TOWARDS THE DEVELOPMENT OF AN INTELLIGENT EVAPORATIVE COOLING SYSTEM FOR POST-HARVEST STORAGE OF SELECTED FRUITS

O. R. Isah[1]*, S. E. Adebayo[2], B. K. Nuhu[3], B. U. Umar[4], D. Maliki[5], I. M. Abdullahi[6], E. M. Dogo[7], O. M. Olaniyi[8] & J. Agajo[9]

[1,3,4,5,6,7,8,9] Department of Computer Engineering, Federal University of Technology, Minna
[2,] Department of Agricultural and Bio Resources Engineering, Federal University of Technology, Minna
***Corresponding author**: isah.rabiu@futminna.edu.ng

ABSTRACT

Poor management of post-harvest storage of fruits and vegetables has led to enormous food wastage and economic loss globally. Refrigerating systems have been adopted over the years to avert these losses; however, installing them is expensive and can cause chilling injury and moisture loss to the fruits and vegetables when they go below 20℃ temperature. An evaporative cooling system has recently been widely used to preserve fruits and vegetables because it's cheap to implement, especially for small-scale farmers. This system reduces the temperature and increases the air humidity in their chamber by removing latent heat from the evaporated water when exposed to sunlight. The existing evaporative system has been efficient in preserving the quality of fruits and vegetables as well as extending their shelf-life; however, they lacked automated operation and control mechanisms, intelligent mechanisms capable of identifying the physical state of the fruits, adaptive control techniques for the storage and remote monitoring, feedback scheme of the system for use by the farmers. The abovementioned limitations have prevented the system from achieving optimal performance in preserving fruits. Hence, this research aims to develop a multi-chamber evaporative cooling preservative system for post-harvest storage of fruits. In the first step, Tomato images were collected and trained with the MobileNetV2 model, achieving accuracy, precision and recall of 88%, 89% and 88% respectively. Overall, the model performs well, however, fine-tuning the model or using more training data could help improve its performance further.

KEYWORDS: Intelligent, Evaporative, Cooling system, Tomato, post-harvest, Transfer Learning

INTRODUCTION

Food waste is a global menace that spans the food supply chain from agricultural production to consumption. More than 40% of fruit production is lost to post-harvest loss globally as shown in the attached Figure 1, while 50% is lost in Nigeria annually, according to the Nigerian Stores Products Research Institute (NSPRI) (Amjad, *et al.,* 2023). These contribute largely to hunger, loss of revenue to the government and farmers. Furthermore, fruit waste is an ecological concern due to its severe environmental effects. This is because the release of greenhouse gas emissions can be tied to the amount of disposed fruits' waste from methane generation during decomposition (Anand & Barua, 2022). Hence, proffering a potent solution to fruit waste through an effective post-harvest management system will enhance food security, reduce hunger, and mitigate global greenhouse gas emissions.

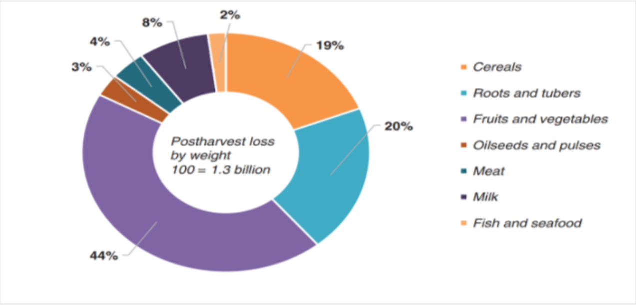

Figure 1: Post-harvest Losses of Commodities in the World (Amjad, *et al.,* 2023).

The post-harvest stage covers the period from which the fruit is harvested until it is consumed or deteriorated. Inherently, the fruits' quality can not improve because the nourishment they receive from the soil has ceased when harvested (Sani, *et al.,* 2023). However, the deterioration process can be decelerated using several existing approaches in the literature. One of these approaches is the refrigerator that can preserve different kinds of fruits; however, it's expensive to install and can lead to moisture loss and chilling injury when it goes below a certain temperature range. This proves the unsuitability of refrigerators because they can not maintain the fruits' optimum storage conditions. Another viable method is using an evaporative cooling system to preserve fruits, which mainly depends on the environmental condition. The effectiveness of this method relies on the ability of the system to maintain the optimum and suitable environmental conditions of the fruits, which is lacking in the existing evaporative cooling systems. This research aims to address this identified problem by developing an intelligent multi-chamber evaporative cooling preservative system for post-harvest storage of fruits capable of preserving the quality of fruits and extending their shelf-life. Consequently, the system will enable farmers to generate more income from their farm products and boost the nation's economy.

REVIEW OF RELATED WORKS

The importance of fruits and vegetables in our daily diet regimen can not be over-emphasized. This underscores why fruits and vegetables were produced in large quantities in recent years. According to FAO, 2022, the production of fruits and vegetables reached 1.2 billion metric tonnes, with 59% production growth in 2021, as shown in Figure 2. The most produced fruit in 2021 was Banana, with 125 million tonnes, and orange, was 76 million tonnes. Moreover, the most grown vegetable was tomatoes, with 189 million in 2021 (FAO, 2022).

Tomatoes, bananas and oranges are highly sought-after fruits and vegetables due to their high nutritional value. However, due to their high susceptibility to spoilage, significant post-harvest losses are always incurred quantitatively and qualitatively. Banana and orange fruits incur 35% and 25% post-harvest losses in Nigeria, according to research carried out by the International Institute of Tropical Agriculture (IITA), while tomatoes incur 40 to 60% of the total number of tomatoes produced in Nigeria (Anajekwu, *et al.,* 2023).

Hence, developing a cooling evaporative system for the selected fruits is essential to minimize this monumental economic loss drastically. This also ensures food availability and security, job opportunities, and environmental preservation for the ever-growing population, boosting economic growth and development in Nigeria's agricultural sector.

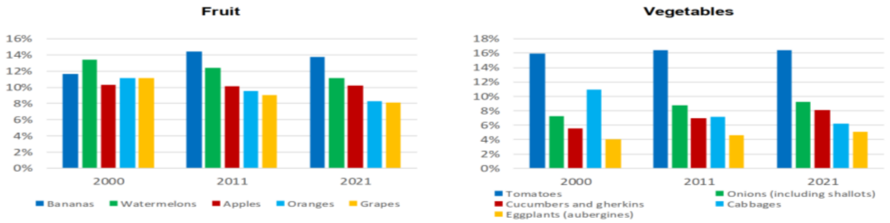

Figure 2: Percentages of Fruits and Vegetables Production in the World (FAO, 2022)

Thus, this research aimed at developing an evaporative cooling system for the optimum preservation of the selected fruits owing to their nutritional and economic value to the human populace. In addition, this section reviews the related works undertaken in this area to bring out the gaps left to be filled.

Defraeye, *et al.* (2022) developed an innovative evaporating cooling system to successfully maintain the quality and freshness of agricultural goods after harvesting. The effort aimed primarily to support marginalised and petite farms in rural and isolated regions. This developed system incorporated an insulation layer as an underlying structure, which can be constructed using charcoal or recyclable substances. This blanket is designed with multiple compartments to facilitate the storage of the charcoals. The trial findings of the produced evaporative cooler showed a significant increase in the longevity of fresh fruits, extending their shelf life to 14 days. The temperature values of both the interior and exterior air were decreased, while the humidity was increased. Several constraints constrained the study's findings. Firstly, the developed system that was constructed lacked full automation. Additionally, the increased shelf-life achieved was quite brief, and the temperature and relative humidity values were not optimised.

Kapilan & Patil (2022) constructed a low-cost evaporative cooling system to store agricultural products. This research addressed the problems related to the high cost of cold storage systems by introducing a solar photovoltaic system to power the evaporative cooling system and coconut coir as the cooling medium. The efficacy of the developed system was measured with the standard metrics, including efficiency, power, discharge and dry bulb temperature, and it was shown to achieve preservation of some agricultural products. However, it fell short in performance when compared with the existing systems due to the nature of the cooling medium adopted. The cooling medium used affected the regulation of temperature and humidity. Yenenh (2023) developed an evaporative cooling system to store horticulture products. This system combined direct and indirect evaporative cooling systems to extend the shelf life of fruits and vegetables, considering varying environmental conditions. The system Temperature was pre-set to 9.6℃ and 10.3℃ and a humidity value of 85% with a capacity of 260kg. The developed system was tested using tomato fruits and maintained the quality of the tomato. However, the system could not maintain the tomatoes' shelf life for extended periods due to the environmental conditions affecting the internal temperature and humidity.

Zhu *et al.* (2023) developed a novel dew-point evaporative cooler based on fibre membrane automatic wicking. In the study, the authors investigated four different kinds of fibre material. The wicking component of the evaporated cooler was automatically powered; however, artificial intelligence to make the system smart was not employed. In extending injera's shelf-life and preventing Fungi's growth, Birhanu & Belay (2023) developed an evaporative cooler clay chamber to regulate the temperature and humidity of this Ethiopian ethnic food. The system reduced the ambient temperature from 28.89℃ to 22.9℃ and the ambient relative humidity from 28.78% to 80.94%. However, the system could not maintain the shelf-life of injera for an extended period.

Attempts have been made to introduce an evaporative cooling system to store various kinds of fruits, reduce post-harvest waste, and improve agricultural productivity (Nkolisa, *et al.,* 2018). However, these systems have limitations such as manual operation and lack of control technology, lack of remote monitoring of the fruits' shelf life and a feedback system for the farmers and lack of intelligent technology. Hence, a system capable of classifying, detecting, and post-harvest storage of the selected fruits is needed. Furthermore, based on the literature reviewed, it is evident that there is a need for an improved system to address the research gaps identified. These gaps include the manual operation and lack of control mechanism, lack of an intelligent mechanism capable of identifying the physical state of the selected fruits, absence of an adaptive control technique for the storage system, and lack of remote monitoring and a feedback scheme of the system for use by the farmers.

MATERIALS AND METHODS

This stage involves collection, processing and storage of the selected fruits (Tomatoes, bananas and orange) in Not Only SQL (NoSQL) database. The selected fruits will be collected from various points (study sites) and the clear images of the fruits will be taken with a high-resolution camera equipped with high memory capacity for further processing.

DATA COLLECTION

Data from the selected fruits will be collected using a high-resolution digital camera with high-capacity memory card.

DATABASE DEVELOPMENT

The collected dataset of ripe and unripe images will be stored in NoSQL database. The choice of the database is informed by the fact the NoSQL is efficient, reliable and faster access as compared to other available databases (de Oliveira, *et al.,* 2021; Tsai, *et al.,* 2022).

DEVELOP AN INTELLIGENT SELECTED FRUIT RECOGNITION AND CLASSIFICATION

Incorporating intelligence into the existing evaporating cooling system is a game changer for the selected fruits' storage as the system will be able to identify the state of the selected fruit and adjust to its suitable parameters' values, including temperature, humidity and carbon dioxide. The steps to achieve this is as shown in Figure 3 .

First, the stored data will be accessed from the image database, as explained earlier. Then, the data will be pre-processed as follows: first, an improved filtering algorithm will be applied to filter the noise on the image. Noise, such as speckle, salt and pepper and other noises, must be filtered as they are obtained during image capture and affect the intelligent system's overall performance if not filtered. After noise filtering, the image will be cropped, followed by erosion and dilation, which will be carried out in this section. Finally, the pre-processed data will be fed into the proposed convolutional neural network (CNN) model. The hyperparameters of the CNN model architecture will be fine-tuned to yield better results.

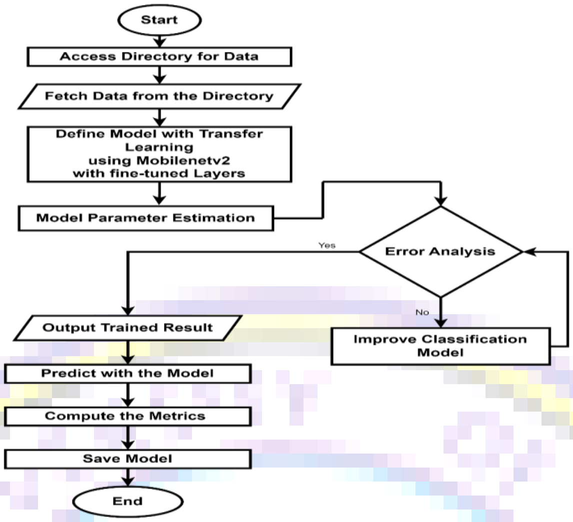

Figure 3: Proposed Deep Learning Model flow chart

Like other deep learning models, the CNN deep learning model is sensitive to hyperparameters (Şen & Özkurt, 2020). Therefore, choosing the optimal parameter leads to better results. The parameters will be fine-tuned using a nature-inspired metaheuristic strategy called Particle swarm optimization (PSO) algorithm (Jain, *et al.,* 2022; Jeelani & Veena, 2018) and the PSO equations are shown in equations 1 and 2.

$$x_i(t+1) = x_i(t) + v_i(t+1)t \qquad (1)$$

$$v_i(t+1) = wv_i(t) + c_1r_1(pbest(t) - x_i(t) + c_2r_2(gbest(t) - x_i(t) \qquad (2)$$

Where,

x is the particle's position

v is the particle's velocity

$gbest$ is the global best

c and r are constant parameters

The particles are described as a 'flock of birds' exhibiting a collective motion in search of the best solution or global optimum in a solution space (Xu, *et al.,* 2023). It has been tested on some combinatorial optimisation problems and has proven very effective.

After optimising the hyperparameters of the CNN model, such as the one shown in Figure 4, it will be trained with the dataset collected and pre-processed as described earlier. After training, the model error will be estimated and checked for several iterations. The model will be saved and deployed when the error reaches an acceptable limit. So, the trained deep learning model will now have the ability to intelligently and autonomously inform the next stage of the ECS pipeline, the state of the selected fruit.

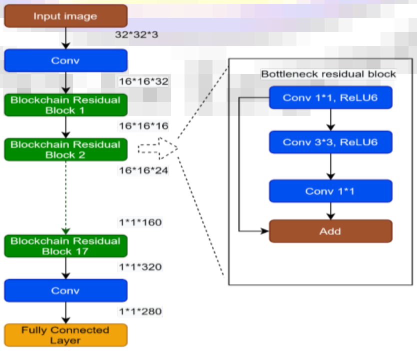

Figure 4: MobileNetv2 Architecture (Akay, *et al.,* 2021)

RESULTS AND DISCUSSION

This section discusses the preliminary results obtained from the collection of tomato fruits (ripe and semi-ripe).

Figure 5: Collected Ripe Tomatoes

Figure 6: Collected Semi-ripe Tomatoes

A thousand images of ripe and semi-ripe tomatoes were collected, washed and snapped. The image samples are shown in Figues 5 and 6. The images were transferred to a computer system and had their backgrounds removed to obtain a clearer images and reduce computational complexity. The images were divided into 70% training, 15% each for testing and validation. Furthermore, the images were trained with a transfer learning architecture, MobileNetV2.

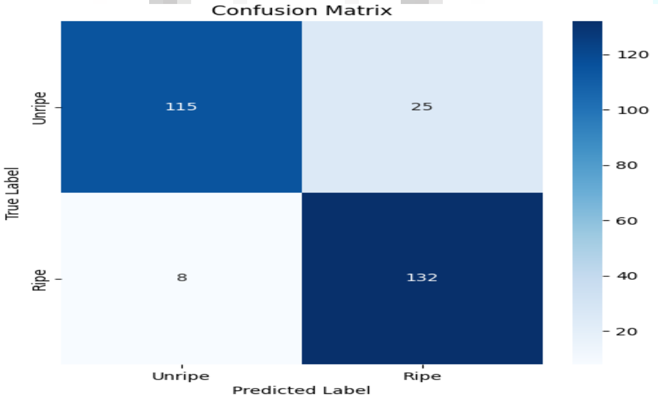

Figure 9: Confusion Matrix of the Trained Model

The confusion matrix shown in Figure 9 is a great way to evaluate the performance of the classification model for distinguishing between ripe and unripe tomatoes. The True Positives (Ripe correctly classified as Ripe): 132; True Negatives (Unripe correctly classified as Unripe): 115; False Positives (Unripe incorrectly classified as Ripe): 25 and the False Negatives (Ripe incorrectly classified as Unripe): 8

The model's accuracy can be calculated as the ratio of correctly classified instances to the total instances. In this case, the accuracy is 88%. This indicates that the model is quite reliable in classifying the tomatoes correctly.

The precision measures the accuracy of the positive predictions. It is calculated as 89%. This means that when the model predicts a tomato is ripe or unripe, it is correct 89% of the time.

The recall measures the ability of the model to identify all relevant instances. It is calculated as 88%. This means that the model correctly identifies 88%% of all ripe and unripe tomatoes.

Furthermore, the model has a high recall for ripe tomatoes, meaning it is very good at identifying ripe tomatoes. The precision for unripe tomatoes is also high, indicating that when the model predicts a tomato is unripe, it is usually correct. In addition, the lower recall for unripe tomatoes suggests that the model sometimes misses unripe tomatoes, classifying them as ripe instead.

Overall, the model performs well, but there is room for improvement, especially in reducing the number of false positives (unripe tomatoes classified as ripe). Fine-tuning the model or using more training data could help improve its performance further.

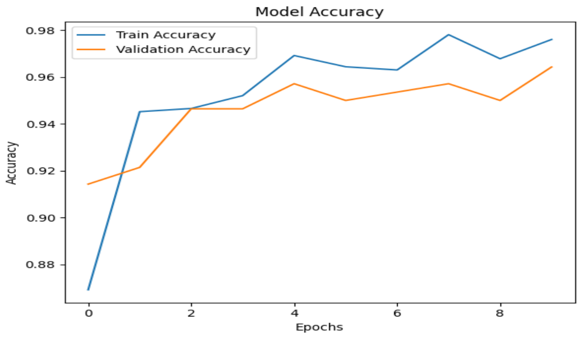

Figure 10: Model Accuracy of the Trained Model

Figure 10 shows the accuracy of a machine learning model trained to classify tomato images into ripe and unripe categories over 10 epochs. The blue line represents the training accuracy, which starts at approximately 0.88 and increases rapidly, reaching around 0.96 by epoch 2. It continues to fluctuate slightly but generally trends upwards, peaking at around 0.98 by epoch 9.

The orange line represents the validation accuracy, which starts at approximately 0.90 and increases steadily, reaching around 0.94 by epoch 2. It then fluctuates slightly but generally trends upwards, reaching around 0.96 by epoch 9. Thus, the increasing trend in both training and validation accuracy indicates that the model is learning effectively. The model's ability to generalize well to unseen data is demonstrated by the close alignment of the training and validation accuracy lines.

Also, The close alignment of the training and validation accuracy lines suggests that the model is not overfitting. Overfitting occurs when a model performs well on training data but poorly on validation data. In this case, the model's performance on both training and validation data is similar, indicating good generalization.

The high accuracy values (around 0.96 to 0.98) suggest that the model is reliable in classifying tomato images into ripe and unripe categories. This high level of accuracy is promising for practical applications, such as automated identification of tomato fruits.

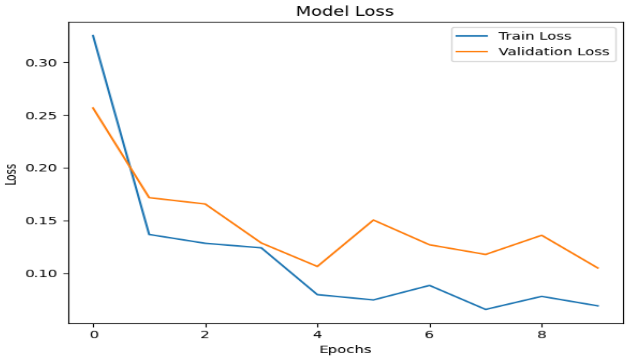

Figure 11: Model Loss of the Trained Model

Figure 11 depicts the model loss over 10 epochs for a machine learning model trained to classify tomato images into ripe and unripe categories. The blue line represents the training loss, which starts at around 0.35 and decreases steadily, showing a significant drop in the first few epochs and then gradually decreasing to around 0.05 by the 9th epoch. Then, the orange line represents the validation loss, which starts at around 0.25 and decreases, but it fluctuates more than the training loss, ending at around 0.10 by the 9th epoch. Thus, the decreasing trend in both training and validation loss indicates that the model is learning effectively. The model's ability to generalize well to unseen data is demonstrated by the decreasing validation loss. The fluctuations in the validation loss suggest that there might be some overfitting or variability in the model's performance on unseen data. Overfitting occurs when a model performs well on training data but poorly on validation data. In this case, the model's performance on both training and validation data is similar, indicating good generalization, but the fluctuations in validation loss suggest that there might be some overfitting. Furthermore, the low loss values (around 0.05 to 0.10) suggest that the model is reliable in classifying tomato images into ripe and unripe categories.

CONCLUSION

This research proposed an Intelligent Evaporative Cooling System that reduces the post-harvest wastage of the selected fruits including tomatoes, orange and banana while increasing the food security potential. The system is aimed at classifying stored fruits and adapts to temperature and humidity states suitable for storing, preserving quality, and improving the shelf life of the fruits, thus providing enough market time for the farmer to get his fruits to the customers. Tomatoes fruits have been collected and trained to show the efficacy of the pre-trained model. An intelligent storage, Automatic control, and remote monitoring will be achieved after the implementation of this research.

ACKNOWLEDGMENT

The authors appreciate TETFund for funding this research. They are also grateful to the management of the Federal University of Technology, Minna, for providing the enabling environment for the execution of the study.

REFERENCES

Akay, M., Du, Y., Sershen, C. L., Wu, M., Chen, T. Y., Assassi, S., ... & Akay, Y. M. (2021). Deep learning classification of systemic sclerosis skin using the MobileNetV2 model. *IEEE Open Journal of Engineering in Medicine and Biology, 2,* 104-110.

Amjad, W., Munir, A., Akram, F., Parmar, A., Precoppe, M., Asghar, F., & Mahmood, F. (2023). Decentralized solar-powered cooling systems for fresh fruit and vegetables to reduce post-harvest losses in developing regions: a review. *Clean Energy, 7*(3), 635-653.

Anajekwu, E. O., Alamu, E. O., Awoyale, W., Amah, D., Akinoso, R., & Maziya-Dixon, B. (2023). Influence of processing methods on the sensory acceptability of products from selected hybrid plantains (Musa species AAB) cultivars. *IITA Annual Report, 2,* 1-111.

Anand, S., & Barua, M. K. (2022). Modeling the key factors leading to post-harvest loss and waste of fruits and vegetables in the agri-fresh produce supply chain. *Computers and Electronics in Agriculture*, *198*, 106936.

Birhanu, G. A., & Belay, A. N. (2023). Enhancing the shelf life of injera: design of an evaporative cooler clay chamber derived from local clay in Bahir Dar, Ethiopia. *Design Science*, *9*, e8.

Defraeye, T., Schudel, S., Shrivastava, C., Motmans, T., Umani, K., Crenna, E., ... & Onwude, D. (2022). The charcoal cooling blanket: A scalable, simple, self-supporting evaporative cooling device for preserving fresh foods.

de Oliveira, V. F., Pessoa, M. A. D. O., Junqueira, F., & Miyagi, P. E. (2021). SQL and NoSQL Databases in the Context of Industry 4.0. Machines, 10(1), 20.

Food and Agriculture Organization of the United Nations (FAO) (2022). *FAOSTAT.* Available:www.fao.org/food-agriculture-statistics/en/

Food and Agriculture Organization of the United Nations Rome, Italy.

Jeelani, A., & Veena, M. B. (2018). Hybridization of PSO and Anisotropic Diffusion in, Denoising the Images. *Lecture Notes in Electrical Engineering*, *471*, 463–473. https://doi.org/10.1007/978-981-10-7329-8_47

Jain, M., Saihjpal, V., Singh, N., & Singh, S. B. (2022). An overview of variants and advancements of PSO algorithm. *Applied Sciences*, *12*(17), 8392.

Kapilan, N., & Patil, V. K. (2022). Development and evaluation of a low-cost evaporative cooling system for agricultural product storage. *Research in Agricultural Engineering*.

Sani, M. H., Kadau, R., Sani, R. M., & Danwanka, H. A. (2023). analysis of socio-economic characteristics and post-harvest loss storage facilities used by vegetable crops value chain actors in Adamawa State, Nigeria. *Nigerian Journal of Agriculture and Agricultural Technology*, *3*(1), 210-229.

Şen, S. Y., & Özkurt, N. (2020). Convolutional neural network hyperparameter tuning with adam optimizer for ECG classification. In *2020 innovations in intelligent systems and applications conference (ASYU)* (pp. 1-6). IEEE.

Tsai, C. P., Chang, C. W., Hsiao, H. C., & Shen, H. (2022). The Time Machine in Columnar NoSQL Databases: The Case of Apache HBase. Future Internet, 14(3), 92.

Xu, H. Q., Gu, S., Fan, Y. C., Li, X. S., Zhao, Y. F., Zhao, J., & Wang, J. J. (2023). A strategy learning framework for particle swarm optimization algorithm. *Information Sciences*, *619*, 126-152.

Yenenh, K. (2023). Design, Fabrication and Evaluation of Evaporative Cooling System for the Storage of Fruits and Vegetables. *International Journal of Applied and Structural Mechanics (IJASM) ISSN: 2799-127X*, *3*(04), 9-22.

Zhu, M., Lv, J., Zhou, B., Xi, W., Wang, L., & Hu, E. (2023). Study on the performance of a novel dew-point evaporative cooler based on fiber membrane automatic wicking. *Science and Technology for the Built Environment*, 29(5), 574-587.

EVALUATION OF HERBICIDE MANAGEMENT ON NODULATION OF COWPEA

Ezekiel-Adewoyin, D[1]., E. Olanrewaju[1], R. Aniyikaiye[1], F. Tanko[1] & E. Daniya[2]
[1]Department of Soil Science and Land Management
[2]Department of Crop Production
School of Agriculture and Agricultural Technology
Federal University of Technology
Minna, Niger State, Nigeria
Corresponding authors: eze.dorcas@futminna.edu.ng

ABSTRACT

The use of herbicides will surely have diverse effects on cowpea performance. A screen house trial was conducted in the School of Agric. and Agricultural Technology, Federal University of Technology, Minna. Four treatments (pre-emergence (PE)+manual weeding (MW), pre+post emergence (PPE), manual weeding (MW), and weedy check (WC)) replicated thrice were laid in Completely Randomized Design (CRD). Two cowpea varieties nodulation, shoot, and root biomass were assessed. Manual weeding recorded the highest shoot dry biomass followed by PE+MW, while WC and PPE had the least shoot biomass in Sampea 14. Also, the highest root dry biomass was recorded for MW, followed by PE+MW, while, PPE and WC applications recorded the least root biomass. Similarly, Sampea 14 had the highest number of nodules under MW, followed by WC, PE+MW recorded the least number of nodules, while, PPE treatment had no nodules. Likewise, MW had the highest nodule effectiveness recorded followed by PE and WC. Sampea 14 treated with MW had the highest nodule weight followed by WC and PE+MW. In conclusion, the overall result of the experiment showed that the application of herbicides has a hazardous effect on cowpea nodulation, and shoot and root growth. Therefore, there is an urgent need to conduct further studies on the impact of different herbicides on cowpea growth.

Keywords: Biological nitrogen Fixation, Weedy check, Nodulation, Herbicides

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp) is an important grain and fodder pulse. It's a dual-purpose grain legume crop; it is used as food for humans, fodder for livestock, and income to over 10 million households (Kebede, 2020a). In today's world, man's requirement for protein makes cowpea an acceptable option for food as cowpea provides an affordable source of human dietary protein mostly in developing countries (Xu *et al.,* 2016). It is adapted to dry and low fertility conditions where it still produces leaves even though not to its optimal ability under such conditions (Nagarajan *et al.*, 2019). In Nigeria, cowpeas are one of the important crops that contribute to food security in several ways by constituting part of the daily menu in many households. The seed contains about 25 % protein and 64 % carbohydrates with 27–34 % protein in the leaves (Oloyede *et al.*, 2022). Cowpea is grown all over the world an estimated 14.5 million cultivation of cowpea is mainly to maintain the level of nitrogen in the soil, thereby reducing the expenses of commercial nitrogen fertilizers (Owade *et al.*, 2020). In the agricultural system, it is a control measure for the loss of nitrogen absorbed by cereals, thus, it has a positive effect on the soil properties, due largely to its unique capacity to fix atmospheric nitrogen and performs well even in poor soils. In natural ecosystems, the highest input of nitrogen comes from nitrogen fixed by microorganisms, called *diazotrophs* (Korked *et al.*, 2017). Nitrogen input from cowpeas can be a sustainable source of nitrogen in agricultural systems.

Weeds are a permanent constraint to crop productivity in agriculture they are plants that strive for nutrients, space, and light and they exert lots of harmful effects by reducing the quality as well as quantity of crop yield if the weed population is left uncontrolled (Kavalinus and Bobinas, 2006). Herbicide management in cowpeas has been with a low level of technology this is partly due to being mostly cultivated in less developed countries. The nature of weed interference strongly determines the kinds of weed management practices Adigun *et al.,* (2018). Different methods of weed control in cowpea have been shown to reduce weed competition in cowpea (Singh *et al*., 2006). Weed control methods applicable to crops comprise preventive measures which include all sanitary measures routinely used such as vigilance to note the presence of a strange plant on the field, rouging isolated weeds that have escaped control by other methods, inspection of cowpea seeds at entry points into country to ensure freedom from weed seeds (quarantine) and preventing weed spread to new cowpea fields. Other options are cultural, physical, biological, and chemical weed control methods. According to Abdul Rahman *et al*., (2021), competition of weeds with crops is mainly for available nutrients, moisture, space, and sunlight, thus causing a significant crop yield loss. Weeds may also reduce crop yield by releasing allelopathic compounds into the environment (Marinov-Serafimov 2015) and by providing favorable environments for pests and viruses (Caporaso *et al*., 2020). Hence altering the activities of microorganisms in the soil.

The use of chemical weed control in cowpeas is limited due to the scarcity of studies into the selectivity of herbicides for the crop (Sousa *et al.,* 2017) and there are no registered herbicides for cowpeas. Thus, one of the components of improved production technology is appropriate weed control, but weeds continue to render destruction to the efforts applied towards increasing cowpea yield. Broadleaf weeds also reduce the availability of photosynthetic area radiation (PAR) to the lower layer leaves of the crop canopy (Langyintuo *et al*., 2001), and reduce the longevity and expansion rate of lower leaves due to a decrease in the availability of soil nitrogen and moisture content. Therefore, the Biological Nitrogen Fixation of such plants will be affected because the nodulation and root growth are likely to have been negatively influenced. Resource-poor farmers in Nigeria employ hand-and-hoe weeding for weed control, but this cultural method is time-consuming, energy-depleted, and costly. The common method of weeding such as hand weeding is costly, and labor is not usually available during the growing season due to workload (Abdul Rahman *et al*., 2021). Whereas the use of herbicides gives rapid results, is more convenient to the farmers, increases the yield of crops, and reduces labor costs. Hence, the use of herbicides in cowpeas to control weeds appears to be useful (Osipitan, 2017). However, it is necessary to investigate the effect of weed management on the shoot, root, and nodulation of cowpea, to ascertain which should be efficient, cost-effective, and environmentally friendly. Therefore, the present study was conducted to examine the effect of weed management on the shoot, root, and nodulation of cowpeas (Sampea 14) in Minna.

MATERIALS AND METHODS

Study site

The experiment was conducted in the screen house of the School of Agriculture and Agricultural Technology, FUT, Minna, Niger State. The geographic positioning system (GPS) coordinates of the screen house are latitude 9°31’27’’N and longitude 6°26’ 23’’E, with an elevation of 189.60 m above sea level. Minna is located in the Southern Guinea Savanna of Nigeria. It has a mean annual rainfall of l248 mm and a sub-humid climate. It is also characterized by a dry season of about 5 months occurring from November to March and also has a mean maximum temperature of 33.5 °C from March to June (Abdullahi, 2021).

Collection and preparation of soil sample

Soil sample was collected from the horticultural garden using soil auger from the plot systematically from 40 auger points over the entire landscape of the field at a depth of 0-15 cm. The collected samples were bulked and mixed in the field to form a composite sample. Subsamples were collected into a well-labeled sampling bag, which was air–dried and taken to the Soil Science and Land Management laboratory where it was gently crushed with a porcelain mortar and pestle, screened through 2.0 and 0.5 mm sieve in preparation for routine analysis.

Treatments and Experimental Design

The treatments used are (i) PE+MW (application of herbicides Butaclor with active ingredient (2-Choro-N-(2,6=diethylphenyl) acetamide), (ii) PPE (application of herbicide Butaclor with active ingredient (2-Choro-N-(2,6=diethylphenyl) acetamide) and Upl iris with active ingredients (Sodium Acifluorfen 16.5 + Clodinafop propargyl 8 % EC), (iii) MW (3 and 6 weeks after sowing) and (iv) WC replicated thrice. 5 kg of soil was used per pot in Completely Randomize Design (CRD).

Agronomic Practices

Collected soil was mixed, and weighed and 5 kg of soil was transferred into the labeled polythene pots in the screen house. Water was added at 40 % water holding capacity (WHC) and left to equilibrate. Sowing of two seeds per pot was done. Pre-emergence herbicides application (Butachlor) 5 ml was diluted in 5 liters of water and was sprayed a day after planting. After one week of emergence, 0.33 g of NPK 15:15:15 fertilizer was weighed, basal application of the fertilizer (NPK 15:15:15) was done to all the replicates, and 0.005 g single superphosphate was applied to augment for phosphorus. MW was done at 3 and 6 WAS. Post-emergence herbicides (Upl) were sprayed 5 WAS. Insecticide (Cytalothrin) was sprayed at 6, 8, and 10 WAS.

Laboratory Analysis of the Soil

The physical and chemical properties of the sieved soil were analyzed by the standard method described by IITA (1982) as follows: Particle size of the soil was determined using the hydrometer method. Soil pH was measured in 1:2.5 soil/water and 0.01M CaCl2 suspension with a pH meter. Total nitrogen was determined by the micro Kjeldahl method. Total organic carbon was determined by the Walkey - Black wet oxidation method. Available phosphorous was determined colorimetrically after Bray-Pl extraction. The exchangeable bases were extracted with a neutral 1N NH4OAC solution. Exchangeable Cations: Sodium and potassium in the extract were determined by flame photometry while Calcium and Magnesium in the filtrate were determined with an Atomic Adsorption Spectrophotometer (AAS). Exchangeable acidity was extracted with 1.0 N KCl (potassium chloride) solution. The total acidity from exchangeable Hydrogen and Aluminum was determined by titration. Effective Cation Exchange Capacity was obtained by the summation of exchangeable cations and the exchangeable acidity.

Data collection: Measurement of cowpea growth and nodulation parameters

Shoot and root Weight (Fresh and Dry)

Shoot and root weight in grams (g) was measured immediately after harvesting (Fresh weight) and was measured after drying in an oven at 75oC for 48 hrs and the weight was measured using an electronic weighing balance.

Nodule Count

After 6 weeks of planting, plants were harvested using a sharp scissor to cut the shoot from the plant base. The roots were immediately washed in a 2 mm sieve using water to remove soil and prevent detached nodules from flowing off with the water. The nodules were separated from the roots for counting.

Nodule Weight (Fresh and Dry)

Fresh nodule weight in grams (g) was measured immediately after harvesting. The nodules were oven-dried at 75oC for 48 hrs and dry weight of the nodule was obtained.

Nodule Percentage Effectiveness

Nodules from each treatment were selected randomly and cut open with a blade to determine the effective ones. Nodules with pink to reddish-brown color were considered effective while nodules with green or dark color were considered ineffective (Gwata *et al.,* 2022). The percentage effective numbers were recorded.

Statistical analysis: All data collected were subjected to Analysis of Variance (ANOVA) using the GLM procedure of SAS (SAS Institute, 2012). Comparisons between significant treatment means were made by the Duncan's Multiple Range Test (DMRT) at a 5 % level of significance.

RESULTS AND DISCUSSION

Soil physical and chemical properties before sowing

The result of the particle size analysis showed that the soil contains 809 g kg-1, 56 g kg-1, and 135 g kg-1 of sand, silt, and clay respectively given a textural class of Loamy Sand. The pH in 1:2.5 H20 (6.36) was moderately acidic. The organic carbon (10.8 g kg-1) was moderate and total nitrogen (1.19 g kg-1) was moderately low, available phosphorus (3.36 mg kg-1) was low. The calcium (2 cmol kg-1) was low, potassium (0.33 cmol kg-1), sodium (0.68 cmol kg-1) and magnesium (2.8 cmol kg-1) were all moderate. The Exchangeable acidity value (0.6 cmol kg-1) was very low according to Chude *et al*., (2011).

Effect of Herbicides on Cowpea Shoot and Root Biomass

The effect of herbicides on cowpea shoot dry biomass of Sampea 14 as shown in Figure 1 shows that manual weeding recorded the highest biomass followed by PE, while WC and PPE had the least shoot biomass. The MW had 42 % of the shoot dry biomass than WC, 47 % shoot dry biomass than PPE, and 6 % shoot dry biomass than PE, while PE had shoot dry biomass of 39 % than PPE and 35 % shoot dry biomass than WC respectively. The effect of weed control on root dry biomass of Sampea 14 as represented in Figure 2 shows that MW recorded the highest root dry biomass followed by PE, PPE, and WC recorded the least root biomass. The MW had the highest root biomass of 100 % than the WC, 69 % than PE+MW, and 91 % than PPE, while the PE had a higher root biomass of 13 % than PPE and 18 % than WC, while PPE had 5 % root biomass than WC.

The results of this study revealed that the effect of different weed control methods employed significantly affected the performance of cowpea growth. The presence of weeds in the WC control significantly hindered cowpea growth, this could be as a result of competition for nutrients and water. In contrast, the weed-free condition evident on MW, PE+MW, and PPE-treated plots could have resulted in efficient utilization of nutrients and water by cowpea plants due to reduced weed competition. The various shoot and root dry biomass was significantly influenced by different weed control treatments. MW recorded maximum shoot and root dry biomass, this shows that the reduction in shoot and root dry biomass was apparently due to growth and yield components caused by weed infestation in WC plots.

Herbicides may affect soil microflora, beneficial microflora, and their activities by affecting plant growth or by directly affecting nitrogen-fixing organisms and their efficiency. There are complex processes that are affected by herbicides. The overall effect of herbicides is reflected in dry matter production. Either above-ground plant growth or root growth or both can be affected by the herbicides.

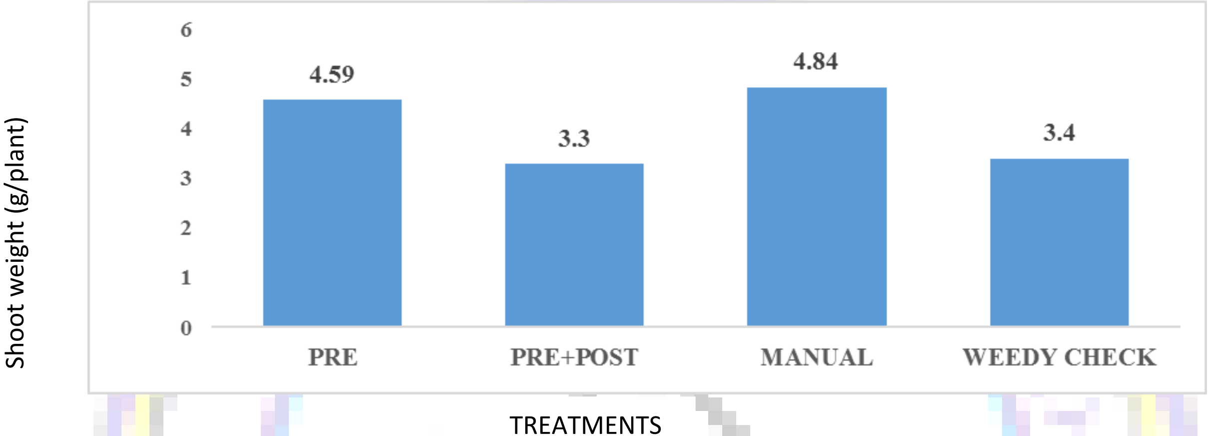

Figure 1: Effect of weed control on Cowpea shoot (Sampea 14)

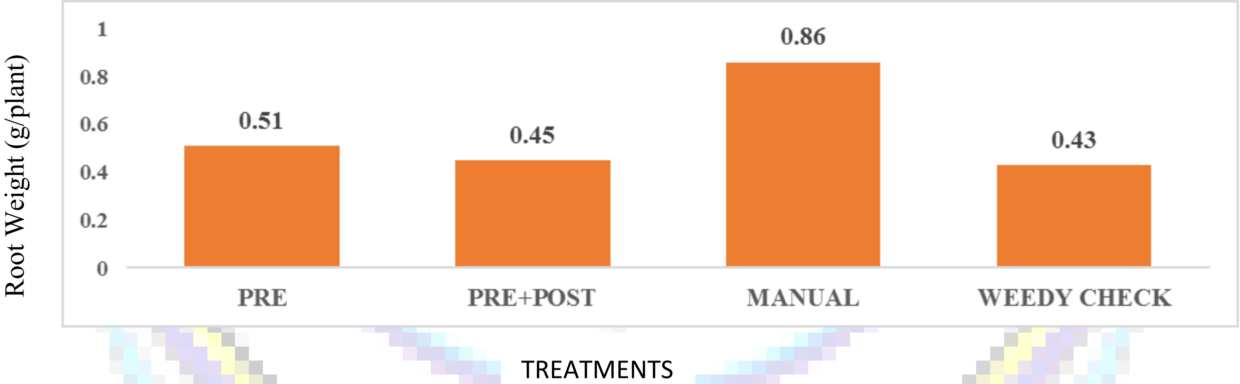

Figure 2: Effect of weed control on Cowpea root (Sampea 14)

The effect of herbicides on the number of nodules and effectiveness

The effect of herbicides on the number of nodules of Sampea 14 as shown in Figure 4 shows that MW had the highest number of nodules followed by WC, PE+MW recorded the least number of nodules, PPE had no nodule, MW100 % over PE+MW and 60 % than weedy check, while WC had 25 % than PE. The nodule effectiveness of Sampea 14 as represented in Figure 5 shows that MW recorded the highest effectiveness followed by PE and WC. MW had 100 % of the mean differences than the WC and PE+MW because there was no weed competition and the effect of herbicides on nodule effectiveness, MW nodule tends to be more effective. This result agrees with other researchers that herbicides can influence the success of legume-rhizobium symbiosis either by affecting the plant or rhizobium or both (Aderson *et al*., 2004). Although many researchers have concluded that the effect of herbicide application on symbiotic partnership is due largely to a direct effect of herbicide on plant growth and consequent photosynthate allocation to the nodules (Ayaz *et al.,* 2001). High concentrations of the herbicides significantly reduce the number of nodules. The results of this study agree with earlier observations that the application of some selected herbicides to soil inhibited nodulation and nitrification in leguminous crops (Singh and Wright,1999). Scientists have reported a decrease in microbial activity when a double quantity of glyphosate was applied to two Romanian soils (Sumalan *et al*., 2010). A low rate of herbicides has been recommended for weed control, to ensure effective nodulation and nitrogen fixation (Osipitan, 2017). The reduced number of nodules recorded with high herbicide concentrations could be attributed to the inhibitory effects of these pesticides on the leguminous crop under symbiotic *Rhizobium*-legume interactions in the soil. Gupta *et al.* (2002) by their experimentation, led to conclude that, the herbicide application can result in substantial loss of nodules from the roots, likely due to the herbicide-induced stress on the plant *Rhizobium* symbiosis.

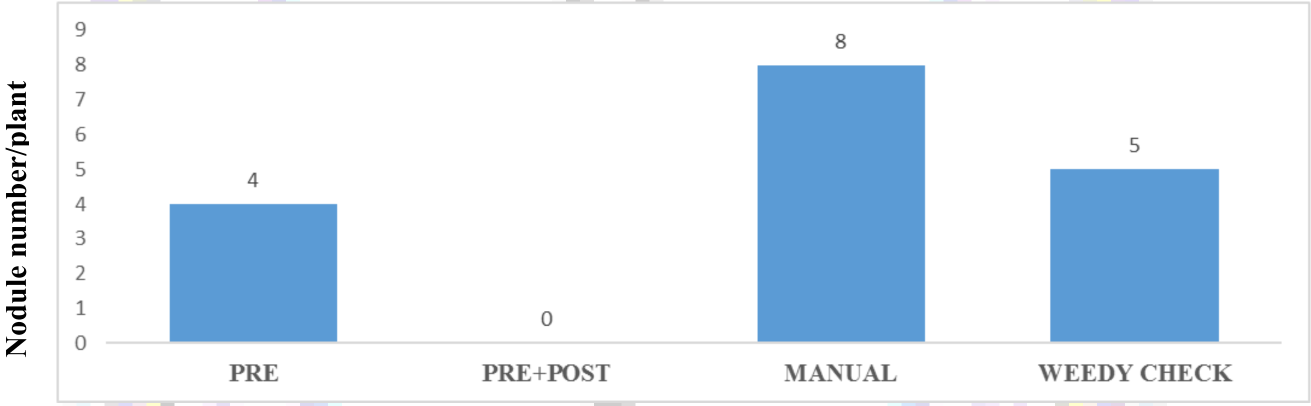

Figure 3: **Effect of weed management** **pea 14)**

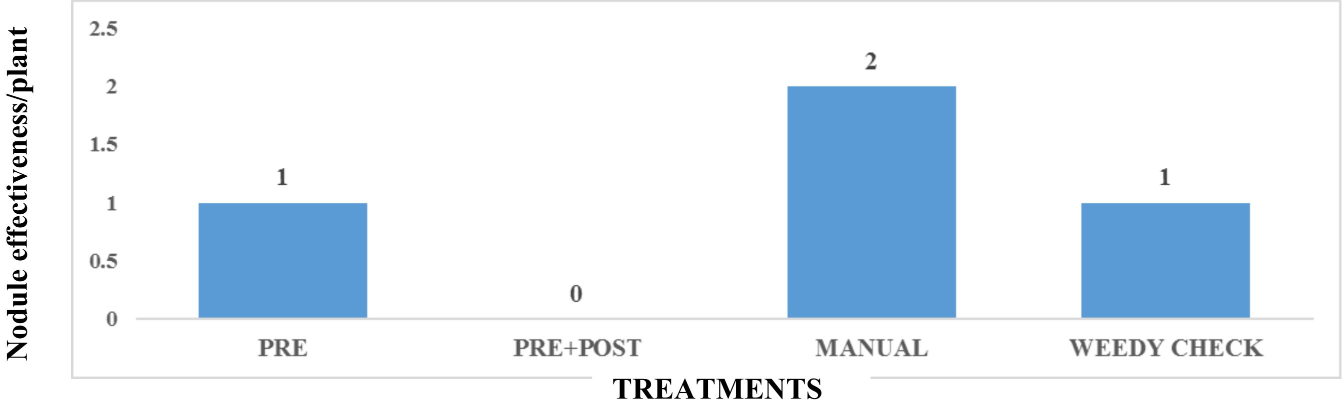

Figure 4: **Effect of herbicides on Nodule effectiveness (Sampea 14)**

The effect of herbicides on nodule dry weight

The effect of herbicides on nodule dry weight of Sampea 14 as represented in Figure 7 shows that MW recorded the highest nodule weight followed by WC, PE+WC, PPE treatment had no record on dry weight, MW recorded 100 % than PE+MW, and WC. The beneficial effects of rhizobia on nodulation are that it enhances nitrogen fixation which by symbiotic N2–fixing bacteria on the morphology and physiology of the root system which promotes vegetative growth. These results were in agreement with those obtained by Bin Ishaq (2002) and El–Waraky et *al.* (2013) on peas which showed a significant increase in the nodule dry weight and seed yield compared with the WC.

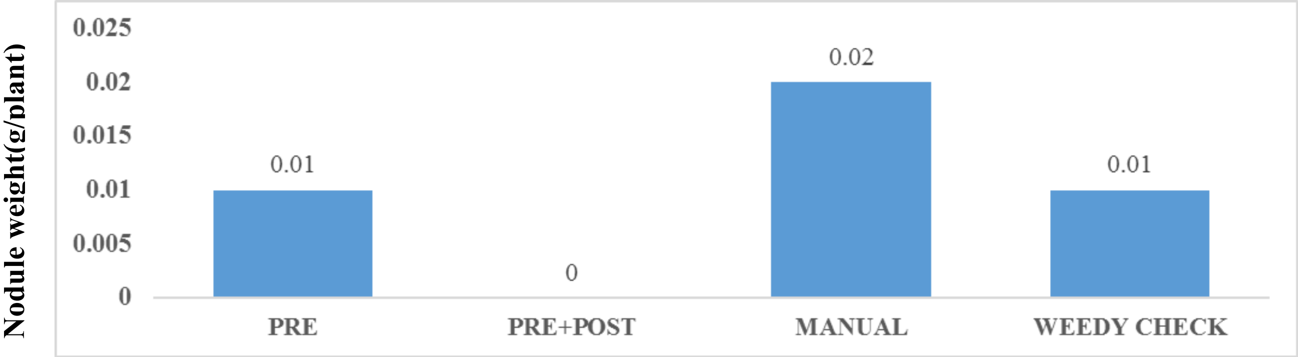

Figure 5: Weed management on Nodule Dry Weight (Sampea 14)

Although this research contradicts many studies that herbicides affect nitrogen fixation largely via indirect effects on plant growth and consequent availability of photosynthate to the root nodules (Fran *et al*., 2006), there is evidence that some herbicides might impair the ability of the rhizobia to recognize appropriate host plants. However, according to Fran *et al*., (2006), not all herbicides had a negative impact on nodulation and the degree to which nodulation was inhibited was dependent on herbicide concentrations. These contrasting results suggest that the impact of various herbicides on specific nodulation events may be highly dependent on specific environmental conditions, including different soil characteristics (i.e., pH, organic matter, moisture, etc.) and weather conditions.

In conclusion, the overall result of the experiment showed that the application of herbicides had a hazardous effect on the nodulation characteristics of cowpeas. The treatment with manual weeding produced an overall outstanding effect on the nodulation and yield characteristics. The herbicide application resulted in great loss of nodules from the roots, likely due to the herbicide causing stress to the plant-rhizobium symbiosis. The ability of the plant to support a healthy relationship with the rhizobia housed in root nodules. Thus, when assessing the potential for any chemical treatment to have an impact on nitrogen fixation, chemicals that have less negative effect on the plant should be applied, because nodules depend on the host plant for energy supply (in the form of plant photosynthates), striving to maintain healthy, actively growing plants is the first step in achieving optimal levels of nitrogen fixation. Thus, although the research demonstrates the possibility for herbicides to affect nodulation via root hair deformations, it is not known if this phenomenon occurs under field conditions. Therefore, there is an urgent need to conduct further studies on the effect of different herbicides on nodulation and yield characteristics of cowpeas *in situ.*

REFERENCES

Abdul Rahman, N.S.N., Abdul Hamid, N.W. & Nadarajah, K. (2021). Effects of Abiotic Stress on
Soil Microbiome. *International Journal of Molecular Sciences*, 21 Aug 2021, 22(16):9036 DOI: 10.3390/ijms22169036 PMID: 34445742 PMCID: PMC8396473

Abdullahi, I.N. (2021). Parkland Trees under Severe Drought: An Assessment of Species Diversity and Abundance across Three Agroecological Zones of Northern Nigeria. Faculty of Agriculture, University of Abuja, Nigeria DOI: 10.4236/ojf.2021.112009

Adigun J. A., Daramola O.S., Adeyemi O.R., Olorunmaiye P.M., & Osipitan O.A. (2018). Nitrogen and weed management in transplanted tomato in the Nigerian forest-savanna transition zone.*Annals of Agrarian Science* 16 (2018) 281 - 285

Anderson, A., Baldock, J.A.Rogers, S.L. Bellotti,W. & Gill. G. (2004). Influence of chlorsulfuron on rhizobial growth, nodule formation, and nitrogen fixation with chickpea. *Australia Journal. of Agric. Research* 55:1059-1070.

Ayaz, S., McNeil DL, McKenzie, B.A. & Hill, G.D. (2001). Density and sowing depth effects on yield components of grain legumes. Proceeding of Agronomy Society, New Zealand 29: 9-15.

Fran Walley, Angela Taylor1, & Newton Lupwayi. (2006). Herbicide effects on pulse crop nodulation and nitrogen fixation. Proceedings farmtech.

:https://www.researchgate.net/publication/228903508.

Gupta, V., Roget, D.&Davoren, B. (2002). Nitrogen fixation by grain legumes in the low rainfall Mallee soils - Potential effects of herbicide application. *Grain Research and Development Corporation*.On-line: http://www.grdc.com.au/growers/res_upd/south/so2/ru_s_adelaid_2002_p10.htm.

Kebede, E. (2020a). Grain legumes production and productivity in Ethiopian smallholder agricultural system, contribution to livelihoods and the way forward. *Cogent Food & Agriculture,* 6(1), 1722353. https://doi. org/10.1080/23311932.2020.1722353.

Langyintuo, A.S., Lowenberg-DeBoer, J., Fayec, M., Lambert, D., Ibro, G. & Lindquist, J.L. (2001). Mechanisms of crop loss due to weed competition. In: *Biotic Stress and Yield Loss*, Peterson, R.K.D. and L.G. Higley (Eds.), FL, CRC Publishers, Boca Raton, pp. 233-253.

Oloyede-Kamiyo, Q.O., Lawal, B.O., Kareem, K.T., Odeyemi, O.O. and Adelakun O. J. (2022).Assessment of some Cowpea (*vigna unguiculata l.*) genotypes for quantitative and qualitative traits June 2022.

Osipitan, O. A. (2017). Weed Interference and Control in Cowpea Production: A Review. *Journal of Agricultural Science*; Vol. 9, No. 12; 2017. ISSN 1916-9752 E-ISSN 1916 9760 Published by Canadian Center of Science and Education.

Singh, G. and D. Wright, (1999). Effects of Herbicides Nodulation, Symbiotic Nitrogen Fixation, Growth and Yield of Pea (*Pisum sotivum*). The Journal of Agricultural Science, 133(i): 21-30.

Singh S, Kundu SS, Negi AS, Singh PN (2006) Cowpea (*Vigna unguiculata*) legume grains as protein source in the ration of growing sheep. Small Ruminant Res 64(3): 247-254.

Sumalan, R.M., E. Aleva, M. Negrea, R.L. Sumalan, A. Doncean and G. Pop, (2010). Effect of Glyphosate on the Microbial Activity of Two Romania Soils. *Communication Agric. Appl. Biol. Sci,* 75(2): 167-72.

Wei Marcelo Chan Fu, Molin José Paulo (2020). Soybean yield estimation and its components: A linear regression approach. Agriculture 10 (8), 348, 2020.

Xu, P., Wu, X., Mu~ noz-Amatriaın, M., Wang, B., Wu, X., Hu Y., Huynh, B. L., Close, T. J., Roberts, P. A., Zhou, W., Lu, Z.,& Li, G. (2016). Genomic regions, cellular components and gene regulatory basis underlying pod length variations in cowpea (*Vigna unguiculata* L.Walp). *Plant Biotechnology journal.* 10:1-9.