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Determination of Cassava Lifting Coefficient in a Loamy Sand Soil

Ogunjirin O. A., L.A.S. Agbetoye, O.C. Ademosun, O. C. Ogunjirin

***Abstract:** Tractor drawn cassava lifting equipment is required to be sturdy and ready to work against the soil and tuber weight at various moisture content of the soil. This however cannot be achieved if the forces working against the tool is underestimated. This reason why many imported tractor drawn cassava lifter failed when they are employed on the farm in Nigeria is because the soil properties differs considerably. The research study looked at lifting of cassava tuber from the standpoint of soil bulk density, tool geometry, angle of lifting, soil moisture content, speed of lifting and time taken to lift cassava out of the soil. The factors were expressed mathematically and the equation was solved to obtain the cassava lifting coefficient which was determined to be function of angle of lifting, weight of tuber and soil, speed of lifting and time taken to lift cassava out of the soil. Field experiments were carried out to determine the cassava lifting coefficient for loamy sand soil at varied moisture content and speed of lifting. Result showed that the highest lifting coefficient of 539,256.60 was obtained at the moisture content of 1.271% and lifting speed of 8 mm/s. The study further revealed that in loamy sand soil and at moisture content of 1.271%, the average cassava tubers and soil excavated was 23.26 kg. The force required to harvest/uproot 23.26 kg cassava tubers effectively was determined to be 5 kN for loamy sand soil.*

***Keywords:** Cassava lifting coefficient, cassava tuber, lifting force, lifting speed.*

I. INTRODUCTION

Cassava is a crop that is commonly cultivated in Nigeria thus making Nigeria the largest producer of cassava worldwide. While other countries like Thailand, Vietnam, Indonesia, Brazil etc. reap abundant incomes from cassava because they have mechanized farms that produce quantum outputs to meet industrial and other demands, Nigeria is yet to reap fully from cassava despite occupying the position of largest producer in the world. Cassava tuber provides a cheap source of dietary carbohydrate energy (720 x 1012 kJ day-1) ranking fourth after rice, sugarcane and maize, and fifth among starch crops in global production [1]. For any nation or organization that aspires to achieve sustainable cassava business, it must have large mechanized cassava farms for reliable and continuous source of cassava stock [2].

The importance of cassava as human food, animal feed, industrial uses and foreign exchange earning cannot be overemphasized and in line with the emerging trend, the need to improve on the harvesting technique, which presently is predominantly carried out manually, has now become imperative and once this is resolved, farmers would take interest in cultivating the crop. This would make the cassava crop to shift from being famine reserve crop to cash crop because cassava processing factories/cottage industries would have access to raw materials all year round as against the glut experienced only when the soil is wet in the raining season [3].

During harvesting, the weight of the soil above the cassava tuber contributes to the force that is required to be subdued in order to lift the cassava tubers out of the soil in addition to the suction force produced by the individual rootlets which acts as individual anchor. The moisture content and soil bulk density further plays an important role in the determination of weight of the soil on the tubers.

In 2014, it was reported that severely compacted soil impedes root growth and development and restricts plants ability to utilize soil water and nutrients by reducing the soil volume utilized by roots. This therefore calls for appropriate design of a suitable commercial harvester which would reduce compaction because harvesting equipment require high capacity tractor to pull the harvesting tool through the soil to harvest effectively and efficiently. There is the need to know the actual force required to pull the cassava tuber out of the soil. This would assist in coming up with a cost-effective soil loosening and lifting tool. The cassava lifting coefficient, k, a dimensionless constant would bring to fore the combination of lifting parameters (lifting speed, lifting force, weight of tuber and time taken to uproot) to come up with the highest lifting force taking into cognizance the lifting speed at various combination of the soil physical properties (moisture content and bulk density) that represents the various conditions encountered during cassava tuber lifting [4].

The objective of this study is to develop a mathematical equation, through dimensional analysis, for the determination of cassava lifting coefficient and estimation of the cassava lifting force and speed during cassava uprooting.

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* Correspondence Author
Ogunjirin O. A.* Engineering and Scientific Services Department, National Centre for Agricultural Mechanization, P.M.B. 1525, Ilorin, Kwara State, Nigeria. Email:ntslola@yahoo.com
Agbetoye, L.A.S. School of Engineering and Engineering Technology, Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Ondo State, Nigeria. Email:lasagbetoye@yahoo.com
Ademosun, O. C. School of Engineering and Engineering Technology, Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Ondo State, Nigeria. Email: ocademosun@yahoo.com
Ogunjirin O. C. [3]Post Harvest Engineering Research Department, Nigerian Stored Product Research Institute (NSPRI), Ilorin, Kwara State, Nigeria. Email:omololaogunjirin@gmail.com

II. LITERATURE REVIEW

The food and agricultural organization conducted a survey in 2015 on the statistics of African countries which dominate the cassava tuber production in the world. Considering the twenty-two highest cassava

producing countries in the world, 52% of the production comes from Africa and out of these, Nigeria contributed the highest of about 40%. In Nigeria, other root crops that are majorly produced besides cassava are yam, cocoyam and sweet potato but cassava is the most cultivated. Cassava is grown in all the States of the Federation with the current production level of about 53 million metric tonnes per annum. It is widely distributed in and around the warm moist tropical rain forests. There are numerous varieties of cassava but majorly grouped into two categories; sweet and bitter. The tuber could reach a weight of about 10 kg and length of 80 cm at harvest depending on the soil type and condition. Although Nigeria is the world leader in cassava production, about 90% of the annual production in the country is targeted for the domestic food market while only about 10% is processed into other industrial products [5].

Machine improvements for chamomile harvesting should be considering working speed and efficiency in order to achieve better quality of chamomile harvesting. This statement is true for all harvesting machines because harvesting machine to be deployed for cassava tuber should perform better than the manual method and should not damage the tubers in form of bruising or chattering the cassava tubers. Cassava tubers when bruised, its storability reduces and thereby reducing its market value. [6]

In Malaysia, mechanization of cassava is currently limited to land preparation, herbicide spraying and digging of roots. Mechanization for the other operations is needed for more cost-effective commercial production of the crop in view of labour shortages. Is was further reported that cassava harvesting is still preferably performed by hand rather than machine, citing Thailand that used mould-board ploughs recently to assist in soil loosening thus making digging less arduous especially in the dry season. This involves manual lifting of cassava usually by pulling the stem at a height of about 300 mm above the soil surface. The detachment of the aerial parts of the plant is to allow for effective grip by hands. However, under firm rooting conditions, tools such as machete, hoe or digging fork are employed to dig the soil in the root zone to reduce the soil restraining forces before lifting out the roots. [7]

The API root digger-elevator is a semi-mounted tractor implement that digs, elevates and shakes the root clumps free of soil clods, and deposits them on the ground ready for manual picking and gathering. Compared with the traditional method, the implement could give 92 - 95% saving in labor requirement for the root digging operation [8]. The use of the semi-mechanized system, in which the roots are pulled out of the soil and the workers later detach the roots from the stem, allows to increase the efficiency from around 500 kg to nearly 1 tonne of roots harvested per person per day. It was also reported that a digging fork consisting of short handle (60 cm long) ended with 3 lanceolated prongs (19 cm long) used to dig the soil and to lift potatoes out of the ground [9].

The National Centre for Agricultural Mechanization (NCAM) has been at the forefront of developing various cassava production and processing technologies. The Centre has recorded some breakthroughs in most of the cassava production and processing technologies which include peeling, planting and harvesting. In the harvesting of cassava tubers, the Centre came up with a manual cassava lifter that is simple and easy to use. It consists of a frame to which a footboard and immovable griping jaws are attached, a lever (handle) which is hinged to the frame. The griping jaws holds the stem of the cassava plant very close to the soil surface, the handle is then used to shake the stem which further loosens the soil around the root tuber cluster and further lifting the tubers out of the soil [10]. Though, it eliminated the bad posture involved while using the manual/traditional method of harvesting with hoe, cutlass and stick, it can only harvest about 200 plants/man-hour depending on the soil moisture content. The cassava lifter uprooted efficiently regardless of the soil physical properties (i.e. sandy or clay soil).

In order for a soil working tool to perform according to desirable criteria, proper tool design based on its geometry is a critical parameter. The common criteria of tillage tool design have been draught required to operate the tool, the volume of soil failed by the device and total energy requirement. The modified condition of the tilled soil due to tool action depends on the soil mechanical behavior and its initial condition. Pressure exerted by soil on the tillage tool and its distribution with respect to tool wear is an important parameter in determining tool size and shape [11].

Research has shown that compaction has the potential to depress crop yields, since extremely dense soil impedes root growth thereby limiting water consumption by plants [12]. As such it is imperative to come up with the appropriate harvester that would not unnecessarily increase power requirement as well as increase soil compaction. Thus, farm managers must design strategies to manage soil compaction in order to minimize its detrimental effects. In this regard, researchers have also adopted modeling approach to simulate soil compaction in order to address the problem [13].

III. METHODOLOGY

In manual method of harvesting cassava tubers, the farmer bends down and pulls the stem to lift up the cassava tubers out of the ground. The harvesting is achieved when the soils surrounding the cassava tubers loosen thereby allowing the tubers to be lifted up with the aid of the stem out of the soil. By bending down and pulling the stem to lift the cassava tuber out of the soil, a force vertically upward, equal and opposite to the weight of the cassava tuber, weight of rootlets which are at the tip of the main root and the soil above it must be generated before any harvesting operation is achieved.

Non-vibrating tools used in root crop harvesting must have considerable power to provide the traction required to pull them through the soil [14]. This research work studied the lifting of cassava tuber by looking at parameters such as depth of cassava tuber, soil bulk density, soil moisture content, angle of lifting, lifting force, tool geometry and speed of lifting. This is expressed mathematically as follows: -

$$L_f \propto f(D, \gamma_s, S_v, M_c, \theta, A_c, T_g, T, W_r) \quad (1)$$

Where,

L_f is Lifting force, N
D is Depth of cassava tubers, m
γ_s is Bulk density of surrounding soil, g/m^3
S_v is Lifting speed, m/s
M_c is Moisture content, %
T_g is Tool geometry
θ is Angle of approach of tool, °
A_c is Surface area of cassava tuber spread, m^2
T is Time taken to lift cassava tuber out of the soil, sec
W_r is Weight of cassava tuber, g

To come up with a mathematical solution for the expression, the angle of approach and tool geometry were stepped down because this could be studied independently after the tool is developed. The angle of approach and the tool geometry shall be considered when the tool is developed and ready to be evaluated in the field to uproot cassava tubers. The moisture content and the soil type are parameters that would be looked into during the determination of the lifting force for lifting the cassava tuber.

Therefore, the equation is further simplified and expressed as: -

$$L_f \propto f(A_c, D, \gamma_s, S_v, T, W_r) \quad (2)$$

But

$$W_s = \gamma_s \times V_s \quad (3)$$

Where,

W_s is Weight of soil, g
V_s is Volume of soil, mm^3

Total weight that is opposing the lifting force of the harvesting tool, WT, is expressed as: -

$$W_T = W_s + W_r \quad (4)$$

Where,

W_r is Weight of cassava tubers
W_T is Weight of soil and cassava tuber

V_s can be expressed as the product of area of tuber coverage, A_c, and depth of tuber coverage, D, depending on the shape of the area of root coverage in the soil. Substituting W_T into equation 3, the equation is further simplified as follows: -

$$L_f \propto f(S_V, T, W_T) \quad (5)$$

Applying dimensional analysis to solve equation 5

$$L_f = MLT^{-2}$$

$$W_T = M$$

$$S_V = LT^{-1}$$

$$T = T$$

$$MLT^{-2} = M^x T^y (LT^{-1})^Z$$

Taking coefficient of each variable

$$M : 1 = x$$

$$L : 1 = z$$

$$T : -2 = y - z$$

From above expression, x and z = 1

By substitution,

$$-2 = y - 1$$

$$\therefore$$

$$y = -1$$

$$L_f = \frac{kW_T S_V}{T} \quad (6)$$

$$k = \frac{L_f T}{W_T S_V} \quad (7)$$

Where,

k is lifting coefficient for cassava tuber.

k is a function of speed of lifting, soil moisture content, soil type and the weight of the cassava tuber as shown in equation 7.

IV. RESULT AND DISCUSSION

The location and soil type description of the experimental site is as described in [2]. The cassava lifting coefficient, k as determined theoretically using dimensional analysis in equation 7 in this study is a function of lifting force, L_f, time of lifting, T, speed of lifting, Sv and weight of the soil and cassava tuber, W_T. The cassava lifting coefficients were obtained at various moisture contents, bulk densities and speed of lifting. The result is as detailed in Table I.

Figure 1 showed the relationship between lifting coefficient, speed of lifting and moisture content. It was discovered that as the soil moisture decreases, the lifting coefficient increases. When the moisture content was 1.271 % and at a speed of 8 mm/s, the maximum lifting coefficient of 539255.6 was recorded (Table I). It was also observed that it reduces as the speed increases. This is caused by the breakage of the rootlets which could have contributed to the force required to harvest but is broken due to high speed thus resulting in lower lifting coefficient.

The low cassava lifting coefficient recorded as the moisture increases was because the soil moisture acted as lubricant for the rootlets and the cassava tuber thereby making it easy for the cassava tuber and the rootlets to pull out of the soil as against when the soil was dry and the friction between the cassava tuber, rootlets and the soil was high. A cursory look at Figure 1 revealed that lifting coefficient generally decreases as the speed of lifting increases and vice versa. This could be explained by the fact that the rootlets of the cassava tuber were intact and were not damaged at a lower speed as observed when it was lifting at higher speed.

Result of analysis of variance test on effect of speed and moisture content on lifting coefficient revealed that it is significant at 5% level. The interaction between the two factors was also significant at 5 % level (Table II). Figure 2 further revealed that as the moisture increases, the cassava lifting force coefficient reduces. The correlation between these two variables was almost perfect implying inversely proportionate relationship.

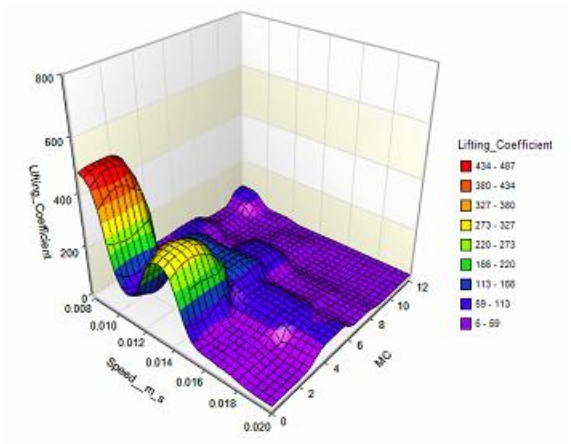

Fig. 1. Surface plot of cassava lifting coefficient versus speed of lifting at various moisture content

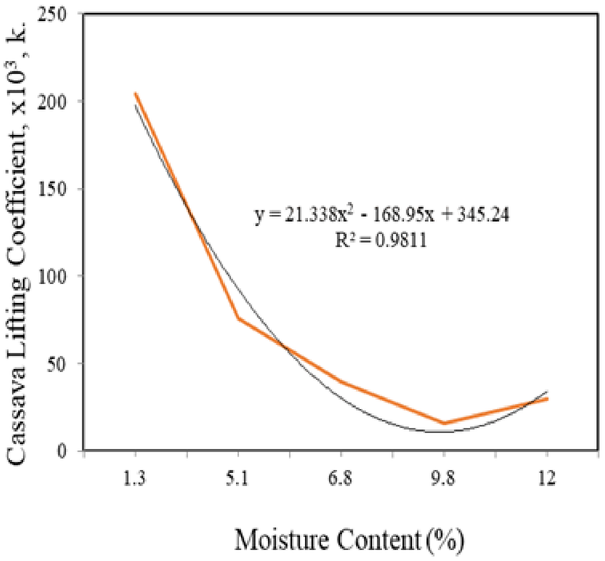

Fig. 2.Graph of lifting coefficient versus moisture content

As the speed of lifting increases, the lifting coefficient reduces. This further explained the observation in the field because at a low speed of lifting, the tuber lifting was done properly taking into cognizance the pulling out of all the rootlets which also added some restraint to the ease of lifting the cassava tuber. At higher speed of lifting, it was discovered that some of the rootlet breaks and thus the force of pulling the rootlets out of the soil were not accounted for.

V. CONCLUSION

A study to look at some factors affecting harvestability of cassava tuber was studied. The factors were expressed mathematically and solved using dimensional analysis. Thereafter a model was developed, using dimensional analysis, whereby the cassava lifting coefficient, k, was expressed as a function of lifting force, time of lifting, speed of lifting and weights of cassava tuber and soil above the cassava tuber. The solution revealed that Cassava lifting force is directly proportional to the total weight (soil and tuber), speed of uprooting and inversely proportional to the uprooting time. This paved the way for the calculation of cassava lifting coefficient which was obtained experimentally for loamy sand soil. Result showed that the highest lifting coefficient of 539,256.60 was obtained at the moisture content of 1.271% and lifting speed of 8 mm/s. This indicated the toughest condition for cassava lifting in a loamy sand soil with the corresponding force of 367 N for a cassava tuber and soil weight of 1.7 kg. At the moisture content of 1.271%, the average cassava tubers and soil excavated is 23.26 kg thus the force required to harvest/uproot cassava tubers effectively was 5 kN for loamy sand soil. The study is recommended to be repeated on other soil types, moisture contents and speeds of uprooting in order to be able to develop a suitable cassava harvester that would be applicable in all soil types in Nigeria.

Table I: Mean data generated for determination of cassava lifting coefficient

S/No.	EXP. No.	Av. W_T, g	Av. L_f, N	Av. Speed, m/s	Av. Mc, %	Av. Disp., m	Av. C.I, N/mm^2	Av. k
1.	MIS1	7672.088	545.703	0.008	11.959	0.091	0.301	86721.090
2.	M1S2	7151.316	404.903	0.011	11.959	0.048	0.301	25364.460
3.	M1S3	6888.801	266.930	0.013	11.959	0.048	0.301	11385.670
4.	M1S4	6255.317	264.337	0.016	11.959	0.075	0.301	12836.230
5.	M1S5	6542.283	395.450	0.020	11.959	0.093	0.301	14036.110
6.	M2S1	3950.145	228.767	0.008	6.759	0.061	1.341	60361.860
7.	M2S2	3204.001	239.403	0.011	6.759	0.044	1.341	26461.620
8.	M2S3	2307.694	173.190	0.013	6.759	0.156	1.341	62850.470
9.	M2S4	2871.425	286.113	0.016	6.759	0.064	1.341	24653.740
10.	M2S5	2963.306	310.787	0.020	6.759	0.087	1.341	22731.810
11.	M3S1	5676.766	317.310	0.008	9.836	0.035	0.345	29830.550
12.	M3S2	4272.181	183.383	0.011	9.836	0.029	0.345	10236.460
13.	M3S3	4018.294	188.367	0.013	9.836	0.065	0.345	22975.730
14.	M3S4	4010.685	128.170	0.016	9.836	0.037	0.345	4981.459
15.	M3S5	4193.107	131.443	0.020	9.836	0.140	0.345	10202.100
16.	M4S1	2652.956	191.617	0.008	5.129	0.048	1.078	54383.810
17.	M4S2	2837.502	427.613	0.011	5.129	0.073	1.078	123195.000
18.	M4S3	1624.205	249.280	0.013	5.129	0.104	1.078	98347.680
19.	M4S4	1456.136	238.607	0.016	5.129	0.091	1.078	57339.900
20.	M4S5	1458.239	219.630	0.020	5.129	0.180	1.078	46553.950
21.	M5S1	1699.950	367.200	0.008	1.271	0.083	1.732	539255.600
22.	M5S2	1274.814	325.100	0.011	1.271	0.029	1.732	89307.540
23.	M5S3	617.931	462.620	0.013	1.271	0.052	1.732	338493.900
24.	M5S4	1670.209	319.917	0.016	1.271	0.053	1.732	39998.070
25.	M5S5	3778.841	367.857	0.020	1.271	0.067	1.732	15490.100

Table II. Result of analysis of variance test on effect of speed and moisture content on lifting coefficient

Source	Sum of Squares	df	Mean Square	F	Sig.
S	190481.122	4	47620.280	3.819	0.009
MC	353462.497	4	88365.624	7.087	0.000
S * MC	459601.404	16	28725.088	2.304	0.013
Error	623444.525	50	12468.891		
Total	1626989.548	74			

S-lifting speed, MC-moisture content

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AUTHORS PROFILE

Engr. Dr. Olusola Adetola OGUNJIRIN was born on 3rd August, 1967 in Lagos State, Nigeria. He had his first and master degrees in Agricultural Engineering in 1991 and 1995 respectively from the University of Ilorin, Kwara State, Nigeria. He later obtained his Doctor of Philosophy in Agricultural Engineering (Farm Power and Environmental Engineering) from the Federal University of Technology, Akure, Ondo State.

He is highly experienced in the area of development of farm machinery for small scale farmers, tillage studies, farm and machinery management, land development and tractor hiring services. He is widely traveled to include but not limited to the followings Japan, South Africa, Zambia and USA. He is a Fellow, Nigerian Institution of Agricultural Engineers, (NIAE), Member, International Soil Tillage Research Organization, (ISTRO), Member, American Society for Agricultural and Biological Engineers (ASABE), Member, Nigerian Society of Engineers (NSE). He is a registered engineer with the Council for the Regulation of Engineering in Nigeria (COREN). He has publications in highly revered journals both nationally and internationally to his credit.

He presently works with the National Centre for Agricultural Mechanization (NCAM), Nigeria and Heads the Engineering & Scientific Services Department. He has pioneered machines in tillage studies, crop processing, cassava harvesting and instrumentation of machines. He is the Chairman, Nigeria Institution of Agricultural Engineers, Kwara State Chapter.

Professor AGBETOYE, Leo Ayodeji Sunday is an Alumnus of the Federal University of Technology, Akure, Nigeria from where he graduated with a B.Tech. (Hons.) degree in Agricultural Engineering in 1987 and M.Eng. degree in 1992. In 1996, he obtained the Ph.D degree in Agricultural Engineering from Cranfield University, United Kingdom. He belongs to many professional bodies within and outside Nigeria including; Nigerian Society of Engineers (NSE); Nigerian Institution of Agricultural Engineers (NIAE); West African Society for Agricultural Engineering (WASAE); American Society of Agricultural & Biological Engineers (ASABE); Canadian Society for Bio-Engineering (CSBE); International Soil Tillage Research Organization (ISTRO); and Institution of Agricultural Engineers, U.K. (IAgr.E). He is a registered Engineer by the Council for the Regulation of Engineering in Nigeria, COREN Registered.

Professor Agbetoye joined the services of the Federal University of Technology, Akure, Nigeria as Graduate Assistant in 1989. He rose steadily through the ranks to the position of Professor on 1st October, 2007. He has taught many courses in the areas of Farm Power and Machinery Engineering, as well as Processing and Storage Engineering at both undergraduate and postgraduate levels. He has supervised several undergraduate and over forty postgraduate (M.Eng. & Ph.D.) students to completion. He has conducted many individual and group research projects within the University. He has to his credit over one hundred publications in learned journals and conference proceedings. His specific interests include Machine Design, Development of Agricultural Machinery for Mechanized Production and Processing of Tropical Crops and Soil Tillage Dynamics. He has won many individual and group research grants within the University and at national and international levels. These include University Senate and TETFund Research Grants as well as the International Foundation for Science (IFS), (Sweden) Research Grant.

Professor ADEMOSUN, Olugboyega Cornelius was born on 22nd January, 1946 at Ile-Oluji, Ondo State, Nigeria. He is native of Ile-luji in Ile-Oluji/Okeigbo Local Government Area of Ondo State Nigeria. An Alumnus of the University of Ife, Ile-Ife from where he graduated with a B.Sc (Hons) Agricultural Engineering in 1974. In 1977 and 1980, he was awarded M.Sc and Ph.D Agricultural Engineering by Cranfield Institute of Technology, Cranfield (now Cranfield University), United Kingdom. He is Member and Fellow of many professional bodies including the Nigerian Society of Engineers and the Nigerian Institution of Agricultural Engineers, Council for the Regulation of Engineering in Nigeria (COREN), Howard Agricultural Machinery Company, England, Agricultural and Rural Management Training Institute, Ilorin, Nigeria Institute of Engineering Management, Nigerian Institute of Management and Institute of Administrative Management of Nigeria.

Professor Ademosun has been a former employee of the Federal University of Technology, Akure, Nigeria since 1986, starting as a Senior Lecturer and was promoted to the rank of Professor in 1994. He retired after a successful career in 2016. He has several publications to his credit, which include Thesis/Dissertation, Book/ Monographs, Articles, Technical and Conference Papers. The major area of his research is Soil Tillage Dynamics. As an Agricultural Engineer, he has produced 9 (nine) original Technological Tools and was also the Project Team Leader for the development and installation of all the machines for Fruit Processing Factory at the Federal University of Technology, Akure.

He has to his honour several awards and commendations at local, national and international levels. At the Federal University of Technology, Akure, he has served in the University in various capacities including Headship of Department and Dean of School and Deputy Vice- Chancellor (Academic) of the University.

Engr. Mrs. Omolola Cecilia OGUNJIRIN had her Post Graduate Diploma in Agricultural Engineering in 2004 (Farm Power and Machinery option) and master degrees (Crop processing and storage option) in view from the Federal University of Technology, Akure, Ondo State Nigeria and Ladoke Akintola University of Technology, Ogbomosho, Oyo State, Nigeria respectively. She has experiences in the area of crop processing and storage, development of storage structures for small and medium scale farmers, tillage studies. She is a corporate member, Nigerian Institution of Agricultural Engineers, (NIAE), Corporate member, Nigerian Society of Engineers (NSE). She is a registered engineer with the Council for the Regulation of Engineering in Nigeria (COREN). She presently works with the Nigerian Stored Products Research Institute in the Post-harvest Engineering Research Department. She oversees storage structure and dryers such as solar dryers, charcoal fired dryers and hybrid dryers.