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Models Establishment for Predicting Interaction between Tillage Practices and Some Selected Engineering Properties of Cassava (*Manihot esculenta*) Tubers

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Authors' contributions

This work was carried out in collaboration among all authors. Authors OAA, OJO, APO and OOO designed the study, wrote the protocol, managed the analyses of the study and managed the literature searches. Author OAA performed the statistical analysis and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Enough technical data on the physical and mechanical properties of tubers are needed for machine design and crop parameters in modeling and designing cassava processing. The main objective of this study was to establish models for forecasting interaction between the tillage practices and some physical and mechanical properties of cassava tubers. Eight tillage practices have been used and are coded in alphabets such as, ploughing + harrowing (A); ploughing + harrowing + ridging (B); manual ridging (C); flat manual clearing (D); ploughing + harrowing + manual digging to a depth of 30 cm + 10 cm of saw-dust placed at the base (E); ploughing + harrowing + ridging +10 cm of saw-dust placed at the base (F); manual ridging + 10 cm of saw-dust placed at the base (G) and manual digging to a depth of 30 cm + 10 cm of saw-dust placed at the base (H). The experiment was conducted in TME (Tropical *Manihot esculenta*) 419 with two soil conditions using recommended nutrient dosage. The experimental design was split-split plot

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design with three replications. The physical and mechanical properties of cassava were determined 10 months after planting using standard equations and methods. Statistical Package for Social Science window 21 versions was used for data analysis. Models were developed using Linear Regression. Manual Ridging + 10 cm Sawdust placed at the base + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer tillage practice gave the highest yield of 15.02 tons/ha with uniform physical and mechanical properties. The model equations revealed that tillage had positive impact on the selected physical and mechanical properties of cassava tubers such as length, width, thickness, size, aspect ratio, surface area, sphericity, roundness, unit mass, unit volume, true density, bulk mass, bulk volume, bulk density, porosity, angle of repose, coefficient of static friction, compressive extension at break, compressive strain at break, compressive load at break, compressive stress at break, energy at break, modulus automatic, compressive load at yield, compressive extension at yield, and compressive strain at yield and compressive stress Models developed could be used by engineers in designing improved equipment and machineries for harvesting and processing of cassava tubers into useful products.

Keywords: Cassava; model; predicting; properties; tillage.

1. INTRODUCTION

Tillage makes a suitable seedbed state for sprout appearance, growth and unhindered root development [1]. Unsuitable tillage practices may reduce crop development and production. However, careful choice of good tillage method is essential criteria for meaningful development and production of crop [2]. Tillage practice accounts for about twenty per cent of crop growth and [3,4]. Hammel [5] reported that tillage practice influences the bearable usage of land by affecting the soil characteristics.

Olakulehin and Ajibola [6] reported that cassava is one of the most important staple crops in tropical Africa with high energy content. Root and tuber crops respond to zero or minimum tillage in a different way. Jongruaysup et al. [7] stated that the fresh root yield of cassava (*Manihot esculenta* Crantz.) grown under a zero-tillage method was significantly higher than that of cassava grown in Thailand using traditional tillage on fine loamy soil (Oxic Paleustults). But the yield of cassava tuber was comparable at the Khaw Hin Sorn and TTDI sites in Thailand while the lowest yield was obtained at the same country's Huay Pong and Rayong sites. Peeling is one of the important and first procedure performed after harvesting of cassava tubers, which is used to clean the debris form tubers. Since the peels of tubers can be put to various uses, the process must ensure that which layer is to be removed. It involves peeling off the outer skin of the cassava tuber or removing the thin layer from the tuber (usually called the peel). Other problems currently encountered in cassava peeling include peeling off an unacceptable percentage of useful flesh during mechanical peeling, reduced peeling efficiency with increased time and operating speed. Manual peeling being either slow, labor intensive or ineffective. Insufficient technical data on the engineering properties of cassava tubers required for machine design as well as the crop and machine operating parameters needed to model and design the peeling process [8-10] that affect the tuber properties.

Attempts at mechanizing the cassava peeling operation have been acknowledged but machines have not been fully developed yet [11] as no efficient cassava peeler is presently in the market in Nigeria [12,13,10]. This is attributed to the irregularity in the shape of the tubers as well as the wide variations in the thickness of the peel, tuber size and weight across different varieties of the crop [8,14]. According to [12] a successful cassava peeler should, among other things, be efficient in removing the cortex of the tubers without substantial loss of useful flesh.

Thus, it is difficult to design a cassava peeling machine that is capable of efficient peeling all roots due to the wide differences in properties of roots from various sources. A good knowledge of models for predicting the relationship between tillage practices and some engineering properties are necessary to design machines required for mechanization of cassava handling and processing operations. The major objective of this study was to establish models for forecasting the interaction of tillage practices and some engineering properties of cassava tubers.

Table 1. Field experimental treatment details in tropical cassava

Treatments	Description	Codes
T_1	Ploughing + Harrowing + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	AV1RfdF3
T_2	Ploughing + Harrowing + ridging + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	BV1RfdF3
T_3	Manual Ridging + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	CV1RfdF3
T_4	Zero or No-till + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	DV1RfdF3
T_5	Ploughing + Harrowing + Manual digging to a depth of 30 cm + 10 cm Sawdust placed at the base + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	EV1RfdF3
T_6	Ploughing + Harrowing + ridging +10 cm Sawdust placed at the base + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	FV1RfdF3
T_7	Manual Ridging + 10 cm Sawdust placed at the base + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	GV1RfdF3
T_8	Manual Digging to a depth of 30 cm + 10 cm Sawdust placed at the base + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer	HV1RfdF3
T_9	Ploughing + Harrowing + TME 419 + Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	AV1IrdF3
T_{10}	Ploughing + Harrowing + ridging + TME 419 + Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	BV1IrF3
T_{11}	Manual Ridging + TME 419 + Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	CV1IrF3
T_{12}	Zero or No-till + TME 419 + Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	DV1IrF3
T_{13}	Ploughing + Harrowing + Manual digging to a depth of 30 cm + 10 cm Sawdust placed at the base + TME 419 + Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	EV1IrF3
T_{14}	Ploughing + Harrowing + ridging +10 cm Sawdust placed at the base + TME 419 + Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	FV1IrF3
T_{15}	Manual Ridging + 10 cm Sawdust placed at the base + TME 419 + R Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	GV1IrF3
T_{16}	Manual Digging to a depth of 30 cm + 10 cm Sawdust placed at the base ++ TME 419 + Irrigated + 933.75 kg/ha of NPK 15:15:15 fertilizer	HV1IrF3

Where T is treatment, A is ploughing + harrowing, B is ploughing + harrowing + ridging, C is manual ridging, D is flat manual clearing, E is ploughing + harrowing + manual digging to a depth of 30 cm + 10 cm of saw-dust placed at the base, F is ploughing + harrowing + ridging +10 cm of saw-dust placed at the base, G is manual ridging + 10 cm of saw-dust placed at the base, H is manual digging to a depth of 30 cm + 10 cm of saw-dust placed at the base, TME is Tropical Manihot Esculenta, Rfd is Rainfed soil, F3 is 933.75 kg/ha of NPK 15:15:15 fertilizer, Ir is Irrigated soil and TME is Tropical Manihot Esculenta

Table 2. Determination of physical properties of harvested cassava tubers

Property	Method or equation for determining of physical properties	Reference
Length (cm)	Measuring tape	" Reference [15] "
Width (cm)	Digital vernier caliper	" Reference [15] "
Thickness (cm)	Measuring three different segments of the cassava tubers using digital vernier caliper	" Reference [15] "
Size (cm)	$D_g = (abc)^{1/3}$	" References [16,17] "
Aspect ratio (%)	$R_{a=\frac{b}{a}}$ 100%	" Reference [18] "
Surface area (cm^2)	$S_a = \pi D_g{}^2$	" References [19,15] "
Sphericity (cm)	$S_p = \frac{(abc)^{1/3}}{a}$ 100%	" References [19,15] "
Roundness	$R_o = \frac{A_P}{A_C}$	" References [19,15] "
Angle of repose (^{0})	The apparatus consisting of plywood box with a fixed stand attached with a protractor and an adjustable plate at the surface	" Reference [20] "
Coefficient of friction	$\mu = \tan \alpha$	" References [19,15] "
Mass (kg)	A digital weighing balance 10 kg was used in weighing each of the cassava tubers	" References [19,15] "
Volume (m^3)	By putting a known mass of a (unit) sample into a cylindrical container of water, change in level of the liquid in the cylinder gives the unit volume	" Reference [14] "
True density (kg/m^3)	$\rho_t = \frac{W_t}{V_t}$	" References [17,19] "
Bulk density (kg/m^3)	$\rho_b = \frac{W_s}{V_s}$	" References [17,19] "
Bulk mass (kg)	By weighing together all the cassava in a bucket	" Reference [15] "
Bulk volume (m^3)	The whole sample in a stand was put into the cylindrical container of water, and the change in level of the liquid in the cylinder	" Reference [16] "
Porosity (%)	$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100$	" Reference [17] ".

Where D_g is the equivalent diameter in cm; a is the length in cm; b is the width in cm and c is the thickness in cm, R_a is the aspect ratio in %; S_a is the surface area in cm^2; S_p is the sphericity in cm; R_o is the roundness; A_p is the largest projected area of object in natural resting position in cm^2; A_c is the area of the smallest circumscribing circle in cm^2; μ is the coefficient of static friction and α is the angle of repose in ^{0}; ρ_t is the true density in kg/m^3; W_t is the true weight in kg; V_t is the true volume in m^3; ρ_b is the bulk density in kg/m^3; W_s is the weight of the sample in kg; V_s is the volume occupied by the sample in m^3; ε is the porosity, ρ_t is the true density in kg/m^3 and ρ_b is the bulk density in kg/m^3

2. MATERIALS AND METHODS

2.1 Site Description and Experimental Design

Field experiment was conducted from May 2014 to July 2015 in Teaching and Research Farm of the Federal University of Technology Akure (7°15^{1}N, 5°15^{1}E). Weather conditions during the growing period were recorded using digital thermometer, rainguage, hygrometer and barometer. The total area of experiment is 10 x 22 meters (220 m^{2}) and a line spacing of 1 meter between the plots and cassava stand was observed. The cassava stems of 15-20 cm long were planted at a depth of 15-20 cm in May 2014 and May 2015 then they were harvested in July 2015 and July 2016, respectively. The treatment details of the experiment are presented in Table 1.

2.2 Determination of Physical Properties of Cassava Tubers

The physical properties of cassava tubers were determined using standard methods and equations as presented in Table 2.

2.3 Determination of Mechanical Properties of Cassava Tubers

The mechanical properties of cassava tubers were carried at the laboratory of Engineering Materials Development Institute, Ondo Road, Akure, Ondo State using INSTRON 3369 universal testing machine.

2.4 Statistical Analysis

Excel was used to compute the raw data. Models were developed using Linear Regression. Statistical Package for Social Science (SPSS 21 version) was used to analyze some physical and mechanical properties of the data generated from this study.

3. RESULTS AND DISCUSSION

3.1 Effect of Tillage Practices on Physical and Mechanical Properties of TME 419 Cassava Tubers for a Rain-fed Soil + 933.75 kg/ha Fertilizer

The effect of tillage practices on selected engineering properties of TME 419 cassava tubers for a rain-fed soil + 933.75 kg/ha fertilizer is presented in Tables 3 and 4. Figs. 1a - 1h showed the effect of tillage practices on compression test of TME 419 cassava tubers for a rain fed soil + 933.75 Kg/Ha fertilizer. The results revealed that the physical properties of cassava tubers such as length, width, thickness, size, aspect ratio, surface area, sphericity, roundness, unit mass, unit volume, true density, bulk mass, bulk volume, bulk density, porosity, angle of repose and coefficient of static friction ranged from 21.11±3.18^{a} - 37.92±5.41^{b} cm, 4.19±0.28^{ab} - 6.82±0.39^{bc} cm, 4.07±0.25^{a} - 5.76±0.34^{b} cm, 7.12±0.51^{a} - 10.67±0.83^{a} cm, 13.94±1.72^{a} – 27.93±3.85^{b} %, 165.93±23.29^{a} – 376.96±54.36^{a} cm^{2}, 25.15±1.98^{a} – 40.24±3.57^{c} cm, 23.46±7.82^{a} – 103.06±22.58^{a}, 0.35±0.06^{a} – 0.88±0.16^{b} kg, 0.30±0.05^{a} – 0.79±0.17^{c} m^{3}, 0.83±0.12^{a} – 2.21±1.07^{a} kg/m^{3}, 3.22^{a} - 15.02^{h} kg, 3.22^{a} - 13.70^{h} m^{3}, 0.96^{a} - 1.16^{h} kg/m^{3}, -114.07±10.45^{a} - 19.35±7.33^{c} %, 68.56±0.88 ^{a}-72.44±0.5^{b} and 2.55±0.12^{a} - 3.19±0.11^{b} respectively. The mechanical properties of cassava tubers such as compressive extension at break, compressive strain at break, compressive load at break, compressive stress at break, energy at break, modulus automatic, compressive load at yield, compressive extension at yield, compressive strain at yield and compressive stress at yield ranged from 31.33±0.480^{a} - 45.27±0.69^{b} mm, 1.87±0.047^{a} - 101.01±97.99^{a} mm/mm, 4310.76±65.84^{a} - 46597.00±1497.88^{g} N, 1.45±0.02^{a} - 28.04±0.90^{e} Mpa, 63.47±0.97^{a} - 249.58±8.03^{f} J, 1.53±0.024^{a} - 2.50±0.037^{e} Mpa, 1404.77±21.45^{a} - 4858.60±128.54^{g} N, 13.05±0.199^{a} - 19.35±0.62^{e} mm, 0.63±0.008^{a} - 1.13±0.02^{e} mm/mm and 0.77±0.012^{a} - 1.51±0.024^{e} Mpa, respectively.

The cassava tubers from the eight tillage practices behave differently for the measured mechanical properties of stress- strain and compression test. The tillage practice that gave the uniform and regular length, width, thickness, size, aspect ratio, surface area, sphericity, roundness, unit mass, unit volume, true density, bulk mass, bulk volume, bulk density, porosity, angle of repose and coefficient of static friction was Manual Ridging + 10 cm Saw-dust placed at the base (treatment 7). While tillage H Manual Digging to a depth of 30 cm + 10 cm Sawdust placed at the base + TME 419 + Rainfed + 933.75 kg/ha of NPK 15:15:15 fertilizer (treatment 8) gave the lowest bulk mass. Manual Ridging + 10 cm Saw-dust placed at the base tillage practice enhanced the better performance of the automated cassava peeling machine with tuber length of 33.04±2.30^{ab} cm, width of 5.04±0.47^{ab} cm, thickness of 4.36±0.40^{a} cm, size of 8.86±0.69^{a} cm, aspect ratio of 16.80±1.81^{ab} % , surface area of 266.50±37.4^{a} cm^{2}, sphericity of 28.37±1.95^{ab} cm, roundness of 73.68±14.14^{ab}, unit mass of 0.57±0.12^{ab} kg, unit volume of 0.55±0.11^{ab} m^{3}, true density of 0.99±0.09^{a} kg/m^{3}, bulk mass of 9.39±0.00^{h} kg, bulk volume of 8.8±0.00^{h} m^{3}, bulk density of 0.99±0.00^{c} kg/m^{3}, porosity of -56.51±7.25^{ab} %, angle of repose of 71.17±0.44^{b} coefficient of static friction of 2.86±0.07^{ab}, compressive extension at break of 45.27±0.69^{b} mm, compressive strain at break of 3.02±0.04^{a} mm/mm, compressive load at break of 31596.59±482.65^{f} N, compressive stress at break of 11.18±0.17^{d} MPa, energy at break of 239.09±3.65^{f} J, modulus automatic of 1.95±0.03^{b} MPa, compressive load at yield of 3594.28±54.91^{e} N, compressive extension at yield of 15.95±0.24^{c} mm, compressive strain at yield of 1.06±0.02^{d} mm/mm, and compressive stress at yield of1.27±0.02^{c} MPa respectively. Thus, the challenge of peeling off of unacceptable percentage of useful flesh during mechanical peeling could be solved using Manual Ridging + 10 cm Saw-dust placed at the base as reported by researchers that attempts at mechanizing the cassava peeling operation have been acknowledged but machines have not been fully developed yet due to the irregularity in the shape of the tubers as well as the wide variations in the thickness of the peel, tuber size and weight across different varieties of the crop [21] as no efficient cassava peeler is presently in the market in Nigeria [22-25].

Table 3. Effect of tillage practices on physical properties of TME 419 cassava tubers for a rain fed soil + 933.75 Kg/Ha fertilizer

Parameters	A	B	C	D	E	F	G	H
L (cm)	34.53±6.75^{ab}	25.92±3.70^{ab}	28.78±4.09^{ab}	28.76±5.20^{ab}	21.11±3.18^{a}	37.91±5.407^{b}	29.45±2.65^{ab}	21.71±2.36^{a}
W (cm)	5.25±0.79^{ab}	5.72±0.26^{b}	5.75±0.23^{b}	4.95±0.37^{ab}	5.21±0.63^{ab}	4.99±0.28^{ab}	5.002±0.33^{ab}	4.19±0.28^{a}
T (cm)	4.71±0.73^{a}	5.12±0.21^{a}	4.89±0.32^{a}	4.46±0.33^{a}	4.57±0.39^{a}	4.52±0.34^{a}	4.38±0.30^{a}	4.07±0.25^{a}
DG (cm)	9.27±1.42^{a}	8.95±0.59^{a}	9.12±0.47^{a}	8.44±0.75^{a}	7.80±0.75^{a}	9.31±0.83^{a}	8.51±0.58^{a}	7.12±0.51^{a}
AR (%)	18.73±4.33^{ab}	26.04±3.22^{ab}	23.47±3.66^{ab}	19.74±2.34^{ab}	27.93±3.85^{b}	17.28±2.49^{a}	19.65±1.90^{ab}	20.69±2.02^{ab}
SA (cm^2)	301.71±94.82^{a}	263.08±33.38^{a}	266.34±27.50^{a}	239.52±42.41^{a}	205.44±38.41^{a}	298.46±44.18^{a}	252.41±34.23^{a}	165.93±23.28^{a}
SP (cm)	29.58±3.55^{ab}	38.79±3.29^{bc}	35.26±3.84^{abc}	32.25±2.43^{abc}	40.24±3.57^{c}	28.87±2.60 ^{a}	31.59±1.91^{abc}	34.25±1.92^{abc}
R	68.71±19.53^{b}	46.60±16.41^{ab}	63.23±19.60^{ab}	67.18±15.52^{b}	23.46±7.82^{a}	66.44±13.49^{b}	43.69±5.69^{ab}	31.61±5.84^{ab}
M (kg)	0.77±0.31^{ab}	0.49±0.09^{ab}	0.56±0.11^{ab}	0.35±0.06^{a}	0.41±0.09^{ab}	0.88±0.16 ^{b}	0.62±0.12^{ab}	0.35±0.07^{a}
V (m^3)	0.72±0.28 ^{a}	0.46±0.083^{a}	0.51±0.10^{a}	0.30±0.05^{a}	0.37±0.09^{a}	0.66±0.12^{a}	0.56±0.12^{a}	0.33±0.07^{a}
TD (kg/m^3)	1.03±0.03^{a}	1.09±0.01^{a}	1.12±0.01^{a}	1.16±0.02 ^{a}	1.17±0.08 ^{a}	2.21±1.07 ^{a}	1.15±0.05^{a}	1.06±0.05^{a}
BM (kg)	4.62^{e}	5.43^{f}	4.55^{d}	3.68^{c}	3.47^{b}	8.33^{g}	15.02^{h}	3.22 ^{a}
BV (m^3)	4.18^{e}	4.91^{f}	4.12^{d}	3.33^{b}	3.50^{c}	8.70^{g}	13.70^{h}	3.20 ^{a}
BD (kg/m^3)	1.11^{f}	1.11^{e}	1.11^{f}	1.11^{e}	0.99^{b}	0.96 ^{a}	1.01^{d}	1.01^{c}
P (%)	-8.54±3.11^{a}	-1.34±0.98^{ab}	0.78±1.22^{ab}	4.90±1.25^{abc}	12.30±5.17^{bc}	19.35±7.33^{c}	1.05±4.04^{ab}	3.19±4.72^{ab}
AP (^{0})	71.17±0.60^{b}	71.18±0.29^{b}	71.25±0.41^{b}	71.2±0.32^{b}	72.44±0.5^{b}	71.31±0.58^{b}	71.17±0.44^{b}	68.56±0.88 ^{a}
CF	2.94±0.10^{b}	2.94±0.052^{b}	2.96±0.07^{b}	2.94±0.06^{b}	3.19±0.11^{b}	2.99±0.10^{b}	2.98±0.09^{b}	2.58±0.12 ^{a}

Values are means of triplicates and standard error. Means values having different superscript within the same row are significantly different ($P<0.05$). Where L is the length in cm, W is the width in cm, T is the thickness in cm, DG is the size in cm, AR is the aspect ratio in %, SA is the surface area in cm^2, SP is the sphericity in cm, R is the roundness, M is the unit mass in kg, V is the unit volume in m^3, TD is the true density in kg/m^3, BM is the bulk mass in kg, BV is the bulk volume in m^3, BD is the bulk density in kg/m^3, P is the porosity in %, AP is the angle of repose in ^{0} and CF is the coefficient of static friction

Table 4. Effect of tillage practices on mechanical properties of TME 419 cassava tubers for a rain fed soil + 933.75 Kg/Ha fertilizer

Parameters	A	B	C	D	E	F	G	H
CE (mm)	44.87±1.18^{b}	44.98±1.45^{b}	44.68±0.68^{b}	45.05±0.68^{b}	32.12±0.49^{a}	31.33±0.48^{a}	45.27±0.69^{b}	33.89±0.52^{a}
CS (mm/mm)	1.87±0.05^{a}	101.01±97.99^{a}	1.94±0.03^{a}	2.15±0.03^{a}	2.14±0.03^{a}	2.09±0.03^{a}	3.02±0.05^{a}	2.42±0.04^{a}
CL (N)	10520.37±278.34^{d}	46597.00±1497.88^{g}	4310.76±65.84^{a}	7597.89±116.06^{c}	6378.17±97.43^{bc}	4811.37±496.00^{ab}	31596.59±482.65^{f}	14982.90±228.86^{e}
CSR (MPa)	2.26±0.05^{ab}	28.04±0.90^{e}	2.38±0.04^{ab}	3.32±0.04^{b}	2.49±0.04^{ab}	1.45±0.02^{a}	11.18±0.17^{d}	5.30±0.08^{c}
EB (J)	200.83±5.31^{e}	249.58±8.03^{f}	63.47±0.97^{a}	118.47±1.80^{c}	86.07±1.31^{b}	82.42±1.26^{b}	239.09±3.65^{f}	154.83±2.36^{d}
MA (MPa)	2.06±0.05^{bc}	2.22±0.07^{d}	2.24±0.04 ^{d}	2.50±0.04^{e}	2.15±0.03^{cd}	1.53±0.02^{a}	1.95±0.03^{b}	2.18±0.03^{cd}
CLY (N)	4858.60±128.54^{g}	2362.57±75.95^{b}	1404.77±21.45^{a}	2989.04±45.66^{c}	3305.22±50.488 ^{d}	4067.68±62.133^{f}	3594.28±54.905^{e}	4262.57±65.112^{f}
CSY (mm)	18.15±0.48^{d}	19.35±0.62^{E}	14.45±0.22^{b}	18.95±0.29^{de}	15.95±0.24^{c}	17.00±0.26^{c}	15.95±0.24^{c}	13.05±0.19^{a}
CSTY (mm/mm)	0.76±0.02^{b}	1.29±0.04^{f}	0.63±0.01^{a}	0.90±0.01^{c}	1.06±0.02^{d}	1.13±0.02^{e}	1.06±0.02^{d}	0.93±0.01^{c}
CSTYZ (MPa)	1.04±0.03^{b}	1.42±0.05^{d}	0.77±0.01^{a}	1.31±0.02^{c}	1.29±0.01856^{c}	1.23±0.02^{c}	1.27±0.02^{c}	1.51±0.02^{e}

Values are means of triplicates and standard error. Means values having different superscript within the same row are significantly different (P<0.05). CE is the Compressive extension at Break (Standard) is in mm, CS is the compressive strain at break (standard) is in mm/mm, CL is the Compressive load at Break (Standard) is in N, CSR is the compressive stress at break (standard) is in MPa, EB is the energy at break (standard) is in J, MA is the modulus Automatic is in MPa, CLY is the compressive load at yield is in N, CSY is the compressive extension at yield (zero slope) is in mm, CSTY is the compressive strain at yield (zero slope) is in mm/mm and CSTYZ is the compressive stress at yield (zero slope) is in MPa

Table 5. Effect of tillage practices on physical properties of TME 419 cassava tubers for an irrigated soil + 933.75 Kg/Ha fertilizer (2014/2015 Planting Season)

Parameters	A	B	C	D	E	F	G	H
L (cm)	22.55±1.97^{ab}	27.80±2.07^{b}	18.33±1.28^{a}	24.03±3.45^{ab}	25.42±3.39^{ab}	26.18±1.91^{ab}	26.97±3.22^{ab}	22.36±4.21^{ab}
W(cm)	5.64±0.40^{a}	5.44±0.59^{a}	4.79±0.59 ^{a}	6.33±0.62 ^{a}	6.12±0.27^{a}	5.87±0.33^{a}	4.82±0.48^{a}	5.38±0.52^{a}
T (cm)	4.41±0.29^{a}	4.28±0.42^{ab}	4.29±0.51^{ab}	5.38±0.57^{ab}	5.36±0.24^{ab}	4.69±0.43^{b}	3.70±0.37^{ab}	3.99±0.40^{ab}
DG (cm)	8.22±0.56^{ab}	8.56±0.72^{ab}	7.07±0.56^{ab}	9.07±0.62^{ab}	9.28±0.59^{a}	8.82±0.54^{ab}	7.64±0.54^{b}	7.65±0.76^{ab}
AR (%)	25.58±1.46^{ab}	19.89±1.83^{a}	27.41±3.74 ^{a}	31.24±6.22^{a}	27.79±3.69^{a}	24.13±2.24^{a}	20.41±3.61 ^{a}	28.24±5.16^{a}
SA (cm^2)	219.05±27.35^{a}	244.76±41.75^{ab}	165.66±26.93^{ab}	266.88±36.76^{ab}	279.36±33.70^{a}	256.874±30.21^{ab}	190.58±24.90^{b}	194.98±36.71^{ab}
SP (cm)	37.09±1.52^{ab}	31.32±2.16^{a}	39.86±3.63^{ab}	42.16±5.61^{ab}	40.05±3.42^{ab}	35.047±2.09^{b}	30.48±3.22^{ab}	38.14±4.70^{ab}
R	40.83±6.33^{a}	77.78±15.11^{b}	27.73±7.37^{a}	36.49±11.69^{b}	20.96±5.06^{a}	26.69±5.65^{a}	51.72±15.29^{a}	23.04±7.49^{a}
M (kg)	0.39±0.07^{a}	0.48±0.11^{a}	0.29±0.07^{a}	0.60±0.15^{a}	0.57±0.09^{a}	0.61±0.08^{a}	0.460.08^{a}	0.36±0.09^{a}
V (m^3)	0.36±0.07^{a}	0.42±0.09^{ab}	0.26±0.06^{ab}	0.63±0.14^{ab}	0.61±0.12^{a}	0.64±0.08^{b}	0.56±0.07^{b}	0.44±0.08^{b}
TD (kg/m^3)	1.16±0.02^{ab}	1.15±0.02^{b}	1.14±0.02^{b}	1.14±0.02^{b}	1.09±0.16^{b}	0.96±0.07^{b}	0.79±0.08^{b}	0.75±0.08^{ab}
BM (kg)	3.23^{c}	4.86^{f}	2.9^{b}	4.80^{e}	5.29^{g}	7.95^{h}	4.13^{d}	2.52^{a}
BV (m^3)	2.92^{b}	4.40^{e}	2.62^{a}	4.34^{d}	5.7^{g}	7.85^{h}	5.4^{f}	3.6^{c}
BD (kg/m^3)	1.11^{f}	1.11^{f}	1.11^{f}	1.11^{e}	0.93^{d}	0.82^{c}	0.76^{b}	0.70^{a}
P (%)	3.84±1.82^{a}	3.46±1.93^{a}	2.61±1.70^{a}	2.39±1.3^{a}	1.33±12.38^{a}	3.22±13.43^{a}	-7.27±14.74^{a}	-1.26±11.35^{a}
AP (^{0})	71.25±0.41^{a}	71.20±0.33^{a}	68.70±0.45^{d}	67.00±0.42^{d}	68.22±0.662^{bc}	69.47±0.46^{a}	69.78±0.46^{ab}	70.00±0.76 ^{bc}
CF	2.96±0.07^{cd}	2.94±0.06^{d}	2.58±0.06^{d}	2.37±0.05^{d}	2.53±0.09^{bc}	2.69±0.06^{a}	2.7267±0.06^{ab}	2.78±0.11^{bc}

Values are means of triplicates and standard error. Means values having different superscript within the same row are significantly different (P<0.05)

Table 6. Effect of tillage practices on mechanical properties of TME 419 cassava tubers for an irrigated soil + 933.75 Kg/Ha fertilizer

Parameters	A	B	C	D	E	F	G	H
CE (mm)	44.76±0.68^{c}	44.71±0.68^{c}	39.89±0.60^{b}	39.66±0.60^{b}	40.58±0.62^{b}	32.7±0.50^{a}	32.68±0.50^{a}	31.39±0.48^{a}
CS (mm/mm)	1.66±0.02 ^{a}	2.35±0.04^{d}	1.59±0.02^{a}	2.08±0.03^{bc}	2.02±0.03^{b}	2.17±0.03^{c}	2.17±0.03^{c}	2.09±0.03^{bc}
CL (N)	5016.63±76.62^{b}	48728.0±744.33^{e}	4962.68±75.81^{b}	5210.89±79.60^{b}	15780.2±241.05^{d}	11128.6±169.99^{c}	4021.66±61.43^{a}	5371.51±82.05^{b}
CSR (MPa)	1.83±0.02b^{c}	13.03±0.20^{g}	1.592±0.02^{ab}	2.36±0.03^{d}	4.82±0.07^{f}	3.94±0.06^{e}	2.05±0.03^{c}	1.48±0.02^{a}
EB (J)	120.84±1.85^{de}	408.22±6.23^{g}	122.41±1.87^{e}	95.80±1.46^{c}	180.42±2.76^{f}	112.67±1.72^{d}	57.36±0.88^{a}	85.90±1.31^{b}
MA (MPa)	2.03±0.03^{a}	2.67±0.04^{d}	2.13±0.03^{a}	2.69±0.04^{d}	2.34±0.03^{b}	2.69±0.04^{d}	2.89±0.04^{e}	2.50±0.03^{c}
CLY (N)	3466.04±52.94^{c}	5788.11±88.41^{e}	4185.46±63.93^{d}	3020.36±46.13^{b}	4144.51±63.31^{d}	3432.30±52.43^{c}	2325.61±35.53^{a}	4509.61±68.89^{e}
CSY (mm)	26.10±0.40^{f}	20.35±0.31^{d}	22.5±0.34^{e}	17.35±0.27^{c}	19.87±0.31^{d}	12.55±0.19^{a}	13.6±0.21^{b}	17.60±0.27^{c}
CSTY (mm/mm)	0.97±0.02^{c}	1.07±0.02^{d}	0.90±0.01^{b}	0.91±0.01^{b}	0.96±0.02^{c}	0.84±0.01^{a}	0.91±0.01^{b}	1.17±0.018^{e}
CSTYZ (MPa)	1.27±0.02^{b}	1.55±0.02^{d}	1.34±0.02^{c}	1.37±0.02^{c}	1.41±0.02^{c}	1.22±0.02^{ab}	1.19±0.019^{a}	1.24±0.02^{ab}

Values are means of triplicates and standard error. Means values having different superscript within the same row are significantly different (P<0.05)

3.2 Effect of Tillage Practices on Physical and Mechanical Properties of TME 419 Cassava Tubers for an Irrigated Soil + 933.75 kg/ha Fertilizer

The influence of tillage practices on selected engineering properties of TME 419 cassava tubers for an Irrigated Soil + 933.75 kg/ha fertilizer and the performance of an automated cassava peeling machine are presented in Tables 5 and 6 respectively. Figs. 2a - 2h showed the effect of tillage practices on compression test of TME 419 cassava tubers for an irrigated soil + 933.75 Kg/Ha fertilizer. The results reveal that the physical properties of cassava tubers such as length, width, thickness, size, aspect ratio, surface area, sphericity, roundness, unit mass, unit volume, true density, bulk mass, bulk volume, bulk density, porosity, angle of repose and coefficient of static friction ranged from 18.33 ± 1.28^{ab} - 37.78 ± 2.66^{ab} cm, 4.79 ± 0.59^{a} - 6.33 ± 0.62^{a} cm, 0.93 ± 0.18^{a} - 5.377 ± 0.57^{ab} cm, 5.54 ± 0.73^{a} - 10.23 ± 0.57^{d} cm, 13.75 ± 1.92^{a} - 31.24 ± 6.22^{a} %, 111.71 ± 23.92^{a} - 339.04 ± 34.25^{d} cm^2, 15.75 ± 1.13^{a} - 42.16 ± 5.61^{ab} cm, 20.96 ± 5.06^{a} - 106.02 ± 19.57^{c}, 0.29 ± 0.07^{a} - 1.66 ± 0.89^{c} kg, 0.26 ± 0.06^{ab} - 1.62 ± 0.06^{c} m^3, 0.75 ± 0.08^{ab} - 1.36 ± 0.16^{a} kg/m^3, 2.52^{a} - 8.87^{h} kg, 2.62^{a} - 8.00^{g} m^3, 0.70^{a} - 1.28^{h} kg/m^3, -54.10 ± 44.72^{a} - 37.16 ± 3.35^{b} %, 67.00 ± 0.42^{d}-71.25 ± 0.41^{a} and 2.37 ± 0.05^{d} - 2.96 ± 0.073^{cd} respectively. The mechanical properties of cassava tubers such as compressive extension at break, compressive strain at break, compressive load at break, compressive stress at break, energy at break, modulus automatic, compressive load at yield, compressive extension at yield, compressive strain at yield and compressive stress at yield ranged from 31.39 ± 0.48^{a} - 44.76 ± 0.68^{c} mm, 1.59 ± 0.02^{a} - 2.35 ± 0.04^{d} mm/mm, 4021.66 ± 61.43^{a} - 48728.00 ± 744.33^{e} N, 1.48 ± 0.02^{a} - 13.03 ± 0.20^{g} Mpa, 57.36 ± 0.88^{a} - 180.42 ± 2.76^{f} J, 2.03 ± 0.03^{a} - 2.89 ± 0.04^{e} Mpa, 2325.61 ± 35.525^{a} - 5788.11 ± 88.413^{e} N, 12.55 ± 0.19^{a} - 26.10 ± 0.40^{f} mm, 0.84 ± 0.01^{a} - 1.17 ± 0.018^{e} mm/mm and 1.19 ± 0.02^{a} - 1.55 ± 0.02^{d} Mpa respectively.

The cassava tubers from the eight tillage practices behaved differently for the measured mechanical properties of stress- strain and compression test which means tillage practices had influence on the mechanical properties of cassava tubers under different tillage practices. The best tillage practice that enhanced the better performance of the automated cassava peeler was recorded in Ploughing + Harrowing + ridging +10 cm Saw-dust placed at the base tillage practice (treatment 14) with tuber length of 33.365 ± 1.91^{ab} cm, width of 5.785 ± 0.37^{b}cm, thickness of 4.73 ± 0.43^{b} cm, size of 9.53 ± 0.54^{ab} cm, aspect ratio of 19.62 ± 1.65^{a} %, surface area of 297.96 ± 34.25^{d} cm^2, sphericity of 30.72 ± 1.88^{bc} cm, roundness of 66.36 ± 5.65^{a}, unit mass of 0.70 ± 0.13^{ab} kg, unit volume of 0.72 ± 0.08^{b} m^3, true density of 0.93 ± 0.07^{b} kg/m^3, bulk mass of 6.90^{g} kg, bulk volume of 9.05^{g} m^3, bulk density of 0.76^{c} kg/m^3, porosity of 3.72 ± 13.43^{a} %, coefficient of static friction of 2.77 ± 0.08^{cd}, compressive extension at break of 32.7 ± 0.50^{a} mm, compressive strain at break of 2.17 ± 0.03^{c} mm/mm, compressive load at break of 11128.60 ± 169.99^{c} N, compressive stress at break of 3.94 ± 0.06^{e} MPa , energy at break of 112.67 ± 1.72^{d} J, modulus automatic of 2.69 ± 0.04^{d} MPa, compressive load at yield of 3432.30 ± 52.43^{c} N, compressive extension at yield of 12.55 ± 0.19^{a} mm, compressive strain at yield of 0.84 ± 0.01^{a} mm/mm and compressive stress at yield of 1.22 ± 0.02^{ab} MPa, respectively.

Variation in the engineering properties might be caused by variation in soil factors. This is in agreement with [26] findings that irregular size and shape of cassava tubers are caused by soil factors. If cassava farmers could adopt Ploughing + Harrowing + ridging +10 cm Saw-dust placed at the base tillage practice in planting cassava stems, then the cassava tubers would come with regular shape and size. Attempts at mechanizing the cassava peeling operation have been acknowledged but machines have not been fully developed yet [21] as no efficient cassava peeler is presently in the market in Nigeria because irregularity in the shape of the tubers as well as the wide variations in the thickness of the peel, tuber size and weight across different varieties of the crop [22–24].

3.3 Stepwise Model for Predicting Effect of Tillage Practices on Physical Properties of TME 419 Cassava Tubers for a Rain-fed soil + 933.75 kg/ha Fertilizer for 2014/2015 Planting Season

The stepwise models for predicting effect of tillage practices on physical properties of TME 419 cassava tubers for a rain-fed soil + 933.75 kg/ha fertilizer is presented in equations 1 and 2 respectively. The equations show that the physical properties such as the bulk mass, bulk density, porosity, aspect ratio, unit mass, true density and bulk volume with small coefficients had a little impact on the tillage practices. While the width, roundness, unit volume, coefficient of static friction, thickness, size and sphericity with negative coefficients mean the magnitudes were the exact opposite of the tillage practice. This clearly indicates that not all the physical properties measured were enhanced by the tillage practice. Root and tuber crops react in a different way to tillage practice. This might be due to tillage practice adopted for planting since tillage practice enhances the physical state of the soil by manipulating and pulverizing the soil, which not only make available appropriate setting to the crops, but also delivers free oxygen and approachability of soil moisture and dynamic nutrients to plants. Earlier study by [8,14] also supports the results of this study.

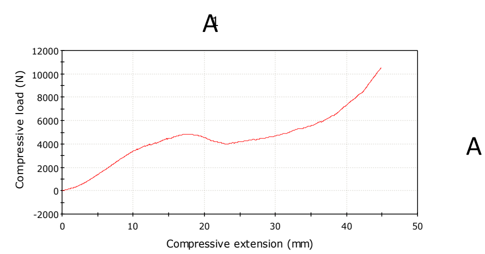

Fig. 1a

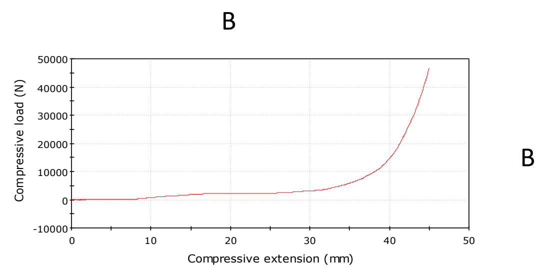

Fig. 1b

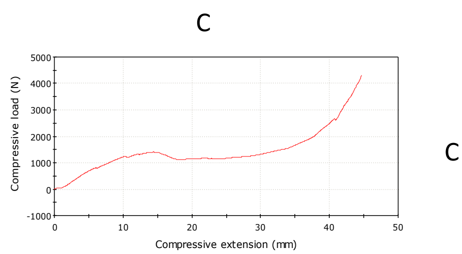

Fig. 1c

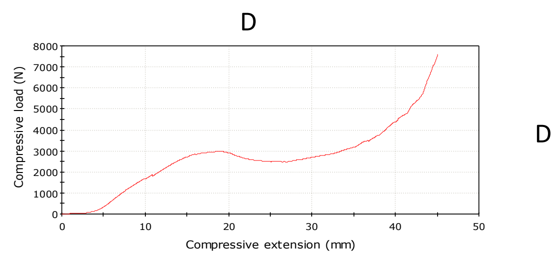

Fig. 1d

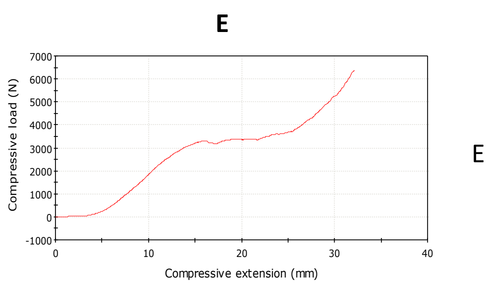

Fig. 1e

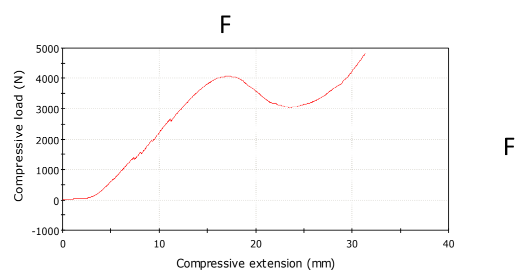

Fig. 1f

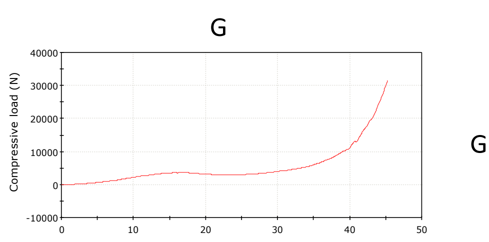

Fig. 1g

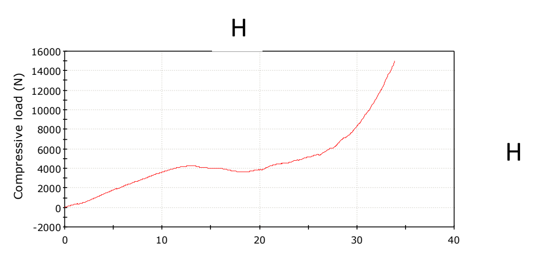

Fig. 1h

Fig. 1a - 1h. Effect of tillage practices on compression test of TME 419 cassava tubers for a rain fed soil + 933.75 Kg/Ha fertilizer

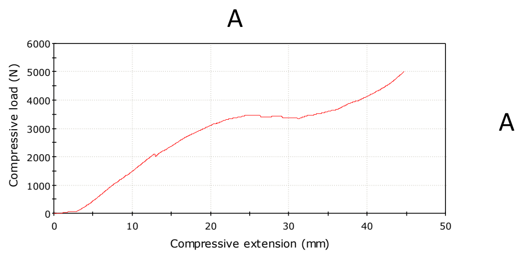

Fig. 2a

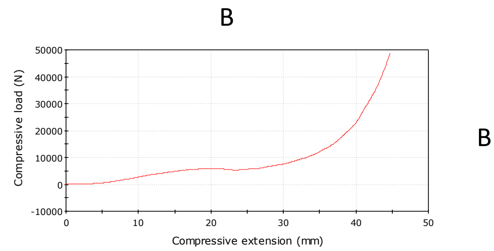

Fig. 2b

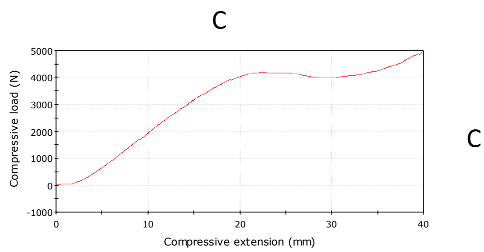

Fig. 2c

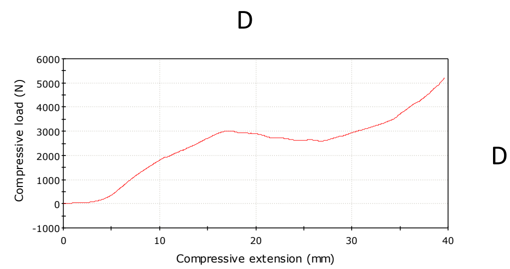

Fig. 2d

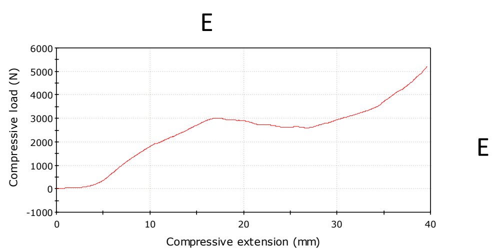

Fig. 2e

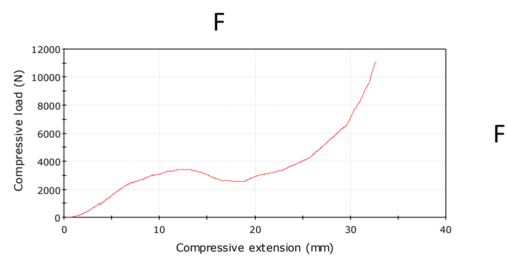

Fig. 2f

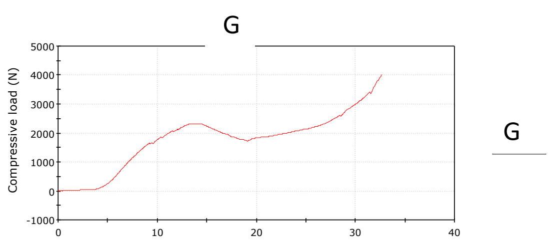

Fig. 2g

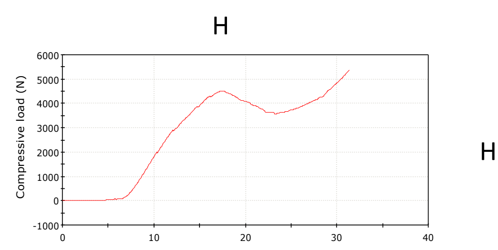

Fig. 2h

Fig. 2a - 2h. Effect of tillage practices on compression test of TME 419 cassava tubers for an irrigated soil + 933.75 Kg/Ha fertilizer

$$Y_{1T}a = 27.4(0.00) - 0.2W(0.00) - 0.05R(0.00) - 2.7V(0.00) + 0.3BM(0.00) + 1.8BD(0.00) + 0.15P(0.00) - 8CF(0.00)[R^2 = 1.0] \quad (1)$$

$$Y_{1T}b = 9.45(0.00) - 0.1.T(0.00) - 2.5DG(0.00) + 3.3AR(0.00) + 3M(0.00) + 2TD(0.00) - 0.05SP(0.00) + 3M + 2TD - 0.05SP(0.00) + 0.3BV(0.00)[R^2 = 1.0] \quad (2)$$

Where Y_{IT} tillage practices on physical properties of TME 419 cassava tubers for a rain-fed soil + 933.75 Kg/ha fertilizer, L is the length, W is the width, T is the thickness, DG is the size, AR is the aspect ratio, SA is the surface area, SP is the sphericity, R is the roundness, M is the unit mass, V is the unit volume, TD is the true density, BM is the bulk mass, BV is the bulk volume, BD is the bulk density, P is the porosity, CF is the coefficient of static friction.

3.4 Stepwise Model for Predicting Effect of Tillage Practices on Physical Properties of TME 419 Cassava Tubers for an Irrigated Soil + 933.75 Kg/ha Fertilizer for 2014/2015 Planting Season

Equations 3 and 4 present the stepwise models for forecasting outcome of tillage practices on physical properties of TME 419 cassava tubers for an irrigated soil + 933.75 Kg/ha fertilizer. The stepwise model revealed that the physical properties such as the length, sphericity, roundness, true density, coefficient of static friction, width, unit mass, unit volume and bulk volume with small coefficients had a little impact on the tillage practices. While the bulk density, porosity, size, aspect ratio and bulk mass with negative coefficients mean the magnitudes were the exact opposite of the tillage practice. This indicates that tillage practice has a significant effect on some selected physical properties of cassava tubers which might be caused by variations in soil characteristics brought about by the tillage operation Unsuitable tillage practices may decrease crop development and produce. Selection of a proper tillage practice for crop production is very significant for best growth and yield. These results are similar with other researchers (AO Akyea, Kwame Nkrumah University of Science and Technology, Kumasi Ghana, Unpublished results).

$$\begin{aligned} Y_{1TIR}a &= -22.59(0.00) + 0.8L(0.00) + 0.3SP(0.00) + 0.01R(0.00) \\ &+ 9TD(0.00) - 16BD(0.00) - 0.3P(0.00) + 0.3CF(0.00)[R^2 = 1.0] \end{aligned} \tag{3}$$

$$\begin{aligned} Y_{1TIR}b &= -4.30(0.00) + 20W(0.00) - 9DG(0.00) - 1.2AR(0.00) \\ &+ 2M(0.00) + 7V(0.00) - 3BM(0.00) + 3BV(0.00)[R^2 = 1.0] \end{aligned} \tag{4}$$

3.5 Stepwise Model for Predicting Effect of Tillage Practices on Physical Properties of TME 419 Cassava Tubers for a Rain-fed Soil + 933.75 kg/ha Fertilizer for 2015/2016 Planting Season

Stepwise models are presented in equations 5 and 6 for foreseeing consequence of tillage methods on physical properties of TME 419 cassava tubers for a rain-fed soil + 933.75 Kg/ha fertilizer for 2015/2016 planting season. The stepwise model revealed that the physical properties such as the size, volume, true density, bulk density, length, aspect ratio and surface area with small coefficients had a little impact on the tillage practices. While the sphericity, bulk volume, coefficient of static friction, thickness, roundness, unit mass and porosity with negative coefficients mean the magnitudes were the exact opposite of the tillage practice. The model specified that tillage practice influences the physical properties of cassava tubers as root and tuber crops react in a different way to tillage. "Reference [7]" reported that the fresh root yield of cassava (*Manihot esculenta* Crantz.) grown under zero tillage system was meaningfully more than that of cassava cultivated using conventional tillage on fine loamy soil (Oxic Paleustults) in Thailand.

$$\begin{aligned} Y_{1T}d &= 1383(0.00) + 7.5DG(0.00) - 0.7SP(0.00) + 128V(0.00) \\ &+ 96TD(0.00) - 9BV(0.00) + 17BD(0.00) - 19CF(0.00)[R^2 = 1.0] \end{aligned} \tag{5}$$

$$\begin{aligned} Y_{1T}e &= -39.31(0.00) + 2.5L(0.00) - 31T(0.00) + 1.3AR(0.00) \\ &+ 0.8SA(0.00) - 0.4R(0.00) - 211M(0.00) - 0.0P(0.00)[R^2 = 1.0] \end{aligned} \tag{6}$$

3.6 Stepwise Model for Predicting Effect of Tillage Practices on Physical Properties of TME 419 Cassava Tubers for an Irrigated Soil + 933.75 kg/ha Fertilizer for 2015/2016 Planting Season

Equations 7 and 8 present the stepwise models for predicting effect of tillage practices on physical properties of TME 419 cassava tubers for an irrigated soil + 933.75 Kg/ha fertilizer. The stepwise model revealed that the physical properties such as the width, aspect ratio, roundness, true density, porosity, coefficient of static friction, surface area, sphericity and unit mass with small coefficients had a little impact on the tillage practices. While the volume, length, thickness, bulk volume and bulk density with negative coefficients mean the magnitudes were the exact opposite of the tillage practice. This model indicates that tillage has significant effect on selected engineering properties of cassava tubers. "Reference [27]" reported that despite the wide range of land in the world, all of it is not for crop production. Therefore, to bring these lands into an economical fit condition for crop production, various mechanical operations must be performed. Consequently, the enormous effect of tillage on physical properties of cassava tubers cannot be under-estimated. These findings are in line with other researchers [21].

$$\begin{aligned} Y_{1TIR}d &= -32.76(0.00) + 1W(0.00) + 0.4AR(0.00) + 0.03R(0.00) \\ &- 3V(0.00) + 0.2TD(0.00) + 0.08P(0.00) + 9CF(0.00)[R^2 = 1.0] \end{aligned} \tag{7}$$

$$\begin{aligned} Y_{1TIR}e &= 43.33(0.00) - 0.9L(0.00) - 3.5T(0.00) + 0.08SA(0.00) \\ &+ 0.09SP(0.00) + 3M(0.00) - 0.4BV(0.00) - 14BD(0.00)[R^2 = 1.0] \end{aligned} \tag{8}$$

3.7 Stepwise Model for Predicting Effect of Tillage Practices on Mechanical Properties of TME 419 Cassava Tubers for a Rain-fed Soil + 933.75 kg/ha Fertilizer

Equations 9 and 10 present the stepwise model for predicting effect of tillage practices on mechanical properties of TME 419 cassava tubers for a rain-fed soil + 933.75 kg/ha fertilizer. The stepwise model revealed that the physical properties such as the energy at break, compressive stress at yield, compressive load at break, compressive strain at maximum compressive extension, maximum compressive extension and compressive stress at maximum compressive extension of cassava tubers with small coefficients had a little impact on the tillage practices. While the area, compressive strain at break, modulus automatic and compressive strain at yield of cassava tubers with negative coefficients mean the magnitudes were the exact opposite of the tillage practice. This might be due to the type of tillage adopted. Conservation tillage usually leaves a layer of crop residue on top of the soil. This method changes soil properties that affect plant growth [27].

$$\begin{aligned} Y_{1T}g &= 17.60 - 0.06Cs + 0.001EB(0.00) - 0.2AR(0.00) - 6MA(0.00) \\ &- 0.2CSY(0.00) - 4CSTY(0.00) + 9CSTYZ(0.00)[R^2 = 1.0] \end{aligned} \tag{9}$$

$$\begin{aligned} Y_{1T}h &= 8.71(32.47) + 0.001CL + 5CSM(9.1) - 0.2MCE(-0.145) \\ &- 0.5CSMC(-0.49) - 0.2DI(-0.0.217) + 0.001CLY[R^2 = 0.95] \end{aligned} \tag{10}$$

CE is the Compressive extension at Break, CS is the compressive strain at break, CL is the Compressive load at Break, CSR is the compressive stress at break, EB is the energy at break, EX is the Extension at Break, CLM is the Compressive load at Maximum Compressive extension, CSM is the Compressive strain at Maximum Compressive extension, MCE is the Maximum Compressive extension, CSMC is the Compressive stress at Maximum Compressive extension, AR is the Area, D is the Diameter, MA is the modulus Automatic, CLY is the compressive load at yield, CSY is the compressive extension at yield, CSTY is the compressive strain at yield and CSTYZ is the compressive stress at yield.

3.8 Stepwise Models for Predicting Effect of Tillage Practices on Mechanical Properties of TME 419 Cassava Tubers for an Irrigated Soil + 933.75 kg/ha Fertilizer

Stepwise models for forecasting consequence of tillage practices on mechanical properties of TME 419 cassava tubers for an irrigated soil + 933.75 Kg/ha fertilizer are presented in equations 11 and 12. The stepwise model revealed that the physical properties such as the compressive strain at break, compressive stress at break, compressive strain at yield, compressive stress at yield, compressive strain at maximum compressive extension, compressive stress at maximum compressive extension, compressive load at yield, compressive extension at yield, energy at break, extension at break and compressive load at maximum compressive extension with small coefficients had a little impact on the tillage practices. While the compressive extension at break, diameter, modulus automatic, compressive load at break, maximum compressive extension and area with negative coefficients mean the magnitudes were the exact opposite of the tillage practice. Mechanical properties may be defined as those having to do with the behavior of the material under applied force [28].

$$Y_{1TIR}g = 43.2 - 0.8CE + 4.2Cs + 0.2CSR - 0.3DI - 9MA + 7CSTY + 12CSTYZ[R^2 = 1.0] \quad (11)$$

$$Y_{1TIR}h = 18.16 - 0.002CL + 6CSM - 2MCE + 8.2CSMC - 0.9AR + 0.007CLY + 1.5CSY[R^2 = 1.0] \quad (12)$$

$$Y_{1TIR}i = 21.6(4.4) + 0.006EB(0.037) + 0.5EX(0.17) + 0.02CLM(0.00)[R^2 = 0.9] \quad (13)$$

4. CONCLUSION

Tillage practice influence both the physical and mechanical properties of cassava tubers. Thus, it is necessary for farmers to carefully choose appropriate and suitable tillage practice required to get the optimum and uniform engineering properties of cassava tubers. Models had been established to forecast the interaction between tillage practices and some selected engineering properties. These models are important for engineer to design improved equipment and machineries for harvesting and processing of cassava tubers into useful products. Establishment of these models revealed the interaction between tillage practice and some engineering properties which would ensure full automation of cassava peeling process which remain the only un-mechanized process in processing of cassava tubers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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