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# JOURNAL OF AGRICULTURAL MECHANIZATION (AGRIMECH)

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## TABLE OF CONTENTS

# LAND CAPABILITY CLASSIFICATION OF THE NATIONAL CENTRE FOR AGRICULTURAL MECHANIZATION (NCAM) FARMLAND

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## ABSTRACT

*Land capability is the ability of a piece of land to sustainably support the growth of Agricultural crop without damage to the soil. NCAM farmland that has been used for crop production measuring 14 hectares was divided into 8 plots based on their location and accessibility. Samples were taken from each plot to determine the soil physical properties such as textural class, bulk density, moisture content and determination of the chemical properties of the soils, such as electrical conductivity, pH, organic matter content, nitrogen, phosphorus and potassium were carried out for all samples. The results of macro nutrients like soil nitrogen fell below 1% for all the plots, soil potassium was less than 50mg/kg as recommended by FAO and the soil phosphorous fell between 25.12 to 32.38 mg/kg and pH ranges between 7.00 to 8.30. The results showed the capacity of the soil in each plot to sustain a particular agricultural crop production in a sustainable way with minimal cost of production.*

**Keyword:** Land capability, crop production, soil properties, production cost

## 1. INTRODUCTION

Agriculture has been identified as a strategic sector that would address the multiple challenges of achieving a broad based objective of economic growth, creating wealth and employment, reducing poverty, and attaining national food security as well as putting Nigeria among the 20 world leading economies by the year 2020. The 2006 population census figure for Nigeria was about 150 million people. This is expected to increase to about 220 million by the year 2025 (Musa, 2000). Musa (2001) further postulated an increase in food production from 0.26 million tons/ha to 0.9 million tons/ha in 2025.

The need for increased production has fostered ecologically unsustainable agricultural intensification in many places, leading in particular to soil degradation. Declining Sub-Saharan Africa agricultural productivity is both a cause and a consequence of the deterioration of soil and water resources. One of the objectives of the Millennium Development Goals is to reduce hunger and poverty by half, by the year 2015, and the national food security programme of the present administration is aimed at achieving this objective. Nigeria could be said to be majorly an agrarian society and this has continued to be so because agriculture is still the largest employer of labour. About 82 million hectares out of Nigeria's total land area of about 91 million hectares are arable, (FMA, 2001).

Increased land productivity (greater output/unit of land) generally depends on the application of higher technology and a higher level of knowledge and management ability. Agricultural mechanization is an instrument of farm management and as such changes in mechanization level can have a multiplier effect on output per unit of land. Agricultural mechanization has now been accepted as the most crucial input not only to increase agricultural productivity and promote industrialization of the rural sector but also to promote the overall economic development of nations.

Plants require at least 16 elements for normal growth and for completion of their life cycle. Those used in the largest amounts, carbon, hydrogen and oxygen, are non-mineral elements supplied by air and water. The other 13 elements are taken up by plants only in mineral form from the soil or must be added as fertilizers. Plants need relatively large amounts of nitrogen, phosphorus, and potassium. These nutrients are referred to as primary nutrients, and are the ones most frequently supplied to plants in fertilizers. The three secondary elements, calcium, magnesium, and sulphur, are required in smaller amounts than the primary nutrients. Calcium and magnesium are usually supplied with liming materials, and sulfur with fertilizer materials. Contaminants in rainfall also supply 11.35 to 22.70 Kilograms of nitrogen and sulfur per hectare each year, depending on local air quality (www.soil.ncsu.edu/.../nutrient%20management%20for%20CCA.pdf).

Farouque and Tekeya (2008) observed that the most pressing problem for Bangladesh agriculture was the state of gradual decreasing of soil fertility, stagnating crop yields and declining productivity in a range of food crops.

A similar study carried out by Hasan and Allam (2006) in Bangladesh showed that about 5.6 million ha of Bangladesh’s land is deficient in phosphorus, 7.5 million ha are deficient in potassium and 8.7 million ha are deficient in sulfur for the production of upland crops. They further reported incidence of zinc deficiency in about 1.74 million ha of Bangladesh’s land and that boron deficiencies are now being noticed; all these are as a result of the major cultivable crops of Bangladesh removing huge amount of nutrient elements from soil.

The technique which allows determination of the most suitable use for any area of land is called land classification. Land capability classification has been defined in different fields to meet targeted objectives, but for the purpose of this work, land capability is referred to as categorization of land according to its capability for optimum agricultural production with the damage to the land reduced to the barest minimum.

According to Onyekwere et al. (2008), African Sub-Saharan region is characterized by chronic food deficit as the net growth in the global population between now and 2050 will occur in the cities of lower income countries, leading to an increase in urbanization (FAO and WWC, 2015). He went further to enumerate some of the factors responsible for the slow pace of food production; this includes vagaries of weather, notably unavailability and uneven monthly distribution of rainfall (Farmer and Wigley, 1985), unfavourable soil conditions such as low effective cat-ion exchange capacity (CEC), low phosphorus and potassium reserves, rapidly declining organic matter and proneness to compaction (Lal, 1993).

To satisfy the food demand and ensure sustainable food production in the area, agricultural production needs to be increased by 2.3% annually over the next decade in order to even maintain the currently substandard national level (Pendleton and Lawson, 1985). The implication of this is that there is a great need for larger agricultural expansion and intensification. Unfortunately the potential for intensification of crop production in agricultural land is fast declining; declining soil fertility being a major factor in the decline (Onyekwere et al. 2008).

Farmers are often advised to use chemical fertilizers for improving soil fertility. However, owing to its unavailability and unaffordability to resource poor farmers as well as its damaging effect on the soil and the environment, an affordable, ecologically stable and sound fertility maintenance measures need to be adopted by farmers for increased crop production. Since soil nutrients are the main contributors to crop production, it becomes imperative that the nutrient status of soils be determined and therefore categorized to support commonly produced crops.

Studies have shown that continuous use of land for crop production without adoption of effective soil conservation techniques often leads to soil degradation, hence reduced crop production over time. Soil degradation was defined by UNEP (1982) as the decline in soil quality as a result of its misuse by humans. Soil degradation is also an outcome of depletive human activities and their interaction with natural environments (Lal and Stewart, 1990). According to Ahaneku (1997), there are three major types of soil degradation; physical chemical and biological. Physical degradation refers to the deterioration of the physical properties of the soil; chemical degradation refers to depletion of soil fertility status through leaching, erosion or crop removal, while biological degradation refers to loss of soil organic matter content.

The basics of balanced fertilization are governed by Liebig's law of the minimum (discussed in Chapter 3). Formerly, it was rightly concluded that, on many soils, the application of N without simultaneous supplies of phosphate and K made little sense. Today, in view of multiple nutrient deficiencies and increasing costs of crop production, fertilization with N or NPK without ensuring adequate supplies of all other limiting nutrients (S, Zn, B, etc.) makes little sense and, in fact, becomes counterproductive by reducing the efficiency of the nutrients that are applied. Therefore, in view of the widespread occurrence of other nutrient deficiencies, the scope and content of balanced fertilization itself has changed. It now includes the deliberate application of all such nutrients that the soil cannot supply in adequate amounts for optimal crop yield. There is no fixed recipe for balanced fertilization for a given soil or crop. Its content is crop and site specific, hence the growing emphasis on Site Specific Nutrient Management (SSNM).

The goal of optimal plant nutrition is to ensure that crop plants have access to adequate amounts of all plant nutrients required for high yield. The nutrients have to be present in the soil or provided through suitable sources in adequate amounts and forms usable by plants. The soil water should be able to deliver these nutrients to the roots at sufficiently high rates that can support the rate of absorption, keeping in view the differential demand at various stages of plant growth. Optimal plant nutrition must ensure that there are no nutrient deficiencies or toxicities and that the maximum possible synergism takes place between the nutrients and other production inputs. The ideal state of optimal plant nutrition may not be easy to achieve in open fields. However, it is possible to come close to it by basing nutrient application on the soil fertility status (soil test) (FAO, 1996).

Crop production yield from NCAM farmland over the years had been dwindling, oftentimes; it is sustained by using lots of fertilizers, costing enormously. Therefore, this project will assist in ensuring sustainability of land fertility and productivity, also reducing production cost to a large extent. Adequate Soil Conservation management can also be ensured by a good soil nutrient management emanating from a study as this.

The objective of this study is to determine the Physicochemical characteristics of NCAM land used for annual crop production so as to guide the farmers on which crop can thrive on each plot with minimum cost of production with less damage to the soil structure.

## 2. METHODOLOGY

Reconnaissance survey of NCAM farm plots under cultivation was carried out; subsequently, measurement of each plot was be carried out according to the types of crop planted on each. Table 1 shows the NCAM farmland divided into plots according to their location. Three samples were taken from each of the plots for determination of some soil physical properties such as (i) Particle size determination (ii) Field capacity and (iii) Soil bulk density. Determination of the chemical properties of the soils, such as (i) Electrical conductivity, (ii) Soil pH, (iii) Soil organic matter content, (iv) Soil Nitrogen, (v) Soil Phosphorus and (vi) Soil Potassium were carried out for all samples. Parameters such as particle density was determined using sieve analysis. The soil pH was determined using a glass electrode pH meter in a 1:1 soil to water ratio. Organic matter was determined by the wet oxidation method (Nelson and Sommers, 1982), while exchangeable cat-ion was extracted with normal neutral ammonium acetate with sodium and potassium in the extract analyzed by the flame photometry method; calcium and magnesium were determined by the benzoate titration method. Available phosphorus was determined using the Bray method (Bray and Kantz, 1945). The Macro-Kjeldahl method was employed in the total Nitrogen determination (Black, 1965).

Table 1. Field measurement of NCAM farmland

| PLOT NO. | PLOT SIZE (Ha) | LOCATION |
|---|---|---|
| PLOT 1 | 1.4296 | Beside Maintenance Block |
| PLOT 2 | 0.6533 | Opposite Plot 1 |
| PLOT 3 | 1.0405 | Back of Former Admin |
| PLOT 4 | 1.1668 | Next to Road to ARMTI |
| PLOT 5 | 1.353 | NIFAP PLOT |
| PLOT 6 | 0.5415 | Next to NIFAP Plot |
| PLOT 7 | 3.1031 | Cassava Mech. Plot to right |
| PLOT 8 | 4.7512 | Cassava Mech. Plot to left |
| **TOTAL HECTERAGE** | **14.039** | |

## 3. RESULTS

Results of the analysis carried out showed that the textural class of the soil is the same in all the fields sampled for this research work , i.e. loamy sand, with sand having the highest percentage of the aggregates using USDA classification of soil texture classes according to proportions of sand, silt and clay as shown in Table 1.

Table 2. Textural Classification of soil

| | **Sand (%)** | **Silt (%)** | **Clay (%)** | **Textural Class** |
|---|---|---|---|---|
| Plot 1 | 82.96 | 16.87 | 0.17 | Loamy sand |
| Plot 2 | 85.55 | 14.43 | 0.02 | Loamy sand |
| Plot 3 | 84.05 | 15.49 | 0.00 | Loamy sand |
| Plot 4 | 86.30 | 13.58 | 0.12 | Loamy sand |
| Plot 5 | 89.00 | 10.25 | 0.75 | Loamy sand |
| Plot 6 | 84.46 | 15.40 | 0.14 | Loamy sand |
| Plot 7 | 87.14 | 12.74 | 0.13 | Loamy sand |
| Plot 8 | 87.64 | 11.40 | 0.96 | Loamy sand |

The result on Table 3 shows the soil pH and the soil chemical compositions in the different plots (1~8) considered for this study. The soil pH-value from plot 1 to plot 8, are as follows; 7.10, 7.00, 6.93, 6.50, 6.47, 8.30, 7.17 and 6.30, respectively. According to soil pH classification by Brady and Well (1996), the soil sampled based on plots fall under the following pH indicators; the soil sampled from plot 2 alone has a neutral pH value, while plots 2 and 7 are very slightly alkaline. On the other hand, plots 3, 4, 5 and 8 are slightly acidic, while plot 5 only can be considered as very slightly acidic, with the exception of plot 6 which is a medium alkaline soil. For the soil chemical compositions, the EC-values (EC) from plot 1~8 are as follows; 0.03, 0.03, 0.06, 0.03, 0.02, 0.03, 0.05 and 0.06 µS cm$^{-I}$ respectively. These values falls between the EC-value for a normal loamy sandy soil, because according to Smith and Doran (1996) the EC-values for normal loamy sandy soil ranges between 0~1.2 µS cm$^{-I}$. Nevertheless, for the soil moisture content (MC), the plot 1 had the highest value of 14.23 %, followed by plot 6 with MC value of 12.23 %. MC value for plot 7 was also fair with 11.69 % MC, while plots 2, 3 and 4 have closely related MC values, with values 9.35, 9.10 and 9.34 % respectively. Plots 8 and 5 have the lowest MC values of 8.45 and 7.60 %, respectively. Evaluation of moisture content from the various plots revealed that they were within the limit of a normal Sandy loam soil, (Taylor and Ashcroft, 1972). The Bulk density (BD) from the various plots seemed to be similar from plot 1~8 with values as 1.40, 1.37, 1.28, 1.43. 1.21, 1.33, 1.43 and 1.21g cm,$^{-3}$ respectively. On the other hand, the Organic matter (OM) varied from plot to plot and the OM for plot 4 has the highest value of 4.26 % while the OM from plot 1 and 3 were relatively high with values as 3.56 and 3.29 %, respectively, but the OM from plots 6, 2, 5 and 7 were closely related (2.90, 2.67, 2.49 and 2.27 %) and they are lower when compared to plots 1 and 3. Plot 8 has the lowest value of OM of 1.94 % compared to other plots. The soil primary nutrients (N, P, K, MgO) composition varies from plot to plot. $NH_3$-N value for each soil, are all less than 1 %, therefore their values are negligible and can be improved upon by addition of organic/inorganic soil amendment. The soil phosphate value from plots 1, 2, 3, 4, 5, 6 and 8 are 29.52, 26.99, 32.21, 25.12, 25.46, 29.77 and 32.38 mg kg$^{-1}$, respectively. According to FAO (1980), all seven are classified as soil with very high fertility of phosphate, while plot 7 with phosphate content 23.67 mg kg-1 fall in the category of soil with high fertility of phosphate. For the soil potassium analysed from all the plots sampled, the potassium concentrations are 34.67, 30.67, 33.33, 30.67, 32.00, 36.00, 30.67 and 28.00 mg kg,$^{-1}$ respectively. According to the soil fertility classification (FAO, 1980), they all fall under the same category of soil with very low fertility of soil potassium-oxide (< 50 mg $kg^{-1}$), while the soil magnesium-oxide analysed from all the plots sampled, the amount of magnesium from plots 1~8 are 13.20, 15.76, 16.60, 12.35, 15.83, 17.71, 12.53 and 14.04 mg $kg^{-1}$, respectively. They all fall, under the same category of soil with very low fertility of soil magnesium-oxide (< 20 mg $kg^{-1}$) according to the soil fertility classification (FAO, 1980). For calcium oxide (CaO) analysed from all the plots sampled, the amount of calcium from plots 1~8 are 54.67, 46.67, 64.0, 49.33, 61.33, 80.0, 69.33 and 66.67 mg $kg^{-1}$, respectively. Although, the amount of calcium in all the plots are in the range value for tropical soils climate (Brady, 1974). While for iron (Fe), the result from the chemical analysis from all the plots (1~8) are; 112.10, 110.32, 215.14, 221.71, 175.20, 142.48, 128.46 and 140.60 mg $kg^{-1}$ respectively. Also, for manganese (Mn), analysed from all the plots sampled, the amount of calcium from plot 1~8 are 1.31, 1.42, 0.70, 0.65, 0.81, 1.06, 0.92 and 0.35 mg $kg^{-1}$ respectively. The amount of Fe and Mn, should not be worrisome, because they are micronutrient for plant benefit, and most chemical fertilizer contain considerable amount of both mineral nutrient for plant usage.

Table 3: Mean value of the soil chemical compositions at different locations in the NCAM farm land

| Location (Plot) | pH | EC µS cm$^{-1}$ | MC % | BD g cm$^{-3}$ | OM % | $NH_3$-N % | $P_2 0_5$ mg kg$^{-1}$ | $K_2O$ mg kg$^{-1}$ | MgO mg kg$^{-1}$ | CaO mg kg$^{-1}$ | $Fe^{2+}$ mg kg$^{-1}$ | MnO mg kg$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.10 | 0.04 | 14.23 | 1.40 | 3.56 | 0.46 | 29.52 | 34.67 | 13.20 | 54.67 | 112.10 | 1.31 |
| 2 | 7.00 | 0.03 | 9.35 | 1.37 | 2.67 | 0.63 | 26.99 | 30.67 | 15.76 | 46.67 | 110.32 | 1.42 |
| 3 | 6.93 | 0.06 | 9.10 | 1.28 | 3.29 | 0.70 | 32.21 | 33.33 | 16.60 | 64.00 | 215.14 | 0.70 |
| 4 | 6.50 | 0.03 | 9.34 | 1.43 | 4.26 | 0.48 | 25.12 | 30.67 | 12.35 | 49.33 | 221.71 | 0.65 |
| 5 | 6.47 | 0.02 | 7.60 | 1.21 | 2.49 | 0.28 | 25.46 | 32.00 | 15.83 | 61.33 | 175.20 | 0.81 |
| 6 | 8.30 | 0.03 | 12.25 | 1.33 | 2.90 | 0.69 | 29.77 | 36.00 | 17.71 | 80.00 | 142.48 | 1.06 |
| 7 | 7.17 | 0.05 | 11.69 | 1.43 | 2.27 | 0.31 | 23.67 | 30.67 | 12.53 | 69.33 | 128.46 | 0.92 |
| 8 | 6.30 | 0.06 | 8.45 | 1.21 | 1.94 | 0.60 | 32.38 | 28.00 | 14.04 | 66.67 | 140.60 | 0.35 |

pH= Acidity or Alkalinity; EC=Electrical Conductivity; MC=Moisture Content; BD=Bulk Density; OM=Organic Matter

Soil nutrients, as well as its availability are important not only as they affects crop plant productivity, but as it determines the potential movement of nutrients outside the boundaries of the crop field, and their impact on air, water resources and native ecosystem. The fertility recommendation of the various plots, due to the results of the soil chemical compositions, can be best explained by the bioavailability of the essential plant nutrients. The bioavailability of these nutrients is most associated with the inherent pH-value of the field (Brady and Well, I996). Plant bioavailability by Peck and Soltanpour (1990), can be defined as the chemical form or forms of an essential plant nutrient in the soil whose variation in amount is reflected in variation with plant growth and yield. Most plants do well on pH-value between 6.0~7.5, but some plants are exceptional. However, this is the pH-value range for the bioavailability of most of the essential nutrients required by crop, for adequate growth and yield. Therefore, from the results above, most of the plots (1, 2, 3, 4, 5, 7 and 8) fall between the pH-value range of 6.0~7.5, except for plot 8, that had a pH-value higher than 7.5. As a result, all the plots, except plot 8, are expected for all their inherent essential nutrients to be available for plant uptake, while for plot 8 being an alkaline soil in nature, all its essential plant nutrient may not be available for plant uptake, even though they are present in the soil (Brady and Weil, I996), so there may be need for the soil (plot 8) to be ameliorated for agricultural benefit. In this regard, organic fertilizer with a cation charge, for example ammonium ($NH_4^+$) can be utilized to reduce the soil pH-value. Many studies had been reported using the concept of rhizosphere acidification, which occurs as a consequence of $N_2$ fixation from either legume or ammonium fertilizer supply, can lead to pH decrease of about 2pH units (Gahoonia et al., 1992; Li et al., 2008). Therefore, this concept will ameliorate the bioavailability of the essential plant nutrient present in the soil. On the other hand, some other properties of the field, such as moisture content (MC), bulk density (BD), and salinity (EC) affected the rate of Phosphate mineralization from organic matter (OM) decomposition. OM decomposition and release of Phosphate ($P_2O_5$) is faster in the tropical climate and slower in temperate climate. $P_2O_5$ is released faster also, when soil is well aerated (good BD), and much slower on saturated wet soils. Nevertheless, soils with inherent pH values between 6 and 7.5 are ideal for $P_2O_5$-availability, while pH-value below 5.5, and between 7.5~8.5 limits $P_2O_5$-availability to plants due to fixation by aluminum ($Al^{3+}$), iron ($Fe^{2+}$), or calcium ($Ca^{2+}$), these had been reported by the California Fertilizer Association, 1995. Phosphorus does not readily leach out of the root zone, but the potential for $P_2O_5$-loss is mainly associated with erosion and runoff. Therefore, the plots that are most prone to erosion, runoff, or are in close proximity to streams, lakes and other water bodies needs to be closely managed to avoid $P_2O_5$ loss. Additionally, Fe deficiency is mostly triggered by the high availability of Mn or high pH soil as mentioned, though not all crop can be affected, but crops like Sorghum, Maize, Alfalfa, together with tree crops etc. are likely to be affected. For the potassium, the amount of potassium from all the plots were in the category of soil with very low fertility of soil potassium-oxide (they are < 50 mg $kg^{-1}$) according to the soil fertility classification (FAO, 1980). Therefore, the eight (8) plots soil potassium concentration needed to be ameliorated. These can be done using organic/inorganic fertilizers, organic fertilizer like coconut peat, oil palm ash (James et al., 2016) can be used to improve the soil potassium concentration. Also, inorganic fertilizer can be used solely, such as sulphate of potash (SOP) or it can be incorporated with the inorganic fertilizer for potassium amelioration. For, Magnesium amount from all the plots, were in the category of soil with very low fertility of soil magnesium-oxide (they are < 20 mg $kg^{-1}$) according to the soil fertility classification (FAO, 1980); this can be ameliorated using organic/inorganic fertilizers, organic fertilizer like animal manure can be used to improve the soil magnesium concentration. Also, inorganic fertilizer can be used solely, such as Epsom salts, and sulphate of potash magnesia or it can be incorporated with the inorganic fertilizer for magnesium amelioration. Although, the amount of calcium might not be necessary ameliorated because they are in the range value for tropical soils climate (Brady, 1974).

Magnesium is indispensable in the processes of protein hydrolysis in plant vegetative organs as well as for the transfer of assimilation products from leaves to ears. This nutrient takes part in photosynthesis (prolongs the stage of green leaves) and transportation of proteins from plant vegetative organs to seeds or kernels (Cakmak, Kirkby 2008). The yield forming effect of magnesium is particularly evident under the conditions of insufficient supply of nitrogen to plants (Grzebisz 2013). Calcium regulates osmotic and ionic processes in cell membranes, and magnesium works as a cofactor in enzymatic reactions (White, Broadley 2003).

The effects of calcium and magnesium deficiency are evident in plants growing on excessively acidic soils, with a low Ca content caused by the leaching of Ca2+ cations or with low cation-exchange capacity (CEC), as well as under the conditions of aluminium toxicity to the plant root system (Rengel, Elliot 1992, Ryan et al. 1994).

Table 4: Soil pH classification and nutrient availability

| pH | Classification | Available Nutrient |
|---|---|---|
| 4.0-5.5 | Strongly acidic | Fe, Mn, B, Cu and Zinc |
| 5.5-6.0 | Medium acidic | Fe, Mn, B, Cu and Zinc |
| 6.0-6.5 | Slightly acidic | N, P, K, S, Ca and Mg |
| 6.5-7.0 | Very Slightly acidic | N, P, K, S, Ca and Mg |
| 7.0-7.5 | Very Slightly alkaline | N, P, K, S, Ca and Mg |
| 7.5-8.0 | Slightly alkaline | N, P, K, S, Ca and Mg |
| 8.0-8.5 | Medium alkaline | Mo |
| 8.5-10 | Strongly alkaline | Mo |

Source: Brady and Well (1996)

The soil pH of all the sampled plots varied from 6.0 to 8.4. With reference to Table 1 above, pH results for Plot 1 showed that the soil is very slightly alkaline with the possibility of availability of nutrients as N, P, K, S, Ca and Mg ions. The plot has an average pH of 7.1. Plot 2 showed a pH range from 7.2 for 0-7 cm depth to 6.9 for depths 7-14 an 14-21, respectively, but with an average pH of 7.0; this plot fall in the class of very slightly acidic soil, also with the possibility of availability of nutrients such as N, P, K,S, Ca and Mg ions.

Plot 3 showed a slight pH variation of 7.1 for 0-7 cm depth and 6.9 to 6.8 for depths 7-14 and 14-21 cm depths respectively, but with an average pH of 6.9, it falls in the class of  with the possibility of availability nutrients as N, P, K,S, Ca and Mg ions. Plot 4 on the other hand showed a consistence in pH of 6.5 down the soil profile and falls between the classes of very slightly acidic and slightly acidic also with the possibility of nutrients as N, P, K,S, Ca and Mg ions. Plot 5 showed a decrease in pH from 6.6 to 6.4 down the soil profile, but with an average pH of 6.47, meaning it falls in the class of slightly acidic soil with the possibility of availability of such nutrients as N, P, K, S, Ca and Mg ions. In Plot 6, the results showed a moderately alkaline soil with a pH range of 8.2 to 8.4, but with an average pH of 8.3; this plot is in medium alkaline soil class with the possibility of availability of Mo. The pH of the plot 7 soil ranged from 7.0 to 7.3 with an average of 7.2, placing it in the pH class of very slightly alkaline soils with the possibility of availability of N, P, K,S, Ca and Mg ions. Plot 8 has a pH range from 6.0 to 6.5 but with an average of 6.3, placing it in the pH class of slightly acidic soils with the possibility of availability of N, P, K, S, Ca and Mg ions.

Table 5. Soil fertility classification

| **Soil Fertility Class** | **AVAILABLE EXTRACTABLE NUTRIENT** | | | **EXPECTED RELATIVE YIELD** |
|---|---|---|---|---|
| | **Phosphorus (P) (mg/kg)** | **Potassium (k) (mg/kg)** | **Magnesium (Mg) (mg/kg)** | **WITHOUT FERT. (%)** |
| Very Low | $< 5$ | $< 50$ | $< 20$ | $< 50$ |
| Low | 5-9 | 50-100 | 20-40 | 50-80 |
| Medium | 10-17 | 100-195 | 40-80 | 80-100 |
| High | 18-25 | 175-300 | 80-180 | 100 |
| Very High | $> 25$ | $> 300$ | $> 180$ | 100 |

Source: FAO (1980)

With reference to the above table of fertility classification, soil in plot 1 has phosphorus content ranging between 27.72 mg/kg to 31.51 mg/kg, with an average Phosphorus content of 29.52. This shows that the phosphorus content is quite sufficient to support crop growth, i.e. very high. The same thing goes for plot 2 with phosphorus content ranging from 24.25 to 30.01 mg/kg and an average content of 26.99 mg/kg. Plot 3 has higher Phosphorus than plots 1 and 2 with the Phosphorus content ranging from 28.99 to 35.06 mg/kg of soil. The average Phosphorus content of plot 3 being 32.21 mg/kg; this plot does not have any Phosphorus problem as the Phosphorus content is very high and adequate enough to support plant growth. The Phosphorus content of plot 4 ranged from 21.46 to 29.17 mg/kg with an average 25.12 mg/kg; this with reference to FAO (1980) is also very high in Phosphorus and adequate to support plant growth. Plot 5 has Phosphorus content ranging from 22.75 to 28.17 mg/kg with an average content of 25.49 mg/kg; this also is very high and adequate enough to support growth. In plot 6, the Phosphorus content ranged from 28.38 to 30.83 mg/kg with an average content of 29.77 mg/kg. The fertility class relative to its phosphorus content shows it is very high and adequate for plant growth. The soil of plot 7 showed a range of Phosphorus between 20.98 and 27.00 with an average of 23.67. The FAO standard for fertility shows that with respect to phosphorus, plot 7 falls in the high class, still sufficient enough to support growth while plot 8 contains between 26.18 and 37.02 mg/kg of phosphorus, the average Phosphorus content being 32.38 mg/kg. The results showed that there is no issue with any of the sampled plots with reference to Phosphorus.

The Magnesium content of plot 1 showed a slight variation from 10.88 to 16.28 mg/kg with an average of 13.20 mg/kg. This shows a Magnesium content of less than 20 mg/kg; this, according to the soil fertility standard of FAO (1980) is in the very low class and may not be able to support plant growth adequately. The Magnesium content of plot 2 ranged from 11.40 and increased down the soil profile to 22.04 mg/kg with an average of 15.59 mg/kg; this is also less than 20 mg/kg and therefore too low to support growth adequately. The variation in magnesium content of plot 3 ranged from 16.32 to 20.24, but with an average of 16.6. The soil of this plot also fall in the class of very low and may not support growth adequately. The variation in Magnesium content of the soil in plot 4 ranged from 7.88 in the 0-7 cm depth and increased to 17.16 mg/kg in the 14-21 cm depth; the average Magnesium content being 12.35 mg/kg. This is far too low to the benchmark of 20, therefore in the fertility class of very low. Magnesium content of plot 5 varied from 15.00 to 16.52 mg/kg with an average content of 15.83 mg/kg of soil; this also is in the very low class and may not sufficiently support crop growth. Plot 6 has Magnesium content ranging from 15.12 to 20.00 mg/kg, but with an average of 17.71; this also fall in the class of very low. Magnesium content of Plot 7 varied from 10 to 16.04 with an average of 12.53; in the Very Low class and may be insufficient to support plant growth adequately. The Magnesium content in plot 8 increased down the profile from 8.12 to 20 mg/kg, but with an average of 14.04. The results of the Magnesium content of all the plots fell below the minimum; this may likely have negative implications on the productivity of the plots.

The result of the analysis showed that Potassium level in plot 1remain unchanged at 36 mg/kg for the layers 0-7 and 14-21, respectively but reduced to 32 in the 14-21 soil layer. The average of the three reading is 34.67 mg/kg. Reference to the FAO (1980) fertility standards showed that it is very low (I.e. less than 50); the productivity of this plot may likely be affected by this result. The Potassium content of plot 2 increased down the profile from 28 to 32 but with an average of 30.67; this value is less than the minimum and therefore too low to support substantial productivity. The soil in plot 3 showed a Potassium content decreasing don the soil profile from 36 in the upper layer to 32 mg/kg in the lower level; the average being 33.33 mg/kg; this also is very low and may likely result in low productivity. The Potassium content of plot 4 also reduces from a value of 32 mg/kg in the first two layer of the soil to 28 mg/kg in the last layer; the average Potassium content being 30.67 mg/kg; it also falls in the class of very low. There is consistency down the profile for Potassium content of plot 5; it remained 32 mg/kg in all the layers of the plot, the average also being 32 mg/kg. This average potassium content ranks this plot in the very low class, hence may affect productivity. The analysis results of plot 6 revealed a reduction in the content of Potassium down the profile from 36 mg/kg in the first two layers to 32 mg/kg in the last layer; the average of the three being 34.67. This again is in the class of very low and may affect its productivity. On the contrary, the is an increase down the profile in the Potassium content of plot 7; it increased from 28 mg/kg in the upper 0-7 cm layer to 32 mg/kg in the two lower layers. The average Potassium in this plot is 30.67 mg/kg; it falls in the class of very low in the soil fertility class, hence may affect productivity. Plot 8 showed a consistency in its Potassium content down the profile; its 28 mg/kg all through, therefore the average Potassium is 28 mg/kg. The results in all the plots for Potassium also revealed a very low level of Potassium in all the plots, this may have negative impact on the productivity in all the plots.

## 4. CONCLUSION

The pH-value of the various plots sampled fall within the range of soil with nutrient availability for plant uptake, except for plot 6. The soils are all classified as a loamy sand soil. While plot 6, needed to be ameliorated by a decrease in soil pH-value to at most 2 pH units.

### 4.1 Recommendation

The following recommendations are made to ameliorate the effects of highlighted deficiencies, i.e. in Magnesium and Potassium for all the plots

**Magnesium Remediation**

Natural reserves of Mg are very large, both in salt deposits (MgCl2, MgCO3, etc.) and in mountains consisting of dolomite limestone (CaCO3.MgCO3). There are several commercially available materials of acceptable quality that can be used to provide Mg to soils and plants. There are two major groups of Mg fertilizers, namely, water soluble and water insoluble. Among the soluble fertilizers are magnesium sulphates, with varying degree of hydration, and the magnesium chelates. The sulphates can be used both for soil and foliar application whereas the chelates, such as magnesium ethylenediaminetetra acetic acid (Mg-EDTA), are used mainly for foliar spray. Some sources of Mg are:

(i) magnesium oxide (MgO): contains 42 percent Mg (Mg × 1.66 = MgO)
(ii) magnesite (MgCO3): contains 24–27 percent Mg.s
(iii) dolomitic limestone (MgSO4.CaSO4): contains 3–12 percent Mg.
(iv) magnesium sulphate anhydrous (MgSO4): contains 20 percent Mg
(v) magnesium sulphate monohydrate (MgSO4.H2O): contains 16 percent Mg.
(vi) magnesium sulphate heptahydrate (MgSO4.7H2O): contains 10 percent Mg.
(vii) magnesium chloride (MgCl2.6H2O): contains 12 percent Mg
(viii) potassium magnesium sulphate (K2SO4.2MgSO4): contains 11 percent Mg.

Magnesium sulphate is the most common Mg fertilizer. In anhydrous form, it contains 20 percent Mg. As a hydrated form, MgSO4.7H2O (Epsom salt), it contains10 percent Mg. (FAO, 1996).

**Soil Remediation for Potassium Deficiency**

Potash fertilizers are predominantly water-soluble salts. For historical reasons, their Potassium concentration is generally still expressed as percent K2O, particularly by the industry, trade and extension. As such, the nutrient K does not exist as K2O in soils, plants or in fertilizers. It is present as the potassium ion K+ in soils or plants and as a chemical compound (KCl, $K_2SO_4$) in fertilizers.

(i) The first potash fertilizers were ground crude K salts containing 13 percent $K_2O$.These are still used to some extent for fertilization of grassland in order to supply K and Na.
(ii) Potassium chloride (KCl), also called muriate of potash (MOP), is the most common Potassium fertilizer. It is readily soluble in water and is an effective and cheap source of K for most agricultural crops.
(iii) Potassium sulphate (SOP) is actually a two-nutrient fertilizer containing 50 percent K2O and 18 percent S, both in readily plant available form. It is

costlier than MOP but is particularly suitable for crops that are sensitive to chloride in place of KCl. It has a very low salt index (46.1) as compared with 116.3 in case of MOP on material basis (FAO, 1996).

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*Soil fertility basics:*

*www.soil.ncsu.edu/.../nutrient%20management%20for%20CCA.pddf*

# SUSTAINABLE CASSAVA (*MANIHOT ESCULENTUM*) PRODUCTION IN THE RAIN FOREST AGRO-ECOLOGICAL ZONE OF OSUN STATE, NIGERIA

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## ABSTRACT

*Different tillage practices of cassava (Manihot esculentum) plants, roots' yield and quality in the rain forest of Osun State, Nigeria were studied. Plots of land were planted with bitter variety 98/0581 fresh cassava stems. Three treatments: zero tillage (0), minimum tillage (1) and maximum tillage (2) were used; each treatment replicated thrice; 0A, 0B, 0C; 1A, 1B, 1C and 2A, 2B, 2C respectively. Selected agronomic parameters (i.e. Heights of cassava plants, Leaf Area Index (LAI), weights of harvested roots per hectare, and quality of roots) were determined. All collected data were analyzed using one-way analysis of variance – ANOVA. Results showed statistical differences among (1) mean values of the heights of cassava plants, (2) mean areas of cassava leaves. There were stronger correlations depicting stronger relationships between methods of tillage and LAI and average growth rate of cassava; $R^2$ = 0.999, 0.998, 0.996 for zero, minimum and maximum tillage respectively for LAI and $R^2$ = 0.989, 0.991 and 0.992 for zero, minimum and maximum tillage respectively for average growth rate. The highest yield of cassava roots was 11.33 t/ha in maximum tillage, zero tillage gave lowest, 10.77 t/ha representing 5.2% decrease. Maximum tillage resulted in high quality cassava tubers in term of nutrient composition than other tillage methods. Farmers in rain forests are encouraged to till soil to maximum level so that they will have more income, rural development and livelihoods of farmers will be guaranteed together with right management of land and natural resources.*

**Keywords:** Cassava, Tillage, Rain forest, Leaf Area index

## 1. INTRODUCTION

Cassava (*Manihot esculentum*) is a tropical tuber broadly categorized into bitter cassava (*Manihot utilisssima*) and sweet cassava (*Manihot palmate*). It is between 2 m and 3 m tall when fully matured, some species may reach up to 4 m height and their maturity period ranges between 9 months and 2 years (IITA, 2017).

Tillage encompasses different soil cultivation systems using mechanical/manual equipment before planting. It is a disruptive and energy-intensive task that should be limited to modifying the soil to alleviate productivity constraints in the rooting zone. The tillage depth of soil depends on factors like the soil developmental stages, equipment' properties like orientations and tilting angle of discs (Lamidi, *et al.*, 2021). Good tillage practices are good steps toward proper soil management as they reduce weed growth; incorporate fertilizer, manure and organic matter into the soil and speed up crops' growth (Lamidi *et al.*, 2021; Horton, 2019). Proper soil management is a key to sustainable agricultural production (Wang *et al.*, 2019). Most commercial farmers in southwest Nigeria (a tropical humid region) use minimum tillage, some peasant farmers use zero tillage while few commercial farmers use maximum tillage systems, this was because of the high costs of hiring the relevant equipment.

Cassava can be processed into 'Gari', Cassava flour, '*Fufu'*, Tapioca, Cassava snacks and so on. The first three mentioned are common to the Southern Nigeria. Sustainability of gari business among women-in-agriculture depends on many factors, soil on which cassava grows is one of these factors. There have been many researches on cassava production and its derivatives in Nigeria (Ikuemonisan *et al.*, 2020; James *et al.*, 2012; Akinpelu *et al*., 2011; Ande *et al*., 2008) but literatures on the relationship between the cassava tubers produced and the tillage management practices are still few and especially, a statement whether tillage system on the soil may affect the quality of cassava tubers produced. The (not-yet documented) assertion from the responses to oral-questions that were asked from some women-in-gari production in Osogbo (Olorunda and Osogbo LGAs), Ifon-osun (Orolu LGA), Ilobu (Irepodun LGA), Ile Ogbo (Ayedire LGA), Iwo (Iwo and Ola-oluwa LGAs and Ejigbo (Ejigbo LGA) which were in eight of the thirty local governments areas (LGA) of Osun State on if end products of cassava tubers really depend on soil where it grows is yet to be scientifically proved. If their assertion is true, then cassava flour or Gari or *Fufu* derivatives from cassava roots will also depend on many factors namely season of the year, type of soil management on which it grows (which includes tillage methods), soil nutrients available and the breeds of cassava stems planted. The veracity of the women–in-gari /*fufu*/ cassava flour production needs to be researched into, if truly tillage as a soil management will affect the quality of the end products of cassava tubers. Hence, the objectives of this research were to investigate effects of various types of soil tillage methods on cassava plants production in the rain forest of Osun State and to determine the type of tillage practices that give optimum yield of cassava tubers with good quality tuber extracts toward efforts in sustainability of people's dietary lives and cassava production in the area.

## 2. MATERIALS AND METHODS

### 2.1 Site Selection

The research site, Aba Odan, has large expanse of unique arable land spanning over hundred hectares bounded by other research sites namely *Kejo, Ile Igbo* Station and *Eleni* villages, all in Osun State, Figure 1. An expanse of well-drained land of 2 acres with sandy-loam soil in Aba Odan village in Ile Ogbo, Ayedire Local Government Area of Osun State on 7° 30' 57" N, 4° 19' 30" E was used. The land had not been tilled for more than five years before clearing, this was to make sure that soil nutrients were intact. Osun State - South West Nigeria occupies approximately 14,875 sq. km, between longitude 4.545$^{o}$'E; latitude 7.785$^{o}$N. Though, with clay deposit, hilly lands and rocks in some Local Government Areas (LGAs), 85% of this land mass is cultivable and about 80% (11,900 sq. km) of this supports cassava production (Osun State Diary, 2018). The soil-profile throughout the area where the research was conducted are almost uniform and in conformity with other parts of Osun State. Thereby, all portraying same geographic location and soils formed from the same parent materials. Hence, it is appropriate to say that the experiment in a part of the state may be a representation of the whole Osun State, Nigeria.

Fig. 1. Map of Aba Odan village (in yellow spot) with adjoining villages in Ile Ogbo environs

## 2.2 Soil Sample Preparation and Sample Analysis

Soil samples were air-dried, lightly crushed and passed through a 2 mm sieve. The fraction less than 2 mm was used for the determination of various soil parameters. Soil tests were carried out on the soil samples taken. The bounded areas to the research site Aba Odan also have their soil test analyses to know if there is any homogeneity of soil in the area. The results as shown in Table 1 show the homogeneity of the area and due to the homogeneity of the study area, site in each of the villages and the experimental sites were treated as a unit. The prove of homogeneity of the soil would ascertain that soil management system, that is, tillage practices could be the reason for the differences in the quality of cassava tubers produce at the end of the research.

The particle size was determined with the modified hydrometer method of (El Kebch *et al.*, 2019) using 0.2 M NaOH solution as the dispersing agent. Soil pH was determined with a glass electrode pH meter in distilled water using 1:1, soil: water, as described by Sainju *et al.*, 2021). Soil organic carbon was determined by the chromic acid digestion method reported by Husein *et al.*, 2019). Total N was determined by the macro-Kjeldahl method (Cao *et al.*, 2017) and available P by the Bray-1 method as described by Morad, (2020). Exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$) were extracted with neutral solution of 1.0 M $NH_4OA_C$. The $K^+$ and $Na^+$ concentrations in the extract were determined using the flame photometer while $Mg^{2+}$, $Ca^{2+}$ and the trace elements were determined using the atomic absorption spectrophotometer (AAS). The exchangeable acidity ($H^+$ and $Al^{3+}$) was extracted using 1.0 M KCl (Dhillon and Raun, 2020). Aliquot of the extract was titrated with 0.05 M NaOH to a permanent pink endpoint using phenolphthalein as indicator. The amount of NaOH used was taken to be equivalent to the total amount of exchangeable acidity in the aliquot taken. The soil test is necessary in order to know if the nutrient content of the soil can sustain the productivity of the test crop.

## 2.3 Experimental Design

Three treatments were involved namely: zero tillage-0; primary or minimum tillage-1 and secondary or maximum tillage-2. Each treatment was replicated three times. 2 acres, (8,000 $m^2$) area was used in the site. 2,670 $m^2$ of land each was cultivated for each of the three treatments. Each treatment was divided into three plots (as replicates) with designations 0A, 0B and 0C for zero tillage, 1A, 1B and 1C for the minimum tillage and 2A, 2B and 2C for the maximum tillage. Each of the plots was planted with 98/0581 bitter cassava species. For zero tillage, cassava stems were planted without tillage. Spacing was 120 cm by 90 cm, making a total of 9262.5 cassava plants per hectare. 100 kg of NPK fertilizer was applied to the crop 5 weeks after planting, because of low organic matter content on planting area that can sustain the crops, Akinrinde and Obigbesan 2000, for good growth and yield despite the land fallow. For minimum tillage, plots were ploughed once and latter sprayed with herbicides containing the active ingredient dimethyl 2, 4-D amine. For zero tillage, no any tillage was done, plots were sprayed with mixed herbicides containing the active ingredient of dimethyl 2, 4-D amine and Paraquat dichloride which each concentration was 825 g/L and 297 g/L was applied. In the plots for minimum tillage, ploughing was done once and for maximum tillage, it was ploughed twice followed by harrow and finally ridging

Wherever the soil was worked upon, it was done in such a way that the soil was allowed to flow laterally around the implement during the operations in order to have lower penetration resistance at the surface and sub-surface layer that can favour tuberization of cassava (Shittu *et al.*, 2023). Both the minimum and the maximum operations were done to the required standards respectively to be assured that plants had necessary conditions under the required tillage methods.

## 2.4 Selected Agronomic Parameters of Cassava Crop

The average heights of the cassava shoots for the first three months at 10 days intervals were measured using measuring tape. Similarly, widths (longest widths of the leaves) were also measured in every ten days, the averages were recorded. The random sampling of the heights of shoot and leaves' areas were taken in 3 replicates ($n_1$ = 160) and in whole plot ($n_2$ = 480). The average growth rates (increase in heights of cassava shoot per unit period of time (number of days) were calculated using initial and final heights during the days of measurement, Equation 1. The total cassava roots (per hectare) in each plot and their replicates were uprooted and weighed to record their yield/ha, this was done at the end of the nine months. Growth rate is the difference in growth over a specific period of time divided by the time interval in between, that is

$$Growth\ rate = \frac{Final.height - initial.height}{Number.of.days.in.between} \qquad (1)$$

## 2.5 Leaf Area Measurements

Leaf Area Index (LAI) is defined as the leaf area per unit ground area was calculated from measured data. The leaf area was determined through repeated area measurements on 'single leaf' and area (accumulation), these methods are hence considered the most accurate, and for that reason they are often implemented as calibration tools for indirect measurement techniques (Lamidi *et al.*, 2020). In this experiment, the model tree method- a direct method of measuring LAI was used. It consists of measuring the vertical distribution of leaf areas from the destructive sampling of a small amount of representative cassava plants out of the stands with even-aged plants like cassava plants of this research (with normal leaves' distribution, 3 or 5 plants' sampling was sufficient).

## 2.6 Proximate Composition of Cassava Paste

Some fresh cassava roots were randomly selected, processed into cassava paste using burr mill, this was to evaluate quality of the roots using proximate analysis via percent crude fibre and ash content (dry matter content), carbohydrate, crude protein and moisture content. The reason for using paste rather than cassava flour was to minimize the interference of possible external factors like fermentation, dewatering, sun drying or oven drying, milling or pulverizing and others, during their preparations. Such could have totally changed their compositions or interfere with them.

Crude protein of the paste was determined by micro-kjeldahl method (AOAC, 2019). Crude fibre and ash contents, moisture content and ether extract of the paste were determined by method explained by Simone *et al*., 2022) method. Each analytical method for each treatment ($n_{treatments}$=3) and each replicate ($n_{replicates}$=3) were done three ($n_{trial}$ times=3) times (n=27). The proximate analysis of the cassava tubers was to ascertain the quality produced with reference to different tillage methods used.

## 2.7 Data Analysis

All collected data were analyzed using one-way analysis of variance – ANOVA. Regression analysis was used for LAI and average growth rate of cassava plants under different tillage methods. Where significant differences existed, treatment means were separated using Duncan Multiple Range Tests.

## 3. RESULTS AND DISCUSSION

The results of the soil analysis for the soil in each of the acreage of land used in the four different experimental sites are shown in Table 1. The results show that the mean values of different physical and chemical properties of the soil are not statistically different from one another for a parameter of the soil chemical properties. Thus the soil could not have significantly affected the cassava planted in each of the soil in each of the sites since the soil properties are not significant from a site to the other.

Table 1. Chemical and physical properties of soil before the experiment

| **Soil Parameters** | **Values** | | | |
|---|---|---|---|---|
| | Aba Odan village | Kejo village | Eleni village | Ile Igbo Station |
| | | **Chemical Properties** | | |
| pH (H2O) | 7.20a±0.61 | 6.63a±0.40 | 6.57a±0.53 | 6.97a±0.42 |
| Organic matter (%) | 2.39a±0.05 | 1.96b±0.03 | 1.41b±0.01 | 1.82b±0.02 |
| Available P (ppm) | 1.52b±0.02 | 1.59b±0.01 | 1.50b±0.02 | 2.58a±0.01 |
| CEC, (meg/100g) | 8.26a±0.54 | 7.60b±1.02 | 6.30b±0.45 | 8.10a±0.47 |
| K (ppm) | 32.12b±5.67 | 31.03b±0.01 | 40.15a±2.03 | 46.08a±2.02 |
| Ca (ppm) | 40.00a±5.02 | 34.20a±1.02 | 32.02a±4.03 | 29.00a±3.03 |
| Mg (ppm) | 35.40a±3.01 | 19.00b±2.02 | 29.80a±5.04 | 16.40b±2.04 |
| Nitrogen (%) | 0.72a±0.02 | 0.34a±0.01 | 0.52a±0.01 | 0.28a±0.01 |
| Sodium (ppm) | 42.33±3.89 | 26.63±3.42 | 32.50±6.01 | 38.58±3.03 |
| $Cu^{2+}$ (ppm) | 1.15a±0.04 | 1.14a±0.01 | 1.29a±0.01 | 1.37a±0.01 |
| $Mn^{2+}$ (ppm) | 99.37a±7.02 | 70.92b±6.07 | 80.50b±7.89 | 79.59b±2.02 |
| $Co^{3+}$ (ppm) | 0.20c±0.01 | 1.26b±0.02 | 4.21a±0.20 | 1.38b±0.01 |
| $Fe^{2+}$ (ppm) | 40.20a±3.40 | 37.6a±3.01 | 42.10a±3.56 | 42.77a±3.04 |
| $Zn^{2+}$ (ppm) | 3.40a±0.12 | 1.03b±0.51 | 1.92b0.02 | 1.77b±0.02 |
| | | **Physical properties** | | |
| Sand (g/kg) | 640.30 | 683.90 | 800.40 | 700.20 |
| Silt (g/kg) | 230.40 | 203.05 | 49.40 | 172.50 |
| Clay (g/kg) | 129.30 | 113.05 | 150.20 | 127.30 |
| Textural class | Sandy loam | Sandy loam | Sandy loam | Sandy loam |

abc - Mean values with the same letter(s) along same row are not statistically different at ($p \leq 0.05$)

### 3.1 Heights and Mean Heights values of Cassava Plants for the first 90 days

Significant effects ($p < 0.05$) of minimum tillage and maximum tillage were observed ($p = 0.027$ and 0.014) on cassava yield, while no significant effect ($p > 0.05$) of zero tillage was observed ($p = 0.137$) on cassava yield at harvest. The results of the average heights and the resulted mean values were respectively given in Table 2 at 10, 20, 30, 40, 50, 60, 70, 80 and 90 days when the heights' growths were stabilized. Table 2 shows statistical differences among the mean values of the heights of cassava plants. Heights of shoot for maximum tillage were higher throughout the period. The mean values show significance between 10 and 50 days and at 80 days especially at maximum tillage.

Table 2. Mean values of heights of cassava shoots in the first three months

| Days | Heights of cassava shoots in plots (cm) | | |
|---|---|---|---|
| | Zero tillage (0) | Minimum (1) | Maximum (2) |
| 10 | $5.28 \pm 50.02^{c}$ | $5.87 \pm 20.00^{b}$ | $6.12 \pm 40.32^{a}$ |
| 20 | $18.24 \pm 40.080^{c}$ | $19.03 \pm 40.6^{b}$ | $21.20 \pm 50.22^{a}$ |
| 30 | $27.40 \pm 20.01^{c}$ | $29.82 \pm 51.14^{b}$ | $30.02 \pm 42.2^{a}$ |
| 40 | $37.84 \pm 20.24^{ab}$ | $37.90 \pm 39.17^{b}$ | $40.63 \pm 31.4^{a}$ |
| 50 | $54.40 \pm 30.3^{c}$ | $71.10 \pm 40.20^{b}$ | $71.22 \pm 36.8^{a}$ |
| 60 | $90.00 \pm 31.10^{b}$ | $89.28 \pm 40.21^{c}$ | $90.52 \pm 38.27^{a}$ |
| 70 | $111.20 \pm 22.32^{c}$ | $112.00 \pm 50.22^{b}$ | $112.4 \pm 40.22^{a}$ |
| 80 | $129.40 \pm 21.03^{c}$ | $130.15 \pm 38.13^{b}$ | $131.90 \pm 50.00^{a}$ |
| 90 | $150.10 \pm 18.55^{c}$ | $149.00 \pm 41.22^{b}$ | $150.02 \pm 48.22^{a}$ |

$^{abc}$Mean values with the same superscript(s) along same row are not statistically different at ($p \leq 0.05$)

At early stage on growth, the internodes were smaller, whereas, internodes were longer at higher growth period in their heights with average 13.0 cm in zero tillage between 10 days and 20 days compare to 14.6 cm or 14.4 cm at between 40 and 50 days, these account for higher heights, the same goes for minimum and maximum tillage. The results of the heights of the shoot at 10 days interval showed the increasing values for maximum tillage than other two methods of tillage. Also, there were increase lengths and widths of the laminas for the maximum tillage than their respective zero tillage and minimum tillage. There were statistical differences among the mean values along the same row for each classification, Table 2.

### 3.2 Leaf Area Index (LAI)

LAI average values were close as the graph shows, but maximum tillage treatment slightly had high values than others as shown in the graphical representation, Fig 2. Leaf Area Index (LAI) increases as the number and size of individual leaves increase, reaching a peak at 210 days after planting. It must be noted that the LAI has increased values because of the canopy formed by the shoots (69, 70 and 72 $m^2$ for zero, minimum and maximum tillage respectively). Regression equations found from Figure 2, Equations 2 – 4 show that there were stronger relationships between methods of tillage and cassava leaves' growth as shown by their higher $R^2$ values ($R^2$ = 0.999, 0.998, 0.996). (In these equations, independent variable $Y$ = methods of tillage and $X$ = LAI average values of the leafiness of the cassava).

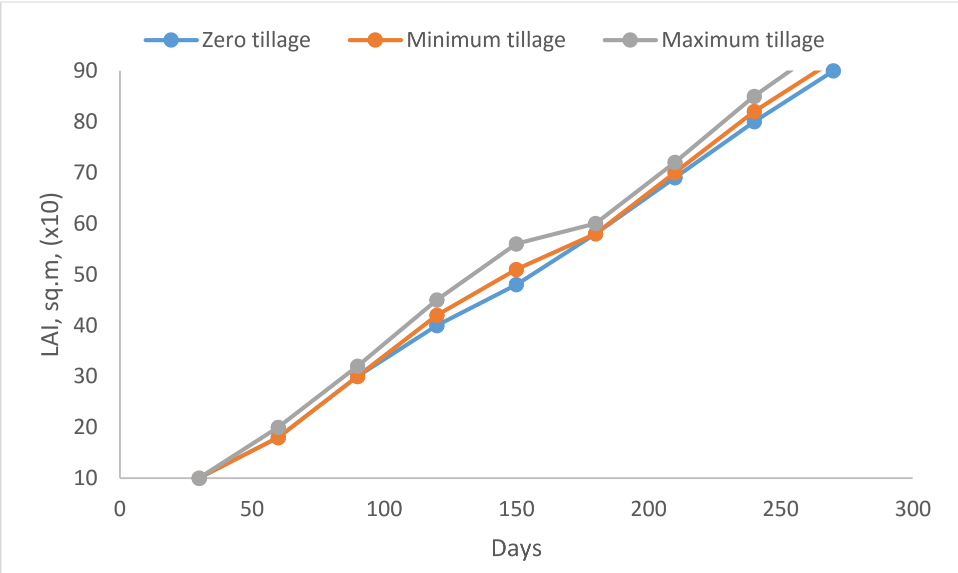


Figure 2.Average values of Leaf Area Index, LAI; is a dimensionless parameter

For zero tillage,

$$Y_{zero} = -0.0078X^3 + 0.0002X^2 + 0.3401X + 0.5397 \quad R^2 = 0.999 \text{ Equation 2}$$

For minimum tillage,

$$Y_{minimum} = -0.06X^3 + 0.0005X^2 + 0.3931X + 2.29 \quad R^2 = 0.998 \quad \text{Equation 3}$$

For maximum tillage,

$$Y_{maximum} = -0.006X^3 + 0.0014X^2 + 0.5312X - 5.84 \quad R^2 = 0.996 \quad \text{Equation 4}$$

Maximum tillage method gave more leafiness and shoots development and was the fastest growing. Leafiness of shoots leads to high photosynthetic rates of plants; and eventual slightly higher LAI values. This led to significant number of tonnes (greater than 4 tonnes in all cases in the yield of cassava roots produced. Thus, at the time of formation of canopy, there was much initiation of canopy to intercept radiation which provided more water and nutrients at the period for rapid growth. In maximum tillage, soil undergone much needed pulverization and thereby with virtually all soil clods broken, the crop roots were able to respire and then were well developed and good soil aeration were ensured. It is obvious that maximum tillage made crops to do well because it allows the soil to be well aerated from the time of planting of cassava stems to the time of its harvesting. High LAI values could also be that maximum tillage obviously allows easy tillage of the soil around the mature roots (that may be ready for harvesting) thereby leading to easy uprooting of these roots. This easy tillage may equally summarizes the high yield recorded for maximum tillage which is 5.2% increase of maximum tillage over the zero tillage.

The extents of performance of different plots on the plants were evident on their heights in the first three months and in the growth rate and up to nine months, on the 0A, 0B and 0C replicates/plots. Cassava plant height values for zero tillage were lower than other tillage methods, this was because cassava plants were not quickly able to form canopy as in others, thereby, decreasing the rate of evaporation of water beneath the soil, around the cassava roots, this could have helped in the roots development.

### 3.3 Growth, Development and Average Yield of Cassava Roots

The mean values of area for the longest and widest leaves are recorded in Table 3. There were statistical differences ($p<0.05$) among the values recorded for each of the mean areas for the longest and widest leaves. Maximum tillage system had the highest areas for the leaves at 90 days and zero tillage had less. The graph of the growth rate in ninety days is shown in Fig 3.

Table 3. Mean values of area of cassava leaves in the first three months

| Days | Classifications of leaves as to longest or widest | | | | | |
|---|---|---|---|---|---|---|
| | For the longest leaves, $cm^2$ | | | For the widest leaves, $cm^2$ | | |
| | 0 | 1 | 2 | 0 | 1 | 2 |
| 10 | 7.2 ± 70.01[c] | 8.0 ± 41.02[a] | 7.9 ± 22.1[b] | 2.2 ± 40.4[c] | 2.1 ± 38.1[b] | 2.2 ± 53.01[a] |
| 20 | 10.0 ± 50.02[c] | 9.8 ± 32.42[b] | 10.4 ± 31.6[c] | 4.1 ± 50.12[b] | 4.4 ± 22.21[a] | 4.0 ± 32.2[c] |
| 30 | 11.8 ± 20.4[b] | 11.1 ± 10.03[c] | 11.9 ± 21.41[a] | 4.4 ± 11.0[a] | 4.3 ± 18.8[c] | 4.3 ± 22.1[b] |
| 40 | 11.9 ± 24.3[c] | 12.0 ± 32.6[b] | 12.4 ± 12.08[a] | 4.5 ± 32.2[b] | 4.5 ± 32.0[b] | 4.5 ± 40.0[a] |
| 50 | 12.8 ± 70.2[b] | 12.6 ± 42.3[c] | 12.9 ± 30.04[a] | 4.8 ± 40.5[b] | 4.8 ± 10.02[b] | 4.7 ± 34.3[a] |
| 60 | 14.2 ± 40.0[c] | 14.5 ± 32.6[b] | 14.7 ± 44.11[a] | 5.0 ± 10.0[b] | 5.2 ± 30.0[a] | 5.0 ± 20.2[b] |
| 70 | 15.4 ± 30.24[b] | 15.3 ± 40.05[c] | 15.7 ± 160.4[a] | 5.6 ± 28.1[b] | 5.6 ± 30.3[b] | 5.8 ± 45.0[a] |
| 80 | 16.7 ± 82.06[c] | 16.7 ± 120.7[b] | 16.8 ± 110.3[a] | 6.3 ± 40.0[c] | 6.4 ± 60.0[b] | 6.6 ± 40.1[a] |
| 90 | 18.1 ± 112.7[c] | 18.4 ± 80.3[b] | 18.8 ± 120.02[a] | 6.7 ± 90.1[c] | 6.7 ± 85.02[b] | 6.8 ± 100.1[a] |

[abc]Mean values with the same superscripts along the same row for the same classification are not significantly different at 5% level.

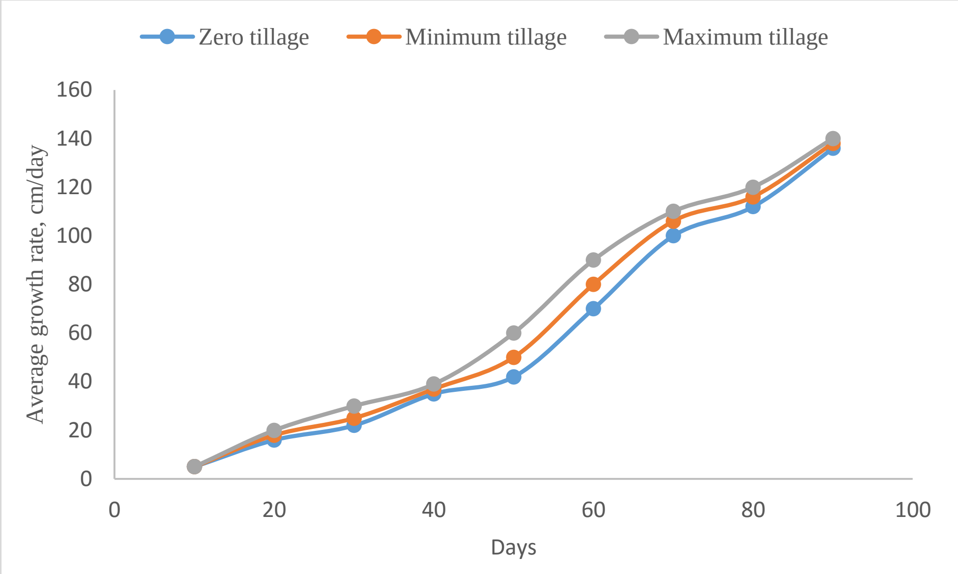


Figure 3. Average growth rate of cassava in 90 days

Maximum tillage has the highest average growth rate with 140 cm/day highest at the 90 days. Regression equations 5 – 7 for the treatments (independent variable $Y$, that is, methods of tillage) and $Z$ (average growth rate values for cassava) show that there were stronger relationships between method of tillage and average growth rate as shown by their higher $R^2$ values ($R^2$ = 0.989, 0.991 and 0.992 respectively for zero, minimum and maximum tillage methods Figure 3.

$$Y_{zero} = -0.0001 Z^3 + 0.035 Z^2 - 0.562 Z + 10.14; \quad R^2 = 0.989 \qquad \text{Equation 5}$$

$$Y_{minimum} = -0.0002 Z^3 + 0.0431 Z^2 - 0.166 Z + 10.80; \quad R^2 = 0.991 \qquad \text{Equation 6}$$

$$Y_{maximum} = -0.0003 Z^3 + 0.0447 Z^2 - 0.0463 Z + 8.262; \quad R^2 = 0.992 \qquad \text{Equation 7}$$

The harvesting was done after nine months of planting, it was found out that plots 2A, 2B and 2C replicates gave the highest yield in tonnes per hectare of 11.33 t/ha, 10.77 t/ha and 11.05 t/ha respectively or 2.5% higher in 2A than 2C. The zero tillage plots 0A and 0B gave the lowest yield of 10.2 t/ha, 10.3 t/ha and 10.77 t/ha respectively. These were not the same as the range of yield of cassava of 10 t/ha to 11 t/ha found in the country when all necessary requirements are available (Ikuemonisan *et al*, 2020; FAOSTAT, 2019). So also, from the yield received, the maximum tillage, though it was more capital intensive than other two methods of tillage, it was more profitable than others. Also, it have ease of harvesting as the roots' uprooting were easy because the soil was well aerated than the soil in the minimum and zero tillage plots. This was calculated from man-hours during the uprooting as same conditions of soil wetness (rain fell during the period to make soil moisture almost the same), same soil homogeneity, same equipment provided. Same men ((3 men) spent 3 hours for an acre in maximum tillage whereas four hours was sent per acre in the minimum tillage plot and 6 hours per acre in the zero tillage plot when all other conditions were the same (their fatigue was taken care of with in between days rest).

### 3.4 Quality Test on Cassava Roots

Significant effects ($p < 0.05$) of minimum tillage and maximum tillage methods were observed (respectively p = 0.041 and 0.008) on the quality of cassava paste. The results of the mean values of the proximate analysis at the end of nine months when the roots were harvested are given in Table 4 with the results showing statistical differences ($p < 0.05$) among the values for crude protein, moisture, dry matter content, ether extract and ash content of the paste. This means that since the soil properties were not significant on the cassava tubers, then it must be the system of the management used, that is, the tillage method that must have been the reason for this significance. Between replicates, there were small range as $\pm$0.04, (difference between 0.77 and 0.81 for 1A and 1B respectively), for ether extract and $\pm$0.40, (difference between 19.60 and 19.20 for 1A and 1B respectively) for crude fibre for the minimum tillage. This may be surmised to show that the replicates have close values. The standard deviation shown for each value in Table 4 revealed the closeness of the values although with statistical differences among them.

Table 4. Mean values from the proximate analysis of the cassava paste

| Treatment replicates | Mean proximate values, % | | | | |
|---|---|---|---|---|---|
| | Protein | Ether Extract | Moisture content | Ash | Crude fibre |
| 0A | $1.54 \pm 0.02^{ac}$ | $0.31 \pm 0.04^{bca}$ | $76.48 \pm 0.02^{a}$ | $3.49 \pm 0.00^{b}$ | $18.18 \pm 0.03^{abc}$ |
| 0B | $1.50 \pm 0.04^{bcd}$ | $0.28 \pm 0.00^{ad}$ | $76.48 \pm 0.03^{a}$ | $3.54 \pm 0.03^{ab}$ | $19.60 \pm 0.01^{b}$ |
| 0C | $1.52 \pm 0.00^{abd}$ | $0.29 \pm 0.02^{ad}$ | $76.44 \pm 0.02^{b}$ | $3.56 \pm 0.00^{a}$ | $19.59 \pm 0.02^{c}$ |
| 1A | $1.57 \pm 0.00^{c}$ | $0.77 \pm 0.04^{c}$ | $76.20 \pm 0.0^{ab}$ | $2.86 \pm 0.04^{c}$ | $19.60 \pm 0.0^{bd}$ |
| 1B | $1.60 \pm 0.01^{d}$ | $0.81 \pm 0.00^{bc}$ | $75.60 \pm 0.00^{c}$ | $2.79 \pm 0.02^{bc}$ | $19.20 \pm 0.01^{ca}$ |
| 1C | $1.59 \pm 0.03^{abc}$ | $0.88 \pm 0.01^{d}$ | $76.48 \pm 0.00^{ac}$ | $2.54 \pm 0.01^{d}$ | $18.51 \pm 0.02^{ac}$ |
| 2A | $1.65 \pm 0.00^{bc}$ | $0.88 \pm 0.02^{bcd}$ | $75.20 \pm 0.00^{bc}$ | $2.77 \pm 0.02^{ca}$ | $19.50 \pm 0.02^{abc}$ |
| 2B | $1.68 \pm 0.01^{ab}$ | $0.94 \pm 0.04^{ab}$ | $76.80 \pm 0.02^{d}$ | $2.10 \pm 0.01^{ad}$ | $19.48 \pm 0.01^{ab}$ |
| 2C | $1.70 \pm 0.02^{a}$ | $0.98 \pm 0.01^{a**}$ | $74.40 \pm 0.00^{e}$ | $2.54 \pm 0.00^{bd}$ | $20.38 \pm 0.00^{c}$ |

$^{abc}$Mean values with the same superscripts along the same column are not significantly different at 5% level.

## 3.5 Plant Heights and Growth Rate Mean Analysis

The resulted considerable nodes' distance observed in the shoot depicted that cassava shoots developed new branches almost every week in all the treatments. This was a result of some factors like common genotypes, similar levels of soil fertilities and same climatic conditions. The increase in node distance from each other gave rise to the heights recorded and since maximum tillage had more height than others, it is only reasonable to say that it has highest development than others within the same period of time.

## 3.6 Quality Test on Cassava Roots

The proximate composition of the different cassava roots from each method of tillage got from proximate analysis shows statistical differences among the mean values implying that the different tillage operations have significant influence on the proximate compositions of the cassava roots. There are obviously some capabilities of these cassava roots to reach where nutrients are located in the soil for absorption to carry their out photosynthetic roles and thereby resulting in eventual significant levels of roots development which also affect the roots' contents giving rise to statistical differences in the proximate values recoded. Thus, the quality of the cassava roots was affected by different tillage methods and was better in the maximum tillage than other methods of tillage. Therefore, maximum tillage if practiced will help to increase the nutrient contents in the cassava tubers in the area where the experiment was carried out, implying that more nutrients will be delivered to the people, thus solving the sustainable development goals SDG of the United Nations (UN) number 1, poverty eradication, 2, zero hunger and 3 good health and well-being of Aba-Odan and the environs There may be other possibilities like the nature of soil where the cassava was grown, the prompt removal of weeds from the plot at due time that curb any external agents' invasion and the seasons of the year that might have caused differences in paste's quality differences.

## 4. CONCLUSION

Tillage practices significantly affect the height, LAI, yields and the proximate quality of the cassava roots. The maximum tillage cassava plot was better in term of plant heights reached, length of leaves and proximate quality than minimum or zero tillage and resulted in more nutrients in the cassava roots in the maximum tillage. If maximum tillage is practiced by the farmers in the study area, sustainable development in term of good health and wellbeing and zero hunger will be achieved. There will also be more profit margin which will increase their welfare and their standard of living. Maximum tillage, because of its higher yield got in the research, may be recommended for soil and cassava tuber production and the higher productivity of maximum tillage plot over others.

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# FIELD SOIL DETERMINATION ASSESSMENT FOR PARTICLE SIZE DISTRIBUTION

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## ABSTRACT
*Sieving method of particle size distribution is practically most common in laboratories but most times, silt and clay are always lumped together and not distinctly separable. Besides, clogging of soil would definitely result in errors in the finest soil particles of soil composition therefore the method is better used for more coarse sizes rather than finer ones. Soil particles distribution is largely dependent on its solubility (suspension) in appropriate solution (suitably chemical basic). Distinct particles that are made up of soil were found to be dependent of settlement time, colloidal forms and their visual clarity in solution. This research work was conducted at University of Ilorin main campus, Ilorin, Nigeria. The institution lies on the latitude $8^0$ $30^1$ N and longitude $4^0$ $35^1$ E at an elevation of about 340 m above the sea level. Both sieving and sedimentation hydrometer methodology were adopted for the site soil assessment. The experiment was conducted using Latin Square Design of four samples with four replications. Results from sieving indicated that 96%, 95%, 96% and 96% of soil samples are finer than 2 mm with approximately 10%, 9%, 9 % and 8% finer than 0.075 mm for experimental soil sample I, sample II, sample III and sample IV respectively. Sedimentation hydrometer assessment confirmed that the field soil contains 28.6% clay-silt, 13.22% clay, 71.23% sand and 15.52% silt on an average. Textural class of the experimental soil was found to be sandy loam. Analysis of the soil sample inferred 0.98, 0.96 and 0.2 for $R^2$, adjusted $R^2$ and Mean Square Error (MSE) respectively.*

***Keywords**: Particle size, Sieving, Sedimentation Hydrometer.*

## 1. INTRODUCTION
Physical and mechanical properties of any soil cannot be completely determined without the soil particle size distribution (Gorasczko and Topolinski, 2020). Sieving and sedimentation hydrometer methods are popular methods of determining the particle size distribution in soil. Buretta et al. (2014) used pipette method as a control while comparing modifications of Bouyoucus method (hydrometer) to access soil texture class, erodibility coefficient (k), permanent wilting point (PWP) and field capacity (FC). It was found that both hydrometer and pipette methods were well correlated. Poullet et al. (2019), Malewski (2017) and Wen (2002) simulated sieve equipment and thereby confirmed that particle distribution does not represent the true grain distribution of soil sample. It was discovered that sieve analysis reliability is largely dependent of laboratory techniques and standard procedures involved. A combination of sieve analysis and sedimentation hydrometer was used to affirm that particle size distribution determine to a large extent the soil type of a region (Adeniran and Awoniyi, 2017). It has been discovered that hydrometer method accuracy is

slightly less in sand compare to pipette method nonetheless, it is better in determining texture of soils (Elfaki et al., 2016). Drainage catchment radar discharge has been found to be dependent of intrinsic properties of the catchment soil particle distribution (Awoniyi et al., 2020).

Description of the grain size distribution of soil particles according to their texture (particle size, shape, and gradation) is summarized in Table 1 (Michael, 2008). Further classification of soil into agricultural soils such as clay loam, sandy loam, silt loam, etc., could be obtained using textural triangle after the determination of the soil particle sizes (Pannel, 2002). This research aimed at assessing and analyzing both sedimentation hydrometer and sieve method in determining particle size distribution in agricultural soil and thereby determine the class of agricultural soil present in the experimental field.

Table 1. Soil Class according to their Particle Size

| S/No | Soil | Size (mm) |
|---|---|---|
| 1 | Gravel | < 2 |
| 2 | Sand | 0.1 – 2 |
| 3 | Silt | 0.01 – 0.1 |
| 4 | Clay | < 0.01 |

Source: Michael (2008)

## 2. METHODOLOGY

This research experimental site was located at University of Ilorin main campus, Ilorin, Kwara State, Nigeria. The institution is situated at Ilorin South Local Government Area, Ilorin, Nigeria which lies on the latitude $8^0$ $30^1$ N and longitude $4^0$ $35^1$ E at an elevation of about 340 m above the sea level (Ejieji and Adeniran, 2009). Ilorin, the capital city of Kwara State is in Southern Guinea Savannah Ecological Zone of Nigeria with an annual rainfall of about 1300 mm. Samples were taken from four strategic places marking the out sketch of the university premises. This made the soil of four samples with each sample having four blocks where replicates were made. Experimental planning is indicated in Tables 2 and 3.

Table 2. Initial Experimental Planning

| **Block** | **Observation (g)** | | | |
|---|---|---|---|---|
| $X_1$ | $Y_{a1}$ | $Y_{a2}$ | $Y_{a3}$ | $Y_{a4}$ |
| $X_2$ | $Y_{b1}$ | $Y_{b2}$ | $Y_{b3}$ | $Y_{b4}$ |
| $X_3$ | $Y_{c1}$ | $Y_{c2}$ | $Y_{c3}$ | $Y_{c4}$ |
| $X_4$ | $Y_{d1}$ | $Y_{d2}$ | $Y_{d3}$ | $Y_{d4}$ |

Table 3. Final Experimental Planning

| **Sample (Soil)** | **Observation (g)** | | | |
|---|---|---|---|---|
| 1 | $X_1Y_{a1}$ | $X_1Y_{a2}$ | $X_1Y_{a3}$ | $X_1Y_{a4}$ |
| 2 | $X_2Y_{b1}$ | $X_2Y_{b2}$ | $X_2Y_{b3}$ | $X_2Y_{b4}$ |
| 3 | $X_3Y_{c1}$ | $X_3Y_{c2}$ | $X_3Y_{c3}$ | $X_3Y_{c4}$ |
| 4 | $X_4Y_{d1}$ | $X_4Y_{d2}$ | $X_4Y_{d3}$ | $X_4Y_{d4}$ |

Sieving and sedimentation hydrometer experiments were carried out for the field soil mainly to determine the experimental soil type. At the start of the hydrometer sedimentation experiment, all particles were in suspension while after 40 seconds, only clay and silt were in suspension while clay particles only were in suspension after 2 hours and above (See plate 1). The various percentages particles that made up the experimental soil was determined using equation (1) to equation (4) (SFU, 2020).

$$\text{Percentage (Silt + Clay)} = \text{40 seconds corrected hydrometer reading} \times \frac{100}{\text{Wt of Sample}} \quad (1)$$

$$\text{Percentage Clay} = \text{2 hrs corrected hydrometer reading} \times \frac{100}{\text{Wt of Sample}} \quad (2)$$

$$\text{Percentage Sand} = 100 - \text{Percentage (Silt + Clay)} \quad (3)$$

$$\text{Percentage Silt} = \text{Percentage (Silt + Clay)} - \text{Percentage Clay} \quad (4)$$

Corrected Hydrometer Reading:

1. For every 1 $^0$C above 20 $^0$C add 0.36 g/l
2. For every 1 $^0$C below 20 $^0$C subtract 0.36 g/l

The room temperature during the sedimentation hydrometer experiment was 29 $^0$C.

Plate 1. Sedimentation Hydrometer Experiment for Soil Particle Size Determination

## 2.1 Analysis and Modeling

Regression Calculator statistical software was employed for regression analysis of the experimental data. It does not require any programming or some sort of command. Couple of options was adopted for data input. This include making data on screen, restoration of software from that of the last session and generating a random data set. Hence, OLS (Ordinary least squares) estimates for regression slope parameters, t-statistics for each slope parameter and its p-value, analysis of variance, other model statistics such as F, $R^2$, and the like, critical values for t-distribution and F-distribution were obtained.

## 3. RESULTS AND DISCUSSION

Results from obtained from sieving is given in Table 4, Table 5, Table 6 and Table 7 for soil samples I, II, III and IV respectively. While sedimentation hydrometer readings as obtained from the experiment is shown in Table 8, Table 9 Table 10 and Table 11 for soil samples I, II, III and IV respectively. Meanwhile, Table 12 shows the sample average for sedimentation hydrometer reading. Regression analysis conducted for the experiment is given in Table 13. Figure 1 – 5 shows the graphical analyses for the sieve analyses. Adopting a polynomial function of order 2, Sample I, II, III, IV and sample mean gave $R^2$ of 0.986, 0.985, 0.987, 0.981 and 0.985, respectively.

Table 4. Sieve analysis of the experimental field (Sample I)

| Sieve Size (mm) | weight retain (g) | % retain | % passing |
|---|---|---|---|
| 2 | 91 | 4.12 | 95.88 |
| 1.7 | 72 | 3.26 | 92.61 |
| 1.4 | 86 | 3.90 | 88.72 |
| 0.3 | 1011 | 45.81 | 42.91 |
| 0.15 | 509 | 23.06 | 19.85 |
| 0.075 | 229 | 10.38 | 9.47 |
| < 0.075 | 209 | 9.47 | 0.00 |

Table 5. Sieve analysis of the experimental field (Sample II)

| Sieve Size (mm) | weight retain (g) | % retain | % passing |
|---|---|---|---|
| 2 | 112 | 4.98 | 95.02 |
| 1.7 | 62 | 2.76 | 92.26 |
| 1.4 | 78 | 3.47 | 88.79 |
| 0.3 | 1020 | 45.39 | 43.39 |
| 0.15 | 503 | 22.39 | 21.01 |
| 0.075 | 270 | 12.02 | 8.99 |
| < 0.075 | 202 | 8.99 | 0.00 |

Table 6. Sieve analysis of the experimental field (Sample III)

| Sieve Size (mm) | weight retain (g) | % retain | % passing |
|---|---|---|---|
| 2 | 101 | 4.22 | 95.78 |
| 1.7 | 49 | 2.05 | 93.74 |
| 1.4 | 87 | 3.63 | 90.10 |
| 0.3 | 1120 | 46.76 | 43.34 |
| 0.15 | 603 | 25.18 | 18.16 |
| 0.075 | 230 | 9.60 | 8.56 |
| < 0.075 | 205 | 8.56 | 0.00 |

Table 7. Sieve analysis of the experimental field (Sample IV)

| Sieve Size (mm) | weight retain (g) | % retain | % passing |
|---|---|---|---|
| 2 | 98 | 4.32 | 95.68 |
| 1.7 | 58 | 2.55 | 93.13 |
| 1.4 | 87 | 3.83 | 89.30 |
| 0.3 | 998 | 43.95 | 45.35 |
| 0.15 | 540 | 23.78 | 21.58 |
| 0.075 | 301 | 13.25 | 8.32 |
| < 0.075 | 189 | 8.32 | 0.00 |

Table 8. Sedimentation Hydrometer Particle Size Distribution (Sample I)

| **Block** | **Hydrometer Readings after 40 s (g/l)** | **Hydrometer Readings after 2 hrs (g/l)** | **Silt + Clay (%)** | **Clay (%)** | **Sand (%)** | **Silt (%)** |
|---|---|---|---|---|---|---|
| 1 | 15 | 5 | 33.24 | 13.24 | 66.76 | 20.00 |
| 2 | 13 | 5 | 29.24 | 13.24 | 70.76 | 16.00 |
| 3 | 13 | 5 | 29.24 | 13.24 | 70.76 | 16.00 |
| 4 | 10 | 5 | 23.24 | 13.24 | 76.76 | 10.24 |
| **Mean** | | | **28.24** | **13.24** | **71.26** | **15.56** |

Table 9. Sedimentation Hydrometer Particle Size Distribution (Sample II)

| **Block** | **Hydrometer Readings after 40 s (g/l)** | **Hydrometer Readings after 2 hrs (g/l)** | **Silt + Clay (%)** | **Clay (%)** | **Sand (%)** | **Silt (%)** |
|---|---|---|---|---|---|---|
| 1 | 14 | 5 | 31.05 | 13.27 | 68.95 | 17.78 |
| 2 | 13 | 5 | 30.34 | 12.94 | 69.66 | 17.40 |
| 3 | 15 | 5 | 29.16 | 13.51 | 70.84 | 15.65 |
| 4 | 10 | 5 | 25.54 | 13.26 | 74.46 | 12.28 |
| **Mean** | | | **29.02** | **13.25** | **70.98** | **15.78** |

Table 10. Sedimentation Hydrometer Particle Size Distribution (Sample III)

| **Block** | **Hydrometer Readings after 40 s (g/l)** | **Hydrometer Readings after 2 hrs (g/l)** | **Silt + Clay (%)** | **Clay (%)** | **Sand (%)** | **Silt (%)** |
|---|---|---|---|---|---|---|
| 1 | 15 | 5 | 28.26 | 13.24 | 71.74 | 15.02 |
| 2 | 12 | 5 | 30.56 | 13.35 | 69.44 | 17.21 |
| 3 | 15 | 5 | 29.64 | 13.31 | 70.36 | 16.33 |
| 4 | 12 | 5 | 26.04 | 13.08 | 73.96 | 12.96 |
| **Mean** | | | **28.63** | **13.25** | **71.38** | **15.38** |

Table 11. Sedimentation Hydrometer Particle Size Distribution (Sample IV)

| **Block** | **Hydrometer Readings after 40 s (g/l)** | **Hydrometer Readings after 2 hrs (g/l)** | **Silt + Clay (%)** | **Clay (%)** | **Sand (%)** | **Silt (%)** |
|---|---|---|---|---|---|---|
| 1 | 15 | 5 | 31.01 | 12.98 | 69.00 | 18.03 |
| 2 | 13 | 5 | 28.65 | 13.29 | 71.35 | 15.36 |
| 3 | 13 | 5 | 26.24 | 13.22 | 72.76 | 13.02 |
| 4 | 12 | 5 | 28.04 | 12.99 | 71.96 | 15.05 |
| **Mean** | | | **28.49** | **13.12** | **71.28** | **15.37** |

Table 12. Sedimentation Hydrometer Particle Size Distribution (Sample Mean)

| **Sample** | **Silt + Clay (%)** | **Clay (%)** | **Sand (%)** | **Silt (%)** |
|---|---|---|---|---|
| 1 | 28.24 | 13.24 | 71.26 | 15.56 |
| 2 | 29.02 | 13.25 | 70.98 | 15.78 |
| 3 | 28.63 | 13.25 | 71.38 | 15.38 |
| 4 | 28.49 | 13.12 | 71.28 | 15.37 |
| **Mean** | 28.60 | 13.22 | 71.23 | 15.52 |

Table 13. Regression Analysis

| | | | | |
|---|---|---|---|---|
| β Estimates | | | | |
| | | | | |
| Variable | β estimate | SE | t-value | Pr> \|t\| |
| X0 | -1.72 | 0.33 | -5.19 | 0 |
| X1 | 0.05 | 0 | 11.63 | 0 |
| | | | | |
| ANOVA | | | | |
| Source | DF | SS | MS | F |
| Model | 1 | 5.2 | 5.2 | 135.37 |
| Error | 14 | 0.54 | 0.04 | |
| Total | 15 | 5.74 | | |
| | | | | |
| Other Stats | | | | |
| F | 135.37 | | | |
| p-value(F) | 0 | | | |
| R-SQR | 0.98 | | | |
| Adj. R-SQR | 0.96 | | | |
| root MSE | 0.2 | | | |

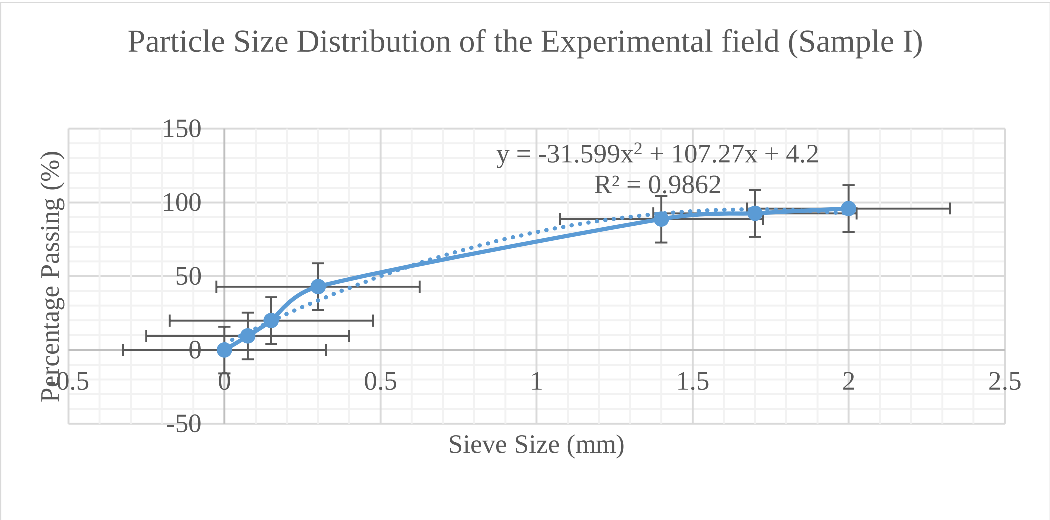



Figure 1. Particle Size Distribution of the Experimental field (Sample I)

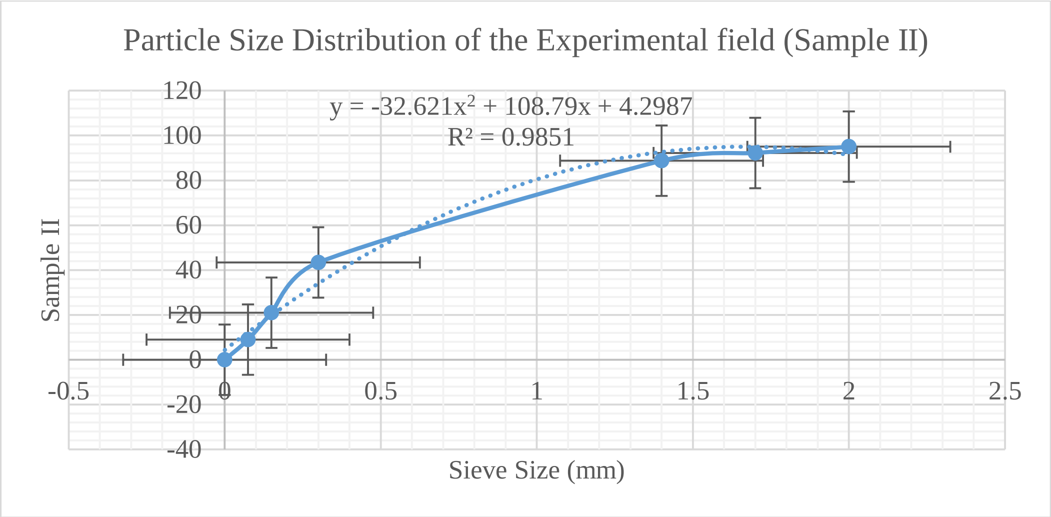



Figure 2. Particle Size Distribution of the Experimental field (Sample II)

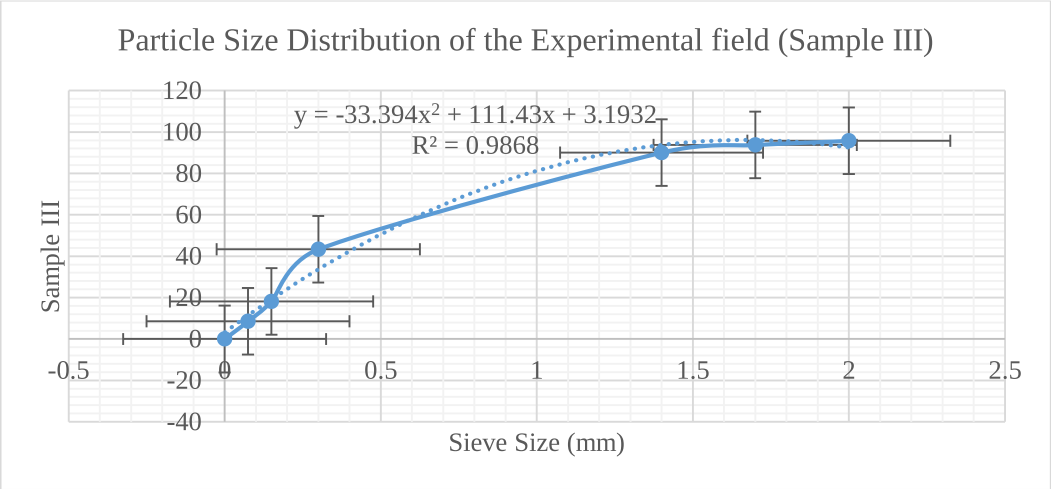



Figure 3. Particle Size Distribution of the Experimental field (Sample III)

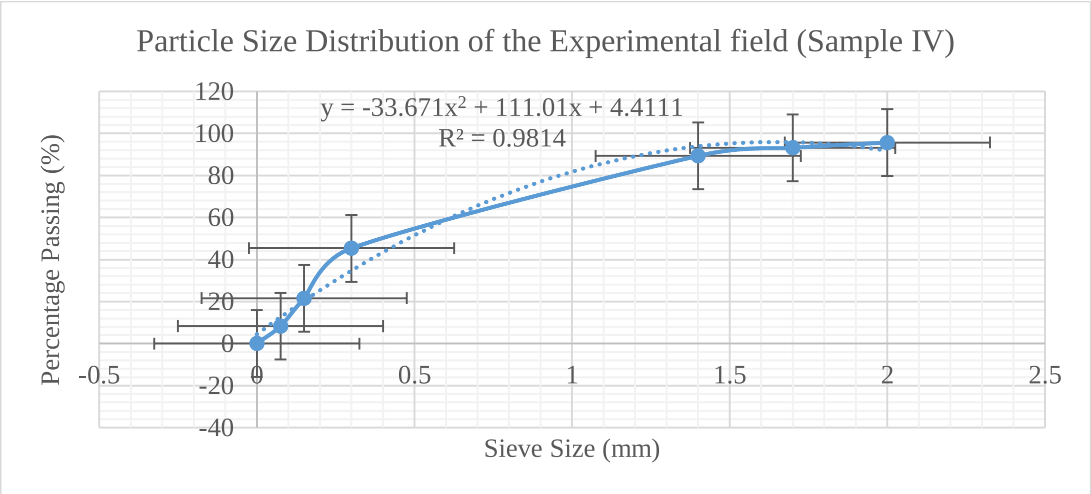



Figure 4. Particle Size Distribution of the Experimental field (Sample IV)

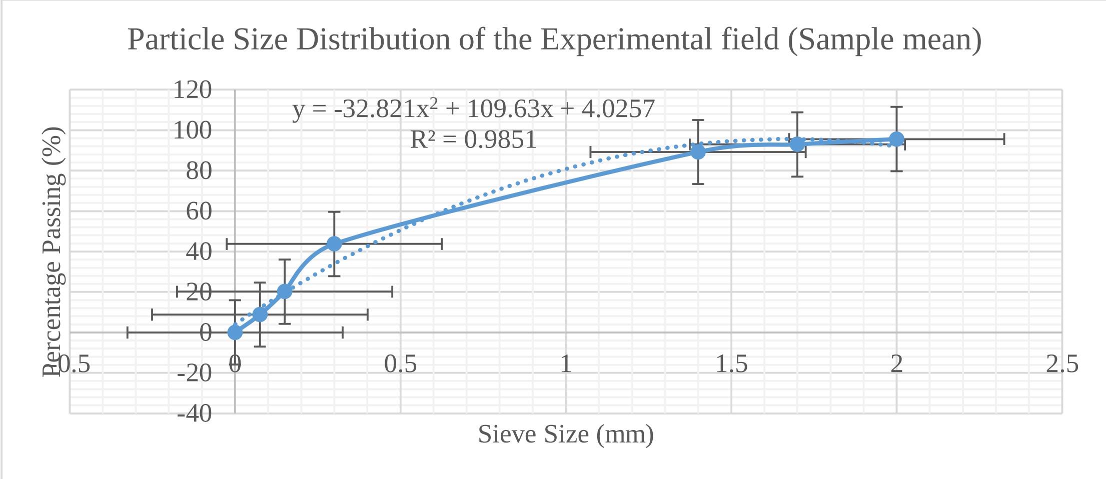
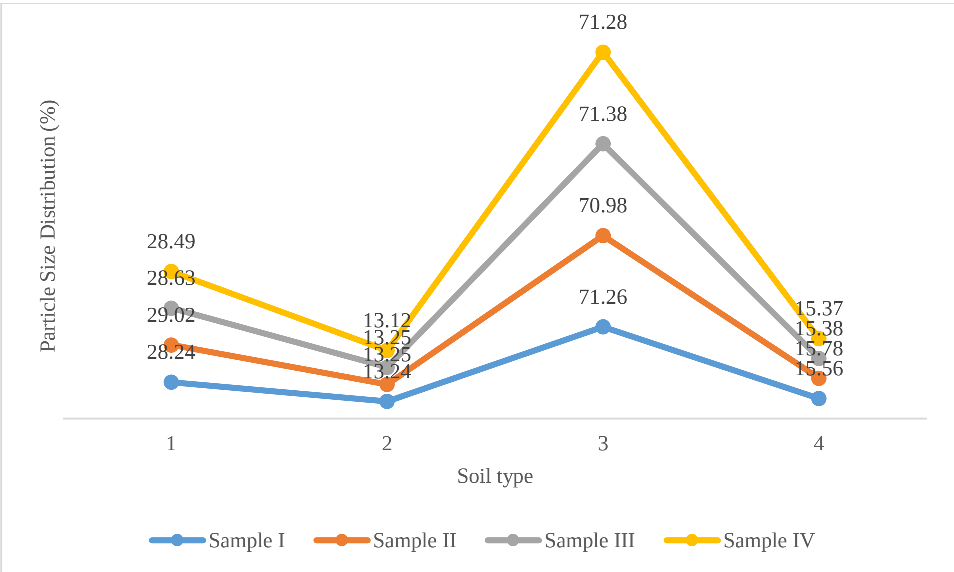



Figure 5. Particle Size Distribution of the Experimental field (Sample mean)

## 3.1 Result Validation

Sedimentation hydrometer observation means were used to validate the results of the experiment through graphical analysis of individual sample mean at every distinct soil composition (clay, silt and sand) (see Figure 6). Block mean for each sample were correlated with overall sample mean as obtained in Figure 7, 8, 9 and 10, respectively. Sample blocks means were adequately correlated with sample mean with $p < 0.05$ and $R^2$ of 0.99, 0.99, 1.00 and 1.00 for Sample I, Sample II, Sample III and Sample IV respectively. This showed that there is no significant difference between the soil samples. The experimental field soil was established to be sandy-loam using textural triangle (see Figure 11).




LEGEND

| | |
|---|---|
| I | Silt + Clay |
| II | Clay |
| III | Sand |
| IV | Silt |

Figure 6. Graphical Analysis of Sample Block mean

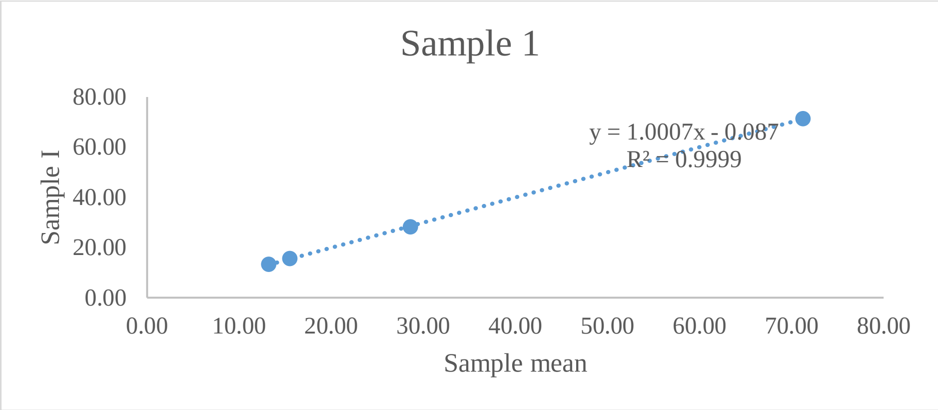



Figure 7. Sample I (Block mean vs Sample mean

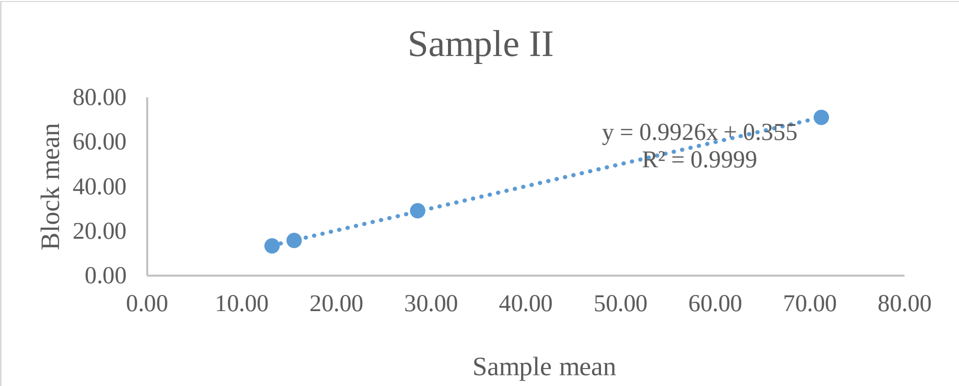



Figure 8. Sample II (Block mean vs Sample mean)

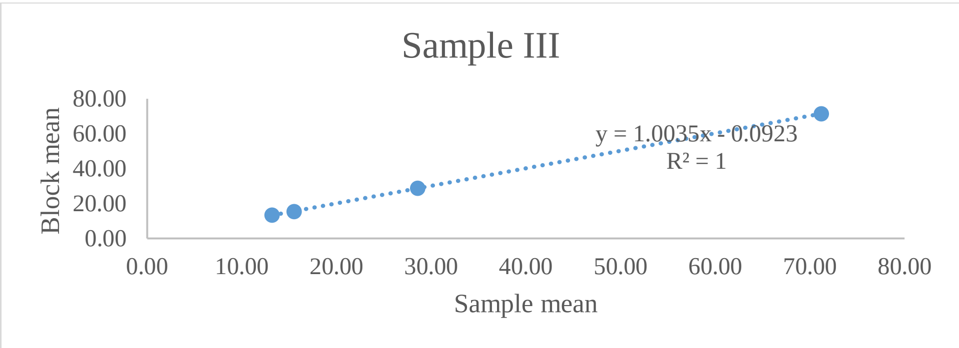



Figure 9. Sample III (Block mean vs Sample mean)

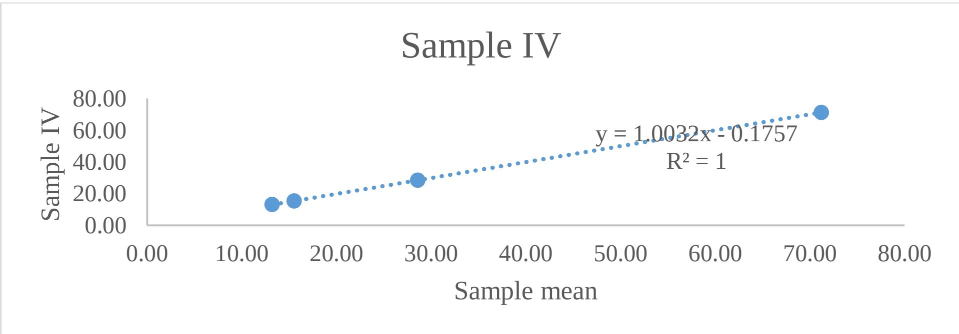



Figure 10. Sample IV (Block mean vs Sample mean)

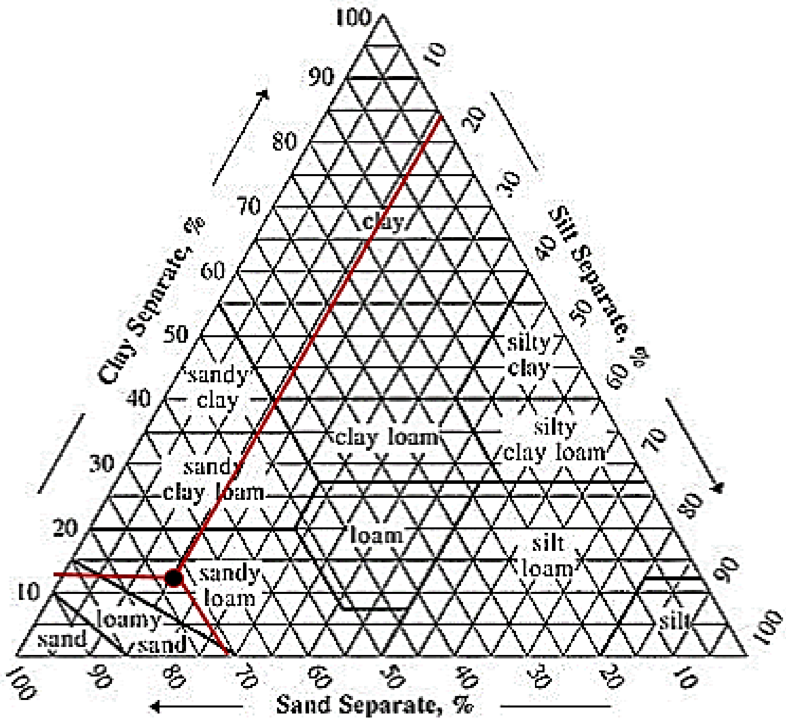



Figure 11. Textural Triangle Showing Sandy loam Soil Analyzed from Particle Size Distribution

## 4. CONCLUSION

Sieving method of particle size distribution is less technical but most time not adequately enough to determining the soil type. The usage would not be enough to determine field soil type as always experienced in soil with much combined clay and silt particles which cannot be distinctly separated especially when appropriate sieve size is not readily available. Moreover, finer soil particles are easily suspended in solution since they have different densities and would always settle at different time and phases. Settlement time, colloidal forms and clarity in solution are functions of individual particles that made up the soil.

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# DESIGN MODIFICATION, FABRICATION AND TESTING OF FOUR ROW TRACTOR DRAWN MULTI-SEED PLANTER WITH FERTILIZER APPLICATOR

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## ABSTRACT
*The problem of planting is a major challenge for farmers all over the world for a long time. This has led to demand from various farmer groups and societies through the various states ADPs for an improved, effective and faster means of carrying out the planting operation since the imported planter are majorly beyond the purchasing power of an average farmer in Nigeria. In response to the demands NCAM developed a tractor drawn multi-seed planter with aim of solving the problem and encouraging farmers to increase their production scale. The planter was designed for planting seed crops namely maize; beans and guinea corn and the crops were used to test the three available seed plates for the machine. The field test was carried out gave a seed metering efficiency of 85%, field efficiency of 75.68%,effective field capacity of 0.7675 ha/h, at an average planting depth of 2.53cm, and an average spacing of 48 cm intra row. The result showed that NCAM developed multi-seed planter performed satisfactorily when subjected to field operation and can as well reduce drudgery faced by Nigerian farmers during planting operation.*

***Keywords:*** *planting, tractor drawn, seed planter, developed, testing*

## 1. INTRODUCTION
Grains are small, hard, dry seeds, with or without hulls/covering. There are two classes of grain producing crops namely cereal and legume crops. Examples of cereal crops are wheat, rice, maize etc. and legume crops are soybeans, cowpea, groundnut etc. After harvesting, dry grains are more durable than other staple foods like plantain, breadfruit and tubers like yam, arish potatoes and cassava. Grains are vital food component of humans and animals. Eating grains, especially whole grains, provides health benefits and also gives strength. It is a well-known fact that people who eat grains as part of healthy diet have reduced risk of some chronic diseases. Grains are used in producing most animal feeds so the importance and awareness continues to increase. Khan *et al*. (2015) reported that it is necessary that more grains be produced and this can only be achieved through some level of mechanization of which planting activity is a very important process which needs mechanization.

Maize also referred to as corn is a popular staple food in Nigeria as well as an important raw material for industries. It is processed in different forms as livestock feed. Maize is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Nigerians and other Africans consume maize as starch base in a wide variety such as porridges, pastes, grits, and beer.

The first activity in crop farming after land preparation is planting. The importance of this operation cannot be over emphasized. A seed planter is a sowing device that sows seed in rows with high precision and accuracy. This implement carries out an important operation that determines the successful germination of planting process.

The planter ensures precise positioning of seeds in the soil, to a large extent not more than two seeds per hole/stand and their adequate covering with soil. Specific features that need to be well addressed in planting are, distance between plant stands, distance between rows, depth of planting and covering of the planted seeds with soil. Before the invention of seed planters, planting was done by hand (manually), this was time consuming, wasteful, tedious and made planting without precision. According to Bamgboye and Mofolasayo (2006), the traditional planting method is tedious, causing fatigue and backache due to the longer hours required for careful hand metering of seeds if crowding or bunching is to be avoided. Planting machines are normally required to increase production but they are beyond the buying capacity of small-scale farmers (Kalay *et al.*, 2015).

In Nigeria, various types of planters have been designed and developed at different levels to solve specific problems as they arise using different approaches. Aniekwe *et al*. (2014) reported that most of the existing planters in Nigeria are manually operated, whereas, tractor drawn planters are usually preferred in large farms. Olajide and Manuwa (2014) also designed, fabricated and tested a low-cost grain planter capable of planting three types of grains- maize, soybean and cowpea. The planter had an average field capacity of 0.36 ha/h and efficiency of 71% with a percentage seed damage of 2.58%, spacing of 50.2 cm and an average depth of 4.28.

However, in this research work, a tractor drawn multi-seed planter was developed and evaluated to overcome the challenges in seed planting faced by farmers and as well improve food security in Nigeria.

## 2. MATERIAL AND METHODS

### 2.1 Description of the Seed Planter

The four-row tractor drawn multi-seed planter comprises of seed hopper, metering mechanism, ground wheel made from mild steel, chains and sprocket, furrow opener and closer, handles and frame. Figs. 1 and 2 show the orthographic and exploded view of the planter.

i. Seed hopper - This component holds the seeds being planted.
ii. Metering device - This controls the efficient delivery of seeds during the planting operation, thus ensuring the right number of seeds are planted per stand and the spacing within rows is effectively maintained.
iii. Delivery chute/ pipe - This directs the seed from the metering device accurately into the marked soil.
iv. Furrow opener and closing devices – The furrow opener opens the soil at the point of planting and the closing device closes it after the seed has been delivered into the soil.
v. Ground wheel - This supports the whole assembly and controls the planting distance.
vi. Transmission Assembly - This operation connects the metering device with the ground wheel and control seed droppings. In doing its operation, the precision in number of seed per stand and distance from one stand to the other is uniform and standardized. The transmission is a manual process.

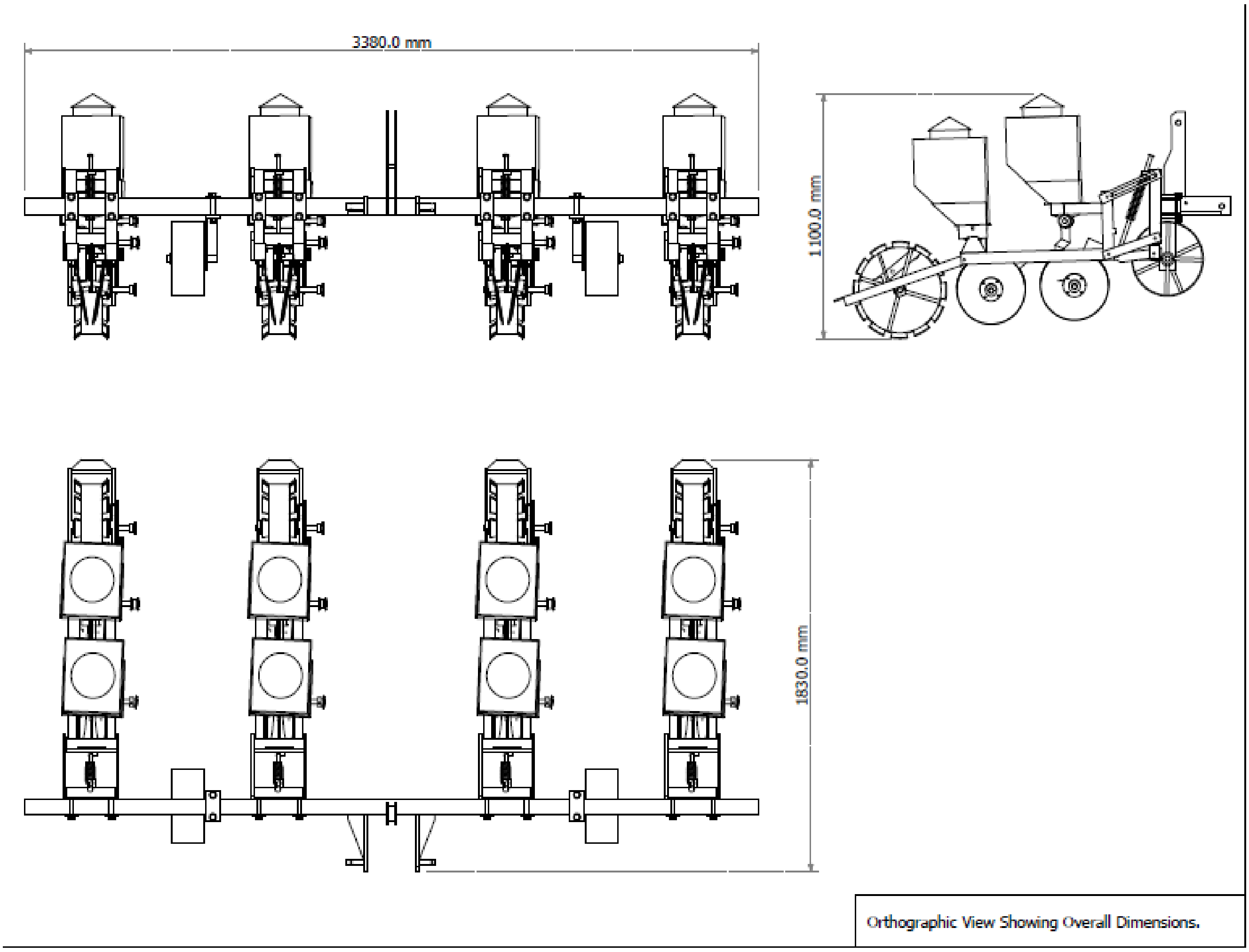


Fig. 1. Orthographic view of the Seed Planter

| PARTS LIST | | | |
|---|---|---|---|
| ITEM | QTY | PART NUMBER | DESCRIPTION |
| 1 | 1 | Frame of Planter | |
| 2 | 4 | Angle Iron | |
| 3 | 8 | Flat Bar | |
| 4 | 8 | Flat Bar | |
| 5 | 4 | Frame | |
| 6 | 4 | Part3 | |
| 7 | 4 | Frame 2 | |
| 8 | 4 | Spring Shaft | |
| 9 | 4 | Fertilizer Metering Unit | |
| 10 | 16 | Plate 1 | |
| 11 | 16 | Wheel 1 | |
| 12 | 4 | Shaft 2 | |
| 13 | 4 | Support | |
| 14 | 8 | Roller Chain Sprocket11 | |
| 15 | 8 | Hopper Base | |
| 16 | 8 | Hopper | |
| 17 | 4 | Auger | |
| 18 | 8 | Part6 | |
| 19 | 4 | Grain Metering Device | |
| 20 | 4 | Bevel Gear 1 | |
| 21 | 4 | Bevel Gear2 | |
| 22 | 4 | Rolling bearing 23 | Rolling Angular ball bearings |
| 23 | 4 | Stopper 1 | |
| 24 | 4 | Stopper 2 | |
| 25 | 4 | Stopper 3 | |
| 26 | 4 | Seed Meter | |
| 27 | 4 | Part1 | |
| 28 | 4 | Wheel | |
| 29 | 8 | Hopper Cover | |
| 30 | 4 | Roller Chain Sprocket12 | |
| 31 | 8 | Part3 | |
| 32 | 16 | ISO 7089 - 140HV | Plain washers - Normal series |
| 33 | 16 | ISO 4014 - M18 x 100 | Hexagon head bolt - |
| 34 | 2 | Part of Wheel | |
| 35 | 2 | Wheel 2 | |
| 36 | 2 | Part1 2 | |
| 37 | 2 | Part7 1 | |
| 38 | 8 | ISO 7092 140 HV | Plain washers grade A |
| 39 | 4 | ISO 4014 - M18 x 120 | Hexagon head bolt |
| 40 | 4 | ISO 4034 - M18 | Hexagon nuts - grade C |

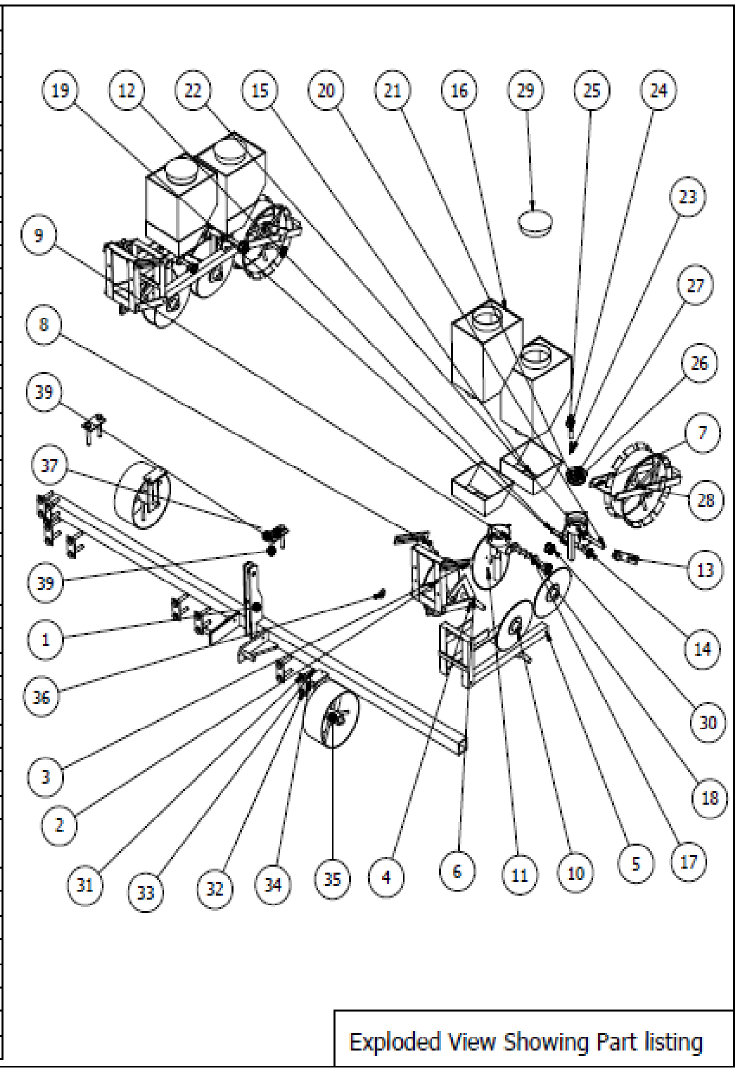


Figure 2. Exploded view of the Planter showing component names

## 2.2 Design Consideration

The design of the planter is based on the following considerations.

i. The ease of fabrication of component parts.
ii. The safety of the operator
iii. The operation of the machine simplified for small scale or rural farmers to handle easily.
iv. The materials used for the fabrication of the machine are locally available to ensure ease of getting the spare parts.
v. The materials used for construction are readily available and cheap thereby making the machine components/spare parts affordable.

## 2.3 Design Calculations

### 2.3.1 Seed hopper

The seeds hopper as the name implies is a device in which the seeds to be planted are kept (transitionally) before their gradual release into the furrowed tunnel. The hopper is trapezoidal on the inside with the shape of a frustum of a pyramid truncated at the top as shown in Figure 1. To ensure free flow of seeds, the slope of the hopper was fixed at $30^o$, which is modestly higher than the average angle of repose of the seeds. The seed hopper also has a lid, with a handle on top to ease opening. Volume of the hopper is 252,665 $cm^3$.

$$V = \frac{h}{3}[A_1 + A_2 + \sqrt{A_1}A_2] \quad (1)$$

2.3.2 Seed metering mechanism

The metering mechanism is a major component in a planter. It picks required number of seeds and delivers them into the soil through the chute at required depths determined by the adjustments on the furrow openers. The metering mechanism of the planter also controls/determines seed spacing in a row. For efficient performance of a planter the following were put into consideration, the size of the seed, the intra and inter row spacing for each seed, which usually differs from one crop to another, and for different desired plant populations.

Different seed plates were designed for different types of seeds. The seeds are maize, guinea corn and soybeans. Proper design of the metering device is an essential element for satisfactory performance of the seed planter. The number of cells on the seed plate may be obtained from the expression given in Equation (2).

$$Number\ of\ cells = \frac{\pi \times Diameter\ of\ the\ planters\ ground\ wheel}{Intra-row\ spacing\ of\ seeds} \quad (2)$$

2.3.3 Determination of the shaft diameter

Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. Design of shafts of ductile material based on strength is controlled by maximum shear theory. The material for the shaft is mild steel rod. For a shaft having little or no axial loading, the diameter may be obtained using the ASME code equation given as:

$$d^3 = \frac{16}{\pi Sa}\sqrt{(k_b\, m_b)2 + (k_t\, m_t)2} \quad (3)$$

*where,*

*d = Diameter of the shaft*
*$M_b$ = Bending moment*
*$M_t$=Torsional moment*
*$K_b$= Combined shock and fatigue factor applied to bending moment*
*$K_t$= Combined shock and fatigue factor applied to torsional moment*
*$S_a$= Allowable stress*

For rotating shafts, when load is suddenly applied (minor shock):
$K_t$ = 1.5 to 2.0 $k_t$ = 1.0 to 1.5
For shaft without key way, allowable stress $S_a$ = 55MN/m$^2$
For shaft with key way, allowable stress $S_a$ = 40MN/m$^2$

2.3.4 Sprocket

This is one of the power transmitters to both the metering device and the fertilizer auger. The power is considered, the speed of the driver and the driven, and centre distance are all considered. The permissible working stress of the thickness of a tooth of the sprocket was determined using Equation (4).

$$\sigma_w = My/I \quad (4)$$

*where,*

$\sigma_w$= Permissible working stress
M= Maximum bending moment at the critical section BC which is the same as t =$W_t$ x h
$W_t$ = Tangential load acting at the tooth,
h = Length of the tooth,
y = half the thickness of the tooth (t) at critical section BC= t / 2,
I = Moment of inertia about the centre line of the tooth = b.$t^3$ /12,
b = width of gear face.

When the value of 'y' is independent of the size of the tooth and depends only on the number of teeth on a gear and the system of teeth.

y = 0.124 - $\frac{0.684}{T}$ for $14^{1/2}$ composite and full depth involute system.

2.3.5 The furrow opener
This consist of a disc positioned in a v shape to make a open to the soil as it travels. It has a hub with a bearing in it to rotate the disk as it travels. The bearing; the dynamic load rating for the furrow opener was determined using Equation (5).

$$L = \left(\frac{C}{W}\right)^k x\ 10^6 \quad (5)$$

where,

L = Rating life
C = Basic dynamic load rating which is c=w $(l/10^6)^{1/k}$
W = Equivalent dynamic load rating
K=3 for ball bearings

2.3.6 The ground wheel
This is the source of power to the metering device and the fertilizer auger. It also determine the distance at which the metering device will drop seed with a revolution. The circumference of the wheel is determined using Equation (6).

$$C = \pi d \quad (6)$$

Since the diameter of the wheel is 52cm then the circumference is:

$$C = 3.142 \ \times 520$$
$$C = 1633.84\ mm$$

2.3.7 Frame
This is made of a 5mm angle iron, flat bar, and 1mm flat sheets. Which are cut, and welded together to form a desirable structure, that houses and carry other components of the implement. On the main frame is the hatching point.

## 3. PRELIMINARY TEST

Maize seed was the main seed used for the performance evaluation of the planter and the seed was procured from the Farm Management unit of the Centre. The standard code suggested by Mehta *et al.* (1995) for seed drill performance test as reported by Bamgboye and Mofolasayo (2006) was adopted in the evaluation of the machine performance. Laboratory and field tests were conducted to determine the performance of the machine.

Laboratory tests were carried out on the fabricated planter to determine the seed dropping rate and spacing efficiency. The test was done on a flat soil surface with a tractor driving the plantet to set and do the necessary adjustment for effective working of the mechanisms. Three different types of crop seeds were used.Two varieties of each seed crop was used, that is the large and small size respectively. These are, Maize, beans and guineacorn using the seed plate specified for each of the seeds. For each of the three seed types the machine dropped seeds between two and three per stand.

Further test was conducted on a piece of land of dimensions 10m by 50m to ascertain that the main functional parts are working as expected. Two runs of the tractor on a 50m stretch were used to ascertain the effective functioning of the operational components like the soil opener, the closer, the seed delivery chute and the rolling parts. The planter hopper was filled with maize seeds and right adjustments effected appropriately on each of the 4-row gang and the planter used to plant the measured area. Number of seeds dropped per planting point and seeds damaged were noted and recorded by picking samples and other functionality component determined. Time of operation was measured using a stop watch.

## 4. RESULTS AND DISCUSSION

The picture of the four-row tractor drawn multi-seed planter shown in Plate 1. Planting tests were carried out to ascertain that the main functional parts are working as expected and it was observed that the planter could successfully plant an average of two seeds per hole. The metering mechanism could successfully pick the required number of seeds from the hopper; deliver them into the chute through which the seeds are dropped along the rows at about 30cm intra row spacing. The ground wheel transmitted power to the metering device through the chain and sprocket system.

Plate 1. Picture of four-row tractor drawn multi-seed planter

### 4.1 Determination of Field Efficiency

The field efficiency of the planter was determined as 75.68% using Equation (7).

$W = T_a$ (7)

$T_a$ is the time taken for actual

$T_t \backslash T_a$

where,

$T_a$ is the time taken for actual planting operation;
$T_t$ is the total time taken.

### 4.2 Determination of Effective Field Capacity

The effective field capacity, is a function of the theoretical field capacity and field efficiency. The effective field capacity was determined as 0.7675 ha/h using the expression given by Oyelade and Oni (2011) as:

$$D = E\,\frac{(3600)}{F} \quad (8)$$

where,

D = effective field capacity (ha/h)
E = area of field (ha)
F = total time taken in completing the whole tillage operation (sec)

Table 1. Laboratory calibration of Tractor drawn four row seed Planter

| **Replications** | **Weight of seeds discharged** | **Time for 100 rev. (sec)** | **Speed (rpm)** |
|---|---|---|---|
| 1 | 505.5 | 310 | 7.5 |
| 2 | 520.5 | 305 | 6.2 |
| 3 | 490.0 | 287 | 5.9 |
| 4 | 530.0 | 313 | 6.4 |
| 5 | 510.0 | 303 | 6.2 |
| 6 | 505.5 | 307 | 6.3 |
| 7 | 510.0 | 300 | 6.1 |
| 8 | 520.5 | 312 | 6.4 |
| 9 | 505.5 | 304 | 6.2 |
| 10 | 510.0 | 300 | 6.1 |
| TOTAL | 5177.5 | 341 | 63.3 |
| MEAN | 5.17.0 | 304 | 6.33 |

Table 2. Determination of seed rate and planting distance of the machine

| **Rep** | **kg/trip in stretch (kg/h)** | **Speed (km/h)** | **Laboratory Spacing (cm)** | **Field Spacing (cm)** |
|---|---|---|---|---|
| 1. | 1.3 | 0.2 | 38.0 | 45.0 |
| 2. | 1.3 | 0.2 | 44.0 | 44.0 |
| 3. | 1.3 | 0.2 | 57.0 | 48.0 |
| 4. | 1.3 | 0.2 | 46.0 | 40.0 |
| 5. | 1.3 | 0.2 | 39.0 | 43.0 |
| 6. | 1.3 | 0.2 | 46.0 | 52.0 |
| 7. | 1.3 | 0.2 | 38.0 | 51.0 |
| 8. | 1.3 | 0.2 | 45.0 | 50.0 |
| 9. | 1.3 | 0.2 | 41.0 | 55.0 |
| Mean row spacing | 1.3 | 0.2 | 43.8 | 47.6 |

Table 3. Percentage seed damage rate of the planter

| Replication | Time for 20 rev. (sec) | Weight of seed discharged (g) | Weight of broken seed (g) | Percentage of damages (%) |
|---|---|---|---|---|
| 1. | 73 | 20.7 | 0.4 | 0.03 |
| 2. | 65 | 20.5 | 0.6 | 0.04 |
| 3. | 58 | 22.7 | 1.2 | 0.08 |
| 4. | 55 | 17.2 | 0.5 | 0.03 |
| 5. | 60 | 20.0 | 6.4 | 0.43 |
| 6. | 57 | 15.4 | 2.4 | 0.16 |
| 7. | 50 | 16.0 | 1.8 | 0.12 |
| 8. | 60 | 19.2 | 0.8 | 0.05 |
| Total | 42.08 | 151.68 | 14.08 | 0.96 |
| Mean | 5.26 | 18.96 | 1.76 | 0.12 |

### 4.3 Test Result

During the laboratory test, the planter was tested for seed discharge rate as reported in table 1.It was found to be an average of 5seeds at a speed of 6.33rpm. And test for seed spacing by the planter was found to be an average of 44cm between ridges in the laboratory and in the field an average of 48cm on the ridge i.e., between stands, as shown in table 2. The row to row spacing is standard as this is adjustable by setting the ridge gang within the main frame of the planter.

From Table 3, the rate of damages of the planter was found to be 0.12% of the full load of the planter when the planter was operated at the forward speed of 1.25 m/s. The moisture content and the bulk density of the soil during the test were found to be 10.3 per cent (db) and 2.36 $Mg/m^3$. The average draft required during operation was 2300 N and the percentage of missing points obtained for planter was 3.50 per cent.

## 5. CONCLUSION

A four row tractor drawn seed planter was replicated in NCAM using locally available materials thus making it cheaper, and with spare parts available and affordable than the imported version. An extensive performance evaluation test was carried out on it using maize on a clay-loamy soil to get its performance rate. It has seed metering efficiency of 85%, field efficiency of 75.68%, effective field capacity of 0.7675 ha/h, planting depth 2.53cm and planting rate of two seed per stand. The planter is economical and simple to use with handling made less cumbersome compared to the imported version.

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# IMPACT OF AGRICULTURAL INPUTS ON POTABILITY OF WATER IN ILORIN CATCHMENT AREA

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**ABSTRACT**

*An investigation was carried out on available water sources on the campus of the National Centre for Agricultural Mechanization (NCAM), Ilorin and its surrounding communities to ascertain the extent of their pollution. Nine water sources were sampled during the rainy season of 2008; these samples include both surface and underground water sources. All sources were sampled on three different occasions and analyzed in a standard laboratory. The results of the analysis, compared with the World Health Organization (WHO, 2006) Drinking Water Quality Standards, showed that the activities of NCAM had no significant effect on the quality of the downstream water sources. It also showed that upstream sources are highly polluted and not potable until adequate treatment is applied. The results also revealed that NCAM borehole stood the best of all the sources, both from the chemical as well as the bacteriological stand point. As at the time of sampling, five water sources were not potable due to their bacteriological state. Some chemical constituents were also found to be above the Maximum Permissible Limit (MPL), most of which do not have a direct effect on the health of their consumers, but may also be given the necessary treatment to improve on their quality.*

**Keyword:** Water sources, Pollution, Water quality, Water quality standards, Potability

## 1. INTRODUCTION

Water is essential for the sustenance of life, and a satisfactory (adequate and safe) supply must be accessible to all. Improving access to safe drinking water can result in tangible benefits to health; therefore every effort must be made to achieve a drinking water quality as safe as practicable (WHO, 2006). Water shortages already exist in many parts of the world with more than a billion people without access to adequate drinking water. As the world population increases, water need also increases; however as a result of human activities, water resources are decreasing, polluted and still used unconsciously (Kilic, 2020). Water sources are either surface, e.g. river, stream, etc. or underground, e.g. well, borehole, etc.

The provision of reliable and clean water supplies is an essential element in improving the quality of life of rural populace. Water quality is the physical, chemical and biological characteristics of water in relationship to a set of standards. Water is considered polluted if some substances or condition is present to such a degree that the water cannot be used for a specific purpose. Olaniran (1995) defined water pollution to be the presence of excessive amounts of a hazard (pollutants) in water in such a way that it is no long suitable for drinking, bathing, cooking or other uses. Pollution is the introduction of a contamination into the environment (Webster.com, 2010). The presence of National Centre for Agricultural Mechanization (NCAM), Ilorin, a Centre whose activities include testing of tractors, use of fertilizers and agro-chemicals and other mechanization activities such as irrigation and processing of crops may impair negatively on the quality of water around its catchment.

Pollutants entering surface waters during precipitation events are termed polluted runoff. Daily human activities result in deposition of pollutants on roads, lawns, roofs, farm fields, etc. When it rains or there is irrigation, water runs off and ultimately makes its way to a river, lake, or the ocean. Ilorin and its surrounding rural communities are blessed with different sources of water, both surface and underground, but due to human activities within and around these target communities, these water sources are polluted to varying degrees.

Impurities resulting from man's activities may be classified into five (5) groups, i.e. wastes of animal or human origin, run-off from farms in which case fertilizers and pesticides are included. Also included are domestic sewage, such as bathing or washing water, industrial wastes or accident pollution such as that resulting from discarded engine oil.

The quality of water is usually considered in terms of its physical, chemical and bacteriological parameters. The impact of drinking water quality cannot be over-emphasized. It ranges from massive outbreak of communicable diseases to chronic infections which may lead to death. Investigations carried out by Olla and Ahaneku (2004) concluded that most of the water sources analyzed for quality test in Ilorin were not fit for consumption mainly due to their bacteriological status. This was not unconnected with the unprotected nature of the water sources.

The parameters for water quality are determined by the intended use. Furthermore, it has been generally observed that most physical properties are manifested when some chemical elements are present in excess. Common physical properties like taste, odour, colour, temperature, turbidity, etc. 'may be first alarm signal' for a potential health hazard and they play an important role in the consumers' evaluation of drinking water.

The increasing use of artificial fertilizers, the disposal of wastes and changes in land use are the main factors responsible for progressive increase in nitrate levels in groundwater (WHO, 1998). Therefore, NCAM's presence is a likely contributor to high nitrate concentration in water sources within its environ due to high dosage application of nitrogenous fertilizers on NCAM farmlands.

WHO (1984) identified more than 600 organic contaminants in drinking water. Safe drinking water is the birthright of all humankind – as much a birthright as clean air. The majority of the world's population, however, does not have access to safe drinking water. This is certainly true in most parts of Africa and Asia. Even in relatively advanced countries such as India, safe drinking water is not readily available, particularly in rural areas. One reason safe drinking water is of paramount concern is that 75 percent of all diseases in developing countries arise from polluted drinking water (TWAS, 2002). Water-borne and water related diseases are among the most serious health problems in the world today, thus, the cost to the world economy is staggering. Microbial pollution includes bacteria, protozoa, and viruses that are common in the natural environment, as well as those that come from human sources (Field and Pitt, 1990; Mallin et al., 2000).

The objectives of this study are to identify and analyze the quality of water from different sources at NCAM, Ilorin and its surrounding communities; determine the effects of NCAM activities on the downstream water sources; evaluate the level of impurities in the available water sources and suggest ways of amelioration. The study will also provide a water quality database for NCAM and the surrounding communities, which may be useful for future research work.

## 2. MATERIALS AND METHODS

### 2.1 Brief Description of Study Area

All water sources were located in and around the National Centre for Agricultural Mechanization (NCAM). NCAM is located about 20 Km to Ilorin city of Kwara State, Nigeria.  has an estimated average terrain elevation of 470 m above sea level and lies between Latitudes $9^0$50’ and $8^0$24’ and Longitudes $4^0$38’ and $4^0$3’East (Abdulkadir, 2016). Water sources such as NCAM borehole, NCAM well are within the NCAM premises, while NCAM rock-filled dam Is though within NCAM land area, but is along the path of Odomu river and downstream a concrete dam jointly owned by NCAM and Kwara State Water Corporation. Elerinjare dam raw water was sampled from the concrete dam, while the Elerinjare treated water was sampled from the treatment plant situated at the dam. Oyun rver sample was taken downstream NCAM, along the path of the dammed river. Samples like Jimba Oja well and borehole were sampled downstream NCAM very close to the Jimba Central Mosque.

### 2.2 Water Sources and Locations

Nine different water sources were sampled during the wet season of 2008 and analyzed for potability consideration. These sources include Idofian well, Elerinjare dam water (raw water), Elerinjare (treated water), Jimba-Oja Borehole, Jimba-oja Well, NCAM borehole, NCAM rock-filled dam, NCAM well and Oyun river. Idofian well is located upstream NCAM and it serves the community for drinking and laundry purposes. Elerinjare dam, also upstream NCAM, water from here is treated for supply to Idofian, NCAM and other communities. Treated water from this source was also sampled to know the state of the treated water consumed by the population served. NCAM rock-filled dam is a partly completed rock-filled dam, designed and constructed through direct labour in 2004 by NCAM Engineers. The dam is downstream the dam at Elerinjare. NCAM borehole is located on NCAM campus and serves as drinking water source for NCAM residents as well as staff living off the campus. NCAM well is a shallow well located in NCAM residential quarters. This is often times used for washing by the dwellers, but in case of scarcity, people may resort to it as a source of drinking water. Jimba-Oja borehole, located downstream of NCAM, it serves as drinking water source. Jimba-Oja well, also located downstream NCAM serves as drinking water source for cattle rearers who often take their cattle on open range. Oyun river is a river downstream of NCAM. The runoff from the dam at Elerinjare is emptied into this river. There are possibilities that the cattle rearers and some of the people of the local communities might consume the water. The location of these water sources are indicated in Fig. 1.

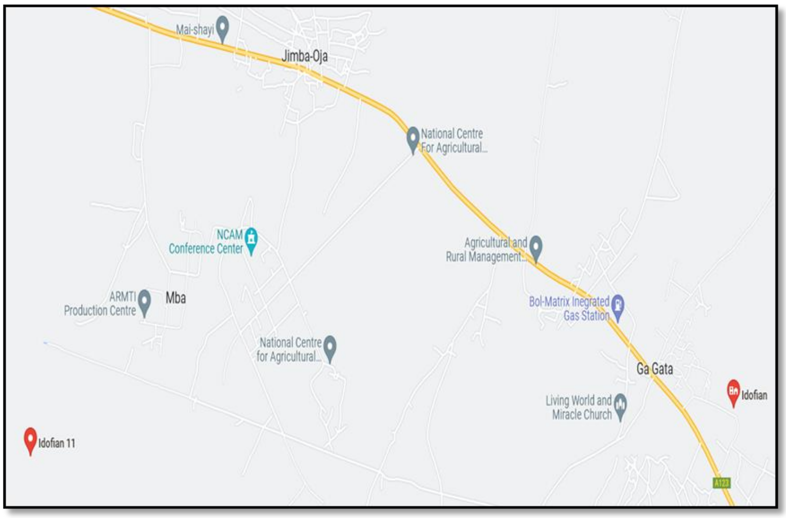


Fig. 1. Google Map of Part of Ifelodun Local Government Area of Kwara State Showing Sampling Points

Scale: 600m: 1 Km

## 2.3 Quality Analyses

Sampling was carried out with the aid of sterilized sampling bottles and quality analysis of all samples carried out in a laboratory. This entailed the physical, chemical and bacteriological analysis. The data was analyzed using descriptive statistics.

## 3. RESULTS AND DISCUSSION

### 3.1 Physico-Chemical Analysis

Table.1 shows the results of the physical and chemical analysis of the nine water sources sampled. When compared with the World Health Organization (2006) Standards, the results show the value of **colour** to be above the maximum permissible limit (PML) in four out of the nine sources, namely Elerinjare dam (raw), Oyun river, NCAM rockfill dam, and the Jimba-oja well samples with values of 26.67 ± 2.89, 23.00 ± 2.65, 22.33 ± 2.52 and 20.00 ± 2.00, respectively. **Turbidity** result showed that seven out of nine samples have their average turbidity values above the maximum permissible limit (MPL). These include Elerinjare dam (raw), Elerinjare (treated), Jimba-Oja shallow well, NCAM well, NCAM Rockfill dam, Idofian well and the Oyun river samples with average values of 9.50 ± 1.00, 5.43 ± 0.40, 11.00 ± 1.00, 6.33 ± 1.04, 8.83 ± 1.04, 5.17 ± 0.29 and 9.17 ± 0.76, respectively.

**Magnesium** value was observed to be in excess in all the samples tested in the three consecutive tests; averages were also above the MPL for all samples. The **iron** content of the samples taken from Elerinjare dam, Idofian well, Jimba-Oja well, NCAM dam, NCAM well and the Oyun river, with averages of 0.68 ± 0.08, 0.45 ± 0.05, 0.34 ± 0.01, 0.48 ± 0.03, 0.32 ± 0.03 and 0.62 ± 0.03, respectively were observed to be above the MPL. The **manganese** content of the samples from Elerinjare dam, NCAM Rockfill dam, Jimba-Oja well and the Oyun river, with averages of 0.37 ± 0.06, 0.33 ± 0.06, 0.24 ± 0.01 and 0.45 ± 0.13 was found to be above the MPL.

**Lead** was found to have exceeded the MPL only in the Elerinjare dam (raw) sample, with an average value of 0.12 ± 0.03. The **pH** of samples from Elerinjare treated water, Jimba-Oja borehole, Jimba-Oja well and NCAM well was found to be below the allowable range, with average values of 6.13 ± 0.12, 6.40 ± 0.00, 6.17 ± 0.12 and 6.47 ± 0.12, respectively. The samples from Elerinjare dam, Jimba-Oja well, NCAM dam and Oyun river were found to contain **Chromium** above the MPL. Their averages are 0.07 ± 0.01, 0.06 ± 0.01, 0.07 ± 0.01 and 0.06 ± 0.04, respectively. The implications of the result of the above quality analysis of all the water samples are as follows:

The high colour and turbidity values above the MPL have no health impact, but may not be acceptable by consumers. However, high turbidity levels may be associated with high levels of disease-causing micro-organisms On the other hand, it may cause discolouration of fabrics if used for laundry. Similarly, the excess magnesium in the samples has no health impact.

High concentration of iron observed in samples from Elerinjare dam, Idofian well, Jimba-Oja well, NCAM rock fill dam and the Oyun river also has no negative health impact on the consumers. High manganese content of samples from Elerinjare dam, Jimba-Oja well, NCAM dam and the Oyun river is of concern as it has a health impact on their consumers, and may lead to neurological disorder. Similarly, excess lead observed in Elerinjare dam sample could cause any of the following diseases: cancer, interference with vitamin D metabolism, defect in infant mental development and toxicity to the central and peripheral nervous systems. Presence in excess of chromium in samples from Elerinjare dam (raw), NCAM dam, Jimba-Oja well and the Oyun river is a signal to cancer infection by the consumers.

Table 1.Results of physico-chemical analysis of water samples

| PARAMETERS | ELERINJARE DAM (RAW) | | ELERINJARE DAM (TREATED) | | IDOFIAN WELL | | JIMBA-OJA BOREHOLE | | JIMBA OJA WELL | |
|---|---|---|---|---|---|---|---|---|---|---|
| | AVE | STD DEV | AVE | STD DEV | AVE | STD DEV | AVE | STD DEV | AVE | STD DEV |
| Phenolphthalein alkalinity (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |
| Methyl Orange alkalinity (mg/l) | 61.67 | ±2.89 | 50.00 | ±0.00 | 65.00 | ±0.00 | 55.00 | ±0.00 | 48.33 | ±5.77 |
| Total hardness (mg/l) | 48.00 | ±0.00 | 39.67 | ±3.51 | 53.33 | ±2.31 | 60.00 | ±0.00 | 71.67 | ±4.73 |
| Ca2+ hardness (mg/l) | 28.00 | ±0.00 | 24.67 | ±1.15 | 32.00 | ±0.00 | 36.00 | ±0.00 | 41.67 | ±2.08 |
| Mg2+ hardness (mg/l) | 20.00 | ±0.00 | 14.67 | ±2.31 | 21.33 | ±2.31 | 24.00 | ±0.00 | 26.67 | ±1.15 |
| Ca2+ (total) mg/l | 11.20 | ±0.00 | 9.60 | ±0.00 | 12.80 | ±0.00 | 14.40 | ±0.00 | 17.07 | ±0.92 |
| Mg2+ (total) mg/l | 8.60 | ±0.00 | 6.10 | ±1.35 | 9.33 | ±0.23 | 9.20 | ±0.00 | 10.77 | ±1.39 |
| CO2 (mg/l) | 6.17 | ±1.26 | 2.17 | ±0.29 | 4.17 | ±0.58 | 3.67 | ±1.76 | 4.50 | ±0.87 |
| CL-(mg/l) | 6.17 | ±0.29 | 3.67 | ±0.29 | 2.50 | ±0.50 | 3.50 | ±0.50 | 3.67 | ±0.58 |
| Fe2+ (mg/l) | 0.68 | ±0.08 | 0.15 | ±0.05 | 0.45 | ±0.05 | 0.25 | ±0.05 | 0.34 | ±0.01 |
| Cu2+ (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |
| Mn2+ (mg/l) | 0.37 | ±0.06 | 0.06 | ±0.01 | 0.19 | ±0.01 | 0.18 | ±0.03 | 0.24 | ±0.01 |
| Pb2+ (mg/l) | 0.12 | ±0.03 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |
| F-(mg/l) | 0.06 | ±0.01 | 0.03 | ±0.01 | 0.05 | ±0.02 | 0.03 | ±0.01 | 0.05 | ±0.01 |
| SO42- (mg/l) | 9.83 | ±0.58 | 11.63 | ±0.71 | 7.57 | ±0.40 | 9.50 | ±0.00 | 7.73 | ±1.27 |
| NO3-(mg/l) | 4.57 | ±0.12 | 0.33 | ±0.15 | 0.58 | ±0.16 | 0.12 | ±0.03 | 0.93 | ±0.23 |
| PO4-(mg/l) | 1.00 | ±0.36 | 0.03 | ±0.05 | 0.20 | ±0.05 | 0.37 | ±0.64 | 0.14 | ±0.01 |
| Na+ (mg/l) | 0.93 | ±0.49 | 0.23 | ±0.08 | 0.93 | ±0.25 | 0.53 | ±0.47 | 1.08 | ±0.23 |
| K+ (mg/l) | 0.53 | ±0.06 | 0.13 | ±0.03 | 0.80 | ±0.00 | 0.57 | ±0.06 | 0.93 | ±0.12 |
| Total solids (mg/l) | 319.33 | ±4.16 | 209.33 | ±12.86 | 195.67 | ±3.51 | 179.33 | ±3.06 | 323.33 | ±15.53 |
| Dissolved solids (mg/l) | 276.00 | ±7.21 | 185.33 | ±7.02 | 174.67 | ±7.02 | 162.67 | ±1.15 | 315.00 | ±7.55 |
| Suspended solids (mg/l) | 43.33 | ±4.16 | 22.67 | ±5.03 | 24.67 | ±3.06 | 16.67 | ±2.31 | 22.00 | ±2.00 |
| COD (mg/l) | 4.47 | ±0.42 | 5.20 | ±0.40 | 2.67 | ±0.42 | 3.33 | ±0.50 | 3.33 | ±0.31 |
| Turbidity (NTU) | 9.50 | ±1.00 | 5.43 | ±0.40 | 5.17 | ±0.29 | 4.33 | ±0.29 | 11.00 | ±1.00 |
| pH | 6.77 | ±0.06 | 6.13 | ±0.12 | 6.73 | ±0.06 | 6.40 | ±0.00 | 6.17 | ±0.12 |
| Color (HU) | 26.67 | ±2.89 | 6.33 | ±1.15 | 7.67 | ±1.15 | 6.33 | ±0.58 | 20.00 | ±2.00 |
| Dissolved O2 (mg/l) | 3.73 | ±0.50 | 4.47 | ±0.31 | 2.27 | ±0.50 | 2.67 | ±0.31 | 2.87 | ±0.31 |
| BOD (mg/l) | 3.13 | ±0.42 | 1.13 | ±0.12 | 1.57 | ±0.35 | 0.67 | ±0.12 | 1.57 | ±0.21 |
| Conductance (µS) | 86.47 | ±0.51 | 92.94 | ±3.10 | 82.13 | ±5.55 | 90.16 | ±0.45 | 82.43 | ±0.92 |
| SiO2 (mg/l) | 11.17 | ±0.76 | 7.43 | ±0.90 | 24.33 | ±1.53 | 30.00 | ±2.00 | 18.17 | ±0.29 |
| NH3 (mg/l) | 0.04 | ±0.00 | 0.00 | ±0.00 | 0.01 | ±0.00 | 0.00 | ±0.00 | 0.01 | ±0.00 |
| Cr2+ (mg/l) | 0.07 | ±0.01 | 0.00 | ±0.00 | 0.05 | ±0.05 | 0.00 | ±0.00 | 0.06 | ±0.01 |
| Zn2+ (mg/l) | 0.32 | ±0.03 | 0.04 | ±0.04 | 0.13 | ±0.03 | 0.03 | ±0.06 | 0.11 | ±0.02 |
| Oil and Grease (mg/l) | 0.55 | ±0.09 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |
| Phenol (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |

Table 1.Results of physico-chemical analysis of water samples contd.

| PARAMETERS | NCAM WELL | | NCAM BOREHOLE | | NCAM DAM | | OYUN RIVER | |
|---|---|---|---|---|---|---|---|---|
| | AVE | STD DEV | AVE | STD DEV | AVE | STD DEV | AVE | STD DEV |
| Phenolphthalein alkalinity (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |
| Methyl Orange alkalinity (mg/l) | 55.00 | ±0.00 | 63.33 | ±2.89 | 65.00 | ±0.00 | 68.33 | ±2.89 |
| Total hardness (mg/l) | 60.00 | ±0.00 | 43.33 | ±1.15 | 44.00 | ±0.00 | 41.33 | ±2.31 |
| $Ca^{2+}$ hardness (mg/l) | 33.33 | ±2.31 | 20.67 | ±1.15 | 24.00 | ±6.93 | 22.67 | ±6.11 |
| $Mg^{2+}$ hardness (mg/l) | 26.67 | ±2.31 | 22.00 | ±0.00 | 16.00 | ±0.00 | 16.00 | ±0.00 |
| $Ca^{2+}$ (total) mg/l | 13.33 | ±0.92 | 8.47 | ±0.42 | 11.20 | ±0.00 | 10.13 | ±0.92 |
| $Mg^{2+}$ (total) mg/l | 9.47 | ±0.23 | 8.93 | ±0.12 | 7.20 | ±0.00 | 7.20 | ±0.00 |
| $CO_2$ (mg/l) | 4.67 | ±0.58 | 3.17 | ±0.76 | 5.17 | ±0.58 | 5.50 | ±1.00 |
| $CL^-$(mg/l) | 3.17 | ±0.29 | 2.33 | ±0.29 | 4.67 | ±0.76 | 5.00 | ±1.00 |
| $Fe^{2+}$ (mg/l) | 0.32 | ±0.03 | 0.18 | ±0.03 | 0.48 | ±0.03 | 0.62 | ±0.03 |
| $Cu^{2+}$ (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |
| $Mn^{2+}$ (mg/l) | 0.15 | ±0.05 | 0.10 | ±0.00 | 0.33 | ±0.06 | 0.45 | ±0.13 |
| $Pb^{2+}$ (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.02 | ±0.02 | 0.03 | ±0.03 |
| $F^-$(mg/l) | 0.03 | ±0.01 | 0.05 | ±0.01 | 0.01 | ±0.01 | 0.01 | ±0.01 |
| $SO_4^{2-}$ (mg/l) | 8.50 | ±0.50 | 8.00 | ±0.00 | 10.50 | ±0.87 | 10.67 | ±0.76 |
| $NO^{3-}$(mg/l) | 0.07 | ±0.03 | 0.04 | ±0.01 | 3.20 | ±0.40 | 3.50 | ±0.44 |
| $PO_4^-$(mg/l) | 0.37 | ±0.46 | 0.17 | ±0.29 | 0.77 | ±0.21 | 1.07 | ±0.15 |
| $Na^+$ (mg/l) | 0.40 | ±0.30 | 0.20 | ±0.26 | 0.68 | ±0.25 | 0.70 | ±0.26 |
| $K^+$ (mg/l) | 0.43 | ±0.06 | 0.23 | ±0.06 | 0.52 | ±0.18 | 0.53 | ±0.15 |
| Total solids (mg/l) | 198.67 | ±8.33 | 190.00 | ±2.00 | 310.00 | ±3.46 | 324.67 | ±5.03 |
| Dissolved solids (mg/l) | 178.67 | ±4.62 | 172.00 | ±0.00 | 274.00 | ±2.00 | 284.00 | ±3.46 |
| Suspended solids (mg/l) | 20.00 | ±4.00 | 18.00 | ±2.00 | 36.00 | ±4.00 | 40.67 | ±3.06 |
| COD (mg/l) | 3.80 | ±0.20 | 2.80 | ±0.40 | 3.87 | ±0.31 | 4.07 | ±0.50 |
| Turbidity (NTU) | 6.33 | ±1.04 | 4.17 | ±0.29 | 8.83 | ±1.04 | 9.17 | ±0.76 |
| pH | 6.47 | ±0.12 | 6.73 | ±0.06 | 6.80 | ±0.00 | 7.00 | ±0.17 |
| Color (HU) | 11.00 | ±6.08 | 5.67 | ±0.58 | 22.33 | ±2.52 | 23.00 | ±2.65 |
| Dissolved $O_2$ (mg/l) | 3.13 | ±0.23 | 2.07 | ±0.31 | 3.53 | ±0.50 | 3.80 | ±0.53 |
| BOD (mg/l) | 2.13 | ±0.31 | 0.67 | ±0.12 | 2.53 | ±0.23 | 2.87 | ±0.31 |
| Conductance (µS) | 79.75 | ±0.53 | 83.83 | ±0.43 | 89.56 | ±0.87 | 90.52 | ±1.30 |
| $SiO_2$ (mg/l) | 20.83 | ±1.26 | 15.50 | ±0.87 | 10.33 | ±1.04 | 11.50 | ±1.50 |
| $NH_3$ (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.03 | ±0.00 | 0.04 | ±0.00 |
| $Cr^{2+}$ (mg/l) | 0.04 | ±0.00 | 0.00 | ±0.00 | 0.07 | ±0.01 | 0.06 | ±0.04 |
| $Zn^{2+}$ (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.23 | ±0.03 | 0.25 | ±0.00 |
| Oil and Grease (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.17 | ±0.03 | 0.25 | ±0.05 |
| Phenol (mg/l) | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 | 0.00 | ±0.00 |

### 3.2 Bacteriological Analysis

Table 2 shows the average results of the bacteriological test carried out on all the water samples. All water samples showed the presence of coliform bacteria for the three tests carried out. With the exception of Elerinjare dam raw water sample, Idofian well, Jimba-Oja well and NCAM dam and the Oyun river samples, all other four samples were within permissible range. Four out of the nine sources also indicated the presence of E. coli for the three set of samples tested, while one indicated the presence of E. coli in the two out of the three samplings. This is an indication of faecal pollution of these water sources. The implication of the bacteriological result is that water sources, such as Elerinjare dam (raw), Idofian well, Jimba-oja well, NCAM dam and Oyun river are not fit for human consumption until shock chlorination is carried out to correct their bacteriological status. The population of coliform bacteria detected in the treated Elerinjare dam raw water is comparable to that of untreated water sources, unlike the case of NCAM borehole. This should not be so. It may not be unconnected with insufficient treatment at the treatment plant. Our reconnaissance survey revealed a bad state of the treatment plant. Such indicators include dirty clear water tank, leaking sedimentation tank, rusted pipes, abandoned heavy duty generator, among others.

Table 2. Bacteriological results of water samples

| DESCRIPTION | COLONIES/cc ON NUTRIENT AGAR AT 320C IN 24 HRS | MOST PROBABLE NUMBER OF COLIFORM ORGANISMS IN 100cc | MOST PROBABLE NUMBER OF E.COLI PER 100cc |
|---|---|---|---|
| ELERINJARE DAM (RAW) | >300 | 180+ | 10 |
| ELERINJARE DAM (TREATED) | 37 | 14 | NILL |
| IDOFIAN WELL | 62 | 180+ | 2 |
| JIMBA BOREHOLE | 52 | 13 | NILL |
| JIMBA WELL | 70 | 20 | 2 |
| NCAM WELL | 47 | 19 | NILL |
| NCAM BOREHOLE | 18 | 5 | NILL |
| NCAM DAM | >300 | 180+ | 4 |
| OYUN RIVER | >300 | 180+ | 5 |

It can also be concluded that agricultural activities involving the use of agro-chemicals had no significant effect on the quality of water in and around NCAM as at the time of this study. This may be due to effective application of fertilizers and agro-chemicals on NCAM farm and that percolation of chemicals downstream NCAM is not significant.

## 4. RECOMMENDATIONS

It is recommended that people be given notice not to drink water from the affected sources. It is further recommended that two more samples from all sources be taken in the dry season to confirm their level of pollution. The sources of pollution of these water sources should then be traced and appropriate steps taken to improve the quality of the water from the affected sources in terms of treatment, source protection, or both.

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# APPLICATION OF BUCKINGHAM PI THEOREM IN DEVELOPMENT OF TRACTOR FUEL CONSUMPTION MODEL FOR PLOUGHING OPERATION

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## ABSTRACT

*The estimation of tractor fuel consumption during ploughing operation has been consistently receiving attention as a result of diverse nature, varieties and development in prime movers and dynamic response of soil to tillage operation treatment. The need to use selected soil-implement-machine parameters as factors affecting fuel consumption is necessary. Fuel consumption model for estimating tractor fuel consumption per working area for ploughing operation has been developed using Buckingham's pi theorem. Generalized reduced gradient (GRG), a nonlinear method of Excel solver was used for the establishment of the model's constant. The model was validated by simulating the experimental results into the equation, coefficient determination ($r^2$), graphical comparison, root mean square error, and paired t-Test. The field experiment was performed at Rivers Institute of Agricultural Research and Training (RIART) Farm in Rivers State University, Port Harcourt. Port Harcourt lies on the latitude of 4° 49′ 27″ N, and longitude of 7° 2′ 1″ E; with an altitude of 274mm above mean sea level; and average annual rainfall depth of 2310.9 mm The experimental land area was 138 m by 50 m (6900 $m^2$) which was divided into three blocks of 9 plots each. Each plot was marked out 50 m by 2 m each along with the paths dimension of 1 m between each plot was provided for different treatment options and with a space of 2 m between each block and 1 m at the sides of the of the outer blocks. The group balanced block design (GBBD) was adopted. The design consisted of 9 experimental treatments with three replicates. The experimental fuel consumption per working area was determined by quantity of fuel used per working area with the aid of fuel flow meter. The field test parameters (speed, depth, forward speed, cone index, bulk density) were measured accordingly with their specific standards procedures. The field test parameters (speed, depth, forward speed, cone index, bulk density) results were simulated with fuel consumption to obtain the constants in the estimation model. The developed model displayed good agreement between measured and estimated results with high coefficient of determination ($r^2$) of 0.9974, and low root mean square error of 0.74. The paired t-Test results also showed no significant difference at 95 and 99 % confidence levels. It is as a result, recommended that the model be used for estimating tractor fuel consumption during ploughing operation.*

**Keywords:** Buckingham Pi Theorem, fuel consumption, model, soil-machine-implement parameters

## 1. INTRODUCTION

Ploughing is a primary tillage operation that involves the use of implement such as plough for physical and mechanical soil disturbance for preparing seedbed conducive for crop production. This can be done at sufficient soil moisture content and strength to permit ploughing and provide sufficient and well-organized traction. Ikpo and Ifem (2005) reported that tractor used more energy at the lowest work rate during ploughing operation. Tractor's fuel consumption is affected by many parameters during tillage operation, these include type and structure of soil, climate, tractor type, tractor size and tractor-implement relationship

(Fathollahzadeh *et al*., 2010; Ajav and Adewoyin, 2012; Adewoyin, 2013; Adewoyin and Ajav, 2013). Other fundamental factors that affect fuel consumption in ploughing operation include power consumption increment by increasing the working speed, actual width of cut, soil strength, moisture content and the working depth (Cortez *et al*., 2008; Kichler *et al*., 2011; Silveira *et al*., 2013; Moitzi *et al*., 2014; Leghari, *et al*., 2016; Nasr, 2016). It has been reported by Ekemube *et al*. (2021a, 2021b, 2022a) that the variability in tractor hourly and tiled area fuel consumption during ploughing, harrowing, and ridging operations are influenced by differences in the soil-implement-machine parameters and hence become the decisive factors for the management of fuel consumption during ridging. These soil-implement-machine parameters were the variables to be used in predicting tractor fuel consumption during tillage operations

The prediction of tractor fuel consumption during ploughing operation has been determined by different approaches. These approaches are usually focused on supplies of power and individual engines, which call for extensive engine testing to validate the amount of fuel consumed (Grisso *et al*., 2004; 2010; 2011). Different models have been developed by various researcher to predicted tractor fuel consumption per working area during ploughing operation. Series of linear regression model were used by Serrano *et al.* (2005); Moitzi *et al*. (2014); Ajav and Adewoyin (2012); Adewoyin (2013); Adewoyin and Ajav (2013); and Ranjbarian *et al.* (2015) to develop tractor fuel consumption model for ploughing operation that can express the equation reasonably. Kumar and Pandy (2015) used a visual basic programme for predicting gear and throttle position for best fuel economy with multiple linear regression analysis were used and the collected data in excel spread sheet was fitted to the model structure formulae to determine the coefficients. Similarly, Almaliki *et al.* (2016a); and Lee *et al.* (2016) developed tractor fuel consumption model for predicting fuel consumption during ploughing. Furthermore, Rahimi-Ajdadi and Abbaspour-Gilandeh (2011); Almaliki *et al.* (2016b), development models based on artificial neural network and stepwise multiple range regression for prediction of tractor fuel consumption. Fuel consumption was assumed to be a function of engine speed, throttle and load conditions, chassis. Finally, Shafaei *et al.* (2018); Karparvarfard and Rahmanian-Koushkaki (2015); Nkakini *et al.* (2019a) used dimensional amalysis to develop tractor fuel consumption model during ploughing operation. Igoni *et al*. (2019); and Nkakini *et al.* (2019b) also use dimensional analysis to predict fuel consumption during ridging operation. Further studies were carried out by Ekemube *et al*. (2022b, 2022c) using dimensional analysis to predict fuel consumption per working area during harrowing and ridging operations. The following variables, speed, height, forward speed, cone index, bulk density were used as dependent variables. But, in literature there is a dearth of information on tractor fuel consumption model for predicting fuel consumption per working area for ploughing operation. Therefore, there is need to develop a fuel consumption model in terms of working area using dimensional analysis. The aim of this study is to develop a predictive model for estimating tractor fuel consumption per working area for ploughing operation.

## 2. MATERIAL AND METHODS

### 2.1 Model Derivation

The significance of accurate prediction in any field of engineering cannot be puffed up. Therefore, the mathematical tool that was employed in this work is dimensional analysis using the Buckingham pi theorem. Hence, in this research fuel consumption model development was done using the method of fuel consumption per working area (FCwa, L/ha). Some of the factors affecting tractor fuel consumption were presented in Table 1 and the dimensional matrix in Table 2.

Table 1. Dimensions of Some Variables Influencing Fuel Consumption

| Variables | Symbol | Unit | Dimensions |
|---|---|---|---|
| **Dependent Variable** | | | |
| Fuel consumption | $FCw_a$ | L/ha | $L^3$ $L^{-2}$ (L) |
| Independent Variables | | | |
| Forward speed | V | Km/h | $LT^{-1}$ |
| Ploughing depth | d | m | L |
| Cone index | CI | $N/cm^2$ | $ML^{-1}T^{-2}$ |
| Bulk density | P | $g/cm^3$ | $ML^{-3}$ |
| Width of cut | W | m | L |

Table 2. Dimensional Matrix of the Variables

| Dimension s | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | $FC_{wa}$ | V | d | CI | $\rho_b$ | W |
| M | 0 | 0 | 0 | 1 | 1 | 0 |
| L | 1 | 1 | 1 | -1 | -3 | 1 |
| T | 0 | -1 | 0 | -2 | 0 | 0 |

Fuel consumption, $FC_{wa}$ is a function of (d, W, V, CI, $\rho_b$)
Mathematically;
$FC_{ta} = f(d, W, V, CI, \rho_b)$ (1)
The dependent variable = $FC_{wa}$
Total number of variables, n = 6
Total number of fundamental dimensions, m = 3
Therefore, number of dimensionless groups ($\pi$- terms) to be formed = n – m = 6 – 3 = 3
Equation 2 can be written as:
$f(\pi_{1,}\pi_2, \pi_3)$ (2)
Each $\pi$- term contains (m + 1) variables, where m = 3 and is also equal to repeating variable choosing from $\rho_b$, W, S as repeating variables, we get five $\pi$- terms as:
$\pi_1 = \rho_{b,}{}^{a_1}. W^{b_1}. V^{c_1}. FC_{ta}$ (3)
$\pi_2 = \rho_{b,}{}^{a_2}. W^{b_2} V^{c_2}. d$ (4)
$\pi_3 = \rho_{b,}{}^{a_4}. W^{b_4} V^{c_4}. CI$ (5)

2.1.1 Transformation to dimensionless parameters

A new set of pi terms can be generated by multiplying or dividing present pi terms with each other. In addition, the present pi terms can be reversed to make a new pi term. This is to ensure simplicity in the experimentation process. The present pi terms($\pi_{1,}\pi_2, and\ \pi_3$) can be adjusted to generate a new pi term (Langhaar, 1980; Tarham and Carman, 2004; Nkakini *et al*., 2019a, 2019b; Igoni *et al*., 2019).

$\pi_1$Terms
$\pi_1 = \frac{FC_{tw}}{W}$ (6)

$\pi_2$ – Terms

$$\pi_2 = \frac{d}{W} \quad (7)$$

$\pi_3$ – Terms

$$\pi_3 = \frac{CI}{\rho_b S^2} \quad (8)$$

Substituting the values of $\pi_{1,}\pi_2, \pi_{3,}\pi_4 and \pi_5$ in equation (2), we get;

$$f\left(\frac{\mathrm{FC}_{wa}}{\mathrm{W}}, \ \frac{d}{W,} \frac{CI}{\rho_b V^2}\right) = 0 \quad (9)$$

2.1.2 Formulation of the fuel consumption model

The method of product and quotient component functions of pi terms were adopted for development of the fuel consumption model. This prognostic model was developed by simple multiplication and division of the component equations. The validity of combining the equation components by multiplication and division were tested by assuming that the general prediction model is obtained by simple multiplication and division of the pi terms (equations 10 and 11).

Let establish $\pi_1^1$ by dividing equation 7 by equation 8, we get;

$$\pi_1^1 = \frac{\pi_2}{\pi_3} = \frac{\frac{d}{\mathrm{W}}}{\frac{CI}{\rho_b V^2}} \quad (10)$$

$$\pi_1^1 = \frac{\rho_b s^2 d}{CIW} \quad (11)$$

Hence, the relationship becomes

$$\pi_1 = K_{FC} f(\pi_1^1) \quad (12)$$

$$\frac{\pi_1}{\pi_1^1} = K_{FC} \quad (13)$$

Substituting the values of $\pi_1$ and $\pi_1^1$ into equation (123.69), we get:

$$\frac{\mathrm{FC}_{wa}}{\mathrm{W}} = K_{FC}\left[\frac{\rho_b V^2 d}{CIW}\right] \quad (14)$$

$K_{FC}$ can be calculated using method of GRG in excel solver and the constant obtained becomes the $K_{FC}$ value

$$\therefore K_{FC} = \frac{\mathrm{FC}_{wa} CI}{\rho_b V^2 d} \quad (15)$$

Rearranging equation (143.71), it becomes:

$$FC_{ta} = K_{FC}\left[\frac{\rho_b V^2 d}{CI}\right] \quad (16)$$

The equation (16) expresses the tractor fuel consumption per working area during ploughing operation.

where,

$FC_{wa}$ = Fuel consumption per working area (L/ha),
$K_{FC}$ = Fuel consumption constants
CI = Cone Index (N/cm$^2$),
V = Tractor forward speed (Km/h)
d = ploughing depth (m)

2.1.3 Model validation

The developed model was validated by simulating the experimental data in to the model and then compare the experimental with the prediction data. Under the varying factors of treatment parameters (ploughing depth, forward speed, cone index and bulk density) that were used for ploughing operation. These parameters were determined experimentally and substitute into the formulated model to compute the predicted fuel consumption per working area. Also, the root mean square error (RMSE) was used to check the error difference as represented in equation (17).

$$RMSE = \sqrt{\frac{\sum_{i-1}^{i-N}\left(FC_{wa(m)} - FC_{wa(E)}\right)^2}{N}} \tag{17}$$

where,

N = number of samples,

$FC_{wa(m)}$ = measured fuel consumption (L/ha)

$FC_{wa(E)}$ = estimated fuel consumption (L/ha).

Furthermore, the developed model was validated with regression curve and coefficient of determination ($r^2$) to check if the measured and predicted results have good agreement and graphical comparison of measured and predicted results as well the paired t- test as presented in equation (18) was considered as significant at $t_{computed} > t_{table}$ (95 and 99 % confidence) levels.

$$t = \frac{\sum D/N}{\sqrt{\frac{\sum D^2 - \left(\frac{(\sum D)^2}{N}\right)}{(N-1)(N)}}} \tag{18}$$

where,

$\sum D$ = summation of the differences.

$\sum D^2$ = summation of the squared differences,

$(\sum D)^2$ = summation of the differences squared.

N = number of samples

## 2.2 Experimental Site Description

This experiment was performed at the Rivers Institute of Agricultural Research and Training (RIART) farm at Rivers State University, Port Harcourt. In Port Harcourt, agriculture is well practiced and the agricultural products are namely food crop, cash crop, fish and animal. Port Harcourt lies on the latitude of 4° 49′ 27″ N, and longitude of 7° 2′ 1″ E; with an altitude of 274mm above mean sea level; and average annual rainfall depth of 2310.9 mm. The ambient environment (i.e., Port Harcourt metropolis) having a mean monthly relative humidity of 85%, a daily minimum temperature about $23^0$C and a mean daily maximum temperature of $32^0$C.

## 2.3 Experimental Design

The experimental design used in this study is group balanced block design (GBBD). A farm size of 138 m by 50 m (6900 $m^2$) was divided into three plots of 9 sub-plots each. Each sub-plot of 50m by 2m was marked with a 1m alley. The sub-plot was provided for different treatment options and with a space of 2 m between each block and 1 m at the sides of the outer blocks (Figure 1).

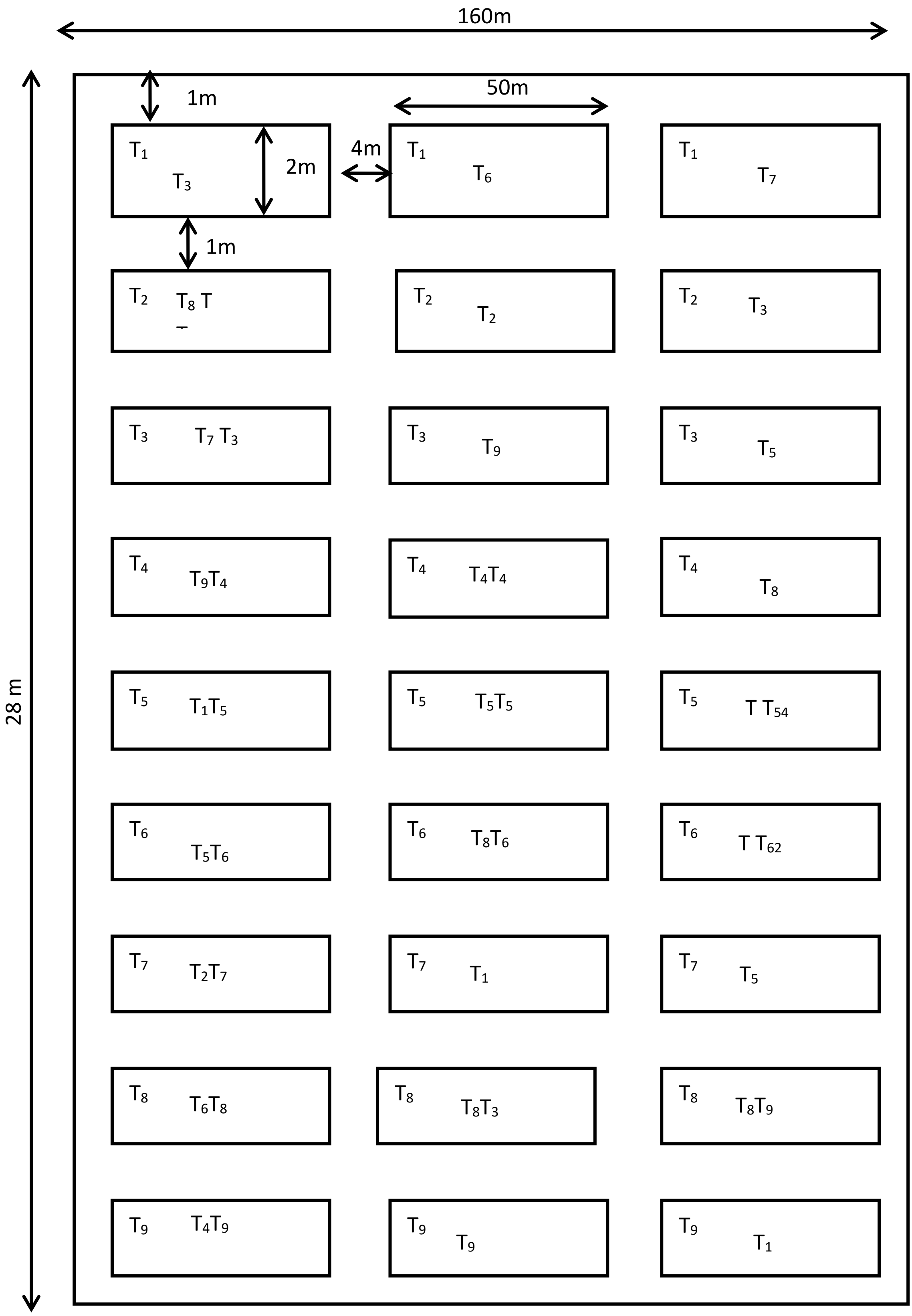


Figure 1. Layout of nine treatment randomized with three replications (note: the diagram is not to scale)

$T_1$: Ploughing with depth of 0.10 m at speed of 5 $Kmh^{-1}$

$T_2$: Ploughing with depth of 0.10 m at speed of 7 $Kmh^{-1}$

$T_3$: Ploughing with depth of 0.10 m at speed of 9 $Kmh^{-1}$

$T_4$: Ploughing with depth of 0.20 m at speed of 5 $Kmh^{-1}$

$T_5$: Ploughing with depth of 0.20 m at speed of 7 $Kmh^{-1}$

$T_6$: Ploughing with depth of 0.20 m at speed of 9 $Kmh^{-1}$

$T_7$: Ploughing with depth of 0.30 m at speed of 5 $Kmh^{-1}$

$T_8$: Ploughing with depth of 0.30 m at speed of 7 $Kmh^{-1}$

$T_9$: Ploughing with depth of 0.30 m at speed of 9 $Kmh^{-1}$

## 2.4 Tractor and Implement Specifications

The tractor used to perform the ploughing operation was A two-wheel drive tractor Swaraj 978 FE (Swaraj, India) was used for this study (Plate 1). The tractor has a total weight of 3015kg, engine horsepower of 72 hp and lifting power of 2200 kg. Front and the rear tyres were 7.5–16, 8 ply and 16.9 – 28, 12 radial respectively. A 1180 mm frame width mounted-type disc plough with disc diameter of 300 mm of disc plough (Baldan Implementos Agricolas, Brazil) with 3-disc bottom mounted on a gauge wheel was used for the experiments (Plate 2). Also, a DFM 100CD fuel flow meter (Technoton Engineering, Belarus) has nominal fuel pressure 0.2 MPa, maximum fuel pressure 2.5 MPa, minimum kinematic viscosity 1.5mm$^2$/s, maximum kinematic viscosity 6.0 mm$^2$/s, minimum supply voltage 10 V and maximum supply voltage 45 V (Plate 3).

Plate 1. The Swaraj 978 FE Tractor (Swaraj, India**)**

Plate 2. The disc plough (Baldan Implementos Agricolas, Brazil) used in this study

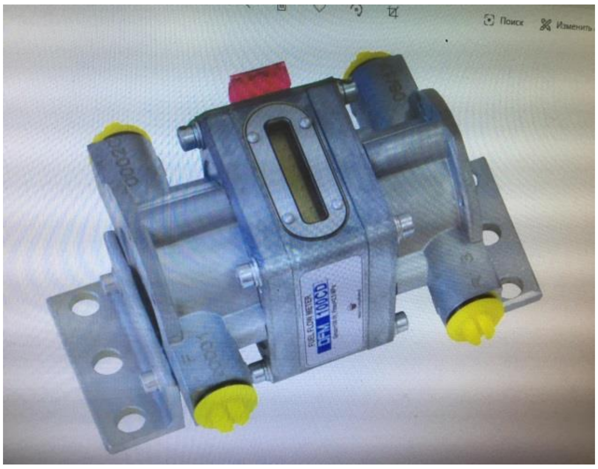


Plate 3. DFM 100CD fuel flow meter (Technoton Engineering, Belarus) used in thisstudy

### 2.5 Methods

Preceding ploughing operation, soil core was used for obtaining the soil sample from the depth of 0 – 10, 10 – 20 and 20 - 30 cm respectively at random in the field to determined textural classification of the soil and the bulk density. The collected soil samples were taken to the laboratory for analysis. The parameters such as textural classification of the soil was determined by hydrometer method and the bulk density was determined using core method (Walter *et al.*, 2016).

The disc plough was attached to the tractor and levelled using the top links of the tractor in order to reduce parasitic forces. Then, harrowing depths were determined by setting the level control of the lifting mechanism (three-point linkage height) to lower the disc plough to the desired ploughing depth. Tractor forward speeds were determined by selecting a particular gear that gave the desired speed. This was done in a practice area in advance for each test plot to maintain the desired treatment. The ploughing depth measurement was done by placing the meter rule from furrow bottom to the surface of the ploughed land, while the width of cut was measured by placing a steel tape from one side of the furrow wall to the other end. These were done after each operation. Time was determined with a stopwatch set at zero before each operation. The cone index was also determined using a cone penetrometer.

The digital method of measuring the quantity of fuel used was adopted to determine tractor fuel consumption. During this process, the use of DFM fuel flow meter was employed to measure fuel consumption. The metre was mounted on the fuel line between the tractor's fuel tank and the pump. At the end of each test operation the data was taken from the fuel flow meter as display information, switching is performed by light touch to the top cover of fuel flow meter by iButton key. Mathematically, fuel consumption per working area was calculated by expression in equation 19:

$$FC_{wa} = \frac{10 \times T_{fc}}{V \times W \times E \times h} \quad (19)$$

where,

FCwa = Tilled area fuel consumption, L/ha;
$T_{fc}$= Tractor fuel consumption, L;
V = Forward speed, Km/h;
W = Implement width, m
E = Implement field efficiency, %;
h = Working hour h

## 3. RESULTS AND DISCUSSION

### 3.1 Establishment of constant($K_{FC}$) for Fuel Consumption per working Area

From equation 16, $K_{FC}$was constants for the fuel consumption model developed using Buckingham pi theorem. The generalized reduced gradient (GRG) method of excel solver was used to compute the constants by simulating measured field test results d, V, CI, $\rho_b$, measured FCwa, predicted FCwa, and error sum of squared. Therefore, the values for the constants ($K_{FC}$) was established for tractor fuel consumption model for ploughing operation (Table 3). It is represented as:
$K_{FC} = 113.2993$

The computed constant ($K_{FC}$) of the model developed was fitted into the fuel consumption model established. Thus, from the model constants of 113.2993 has been established. The results showed acceptable agreement with minimum error ranging from 0.00169 to 0.253165, revealing the reliability and acceptability of the model applied. Therefore, fuel consumption per working area model established for ploughing operation attractor forward speed of 1.39, 1.94 and 2.50 m/s; ploughing depths of 0.10, 0.20 and 0.30 m; cone index of 195.31, 234.38 and 273.44 N/cm$^2$ respectively is:

$$FC_{ta} = 113.2993 \left[\frac{\rho_b s^2 d}{CI}\right] \quad (20)$$

This model is similar Ekemube *et al*. (2022b, 2022c) that used generalized reduced gradient (GRG) method of excel solver was used to compute the constants by simulating measured field test results d, V, CI, $\rho_b$, measured FCwa, predicted FCwa, and error sum of squared.

Table 3. Fuel Consumption per working area and operating conditions for ploughing

| Treatment | Parameters | | | | | | (Error)$^2$ |
|---|---|---|---|---|---|---|---|
| | ρb (g/cm$^3$) | V Km/h | CI (N/cm$^2$) | d (m) | Measured FCwa, L/ha | Estimated FCwa, L/ha | |
| 1 | 1.55 | 5.00 | 195.31 | 0.10 | 2.08 | 2.2479 | 0.028186 |
| 2 | 1.55 | 7.00 | 195.31 | 0.10 | 4.59 | 4.4059 | 0.033908 |
| 3 | 1.55 | 9.00 | 195.31 | 0.10 | 6.78 | 7.2832 | 0.253165 |
| 4 | 1.69 | 5.00 | 234.38 | 0.20 | 4.15 | 4.0847 | 0.00426 |
| 5 | 1.69 | 7.00 | 234.38 | 0.20 | 8.49 | 8.0061 | 0.234185 |
| 6 | 1.69 | 9.00 | 234.38 | 0.20 | 13.21 | 13.2345 | 0.000602 |
| 7 | 1.85 | 5.00 | 273.44 | 0.30 | 5.68 | 5.7491 | 0.004772 |
| 8 | 1.85 | 7.00 | 273.44 | 0.30 | 11.23 | 11.2682 | 0.001459 |
| 9 | 1.85 | 9.00 | 273.44 | 0.30 | 18.64 | 18.6270 | 0.000169 |

$K_{FC}$ = 113.2993 and $SS_E$ = 0.560705, d = depth of cut, V = forward speed, CI = cone index, $\rho_b$ = bulk density, measured FCwa = measured fuel consumption per working area, and predicted FCwa = predicted fuel consumption per working area

### 3.2 Validation of Mathematical Models for Estimating Tractor Fuel Consumption per Working Area

The representativeness of a developed model for solving a particular problem depends on its estimates and validation. Results of the developed fuel consumption model for ploughing operation was by substitution of the results of a number of measured data which is being compared with the measured tilled fuel consumption per working area as shown Table 3. Figures 2 and 3 showed the graphical comparison between measured and estimated fuel consumption per working area values. It was observed that the model has a high relationship with measured data from the ploughing operation with coefficient of determination ($r^2$) value of 0.9974. This showed that the model can expressed the experimental data 99.74 %. Also, comparing the means of estimated and measured data statistically, it was revealed that the root mean square error (RMSE) analysis which illustrated the error differences between the measured and estimated results is 0.74. In addition, the paired t-Test was used to determine the level of significance between the means of measured and estimated tilled area fuel consumption at 0.05 and 0.01 significance levels. The value of the paired t-Test is $t_{calculated}$ (0.13) that is less than $t_{table}$ values (2.306 and 3.355) (i.e., $t_{cal} < t_{tab}$). This pointed out that there is no significant difference between the measured and the estimated data. This was comparable to the findings Ekemube *et al*. (2022b, 2022c) that developed fuel consumption model of a tractor during harrowing and ridging using dimensional analysis. Also, Nkakini *et al*. (2019a, 2019b) used dimensional analysis in Buckingham pi theorem to develop fuel consumption model for ploughing and harrowing operations. As well, Igoni *et al*. (2019) used dimensional analysis to modelled fuel consumption for ridging operation.

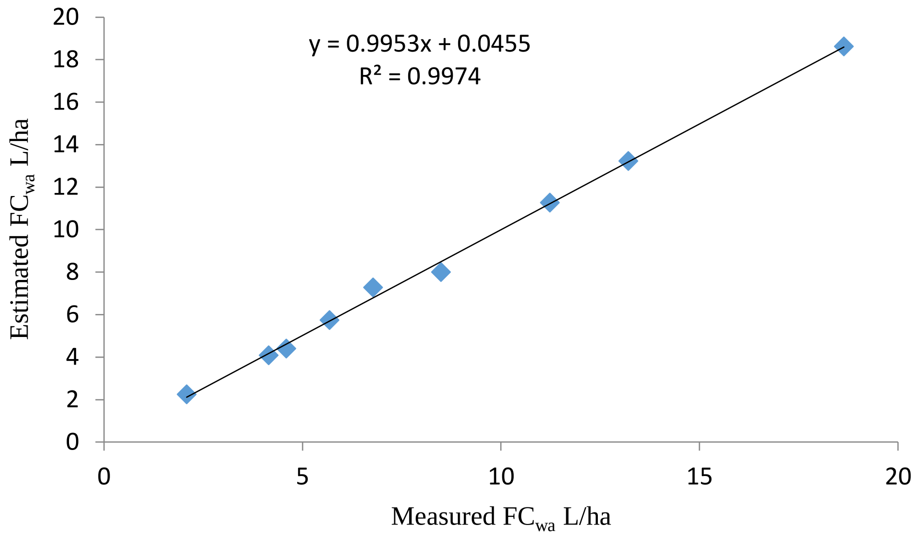


Figure 2. Estimated Vs measured fuel consumption per working hour for ploughing

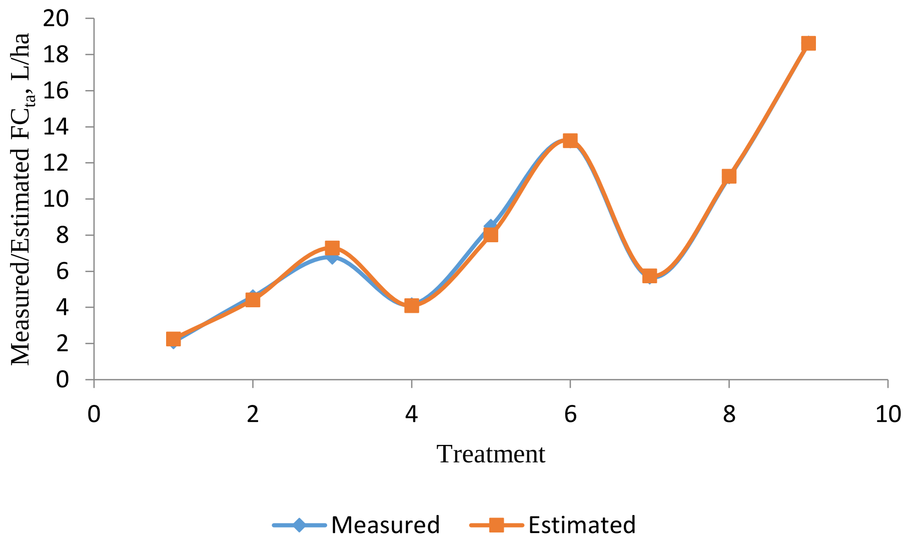


Figure 3. Measured and estimated fuel consumption per working area Vs treatment for ploughing

## 4. CONCLUSION

This study had developed a tractor fuel consumption model for ploughing operation to ensure estimation of fuel consumption per working area usage. The following conclusions were drawn from the obtained results:

i. A model for estimating tractor fuel consumption per working area in course of ploughing operation has been developed.

ii. The developed model constant ($K_{FC}$) for ploughing operation with respect to the equipment used was obtained as 113.2993.

iii. Model estimation achieved in this study can be categorized as almost good for high coefficient of determination ($r^2$), low root mean square error, and paired t Test calculated was less than the table value.

iv. Therefore, these results showed acceptable agreement with measured and estimated model results. These proved that the model can estimate experimental data precisely.

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