Mathematical Model Equation for Tolerance of Okra Plant Yield to Soil Densification

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***Abstract*- Soil plays vital role in plants performance. A densified agricultural soil has lost its nutrients availability to plants. Thus the study is on modelling the tolerance of Okra *(Abelmoschus esculentus L.)* to soil densification under varying degrees of tractor passes on the sandy loam soil. The research was conducted at the Rivers Institute of Agricultural Research and Training, South-South, Nigeria. The plot of area 46m by 36m was cleared of grasses, debris and stumps. The soil samples were randomly collected for soil tests before and after tillage operations such as ploughing and harrowing + harrowing which were carried out respectively. The land space was marked out into randomized complete block design of four replicates compacted at i = 0, 5, 10, 15 and 20 passes per replicate of which there were twenty subplots altogether with a SWARAJ 978 FE Tractor Model used for the compaction routines. A duly certified Okra seeds bought from the Government of the Rivers State Ministry of Agriculture, Crop Department with minimum percentage germination and purity of 85% and 99% were sown by placing 3 seeds per hole at a considerable depth of about 0.03m beneath soil surface, with inter-row and intra-row spacing of 0.6m by 0.6m and a 4m by 4m alley dimension which was marked out to separate each subplot from the other. The seedlings were later thinned to two Okra plants per stand at two weeks after emergence. The data obtained were employed in model development. A mathematical model equation $(\gamma_p)_i = \varphi \frac{(\dot{\omega}_p)_i \sqrt{(\rho_d)_i (CI)_i}}{D_c} + C_1$, was developed based on Buckingham pi theorem using dimensional analysis to predict tolerance of Okra yield under soil compaction. A Least Square estimation to depict φ, the constant of proportionality of the modelled equation was estimated at 4 x 10^6 and C_1= 3 x 10^{-5}. The model obtained was verified and validated using Analysis of variance (ANOVA) and t-test to determine if there were significant differences between the experimented and predicted values of Okra yield measurements. It was clear evident after the tested modelled equation that there was an approximately closed agreement between the experimented and modelled values of Okra yield in tolerance to soil compaction at varying tractor passes in different subplots. Hence, it was suggested that the model be used for Okra yield prediction in a densified soil.**

***Keywords:* Tillage operations, densified soil, tractor passes, tractor model, tolerance, okra yield**

I. INTRODUCTION

Okra (*Abelmoschusesculentus L.*) is widely grown all over the world because of its apt adaptation to survive on any kind of soil at any period of the season year round. Okra originally originated from the tropics of Africa and is of many varieties of which the wild forms are found in India. Okra cultivation hit the roof respectively during the year 2009, when its total annual production in the world was about 4.8 million tonnes in which India was reported to have had the highest Okra yield of about 4.528 million tonnes accounting for 70% of its production worldwide [15].

Nigeria has increasingly engaged in the production of Okra as vegetable in recent years because of its nutritional noodles derived from it as protein, carbohydrate, and vitamin C and plays a vital role in human diet [13]. Okra among others contains vitamins A and B, and as well rich in minerals and very high in iodine content. Okra fruits can be boiled fried or cooked [3]. Due to its medicinal quality, Okra has been known to be beneficial to people suffering from leucorrhoea, goitre, ulcers, relief from haemorrhoids and general weakness [12].

In other vein, few of the Soil-Machinery System factors if not all, have been known to induce certain impairments to Okra growth and yield efficiency in the agronomical periscope. Obviously, over (30-45 per cent) loss of Okra had been recorded in recent years worldwide due to type of cultural practice adopted towards cultivation of Okra plant. Established facts of these are obvious on densification (compaction) of agricultural soil and the effects of stress imposed towards growth and yield of crops generally.

The term densification means compaction, which is a condition by which soil air pores are being eliminated with increase in both soil strength and bulk density which involves gradual decrease in soil total volume. Soil compaction is the compressing of soil particles together by an external force, thereby eliminating the pore spaces and reducing the soil volume and this bears serious consequences on the productivity of the soil and environmental quality [20]. It may decrease soil porosity and change pore shape and size distribution, decrease aeration decreases water infiltration and increase preferential flow, including increase surface run-off resulting in soil erosion [9]. The degree of compaction depends on the soil strength which is influence by intrinsic soil properties such as texture and soil, organic matter contents structure of the tilled layer at wheeling and its water content [16]. The effect traffic causes depends on the soil strength, its distribution with depth [38] and soil moisture status [39]. These researchers [10] used several numbers of wheel passes in their work and found that both bulk density and penetration increase with number of wheel passes. The findings of [37],[19] opined that compaction of agricultural soils is a global concern since it has adverse effects on the environment and consequently, agricultural production.

Many researchers have used these parameters such as cone penetration resistance, bulk density, porosity, hydraulic conductivity and air permeability to measure vehicle-soil interaction [34].

Generally, with compaction, there is usually a complete alteration of the physical properties of the soil, with notable changes in the soil bulk density, soil strength, porosity and hydraulic properties such as infiltration rate and hydraulic conductivity. The investigation results on the effect of soil compaction on soils in Southern Adamawa State, Nigeria proved that soil "compaction due to heavy tractor traffic changes the numerical values of soil bulk density" [24]. It increases the soil bulk density and consequently retards or diverts the flow of water in the soil resulting in excessive runoff. This is because there is a reduction in the hydraulic properties of the soil, like infiltration and percolation, which are determined as functions of time, in rates. It has been evident over the time that concurrent tractor passes of heavy agricultural machines on agricultural soil results in stiffness of the soil capable of affecting both the soil properties and the life span be it cultivated agricultural crops. In mechanized cropping system, the continual use of tillage implements, especially disc plough, disc harrow, mould board plough, and rotavators, overtime, can result in soil-plant restoration problem. Thus, consideration is given to the advert effects of an increased use of farm machinery in agricultural operations. It has become obvious fact that when off-road vehicles are used on agricultural fields, they cause compaction of the soil; the degree of compaction being "related to soil type, soil moisture and machinery traffic (number of passes and contact pressure)"[26]. Furthermore[8] stated that "The severity of soil compaction on crops is a function of soil type, soil water content, vehicle weight, speed, ground contact pressure, number of passes and their interactions with cropping frequency and farming practices.

Agricultural traffic is the main cause of decreased soil structural macro porosity [5]. Compaction can reduce yield by reducing the quality, weight and size of the fruit. It equally delays plant development and maturity, reduces plant stand, height and seedling emergence.

Continuous passage of farm machineries across agricultural fields eventually resulted in soil structure degradation, and reflected changes in soil physical properties such as bulk density, aeration, porosity, soil strength and hydraulic conductivity [33].

Growth and yield of Okra depend on many factors including, seed quality, nutrition, climatic conditions and cultural practices. In a good seedbed environment, the interaction between the soil and weather, practices involving the preparation of land for growing crops and method of planting determine the success or failure of crop production system. A harsh seedbed environment is likely to stress the seeding to limit the plants productive potential [22].

Available models and measurements on soil compaction and crop growth responses are geared towards soil stresses caused by vehicular weights and their dependence on the ground contact pressure [18].

Based on this premise, plant growth and development models are being elaborated to supply adequate basis for planning and managing crop production under soil degradation. Model equation can be used to analyse the effect of certain soil-plant-machinery continuum especially that of soil compaction effect due to use of agricultural machinery on the crop natural thriving environment.

Hence, [20] opined that a predictive model can be deployed in the estimation of degree of soil densification by a tractor during tillage operations and to predict the variation of dependent and independent variables involved in the process. In view of this, there would be enhancement in operational cost reduction and increase in agricultural productivity, with an accompanying increase in profitability in crop production.

A model equation using sensitivity analysis for prediction of tractive force for disc harrowing tillage operation was developed [28]. Furthermore,[20] developed a model using the Rayleigh's modeling method of dimensional approach to experimental analysis, to predict and monitor maize crop performance on both the compacted and un-compacted soils.

However, the high spectrum of significant difference created by agricultural machinery impacts in consolidating agricultural soils during field operation can never be over emphasized in height of economic loss significant enough to cause havoc to plants' life during their stages of growth and maturity.

The mathematical model of plant root penetrating into soils can be represented by the movement of a cone being depressed into the soil and the functional relationship between the resistance of the soil to penetration and parameters using a cone of a particular dimension [27].

To this end, the effect of wheel traffic on the soil is fairly predictable but its response to crops still varies for different crops. Despite the large volume of literatures on the effect of wheel traffic on non-cereal and cereal crops, little or none has been reported on Okra.

This research work, reports the results of an experiment carried out in growing seasons to know the tolerance of Okra to compacted soil by agricultural machinery with respect to different passes of tractor wheel on some soil properties and the yield of Okra in the South Southern part.

Therefore, the aim of this study was to model the tolerance of Okra plant to soil densification. The objective of this work is to develop a formulated mathematical equation that could be used to predict the tolerance of Okra yield performance when subjected to certain soil physical characteristics and parameters.

Thus, certain soil physical parameters are being considered worthy of modelling the tolerance of a test crop in Okra (*Abelmoschusesculentus*) when subjected to various degrees of soil compaction effect by varying tractor wheel passes.

At the end of this research, establishing the best probable formulated model using dimensional analysis from Buckingham Pi-theorem to simulate the tolerance of Okra to yield effect in series of compacted level of soil would be predictable considering this research.

II. MATERIALS AND METHODS

A. Description of Experimental Site

The experiment was conducted towards the end of dry season and prior to the early period of raining season at the Rivers Institute of Agricultural Research Training field located within the study area of the Rivers State University, Port Harcourt, Rivers State, Nigeria. Port Harcourt is on latitude of 0.5^0 01'N, longitude of 0.6^0 57'E with an attitude of 274mm above mean sea level[29]. The study area is characterized by tropical rainforest vegetation, with a rainfall depth raining from 2000-2484mm per annum, of which 70% occur between the month of May and August. The soil type according to United State Department of Agriculture (USDA) classification is sandy loam.

Before subjecting the soil area to compaction with tractor, certain soil samples were collected from the area. Soil auger was used for collecting the samples up to 0.3m depth from the different parts of the experimental field. Two of the instruments used at in-situ were auger and cone penetrometer, the later used to measure the soil strength at both the controlled plot and compacted plots. The data collected were estimated for cone penetrometer, soil bulk density, dry bulk density and soil particle density at different compaction levels.

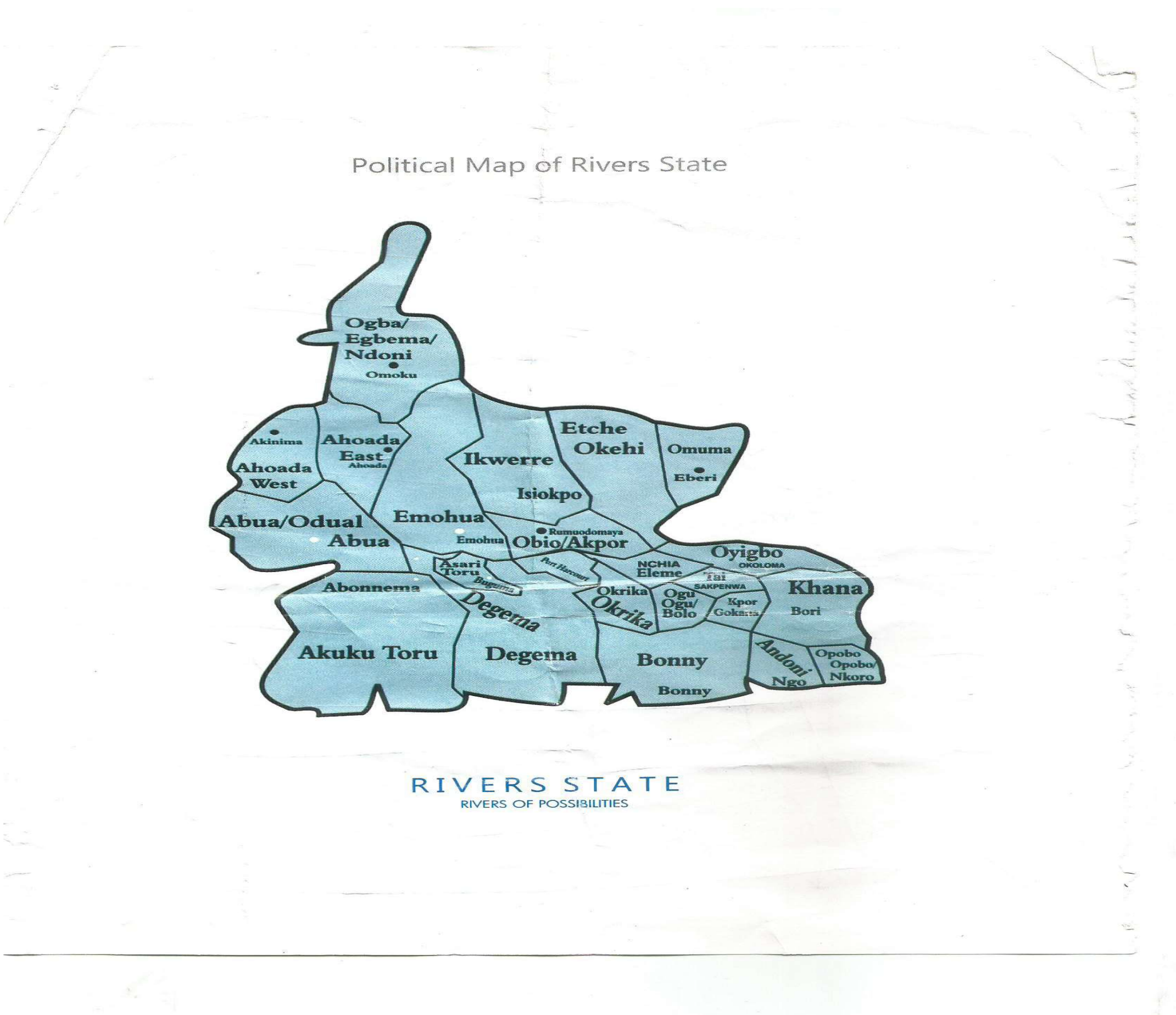

Figure 1: The location of the study area in Port Harcourt

B. Experimental Field Procedure

The soil samples collected were analysed in the Civil Laboratory of the Rivers State University. The soil samples collected at in-situ were wrapped in different sample bags retention of moisture content before taken down to the Laboratory for analysis. The field area measuring 46m x 36m, was cleared of grasses, removed of stumps, ploughed, harrowed + harrowed before compaction was embarked upon. A completely randomized block design at five compaction levels by tractor wheels, consisting of 0, 5, 10, 15 and 20 passes was laid out on the field in four replicates. The amount of rainfall from the meteorological centre in Port Harcourt was taken. After the treatments, certified Okra seeds of Cultivar Type - certified seeds, Lot Number – VG- PV 0-423K were planted. Planting was done manually, three seeds per hole in four rows at each treatment plot at 3cm deep with inter-row spacing of 0.6 m apart and 0.6 m between seed. Cone index (CI) or soil resistance was measured with the simple measuring device called cone penetrometer. The probe records the resistance force (KN) with respect to the depth of penetration of the probe shaft measured in(cm) and later converted to meter (m) for study purposes. Soil-plant-machinery data were taken before, during and after planting respectively. Stem girth was determined using thread and meter rule, numbers of leaves were determined by visual counting, plant height was determined using meter rule, leaf area was determined by multiplying the correction factor (0.56) by length of leaf and width of leaf (cm) according to [4], also number of pods were determined by counting per plant, and finally the Okra pod yield computed using the following formula [1].

$$\text{Yield } (\text{Kg ha}^{-1}) = \frac{\text{Crop Weight per subplot (kg)}}{\text{Area of sub plot } (\text{m}^2)} \text{ x } \frac{10000(\text{m}^2)}{(\text{ha})}$$

C. *Materials used for the Study*

TABLE 1: EQUIPMENT AND INSTRUMENTS USED FOR THE STUDY

Instruments	Implements	Weight (KN)	Tractor Specifications	Dimensions (mm)
Stop watch, cone penetrometer, soil auger, sample bags, fibre tape, weighing balance, disc harrow, tractor, meter rule,	Disc plough and disc harrow.		Swaraj Tractor, Model no.: 978 FE, Weight = 3050 kg Weight = 30.5KN, Tyre inflation pressure = 179.3 bars, Power rate = 53.7 KN/s, Front (7.5- 16, 8- ply) and Rear (16.9-28, 12- ply)	Length = 4140 Width = 2030 Wheel base = 2225

D. Mathematical Modelling

Mathematical models are basically simplified description of systems. In soil densification (compaction), modelling does not only provide a better way to quantifying the processes involved in the soil compaction but also helps us to predict the vulnerability of a particular soil to compaction.

E. Theoretical Development

The application of Dimensional Analysis (Buckingham's pi theorem) for developing an appropriate model equation for the determination of optimum tractor fuel consumption in harrowing operation was done [30].

In agricultural soils, the most relevant properties are the reactions of soils to applied forces. These properties are often called strength properties, for a particular soil, the properties can change with time under the influence of climate, soil management, and plant growth. The strength of any particular soil and their change in time can be determined by measuring the soil shear strength, bulk density, penetration resistance and transmissivity of the soil [31]. The degree to which soil is being compacted-Degree of Compaction, D_c depends on the moisture content at which the compaction takes place due to effect of traffic passes overtime over the land area. At a given pressure, there will be optimum moisture content for this compaction. But, according to [6], it was stated that the relative degree of compaction was calculated to be the product of the mean tyre contact pressure and the tyre contact width. Thus, Degree of Compaction, $D_c = \sigma_m \text{ x } w_t$. Where Dc = Degree of Compaction (KNm^{-1}), σ_m = Mean tyre contact pressure (KNm^{-2}) and w_t = Tyre contact width (m)

However, a soil with low moisture will show less compaction because of higher resistance to compaction while wet soil will give low compaction because the soil may become saturated and incompressible.

F. Modelling Factors

The major effects of compaction are on soil strength, soil density, and change in water transmission and evaporation properties of the soil. The effects of compaction are dependent on the amount of root zone that is compacted, continuity of compacted zone and susceptibility of crops to compaction [7].

G. Dimensional Analysis

The principle of dimensional analysis using Buckingham pi theorem was used in the formulation of the predictive model equation with functional relations to combine various parameters, into groups of dimensionless terms selected as pi terms, which reduce the number of variables in a multifaceted phenomenon to a smaller set of dimensionless ratio [21]. The dimension of a physical quantity can be expressed as a product of the fundamental dimensions; length (L), mass (M), time (T) and temperature (θ). In engineering, and other fields like applied mathematics the Buckingham π (pi) theorem is imperative in dimensional analysis.

H. Determination of 'pi' terms

Several methods have been used to form dimensionless products (pi terms) in dimensional analysis. However, a systematic procedure called method of repeating variables that allows in deciding the dimensionless and independent pi terms was employed in this study. List of variables in this problem are given below in table 2:

Table 2: Some Variables affecting Okra Growth and Yield in Compacted Soil

Parameter	Symbol	Unit	Dimensions (M, L, T)
Dependent variables			
Crop yield	γ	Kg/m^2	ML^{-2}
Independent variables			
Pod weight	ω_p	Kg	M
Dry bulk density	ρ_d	Kg/m^3	ML^{-3}
Time Interval of Yield	T	Sec	T
Degree of compaction	D_c	KN/m	MT^{-2}
Cone Index	CI	KN/m^2	$ML^{-1}T^{-2}$

I. Certain Soil-Plant-Machinery Parameters considered are as follows:

Soil Parameters**:** Cone Index, Porosity, Moisture Content, Soil Particle Density, Bulk Density, and Dry Bulk density. Plant parameters**:** Crop Yield and Rate of Pod weight to develop. Machinery Parameters: Wheel Numeric and Degree of compaction by traffic wheels.

III. MODEL DEVELOPMENT

The functional relationship between the resistance of Okra to soil compaction, soil parameters and dimensional analysis can be represented as shown in table 2 above.

The model was developed based on assumptions and theories from other researchers and based on current field work data of this study. Crop yield, γ, is a function of the variables:

$$\gamma = f(\omega_p, T, CI, \rho_d, D_c) \quad (1)$$

$$\Rightarrow f(\gamma, CI, \rho_d, D_c, \omega_p, T) = 0 \quad (2)$$

Where, f is a functional relation notation of the enlisted variables,

$$S = n - b \quad (3)$$

Where, S= No. of π-terms, n = Total number of physical quantities , b = No. of fundamental dimensions (i.e, MLT) , From equt.(3) , 3 π – terms were involved in the model development

$$\gamma = f(\pi_1, \pi_2, \pi_3) \quad (4)$$

$$\text{Hence, } \pi_1 = f(\pi_2, \pi_3) \quad (5)$$

Taking ρ_d, CI and T as repeating variables,

$$: \pi_1 = \rho_d^{a_1}.CI^{b_1}.T^{c_1}.\gamma \ , \quad (6)$$

$$\pi_2 = \rho_d^{a_2}.CI^{b_2}.T^{c_2}.D_c \quad (7)$$

$$\text{and } \pi_3 = \rho_d^{a_3}.CI^{b_3}.T^{c_3}.\omega_p \quad (8)$$

Taking the π-terms one after the other and solving dimensionally, π_1, π_2, and π_3 are determined as follows:

$$: \pi_1 = \rho_d^{a_1}.CI^{b_1}.T^{c_1}.\gamma$$

$$M^0L^0T^0 = (ML^{-3})^{a_1}.(ML^{-1}T^{-2})^{b_1}.(T)^{c_1}.(ML^{-2})$$

$$\therefore \pi_1 = \frac{\gamma}{T.\sqrt{\rho_d.CI}} \quad (9)$$

$$\therefore \pi_2 = \frac{D_c.\sqrt{\rho_d}}{T.CI.\sqrt{CI}} \quad (10)$$

$$\therefore \pi_3 = \frac{\omega_p.\sqrt{\rho_d}}{T^3.CI.\sqrt{CI}} \quad (11)$$

From the above equt. (11),

let

$$\frac{\omega_p}{T} = \dot{\omega}_p, rate\ of\ Okra\ pod\ developement\ over\ the\ expected$$

Thus, new $\pi_3 = \frac{\dot{\omega}_p \cdot\sqrt{\rho_d}}{T^2.CI.\sqrt{CI}}$. (12)

In application of surd notation the under listed is obtained

Since $\frac{\sqrt{\rho_d}}{\sqrt{CI}} = \frac{\sqrt{\rho_d}}{\sqrt{CI}} \times \frac{\sqrt{CI}}{\sqrt{CI}}$ in Surd form, $\Rightarrow \frac{\sqrt{\rho_d}}{\sqrt{CI}} = \frac{\sqrt{\rho_d.CI}}{\sqrt{CI^2}}$

Therefore, the current π- terms of π_1, π_2, π_3 are as follows:

$$New\ \pi_1 = \frac{\gamma.\sqrt{\rho_d.CI}}{T.\rho_d.CI}, \quad \pi_2 = \frac{D_c.\sqrt{\rho_d.CI}}{T.CI^2}, \quad \pi_3 = \frac{\dot{\omega}_p \cdot\sqrt{\rho_d.CI}}{T^2.CI^2}$$

But, $\pi_1 = f(\pi_2, \pi_3)$ (13)

Introducing φ *as a constance of proportionality* into the equation, since the π-term containing the dependent variable is a function of the π-terms bearing its independent variables it directly varies with proportionally.

$$\Rightarrow \frac{\gamma.\sqrt{\rho_d.CI}}{T.\rho_d.CI} = \varphi\left(\frac{D_c.\sqrt{\rho_d.CI}}{T.CI^2}, \frac{\dot{\omega}_p \cdot\sqrt{\rho_d.CI}}{T^2.CI^2}\right) \Rightarrow \gamma = \frac{T.\rho_d.CI}{\sqrt{\rho_d.CI}}\varphi\left(\frac{D_c.\sqrt{\rho_d.CI}}{T.CI^2}, \frac{\dot{\omega}_p \cdot\sqrt{\rho_d.CI}}{T^2.CI^2}\right)$$

Applying transformation method and considering surd notation for the non-denominator radicals, hence the final mathematical equation formed was:

Hence, $\left(\gamma_p\right)_i = \varphi \frac{(\dot{\omega}_p)_i\sqrt{(\rho_d)_i(CI)_i}}{D_c} + C_1$ (14)

Where, $\varphi = 4 \times 10^6$ and $C_1 = 3 \times 10^{-5}$

i= no. of tractor wheel passes at 5, 10, 15 and 20; $\varphi = 4 \times 10^6$, $D_c = 7.441 \times 10^6\ N/m$ and $C_1 = 3 \times 10^{-5}$ are all constants in their own regard with Dc constant for a particular machinery or tractor used, γ_i = Pod Yield at different subplots in (Kg/m^2)

IV. MODEL VALIDATION

The developed predicted model was validated using statistical tools of Analysis of Variance (ANOVA) and t-Test that use the means from two sampled sets for homogeneous numeric values to determine significant difference at 1% and 5% levels of significance. Microsoft Excel was used to compute results and determine if significant difference existed between them or not. A graphical comparison between the measured and predicted crop yield values were plotted to observe, if there was an acceptable agreement.

V. RESULTS AND DISCUSSION

A. Experimental Results

TABLE 3: SOIL PARTICLE SIZE RESULTS

Sand (%)	Silt (%)	Clay (%)	Organic matter (%)	Specific surface (m^2/g)
74.00	11.40	14.60	2.55	4.80×10^{-5}

Table 3, showed the result of the soil analysis test conducted on the research cultivated farm land and found to be sandy loam soil with 2.55% organic matter and specific surface of 4.80×10^{-5} m^2/g.

TABLE 4: THE CHEMICAL PROPERTIES OF SOIL IN THE STUDY AREA BEFORE AND AFTER PLANTING

S/n	Sample parameters	Before planting	After planting
1	Soil pH (1:2.5)	6.20	5.80
2	Electrical Conductivity (µS/cm)	58.35	26.30
3	Total Nitrogen (%)	0.041	0.031
4	Available P (mg/kg)	47.72	56.14
5	Exchangeable K (cmol/kg)	0.47	2.56
6	Exchangeable Na (cmol/kg)	1.74	4.78
7	Exchangeable Ca (cmol/kg)	1.00	1.00
8	Exchangeable Mg (cmol/kg)	1.80	2.00
9	Bulk Density (g/cm3)	1.26	1.50
10	Organic Carbon (%)	1.48	0.80
11	Organic Matter (%)	2.55	1.38

Table 4 shows chemical properties of the soil before and after planting. Nitrogen, as well as phosphorus, plays an important role in fruiting, seeding and good quality development of Okra plants. Potassium promotes formation of strong straw, with resultant decreased incidence of lodging in plants [25].

The chemical properties of soil in the study area, prior to planting, indicated that the soil was slightly higher acidic, with a pH of 6.20 to 5.80 at the end of 6WAP causing soil acidification due to leaching resulting from soil densification. The electrical conductivity before planting was higher by 58.35 than after planting recording 26.30 indicating significant differences. The total nitrogen of 0.041% was greater than that after planting of 0.031%, both of which are below critical values according to [32] . Available P (mg/kg) before and after planting decreased prior to planting by 47.72 and increased after planting by 56.14, probably may have mixed up with compost manure during densification of soil.

Exchangeable K(cmol/kg) followed the same trend as exchangeable Na(cmol/kg), exchangeable Ca(cmol/kg),exchangeable Mg(cmol/kg). They ranged from 0.47 cmol kg-1 before planting to 2.56 cmol kg-1 after planting, 1.74(cmol/kg) before planting to 4.78(cmol/kg),1.00 (cmol/kg) to 1.00(cmol/kg) and 1.80(cmol/kg) before planting to 2.00(cmol/kg) after planting. The highest increase was observed in exchangeable Na(cmol/kg), followed by exchangeable Ca(cmol/kg), observed to have equality in both planting seasons. This is in agreement with the finding of [23] who stated that total N, available P and exchangeable cations were significantly reduced by Okra cropping in untreated plots and higher content of total N, available P, exchangeable Ca and Mg observed in treated plots can be attributed to the improved organic carbon status of the soil leading to higher organic matter. Organic matter is a natural source of nutrient and exchangeable cations. This revealed the higher potentials effect of soil densification

B. Model Verification And Validation

There is no significant difference between γ_p and γ_ε. Where, γ_p and γ_ε are either predicted or experimented yield. Statistical tools were used to interpret and determine the significant differences between the means of predicted and experimented Okra yield at 0.05 level of significance. The result of the t-test showed that, the t Critical values of 2.131847 and 2.776445 are greater than t Stat of 0.990228 ($t_{tab} > t_{cal}$) at both one and two tails tests. This indicates that there is no significant difference at ($p>0.05$) between experimented and predicted yield of Okra estimated from different levels of soil compaction effects at i = 5, 10, 15 and 20 levels of tractor wheel passes. Thus, $\gamma_p \approx \gamma_e$ depicts that the model is valid because there is no significant difference between predicted and experimented yields.

TABLE 5: MEAN VALUES OF CROP PARAMETERS AFTER PLANTING

No. of Passes	Crop Parameter	No. of Weeks After Crop Emergence		
		2	4	6
Control	Stem Girth (mm)	3.5	4.5	8.5
	Leaf Area (cm^2)	10.57	26.74	94.14
	Plant Height (cm)	11	16.8	33.4
	Pod Yield	-	-	2
	No. of Leaves	5	6	7
	Pod Weight (g)	-	-	49
5	Stem Girth (mm)	3.5	4	5
	Leaf Area (cm^2)	6.84	6.61	49.84
	Plant Height (cm)	8.88	9.14	30.6
	Pod Yield	-	-	2
	No. of Leaves	4	4	4
	Pod Weight (g)	-	-	40.3
10	Stem Girth (mm)	3.6	4	3.8
	Leaf Area (cm^2)	4.55	3.36	65.74
	Plant Height (cm)	7.8	19.5	33.6
	Pod Yield	-	-	2
	No. of Leaves	4	4	6
	Pod Weight (g)	-	-	34.1
	Stem Girth (mm)	3.5	3.5	4.5

15	Leaf Area (cm^2)	4.96	4.64	49.28
	Plant Height (cm)	7	9.24	26.6
	Pod Yield	-	-	1
	No. of Leaves	4	4	5
	Pod Weight (g)	-	-	19.86
20	Stem Girth (mm)	3	3	3.3
	Leaf Area (cm^2)	2.04	5.18	9.72
	Plant Height (cm)	6	7.1	13.06
	Pod Yield	-	-	1
	No. of Leaves	4	4	4
	Pod Weight (g)	-	-	1.3

Tables 5 shows values for the level of Okra parameters measured on the five different subplots with time, indicated in number of weeks after planting; and growth and yield parameters in relation to five levels of soil compaction treatments.

From the table 5, Okra crops at the control plot and uncompacted soil, had the average maximum number of leaf Area(cm^2) of 94.14, plant height(cm) of 33.4, pod yield of 2, no. of leaves count of 7 and pod weight(g) of 49 at 6WAP. Subplots at five(5) compaction levels had the average maximum number of leaf Area(cm^2) of 49.84, plant height(cm) of 30.6, pod yield of 2, no. of leaves count of 4 and pod weight(g) of 40.3 at 6WAP. At ten (10) compaction levels, the average maximum number of leaf Area(cm^2) of 65.8, plant height(cm) of 33.6, pod yield of 1.8, no. of leaves count of 6 and pod weight(g) of 34.1 at 6WAP were obtained. The average maximum number of leaf Area(cm^2) of 49.28, plant height(cm) of 26.6, pod yield of 1, no. of leaves count of 5 and pod weight(g) of 19.86 at 6WAP were realized at fifteen(15)compaction levels. While the minimum average values of number of leaf Area(cm^2) of 9.72, plant height(cm) of 13.06, pod yield of 1, no. of leaves count of 4 and pod weight(g) of 1.3 at 6WAP were obtained at twenty(20) soil densification levels. It is obvious from the results that Okra performances under various soil densifications increased as the weeks after planting increased and decreased as the number of tractor passes increased. At 6WAP the crop parameters at different stages depicted significant increase respectively when compared with 2WAP and 4WAP. This is in line with the statement of [22] that a harsh seedbed environment is likely to stress the seeding to limit the plants productive potential. This indicates that compaction of the soil due to the tractor passes had a slight detrimental effect on the maize crop growth. This result agrees with the findings of [2], when they said that soil structural modification optimizes soil conditions for seed.

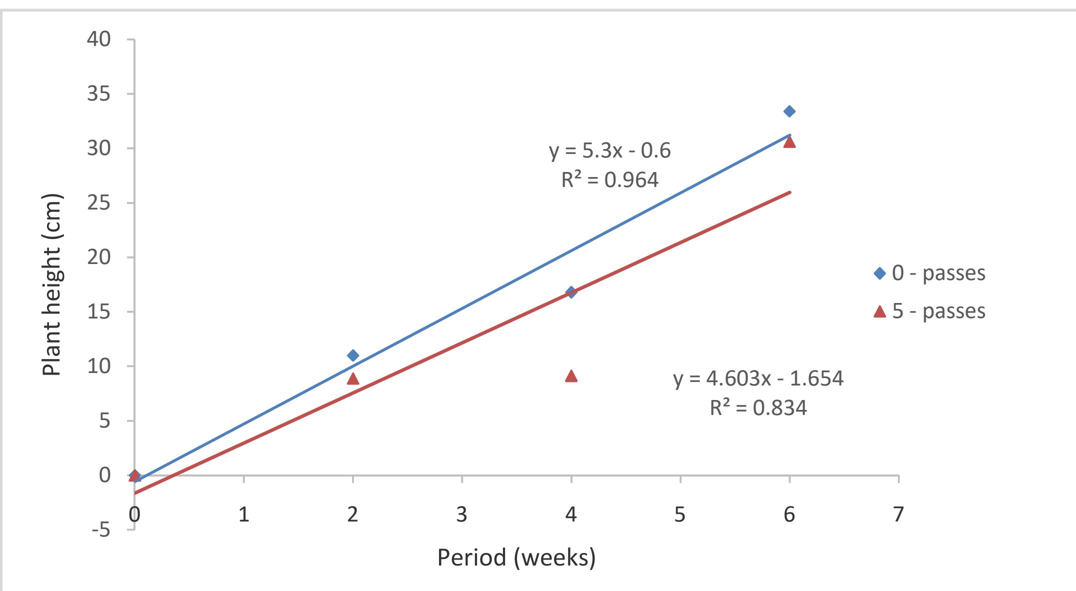

Figure 2: Plant height versus time interval for control plot and 5 – passes

Figure 2, is the graph that shows plant growth rate at 0 and 5 passes of tractor wheels. With the curve fittings regression equations the growth rate at zero (0) and five (5) compaction levels indicated 5.3cm/wk and 4.603cm/wk respectively. The relationship between plant heights at 6WAP shows that the correlation value at zero compaction of plant growth rate was higher than that at 5 compaction levels of subplots of plant growth rate given as 0.964 > 0.834. This might be as a result of the presence of soil nutrients such as nitrogen(N), phosphorus(p) and potassium(K) together making up what is known as NPK, needed by the plants for growth before planting activities were carried out.

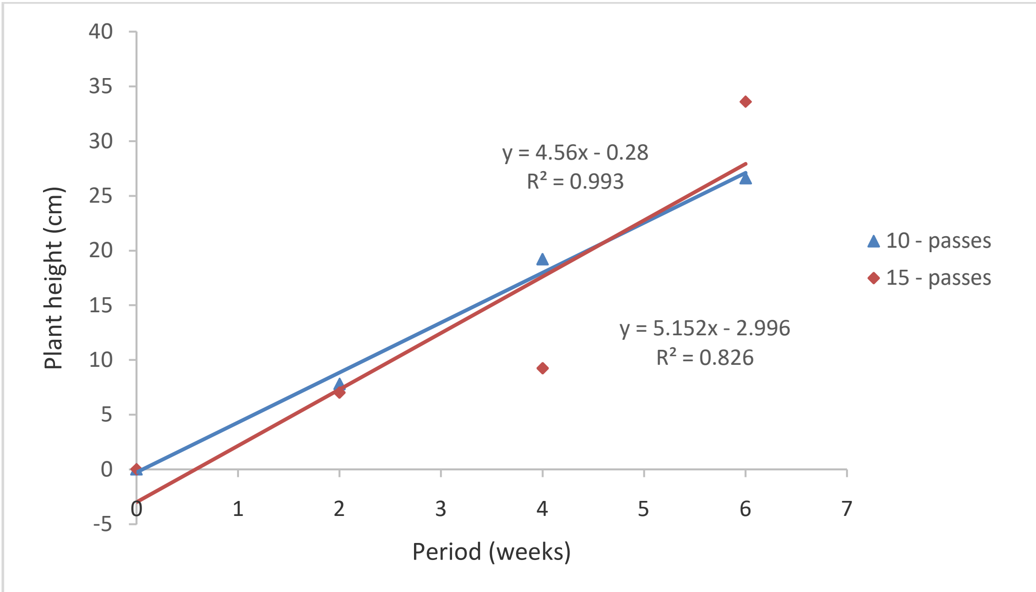

Figure 3: Plant height versus time for 10 and 15 – passes

The above graph of figure 3 shows growth rate at 10 and 15 passes of tractor wheels as: 4.56cm/wk and 5.152cm /wk. The relationship between plant heights after 6^{th} week of planting shows that the correlation value at 10 compaction of plant growth rate was higher than that at 15 compaction subplots of plant growth rate given as 0.993 > 0.826. This could be due to higher nature of free organic content materials and minerals available to Okra plants within the subsoil during this period of growth and development.

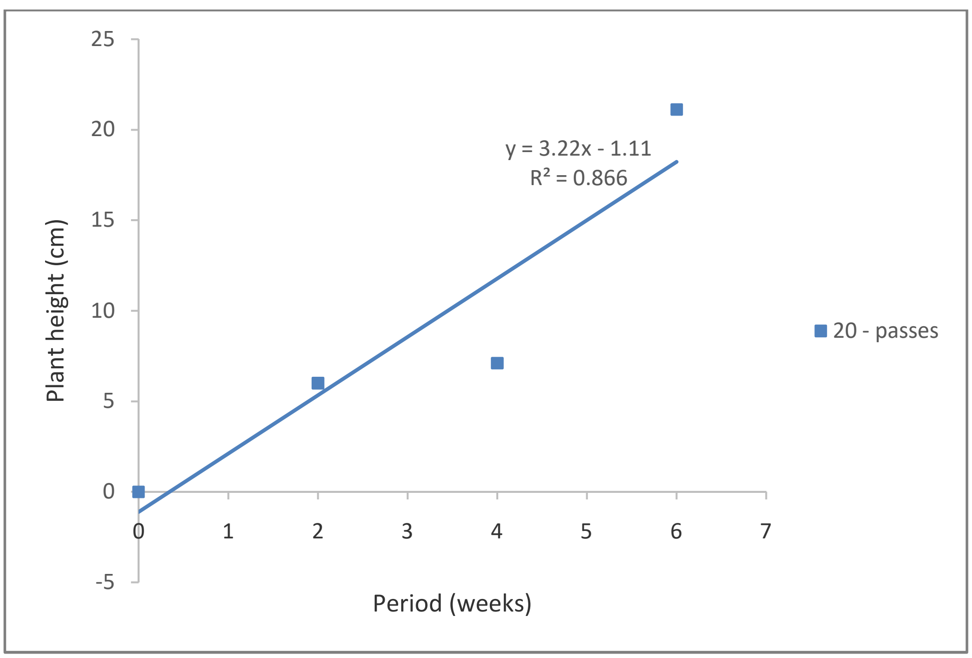

Figure 4: Plant height versus time for 20 – passes

The graph of figure 4 depicts the growth rate of Okra for a period of 6 weeks after planting at twenty (20) compaction levels of tractor wheels as 3.22cm/wk. The growth rate depicted from this graph at twenty (20) compaction of tractor passes could be seen from the simple linear regression equation of Y= 3.22X – 1.11 with coefficient of determination R^2 = 0.8669 for growth of 3.22cm/wk. This might be as a result of adverse effect of high level of soil compaction that seems to limit nutrients intake and infiltration of water content into in the soil reducing crops growth and performances. This agreed with the findings of [17] that from an agronomic point of view, the result of soil compaction decreased fruits growth and consequently a reduction in crop yield.

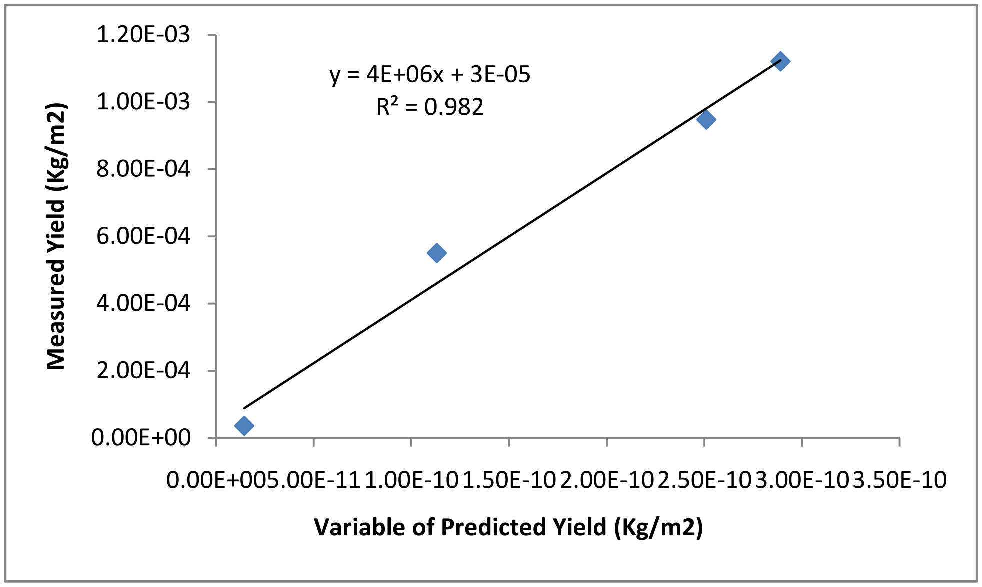

Figure 5: The graph for the determination of slope, φ and intercept, $\boldsymbol{C_1}$ for both predictive and measured yields respectively.

Figure 5, is a graph showing the simple linear regression equation from which the constants $\varphi\ and\ C_1$ for predictive equations Okra yields were estimated as $\varphi = 4\ x\ 10^6$, $C_1 = 3\ x\ 10^{-5}$ from the slope and constant of the regression equation y = 4E+06x + 3E-05.

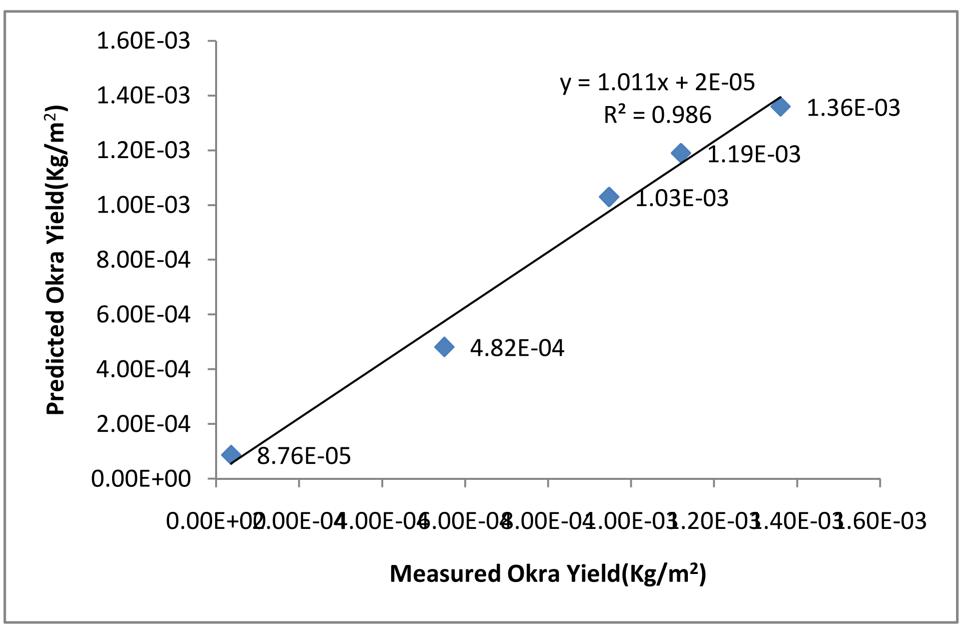

Figure 6: Graph of predicted okra yield vs measured okra yield

The graph depicting the accuracy of presented model for predicted crop yield against measured values as presented in figure 6 above, is evident from the fact that coefficient of determination R^2 = 0.986 from a linear regression equation Y = 1.011X + 2E-05 .This shows the high level of correlation and relationship between predicted and measured pod yields.

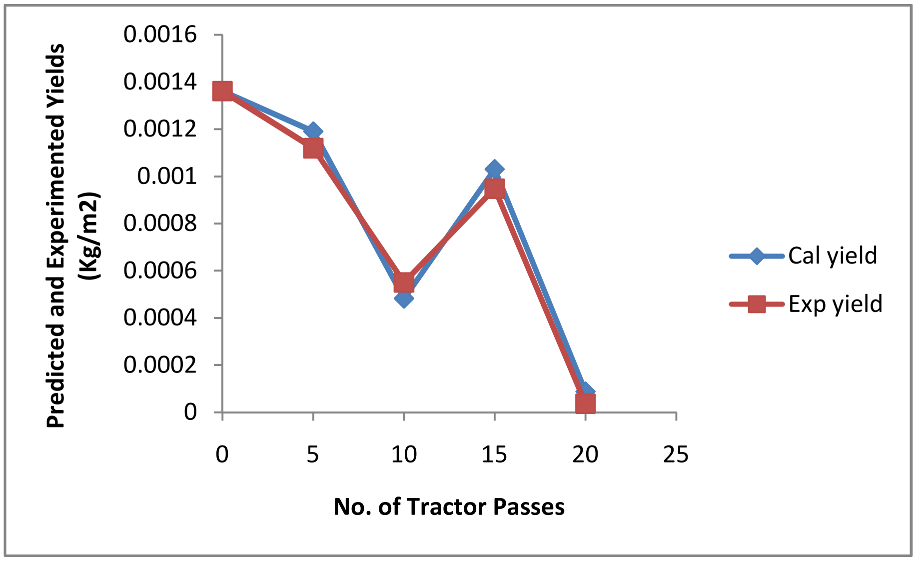

Figure 7: Graph of predicted and experimented yield plotted against no. of wheel passes.

The closeness between the two graphed lines above shows the level of agreement between calculated and experimented yields. And the only anomaly was noticed with subplots of 15 passes of tractor compaction which may be error in data recordings. The values in yield of Okra at both predicted and experimented result are shown in table 6 below

TABLE 6: VALUES OF CALCULATED AND EXPERIMENTAL YIELDS.

Passes	Cal yield	Exp yield
0	0.001361	0.001361
5	0.001190	0.001119
10	0.000482	0.000550
15	0.001030	0.000947
20	8.76E-05	3.61E-05

Plant heights can be simulated from the linear equations generated from figures 2 to 4 for predicting the growth rate. The graph of plant height against period shows that there is a strong and positive relationship between time and plant height with coefficients of determination R^2 = 0.964, 0.834, 0.993, 0.826, 0.866 at 0, 5, 10, 15 and 20 tractor passes. The growth rates generated from the model in cm/week are: 5.3, 4.603, 4.56, 5.125, and 3.22 for 0, 5, 10, 15 and 20 tractor passes respectively.

Compaction increases soil strength and bulk density. At higher levels of soil strength, roots are more sensitive to moisture deficits [11]. A similar relationship was found for the root length of pea [14]

The effect of compaction was highly significant on the growth rate and the plant height. The highest plant height was observed in control plot at 6WAP. However, plant height reduced at 4WAP throughout the compaction process. Average of randomly selected plants while that of 20 – compactions zones remained sparingly unchanged with little significant difference in plant height over the period of 2, 4 to 6 weeks after planting.

Results of findings showed that compaction of agricultural soil can effect both delayed and reduced okra growth, okra pod yield, root density and as well go a long way to be a function of incurred cost on growers.

VI. CONCLUSION

This study had developed predicted model for Okra crop yields in densified soil. The established predictive equation is $(\gamma_p) = \varphi \frac{(\dot{\omega}_p)_i \sqrt{(\rho_d)_i (CI)_i}}{D_c} + C_1$. The model was validated using graphic comparison, ANOVA and t-test with Microsoft Excel Software, between the experimented and predicted Okra crop yields, with relative coefficient of determination value of $R^2 = 0.982$. The result showed no significant difference between them at ($P<0.05$).

There was decrease in Okra crop yield as compaction through traffic passes increased. Results of this study showed that Okra growth rate and yield increased significantly with respect to degenerate traffic passes, and a major portion of the compacted soil at 20-compaction of tractor wheels was observed with reduced Okra yield. The result of the validated model showed an acceptable agreement with the experimented and predicted Okra crop yields.

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