi, *et al*., 2014; Boakye-Danquah *et al*., 2014; Nang, 2015). This therefore affected the MCA of the soils in the Guinea Savanna zone. Damongo series ranked the highest (with an overall score of 5.52) for maize production under different soil management options. It was followed by the other soils in the order: Mimi (5.19) > Ejura (4.45) > Wenchi (4.44) > Lima (4.16) > Varempere (3.78) > Kupela (3.14) > Kpelesawgu (2.86).

Although the MCA used in this study was simple and straight forward, ranking was very sensitive to the influence of each criterion applied (in this case the *effects*). Beyond soil-related limitations, the outcomes of the overall ranking were significantly affected by fertilizer and labour cost (Fig. 2). Moreover, the impact of rainfall on associated runoff (from sheet and rill erosion), estimated with the Fournier index, also affected the MCA outcome. This result was partly due to the relatively higher rainfall in the Forest-Savanna Transition agro-ecological zone than the Guinea Savanna agro-ecological zone.

Conclusions

Generally, Damongo series could be ranked as the most suitable for intensive maize production. Based on all the rankings, Damongo, Lima and Ejura series (Forest-Transition zone) and Mimi series (Guinea Savanna zone) could be considered suitable for intensive maize production. The other soils namely Kpelesawgu, Kupela, Varempere and Wenchi series could be considered marginal for intensive maize production. The results of the study showed that there were more areas in the Forest-Savanna Transition zone suitable for maize production than in the Guinea Savanna zone of Ghana. To decide on the appropriate soil management options for maize production, it was important to consider multiple factors including those that affect the returns of a farmer. From the results of the study, the MCA gave more desirable outcomes than the FAO ratings (SQI) and the DSSAT yield simulations. However, the FAO ratings and the DSSAT yield simulations should not be disregarded but rather be considered and used as basis for evaluating and designing the MCA criteria. Due to the fact that each approach led to a different ranking of the soil series, it is recommended, based on the results of the study that the MCA rather than the FAO ratings are used in identifying alternative management possibilities for maize production. Furthermore, the importance of MCA for effective decision making cannot be overemphasized. Also, farmers' preferences should be considered in decision making rather than solely relying on the traditional FAO soil suitability ratings for soil management. Site specific weather data and field trials are recommended to improve the MCA outputs. It must be emphasized that these overall scores are site dependent (i.e. specific to the study location) and each criterion is important in the decision-making process.

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