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Effect of tillage, fertilizers and storage structures on quality shelf life of white yam (*Dioscorea rotundata Poir*) in south west Nigeria

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Abstract

This study examined the effect of tillage, fertilizers and storage structures on quality shelf life of white yam in South West Nigeria. The study was a factorial experiment consisting of Tillage, Fertilizers and Storage Structure. The tillage system involved Heap Tillage (HT) and Ridge Tillage (RT), while Fertilizers involved Poultry Manure (PM), $N_{15}P_{15}K_{15}$ (NPK) and Control (CLT) and two types of Storage Structures namely; Traditional Barn (TB) and Open Sided Storage Structure (OSSS) were combined to form the treatments. The experiment was a 2x3x2 factorial combination arranged in a Randomised Complete Block Design (RCBD). The treatments were replicated three times for each location respectively. A total of 72 ridges and 144 heaps were used to make a population of 288 plants per location. The tubers were weighed to ensure uniformity before planting. The plot size was 18mx18m square with a pathway of 1.0m between blocks making a total of 324 square metres. At harvest, the tubers were weighed immediately. They were then kept separately in the two storage structures namely: Traditional Barn (TB) and the Open Side Storage Structure (OSSS) for a period of 3 months. After the 3rd months of storage, the tubers were examined and data collected. The weight of each tuber from each storage structure was taken periodically to evaluate the weight loss and assess the keeping quality periodically. The findings of this study demonstrated the significant influence of tillage, fertilizers, and storage structures on the quality, shelf life, nutrient use efficiency, and nutrient composition of white yam. Excessive fertilizer application was found to increase rotting and deterioration levels. Hence, farmers and stakeholders should carefully consider fertilizer application rates to minimize post-harvest losses and enhance food security. Further investigations are needed to explore the underlying mechanisms responsible for the observed effects and to optimize fertilizer management practices for yam storage. Organic fertilization enhances the nutrient use efficiency and nutritional quality of yam, while appropriate storage structures, play a crucial role in preserving the quality and extending the shelf life of the harvested tubers. Based on the result of the study, open sided storage should be considered by producers of yams for storing their harvested tubers due to the facts that, it performed well in minimizing nutrient lost, weight loss and decay to considerable level and prevented pests/rodents attack on yam tubers.

Keywords: Tillage; Fertilizer; Poultry manure; Storage structure; Nutrient use efficiency; Proximate composition

1. Introduction

White yam (*Dioscorea rotundata*) is a widely cultivated staple crop in tropical regions, providing essential carbohydrates and nutrients to millions of people, (Onyeka *et al.*, 2018). It is a significant source of dietary carbohydrate and essential nutrients, thus playing a crucial role in food security (Diby *et al.*, 2008). However, yam production faces numerous challenges, including declining soil fertility, post-harvest losses, and inadequate storage facilities. (Abiodun *et al*, 2017). Therefore, it is essential to explore sustainable agricultural practices that can enhance the quality, shelf life, sustain the nutrient use efficiency, and nutrient composition of white yam (Adeyemi and Omemu, 2018). Tillage, fertilizer, and storage are critical components of yam production, and their combined effects can influence the physical

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and nutritional quality of the harvested tubers. (Alvarenga *et al*, 2019). Ineffective use, poor tillage practices and continuous application of mineral fertilizer for yam production and utilization have considerably resulted in poor quality tubers with rapid rate of deterioration and keeping quality (Agbede, 2010). This has resulted in disintegration of the membrane and has caused tremendous post-harvest loses. Post harvest losses of yam tubers in storage may be attributed to some field cultural practices which could be attributed to the continuous use of synthetic fertilizer or poor storage environment (Mbah and Ikoro, 2019). When white yam is stored in traditional storage structures in Nigeria, such as barns or earth pits, the proximate composition can undergo changes due to the effects of storage conditions, including temperature, humidity, and ventilation (Yusuf *et al*, 2017). For example, the moisture content of yam tubers can decrease during storage, leading to potential weight loss and changes in texture. Additionally, the nutritional composition of yam can be affected by post-harvest handling practices and the duration of storage (Eke-Ejiofor *et al*., 2018). This calls for research into the remote causes of poor quality tubers with low nutrient status. Yam according to **(**Adekoya and Olawuyi, 2019**)** is a heavy feeder and thus constitutes a heavy drain on the soil. However, yam farmers often opine that the tubers produced with mineral fertilizer tend to have shorter shelf life and keeping quality over those produced without mineral fertilizer **(**Agbaire and James, 2009**)**. This may be attributable to poor tillage practices, use of inorganic fertilizers, which may affect its storage ability and keeping quality. Loss of yam in storage may range from 30-66% of the total output in Southwest Nigeria **(**Ojeniyi, *et al*, 2010**)**. Therefore, the type of storage structure, fertilizer types and tillage method will go a long way to improve the shelf life and nutrition value of yam with minimal protein hydrolysis and disintegration **(**Alvarenga et at, 2019, Law-Ogbomo, and Remison, 2018**)**. Hence the objectives of this study are to (i), determine tuber shelf life of white yam grown with fertilizers, (ii), determine the effect of tillage on shelf life, nutrient composition and yield of white yam, (iii), examine the nutrient composition and textural quality of white yam, (iv), assess the effect of different storage structures on keeping quality of white yam, (iv),and to evaluate the nutrient use efficiency (NUE) and residual effect (RE) on soil chemical properties at harvest

2. Material and method

2.1. Study site description

This study was conducted in three locations at the Teaching and Research Farm, Department of Agricultural Technology, of The Federal Polytechnic Ado-Ekiti and laboratory analysis was carried out in the Departments of Agricultural Technology and Science Technology of the Institution as well as IITA, Ibadan, Nigeria. Ekiti is within the yam zone of West Africa. The rainfall comes in bimodal pattern and ranges between 1,500mm-2500mm for about six to seven months of the year. The temperature ranges between 24-35 degrees centigrade with constant sunshine. The humidity is high during the wet season. This encourages fast growth of crops and other vegetables which cannot tolerate frost condition. The existing vegetation is a mixture of grass and broad leaves. The dominant weed is sun flower (*Helianthus annuun*) while the broad leaves are (*gliricidia sepium)* and Siam weed (*Cromoelaena odorata*). The experiment was carried out between February and December, 2023.

2.2. Experimental design and treatments

The study was a factorial experiment consisting of Tillage, Fertilizers and Storage Structure. The tillage system involved Heap Tillage (HT) and Ridge Tillage (RT), while Fertilizers involved Poultry Manure (PM), $N_{15}P_{15}K_{15}$ (NPK) and Control (CLT) and two types of Storage Structures namely; Traditional Barn (TB) and Open Sided Storage Structure (OSSS) were combined to form the treatments. The experiment was a 2x3x2 factorial combination arranged in a Randomised Complete Block Design (RCBD). The treatments were replicated three times for each location respectively. A total of 72 ridges and 144 heaps were used to make a population of 288 plants per location. The tubers were weighed to ensure uniformity before planting. The plot size was 18mx18m square with a pathway of 1.0m between blocks making a total of 324 square metres.

2.3. Treatment application and Crop Husbandry

The setts were treated with yam minisett dust, to protect the setts against insects, nematodes and fungi respectively in the soil. The yam setts were planted on the crests of (1m x 1m). The fertilizers namely Poultry manure (PM) (10t/ha) and $N_{15}P_{15}K_{15}$ (at 400kg/ha) were applied in rings on sides of each tillage method. Three weeding operations were performed. The first was carried out one week before fertilizer application, 7 WAP, and the third at 16 WAP. Shoot emergence scores were taken at 4, 6 and 8 WAP. Shoot vigour assessment was done on a 3 point hedonic scale where 1 = low, 2 = moderate and 3 = high. The tubers were harvested for yield determination after 8 months and thereafter, healthy looking tubers without cuts or bruises during harvest were selected for the storage experiment.

2.4. Determination of Soil properties and poultry manure analysis.

Soil samples were collected using augers from 0-15cm depth diagonally across plots before the commencement of the experiment and at the end of each experiment from treatment plots. The soil samples were air dried and sieved for chemical analysis as described by (Fagbola, *et al*., 2014**)**. In addition, the nutrient composition of the poultry manure was determined. Soil physical properties such as soil bulk density, soil temperature, soil moisture content and soil textural characteristics were determined before the commencement of the experiment. Soil temperature was determined on a fortnightly basis to monitor the temperature changes during the growth period. Staking and mulching was done at 4-6 weeks after planting (WAP) when almost all the yam setts had emerged from the soil and vines long enough to train on the stakes. Stakes were arranged in alternate furrows so that vines from 4-6 stands of yam taken from adjacent ridges were trained to climb the stake. The leaf relative water content (LRWC) and the soil moisture content (SMC) was determined at the end of the experiment according to the procedure described by Asserah, *et al*., (2018).

2.5. Determination of plant Nutrient use efficiency (PNUE)

- **Nutrient Use Efficiency:** Nutrient use efficiency (NUE) was determined as described by (Ofori, 2010**)** as follows: weight of the tubers divided by the amount of N applied to soil, that is, kg grain/kg N-fertilizer. Nutrient use efficiency is made up of two primary components known as N uptake efficiency (NUpE) and N utilization efficiency (NUtE).
- **Nutrient use efficiency:** "Nutrient use efficiency was calculated by dividing the total nutrient uptake (N, P, K, etc.) by the total biomass production" **(**Adu and Addai, 2020)

Nutrient use efficiency **(NUE) =** Nutrient uptake by plants/Nutrient applied x100. The Crop Growth Rate (CGR) was calculated throughout the entire crop duration. The CGR was calculated as $CGR=T^1-T_2/Tx100$ Where T_1 and T_2 respectively represents = Total Biomass (Final biomass-Initial biomass/Time) while T is number of days to maturity

2.6. Growth measurements and parameters evaluated

- **Days to shoot emergence**: This was recorded as the number of days between planting of sprouted tuber and the time the shoot emerged above the ground. (Ofori, 2010**)**
- **Number of leaves and branches**: "The number of leaves was counted manually, while the number of branches was recorded by visually inspecting the plant"(Ofori, 2010**)**
- **Vine length:**"The Vine length was measured from the base of the plant to the tip of the longest vine using a measuring tape" **(**Adopoulou, & Eleftherohorinos, 2019**)**
- **Leaf area**: The Leaf area was determined using a leaf area meter or by manually measuring the length and width of each leaf and calculating the leaf area using appropriate formulas" **(**Asserah, *et al*., 2018**)**
- **Days to First Tuber Initiation:** The bases of the selected clones were opened every other day until all initiated tubers were observed and recorded(Abidoye, *et al*., 2012)
- **Tuber length**: "Tuber length was measured from the base to the tip of the harvested tuber using a ruler or measuring tape" (Abidoye, *et al*., 2012)
- **Tuber diameter**: "Tuber diameter was measured at the widest point of the tuber using a caliper or ruler" (Adekola, *et al*., 2017)
- **Tuber weight in Kg**: "Tuber weight was measured using a digital weighing scale immediately after harvest" (Adu-Dapaah, *et al*, 2018)
- **Tuber weight in ton per ha**: "Tuber weight per hectare was calculated by multiplying the average tuber weight by the number of plants per hectare" (Adekola, *et al*, 2017)
- **Tuber dry matter content:** A representative sample of about 100 g (W1) prepared by thoroughly mixing sliced pieces of tubers was oven dried at 105oC for 48 hours and weighed (W2). Percentage (%) dry matter content was calculated as (W2/W1) x 100 (Adekola, *et al*, 2017**)**
- **Harvest index**: "Harvest index was calculated as the ratio of tuber weight to total biomass (tubers + aboveground biomass)" (Asserah, *et al*., 2018**)**
- **Shoot dry weight:** All vines and leaves per plant were oven dried at 105^{o}C for 48 hours and weighed (Asserah, *et al*., 2018**)**
- **Tuber dormancy period:** Data were collected on tubers harvested from all treatments. Tubers were harvested with their corms intact, and were stored in the Traditional Barn (TB) and the Open Sided Structure (OSSS) for a period of three months.. Data collection on time of tuber sprouting started three weeks after harvest and continued every other day until when 80-100% of all tubers were sprouted. A tuber was considered sprouted when it had a bud of 3 mm long. Dormancy period was calculated as length of time between tuber harvest and sprouting or between tuber initiation and tuber sprouting (Adekola, *et al*, 2017)

2.7. Storage conditions and Measurements

At harvest, the tubers were weighed immediately. They were then kept separately in the two storage structures namely: Traditional Barn (TB) and the Open Side Storage Structure (OSSS) for a period of 3 months. After the 3rd months of storage, the tubers were examined and data collected. The weight of each tuber from each storage structure was taken periodically to evaluate the weight loss and assess the keeping quality periodically. The roof of the improved barn was made of mahogany wood and constructed with leg stand. This feature enhanced air circulation and exclude rodents. Inside the barn, wooden shelves were constructed on which the tubers were placed to allow for ease of ventilation. Conversely, tubers for the OSSS treatment were placed on the wooden shelf of the barn. Dry and wet bulb thermometer was installed for monitoring temperature and relative humidity in the two storage structures. Temperature and relative humidity (RH) of the storage environment were monitored at 10.0 am and 4.0 pm daily using a thermocouple. Sprouting was evaluated visually for presence or absence of sprouts and recorded daily. The duration of complete dormancy was determined which was given as the number of days from the start of the storage to the first visible sign of sprouting. The sprout lengths was measured with tape rule and removed when they attained 1.5m. They were cut at the base and weighed. Sprout relative weight (%) was obtained for each structure. The weight loss, presence and level of rot, storage pests and diseases incidence was taken. Weight loss was determined as:

$$\% \text{ weight loss} = \text{initial weight} - \frac{\text{current weight}}{\text{Initial weight}} \times 100$$

Tuber rot was determined with the formular below.

$$\% \text{ rot} = \frac{\text{Number of tubers that rotted}}{\text{Total number of tubers stored}} \times 100$$

2.8. Proximate Analysis

Proximate analysis was conducted on the stored yam tubers at the end of the experiment to establish the effect of the various storage methods on the Crude Fibre, Crude Protein, Ash, Carbohydrate and Moisture Content.

2.9. Data analysis

Analysis of variance (ANOVA) and General Linear model (GLM) was performed on all data collected using the Statistical Analysis System (SAS) package. Standard error of difference (S.E.D), standard error of the mean (S.E.M), Standard deviation was used as the mean separation tools. Mean separation was done using the DMRT at probability level of 5%.Coefficient of variability was used to estimate the reliability of the sampled data

3. Result and discussion

Table 1 shows the result of soil chemical and physical properties before and after treatment application. The result shows a decrease in the soil pH from 5.95 to 5.55, Increase in total nitrogen, from (0.38% to 0.49%,) available phosphorus, from (10.10mg/kg to 12.76mg/kg), exchangeable calcium, from (1.40cmol/kg to 1.80 cmol/kg), magnesium, (from 0.50 cmol/kg to 0.70 cmol/kg), potassium, from (1.07 cmol/kg to 1.14 cmol/kg), sodium, (from 0.11 cmol/kg to 0.19 cmol/kg). In addition, there was a reduction in the percentage of organic carbon, (from 1.70% to 0.78%) with a corresponding increase in percentage organic matter, (from 1.29% to 1.35%) while the soil physical property before the experiment was, sand, (82.30%), silt, (10.50%), clay, (7.20%), porosity, (35.30%), water holding capacity (whc), (0.061g/g), bulk density, (1.32g/cm$^{3)}$. The relative increase in elemental nutrients at harvest maybe as a result of the addition of poultry manure and NPK fertilizer.

Table 2 shows that poultry manure had N, P and K ranges of 6.73, 13.50 and 8.80 respectively and a pH of 7.9 (that is, slightly alkaline). The exchangeable cations in the soil particularly Ca^{2+} and K+ were high while Mg^{2+} and Na^{2+} are of moderate levels indicating a moderate to high nutrient content. Poultry manure is typically rich in these elements while NPK typically contains a balanced ratio of nitrogen, phosphorus and potassium **(**Gerrard, 2011, **Osunde, 2018**). The addition of poultry manure also increased the organic carbon and organic matter in the soil **(**Djukic, 2010. Wapa, & Oyetola, 2014**).** This can consequently improve the soil structure, water holding capacity and nutrient availability of the soil. It is expected that the tillage effect loosen the soil thereby lowering the soil bulk density, increasing total porosity and water holding capacity of the soil **(**Adeoye and Adegbite, 2018**).**

Table 3 shows the effect of tillage and fertilizers on yield and yield characters of white yam. The result shows that days to shoot emergence was significantly shorter for yam treated with poultry manure and NPK fertilizer (25 days) under the heap and ridge tillage system while it took longer days for the shoot to emerge under the control (34 days). Similarly, days to first tuber initiation was significantly shorter under the heap tillage system treated with poultry manure (52 days) while it took longer days for tuber initiation under the control (59 days). The shoot fresh and dry weight were significantly higher under the heap tillage system with poultry manure application, (334.67g, 112.95g) respectively over other treatment while the control gave the lowest value (149.73g, 49.91g) respectively. The result of yield and yield character of white yam as influenced by tillage and fertilizer also revealed that yam diameter, (41.72cm), tuber length, (35.26cm), average tuber weight (3.00kg), fresh tuber weight per plot (120.00kg/ha) and fresh tuber weight (37.07 t/ha) were significantly better under the heap tillage system treated with poultry manure. This was closely followed by heap tillage treated with NPK fertilizer while the control gave the lowest value.

Effect of tillage and fertilizers on Crop growth rate, (CGR), Leaf relative water content, (LRWC) and Nitrogen use efficiency (NUE) of white yam at harvest is presented in Table 4. The result shows that tillage and fertilizers have a significant influence on CGT, LRWC and NUE of yam. Days to maturity were significantly shorter under the heap tillage system with poultry manure (235 days) while it took longer days to attain maturity under the control (260 days). Similarly, Crop growth rate (CGR) was significantly better under the heap tillage system with poultry manure (48.07%). This was closely followed by ridge tillage system with poultry manure (42.73%) while CGR was lowest for the control (19.19%). There was no significant difference in the LRWC for all the treatments imposed. The result further indicated that the required nutrient uptake for Nitrogen (162.00kg/ha, Phosphorus (17.00kg/ha), Potassium (153.00kg/ha) were significantly higher for yam grown under the heap tillage system treated with poultry manure. This was closely followed by ridge tillage treated with NPK fertilizer for Nitrogen, (148.00kg/ha), Phosphorus, (15.00kg/ha), and Potassium, (14.00kg/ha) with the least recorded for the control. The result of the Nitrogen use efficiency indicated that (NUE), was highest under the ridge tillage system treated with NPK fertilizer for Nitrogen (370.00g/kgN), Phosphorus, (37.50g/kgP) and Potassium (350.00g/kgK) while the least was recorded for the control for Nitrogen (52.50g/kgN), Phosphorus, (10.00g/kgP) and Potassium (48..00g/kgK).

The result of the effect of tillage, fertilizer and Storage Structure on physiology and environmental conditions of white yam is presented in Table 5. The result shows that the average temperature, relative humidity and moisture content in the Traditional Barn (TB) was (25-30^{0c}, 80-85%, 18-23%)respectively while the Open Sided storage structure (OSSS) was (15-25^{0c}, 75-80%, 13-16%)respectively. The result further revealed that at storage condition, the total number of tubers that rotted was significantly higher under TB system treated with poultry manure (4.00) at 75 days to first sprouting while fewer number of yam rot was observed under the TB and the OSSS under the control (1.00, and 0.00) respectively with shorter days to first sprouting for the control under the OSSS (60 days). Similarly, the dormancy period days from harvesting were significantly longer under the OSSS when compared with the TB system with shorter dormancy period days from harvest. Percentage tuber rot was significantly higher under the TB system where yam was treated with NPK fertilizer (17.39%). This was closely followed by the OSSS treated with NPK fertilizer (13.03%). The lowest rot was recorded for the control for TB (5.55%) and OSSS (0.00%) under the heap tillage system. Similar result was obtained under the ridge tillage system for yam in both storage conditions under the application of poultry manure and NPK fertilizer.

The result of proximate composition analysis of white yam before and after storage condition is presented in Table 6. The analysis was done before and after the storage experiment. The nutritional composition analyzed comprises of the moisture content, protein, carbohydrate, fat, fibre and ash content of White yam in the Traditional Barn and .open sided storage. The result showed significant reductions in moisture, fat, protein and carbohydrate except for fibre and ash content of white yam after three months of storage with the two storage structures.

The Interaction effect of tillage and storage systems on physiology and environmental conditions of white yam after storage is presented in Table 7. The interaction shows that there is significant difference in the total number of tubers observed, number of tubers that rotted, days to first sprouting, dormancy seed days from harvesting, sprout weight, % weight loss, and % tuber rot while the interaction effect between fertilizer and storage on physiology and environmental conditions is presented in Table 8. The results show no significant difference on number of tuber that rotted and sprout weight of yam in storage. Similarly, the Interaction effect between Tillage and Fertilizer on physiology and environmental conditions of white yam at storage in Table 9 shows no significant difference in sprout weight in the two storage conditions.

The Interaction effect between Tillage, Fertilizer and Storage on physiology and environmental conditions of white yam at storage is presented in Table 10. The result shows a significant difference among the measured parameters except for sprout weight of white yam under different storage conditions.

According to Egwaikide *et al*, (2017), the specific nutrient content and uptake can differ between yam varieties due to factors such as soil type, climate conditions, cultivation practices, and genetic variations. For instance, the nutrient composition of yam may vary based on the specific soil conditions in which they are grown. Soil nutrient availability greatly influences the nutrient content of crops (Ofori, 2010). Cultivation practices also play a crucial role in nutrient uptake. Proper soil preparation, including adequate organic matter content and appropriate fertilizer application, can enhance nutrient availability for tuber crops.. Farmers may use different types and amounts of fertilizers, based on soil testing and specific crop requirements, to optimize nutrient uptake (Ojeniyi, *et al*, 2010). In this research, different fertilizer types significantly influenced the nutrient use efficiency (NUE) in tuber crops. Application of poultry manure resulted in the highest NUE compared to NPK fertilizer. This could be attributed to its balanced nutrient composition and improved nutrient availability for plant uptake (Ofori, 2010).

According to report from Omolayo *et al*, (2019**),** the Traditional barn (TB) can help maintain the proximate composition of yam by preserving its moisture content and reducing the loss of nutrients, however, the open sided storage system (OSSS) have limitations in controlling humidity and preventing the spread of diseases and pests, which can lead to higher post-harvest losses and deterioration of yam quality. Agbede, (2010), who worked on tillage stressed that minimum tillage significantly influenced the physical quality and yield of tuber crops. Tuber yield was higher in the heap plots compared to the ridge tillage, indicating the beneficial effect on yam production. In the ridge tillage system, early weed interference limits nutrient availability. In addition, the system works best for continuous row crop. Conversely, the heap tillage system resulted in reduced tuber damage and better-shaped tubers, contributing to improved marketable quality. These findings are consistent with previous studies by Agbede, (2010**)**, who opined demonstrated the advantages of minimum tillage in conserving soil moisture, improving soil structure, and enhancing crop yields.

Several studies have investigated the impact of inorganic fertilizers on the proximate composition of tuber crops. According to a study by Eke- Ejiofor *et al*. (2018**)**, the use of inorganic fertilizers can lead to changes in the carbohydrate, protein, and ash content of tubers. The study found that yams grown with inorganic fertilizers had higher carbohydrate and protein content compared to those grown with organic fertilizers. This suggests that the type and amount of fertilizers used can influence the nutritional composition of tuber crops (Yusuf *et al*, 2017**).**

According to (Johnson *et al*., (2021), Adebayo *et al*, (2014), who worked on effect of synthetic fertilizer rates on the rotting and deteriorating levels of tuber crops under storage conditions, observed that higher rates of synthetic fertilizer application tended to increase the susceptibility of yam tubers to rotting and deterioration. Omolayo *et al*., (2019) further opined that the detrimental impact of excessive fertilizer application on yam tuber quality may be attributed to increased susceptibility to microbial attack and accelerated tissue breakdown

In addition to fertilization, poor storage systems can also affect the proximate composition of white yams. Improper storage can lead to moisture loss, which can affect the overall quality and composition of yams (Ahmed and Rahman, 2020). For example, yams stored in environments with high temperatures and humidity may experience higher moisture loss, leading to changes in their proximate composition (Adebayo *et al*, 2014), Poor storage systems can lead to post-harvest losses and deterioration influencing the proximate composition of white yam (Omolayo *et al*., 2019). Yam tubers are prone to physical and physiological changes during storage, including weight loss, sprouting, and changes in chemical composition (Aikpokpodion and Ehbo, 2021). Improper storage conditions, such as high temperatures, humidity, and inadequate ventilation, can accelerate the deterioration of yam tubers, resulting in a decline in their proximate composition, particularly in terms of carbohydrate content and overall nutritional quality (Akinbode and Akobundu, 2019).

According to Boakye *et al*, (2016**),** poor storage systems can also impact the NUE of white yam by promoting the degradation of stored tubers and reducing their capacity to efficiently utilize applied fertilizers. .When yam tubers are stored under suboptimal conditions; their capacity to absorb and utilize essential nutrients from fertilizers is compromised, leading to reduced NUE and lower crop productivity. Therefore, addressing poor storage systems is crucial for maintaining the proximate composition and NUE of white yam. An article by Akinoso *et al*. (2015) examined the impact of storage conditions on the proximate composition of yams. The study found that yams stored in ambient conditions had higher moisture content and lower dry matter content compared to yams stored in controlled conditions. According to Akande *et al*., (2015), Organic fertilization improved the nutrient use efficiency, as indicated by higher tuber yield and enhanced uptake of essential nutrients for plant growth.

Fertilizer application significantly influences the proximate composition and NUE of white yam. Appropriate fertilization practices can enhance yam tuber yield and quality by providing essential nutrients for plant growth and development (Ojeniyi and Adekiya, 2018). Adeyemo *et al*. (2019), Egwaikhide *et al*., (2017), reported that the application of fertilizers improved the growth and tuber yield of white yam. Moreover, the NUE of white yam is closely linked to fertilizer management practices. Efficient use of applied fertilizers is essential for maximizing crop productivity and minimizing environmental impact. Optimizing fertilizer application methods, timing, and rates can improve the NUE of white yam, leading to enhanced nutrient uptake and utilization by the crop. Conversely, poor fertilizer management practices can result in nutrient losses, reduced NUE, and environmental pollution (Eke-Ejiofor *et al*, 2018).

The reduction in moisture content and carbohydrate could be due to respiration, transpiration and sprouting of the tubers (Johnson *et al*, 2021, Odedina, & Babajide, 2014). These are physiological activity that is promoted by high temperature and high relative humidity of the storage environment. Adebayo *et al*, (2014), further reported that, respiration resulted in a steady loss of carbohydrate in the form of carbon dioxide and water, while at the same time, transpiratory loss of water occurs.

4. Conclusion

The findings of this study demonstrate the significant influence of tillage, fertilizers, and storage structures on the quality, shelf life, nutrient use efficiency, and nutrient composition of white yam. The implementation of minimum tillage practices can contribute to improved tuber yield, and reduced damage thereby for better marketable quality. Excessive fertilizer application was found to increase rotting and deterioration levels. Hence, farmers and stakeholders should carefully consider fertilizer application rates to minimize post-harvest losses and enhance food security. Further investigations are needed to explore the underlying mechanisms responsible for the observed effects and to optimize fertilizer management practices for yam storage. In addition, further studies are needed to access the effect of heavy metals concentrations in the soil as a result of the continuous use of synthetic fertilizer on soil chemical properties. Organic fertilization enhances the nutrient use efficiency and nutritional quality of yam, while appropriate storage structures, play a crucial role in preserving the quality and extending the shelf life of the harvested tubers. Based on the result of the study, open sided storage should be considered by producers of yams for storing their harvested tubers due to the facts that, it performed well in minimizing nutrient lost, weight loss and decay to considerable level and prevented pests/rodents attack on yam tubers.

Compliance with ethical standards

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The author (s) have no conflicts of interest relevant to this article.

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Appendix

Variations in weather pattern in the early and late planting season of 2023

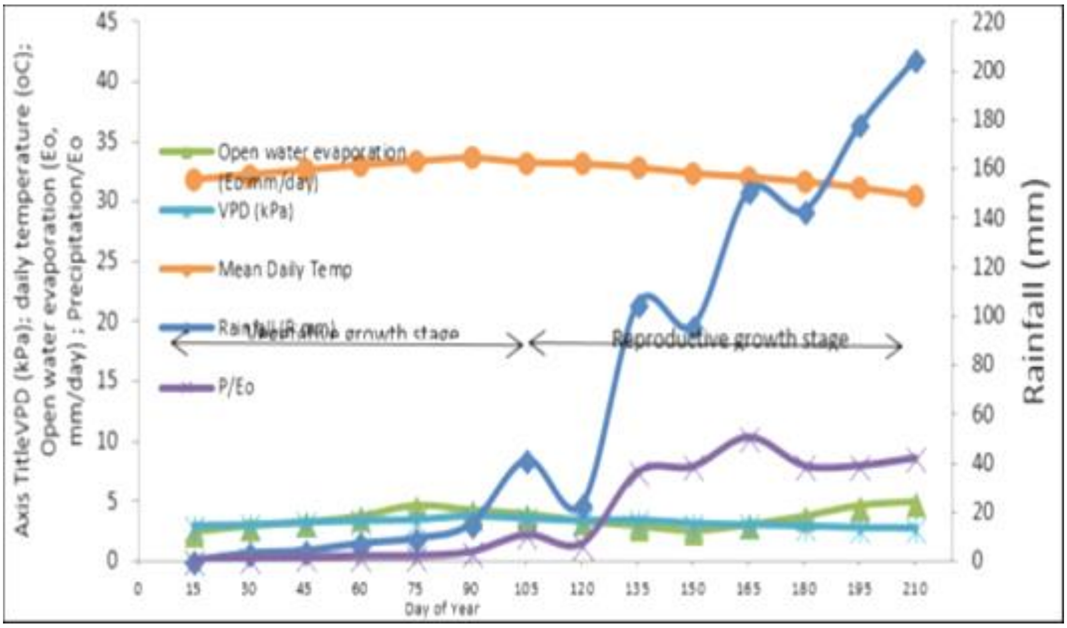

Figure 1 Important weather variables during early rainy season

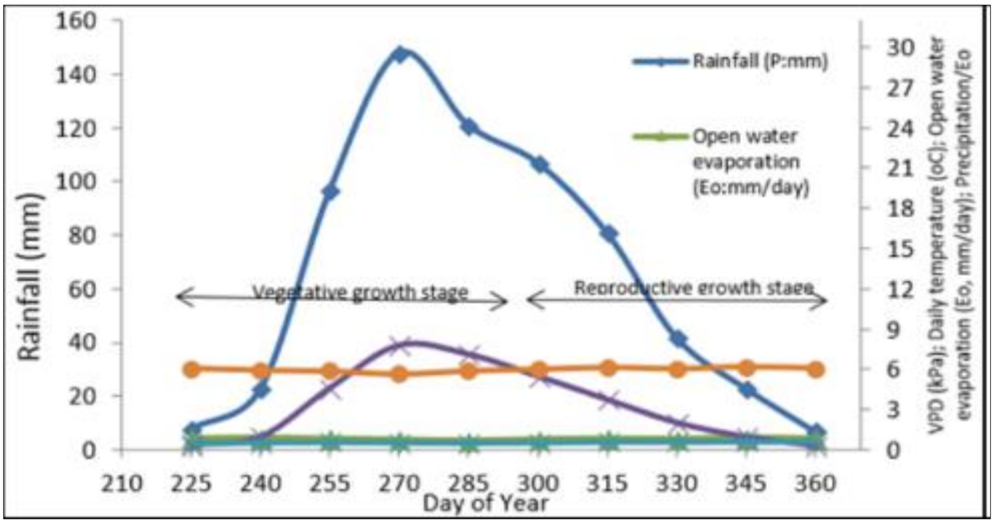

Figure 2 Important weather variables during late rainy season

Table 1 Physical and chemical properties of the soil before and after experiment

Properties	Values Before	Values After
Ph	5.95	5.55
Total N (%)	0.38	0.49
Available P (mg/kg)	10.10	12.76
Exchangeable cations (Cmol.kg^{-1})		
Ca^{2+}	1.40	1.80
Mg^{2+}	0.50	0.70
K^{+}	1.07	1.14
Na^{2+}	0.11	0.19
Organic Carbon (%)	1.70	0.78
Organic matter (%)	1.29	1.35
H+	0.20	0.23
CEC	2.96	2.30
Particle size distribution		
Sand	82.30	-
Silt	10.50	-
Clay	7.20	-
Porosity (%)	35.30	-
Water holding capacity (g/g)	0.061	-
Texture	Sandy loam	Sandy loam
Bulk density (g/cm^3)	1.32	-

Table 2 Characteristics of the poultry manure used for the experiment

Properties	Value
pH	7.90
Total N (%)	6.73
Available P (mg/kg)	13.50
Exchangeable cations (Cmol.kg$_{-1}$)	
Ca_{2+}	19.20
Mg_{2+}	5.45
K_{+}	8.80
Na_{2+}	1.77
Organic Carbon (%)	14.70
Organic matter (%)	25.40

Table 3 Effect of tillage and fertilizers on yield and yield characters of white yam

Tillage	Fertilizer	Days to Shoot emergence	Days to First Tuber Initiation	Shoot fresh weight(g)	Shoot Dry Weight/plant(g)	Yam Diameter (cm)	Tuber Length (cm)	Average Tuber weight(kg)	Fresh Tuber weight/plot (kg)	Fresh Tuber weight/plot (t/ha)
HT	PM	25.00[e]	52.00[d]	336.67[a]	112.95[a]	41.72[a]	35.26[a]	3.00[a]	120.00[a]	37.07[a]
	NPK	25.00[e]	55.00[c]	239.60[b]	97.89[c]	33.01[c]	27.29[b]	2.46[ab]	86.10[b]	35.80[b]
	CLT	30.00[c]	59.00[a]	161.16[c]	53.72[e]	29.56[e]	22.79[d]	2.28[ab]	68.40[c]	27.77[c]
RT	PM	27.00[d]	52.00[d]	296.78[b]	102.56[b]	37.79[b]	30.59[b]	2.79[ab]	86.40[b]	28.29[c]
	NPK	30.00[b]	55.00[c]	246.90[b]	88.65[d]	31.67[d]	25.03[c]	2.30[ab]	55.20[c]	22.22[d]
	CLT	34.00[a]	58.00[a]	149.73[c]	49.91[e]	25.96[f]	20.79[d]	1.63[b]	16.30[e]	5.01[f]
Mean		28.50	54.50	236.83	89.50	34.83	27.16	2.43	76.83	24.60
SD		3.51	2.65	76.67	27.66	5.54	5.04	0.57	38.83	11.62
SE±		1.43	1.08	31.25	11.29	2.26	2.05	0.24	15.83	4.74
LSD (0.05)		3.32	2.49	71.88	26.19	5.24	4.73	0.55	36.69	10.97
CV (%)		10.35	4.90	32.35	30.91	15.90	18.43	23.25	50.60	47.29

SD-Standard deviation.SE-Standard error.CV-Coefficient of variability. HT-Heap Tillage. RT-Ridge Tillage.PM-Poultry manure.CLT- Control.

Table 4 Effect of tillage and fertilizers on (CGR), LRWC and NUE of white yam at harvest

Tillage	Fertilizer	DTM	CGR (%)	LRWC (%)	Total Nutrient Uptake By Plants(N)	Required Nutrient Uptake (kg/ha)(P)	Required Nutrient Uptake (kg/ha)(K)	NUE (g/kgN)	PUE (g/kgP)	KUE (g/kgK)	Tuber dry matter content (%)	Harvex Index
HT	PM	235.00[f]	48.07[a]	66.45[a]	162.00[a]	17.00[a]	153.00[a]	93.75[d]	9.850[e]	88.67[d]	25.27[a]	16.56[b]
	NPK	245.00[d]	39.95[c]	59.14[a]	148.00[b]	15.00[a]	140.00[b]	370.00[a]	37.50[a]	350.00[a]	26.92[a]	25.21[a]
	CLT	265.00[a]	20.27[e]	66.67[a]	102.00[d]	11.00[b]	94.00[c]	255.00[b]	27.50[c]	235.00[b]	27.49[a]	25.74[a]
RT	PM	240.00[e]	42.73[b]	65.44[a]	106.00[d]	12.00[b]	96.00c	265.00[b]	30.00[b]	240.00[b]	23.16[b]	14.58[b]
	NPK	250.00[c]	35.48[d]	64.09[a]	81.00[e]	9.00c	76.00e	203.00[c]	23.00[c]	190.00[c]	25.55[a]	14.06[b]
	CLT	260.00[b]	19.19[d]	66.66[a]	21.00[g]	4.00[d]	19.00g	52.5.00[f]	10.00[e]	48.00[e]	27.09[a]	5.01[c]
Mean		250.00	34.17	64.33	103.33	11.33	96.33	206.67	23.00	191.94	25.83	16.33
SD		10.44	11.17	3.06	51.60	5.30	49.26	114.80	11.87	103.66	1.92	7.11
SE±		4.26	4.56	1.25	21.09	2.16	20.12	46.92	4.85	42.37	0.76	2.90
LSD(0.05)		26.28	30.39	2.77	142.84	2.77	136.20	317.92	32.88	2.77	5.33	19.67
CV (%)		3.81	32.65	4.76	46.27	46.77	47.84	55.51	51.61	51.72	7.43	43.53

DTM-Days to maturity, CGR-Crop Growth Rate LRWC-; Leaf Relative Water Content, NUE-Nutrient Use Efficiency, DMP-Dry matter Partitioning, HI-Harvex Index HT-Heap Tillage. RT-Ridge Tillage.PM-Poultry manure. CLT- Control. WAP-Weeks after planting..NUE-Nitrogen Use Efficiency. PUE-Phosphorus Use Efficiency. KUE-Potassium Use Efficiency.

Table 5 Effect of tillage, fertilizer and Storage Structure on physiology and environmental conditions of white yam

Tillage	Fertilizer	Storage Structure	Temp (0c)	Relative Humidly (%)	Moisture Content (%)	Total numbers of tubers observed	Number of tuber that rotted	Days to first sprouting	Dormancy period days from harvesting	Sprout weight (g)	% weight Loss	% Tuber Rot
HT	PM	TB	25-30	80-85	18-23	0.00[a]	4.00[a]	75.00[a]	75.00[d]	5.56[cd]	6.67[bc]	10.00[c]
		OSSS	15-25	75-80	13-16	40.00[a]	3.00[ab]	60.00[b]	90.00[b]	8.09[ab]	4.03[d]	7.50[d]
	NPK	TB	25-30	80-85	18-23	23.00[b]	4.00[a]	75.00[a]	79.00[c]	5.51[cd]	8.77[ab]	17.39[b]
		OSSS	15-25	75-80	13-16	23.00[b]	3.00[ab]	60.00[b]	95.00[a]	7.86[b]	5.39[c]	13.03[cd]

	CLT	TB	25-30	80.89	18-23	18.00^{c}	1.00^{b}	75.00^{a}	70.00^{e}	6.09^{c}	7.93^{b}	5.55^{d}
		OSSS	15-25	75-80	13-16	18.00^{c}	0.00^{c}	60.00^{b}	90.00^{b}	7.03^{b}	2.03^{f}	0.00^{e}
RT	PM	TB	25-30	80-85	18-23	16.00^{cd}	1.00^{b}	75.00^{a}	75.00^{d}	8.95^{ab}	5.67^{c}	6.25^{d}
		OSSS	15-25	75-80	13-16	16.00^{cd}	0.00^{c}	60.00^{b}	90.00^{b}	6.69^{c}	3.63^{e}	0.00^{e}
	NPK	TB	25-30	80-85	18-23	14.00^{e}	3.00^{ab}	75.00^{a}	78.00^{c}	6.09^{c}	9.77^{a}	21.43^{a}
		OSSS	15-25	75-80	13-16	14.00^{e}	1.00^{b}	60.00^{b}	95.00^{a}	9.67^{a}	4.41^{d}	7.14^{d}
	CLT	TB	25-30	80-89	18-23	12.00^{ef}	0.00^{c}	75.00^{a}	70.00^{e}	5.13^{cd}	2.67^{f}	0.00^{e}
		OSSS	15-25	75-80	13-16	12.00^{ef}	0.00^{c}	60.00^{b}	90.00^{b}	7.04^{b}	2.89^{f}	0.00^{e}
Mean						21.00	1.67	66.25	83.17^{c}	7.57^{b}	5.56^{c}	7.58
SD						10.48	1.62	7.50	9.70	1.56	2.67	7.43
SE±						3.03	0.47	2.17	2.80	0.45	0.77	2.14
LSD(0.05)						8.35	1.27	6.15	7.64	1.00	2.09	6.08
CV (%)						49.91	88.53	11.32	11.66	20.60	48.00	97.91

HT-Heap Tillage. RT-Ridge Tillage.PM-Poultry Manure.CLT-Control.TB-Traditional Barn.OSSS- Open Side Storage Structure (*) Significant at 5% level of probability NS-Not significant

Table 6 Proximate composition analysis of white yam before and after storage condition

Storage Structure	Moisture (%) Before	Moisture (%) After	Protein (%)Before	Protein (%)After	CHO (%)Before	CHO (%)After	Fat (%) Before	Fat (%) After	Fibre (%) Before	Fibre (%) After	Ash (%) Before	Ash (%) After
(TB)	62.30^{b}	58.23^{b}	5.21^{ab}	5.12^{ab}	93.09^{a}	92.46^{a}	1.00^{a}	0.96^{a}	1.63^{b}	1.73^{b}	1.68^{a}	1.78^{a}
(OSSS)	66.97^{a}	64.50^{a}	6.25^{a}	6.19^{a}	91.06^{b}	88.03^{b}	1.80^{a}	0.95^{a}	3.30^{a}	3.08^{a}	1.56^{ab}	1.640^{ab}
Mean	64.64	61.36	5.73	5.66	92.04	90.74	1.40	0.95	2.46	2.41	1.62	1.71
SD	2.33	3.38	0.42	0.45	0.98	1.82	0.45	0.01	2.47	0.68	0.07	0.08
SE±	1.65	2.39	0.30	0.32	0.69	1.29	0.32	0.03	6.00	0.48	0.05	0.06
LSD (0.05)	20.99	30.39	3.75	4.03	8.81	16.38	402	0.04	6.00	6.08	0.61	0.72
CV (%)	3.61	5.51	7.28	7.92	10.65	2.01	.9331	0.52	27.05	28.10	4.14	4.62

TB-Traditional Barn. OSSS-Open sided Storage structure

Table 7 Interaction effect of tillage and storage systems on physiology and environmental conditions of white yam after storage

Tillage	Storage Systems	Temp (0c)	Relative Humidly (%)	Moisture Content (%)	Total numbers of tubers observed	Number of tuber that rotted	Days to first sprouting	Dormancy period days from harvesting	Sprout weight (g)	% weight Loss	% Tuber Rot
HT	TB	25-30	80-85	18-23	40.00[a]	4.00[a]	75.00[a]	75.00[b]	5.56[b]	6.67[a]	10.00[a]
	OSSS	15-25	75-80	13-16	40.00[a]	3.00[ab]	60.00[b]	90.00[a]	8.09[a]	4.03[b]	7.50[ab]
RT	TB	25-30	80-85	18-23	16.00[cd]	1.00[b]	75.00[a]	75.00[b]	8.95[a]	5.67[ab]	6.25[b]
	OSSS	15-25	75-80	13-16	16.00[cd]	0.00[c]	60.00[b]	90.00[a]	6.69[ab]	3.63[bc]	0.00[d]
TSXSS					*	*	*	*	*	*	*
LSD (0.05)					18.56	2.27	11.83	11.83	2.41	2.08	6.76

(*) Significant at 5% level of probability NS-Not significant. TS-Tillage system.FX-Fertilizer.SS-Storage structure

Table 8 Interaction effect of Fertilizers and storage systems on physiology and environmental conditions of white yam after storage

Fertilizer	Storage Systems	Temp (0c)	Relative Humidly (%)	Moisture Content (%)	Total numbers of tubers observed	Number of tuber that rotted	Days to first sprouting	Dormancy period days from harvesting	Sprout weight (g)	% weight Loss	% Tuber Rot
PM	TB	25-30	80-85	18-23	28.00[a]	2.50[a]	75.00[a]	75.00[c]	8.75[a]	6.17[b]	8.13[ab]
	OSSS	15-25	75-80	13-16	28.00[a]	1.50[a]	60.00[b]	90.00[b]	7.38[a]	3.83[c]	3.75[c]
NPK	TB	25-30	80-85	18-23	8.62[c]	3.50[a]	75.00[a]	75.00[c]	5.80[ab]	9.27[a]	19.41[a]
	OSSS	15-25	75-80	13-16	8.62[c]	2.00[a]	60.00[b]	95.00[a]	8.77[a]	6.59[b]	10.09[b]
CLT	TB	25-30	80-89	18-23	15.00[b]	0.50[a]	75.00[a]	70.00[d]	5.61[ab]	5.30[b]	2.78[c]
	OSSS	15-25	75-80	13-16	15.00[b]	0.00[a]	60.00[b]	90.00[b]	7.04[a]	2.46[c]	0.00[d]
FxSS					*	NS	*	*	NS	*	*
LSD 0.05)					9.72	0.94	7.50	9.60	1.21	6.89	6.94

(*) Significant at 5% level of probability. NS-Not significant. F-Fertilizer.SS-Storage structure

Table 9 Interaction effect between Tillage and Fertilizer on physiology and environmental conditions of white yam at storage

Tillage	Fertilizer	Temp (0c)	Relative Humidly (%)	Moisture Content (%)	Total numbers of tubers observed	Number of tuber that rotted	Days to first sprouting	Dormancy period days from harvesting	Sprout weight (g)	% weight Loss	% Tuber Rot
HT	PM	20-28	78-83	16-20	40.00[a]	3.50[a]	70.00[a]	83.00[b]	6.83[a]	5.35[b]	8.75[c]
	NPK	20-28	78-83	16-20	23.00[c]	3.50[a]	68.00[ab]	87.00[a]	6.69[a]	7.08[a]	15.21[a]
	CLT	20-28	78-83	16-20	18.00[d]	0.00[c]	68.00[ab]	80.00[c]	6.56[a]	4.98[b]	2.78[e]
RT	PM	20-28	78-93	16-20	16.00[d]	0.00[c]	68.00[ab]	83.00[b]	7.82[a]	4.65[b]	3.13[e]
	NPK	20-28	78-83	16-20	14.00[d]	2.00[b]	68.00[ab]	87.00[a]	7.88[a]	7.09[a]	14.29[a]
	CLT	20-28	78-83	16-20	12.00[d]	0.00[c]	68.00[ab]	80.00[c]	6.09[a]	2.78[c]	0.00[e]
TSxF					`*	*	*	*	NS	*	*
LSD(0.05)					10.02	1.66	1.00	2.36	0.67	1.31	6.69

(*) Significant at 5% level of probability. NS-Not significant. TS-Tillage system. F-Fertilizer

Table 10 Interaction effect between Tillage, Fertilizer and Storage on physiology and environmental conditions of white yam at storage

Treatments	Temp (0c)	Relative Humidly (%)	Moisture Content (%)	Total numbers of tubers observed	Number of tuber that rotted	Days to first sprouting	Dormancy period days from harvesting	Sprout weight (g)	% weight Loss	% Tuber Rot
Tillage	20-28	78-83	16-20	21.00[b]	1.50[a]	68.30[ab]	81.00[a]	7.00[a]	5.32[a]	7.36[a]
Fertilizer	20-28	78-83	16-20	17.21[c]	1.67[a]	67.50[a]	83.00[a]	7.23[a]	5.60[a]	7.36[a]
Storage	20-28	78-83	16-20	28.00[a]	2.00[a]	68.00[ab]	83.00[a]	7.32[a]	5.00[a]	5.94[a]
TSxSS				*	*	*	*	*	*	*
FxSS				*	NS	*	*	NS	*	*
TSxF				*	*	*	*	NS	*	*
TSxFxSS				*	NS	*	NS	NS	NS	NS
LAS (0.05)				2.76	0.12	0.06	0.54	0.04	0.16	0.40

(*) Significant at 5% level of probability. NS-Not significant.TS-Tillage system.F-Fertilizer.SS-Storage structure