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ASSESSMENT OF FACTORS AFFECTING SOIL MOISTURE FOR THREE AGRICULTURAL LANDUSE MANAGEMENT USING REGRESSION APPROACH

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ABSTRACT

Abstract: The study examines the major factors affecting soil moisture characteristics of three agricultural landuse management in Akwanga. Six sites were selected to measure infiltration and runoff amount on three landuse types. The three sampled landuse types are: farmland, fallow plot and orchard. Data was collected using 17 rainfall events in 3 months (July to September) to cover ten variables which are infiltration amount, runoff from plot, rainfall, slope, land use coefficient, soil porosity, soil moisture, sand, silt and clay. The data were analyzed using correlation and regression analysis. The results of the study shows that there is a significant relationship between the amount of soil moisture with infiltration, run off, landuse coefficient, soil porosity and silt characteristics of the landuse types. Our results indicates that the regression model developed in this study can predict the observed soil moisture reasonably well in our study area. Infact, the total measured soil moisture in the study area was 55.5% while our model predicted total soil moisture is 54.17%. These results further indicates that these major factors identified jointly explained the variation in the amount of soil moisture in the region with the r^2 of 0.95 that can predict soil moisture amount in this study area. These results are very important for policy makers and practicing farmers because this model can be used for deficit irrigation scheduling especially during the critical plant growth stages..

1.0 INTRODUCTION

Soil moisture or soil water, which is the quantity of water contained in a soil, is an important soil component as it serves as a solvent and carrier of food nutrients, regulates soil temperature and essential for photosynthesis among other uses (Aina *et al* 2017) . The available moisture in a particular soil is however, depended on a number of factors such as climate, soil condition; vegetation type, slope, the infiltration capacity; runoff and general land use. These factors contributed to the spatiotemporal variation of soil moisture content in different environments (Yamoumoto 1997). These factors controlling the available moisture over a given surface relates to the characteristics of that surface which is also a factor or a result of the use it is put into.

Wang et al (2016) in their work on the effects of precipitation on soil moisture among different landuse, found out that precipitation greatly affects soil moisture variation in the following descending order: farmland, grassland, shrubland and woodland. While soil moisture under farmland was greatly affected by precipitation, woodland was least affected. Zribi *et al.* (2010) observed the effects of vegetation on soil moisture and stated that vegetation intercepts raindrops reducing their impact (which compacts the soil) thus increase infiltration and organic matter in the soils (which holds moisture). Interception, also substantially reduces not only the volume of water reaching the surface but also the erosive potential of rain drop (Brye *et al*., 2006).

Mariscal *et al.* (2007) noted that structure in soils however is a unique characteristic that affects porosity and permeability. They further stressed that when the soil structure is protected under dense vegetation and undisturbed by tillage, it will possess a surface structure sufficiently stable to allow rapid infiltration of water and to prevent crusting. Inherent factors affecting soil infiltration, such as soil texture, cannot be changed. Brye *et al*. (2003) added that porosity values ranges from soil of different land use, from as low as 25% in compacted sub soils to more than 60% in well aggregate high organic matter surface soils.

Soil texture (percentage of sand, silt, and clay) is the major inherent factor affecting infiltration. Water moves more quickly through large pores of sandy soil than it does through small pores of clayey soil, especially if clay is compacted and has little or no structure or aggregation depending on the amount and type of clay minerals, some clayey soils develop shrinkage cracks as they dry (Haghnazari *et al*. 2015**).** The tillage effect is greater for medium and fine textured soils and is influenced by the initial moisture content (Van Es *et al.*, 1991).

Therefore, several soil moisture studies have been carried out in Nigeria but only focused on other aspects of soil moisture such as the effects of moisture contents on different crops (Shitu *et at.* 2017, Aina *et al*. 2017, Lal 1974) and the relationship between soil moisture and ground water level (Fubara-Manuel 2014), but to the best of our knowledge no effort has been made to evaluate or assess factors affecting soil moisture content on different agricultural landuse management especially in our study area.

Therefore, the objective of this study is to evaluate factors affecting soil moisture on different agricultural landuse in Akwanga using the field measurement approach for the first time in this study area. This will provides researchers with field data for other research.

2.0 MATERAILS AND METHODS

2.1 Study location and Data

This study was carried out at Akwanga local government area of Nasarawa State which is located between latitude $8^0 34^1$ north and $8^0 47^1$ north and longitude $8^0 17^1$ east and $9^0 04^1$ east (See Figure 1). Three different agricultural land use types in the study area and six sites were selected for this work, based on different landuse criteria (See Table 1). These agricultural landuse types are farmland, fallow plot and orchard. For each landuse types, 2 sites were used, to give a total of 6 runoff sites (Plots). The runoff measurement was taken for each of the plots selected.

The data was collected over 3 month's period starting from July to September, 2012. The measurements were taken after each rain storm that produces runoff of 20mm and above; and a total of 17 rain storm was recorded. In September 2012, soil samples were also taken from the six sites for laboratory analysis.

Data was also collected on other parameters such as soil moisture, slope, rainfall, and runoff plots and infiltration capacity. The soil characteristics that were measured in this work include soil texture (sand, silt and clay), porosity and moisture content and these parameters were determined in the laboratory.

This paper made used of rainfall, 6 runoff plots on the 3 agricultural landuse types (2 on each) were selected (Li *et al*. 2011), a mixture of cement and sand was used to delineate the runoff plot (Johnston *et al*. 1980, Hoogmoed W.B *et al*. 1991, Shouse *et al*. 1994, and Heeren *et al*. 2014). 6 runoff collector were used to collect the volume of water passing downslope border of the plot (Hoogmoed W.B *et al*. 1991), 6 cans to collect rain water, one for each runoff plot (Hoogmoed W.B *et al*. 1991), soil samples were analysed using gravimetric method in the laboratory (Reynolds, 1970) and a Pantometer for measuring the slope of runoff plots (Blong, 1972)

Table 1: Landuse types in the study area

Landuse type	Sites	Comments
Farmland	Site 1	Maize farm beside Nacaps Polytechnic (Along Lafia-Wamba road bye pass)
	Site 2	Yam farm behind, Football field, College of Education, Akwanga.
Fallow land	Site 1	Fallow plot near Sports Field, Sports Academy (Kurmin Tagwaye). Km 3, Wamba road
	Site 2	Fallow land behind J.S 1 block, Mada Hills College
Orchard	Site 1	Mango Orchard, Gwanje (km 4, Jos road)
	Site 2	Oil Palm Orchard, Nsakpe (km 3.5, Keffi road)

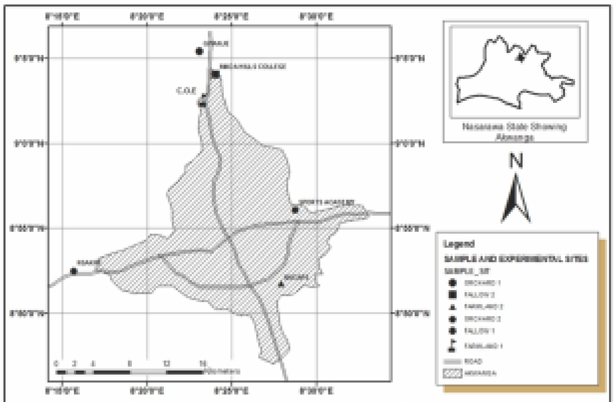

FIG. 2: AKWANGA TOWN SHOWING SAMPLE AND EXPERIMENTAL SITES

Figure 1: Nasarawa State showing the study

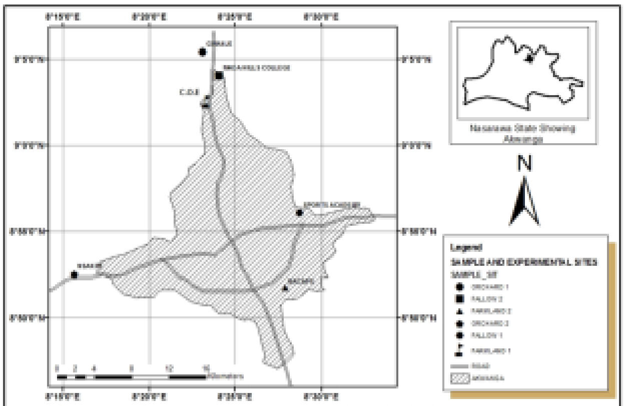

FIG. 2: AKWANGA TOWN SHOWING SAMPLE AND EXPERIMENTAL SITES

location

Figure 2: The study location showing the experimental sites

2.2 Measurement of Infiltration Capacity

The infiltration capacity was measured with the aid of the improvised runoff plots. This study therefore used a simple USDA Soil Conservation Service (1957) equation for calculating infiltration by using the improvised runoffs plots measurement. Mathematically written as

$$I = P - R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, P = Precipitation

R = Runoff, which was determined by the improvised runoff plots

I = Infiltration

The infiltration above is calculated as the excess of rainfall over runoff. This does not account for evaporation, which is especially high in the tropics. Therefore, these results should be interpreted conservatively.

The runoff plots were constructed on the six selected sites using a mixture of cement and sand. A totalizer was used to collect all the runoff, this was fixed at the mouth of the runoff plot constructed while the rain-gauges were used to collect rain fall. The slope was measured using pantometer.

The run off plot was determined by calculation using the method of irregular shape.

Full square = 32

½ square 19 ÷ 2 = 9.5

Total = 41.5

One complete square is 10 cm

Therefore 41.5 x 10 = 415cm^2

Converting cm to m 415 ÷ 100 = 4.15 m^2

The areal precipitation over plot was calculated using the formula of the area of a cylinder

Area = $(^1/_3)\ \pi R^2\ H$.................. (2)

Where, π = 22/7 (Constant)

R = Radius ($^1/_2$ of a diameter)

H = Height

The laboratory analysis of soil characteristics was done at the soil and water laboratory in the Department of Geography, Bayero University Kano. One hundred grams of soil was taken from the six sites as samples in September 2012 and was tested in order to determine the soil moisture content, texture and porosity.

To get the moisture content, fifty grams (50g) of soil sample was used out of the 100g taken from the study area. This was oven dried at 105^{0}c for 24 hours and reweighed. The moisture content was then obtained using the gravimetric method as

$$M = \frac{Ww - Wd}{Wd - Wc} \times 100 \qquad (3)$$

follows:

Where,

M is moisture content (%)

Ww is the weight of soil including moisture content

Wd is the weight of the soil after oven-drying

Wc is the weight of the container holding the soil sample

The particle size analysis was determined using dried soil sample which was sieved through a 2mm diameter mesh, after which the hydrometer method

$$BD = \frac{V}{W} \qquad (4)$$

was used to determine the soil texture of sand, silt and clay.

Soil porosity was determined with the oven dried six samples by first determining the Bulk density through the formula.

Where, BD = Bulk Density

$$\%\ \text{pore space} = \frac{\textit{Bulk density x 100}}{\textit{Particle density}} \qquad (5)$$

W = Weight of oven dry soil

V = Volume of oven dry soil

The land surface characteristics this study evaluated are those of slope and vegetation. The slope angle of the six sample sites was measured with the use of a pantometer.

Slope angle (^{o}) = 90 - Θ

Where, Θ = Actual angle measured on the field 90^o = Constant (Angle on a straight line)

The landuse types in this study area are categorized based on the vegetation cover for each of the study sites. Runoff coefficients of the different vegetation covers were used to represent different vegetation surfaces and land use in the parameters that were used for analysis. The standard landuse coefficient was used taking into cognizance the vegetation, soil type and slope for each landuse type stated as follows: Orchard 0.23, Fallow plot 0.23, and Farmland 0.25 (GSDA 2017, Bengtson 2010) see Table 8. In modeling the relationship that exist between the variables that are significant to the soil moisture in the study area, multiple regression (linear regression equation) was used to determine the effect of the variable on soil moisture in the study area. The soil moisture (X_7), was made the dependent variable, infiltration amount (X_1), runoff amount (X_2), land use coefficient (X_5), soil porosity (X_6), and silt (X_9) are the independent variable. A linear equation results from the association.

$$X_7 = a + b_{x1} + c_{x2} + d_{x5} + e_{x6} + f_{x9} + u \quad \ldots\ldots\ldots\ldots\ldots (6)$$ (Cohen, 2010)

Where M_w = soil moisture (dependent variable), a = constant (moisture intercept), b, c, d, e, f, are the beta values of variable X_1, X_2, X_5, X_6, X_9, which are independent variable of infiltration, runoff, land use coefficient, soil porosity and silt respectively. X can subsequently be replaced with M_w, R_1, R_o, C_1, P_r and S_i which are the symbols of the variables used in the model (See Table 2). Thus the equation can be rewritten as:

$$M_w = a + b_{R1} + c_{Ro} + d_{Cl} + e_{Pr} + f_{Si} + u \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$= 2001 + (0.001_{R1}) + (-0.01_{Ro}) + (-0.017_{Cl}) + (0.20_{Pr}) + (0.016_{Si}) + u$$

Soil moisture (Mw) is therefore a function of the variables RI, Ro, Cl, Pr, Si and so the equation can also be expressed as:

$$M_w = f(R_I, R_o, C_l, P_r, S_I) \quad \ldots\ldots\ldots\ldots\ldots (8)$$

Where Mw is soil moisture, and R_I, R_o, C_1, P_r, S_I are infiltration, runoff amount, land use coefficient, soil porosity, and soil silt (Table 2)

Table 2: Measured variables in the study area and their symbols.

s/n	Parameters	Variable code	Symbol
1	Infiltration amount	X_1	R_I
2	Runoff amount of a plot	X_2	R_o
3	Rainfall	X_3	R_f
4	Slope of runoff plot	X_4	S_p
5	Land use coefficient	X_5	C_I
6	Measure of soil porosity	X_6	P_r
7	Soil moisture weight	X_7	M_w
8	Soil sand content	X_8	S_a
9	Soil silt content	X_9	S_I
10	Soil clay content	X_{10}	C_c

Table 3: Monthly Rainfall of the study area in 2011

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Rainfall (mm)	-	-	8	58	144	189	221	496	240	213	-	-	1569

Source: Dept of Geography, College Of Education, Akwanga.

To further aid the analysis, variable codes and symbols were derived for each parameter used in this research. The variable codes were used when running the data through the multiple correlation and regression analysis while the symbols were used for the actual interpretation.

3.0 RESULTS AND DISCUSSION

3.1. Rainfall in the Study Area

Table 3 present the monthly rainfall total of the study area. The analysis show that even though the rain started in March, it peaked in August with 496mm. The relief effects of the study area gives it a high rainfall amount compared to the surrounding areas. These results also revealed a high seasonality of rainfall in the study area and this rainfall is concentrated in the months of June to October.

3.2. Soil Moisture Amount on the Different Landuse Surfaces

Table 7 present the results of the soil moisture amount of the study area. The results show that orchard 1 has the highest soil moisture amount of 63%, followed by orchard 2 with 61%. The results also revealed that the fallow landuse type has the second highest soil moisture amount. That is, fallow 1 has a soil moisture amount of 60.5% and fallow 2 has 59%. Farmland 1 and 2 both recorded the lowest soil moisture amount of 56% in the study area.

3.4. Soil Moisture Correlation Matrix

Landuse site	Soil moisture (%)
Orchard 1	63
Orchard 2	61
Fallow 1	60.5
Fallow 2	59
Farmland 1	56
Farmland 2	56

Source: authors laboratory work (September 2012)

Table 5 present the results of the soil moisture correlation analysis. The relationship between soil moisture and other parameters in the study area was analyzed. The results show that some of the variables (Infiltration (R_I), Porosity (P_r), Sand (S_a), and Clay (C_c)) have direct (positive) relationship with soil moisture in the study area meaning that an increase in the infiltration amount, pore spaces, sand and clay content encourages better soil moisture content of the soil.

While others (Runoff (R_o), Rainfall (R_f), Slope (S_p), Silt (S_l) and landuse coefficient (C_l) have an opposite (negative) relationship with soil moisture meaning that as runoff, rainfall, slope angle, silt content and landuse coefficient increases, the ability for soil moisture retention in the soil decreases.

The variables that have direct relationship with soil moisture in the study area are those that positively correlated with soil moisture, these are infiltration amount(X_1) with the correlation of 0.98 and soil porosity (X_6) with the correlation of 0.88 (See Table 5). This means that the more the infiltration amount in the soil the more the moisture content of the soil. In the same way, the larger the pore size or porosity, the more the soil moisture present in the soil.

The other variables that act in an opposite direction with soil moisture are negatively correlated, these are: runoff (X_2) with a correlation of -0.97, meaning that the more the surface runoff the lower the soil moisture and when soil moisture is on the increase, runoff will be on the decrease. Landuse coefficient (X_5) correlates with soil moisture at (-0.89), meaning that as soil moisture increases, landuse coefficient decreases and when landuse coefficient increases, soil moisture decreases. Also Silt (X_9) correlates negatively (-0.90), which means that the more silty the soils in the study area, the less the soil moisture in the soil (See Table 5). Soils with less silt have more soil moisture

Table 5: Soil moisture correlation matrix table

	M_W	R_I	R_o	R_f	S_p	C_I	P_r	S_a	S_I	C_c
M_W	1.00									
R_I	0.98*	1.00								
R_o	-0.97*	-0.97	1.00							
R_f	-0.24	-0.12	0.33	1.00						
S_p	-0.45	-0.41	0.50	0.78	1.00					
C_I	-0.89*	-0.82*	0.83*	0.44	0.34	1.00				
P_r	0.88*	-0.90*	-0.96*	-0.45	-0.39	-0.80	1.00			
S_a	0.59	0.59	-0.72	-0.75	-0.98	0.58	0.86*	1.00		
S_I	-0.90*	0.91*	0.97*	0.40	0.55	-0.77*	-0.98*	-0.79	1.00	
C_c	0.26	-0.27	0.27	0.68	-0.59	-0.10	.257	-0.55	-.068	1.00

The soil moisture matrix table above shows the relationship between soil moisture and other parameters in the study area.

3.5. Modeling Soil Moisture in the Study Area

Equation 8 was subsequently used to predict soil moisture in the study area. The results are the expected values while the actual values are the soil moisture collected from the field and the residual amounts are the differences between the actual soil moisture and the expected soil moisture predicted by the equation (Table 6).

The total actual soil moisture in the study area is 55.5% while the expected total soil moisture is 54.17% and the total residual soil moisture amount is 1.34. The model thus have a regression coefficient of 97.5% (r= 0.98) and a coefficient of determination of 95.2% (r^2 = 0.95) (See Table 7). These results indicates that our model predict the observed soil moisture reasonably well in our study area.

Table 6: Soil Moisture Prediction Table

Land use sites	Actual (%)	Expected (%)	Residual (%)
Orchard 1	13	11.26	1.74
Orchard 2	11	11.09	-0.09
Fallow 1	10.5	9.83	0.67
Fallow 2	9	8.47	0.53
Farmland 1	6	6.56	-0.56
Farmland 2	6	6.95	-0.95
Total	55.5	54.17	1.34

Table 7: The Results of the Soil Moisture Model

Model	R	R^2	Residual
Soil moisture	0.98	0.95	1.34%

3.3. Summary of the Results

Table 8 present the summary of our results of the study. The results show the mean value of the infiltration amount (R_I), runoff (R_o) and rainfall (R_f) of the respective landuse types identified in the study area. It reveals that Orchards have a lower amount of rainfall (R_f) of between 191144.12mm and 191388.2mm that gets to the ground probably due to trees intercepting the rain, and much of it infiltrates into the ground having infiltration amount (R_I) of between 190972.76mm and 191168.47mm and also recorded the lowest runoff amount (R_o) in the study area (between 171.35mm and 219.76 mm). Meanwhile, Farmlands recorded the highest value of runoff (between 381.94mm and 411.88mm) while fallow plots has a better infiltration capacities with an infiltration amount of between 191123.65mm and 191087.58mm.

The results also show the degree of sloppiness (S_p), landuse coefficient values (C_I), as well as soil moisture (M_W), soil textural classes of sand (S_a), silt (S_I) and (C_C). The slope value of 3% was observed for the Orchards plots (1 and 2). The fallow plots recorded slope angle of 2^0 and 4^0(1 and 2) while farmlands have between $3^0$and 4^0. In terms of porosity, Orchards have higher pore spaces (P_r) of between 4.2% and 4.6%, followed by fallow plots with porosity of between 3.1% and 3.3% while farmlands have the least pore spaces of between 1.2% and 2.7%. In the textural analysis, Farmland has the lowest content of sand (S_a) of 86.88% and higher silt content (S_I)of 4.73% while Orchard have the lowest silt content of between 2.28% and 2.62%. Although clay content (C_c) is highest in Fallow plots, with Fallow plots 1 having 8.85%, it also has the lowest clay content with Fallow plots 2 having the lowest clay content of 7.12% in the study area.

Table 8: Summary table of the data

S/N	Land use Sites	Parameters									
		R_I (mm)	R_o (mm)	R_f (mm)	S_p (0^0)	C_I	P_r (%)	M_W (%)	S_a (%)	S_I (%)	C_c (%)
1	Orchard 1	190972.76	171.35	191144.12	3	0.23	4.6	63	89.68	8 2.28	8.04
2	Orchard 2	191168.47	219.76	191388.24	3	0.23	4.2	61	88.97	2.62	8.41
3	Fallow 1	191123.65	264.58	191388.24	2	0.23	3.1	60.5	88.04	3.11	8.85
4	Fallow 2	191087.58	300.65	191388.24	4	0.23	3.3	59	89.42	3.46	7.12
5	Farmland 1	190518.06	381.94	191388.24	3	0.25	2.7	56	88.85	3.58	7.57
6	Farmland	190976.36	411.88	191388.24	4	0.25	1.2	56	86.88	4.73	8.39
	2										

Source: authors field work (July – September 2012)

4.0 CONCLUSION

This research used actual field measurements rather than simulated data and it is a combination of existing works in hydrology and soil science thereby contributing to the knowledge in the use of land and soil water management. The paper provides an assessment of soil moisture characteristics on different agricultural land use surfaces

The major parameters influencing soil moisture content in the study area are: infiltration, runoff, land use coefficient, soil porosity and silt. The significance level of these parameters was tested with a linear regression equation in order to develop a model in predicting soil moisture content in this study area. As such, the following equation or model was developed.

$$M_w = f(R_I, R_o, Cl, P_r, S_i) + u \ldots\ldots\ldots\ldots\ldots(8)$$

The results revealed that infiltration, runoff amount, land use coefficient, soil porosity, and soil silt are the dominant factors affecting soil moisture content in the study area.

Soil moisture amount in this study area also varies due to management practice, with soils under bush fallow exhibiting higher values when compared with conventional and minimum tillage practices and this results are consistent with that of Mweso, 2003. Similarly, fallow land uses in the study area have higher percentage of soil moisture than farmland.

In Akwanga study area, topography did not correlate highly with soil moisture, but Porosity, texture (silt), run off and infiltration have a strong influence on soil moisture availability in the study area. These results (except topography) are consistent with that of Houser (2003) who states that soil layering of horizon, preferential flow path, topography, pore spaces, particle size, rainfall intensity, vegetation cover, tillage are the primary factors affecting soil moisture.The total pore volume is highest under orchard landuse and lowest in farmlands, although the difference from other categories was not statistically significant. The average available moisture is highest in the orchards and lowest in farmlands. This agrees with the findings of Yamoumoto, 1997 in his work on soil moisture constants and physical properties of selected soils in Hawaii and Adeogun, 1989 in his work on soil fertility under bush fallow in Erin-Ekiti, which reported that moisture storage capacity in forest soils was higher than those under bush fallow and cropping plain lands.

This study is very relevant especially with increasing demand on land for crop yield, animal rearing, forestry and conservation, and rapid change in land surface due to urbanization. Also, this study is very important to policy makers and practicing farmers because these results can be used for deficit irrigation scheduling especially during the critical plant growth stages

5.0 RECOMMENDATION

This research recommended that: a study like this should be carried out in different parts of the country and in similar ecological zone to test the validity of our predictive model. Such studies should incorporate more parameters other than the ones considered in this study. Such as infiltration rates, evaporation, erosivity, rainfall intensity and duration and soil profile analysis. This will provide more comprehensive information for assessing soil moisture not just for agricultural landuse but also for urban land use surfaces.

We also recommend the practice of bush fallow system in this study area to increase soil moisture content but where not practicable due to the methods and increasing population of the country which continues to place land on very high demand; the alternative, practices involving the use of surface ameliorants such as conservation tillage, use of high residue crops, cover crops, compost manuring and mulching should be incorporated into our farming systems as soil management strategies.

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