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# WATER PRODUCTIVITY OF IMPROVED CASSAVA VARIETIES UNDER TROPICAL RAIN-FED CONDITIONS

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## Abstract
*In most sub-Saharan African countries, cassava propagation occurs through dry farming techniques that involve cultivation without irrigation, which inhibits water management culture. This study investigated the water productivity of enhanced cassava cultivars in tropical rain-fed locations with dry farming conditions. Soil samples were obtained from three locations in the field using a soil auger and sieve analysis. Four enhanced stem cassava varieties free of disease (TMS 30572, TMS 980505, TMS 920326, and TMS 090581) were analyzed for growth characteristics for 90, 120, and 150 days after planting (DAP), and the number of tubers per plant, tuber length, tuber circumference, root depth, above ground biomass, and tuber yield were measured. Agronomic growth metrics, including height of plant, stem diameter, and number of nodes and stems, were also measured. The cassava crop coefficient was obtained and the reference crop evapotranspiration was computed using CropWat 8.0 software. TMS 090581 had the highest tuber productivity of 1.64 kg/m$^3$, 3.77 kg/m$^3$ and 3.05 kg/m$^3$ and the highest average tuber yield value of 5.68 t/ha,16.06 t/ha and 18.75 t/ha at 90, 120 and 150 DAP, respectively. TMS 920326 resulted in the highest stem productivity of 1.98 kg/m$^3$ and 2.72 kg/m$^3$ at 90 and 150 DAP respectively while TMS 30572 had the highest stem productivity of 2.59 kg/m$^3$ at 120 DAP. The highest leaf productivity of 1.94 kg/m$^3$ was attained by TMS 980505 at 90 DAP while TMS 30572 yielded the highest leaf productivity values of 2.32 kg/m$^3$ and 2.02 kg/m$^3$ at 120 and 150 DAP, respectively. Despite being susceptible to white flies, TMS 30572 yielded the highest number of nodes, resulting in increased leaf production. TMS 090581 is recommended for tuber water productivity, and TMS 30572 and 980505 for leaf and stem productivity in water-scarce environments.*

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## 1.0 INTRODUCTION
Cassava (*Manihot excellent*) is a *Tuphorbiallae* perennial woody plant. It is grown for its tuberous roots, although its leaves are consumed in Africa and are fed to animals in Asia. The roots comprise 25-35% starch, whereas the leaves contain proteins and other minerals [1], [2], [3]. Cassava can survive harsh environmental conditions and grow in poor soils. Cassava is a staple plant in tropical regions. Cassava is used to make fufu, gari, fun, and kapu and is an inexpensive carbohydrate source for rural and urban groups [4], [5], [6]. Several researchers have focused on enhancing the resilience of cassava to diseases and pests, as well as increasing its production and promoting early maturity [7], [8], [9]. Water management in cassava propagation has received less attention as the cultivation of cassava in Sub-Saharan

Africa depends on available rain-fed conditions. Water is one of the essential factors needed for plant growth and development therefore, the desire for water conservation and management in the practices of agriculture which include crop production cannot be overemphasized.

Water-deficient areas grow cassava with minimal irrigation and conventional surface irrigation loses most of the irrigation water to evaporation and deep percolation, reducing crop efficiency, and the plant's developing tissue contains more than 80% water. Water is required for most plant processes; hence, the amount, timing, technique, quality, and micrometeorological conditions of irrigation affect plant health and productivity [10]. According to Ahluwalia et al. [11], the plant output is limited by the inability of the root system to meet these demands. An evaluation of cassava production, demand, and use patterns is required in Nigeria to address the renewed focus on cassava production, supply, processing, and utilization. This assessment should also consider the potential of cassava in addressing hunger and providing food security for vulnerable groups, including mothers and infants.

Cassava is considered climatic and soil resistant. It grows when the grains and other crops fail. It grows in drought-prone, low-nutrient soils. Better stem and input management can improve cassava productivity [12], [13]. Most people in the lowlands and sub-humid tropics of West and Central Africa receive dietary energy from cassava [14]. Food policies must prioritize production and use. Owing to limited access to fertilizers and pesticides, cassava farmers still need to achieve technical efficiency [15].

In the 16th century, the cultivation of cassava, a perennial woody shrub possessing edible roots, was initiated in South America and subsequently spread to Nigeria [2]. Nevertheless, cassava is commonly regarded as a staple food for individuals living in poverty [16], [17] and has faced significant criticism due to its propensity to deplete soil nutrients and render arable land susceptible to erosion [18]. Consequently, numerous cassava crops are cultivated in marginal regions characterized by unfavourable terrain, which are generally not conducive to competition with other crops, and some require tractor-friendly conditions. A further challenge associated with cassava production pertains to the land tenure structure in Nigeria and other sub-Saharan African nations, which necessitates the facilitation of mechanization on large-scale farms. Many cassava farmers cultivate tiny parcels of land that may be more advantageous or cost-effective for mechanization.

Abass et al. [19] claimed that enhancing inputs in isolation, without the implementation of mechanization, is insufficient to adequately augment cassava production in Nigeria. Notwithstanding these obstacles, cassava has emerged as a rapidly expanding staple crop in nations relying heavily on cassava consumption [17], [20]. It has become increasingly important for farmers and industrial demand has steadily increased [21]. Globally, cassava is growing steadily at more than 3% per year [22]. According to the FAO [22] and FAO Statistics [23], global cassava production was approximately 278 million tons in 2018, and Africa's overall production was approximately 170 million tons (approximately 56% of global production). During the same era, Nigeria produced approximately 60 million tons [23].

Cassava root and product demands are rising significantly. Food production cannot match the sub-region 's geometrically expanding population demand [22]. Nigeria, the world's largest producer of cassava, needs better yield performance in relation to output per hectare. Ineffective agronomic practices and production resource management may result in poor yield [18]. According to Moyo [24], poor agricultural land management in Sub-Saharan Africa hinders food production. This has resulted in the inefficient utilisation of productive resources in the agriculture sector. [18], [25], although more than 60% of Nigerians work in agriculture [24], [26].

Cassava products are growing in popularity in Nigeria's food and agriculture markets. This provides a compelling motivation for economic stakeholders to engage in the cassava market. According to FAO [22], cassava is highly valued for its potential to promote rural development, alleviate poverty, foster economic growth, and ensure food security. Against this background, key stakeholders have consistently made significant contributions to the discourse around the advancement of the cassava subsector in Nigeria. Eke-Okoro and Njoku [27] established the phases of previous initiatives aimed at enhancing cassava cultivation in Nigeria as follows: the cusp phase, which spanned from 1940 to 1953; the first phase, which spanned from 1970 to 1995; and the preliminary phase, which ranged from 1940 to 1953, and 1996 to the present. This study aimed to estimate the water productivity of four enhanced cassava varieties under rainfed conditions to recommend the best variety to local and partisan cassava growers in Ibadan, Nigeria.

## 2.0 MATERIALS AND METHODS

### 2.1 Description of Study Area

The research was performed in the experimental field of agricultural and environmental engineering, which is located at the Faculty of Technology, the University of Ibadan. The experimental area was located between 7.4417°N and 3.9000°E at an approximate altitude of 227 m and Figure 1 shows the pictorial view of the study area.

**Figure 1:** Pictorial view of the study area

### 2.2 Cassava Varieties

In the experimental research field, four new and enhanced cassava varieties (TMS 30572, TMS 980505, TMS 920326, and TMS 090581) were acquired from the International Institute for Tropical Agriculture (IITA) located in Ibadan, Nigeria. The experiment was designed using a Latin square design with four treatments and four replicates. The land area used for cultivation is $16 \times 8$ m$^2$. Four varieties were planted in the field at a spacing of 1 m × 1 m. Each plot was 4 m × 4 m in size, and there were four plots because they were divided by a 1 m wide area. In addition, 128 cassava stalks 20–25 cm in length were planted at an angle.

### 2.3 Field Measurement

Field measurements were performed using a measuring tape and peg. Land clearing was performed manually using crude implements such as cutlass, hoe, and rake. Land preparation involves using hoes to create ridges. Copex was applied to the stem cuttings before planting to prevent nematode attack on the stem. Cassava stems (cultivars TMS 30572, 980505, 920326, and 090581) were planted. All plots were manually weeded after planting at every two weeks intervals at the initial stage and after three weeks due to the reduced growth rate of the unwanted plants. Soil samples were obtained from three locations in the field, using a soil auger. The samples were weighed using a weighing balance and then dried in an oven at a temperature of 105$^o$C. Sieve analysis was performed using standard sieves, and soil texture was determined using a textural triangle. The soil in the experimental field was sandy loam.

### 2.4 Agronomic Parameter

Agronomic growth metrics included plant height, stem diameter, and number of nodes and stems. Plant height was measured using a meter rule from the base of the plant to the tip of the youngest leaf. The harvested plants were divided into leaves, stems, and tubers, and the production of tubers, stems, and leaves was measured. Average tuber length, root depth, number of tubers per plant, and tuber circumference were measured.

### 2.5 Weather Parameter

A weather station was used to track the amount of rainfall, ambient temperature, relative humidity, wind speed, and daylight hours throughout the experiment. Harvesting operations were carried out 90, 120, and 150 days after planting (the third, fourth, and fifth months, respectively). The various yield parameters obtained from the cassava varieties at 90, 120, and 150 days after planting (DAP) included the number of tubers per plant, tuber length (m), tuber circumference (m), root depth (m), above ground biomass (kg/plant), and tuber yield (t/ha).

### 2.6 Crop Water Requirements

The crop production model methodology is based on the water productivity concept and a yield reduction function based on the ratio of actual evapotranspiration to potential evapotranspiration. The crop water requirement relation was applied, and the cassava crop coefficient (Kc) was obtained from Allen et al. [28], whereas the reference crop evapotranspiration ($ET_o$) was computed using CropWat 8.0 software. The effective rainfall was also computed from CropWat 8.0 software using the fixed percentage (80%) method. The reference evapotransp-iration was computed daily from the temperature, relative humidity, wind speed, and sunshine hour data obtained from the weather station using CropWat 8.0 software. The crop evapotranspiration was computed using a standard method. Crop evaporation values were obtained at 90, 120, and 150 DAP.

### 2.7 Water Productivity

Water productivity expresses the yield that can be produced from a certain volume of water. The productivity values of the water index depend on variety, climate, soil, and water management. Water safety can be attained globally if agricultural produce is transacted between countries with good and poor water productivity [29].

### 2.8 Crop Water Productivity

Molden et al. [30] who originally developed the idea, conducted a groundbreaking study on water productivity (WP). They stated that water productivity can be calculated by dividing crop yield by the total amount of water utilized for effective rainfall. Agricultural water productivity is the yield or biomass output (kilograms $kgm^{-3}$) of the crop water. The crop sample data were gathered monthly from the third 30 days to the fourth 30 days. The amount of water applied to the crops was calculated based on actual rainfall. Using the data gathered, an estimate of the crop yield $kgha^{-1}$ for each variety was made. Utilizing the following relationship, the crop water productivity was calculated:

$$CWP = \frac{Total\ Yield\left(\frac{kg}{ha}\right)}{ER\left(\frac{m3}{ha}\right)} \quad (1)$$

Where, CWP is the crop water productivity ($kg/m^3$) and ER: Effective rainfall ($m^3/ha$).

To ascertain the impact of plant height, cultivar diameter, number of nodes, and stem diameter on aboveground weight biomass and tuber production, growth parameters in response to cassava cultivar yield after 90, 120, and 150 planting days were analyzed using regression analysis.

## 3.0 RESULTS AND DISCUSSIONS

The crop water productivity was expressed in terms of leaf, stem, and tuber productivity. The yield attributes (cassava yield) were determined after harvest and statistical analysis of the growth parameters of cassava varieties TMS 30572, TMS 980505, TMS 920326, and TMS 090581, which were monitored weekly. The results showed variations among cassava varieties based on their growth and productivity under rain-fed conditions. At a 0.05 significance level (95% confidence level), the statistical analysis of the growth parameters showed no variation in the growth among the four varieties planted across the field.

The analysed data on cassava growth parameters showed no significant differences in the number of nodes, plant height, or stem diameter for almost all four varieties and four replicates. This may be because the plants were under the same conditions, that is, water application (rain-fed condition) and soil nutrient assumption to be constant, because of the field Latin-Square experimental design.

The Total Rainfall values at 90, 120, and 150 days after planting were obtained from weather station data and computed to be 431.7, 532.5, and 768.1 mm, respectively. The computed effective rainfall values obtained were 345.3, 425.9, and 614.4 mm at 90, 120, and 150 days after planting, respectively.

Water productivity, expressed in terms of tuber productivity ($kg/m^3$), stem productivity ($kg/m^3$), and leaf productivity ($kg/m^3$), was calculated for each cassava variety. The crop yields (leaf, stem, and tuber) are expressed in kg/ha, whereas the water supplied to the field is expressed in m3/ha. The volume of water supplied to the field during effective rainfall was 3453 $m^3/ha$, 4259 $m^3/ha$, and 6144 $m^3/ha$ at 90, 120, and 150 days after planting, respectively. Table 1 shows the values obtained on the average yield of cassava varieties under rainfed conditions.

**Table 1:** Average Water Productivity (At 90, 120 and 150 DAP)

| Variety | $TY_1$ | $TY_2$ | $TY_3$ | $TP_1$ | $TP_2$ | $TP_3$ | $SP_1$ | $SP_2$ | $SP_3$ | $LP_1$ | $LP_2$ | $LP_3$ | $ABW_1$ | $ABW_2$ | $ABW_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30572 | 4.37 | 15.25 | 15.54 | 1.27 | 3.58 | 2.53 | 1.56 | 2.59 | 2.13 | 1.34 | 2.32 | 2.02 | 1.00 | 2.10 | 1.15 |
| 980505 | 4.97 | 10.02 | 13.35 | 1.44 | 2.35 | 2.17 | 1.95 | 2.02 | 1.84 | 1.94 | 2.16 | 1.51 | 1.34 | 1.78 | 2.06 |
| 920326 | 3.08 | 7.93 | 17.97 | 0.89 | 1.86 | 2.93 | 1.98 | 2.05 | 2.72 | 1.57 | 1.40 | 1.42 | 1.23 | 1.47 | 2.5 |
| 090581 | 5.68 | 16.06 | 18.75 | 1.64 | 3.77 | 3.05 | 1.95 | 2.18 | 1.67 | 1.27 | 1.80 | 1.07 | 1.12 | 1.69 | 1.69 |

Where, $TY_1$ = Tuber Yield at 90 Days after planting (tonnes/ha), $TY_2$ = Tuber Yield at 120 Days after planting (tonnes/ha), $TY_3$ = Tuber Yield at 150 Days after planting (tonnes/ha), $TP_1$ = Tuber Productivity at 90 Days after planting ($kg/m^3$), $TP_2$ = Tuber Productivity at 120 Days after planting ($kg/m^3$), $TP_3$ = Tuber Productivity at 150 Days after planting ($kg/m^3$), $SP_1$ = Stem Productivity at 90 Days after planting ($kg/m^3$), $SP_2$ = Stem Productivity at 120 Days after planting ($kg/m^3$), $SP_3$ = Stem Productivity at 150 Days after planting ($kg/m^3$), $LP_1$ = Leaf Productivity at 90 Days after planting ($kg/m^3$), $LP_2$ = Leaf Productivity at 120 Days after planting ($kg/m^3$), $LP_3$ = Leaf Productivity at 120 Days after planting ($kg/m^3$), $ABW_1$ = Aboveground Biomass Weight (kg/Plant) at 90 Days after planting, $ABW_2$ = Aboveground Biomass Weight (kg/Plant) at 120 Days after planting, $ABW_3$ = Aboveground Biomass Weight (kg/Plant) at 150 Days after planting.

Figures 2–4 show the variation in Tuber, Stem, and Leaf Productivity among the four cassava varieties. Figure 2 showed that TMS 090581 had the highest Tuber Productivity (1.64 $kg/m^3$) while TMS 920326 had the lowest Tuber Productivity (0.89 $kg/m^3$). Figure 3 shows that TMS 920326 had the highest Stem Productivity (1.98 $kg/m^3$), TMS 980505 and 090581 had very close Stem productivity (1.95 $kg/m^3$), while TMS 30572 had the lowest Stem Productivity (1.56 $kg/m^3$). Figure 4 shows that TMS 980505 had the highest Leaf Productivity (1.94 kg/m$^3$) while TMS 090581 had the lowest (1.27 kg/m$^3$).

From Table 1, TMS 090581 gave the highest average tuber yield value of 5.68 t/ha, while TMS 920326 had the lowest average tuber yield value (3.08 t/ha) at 90 DAP under rain-fed conditions. Based on the above biomass weight (kg/plant), TMS 980505 had the highest value on average (1.34 kg/Plant), while TMS 30572 had the lowest average value (1.00 kg/Plant).

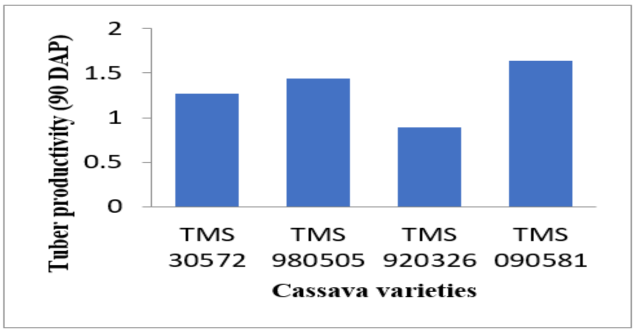


**Figure 2:** Tuber productivity (90 DAP)

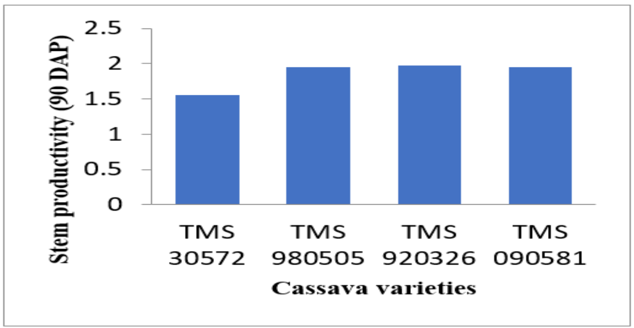


**Figure 3:** Stem productivity (90 DAP)

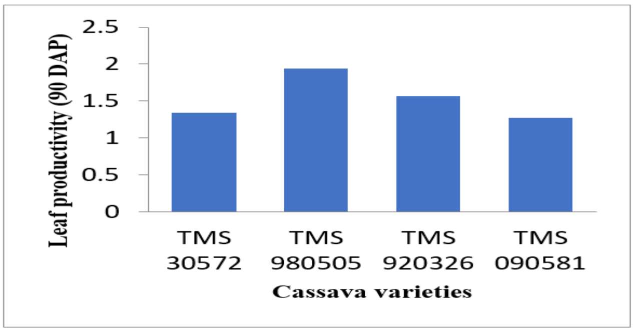


**Figure 4:** Leaf Productivity (90 DAP)

Figures 5–7 show the variation in Tuber, Stem, and Leaf Productivity among the four cassava varieties. Figure 5 showed that TMS 090581 had the highest Tuber Productivity (3.77 kg/m$^3$), TMS 30572 also had a relatively high tuber productivity of 3.58 kg/m$^3$ while TMS 920326 had the lowest Tuber Productivity (1.86 kg/m$^3$). Figure 6 shows that TMS 30572 had the highest Stem Productivity (2.59 kg/m$^3$), whereas TMS 980505 had the lowest (2.02 kg/m3). Figure 7 shows that TMS 30572 had the highest Leaf Productivity (2.32 kg/m$^3$) while TMS 920326 had the lowest Leaf Productivity (1.40 kg/m$^3$). As shown in Table 1, TMS 090581 resulted in the highest average tuber yield value of 16.06 t/ha, TMS 30572 gave a relatively high average tuber yield (15.25 t/ha), and TMS 920326 had the lowest average tuber yield (7.93 t/ha) as at 120DAP under rainfed conditions. Based on the biomass weight (kg/plant), TMS 30572 had the highest value (2.10 kg/plant), whereas TMS 920326 had the lowest value (1.47 kg/plant).

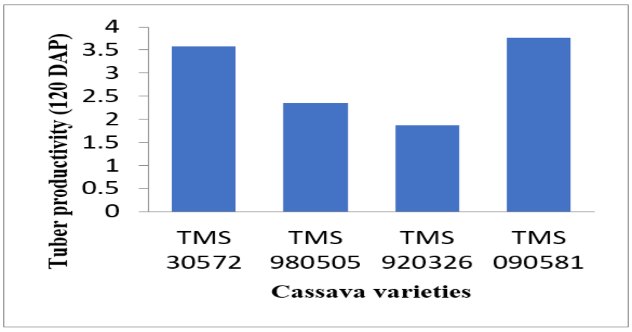


**Figure 5:** Tuber Productivity (120 DAP)

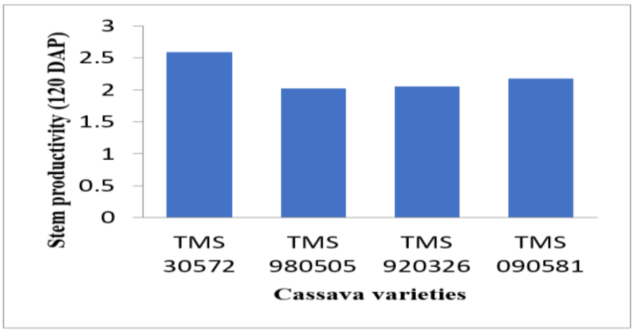


**Figure 6:** Stem Productivity (120 DAP)

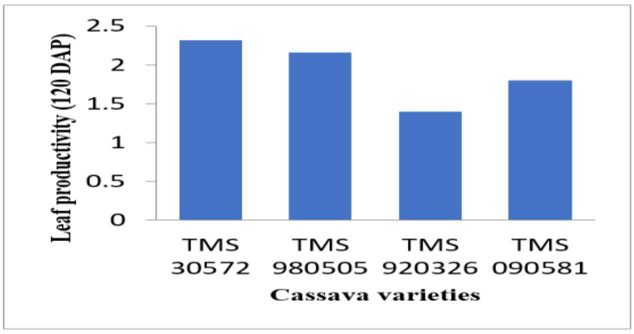


**Figure 7:** Leaf Productivity (120DAP)

Figures 8–10 show the variation in Tuber, Stem and Leaf Productivity among the four cassava varieties. Figure 8 showed that TMS 090581 had the highest Tuber Productivity (3.05 kg/m$^3$), TMS 920326 also had a relatively high tuber productivity of 2.93 kg/m$^3$ while TMS 980505 had the lowest Tuber Productivity (2.17 kg/m$^3$). Figure 9 showed that TMS 920326 had the highest Stem Productivity (2.72 kg/m$^3$), while

TMS 090581 had the lowest Stem Productivity (1.67 kg/m$^3$). Figure 10 shows that TMS 30572 had the highest Leaf Productivity (2.02 kg/m$^3$) while TMS 090581 had the lowest Leaf Productivity (1.07 kg/m$^3$). As shown in Table 1, TMS 090581 had the highest average tuber yield per (18.75 t/ha), TMS 920326 had a relatively high average tuber yield (17.97 t/ha), and TMS 980505 had the lowest average tuber yield (13.35 t/ha) at 150 DAP under rainfed conditions. Based on the above biomass weight (kg/plant), TMS 920326 had the highest value (2.5 kg/plant) while TMS 30572 had the lowest value (1.15 kg/plant).

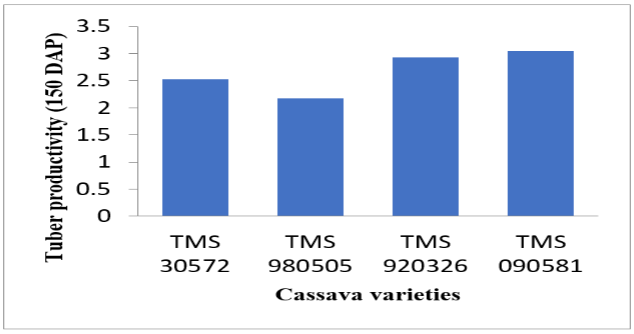


**Figure 8:** Tuber Productivity (150 DAP)

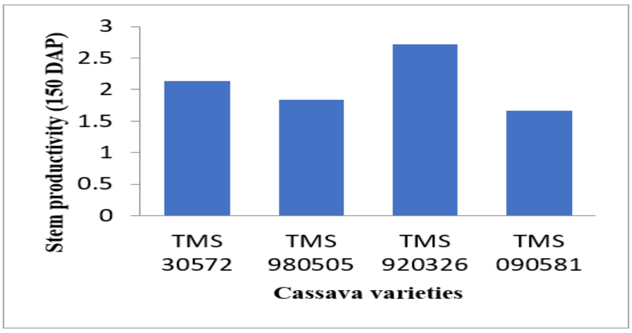


**Figure 9:** Stem Productivity (150 DAP)

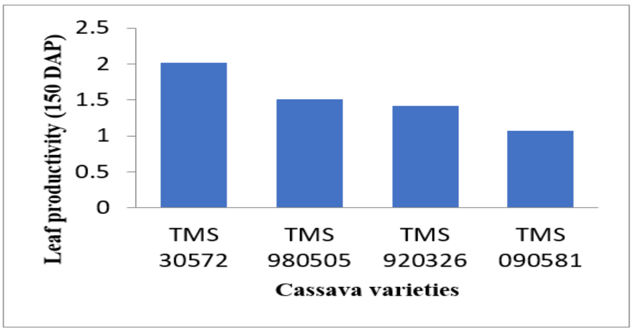


**Figure 10:** Leaf Productivity (150 DAP)

Regression analysis illustrated the connection and effect of growth factors on aboveground biomass weight and tuber yield as presented in Tables 2 and 3. Table 2 shows the effects of the independent variables (plant height, stem diameter, cultivar diameter, and number of nodes) on the dependent variable (above biomass weight). The p-value for the number of nodes is significant ($p < 0.05$). The p-value and coefficient imply that an increase in the number of nodes increases the above biomass weight, and vice versa. The p-values for stem diameter, plant height, and cultivar diameter were insignificant over time ($p > 0.05$) and did not contribute to an increase in aboveground biomass weight. The $R^2$ value (0.625) implies a 62.5% relationship between the growth parameters and biomass weight. A regression model equation can be established based on the growth parameters in response to cassava yield; the equation can be stated as follows:

$$above\ ground\ biomass\ weight_i = -1.173 + 0.004height_i + 0.030stemdia_i + 0.023cultivadia_i + 0.004nodes_i + \varepsilon_t \quad (2)$$

The above biomass weight of cassava is expressed in (kg/plant).

Table 3 shows the effects of the independent variables (plant height, stem diameter, cultivar diameter, and number of nodes) on the dependent variable (tuber yield). The p-values for plant height and cultivar diameter were statistically significant ($p < 0.05$). The p-value and coefficient value for plant height imply that an increase in plant height leads to an increase in tuber yield, and vice versa. The p-value and coefficient value of cultivar diameter imply that an increase in cultivar diameter will increase tuber yield. The $R^2$ value (0.714) implies a 71.4% between growth parameters and tuber yield. A regression model equation can be established based on the growth parameters in response to cassava yield, as follows:

$$yield_i = -15.158 + 0.093height_i + 0.041stemdia_i + 0.030cultivadia_i + 0.241nodes_i + \varepsilon_t \quad (3)$$

The cassava yield is expressed in tonnes per hectare (t/ha).

**Table 2:** Above-Ground Biomass Weight (kg/plant)

| Variable | Coefficient | Standard error | P-value |
|---|---|---|---|
| Constant | -1.173 | 0.480 | 0.019 |
| Height | 0.004 | 0.004 | 0.330 |
| Stem diameter | 0.030 | 0.024 | 0.232 |
| Cultivar diameter | 0.023 | 0.012 | 0.051 |
| Nodes | 0.004 | 0.002 | 0.000 |

$R^2 = 0.625$

**Table 3:** Tuber Yield

| Variable | Coefficient | Standard error | P-value |
|---|---|---|---|
| Constant | -15.158 | 3.708 | 0.000 |
| Height | 0.093 | 0.032 | 0.006 |
| Stem diameter | 0.041 | 0.089 | 0.652 |
| Cultivar diameter | 0.030 | 0.006 | 0.000 |
| Nodes | 0.241 | 0.188 | 0.207 |

$R^2 = 0.714$

## 4.0 CONCLUSION

Four different cassava varieties obtained from the IITA were planted and monitored under rain-fed conditions. The only treatment applied in this study




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was water from rainfall with uniform application across the four cassava varieties. This was based on the variety with the best water productivity. The analyzed data showed a uniform increase in stem diameter, plant height, and number of nodes in the four cassava varieties. However, there were no significant differences across the four replicates at the 95% confidence level. TMS 090581 had the best average tuber yield and productivity among the three harvests. TMS 920326 had the lowest yield during the first two harvests. TMS 30572 harbours white flies, which can negatively affect plant growth. However, this variety also had the highest number of nodes, producing more leaves. Based on these findings, TMS 090581 is recommended for local and peasant farmers due to its superior tuber yield and water productivity. TMS 30572 is highly recommended for its exceptional leaf and stem productivity, particularly in places with limited water availability, and its above-ground biomass weight, which is beneficial for feeding livestock.

## 5.0 AUTHOR CONTRIBUTIONS

TBA and AIO contributed to the design and implementation of the research; TBA, PAU, and AIO analysed the results. TBA, OSA and PAU drafted the manuscript. ETA conceived and supervised the project.

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