MODELLING OF SOIL COMPACTION AND RICE-HUSK INCORPORATION ON MAIZE PRODUCTIVITY UNDER IRRIGATION AT GERIO IRRIGATION PROJECT ADAMAWA STATE NIGERIA

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ABSTRACT

A mathematical model was developed for the predicted of soil Compaction effect an Rice-husk as an organic matter that can be added to the soil to cushion the effect of compaction and to enhance crop and good yield, their effectiveness has not been investigated in soil with different level of compaction. Hence, this study investigated the effects of soil compaction with various levels of rice-husk incorporation and number of tractor wheel passes maize productivity under irrigation at Gerio. The experiment was conducted at Gerio irrigation project of upper Benue River Basin Development Authority Yola, Nigeria. The experimental site was marked out to produced 5 rows of tractor wheel passes; 0,2,4,6,8 and 5 colons of 0%, 20%, 40%, 60%,80% of rice-husk levels which produced 25 subplots as treatment. Also, non-hybridized maize seed was planted in each of the twenty five subplots, one seed per hole at 75cm x 25cm spacing at the depth of 5cm. the plots were irrigated using basin, weeds controlled was manually and the use of atrazine force herbicides. N.P. K. and urea fertilizer were applied at 3 and 7 weeks after planting, respectively and was harvested at 14weeks. Measurement of maize crop emergence, leaf area, plant, root weight and yield were made. Maximum maize crop productivity was obtained in treatment with 2 tractor passes and 20% rice-husk incorporation with maize yield of 2077.6kg/ha. A model equation was developed and used to predict maize crop yield.

Keywords: soil compaction, rice-husk, bulk density, hydraulic conductivity, penetration resistance

1 INTRODUCTION

Hydraulic characteristic of the agricultural soil is greatly influence by compaction, which is defined as the densification of unsaturated soil due to reduction in air spaces without change in mass wetness [1, 2]. During most agricultural practices, soil fragmentation displacement and compaction occur which affects 68mha of land globally [3, 4]. The effect of changes on the hydraulic characteristics of soil due to compaction from tractor wheel passage and other farming activities during cultivation practice on the agricultural soils may increase soil bulk density, soil strength, reduce aeration and water movement in the root zone, [5, 6, 7, 8, 9]. Although soil compaction is regarded as one of the most serious environmental problems caused by conventional agriculture, it is the most difficult type of soil degradation to locate and rationalize, principally as it may show no evident marks on the soil surface. Unlike erosion and salting that give strong surface evidence of the presence of land degradation, the degradation of soil structure requires physical monitoring observation before it is uncovered and its extent, nature and cause resolved [10] However, certain amount of soil compaction is needed to ensure better contact between seeds and soil particles [11,12]. Any extra compaction increases soil strength and could cause several problems. Some of the ways employed to alleviate soil compaction due to farm machinery are: control of water content of soil during cultivation, control of tractor traffic over the soil, reduction of vehicle mass and contact pressure on the soil and addition of organic matter to the soil .the first three measures above employed with conventional methods of cultivation have been found to be time consuming and in most cases, impractical an ineffective [13]. Bulk and particle density of organic materials are lower compared with that of mineral soil [14]. The average bulk density of soil organic matter is 0.3 to 0.6 kg/m3 compared to soil density of 1.4 to 1.6kg/m3; so adding organic residue to the soil decrease the average soil density [15]. Since organic materials poses less bulk density than that of mineral soils, mixing them with soil would improve soil bulk density and porosity [16]. Manure is used extensively by farmers to reduce soil compaction and improve soil fertility [10, 16]. [17] Reported that, organic matter also increases soil consistency limits and consequently increase the rate of soil moisture for optimum traffic ability and workability [18]. Among soil hydraulic properties, bulk density has a marked effect on root system development [19, 20]. According to [19], root growth is reduced in compacted soil while [21] found that maize roots were more tortuous in compacted soil with a greater branching density and shorted lateral roots. Although soil compaction is needed to a certain degree for crop growth and emergence, the cumulative effect of applied pressure can leave the soil in excess of what the crop needs [22]. The method of adding various organic materials to improve the soil physical and hydraulic properties is currently receiving attention of researchers [23]. Most research findings show that addition of organic materials to soil before compaction help in alleviating the problems of compaction on the hydraulic characteristics of agricultural soil. In the north east region of Nigeria 75% of the soil are mainly light and with the fact that human population is on the increase and the agricultural production is far from adequate to meet the need of the people, the use of heavy machines and implements on these soils is continuously employed to increase crop production [24], [25]. Hence the availability of information on the use of Rice-husk as locally available materials that could be incorporated to the soil before compaction will go a long way in solving problem associated with soil hydraulic properties. Compaction processes affect soil bulk density, hydraulic conductivity and soil penetration resistance which are the hydraulic properties associated with soil water movement. Soil water retention and transport properties are altered in response to changes in pore space geometry. The prevalent use of tractor for crop cultivation, natural compaction and trampling by animal during grazing in search of grasses has made the soil compacted and has influenced the hydraulic characteristics of the soil which has become a major problem in the state. This is because the roots of plants are less likely to enter soil layers with massive soil structure that have higher soil strength and as a result leads to reduction of plant population [24]. Hence for effective soil management practices, it is imperative to find and adopt a means of alleviating the effect of soil compaction on soil bulk density, hydraulic conductivity, penetration resistance and to improve maize crop yield at the Gerio irrigation project. Although, northern region of Nigeria has several varieties of organic materials that can be added to soils to cushions the effect of compaction and add nutrients to enhance crop growth and good yield, their effectiveness has not been fully investigated in all the soils used for crop production. In Adamawa state, even though the effect of organic matter on soil physical properties and crop yield has been studied, the effect of compaction on rice-husk as organic matter is limited [24]. The bulk density, penetration resistance and hydraulic conductivity of the soil is greatly influence by the soil compaction although, the compaction is needed to a certain degree for maize crop emergence and growth. However, cumulative effect applied pressure by tractor traffic can change the soil hydraulic properties in excess of the need for maize crop production. The emergence of different varieties of rice has made it to be widely grown in Gerio, incorporating rice husk into soil before cultivation could improve soil structure, increase crop growth, yield and improve water holding capacity of the soil thereby reducing the adverse effect of dry spells which crop experience in Gerio irrigation project. Therefore, the objectives of the research paper is to develop a mathematical model to predict the soil compaction and rice-husk incorporation effect on maize crop production under irrigation at Gerio irrigation project.

2 MATERIALS AND METHOD

2.1 Study are

The experiment was conducted in Gerio of Upper Benue Development Authority Yola which is located between $9^{o}\,0^{'}$ to $9^{o}\,40^{'}$N latitude and $12^{o}\,0^{'}$ to $12^{o}\,40^{'}$E longitude with altitude range of 150 to 180 m above the mean sea level (Figure 1). The area has two major seasons; the rainy and the dry season. The rainy season lasts from the beginning of May to the end of October with average annual rainfall of 958.99 mm, while the dry season lasts from November to the end of April. The driest months are January to April with the average minimum relative humidity of 13%. This is mainly due to the prevalent dry and desiccating north- east trade winds. The dry season is favorable for cultivation of cereals, tubers and vegetables crops under irrigation since there is no rainfall during the period. The wettest months are August and September when the intensity of rainfall reaches up to 25% of total annual rainfall. The relative humidity in the area varies: the hottest months is April with monthly average maximum temperature of 39.7℃, while the coldest months are December and January with minimum average temperature of 16℃

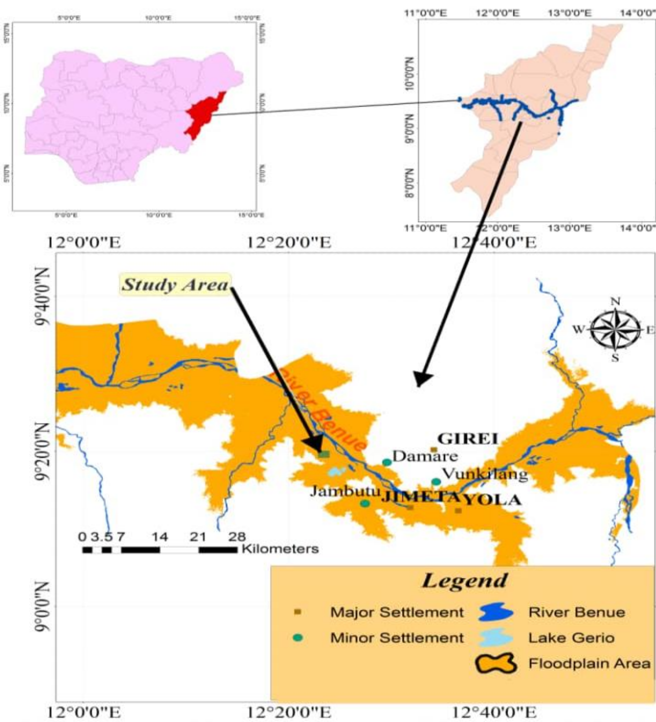

Figure 1. Map of Gerio irrigation scheme, yola

2.2 Land Preparation

The experimental site had a dimension of 25m^2 and the site was cleared manually by removing dry grasses and crop residues. Furthermore, the site was ploughed using marssey ferguson 375 tractor. The site was marked out to produce 25 subplots of 5 m^2 each. The 5 rows produced was the main plot where tractor wheel traffic produce compaction of 0 pass, 2 passes, 4 passes, 6 passes and 8 passes, across the rows and rice-husk as an organic matter was incorporated manually into the columns at 0kg, 200kg, 400kg, 600kg and 800kg as in [32].

2.3 Field Layout and Experimental Design

The experiment was consisting of two factor split plot experiments: The two factors include number of tractor wheel traffic and different level of Rice-husk incorporation in kilogram (kg). The two factors were interacted (5x5) to give a total of twenty-five treatments. Also, in each of the 25 subplot bulk density, hydraulic conductivity, penetration resistance and moisture content were determined daily before the next irrigation scheduling which was determined from the soil textural classification. Non hybridized maize seed was planted in each of the twenty-five sub plot, one seed per hole at 75cm x 25cm spacing manually at the depth of 5cm. The plot was irrigated using basin irrigation. Weeds control was done manually and by spraying Atrazine force herbicide at 250 ml per 15 liter knapsack and NPK fertilizer application was applied at 200kg/ha at 3 weeks and 150kg/ha of UREA at 7 weeks after emergence as in [33], Kamara, et al . [34]. The experiment was carried out according to split plot design with three replications. Tractor wheel traffic was kept in main plots and Rice-husk incorporation treatments was assigned to sub-plots. Each treatment was replicated three times giving a total of seventy-five (75) treatment plots. Split plot Randomized Complete Block Design (RCBD) method was used in planning the experimental layout as in [37].

2.4 Model Development for Effect of Soil Compaction on Maize Crop Yield

The effect of compaction on maize crop yield was developed using the Rayleigh’s method of dimensional approach to experimental analysis. The dependent variables and set of independent variables where identified from the experimental data and by dimensional homogeneity a functional relationship was established between the dependent and independent variables [33].The Rayleigh’s dimensional analysis method consist of: Conceptual modeling frame work, Rayleigh dimensional analysis equation development, Reconstructed data table, Step by step calculation procedure, Graphical modeling approach, Yield validation procedure.

2.5 The modeling variables

The conceptual frame work that relate soil compaction indicators to maize crop yield are: Soil bulk density i.e. root penetration resistance, Soil moisture i.e. aeration and water availability, Root mass i.e. nutrient uptake, Vegetative traits (plant height and leaf area) i.e. biomass production. Final yield i.e. integrated response of all the variables

Table 1. Dimensional representation of variables under consideration

Variables	Symbols	Unit	Dimensional Symbol
Crop yield	Y_c	$Kgha^{-1}$	ML^{-2}
Bulk Density	Pd	gcm^{-3}	ML^{-3}
Moisture Content	M	M%	$M^0L^0T^0$
Plant Height	Hp	M	L
Lead Area	Al	M^2	L^2
Wet root mass	Wr	Kg/ha^{-1}	ML^{-2}

3 RESULT AND DISCUSSION

3.1 Soil Texture

The textural classification of the Gerio agricultural soil determined in the laboratory, From the table the textural class of the soil was found to be silty clay loam which indicate that the soil is suitable for maize product under basic irrigation system at the Gerio irrigation project because of it high water holding capacity (Table 2).

3.2 Maize crop emergence and yield

The result of maize crop emergence and yield of plots with various rice-husk incorporation levels and tractor wheel passes are shown in Table 2 The results shows that at 0 tractor pass the average maize crop emergence was 94.8%. At 2 passes the average emergence was 89%. It further deceases to 74% emergence in 4 passes, 63% emergence in 6 passes and 53.2% emergence at 8 passes. This result shows that soil compaction is needed to a certain degree for crop growth and emergence, but cumulative effort of applied pressure can leave the soil compacted in excess of what the crop nee. [22, 46]. It was also observed that the maize yield was higher at 2 passes with 2859kg/ha and then decreases with the increase in number of tractor passes from 1195.6kg/ha at 4 passes, 1311.6kg/ha at 6 passes and 2320kg/ha at 8passes. It was also observed that maize leaf area was larger for 2 pass which corresponded with the yield. This observation showed the more sunlight was trapped by crop on plot with 2 passes followed 4, 6, and 8 passes hence, the yield of crops are directly related to the photosynthetic activities using sunlight as energy source. The crops with larger leaf area tend to yield more compared to those with less area provided the crop ha better access to moisture and nutrient as reported by [46]. It was also observed that treatment of 6 passes showed reduced percentage crop emergence of 80% and yield of 1311kg/ha compared to other plots that had lesser tractor passes although 8 passes had 75% emergence with 2320kg/ha. This shows that compaction of soil due to tractor passes had detrimental effect on the maize crop development and yield, this could have been caused by the reduction in soil pores pace and the inability of plant root to effectively penetrate the soil to extract nutrient and moisture. It was also observed that the plant height, leaf area and weight root mass in those plots have lower values. This could also be due to poor plant development in the compacted soil that resulted from poor photosynthetic activities using sunlight as energy source. Thus, crop with higher leaf area tends to yield more than compared to those with less leaf area provided the crops had better access to moisture and nutrient this has also been reported by [45, 46].

3.3 Modelling of soil compaction effects on Maize crop yield

The dependent variable in the investigation was crop yield and the independent variable which affect the yield, which in themselves are also altered by the compaction induced by the tractor wheel passes were soil bulk density, moisture content, plant height, leaf area and weight root mass (Table 5).

3.4 Model equation

The Raleigh's configuration representing the dependent variable as function of the independent variables is given by;

$$Y_c = K\left(\rho_b,\ M, H_p,\ A_l,\ W_r\right) \tag{1}$$

Where K = is a dimensionless constant, Y_c = crop yield (kg/ha^{-1}), ρ_b = soil bulk density (gcm^{-3}), M = moisture content (%), H_p = Plant height (m), A_l = leaf area (m^2), W_r = wet root mass (Kgha^{-1}), Using a,r,s,c and d as exponential constants the;

$$Y_c = K(\rho_b, M^r, H_p^s, A_l^c, W_r^d \tag{2}$$

$$ML^{-2}T^0 = k[(ML^{-3})^a(M^0L^0T^0)^r(L)^s(L^2)^c\left(ML^{-2}\right)^d] \tag{3}$$

To satisfy dimensional homogeneity, the mass, the length and time dimensions must equate on either side of the equation. So that, relating equation (2) to (3) gives:

$$Y_c = k\left(\rho_b^a, m^0, H_p^{a-2c}, A_1^c, W_r^{1-a}\right) \tag{4}$$

From where $$Y_c = km^0W_r\left[\left(\frac{\rho_b H_p}{W_r}\right)^a\ \left(\frac{A_1}{H_p^2}\right)^c\right] \tag{5}$$

And $$Y_c = kW_r\left[\left(\frac{\rho_b H_p}{W_r}\right)^a\ \left(\frac{A_1}{H_p^2}\right)^c\right] \tag{6}$$

Substitute f for k at a=1 and c=1, since a uniform soil type is used for experiment, then:

$$Y_c = fW_r\left[\left(\frac{\rho_b H_p}{W_r}\right)\ \left(\frac{A_1}{H_p^2}\right)\right] \tag{7}$$

$$Y_c = fW_r\left[\left(\frac{\rho_b H_p}{W_r}\right)\ \right] \tag{8}$$

$$Y_c = f\ \left[\left(\frac{A_1\rho_b}{H_p}\right)\right] \tag{9}$$

$$(Y_c)_i = (f)_i\left(\frac{A_1\rho_b}{H_p}\right) \tag{10}$$

Equation 3.10 is the model equation relating maize crop yield to some independent variables affected by soil compaction as leaf area, bulk density and plant height. The model shows that the crop yield is directly proportional to the product of the leaf area, bulk density, but inversely proportional to the plant height. Then there is constant of proportionality, *f.* which is dimensionless parameter that varies with (i) the number of tractor passes and soil moisture content. Using the experimental data for validation, the value of '*f* is found as:

$(f)_i = 320.194\ (\textit{moisture content})_i^2$ zeta 11

Where zeta is an error term that varies as 1≤zeta ≤3 with increasing compaction.

3.5 Model Validation

The model developed was validated using the data obtained from the field experimentations Table 3.5 A graphical comparison of the measure and predicted data for yield of maize crop (kg/ha) in relation to the number of tractor passes using the model equation presented in Figure 2. The model prediction on the yield of the maize crop (kg/ha) in relation to the number of tractor passes had an average of 93.19% when compared with the measured data. This indicates that the model can be used effectively to tract maize crop yield on soils with various levels of compaction.

Table 2. Soil Textural Classification of Soil at the Gerio Irrigation Project

Depth of soil (M)	Particle size distribution (%)			Textural class
	Sand	Silt	Clay	
0.00 - 0.15	*20*	*45*	*35*	*Silty clay loam*
0.15 - 0.30	18	44	38	Silty clay loam
0.30 - 0.45	19	42	39	Silty clay loam
0.46 - 0.60	16	43	41	Silty clay loam
0.60 - 0.75	18	40	42	Silty clay loam

Based on USDA textural classification

Table 3. Maize Crop Emergence (%) Leaf Area Crop Height Root of the Maize Productivity at the Gerio Irrigation Project

PLOTS	RICE HUSK (%)	TRACTOR TRAFFIC	EMERGENCE (%)	Dry Matter Maize yield (kg/ha)	Wet Root Mass (kg/ha)	Leaf Area (m2) 3 MAP	Crop Height (m) 14 WAP
PLOT 1	0% RH	0	98	1192	309	0.79	0.193
PLOT 2	20% RH	0	98	1285	2431	1.03	1.38
PLOT 3	40% RH	0	96	1120	683	0.81	1.872
PLOT 4	60% RH	0	92	1195	1022	0.693	1.324
PLOT 5	80% RH	0	90	2330	2378	0.766	1.443
PLOT 6	0% RH	2	98	1856	1480	0.763	1.14
PLOT 7	20% RH	2	88	2859	2320	0.768	1.145
PLOT 8	40% RH	2	82	1310	1820	0.775	1.352
PLOT 9	60% RH	2	80	1458	1041	0.766	1.14
PLOT 10	80% RH	2	82	2905	2432	0.764	1.329
PLOT 11	0% RH	4	80	1132	896	0.86	1.465
PLOT 12	20% RH	4	76	1480	1022	0.978	1.456
PLOT 13	40% RH	4	72	1312	3451	0.794	1.371
PLOT 14	60% RH	4	70	1311	2320	0.892	1.432
PLOT 15	80% RH	4	75	1308	1820	0.632	1.045
PLOT 16	0% RH	6	60	1120	1041	0.645	1.012
PLOT 17	20% RH	6	71	1158	309	0.891	1.452
PLOT 18	40% RH	6	68	1092	2431	0.912	1.122
PLOT 19	60% RH	6	56	1158	683	0.897	1.433
PLOT 20	80% RH	6	60	1140	1041	0.858	1.389
PLOT 21	0% RH	8	55	1320	2432	0.878	1.487
PLOT 22	20% RH	8	51	1211	896	0.854	1.411
PLOT 23	40% RH	8	56	1128	1120	0.823	1.1
PLOT 24	60% RH	8	54	1280	1158	0.833	1.196
PLOT 25	80% RH	8	50	1002	683	0.856	1.101

Table 4. Maize Crop Emergency (%), Yield (kg/ha), Leaf Area (M^2) and Crop Height (m)

Treatment	Emergence (%)	Yield (Kg/ha)	WRM (Kg/ha)	LA (M^2)	CH (m)
OT 0-80%RH	94.8	1192	309.2	0.1150	0.941
2T 0-80%RH	86	2859	2431	0.1974	1.380
4T 0-80%RH	74.6	1195	683.5	0.1112	0.872
6 T 0-80%RH	63.5	1311	1022	0.1490	1.146
8T 0-80%RH	70.5	2320	2378	0.1561	1.402

Mean of tractor traffic

Table 5. Experimental Data for modeling the effect of Compaction on Maize Yield

Treatment	Soil Bulk Density (Mg/m^{-3})	Moisture Content (%)	Plant Height (m)	Leaf Area (m^2)	Maize Yield predicted (kg/ha^{-1})
0T (0-80%RH)	1.68	5.17	0.941	0.1150	1254.6
2T (0-80%RH)	1.69	7.20	1.380	0.1974	2780
4T (0-80%RH)	1.73	4.89	0.872	0.1112	1200
6T (0-80%RH)	1.72	4.90	1.146	0.1490	1279
8T (0-80%RH)	1.70	6.20	1.402	0.1561	1849

Mean of tractor traffic

Table 6. Measured maize crop yield (kg/ha) and Predicted maize crop yield (kg/ha)

Treatment		Measured crop yield	Predicted crop yield
0T	0-80%RH	1192	1254.6
2T	0-80%RH	2859	2780
4T	0-80%RH	2610	2590
6T	0-80%RH	2480	2375
8T	0-80%RH	2100	2204

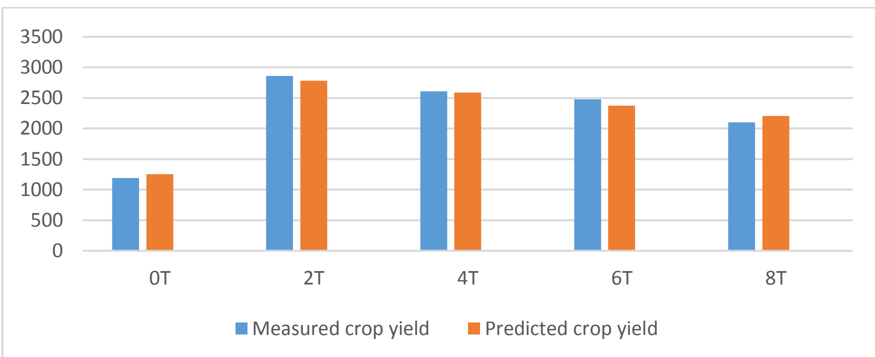

Figure 2. Validation of the predicted and measured data against tractor passes

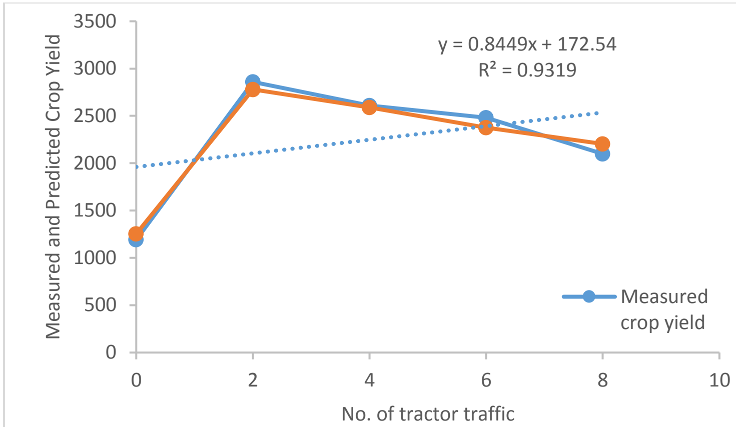

Figure 2. Validation of the predicted and measured data against tractor passes and R^2 value of predicted and measured data

4 CONCLUSIONS

The model developed in this work can be used to predict and monitor maize crop performance on both the compacted and un-compacted soil. Therefore, it is possible to regulate maize crop yield in relation to varying degrees of compaction. Consequently, it is recommended that the soil for maize cultivation be prepared to a desired level of compaction, in order to obtain optimal yield and growth performance of maize. Model equation was determined and can be used to predict the yield of maize against measured data:

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