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SCIENTIFIC JOURNAL

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DEVELOPMENT OF AN AUTOMATED DRIP IRRIGATION SYSTEM USING SOIL MOISTURE SENSOR

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Abstract: Irrigation has been a major boost to agricultural practices but significant amount of water is still wasted due to poor irrigation application and scheduling. To optimize the use of available water, there is a need to improve irrigation systems using internet of things (IoT) approach. In this study, an Arduino board, microcontroller, soil moisture sensors, battery, relay module, soil, and 12V solenoid valve were used and connected together through a wireless communication network (NRF24L01 wireless transceiver module) and a cloud platform (Blynk) for storing data. The system was tested for a period of four weeks. During the period of testing, the system observed eighteen automatically scheduled irrigation events. Simple descriptive statistical analysis of soil moisture data revealed mean values; 37.09, 35.68, 37.05, and 39.26 in weeks 1, 2, 3, and 4 respectively, and mean average of 37.27. Weeks 3 & 4 displayed higher average soil moisture content (38.15) compared to weeks 1 & 2 (36.39), this is due to recorded rainfall in the study area in weeks 3 and 4. Soil moisture content ranged between $66.30m^3m^{-3}$–$16.00m^3m^{-3}$ with standard deviation of ±8.25.

The Analysis of Variance (ANOVA) test confirmed this difference to be statistically significant (p-value=0.001), suggesting potential factors (soil type, sensor type, depth of insertion, etc.) influencing soil moisture over time.
The system achieved 55.25% water saving when compared to manual method of irrigation. More study should be done in integrating stable network connections (Wi-Fi) and solar systems to power the system without fail.

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Key words: *soil moisture, sensors, IoT, automated irrigation, crop water requirement*

INTRODUCTION

Planting is carried out by the farmers only when there is optimum moisture in the soil, since crop performance depends on the early establishment by utilizing available moisture [1]. Various studies [2,3] have reported that soil moisture content is mainly dependent on soil water recharge by rains and other alternate sources like irrigation. Thus plants that develop their canopy rapidly have the advantage of enhancing the effective use of water by reducing moisture loss due to evaporation [1].

Water is one of the most precious resources on the earth, it is therefore imperative to measure, control and preserve for sustainable agricultural production and healthy living [4]. The severe global competition for food and water is due to the effect of increase in world's population and climate change. This has increased the interest on how to achieve optimal use of scarce resources such as water using precision irrigation aimed at increasing food production and water saving [5]. Agriculture plays a vital role in the growth of the country's economy. There are a lot of modern technologies to make agricultural work very easy. Due to the shortage of water in most areas of the world, the watering process is one of the most important and critical processes in modern farming [6]. Hence, there is a need for automatic, intelligent, and smart systems that can make smart utilization of the available amount of water to feed plants for maximum time of farming, reduction of drudgery, stress and improvement in farm yield, and ease of farming, [7].

In manual based irrigation system, intense man power is required for irrigation and water management is not utilized properly. In addition, manual-based irrigation system leads to improper water allocation since labor is not automated at the right time. All these factors impact the growth rate, seed quality and productivity of crops negatively [8]. In order to negate such problems, there is a need to develop an automated irrigation system by using the knowledge acquired in soil-water plant relationship. This study proposes to develop an automated irrigation system enhanced with soil moisture content sensor, which will aid efficient and effective irrigation and irrigation scheduling of farmlands. The most significant advantage of this automated irrigation system is that the right amount of water is supplied and stopped automatically at the right time, to the right depth in the soil for crops when the right crop water requirement (CWR) is achieved, and when the soil moisture content has reached its required volume. The study covers only the use of moisture sensor to determine the irrigation and irrigation schedule of the automatic irrigation system. Other parameters; temperature, humidity, etc. are not covered in this study.

MATERIALS AND METHODS

Study Area

The project was implemented in the Greenhouse at Latitude 5°2'32.81"N and Longitude 7°58'33.03"E which is within the boundary of the Faculty of Engineering, University of Uyo permanent site, Uyo, Nigeria. Uyo is in the tropical rainforest belt of Nigeria, between latitude 5°5'2.288" N and 4°52'32.477" N, longitude 7°47'25.785" E and 8°0'54.393" E. The climate of Uyo is generally humid because of its proximity to the sea.

Based on its geographical location, the climate of Akwa Ibom State can be described as a tropical rainy nature which experiences lots of rainfall with high temperatures. The maximum humidity is reported in July, while the lowest is recorded in January. Average yearly temperature ranges between 26°C and 29°C, while mean annual rainfall ranges from 2.000mm to 3.000mm [9]. The Greenhouse was built in 2020 as a part of the TETFUND demonstration farm project in the University of Uyo. Major activity in the Greenhouse is greenhouse farming.
A drip irrigation system was already installed on a 10 x 5m Greenhouse spaced at 0.5m. The drip irrigation system consisted of 1m High-density polyethylene (HDPE) laterals with twenty emitters spaced at 0.2m. The experimental data was collected from August 28th to September 25th, 2023, resulting in 672 data sets for the soil moisture content.

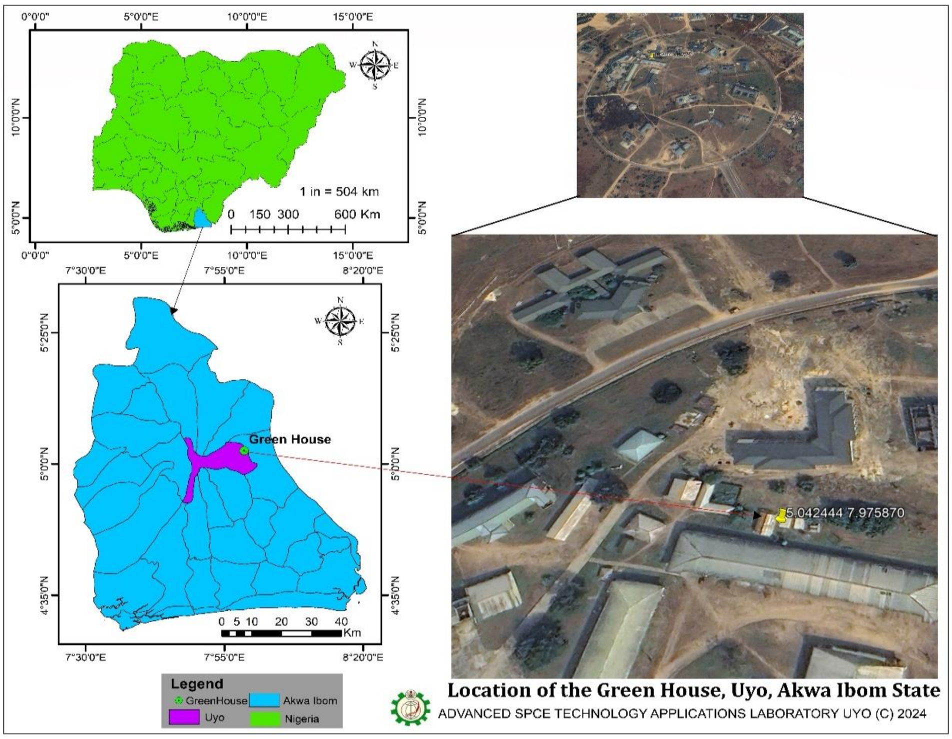

Fig.1. GIS Map of Akwa-Ibom state showing the Greenhouse, [10].

Materials Used

The following materials were used during the course of this work.
Soil sample for collection of soil for analysis: ESP8266 Microcontroller, NRF24L01 Wireless Transceiver Module, Soil moisture sensor, Relay Module, Battery/BMS, 12V Solenoid Valve, Blynk Platform.

Esp8266 Microcontroller

The Esp8266 microcontroller was selected as the central control unit for the irrigation system. It offers built-in Wi-Fi connectivity, control signals for activating or deactivating the solenoid valve through the relay, and sends data recorded by the sensor to an IoT platform (Blynk) wirelessly.

Fig. 2. Esp8266 Microcontroller

The Esp8266 microcontroller was programmed to serve as the central control unit of the irrigation system. It is designed to operate efficiently with low power consumption. This is a critical consideration for battery-powered applications, ensuring that the central control board can function for extended periods without frequent recharging or replacement of batteries.

Soil Moisture Sensor

The soil moisture sensor module was used to detect the moisture of the soil. It uses dielectric constant or contact, electrical resistance, with neutrons as a proxy for moisture.

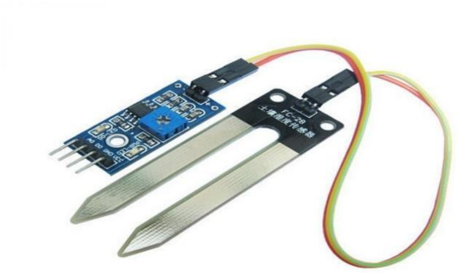

Fig.3. Soil Moisture Sensor

It measured the volumetric content of water inside the soil and produced the moisture level as output. The sensor sent analog signals to the ESP8266 based on the measurement, which is converted to a digital signal by the ESP8266.

Blynk Platform

Blynk is a platform developed for Internet of things. Blynk helps us to control the hardware remotely. It displays the sensor data, stores it, and also represents the data in graphical format.

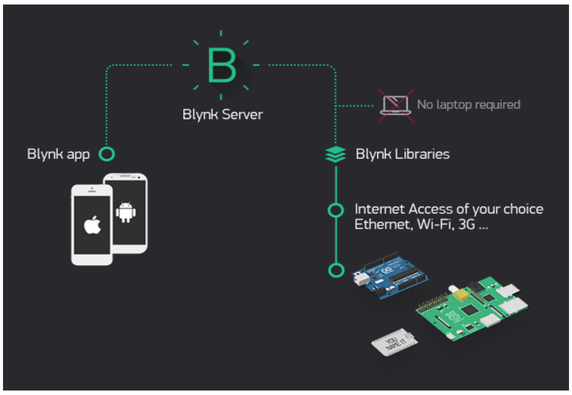

Fig.4. System architecture (Blynk Platform)

- Blynk App- In this you are able to interface your projects. Along with that you are to assign the pin numbers.
- Blynk Server- Blynk server is mainly used for the communication between the hardware and the smartphone.
- Blynk libraries- It helps us to enable communication with the server and process all incoming and outgoing commands between the all the popular hardware platforms.

Battery and Battery Management System (BMS)

The combination of the battery and Battery Management System (BMS) is crucial for maintaining uninterrupted operation of the central control board. The 2P3S configuration enhances power supply longevity, allowing the system to function for extended periods without frequent recharging. The series configuration ensures stable voltage levels required by the control board.

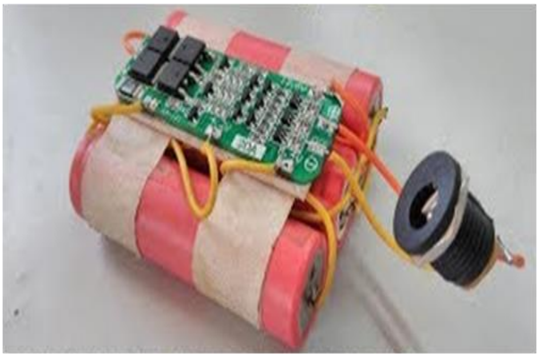

Fig.5. Battery and BMS

The BMS actively monitors each cell, promoting even charging and discharging to prevent overcharging or over-discharging, thereby preserving battery life. Additionally, the BMS incorporates safety features to guard against potential hazards like short circuits and thermal issues, bolstering the overall safety of the system.

This integration of the battery and BMS enables autonomous system operation for extended durations, making it suitable for deployment in environments lacking a continuous power source.

NRF24L01 Wireless Transceiver

The NRF24L01 wireless transceiver module (Fig.6.) plays a pivotal role in establishing communication between the central control board and the wireless soil moisture sensors. This module operates in the 2.4 GHz ISM band and employs the Enhanced ShockBurst (ESB) communication protocol for efficient data transmission [11].

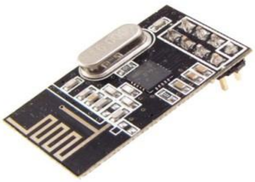

Fig. 6. NRF24L01 Wireless Transceiver

Fig.7. Relay Module

Relay Module

A relay (Fig.7.) is a simple electrically controlled switch. By sending a signal from the ESP8266, we can turn the switch on and supply a 24V AC to the solenoid valve and open and close it.

12V Solenoid Valve

The 12V solenoid valve (Fig.8.) is responsible for actuating the relay module and pump for automatic irrigation. It is an electrically controlled valve. This valve is shown in Figure 8. A solenoid is an electric coil with a movable magnetic core. Applying an electric current to this coil creates a magnetic field, which moves the core and allows water to flow. If the current is cut off, the valve closes, and the water flow stops, [11].

Fig.8. Solenoid valve

Methods

Soil Analysis

Soil texture analysis was performed using Hydrometric method, [15]. The USDA particle size classes viz. sand (2.0–0.05 mm), silt (0.05–0.002 mm) and clay (<0.002 mm), were used when classifying the textural classes. Soil organic carbon (SOC) was determined by the Walkley-Black oxidation method, [12]. Total nitrogen (TN) was determined using the Kjeldahl digestion method, [13] and Available Phosphorous (Av-P) was determined using Olsen's extraction method, [14]. Available potassium (Av-K) and the exchangeable bases (Na+, K+, Ca2+, and Mg2+) were measured by atomic absorption spectrophotometer, [15]. The Cation Exchange Capacity (CEC) was determined by extraction with Ammonium acetate method, [16] and soil pH was determined by potentiometric Methods at a 1:2.5 soil-to water ratio.

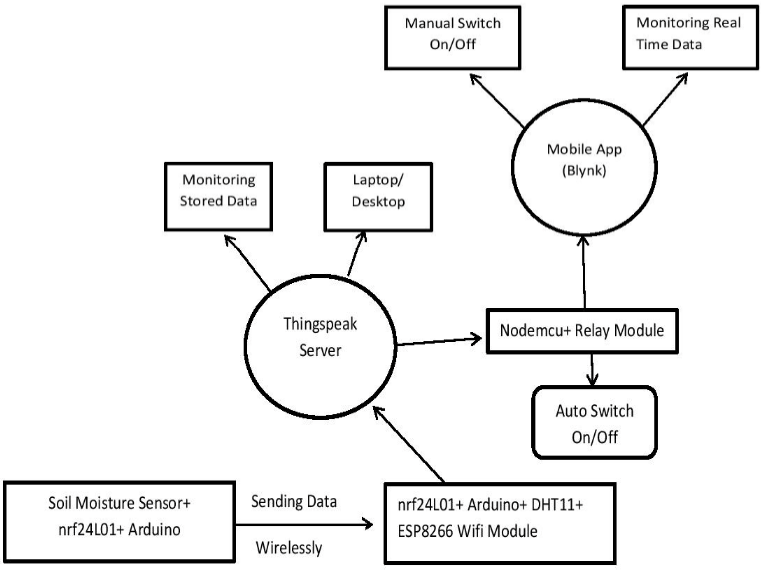

Fig.9. Automatic Irrigation System architecture

Calibration of soil moisture sensor

In the experimental field, soil moisture sensors were tested and installed. Before installation in the field, soil moisture sensors were calibrated. Moisture values were recorded every two hours between 8:00 am and 6:00 pm. The oven-dry method was also used to determine soil moisture content. For real-time data from soil moisture sensors, an account on Blynk.cloud was created.

The moisture sensor in the soil were positioned near one of the drippers. According to [17], soil moisture sensors should be placed at the top of the active root system, relative to drippers and the bottom of the root system; in every case studied, 11 cm between the drip line and 10 cm beneath the surface of the soil was deemed to be the most suitable position.

Primary Tests in the Laboratory

The initial tests were conducted in the lab to test the moisture sensor, temperature sensor, air humidity sensor, water flow sensor, solenoid valve, and firmware. The system was powered using a power supply. Using the relay, the ESP8266 was able to control the solenoid valve. With a loud click noise, we were able to know when the valve was opened or closed. The soil moisture sensor was calibrated by first reading the value of the sensor in the air and then placing the probe in a glass of water and re-reading the value.

After calibrating the moisture sensor, it was confirmed that the ESP8266, moisture sensor, and valve worked well together. To do so, the valve was programmed to open if the ESP8266 was not in the cup of water, then the cup was replaced with a potted plant, re-calibrated the moisture sensor with the soil [18], and repeated the experiments.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

Results of soil physical and chemical properties at 15cm depth are shown in Table 1 and 2 respectively. The particle size distribution of the soils was dominated by the sand fractions. Texture of the surface soils was generally loamy sand (Table 1). Texture of the surface soils was generally loamy sand. The textural composition of soil is highly influenced by parent material, [19].

Table 1. Physical Properties of Soil

Sample	Depth (cm)	Sand %	Silt %	Clay %
Plot A	15	83.13	4.31	12.56
Greenhouse (Control)	15	84.77	4.31	10.44

The textural class for the plot A and the control were Loamy sand. The high percentage sand observed in all the land use patterns could be attributed to the geology of the area. The geology of the area is coastal plain sands which are characterized by sandy soils over a wide expanse of land [20].

Generally, pH was slightly acidic with a value of 5.53 recorded in plot A, and strongly acidic in the control (3.77). This acidity influences the available phosphorus in the soil (88.044mg/kg). Also, the value of 7.91cmol/kg for ECEC was recorded in plot A and 8.92cmol/kg in the control at similar depths (Table 2). Plot A had total nitrogen content of 0.08% at 15 cm soil depth; the control had a value of total nitrogen (0.06%). The total nitrogen (TN) also correlated positively with organic matter and ECEC (Table 2). The result of the present study agrees with the findings of [21] who attributed the decrease in total nitrogen with increasing depth to declining humus with depth.

Table 2. Soil Chemical Properties

Chemical Properties	Plot A	Control
Ph	5.53	3.77
EC ds/m	0.10	0.05
OC %	1.80	1.30
Org. M %	3.12	2.25
TN %	0.08	0.06
AV.P mg/kg	43.355	88.044
K cmol/kg	0.09	0.17
Cacmol/kg	1.80	2.40
Na cmol/kg	0.19	0.09
Mg cmol/kg	1.20	1.45
EA cmol/kg	4.36	5.67
ECEC cmol/kg	7.91	8.92
BS %	42.7	36.2

Soil Moisture Sensor Performance evaluation

Soil moisture sensor was installed 0.1m in a Loamy sand soil to help in irrigation control based on soil moisture content. This device used Internet of Things technology to automate irrigation without the need of human interference. Soil moisture sensor continuously tracked soil moisture levels in the Green house. The wireless soil moisture sensors proved to be highly effective in their operational capacity. They successfully transmitted data wirelessly to the ESP 8266′ s configured Wi-Fi module, if the moisture level falls below the pre-defined value; it triggered the water pump and irrigates the field. The measured variables were continuously recorded automatically and sent to the Blynk cloud based server.

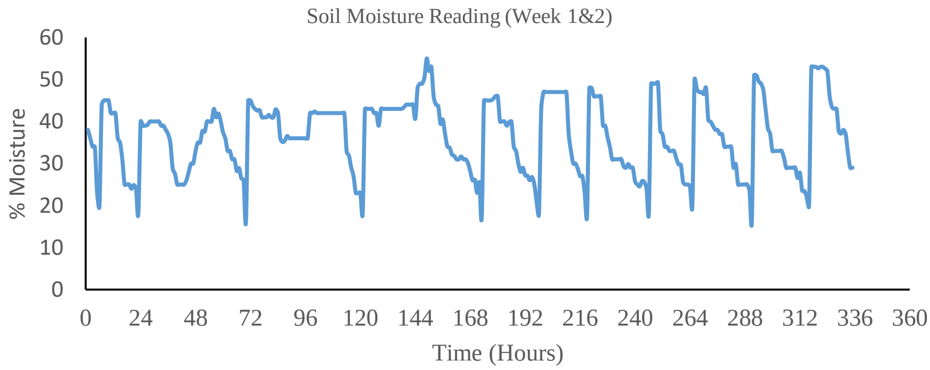

Fig.10. Moisture sensor reading (week 1&2)

The irrigation data were collected over one month and plotted the soil moisture content graph (Figures 10 and 11). The soil was considered to be dry if the moisture reading goes below 20% moisture content, then the ESP8266 opened the solenoid valve to irrigate the field. The soil was considered semi wet between 21 and 29% moisture content, wet if the reading was between 30 and 45%, and very wet if the reading was between 46 and 60%.

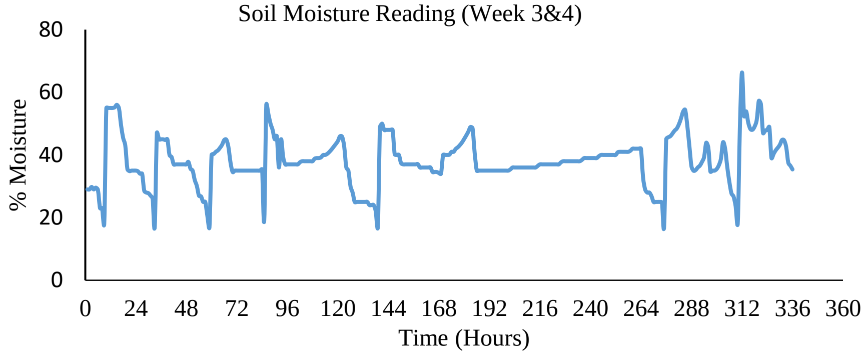

Fig.11. Soil moisture readings (week 3&4)

Irrigation Management

The system was tested to determine water flow rate through drippers. The water from the drippers was collected using a bottle for ten minutes and measured it in a graduated cylinder. The tests were replicated multiple times.

Table 3. Measured flow rate of drippers

Test Number	Flow Rate of Each Dripper (L/h)	Total Flow Rate of Twenty Drippers (L/h)
1	0.93	18.6
2	0.81	16.2
3	0.89	17.8
4	0.85	17
5	0.87	17.4
Average	0.87	17.4

The average flow rate of the drippers was determined to be 0.87 L per hour and 17.4L per hour for the twenty drippers in the greenhouse (Table 3). This indicates a reduced quantity of water applied to the crop compared to manual irrigation. From figures 10 and 11, we can see that the irrigation was scheduled eighteen times an hour each during the four weeks' period.

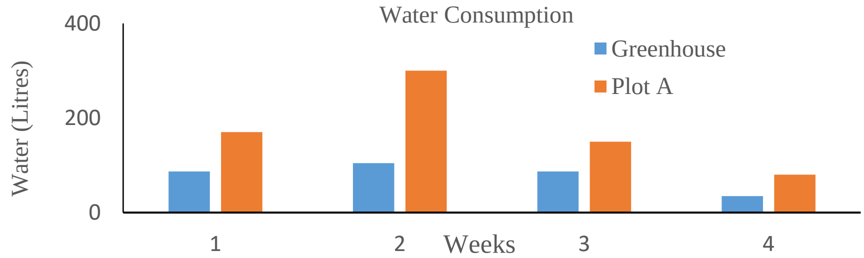

Fig.12. Water Consumption

Each dripper watered a plant for an hour five times in the first week, six times in the second week, five times in the third week, and two times in the fourth week.

The irrigation scheduling was done based on the relay information from the soil moisture sensors. It can also be deduced from Fig. 12, that the moisture sensor enhanced automatic irrigation system was able to achieve 55.25% water saving when compared to manual method of irrigation. Other researchers [22,23] have found consistent results confirming water savings up to 35–65% than standard flood and manual irrigation systems.

Statistical Analysis

Simple descriptive statistical analysis of soil moisture data revealed mean values; 37.09, 35.68, 37.05, and 39.26 in weeks 1, 2, 3, and 4 respectively, and mean average of 37.27. Soil moisture content ranged between $66.30m^3m^{-3}$–$16.00m^3m^{-3}$ with standard deviation of ±8.25. The average moisture content across weeks 1 and 2 (36.39%) was slightly lower compared to weeks 3 and 4 (38.15%) as a result of recorded rainfall in the study area in weeks 3 and 4. The soil moisture data collected over the four-week period was statistically analyzed using a one-way Analysis of Variance (ANOVA) to determine if there were significant differences in soil moisture content throughout the period of the experiment. The one-way ANOVA confirmed our initial observation from the descriptive statistics; there's a statistically significant difference (p-value = 0.001) in the moisture content between the four monitoring weeks, suggesting potential factors (soil type, sensor type, depth of insertion, etc.) influencing soil moisture over time, and at least one week having a moisture content that is statistically different from the others.

Table 4. Weekly Soil Moisture Content Statistics

Week	Mean Moisture Content (%)	Standard Deviation (%)	Variance (%)
Week 1	37.093109	7.403929708	54.81817511
Week 2	35.681081	9.657899982	93.27503207
Week 3	37.050619	8.330377998	69.39519759
Week 4	39.245597	7.056324529	49.79171586

Table 5. ANOVA results for soil moisture content

SUMMARY				
Groups	Count/Hours	Sum	Average	Variance
Week 1	169	6268.73544	37.0931091	54.8181751
Week 2	168	5994.42157	35.6810808	93.2750321
Week 3	168	6224.50402	37.0506192	69.3951976
Week 4	168	6593.26021	39.2455965	49.7917159

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1093.21332	3	364.404441	5.45498561	0.00104155	2.61821785
Within Groups	44690.5983	669	66.8020902			

The observed difference between the four weeks testing period suggests the sensor's responsiveness to varying moisture levels and the system's ability to adjust irrigation accordingly. The standard deviation and variance values indicate some natural fluctuations in moisture content even within designated irrigation cycles, reflecting the dynamic nature of soil moisture.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Water is a limited resource in the world and agriculture is a primary market. Therefore, a sustainable and economic approach is to be adopted for efficient agricultural practice and irrigation scheduling. The use of soil moisture sensors helps farmers with irrigation scheduling by providing information about when to water the crops. The development of wireless sensor applications in agriculture makes it possible to increase efficiency, productivity and profitability of farming operations as well as the maximum crop yield with minimum use of irrigation water.

The Automatic Irrigation System using Soil Moisture Sensor has been developed and tested successfully and found to function automatically. The system was able to execute the pre-established irrigation schedule without human intervention. Also, the effectiveness of the moisture sensor enhanced irrigation system is contingent upon the quality of internet connectivity. This is due to the system being operated by internet connection (wireless).

Recommendations

Despite the good results obtained in this study, some aspects of the system which should further be improved upon include:

- Automatic assessment of the representativeness of the soil moisture sensors and the integration of a sensor that automatically characterizes the water stress of the plant.
- Exploring some portability options and solar energy systems. Integrating pH sensors, etc.

REFERENCES

[1] Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., and Zophaib, A. 2017. Crop production under drought and heat stress: plant responses and management options. Front. Plant Sci. Vol. 8, p. 1147.

[2] Qiu. Y., Fu, B. J., Wang, J., and Chen, L. D.2001. Soil moisture variation in relation to topography and land use in a hill slope catchment of the Loess Plateau, China. *Journal of Hydrology.* Vol. 240, pp. 243-263. https://dx.doi.org/10.1016/S0022-1694(00)00362-0

3] Dercon, G., Deckers, J., Govers, G., Poesen, J., Sanchez, H., and Vanegas, R.2003. Spatial variability in soil properties on slow forming terraces in the Andes region of Ecuador. Soil Tillage Research Vol. 72, pp. 31-41.

[4] Abioye, E. A., Abidin, M. S. Z., Mahmud M. S. A., Buyamin, S., Denis, O., Okino, A., Abiodun, A., and Musbau, O. 2023. Smart agricultural technology a data-driven kalman filter-PID controller for fibrous capillary irrigation. https://doi.org/10.1016/j.atech.2022.100085

[5] Sigrimis, N., Antsaklis, P., and Groumpos, P. 2001. Advances in control of agriculture and the environment, IEEE Control Syst. Mag. Vol. 21, pp.8–12.
[6] Burton, L., Dave, N., Fernandez, R., Jayachandran, K., Bhansali, S. 2018. "Smart gardening IoT soil sheets for real-time nutrient analysis," *Journal of The Electrochemical Society*, Vol. 165, No. 8, p. B3157
[7] Rao, R. N. and Sridhar, B. 2018. IoT based smart crop-field monitoring and automation irrigation system, 2nd International Conference on Inventive Systems and Control (ICISC). IEEE, pp. 478–483.
[8] Frederick, O. E., John, O. A., and Sunday, O. A. 2023. Development of a digital soil moisture sensing based irrigation scheme. *International Journal of Modelling and Applied Science* Research Published by Cambridge Research and Publications IJMASR ISSN-1758-8117. Vol. 27 No.9, p. 36
[9] Essien, O. E. and Essien, I. A. 2012. Rainfall characteristics, runoff rate, and the traffic flow on gully morphometric parameter growth and soil losses in sand-mined peri-urban, Uyo. *Journal of Geology and Mining Research*. Vol. 7, No. 3, pp. 1307-1318
[10] Advanced Space Technology Application Laboratory (ASTAL) Uyo. 2023.
www.diva-gis.org/gdata Accessed November, 2023.
[11] Odiagbe, M., Eronu, E. M., and Shaibu, F. E. 2019. An Effective Water Management Framework Based on Internet of Things (IoT) Technology. *Eur. J. Eng. Res. Sci*. Vol. 4,
pp. 102–108.
[12] Schnitzer, M. 1982. "Total Carbon, Organic Matter and Carbon". In: A. L. Page, R. H. Miller, and D. R. Keeney. (eds.). Methods of Soil Analysis. Part 2, Agronomy Monograph, 2nd ed. American Society of Agronomy, Madison, WI; Vol. 9, pp. 539-577.
[13] Bremner, J. M. and Mulvaney C. S. 1982. "Nitrogen-Total". In: A. L. Page, R. H. Miller, and D. R. Keeney. (eds.), Methods of Soil Analysis, 2. American Society of Agronomy, Madison, WI, pp. 595–624.
[14] Olsen, S. R. and Dean, L. A. 1965. Phosphorous. In: C. A. Black (ed), Methods of Soil Analysis. Part 2: Chemical and Micro-biological Properties. American Society of Agronomy. Inc., Madison, WI; Vol. 9, pp. 1035-1049.
[15] Black, C. A, Evans, D. D., White, J. L., Ensminger, L. E., and Clark, F. E. 1965. "Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties Including Statistics of Measurement and Sampling". American Society of Agronomy. Inc., Madison, Wisconsin. p.88.
[16] Chapman, H. D. 1965. "Cation Exchange Capacity". In: Black, C.A. (ed.), Methods of Soil Analysis. Agronomy 9, American Society of Agronomy. Inc., Madison, Wisconsin, pp. 891-901.
[17] Selim T., Berndtsson, R., Persson, M., Somaida, M., El-Kiki, M., Hamed, Y., and Zhou, O. 2011. Influence of geometric design of alternate partial root-zone subsurface drip irrigation (APRSDI) with brackish water on soil moisture and salinity distribution, Agric. Water Manag. Vol. 103, pp. 182–190, https://doi.org/10.1016/j.agwat.2011.11.013.
[18] Nagahage, E. A. A. D., Nagahage, I. S. P., and Fujino, T. 2019. Calibration and Validation of a Low-Cost Capacitive Moisture Sensor to Integrate the Automated Soil Moisture Monitoring System. Agricu lture, Vol. 9, pp.141.
[19] Oguike, P. C. and Mbagwu, J. S. C. (2009). Variation in some physical properties and organic matters content of soils of coastal plain sand under different land-use types. *World Journal of Agricultural Science*. Vol. 5, pp. 63–67.
[20] Akamigbo, F. O. R and Ukaegbu, C. E. 2003. Influence of Parent Materials on the Soil of South Eastern Nigeria. *Agricultural Journal*; Vol. 4, pp.81-86.

[21] Gbadegesin, A. S., Abugiam, T. A., and Ata, J. E. 2012. Variation in Soil Properties on Cassava production in Southern Nigeria. Journal of Geography and Geology. Canada Center of Science and Edu, Vol. 3, No. 1, pp.94-103.

[22] Sidhu, R. K., Kumar, R., Rana, P. S., and Jat, M. L. 2021. Automation in Drip Irrigation for Enhancing Water use Efficiency in Cereal Systems of South Asia: Status and Prospects. 1st ed. Amsterdam: Elsevier Inc.; DOI: 10.1016/bs.agron.2021.01.002.

[23] Wang, F., Xue, J., Xie, R., Ming, B., Wang, K., and Hou, P. 2022. Assessing growth and water productivity for drip-irrigated maize under high plant density in arid to semi-humid climates. Agriculture. Vol.12, p.97.

RAZVOJ AUTOMATSKOG SISTEMA ZA NAVODNJAVANJE KAPANJEM PRIMENOM SENZORA VLAŽNOSTI ZEMLJIŠTA

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Apstrakt. Navodnjavanje je veliki podsticaj u poljoprivrednoj proizvodnji, ali značajna količina vode i dalje se potroši zbog loše primene i rasporeda navodnjavanja. Da bi se optimizovala upotreba dostupne vode, postoji potreba da se poboljšaju sistemi za navodnjavanje korišćenjem i pristupom Internet tehnologijama (IoT).

U ovoj studiji, primenjen je Arduino tip osnovne ploče, mikrokontroler, senzori vlage u zemljištu, baterija, relejni modul, i 12V solenoidni relejni ventil, koji su zajedno povezani preko bežične komunikacione mreže (NRF24L01 bežični primopredajni modul) u platformu-oblak (Blink), zbog prikupljanja i skladištenje podataka.

Sistem je testiran u periodu od četiri nedelje. Tokom perioda testiranja, sistem je kontrolisao osamnaest (18) automatski određenih mernih mesta za navodnjavanje.

Jednostavna deskriptivna statistička analiza podataka o vlažnosti zemljišta prikazuje srednje vrednosti; 37,09; 35,68; 37,05 i 39,26 u nedeljama 1, 2, 3 i 4 respektivno, i srednji prosek od 37,27.

Nedelje 3 i 4 su pokazale veći prosečan sadržaj vlage u zemljištu (38,15) u poređenju sa nedeljama 1 i 2 (36,39), što je zbog zabeleženih padavina u oblasti istraživanja u 3 i 4 nedelji ispitivanja.

Sadržaj vlage u zemljištu kretao se od $66.30 m^3m^{-3}$ do $16.00 m^3m^{-3}$ sa standardnom devijacijom od ±8,25.

Analiza varijanse (ANOVA) je potvrdila da je ova razlika statistički značajna (p-vrednost = 0,001), što ukazuje na potencijalne faktore (tip zemljišta, tip senzora, dubina postavljanja, itd.) koji utiču na vlažnost zemljišta tokom vremena.

Sistem je postigao 55,25% uštede vode u poređenju sa ručnim načinom navodnjavanja. Treba uraditi više studija o integraciji stabilnih mrežnih veza (Wi-Fi) i solarnih sistema za napajanje sistema bez greške.

Ključne reči: *Vlaga u zemljištu, senzori, IoT, automatizovano navodnjavanje, potreba useva za vodom*

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HOW DO CLIMATE CHANGE PERCEPTIONS DETERMINE THE CHOICE OF CLIMATE-SMART AGRICULTURAL PRACTICES: EXPERIENCE FROM MAIZE FARMING HOUSEHOLDS IN SOUTHWESTERN NIGERIA

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Abstract. Enhancing maximized agricultural productivity entails farmers adopting synergized climate-smart agricultural practices (CSAPs). This study investigates how maize farmers in Southwestern Nigeria choose key CSAPs based on their perceptions of climate change dynamics. Using a multistage sampling procedure to select 370 smallholder maize farming households, primary data were sourced from the study area using a structured questionnaire with secondary data on temperature and precipitation from the Nigerian Meteorological Agency (NiMet). The data were analyzed using multivariate probit modeling (MVP) and descriptive statistics. Empirical evidence shows that about 86% of farmers were aware of climate change. Also, farmers experienced temperature increases, rainfall decreases, and drought frequency with ensuing consequences of changes in crop yield, soil fertility, and natural cover. According to the study, maize farmers' perceptions of climate change significantly affect the choice of a CSAP practice which farmers employed complimentarily.
Furthermore, the results show that age, education, and farm size significantly affect CSAPs choice. Also, gender, extension visits, climate information, and mean annual precipitation were significant variables affecting farmers’ CSAPs choice.

Hence, policy direction that seek to embolden complimentary adoption of CSAPs that is strengthen with adequate and timely climate information should be provided.

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INTRODUCTION

The agricultural system in Sub-Saharan Africa (SSA) is mostly subsistence and rain-fed without adequate irrigation which makes climate change an alarming threat. Extremely climatic changes in regions around the world [1] have resulted in extreme yield reduction as a result of droughts, soil erosion, and floods [2]. Many of these irreversible changes in the climate have been unprecedented in thousands of years [3]. Literature [4, 5] is replete with incidences of diseases and pests among cultivated crops as a result of climate change. The occurrence of heat stress, which threatens growth and reproduction in livestock, has also been attributed to climate change. Worst still, the economies of SSA are particularly dependent on climate-sensitive Agriculture. Additionally, the astronomical trend of food price increase [6], and insecurity of food and nutrition in SSA, are resultant effects of climate change anomalies.

Nigeria's agricultural cultivation is mostly a rain-fed-dependent system [7]. Meanwhile, climate change has already negatively affected maize yields in many regions [8]. Several studies [9, 10] established the significant effect of rainfall anomalies on maize crop yield. In essence, maize may soon become less suitable for cultivation as a consequence of rising temperatures [11]. Furthermore, climate change can affect food quality, reduce access to food and rural household consumption and incomes [12]. Consequently, about 36% of maize-based farming households in southwestern Nigeria are food insecure [13, 14].

Meanwhile, it may be required that farmers adopt a combination of climate-smart agricultural practices (CSAPs) for the enhancement of household welfare by maximizing agricultural productivity. It is said that without farmers adopting (CSAPs), crop yield in SSA will continue to decline [15, 16]. In Southern Africa, [17] found that higher maize yield and income are obtained by the adoption of a combination of CSAPs. From empirical analysis, [18] concluded that enhanced food security and reduced poverty levels are achieved by farmers' adoption of adaptation practices. Equally, the combined use of CSAPs among smallholder farmers can potentially reduce food insecurity [19]. Given this, however, maize farmers' degree of climate change perceptions determines the extent and type of the strategies employed [20, 21]. This also depends on the extent of locally observable changes [22].

However, what determines farmers' probability of perception of climate change is poorly understood in Nigeria, resulting in little success in climate change communication and policy. This takes the form of lower levels of awareness and gross misperceptions about climate change dynamics among farmers [23]. The situation is worsened by the challenges of uncertainty and skepticism facing the policy strategies for climate change effective communication that must be resolved.

Otherwise, the resultant effect is "maladaptation" or "malmitigation" in climate change response in many instances. More so, there is an urgent need to recognize individual differences in perceptions [23], dissimilarity in perceptual processes, ensuing variation in responses [25, 26] , varied experiences of smallholder farmers, local realities and a good outlook in public opinions required for effective climate change communication and policy.

However, studies that investigate the effects of institutional and socio-cultural factors underlying individual perception response to climate change in the context of Southwestern Nigeria remain scanty. Extant literature [27, 21] has dwelt on the perception of climate change adaptation without inclusive of mitigation efforts. Additionally, climate policies relying solely on climate data may suffer ineffectiveness in implementation as they don't consider the grassroots dynamics, and perceptions of smallholder farmers, which are essential for successful communication [28]. These are marginally insufficient as risks posed by climate change need an all-inclusive approach. Marginal perception can lead to wrong responses and policy inertia.

Therefore, climate change perceptions dynamics are yet to be fully comprehended. The current study aims to investigate the forms and effects of perceptions on the key response options that influence farmers' choice of climate change resilience strategies in Southwestern Nigeria. By understanding smallholder farmers' perspectives, policymakers can gain valuable insights into the local impacts of climate change crucial for developing sustainable policies. This is essential for promoting sustainable climate change mitigation and adaptation efforts, leading to successful policy outcomes that promote excellent food security in Nigeria.

This study is framed upon the conceptual framework of farmers being profit maximizers in their farming enterprise. As farmers are risk averse, and profit maximizing agents, the framework seeks to explore the multi-faceted relationship between farmers' perceptions of climate change and their adoption of CSAPs. It highlights the key variables influencing farmers' decision-making processes and the potential pathways through which perceptions can shape CSAP choices. It links observable changes in weather patterns to climate change, impacting on livelihood with resultant vulnerability. It shows how farmers' climate change perceptions (perceived risks and opportunities) are predicted upon by socio-economic, demographic and institutional factors. Our study contributes to the existing literature by capturing all manners of farmers' climate change amelioration strategies including adaptation, mitigation, and coping/income generation mechanisms for a comprehensive outcome.

MATERIAL AND METHODS

The study design and area

The study was conducted in Southwestern Nigeria, a geopolitical zone comprising six states: Oyo, Ogun, Osun, Ondo, Ekiti, and Lagos. The zone covers an area of 77,818 km2 with a population of approximately 38 million people [29]. It is bounded by neighboring states and the Gulf of Guinea, and its tropical climate features dry and wet seasons with significant annual rainfall ranging from 1500mm to 3000mm [30].
The region's vegetation includes freshwater swamps, mangrove forests, and secondary forests, making it suitable for cultivating various crops like cassava, cocoa, and maize. Maize production is significant in the region, with Osun, Oyo, and Ogun selected for the study, being the top three producer states, accounting for 5,000 and 5,200 hectares of land in 2012 and 2013, respectively [31].

The region's average maize yield is 2 tons/ha [30]. The primary source of income and employment is agriculture accounting for about 75% of the population in the study area.

Sample size, sampling techniques and instruments

This study employed a multistage sampling procedure to select respondents. In the first stage, three top maize-producing states (Oyo, Osun, and Ogun) were purposefully chosen. Next, two Local Government Areas (LGAs) with high concentrations of smallholder maize farmers were purposefully selected from each state. Then, five villages were randomly chosen from each of the six selected LGAs, totaling 30 villages. To determine the appropriate sample size, the study considered the confidence level, level of precision, and degree of variability, as recommended by [32]. Due to the unavailability of a reliable list of registered farmers, the sample size was determined using the confidence level technique (Z-score table) for unknown populations, as described in [33] expressed as follows:

$$n_0 = \frac{z^2 * \mathrm{p}(q)}{e^2} \qquad \text{……………..(1)}$$

Where:
n_o = sample size to be estimated,
z^2 = selected critical value of the desired level of confidence or risk.
p = estimated proportion of an attribute that is present in the population or maximum variability of the population.
q = 1 – p
e = error margin.

Therefore, at the standard and recommended 5% (0.05) error margin (which is a 95% confidence interval), the sample size is:

n_o == 384.16

$$\frac{(1.96)^2 \times 0.5\ (1 - 0.5)}{(0.05)^2}$$

Finally, in the fourth stage, a list provided by the Agricultural Development Programs (ADPs) in the states was used to select 13 smallholder farmers from each of the 30 villages. This resulted in a total of 390 farmers being interviewed for the study. However, due to inadequate data provided, the 20 copies of the questionnaire were not captured in the analysis.

Data collection procedure

This study utilized both primary and secondary data. Primary data were collected through a comprehensive survey of maize farmers in the study area, using a semi-structured questionnaire to gather information on farmers' socio-economic profiles, climate change perceptions, maize inputs and outputs, adaptation, coping, and mitigation strategies. Due to the unavailability of climate data at the local level, secondary data on temperature and precipitation patterns over 39 years (1981-2019) were obtained from the Nigerian Meteorological Agency (NIMET) to supplement the primary data.

Climate-smart agricultural practices (CSAPs)

In this study, classifying CSAPs, we followed [34] coded each group, we classified adaptation strategies into crop management strategies (CMGT), nutrient management strategies (NMGT), soil and water management strategies (SWMGT). Then, mitigation strategies (MSTR) are classified into mulching/crop residue, terracing, agroforestry, and tree planting. Consulting literature, we then modified this methodology to capture all manners of farmers' resilience strategies concurrently adopted against climate change anomalies. We grouped and coded coping strategies/income generation (CSTR) into crop and livestock diversification, off-farm activities, and social networking.

DATA ANALYSIS TECHNIQUES AND MODEL SPECIFICATION

Multivariate Probit (MVP) model

Model specification

To determine the variables influencing smallholder maize farmers in the study area in adopting various climate change resilience strategies, a multivariate probit (MVP) model was used. The MVP model was selected due to the fact that the model can support the concurrent estimation of several resilience strategies utilized by farmers, contingent upon the explanatory factors. Moreover, the model permits a free correlation between the error components of every strategy. The multivariate model is based on the idea that the error terms jointly follow a multivariate normal distribution (MVN), with zero variance and the mean normalized to unity.

Instead of depending solely on one mechanism, farmers are more likely to use a combination of mechanisms to address the impact of climate change on their farms when faced with unfavorable fluctuations in the weather. Therefore, a farmer has the option to implement multiple strategies in adapting to climate change. In this work, we develop a multivariate model that takes into account the it maize farmer (i = 1,..., N) choosing whether or not to use at least one of the various climate change resilience strategies on his farm. Let U_0 represent the utility derived by the ith maize farmer when he/she does not adopt any resilience strategy, and let U_m represent the utility of the ith maize farmer by employing the *m*th resilience strategy, where m represents the choice of crop management strategies (CMGT), nutrient management strategies (NMGT), soil and water management strategies (SWMGT), mitigation strategies (MSTR), and coping strategies (CSTR).

If the net utility (Y^*_{ik}) from using the mth CSA strategy on his or her farm is higher than the net utility from not implementing the resilience strategy, the ith maize farmer will adopt it. Consequently, the latent variable net utility (Y^*_{ik}) resulting from the implementation of the mth resilience strategy is dictated by the socioeconomic factors of maize farmers, climate variables and institutional features jointly represented as X_i, in addition to the error term ():

Following [35], and adopted by [36] involving estimating a model with multiple dependent variables, specifically y_1, ..., y_5., such that:

$$Y_{ik}^{*} = B_m X_i' + \varepsilon_i \qquad \text{…………….. (2)}$$

Transforming Eq. (1) into an observed binary outcome equation, we have:

$$Y_{im}^{*} = \begin{Bmatrix} 1 \; if \;\; Y_{im}^{*} > 0 \\ 0 \; otherwise \end{Bmatrix} \quad \text{………. (3)}$$

Given that *m* = CMGT, NMGT, SWMGT, MSTR and CSTR

$$yi = 1 \; if \; \beta_i x_i + \varepsilon_i > 0 \quad \text{……….(4)}$$

$$yi = 0 \; if \; \beta_i x_i + \varepsilon_i \leq 0 \quad i = 1, 2, \ldots., 10 \quad \text{……………..(5)}$$

RESULTS AND DISCUSSION

Farmers' climate change perception and awareness

Farmers' perception and awareness of climate change play an important role in adopting resilience measures to mitigate its adverse effects. The more farmers recognize the likelihood of climate-related losses, the more likely they implement resilience strategies [34]. From the findings, majority, 86.49% of maize farmers were aware of climate change, while 13.51% were not (Figure 1). This implies that they are more likely to adopt strategic responses to alleviate its negative impacts. These results align with [37], who found most farmers perceive climate change based on their personal experiences.

Also, about 65 percent of farmers expressed a lack of access to climate change information, whereas only 35 percent affirmed their access, meaning, most farmers lack crucial knowledge on the latest technologies of combating climate change adverse effects. Furthermore, more than 70 percent had climate change experience for an average of ten years. The implication is that majority of the sampled households had the requisite experience to help them make informed decisions on climate change resilience measures.

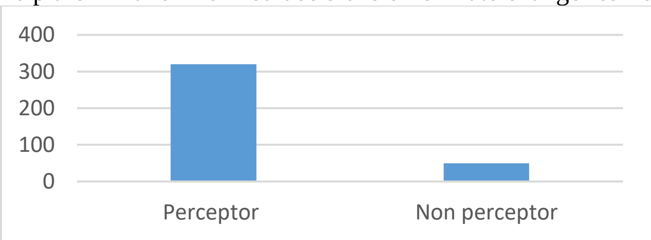

Figure 1. Farmer's perception of climate change
Source: Author construction from survey data, 2023.

Indicators of climate change

Farmers reported indicators that are perceived as proof of climate change in the study area. Most households perceived at least an aspect of temperature and rainfall anomaly (Table 1). Majority 84.59 percent of the sampled households reported an increase in temperature, while the others perceived no change. Most, 79.46 percent of maize farmers reported a reduction in precipitation amount, whereas the remaining 20.54 percent perceived an increasing dimension. Similarly, for drought frequency, 76.5 percent reported extended water scarcity, whereas, 23.5 percent asserted non-committal.

As for flooding frequency, about 51.35 percent had no flooding experience, while the remaining few reported flooding in their farms.

The results suggest that rising temperatures and decreased rainfall are the primary indicators contributing to weather anomalies in the study area. Numerous researches conducted in SSA have reported similar trends. [38, 37] have shown that over 78% and 83% of respondents observed rising average temperatures and declining precipitation, respectively, over the past 10-20 years, pointing to a significant perception of climate change among the respondents.

Table 1. Indicators of climate change

Climate change indicators	Frequency	Percentage
Temperature increase		
Yes	313	84.59
No	57	15.41
Rainfall decrease		
Yes	294	79.46
No	76	20.54
Drought frequency		
Yes	283	76.50
No	87	23.5
Total	370	100
Flooding frequency		
Yes	180	48.65
No	190	51.35
Total	370	100

Source: Author construction from survey data, 2023.

Resultant effect of climate change

Majority (93.51, 83.24, 81.62) percent of farmers perceived that changes respectively in natural forest cover, crop yield change, and soil erosion are the results of climate change (Table 2).

Implications of the consequences are that smallholder farming households were faced with ramifications of the adverse effect of climate change, in tandem with previous research [39, 37].

Table 2. Resultant effect of climate change

Variables	Frequency	Percentage
Climate change consequences		
Soil erosion		
Yes	164	44.32
No	206	55.68
Soil fertility change		
Yes	303	81.62
No	68	18.38
Crop yield change		
Yes	308	83.24
No	62	16.76
Total	370	100
Natural forest cover change		
Yes	346	93.51
No	24	6.49
Total	370	100

Source: Author construction from survey data, 2023.

Forms of farmers' response to climate change

Climate change strategies

This study investigated the strategies employed by respondents to adapt to, mitigate, and cope with climate change, as well as the factors that influence their adoption in the study area. It was hypothesized that the use of these strategies would be affected by several variables, such as climate change perception, socio-economic factors (education level, farm size), demographic characteristics (gender, age, household size), and institutional factors (extension services, information, social networks). The table shows that adaptation strategies were the most adopted among the mechanisms. This is followed by coping mechanisms and the least, mitigation strategies. Overall, farmers integrated various strategies to combat climate anomalies. Smallholder farmers may employ synergized strategies simultaneously to reap complementary benefits, including: enhanced climate resilience, improved agricultural productivity and better livelihoods. As observed by various studies [40, 41]. This multi-faceted approach can lead to synergistic advantages, ultimately supporting farmers' overall well-being and sustainability.

Adaptation strategies

Table 3 show that the major adaptation strategies to climate change employed by maize farmers, as reported by the respondents, were Intercropping (60%), crop rotation (75%), improved crop varieties (54.8), and change in the farming calendar (84%), inorganic fertilizer (36%), animal manure (63.1%), fertilizer + manure (71%), planting strips (18.2%), tied ridging (14.7%), contour farming (34.8%), and only (8%) uses small scale irrigation farming.

A farmer's ability to respond to climate change serves as a pointer to their adaptability. In this study, farm households were asked to rate various adaptation options, and those with a rating of 50% or higher were deemed the most effective strategies in the region, and thus selected as the primary focus for the study.

Mitigation strategies

The research reveals that the major mitigation strategies against climate change adopted by maize farmers in the study area were mulching/crop residue (67%), agroforestry (20%), and terracing (19.3%). Of all the mitigation mechanisms, the most adopted is mulching/crop residue and the least is terracing (Table 3). Generally, among the three identified climate change resilience responses, mitigation mechanisms were the least adopted by farmers. This could be due to its knowledge drawbacks and the financial implications that could not easily be bored by smallholder farmers.

Table 3. Smallholder utilization of adaptation and mitigation mechanisms in response to climate change

Adaptation mechanisms	Adopters		Non-Adopters	
Cropping practices	Freq	Percentage	Freq	Percentage
Intercropping	224	60	150	40
Crop rotation	280	75	94	25
Improved crop varieties	205	54.8	169	45.2
Change farming calendar	314	84	60	16
Nutrient management practices				
Inorganic fertilizer	135	36.0	240	64.0
Animal manure	236	63.1	138	36.9
Soil and water conservation				
Planting strips	68	18.2	306	81.8
Tied ridging	55	14.7	319	85.3
Contour farming	130	34.8	244	65.2
Small scale Irrigation farming	30	8.0	344	92.0
Mitigation mechanisms (Conservation agriculture)				
Mulching/crop residues	248	67	122	33
Agroforestry	75	20	295	80
Terraces	72	19.3	299	80.7

Source: Author construction from survey data, 2023.

Coping/Income diversification strategies

Table 4 reveals coping/income diversification mechanisms employed by farmers were crop and livestock diversification 73%, off-farm activities 61%, and social networking 55%.

It could be deduced that the most prominent coping mechanism adopted by maize farmers was crop and livestock diversification. These responses were thus common short-term measures taken by farmers in the study area to cope with extreme weather events, providing temporary relief from the negative impacts of climate change.

Table 4. Smallholder utilization of coping/income diversification mechanisms in response to Climate Change

Coping/income diversification mechanisms	Adopters	Adopters	Non-Adopters	Non-Adopters
	Frequency	Percentage	Frequency	Percentage
Crop and livestock diversification	270	72.9	100	27
Engage in non and off-farm activities	225	60.8	145	78.1
Social networking	205	55.4	165	44.6

Source: Author construction from survey data, 2023.

Effect of perceptions on specific CSAP synergies choice

The result of the multivariate model which assumes that there should be significant correlations across all equations specified in the model is presented. The Wald test [$X^2(190) = 552.41$; $p = 0.000$] which rejected the null hypothesis that all coefficients in each equation of the model are jointly equal to zero, is statistically significant at the 1% level. The likelihood ratio test result [X^2 (46) = 265.428; $p = 0.0000$] of the model rejected the null hypothesis of uncorrelated covariance of the error terms across the equations of the model. This result justified that MVP is fit for the data collected for this study. Table 5 presents the multivariate probit regression parameter estimates.

The study's outcome of multivariate probit model analysis identified nine key factors across five predictor sets that influence farmers' utilization of CSAPs in responding to climate change. These significant factors include farmers' perception of climate change, gender, age, education, family size, farm size, climate information, extension visits, and annual mean precipitation.

The summary statistics indicate that farmers who perceived losses due to changes in climate conditions were more inclined to use cropping practices (adaptive) and coping/income diversification strategies, while other control covariates significantly affect the choice of soil and water conservation, mitigation, and nutrient preservation. This is to be expected given their potential in improving farmers' capacity to mitigate and adapt to the negative impact of climate change.

The analysis revealed a positively significant correlation between the perception of farmers of climate change and their utilization of adaptive cropping strategies (CMGT) and coping mechanisms (CSTR) at significance levels of 10% and 5%, respectively. The result is in tandem with the previous study [42], suggesting that understanding climate change directly influences perceived risk. In essence, maize farmers' beliefs about climate change and their perceived risks significantly influenced their adoption decisions on adaptive and coping strategies, as well as income-generating activities.

For example, farmers overwhelmingly endorse adaptive measures that prepare them for more extreme weather events, which is linked to their beliefs and perceived risks.
This means that farmers who believe in climate change and see it as a threat to their farming practices are more likely to take action to protect their land from future extreme weather events. In essence, our findings suggest that belief in climate change and perception of its risks are the triggers that motivate farmers to take adaptive action.

Furthermore, we indicate that encouraging creative solutions from farmers to address extreme weather risks may be the best practical approach to climate change adaptation and outreach.

Our findings also reveal a surprising lack of correlation between perceived agricultural risks and the choice of mitigation actions (MSTR). This suggests that maize farming households still have a limited understanding of mitigation strategies, which may be attributed to the high cost of mitigation measures like irrigation farming for smallholder farmers. In contrast, adaptive actions like investing in cropping practices (CMGT) can have immediate benefits at the individual farm level, neutralizing climate risks. Moreover, the long-term and diffuse impacts of government actions on greenhouse gas emissions (mitigation) may not be fully comprehended by maize farmers, contributing to the uncertainty surrounding mitigation actions

The results further indicate that farmers' belief in climate change has a significant and positive ($p < 5\%$) influence on their adoption of coping strategies (CSTR). In other words, the more farmers believe in climate change, the more the likelihood of diversifying their income and adopting coping strategies (CSTR) to mitigate its impacts. Coping strategies are the actual temporary responses to crises associated with livelihood systems in the face of inaccessible, unavailable, and unaffordable food substances. It is a pointer to the existence of strong social networks among rural households [43]. Our research showed that households adopted a combination of strategies to mitigate its impacts

Similarly, regarding explanatory variables in the model, coefficients of age of farmers reduce the likelihood of choosing mitigation (MSTR) and soil and water management (SWMGT) but increase the likelihood of using cropping practices, nutrient management (NMGT), and coping/income generation mechanisms. The results align with the study by [44], which found that farmers' age and the adoption of crop management practices under Climate-Smart Agriculture are positively related. In other words, older farmers were more expected to adopt climate-resilient crop management strategies. Also, the family size and gender of the household head directly affect the use of coping/income generation strategy and cropping practices respectively but reduces the probability of using all other techniques. Furthermore, the coefficients of farm size and extension visits increase the likelihood of using mitigation and soil and water management but reduce the likelihood of choosing all other techniques.

In the same vein, coefficients of access to climate information increase the likelihood of choosing nutrient management and coping mechanisms but reduce the farmer's propensity to use cropping practice (CMGT), soil and water management (SWMGT), and mitigation mechanisms (MSTR). Furthermore, another positively significant variable was the coefficient of annual mean precipitation to crop management strategies (CMGT), nutrient management mechanisms (NMGT), mitigation strategies (MSTR), and coping strategies (CSTR). This indicates that increased precipitation will encourage farmers to plant flood-tolerant maize varieties that withstand adverse climatic changes [20]. In addition, it encourages farmers to diversify in livestock and social networking as a way to cope with the effects of adverse weather.

Our study reveals that various factors, including climate change farmers' perceptions interwoven and have cumulative outcomes that influence the response options adopted by maize farmers in the study area.

While these interactions occur, it's essential to guide farmers in managing the combined effects of these factors to enhance their ability to cope and improve food security. This result conforms to the study [45], which showed that the cumulative impact of multiple shocks influences the choice of coping strategies.

Table 5. Multivariate probit estimates of Climate Change Perceptions on the key Response Options

Variables	CMGT	NMGT	SWMGT	MSTR	CSTR
PERCEPTION	0.6121*	0.2433**	0.4595	0.6505**	0.5842***
	(0.3381)	(0.1158)	(0.4158)	(0.3097)	(0.1884)
AGE	0.2861*	0.3642	-0.2271*	-0.3852*	0.4842
	(0.1580)	(0.3152)	(0.1281)	(0.2122)	(0.3942)
EDU	0.2651**	0.3167*	0.1975	0.4145	0.2983**
	(0.1100)	(0.1809)	(0.2006)	(0.3987)	(0.1269)
GENDER	0.2512	0.309	0.681	0.4252	0.3340*
	(0.2060)	(0.2920)	(0.5190)	(0.3881)	(0.1964)
FAMLY_Z	0.3851*	0.2144	0.4712	0.1045	0.3052
	(0.2115)	(0.1964)	(0.3843)	(0.1045)	(0.3102)
FARM_Z	0.3103	0.7530	0.5432***	0.4679**	0.3470
	(0.3045)	(0.6915)	(0.1866)	(0.2025)	(0.3107)
CLIM_INFO	0.2342	0.3215**	0.3741	0.3972	0.2987***
	(0.2251)	(0.1454)	(0.3190)	(0.3815)	(0.0963)
EXT_VISIT	0.8935	0.6266	0.4817**	0.4895**	0.3156
	(0.7855)	(0.5945)	(0.2015)	(0.2225)	(0.3012)
MTEMP	-0.2031*	-0.3522	-0.4152	-0.2801	-0.3945
	(0.1147)	(0.2972)	(0.3891)	(0.1623)	(0.3231)
MPREC	0.1689***	0.1180***	-0.2292	0.1065*	0.2441***
	(0.0544)	(0.0524)	(0.2348)	(0.0598)	(0.0827)

Source: Authors' calculation, 2023.
*; **; & *** = Statistical significance at the 10 % ; 5 % and 1 %, respectively.

CSAPs correlation matrix from the MVP model

Table 6 reveals the pair-wise correlation of the different climate-smart agricultural practices adopted by maize-based farmers in the study area.

From the results, it is evident that each pair of adaptation strategies, almost all, has positive correlation coefficients between them and had a statistically significant level of 5 %. This is an indication of complementarity among the CSAP strategies as maize farmers employed them as compliments in the study area, [20].

The result revealed that crop management strategies boosted the adoption of diverse CSAP strategies such as nutrient management strategies, soil and water management strategies, mitigation strategies, and coping strategies.

Similarly, farmers who adopted nutrient management strategies also employed soil and water management strategies, mitigation strategies, and coping strategies. Furthermore, soil and water management strategies were adopted concurrently with mitigation strategies and coping strategies. These results imply that maize farmers adopted CSAP strategies complementarily to alleviate climate change's negative threat to their farming practices.

Table 6. Estimates of the correlation among the CSA strategies from MVP model.

Pair-wise correlation of climate smart agricultural practices	Correlation coef.	Standard error
Rho 21 nutrient management strategies and crop management strategies	0.481***	0.106
Rho 31 soil and water management strategies and crop Management strategies	0.372***	0.093
Rho 41 mitigation strategies and crop management strategies	0.432**	0.061
Rho 51coping strategies and crop management strategies	0.751***	0.234
Rho32 soil and water management strategies and nutrient management strategies	0.159***	0.039
Rho 42 mitigation strategies and nutrient management strategies	0.335**	0.139
Rho 52 coping strategies and nutrient management strategies	0.651***	0.072
Rho 43 mitigation strategies and soil and water management strategies	0.153	0.109
Rho 53 coping strategies and soil and water management strategies	0.361***	0.072
Rho 54 coping strategies and mitigation strategies	0.535***	0.059

Source: Authors' calculation, 2023.

CONCLUSION AND RECOMMENDATIONS

The study assessed perceptions outlook of maize-based farming households that influenced their choice of adaptation, mitigation, and coping/income generation strategies in southwestern Nigeria. Using multivariate probit modeling to determine influencing factors that determine the employment of such multiple mechanisms. We strategically used climate data together with the field's cross-sectional data to examine the adoption of such strategies for a better comprehension of the major drivers of farmers' climate change amelioration efforts.

The study's outcome of multivariate probit model analysis identified nine key factors across five predictor sets that influenced farmers' utilization of CSAPs in responding to climate change. Such significant factors include farmers' perception of climate change, which suggests that belief in climate change and perception of its risks are the triggers that motivate farmers to take adaptive, mitigation, and coping actions to combat threats of climate change

It was discovered that adaptive strategies were the most adopted, while mitigation action was the least, probably because of its associated costs, for instance, irrigation farming.

In addition, gender, family size, age of the household head, and farm size were other significant factors that influence farmers' adoption.

Furthermore, extension visits, climate information, and mean annual precipitation, all significantly affected farmers' choice of resilience mechanisms. Our study further reveals that various factors, including climate change farmers' perceptions interwoven and have cumulative outcomes that influence the response practices employed by maize farmers. While these interactions occur, it's essential to guide farmers in managing the combined effects of these factors to enhance their ability to cope and improve food security. Also, encouraging creative solutions from farmers to address extreme weather risks may be the best practical approach to climate change adaptation and outreach.

Therefore, policymakers and development partners should put in place policy frameworks that seek to promote the synergistic use of CSAP strategies in the most complimentary ways. Furthermore, there should be adequate provision of climate information through various media that will keep farmers informed of the current threat and the latest amelioration strategies available on climate change.

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REFERENCES

[1] Masson-Delmotte, V. P., Zhai, P., Pirani, S. L., Connors, C., Péan, S., Berger, N., Scheel Monteiro, P.M. 2021. IPCC, 2021. Summary for policymakers. in: Climate change 2021.The physical science basis contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change, pp.1-32.

[2] IPCC, 2018. IPCC Special Report on the Impacts of Global Warming of 1.5 _C – Summary for Policy Makers. Incheon, Korea.

[3] IPCC 2021. Philippe, C. D., Hamilton, W. M., Penn, A. C., Shultz, J. M. 2021. Innovative health professional leadership for a climate-resilient Bahamas. *The Journal of Climate Change and Health*, 4, 100055.

[4] African Union, 2017. Phytosanitary News Bulletin: Fall Armyworms Storm Africa. Yaounde, Cameroon.

[5] FAO, 2018. Briefing Note on FAO Actions on Fall Armyworm in Africa. Rome, Italy.

[6] Wossen, T., Berger, T., Haile, M.G., Troost, C. 2018. Impacts of climate variability and food price volatility on household income and food security of farm households in East and West Africa. *Agricultural System,* 163, pp.7–15.

[7] Amare, M., Cissé, J.D., Jensen, N.D., Shiferaw, B. 2017. The Impact of Agricultural Productivity on welfare growth of farm households in Nigeria: A panel data analysis. *FAO. Rome*.

[8] FAO (2015), Food and Agricultural Organisation: Climate change and food security: risks and responses. https://www.fao.org/3/i5188e/I5188E.pdf.

[9] Awosika, L., Ojo O., Ajayi, T. 1994. Implications of Climate Change and Sea Level Rise on the Niger Delta, Nigeria – Phase 1. A *report for the United Nations Environmental Programme* OKAPIS/UNEP, p. 92.

[10] Adejuwon, J.O., Odekunle, T.O. 2006. Variability and the Severity of the "little Dry Season" in Southwestern Nigeria. *American Meteorogical Society,* pp. 483-493.

[11] Chapman, S., E Birch, C., Pope, E., Sallu, S., Bradshaw, C., Davie, J., H Marsham, J. 2020. Impact of climate change on crop suitability in sub-Saharan Africa in parameterized and convection-permitting regional climate models. *Env. Research Letters*, *15*(9), 094086.

[12] Ngoma, H., Mulenga, B. P., Snyder, J., Banda, A., Chapoto, A. 2019. Poverty and weather shocks: A panel data analysis of structural and stochastic poverty in Zambia. pp.1-36.

[13] Adepoju, A. A., Sanusi, W. A., Toromade Adekunle, S. 2018. Factors Influencing Food Security among Maize-Based Farmers in Southwestern Nigeria. *International Journal of Research in Agricultural Sciences*, *5*(4), pp.2348-3997.

[14] Jimoh, L.O. 2023. Climate Change Response and Food Security among Maize Farming Households in Southwestern Nigeria. Ph.D. Thesis, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. pp.1-259.

[15] Asfaw, S., Di Battista, F., Lipper, L. 2016. Agricultural technology adoption under climate change in the Sahel: Micro-evidence from Niger. *J. of African Economies*, *25*(5), pp.637-669.

[16] Brown, M.E., Carr, E.R., Grace, K.L., Wiebe, K., Funk, C.C., Attavanich, W., Backlund, P., Buja, L. 2017. Do Markets and Trade Help or Hurt the Global Food System Adapt to Climate Change?. *Food Policy* 68: pp.154–9.

[17] Makate, C., Makate, M., Mango, N., Siziba, S. 2019. Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. *J. of environmental management*, *231*, pp.858-868.

[18] Ali, A., Erenstein, O. 2017. Assessing farmer use of climate change adaptation practice and impacts on food security and poverty in Pakistan. Climate Risk Management, 16, pp.183–194. https://doi.org/10.1016/j.crm.2016.12.001.

[19] Wekesa, B. M., Ayuya, O.I., Lagat, J. K. 2018. Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya. *Agriculture & Food Security*, *7*(1), pp.1-14.

[20] Khan, Z. R., Midega, C. A., Pittchar, J. O., Murage, A. W., Birkett, M. A., Bruce, T. J., Pickett, J. A. 2014. Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 36 9 (1639), 20120284.

[21] Ojo, T. O., and Baiyegunhi, L. J. S. 2020. Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in south-west Nigeria. *Land Use Policy*, 103946, https://doi.org/10.1016/j.landusepol.2019.04.007.

[22] Sultan, B., Gaetani, M. 2016. Agriculture in West Africa in the twenty-first century: Climatechange and impacts scenarios, and potential for adaptation. *Frontiers in Plant Science*. 7, pp.1–20.

[23] Hitayezu, P., Wale, E., Ortmann, G. 2017. Assessing farmers' perceptions about climate change: A double-hurdle approach. *Climate Risk Management*, 17, pp.123-138

[24] Whitmarsh, L., 2011. Scepticism and uncertainty about climate change: Dimensions, determinant determinants and change over time. *G. Environmental Change* 21 (2), pp.690–700.

[25] Vander Linden, S. 2014. The social-psychological determinants of climate change risk perceptions, intentions and behaviours: a national study (Unpublished (PhD Thesis). The London School of Economics and Political Science (LSE), London, UK. pp.1-365.

[26] Weber, E.U., 2010. What shapes perceptions of climate change? Wiley Interdisciplinary Rev.: *Climate Change* 1(3), pp.332–342.

[27] Adeagbo, O.A., Ojo, T.O., & Adetoro, A.A. 2021. Understanding the determinants of climatechange adaptation strategies among smallholder maize farmers in South-west, Nigeria, *Heliyon 7(2) (2021), e06231, https://doi.org/10.1016/j.heliyon.2021.e06231.*

[28] Asare-Nuamah, P., Botchway, E. 2019. Comparing smallholder farmers' climate change perception with climate data: the case of Adansi North District of Ghana. *Heliyon*, *5*(12)

[29] NBS. 2016. Nigerian Gross Domestic Product Report *National Bureau of Statistics* (NBS)

[30] Umar, S. Y., Elinwa, A.U., Matawal, D.S. 2015. Hydraulic conductivity of compacted lateritic soil partially replaced with metakaolin. *J. of Environment and Earth Science*, *5*(4), pp. 53-64.

[31] Iken, J. E., Amusa, N. A., 2004. Maize research and production in Nigeria. *African Journal of Biotechnology*, 3(6), pp.302-307.
[32] Miaoulis G., Michener D. 1976. An Introduction to sampling. Kendel.
[33] Shete, A., Shete, A., Dube, S., & Dubewar, A. 2020. Sample size calculation in bio-statistics with special reference to unknown population. *International Journal for Innovative Research in Multidisciplinary Field*, 6 (7), pp.236-238.
[34] Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. Ngetich, F. K. 2021. Determinants of farmers' perceptions of climate variability,mitigation, and adaptation strategies in the central highlands of Kenya. *W. and Climate Extremes*, 34, 100374.
[35] Chun-lan L, Xiu-ren N, Ji-lan S, Yian L, B Xu. 2005. Environmental changes and the reponses of the ecosystems of the Yellow Sea during 1976-2000. *Journal of Marine Systems,* 55 (3-4), pp.223-234.
[36] Teklewold, H., Mekonnen, A., Kohlin, G. 2019. Climate change adaptation: a study of multiple climate-smart practices in the Nile Basin of Ethiopia. *Climate and Development,* 11(2),180–192.
[37] Teshome, H., Tesfaye, K., Dechassa, N., Tana, T., Huber, M. 2021. Smallholder farmer's perceptions of climate change and adaptation practices for maize production in Eastern Ethiopia. *Sustainability*, 13(17), p.9622.
[38] Tesfahunegn, G. B., Mekonen, K., Tekle, A. 2016. Farmer's perception on causes, indicators and determinants of climate change in northern Ethiopia: Implication for developing adaptation strategies. *Applied Geography*, 73, pp.1-12.
[39] Alam, G. M., Alam, K., Mushtaq, S. 2017. Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. *Cl. risk management*, *17*, pp.52-63.
[40] Mugi-Ngenga, E. W., Mucheru-Muna, M. W., Mugwe, J. N., Ngetich, F. K., Mairura, F. S., Mugendi, D. N. 2016. Household's socio-economic factors influencing the level of adaptation to climate variability in the dry zones of Eastern Kenya. *Journal of RuralStudies,* 43, pp. 49-60.
[41] Asrat, P., Simane, B. 2018. Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. *Ecological processes*, 7 (1), pp.1-13
[42] Arbuckle, J. G., Prokopy, L. S., Haigh, T., Hobbs, J., Knoot, T., Knutson, C., Widhalm, M. 2013. Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. *Climatic change*, 117, pp.943-950.
[43] Monde, N. 2003. Household Food Security of Rural Areas of Central Eastern Cape: The Case of Guquka in Victorial East and and Koloni in Middledrift Districts. Ph.D. Thesis, University of Fort Hare, Alice, pp.1-263.
[44] Getnet, G. T., Bantider, A., Yayeh, D. 2022. Impact of Adoption of Climate-Smart Agriculture on Food Security in the Tropical Moist Montane Ecosystem. Av. at SSRN 4207777. pp.1-27.
[45] Ansah, I. G. K., Gardebroek, C., Ihle, R. 2021. Shock interactions, coping strategy choices and household food security. *Climate and Development*, 13(5), pp. 414-426.

KAKO PERCEPCIJE O KLIMATSKIM PROMENAMA ODREĐUJU IZBOR KLIMATSKI PAMETNIH POLJOPRIVREDNIH PRAKSI: ISKUSTVA DOMAĆINSTAVA KOJA GAJE KURUZ U JUGOZAPADNOJ NIGERIJI

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Apstrakt. Povećanje maksimalne poljoprivredne produktivnosti podrazumeva da faremeri usvoje sinergizovane klimatski pametne poljoprivredne prakse -KPPP, (eng. CSAP-Climate-Smart Agricultural Practices). Ova studija istražuje kako farmeri u gajenju kukuruza u jugozapadnoj Nigeriji primenjuju ključne CSAP (eng. Climate-Smart Agricultural Practices) na osnovu razumevanja dinamike klimatskih promena.

Koristeći višestepenu proceduru uzorkovanja za odabir 370 malih gazdinstava koja se bave gajenjem kukuruza, primarni podaci su dobijeni iz oblasti istraživanja korišćenjem strukturisanog upitnika sa sekundarnim podacima o temperaturi i padavinama iz Nigerijske meteorološke agencije (NiMet). Podaci su analizirani korišćenjem multivarijantnog probit modeliranja (MVP - Multivariate Probit Modeling) i deskriptivne statistike. Empirijski dokazi pokazuju da je približno 86% farmera bilo svesno klimatskih promena. Takođe, farmeri su registrovali povećanje temperature, smanjenje padavina i učestalost suša sa posledicama promene prinosa, plodnost zemljišta i prirodnog pokrivača.

Prema ovoj studiji, saznanja farmera o klimatskim promenama značajno utiču na izbor CSAP prakse koju su farmeri besplatno koristili. Pored toga, rezultati pokazuju da starost, obrazovanje i veličina farme značajno utiču na izbor CSAP. Takođe, pol, stručne dodatne posete, klimatske informacije i srednja godišnja količina padavina bile su značajne varijable koje su uticale na izbor CSAP-a kod farmera.

Zato bi trebalo dati smernice politike koja nastoji podstaći besplatno usvajanje CSAP koje je ojačano adekvatnim i blagovremenim klimatskim informacijama.

Ključne reči: *Klimatski pametna poljoprivreda, MVP model, percepcija klimatskih promena, farmeri proizvođači kukuruza, poljoprivredna proizvodnja*

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MANAGEMENT OF NON-STANDARD AGRICULTURAL EQUIPMENT BASED ON THE ASSESSMENT OF FARM OWNERS AND MANAGEMENT OF HEALTHCARE ORGANIZATIONS USED IN THE TREATMENT OF PATIENTS

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Abstract: In this study, the authors showed the existence of a strong influence between the possible use of non-standard agricultural equipment on the example of the construction of Api chambers on agricultural farms, which makes it possible to increase the efficiency of its use by forming cooperative relations between farms and health institutions that also have an economic interest in using such equipment, in treatment patients.

In addition, we found that based on total income and expenses, the formation of total profit can be predicted because the application of such a business model is statistically significant ($F=183.600$, $p<0.0005$), that is, income and expenses have a significant impact on the prediction of profit in this type of business agricultural farms.

The same applies to such business operations of health institutions, because the obtained model was evaluated with because the obtained model is statistically significant ($F=327.121$, $p<0.0005$) in the way of cooperative business with non-standard agricultural equipment (Api chambers) that can be use in the treatment of patients.

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***Key words**: Agricultural economy, business efficiency, Api chamber, treatment of patients.*

INTRODUCTION

Management and business decision-making was the focus of numerous researches, which is of great importance for business in the field of agriculture [1-6], but also for business in other sectors of the economy, such as the public sector and healthcare.

The decision-making of the business owner is important, and one of the basic principles is the application of valid and economic business, which implies cooperation between different sectors [7-11].

Such business requires finding a management model that connects, for example, agriculture with other business sectors [12-16].

MATERIALS AND METHODS

To prepare this study, the authors surveyed 180 participants, namely 72 owners of agricultural farms in the Republic of Serbia, i.e. 108 managers of health institutions from the territory of the Republic of Serbia. This was done in the period from 01.03. until 31.03. in 2024.

The observation was carried out in such a way that non-standard agricultural equipment was analyzed in terms of additional investments within agricultural holdings. The observation was made regarding the possibilities of individual use of Api chambers on the agricultural farm, but also within the framework of cooperation with health institutions that would bring patients to use this equipment with the aim of improving the health condition of patients.

The analysis covered three categories: income, expenditure and realized profit. As a final analysis, a forecast of the future profit within agricultural holdings was made, that is, the profit that health organizations achieve by using it in the treatment of patients.

After that, the authors performed statistical processing using the software IBM SPSS (Statistical Package of Social Science) version 25, with the application of the t test, and a regression analysis was applied to predict the total profit of agricultural farms and health institutions on this basis.

A level of 0.05 was used for the threshold value of significance.

RESEARCH RESULTS AND DISCUSSIONS

The goal of the research was to determine the existence of differences in the assessment of agricultural farm owners and managers of health organizations regarding the existence of total income, expenses and profits in the use of two forms of business based on the use of non-standard agricultural equipment, i.e. based on investment in Api chambers. All this was observed using the t-test.

The obtained results are given in table 1.

Table 1. Differences in the assessment of farm owners and managers of health organizations for total income, expenses and profit

	Agricultural farms	Health organization	t	p
	Middle value			
Income	19.91 ± 1.02	20.51 ± 1.32	-3.301	0.001*
Cost	13.11 ± 1.39	12.32 ± 1.49	3.410	0.001*
Profit	6.59 ± 1.19	8.11 ± 1.15	-8.269	<0.0005*

Note: Statistical significance at the level of 0.05.

Based on the presented results (Table 1), it can be seen that there is a significant difference in terms of the formation of total revenues, total costs and generated profits, i.e. where managers from health organizations gain more trust, i.e. with higher ratings they valued the generated total revenues and the total profit that they can achieve in cooperation with agricultural holdings regarding the use of non-standard agricultural equipment, that is, Api chambers for the treatment of patients. At the same time, they achieve a lower rating for total costs compared to the owners of agricultural farms, which points to the economic justification of such cooperation.

In the following, multiple linear regression was applied to examine whether, based on total income and expenses, the formation of the total profit for the operation of agricultural farms can be predicted.

Total profit can be predicted on the basis of income and expenses since the model is statistically significant ($F=183.600$, $p<0.0005$).

Based on the results shown in Table 2, it can be seen that income and cost have a significant impact on the prediction of profits for agricultural holdings.

Table 2. Prediction of the total profit of agricultural holdings

	Beta	t	p
A constant	-	2.183	0.032*
Income	0.768	12.770	<0.0005*
Cost	-1.148	-19.101	<0.0005*

Note: Statistical significance at the level of 0.05.

Total profit can be predicted on the basis of income and expenses since the model is statistically significant ($F=327.121$, $p<0.0005$).

Table 3. Predicting total profit in healthcare organizations

	Beta	t	p
A constant	-	5.120	<0.0005*
Income	0.861	16.117	<0.0005*
Cost	-1.279	-21.201	<0.0005*

Note: Statistical significance at the level of 0.05.

CONCLUSION

The general conclusion would be that there is a strong connection between the use of non-standard agricultural equipment and raising the efficiency of its use on agricultural farms by forming cooperative relations between farms and health institutions that use such equipment, for example Api chambers

The next conclusion would be that on the basis of total income and expenses, the formation of total profit for the mentioned business can be predicted, because the determination coefficient of 0.841 was obtained, the model is statistically significant ($F=183.600$, $p<0.0005$) and that income and expenses have a significant impact on the prediction of profits in such operations of agricultural farms.

The results are even more impressive in the case of health institutions because the obtained model was evaluated with 99.98% with the total variance formed, the model of which is statistically significant ($F=327.121$, $p<0.0005$) in such a business with non-standard agricultural equipment (Api chambers) in the treatment of patients.

CONFLICT OF INTEREST

None is declared.

REFERENCES

[1] Arnautović, I., Davidov, T., Nastić, S., Popović, S. 2022. Značaj donošenja racionalne poslovne odluke top menadžmenta u poljoprivrednim preduzećima u Republici Srbiji, *Poljoprivredna tehnika*, Vol. 47(3), pp.1-8.

[2] Popović, S. 2016. Značaj interne revizije u fer vrednovanju javnih preduzeća Republike Srbije, *Revizor*, Vol. 74, pp.71-81.

[3] Popović S, Jovin S, Đuranović D, Popović V, Filipović V, Munitlak-Ivanović O, Grublješić Ž. & Mijić R. 2017. The Importance of Planting Pot Marigolds (Calendula officinalis L.) in degraded public spaces from the agro-ecological and economic perspective. *Contemporary Agriculture*, Vol. 66(1-2), pp.27-31.

[4] Arnautović, I., Davidov, T., Nastić, S., Popović, S. 2022. Značaj poslovnog odlučivanja top menadžmenta u poljoprivrednom preduzeću koja koriste praktičnu primenu novih pristupa softverskih rešenja it sektora u Republici Srbiji, *Poljoprivredna tehnika*, pp. 51-57.

[5] Popović, S., Laban, B., Vukasović, D., Ivić, M., Nastić, S. & Popović, V. 2018. Internal and external audit as a factor in improving the management of the Agricultural enterprise, *Poljoprivredna tehnika*, Vol. 43(4), pp. 8–12.

[6] Rakaščan, N., Popović, V., Dražić, G, Ikanović, J. & Popović, S. 2019. Circular economy in function of obtaining the biogass, 25th–27th September 2019, Novi Sad, Serbia, pp.320-329.

[7] Radović, M., Vitomir, J., Laban, B., Jovin, S., Nastić, S., Popović, V. & Popović S. 2019. Management of joint stock companies and farms by using fair value of agricultural equipment in financial statements on the example of IMT 533 Tractor, *Economics of Agriculture*, Vol. 1, pp.35-50.

[8] Tomas-Miskin S., Vitomir, J., Popović, S. & Vitomir, G. 2022. Decision-making of Top Management and Internal Audit on the Issue of Archiving Documentation in Companies Founded by Local Government Units in the Republic of Serbia, *Lex Localis – Journal of Local Self-Government*, Vol. 20(4), pp. 889 – 995.

[9] Radović, M., Vitomir, J., Popović, S. 2021. Kretanje dokumentacije u sklopu revizijskog izveštavanja top menadžmenta poljoprivrednog preduzeća, *Poljoprivredna tehnika*, Vol. 46(1), pp. 47-53. DOI: 10.5937/POLJTEH2101047R.

[10] Radović, M., Vitomir, J., Popović, S. & Stojanović, A. 2023. The Importance of Establishing Financial Valuation of Fixed Assets in Public Companies whose Founders Are Local Self-Government Units in the Republic of Serbia, *Enginering Economics*, Vol. 34(3), pp. 246-255.

[11] Radović, M., Vitomir, J., Popović, S. & Stojanović, A. 2023. The Importance of Establishing Financial Valuation of Fixed Assets in Public Companies whose Founders Are Local Self-Government Units in the Republic of Serbia, *Enginering Economics*, Vol. 34(3), pp. 246-255.

[9] Radović, M., Vitomir, J. & Popović, S. 2021. Impact of internal control in enterprises founded by local self government units: the case of Republic of Serbia, *Inzinerine Ekonomika-Engineering Economics*, Vol. 32(1), pp. 82–90.

[10] Bakmaz, O., Bjelica, B. & Vitomir, J. 2023. Application of software solutions in companies that strive to achieve increased financial stability in their regular business, *Temel-IJ*, 7:1, 13 – 20.

[11] Popović, S. (2018). Modeling a strategic top management in the importance of the management of the finance companies established for the establishment of fer value, *Poljoprivredna tehnika*, Godina Vol. 43(2), pp. 11–16.

[12] Popović, S., Vitomir, J., Tomaš-Miskin, S., Davidov, T., Nastić., S., Popović, V., Popović, D., Vitomir, G. 2021. The importance of a realistically determined amount of tax on property rights relating to the ownership of agricultural land in the Republic of Serbia adopted by tax authorities of local selfgovernment units, *Ekonomika poljoprivrede*, Vol. 4, pp. 1029-1042.

[13] Jokić, M., Popović, D., Popović, S., 2020. Značaj pripreme revizijskog izveštaja za top menadžment poljoprivrednog preduzeća, Poljoprivredna tehnika, Vol. 2, pp. 21-27.

[14] Radović, M., Vitomir, J., Laban, B., Jovin, S., Nastić, S., Popović, V. & Popović S. 2019. *Management of joint-stock companies and farms by using fair value of agricultural equipment in financial statements on the example of IMT 533 tractor*, Economics of Agriculture, Vol. 1. pp. 35-50.

[15] Vitomir, J., Radović, M. & Popović, S. 2021. The Effect of Public Finance Control on the Improvement of Work of Internal Auditors in Enterprises Founded by the Local Self-government Units on the Example of the Republic of Serbia, *Lex localis - Journal of Local Self-Government*, Vol. 19(2).

[16] Jokić, M., Laban, B., Arnautović, I., Popović, D. & Popović, S. 2020. The importance of preparing an internal audit report in reporting to top management of a company that makes key management decisions in its work, *Annals*, Vol. 2, pp. 1-8.

UPRAVLJANJE NE STANDARDNOM POLJOPRIVREDNOM OPREMOM KOJA SE KORISTI U LEČENJU PACIJENATA NA OSNOVU VREDNOVANJA VLASNIKA POLJOPRIVREDNIH GAZDINSTAVA I RUKOVODSTVA ZDRAVSTVENIH ORGANIZACIJA

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Abstrakt: U ovoj studiji autori su pokazali da postoji snažan uticaj između moguće upotrebe ne standardne poljoprivredne opreme na primeru izgradnje Api komora na poljoprivrednim gazdinstvima, što omogućava povećanje efikasnosti njenog korišćenja formiranjem kooperativnih odnosa između gazdinstava i zdravstvenih ustanova, koje takođe imaju ekonomske interese da koriste takvu opremu u lečenju pacijenata.

Pored toga, konstatovano je da se na osnovu ukupnih prihoda i rashoda može predvideti formiranje ukupne dobiti, jer je primena ovakvom poslovnog modela statistički značajan (F=183.600, p<0.0005), odnosno prihodi i rashodi imaju značajan uticaj na predviđanje dobiti u ovoj vrsti poslovanja poljoprivrednih gazdinstava.

Isto se odnosi i za takvo poslovanje zdravstvenih ustanova, jer je dobijeni model statističkih značajan (F=327,121, p<0,0005) u slučaju kooperativnog poslovanja sa ne standardnom poljoprivrednom opremom (Api komore) koje mogu da se koriste u lečenju pacijenata.

Ključne reči: *Poljoprivredno gazdinstvo, efikasnost poslovanja, Api komora, lečenje pacijenata.*

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ANALYSIS OF COST CONTROL CHALLENGES IN THE CONSTRUCTION INDUSTRY, USING ARTIFICIAL NEURAL NETWORK

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Abstract: The construction industry frequently encounters significant cost control challenges that can impact project efficiency and profitability. Addressing these issues requires advanced predictive models that can accurately forecast construction cost and identify influential factors. This research aims to leverage on Artificial Neural Network (ANN) model to predict and evaluate construction cost challenges using loss function parameters, comparing its performance with that of multiple linear regression (MLR). A comprehensive dataset of 199 responses from a questionnaire and survey result were derived from various construction projects.
The multiple linear regression (MLR) result yielded an R value of 0.669757, R^2 value of 0.448574 and an adjusted R^2 value of 0.43, indicating limited explanatory power or a weak predictive capability and indicating that the model does not account for much of the variability.

These results underscore the limitations of MLR in handling complex, non-linear relationship within the data. In contrast, an ANN architecture of 7-35-1 was implemented and analyzed in MATLAB, using a Feed-Forward Back propagation with a training function of Levenberg-Marquardt. Conversely, the ANN model demonstrated superior performance, with training, testing, and validation R values of 0.993, 0.99221, and 0.98499, respectively, and an overall R^2 value of 0.99216.

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The training state of the ANN showed the best gradient of 7.0860 at epoch 2, while the validation performance peaked at 124932260 at epoch 5. The loss function parameters, root mean squared error (RMSE) of 0.81 was obtained. These findings suggest that ANN provided a more accurate and reliable approach for predicting construction cost challenges compared to MLR, highlighting the potential of advanced machine learning techniques in addressing cost control challenges in the construction industry and as well indicating a robust predictive capability across different subsets of the data.

Keywords*: Construction, Cost, MATLAB, Optimization, Prediction.*

INTRODUCTION

The construction industry plays a pivotal role in the economic development and growth of any country, making it one of the main contributors to the Gross National Product (GNP). This sector encompasses a wide range of activities, including residential, commercial, and industrial building projects, infrastructure development and the maintenance and renovation of existing structures. However, the construction industry is a cornerstone of economic development, driving growth through direct contribution to GNP, employment generation, stimulation of related industries, and infrastructure development. Its broad impact on various aspects of the economy underscores its vital role in fostering national prosperity and improving the standard of living, [1].

Effective cost control is indeed a cornerstone of successful construction project management. It ensures that projects are completed within their allocated budgets, which is crucial for the financial health of construction firms and the satisfaction of clients. This helps ensure that construction projects stay within their allocated budgets, by monitoring and managing costs throughout the project lifecycle, project managers can prevent cost overruns, which can lead to financial loses and damage a contractor's reputation. Cost control in construction project management involves a comprehensive set of strategies, practices, and methodologies aimed at minimizing the risk of cost overruns while optimizing project performance. Successful cost control not only ensures financial stability but also contributes to the timely delivery of high-quality results that meet or exceed stakeholder expectations [2]. Effective cost control is indeed a foundational element of successful construction project management which involves planning, monitoring, and managing all cost associated with a project to ensure that it is completed within the approved budget [3].

Author [4], stated in his studies that construction cost control faces numerous challenges due to the dynamic and complex nature of construction projects. Changes can occur in this project due to unforeseen event or circumstances such as unpredictable site conditions, design changes, material price fluctuations, labor shortages and productivity, regulatory compliance, technological changes, stakeholder's expectations, contractual disputes, weather impact, supply chain disruption, project complexity and financial management. Cost control challenges is a factor of concern; thus, this requires proactive planning, robust risk management, real-time monitoring, and flexibility to adapt to changing conditions. Poor cost performance and cost overruns in construction projects are pervasive issues affecting both developing and developed countries.

These challenges stem from a multitude of complex factors, each contributing to the difficulty of maintaining budgetary control. Inaccurate cost estimation is a major factor, often resulting from reliance on incomplete data or overly optimistic projections. This can lead to significant discrepancies between projected and actual costs. Significant issues also range from frequent design and scope changes during the construction phase, these modifications which may be driven by client requests, regulatory requirement, or unforeseen site conditions, often lead to additional and unplanned expenditures [5]. Supply chain issues are another contributing factor.

Delays in the delivery of materials, equipment failures, and fluctuations in materials prices can disrupt project schedules and budget. Labor issues, including shortages of skilled workers, labor strikes, and low productivity, also add to the financial strain on construction projects. Regulatory and compliance costs can increase unexpectedly when there are changes in laws or new requirement that necessitate additional permits, inspections, or project modifications. Financial mismanagement including poor cash flow planning and the lack of sufficient contingency funds can further worsen cost overruns [6].

Addressing these issues requires a multifaceted approach. Improving cost estimation through the use of advanced tools and techniques can enhance budget accuracy, enhanced project management practices including detailed planning, regular monitoring and effective communication among stakeholders are crucial for maintaining control over cost. Risk management strategies, identifying potential risk early, and developing mitigation plans can help prevent unexpected cost from escalating. However, incorporating contingency funds into project budgets and maintaining flexibility to adapt to changes are essential for managing unforeseen expenses. The adoption of technologies such as Building information modeling (BIM) and project management software can improve coordination, cost tracking, and overall efficiency [7], [8].

Authors [9], conducted a study that revealed a significant issue in construction project budgeting; every project examined experienced cost discrepancies. Their findings indicated that 100% of the projects under study suffered from some form of cost divergence. A deeper analysis of these discrepancies showed 76.33% of the project were underestimated in their initial budget, meaning the actual costs exceeded the projected figures. Conversely, 23.67% of the projects were overestimated, where the initial budget allocations were higher than the actual cost incurred. These findings highlight the pervasive challenge of achieving accurate cost estimation in construction projects, the high incidence of underestimation suggests that many projects encounter unexpected expenses or inefficiencies that were not accounted for during the planning phase. This could be due to a range of factors including unforeseen site conditions, changes in project scope, material price fluctuations, and labor issues.

Overestimation, although less common, also poses problems as it can lead to inefficient allocation of resources and potential financial strain on project stakeholders who may set aside more funds than necessary.

This research is aimed at predicting a model for the challenges of cost control in the construction industry, with the machine learning tool (artificial neural network), the following are the objectives of the study Prediction of ANN model for the cost control challenges using survey questionnaire, Comparative analysis of ANN and MLR and to evaluate the ANN model performance using loss function parameters and multiple linear regression analysis.

This research significance is tailored to improve the cost control process in construction projects, which would lead to more efficient projects, could lead to better understanding of the factors that affects cost control, which could lead to improved cost control practice, to help reduce the financial risk associated with construction projects, and to ensure that projects are completed on time within budget with standardized strategies of cost control.

MATERIALS AND METHODS

This study employs mixed method research incorporating both quantitative and qualitative data to investigate the causes of cost increase in Cross River State. The quantitative data will be gathered through structured questionnaire, while qualitative insights will be derived from open ended questions included in the survey. The data will be analyzed using an artificial neural network (ANN) to identify and predict a cost model.

Study Area

The research is focused on construction project within Calabar Municipal in Cross River State, Nigeria (Figure 1), the area is chosen due to its diverse range of construction activities, which provides a rich dataset for analyzing cost fluctuations and underlying causes. Calabar Municipal is a local government area within Calabar, the capital city of Cross River State, it covers an area of 142km^2. Geographically, it is located between latitude 04^0 15'N, and longitude 08^0 25' E. According to the 2006 census, Calabar Municipal has a population of 179,392, to the north it is bordered by the Kwa River in Odukpani and to the northeast, it is bordered by the Calabar River. The predominant ethnic group in Calabar Municipal, are the Efiks and the Qua people. These groups have rich cultural heritages and play a significant role in the socio- economic activities of the area, the main languages spoken are Efik and Qua, which reflect the dominant ethnic groups.
Calabar Municipal is a hub for various economic activities, including trade, tourism, and construction. However, the city is known for its historical significance and as a center for cultural festivities, such as the annual Calabar Carnival.

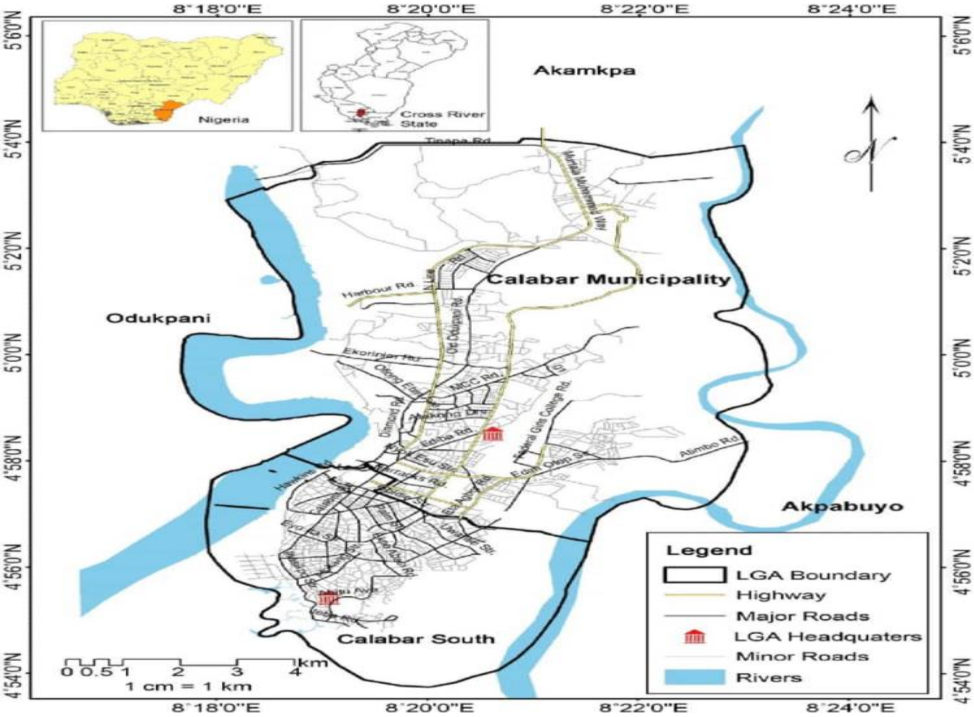

Figure 1. Map of the Study Area (Office of the surveyor general, cross river, [10].

Data Analysis Techniques

The response collected from the questionnaire will be compiled into a structured dataset, data cleaning will be performed to handle missing values, remove duplicate and any inconsistencies. The input variables include, cost control methods, cost estimation accuracy, estimated costs, project duration, economic conditions, resources availability and an output variable of actual cost. The data processing was carried out through normalization where the input variables were scaled to a range suitable for the ANN, typically between 0-5, to ensure efficient training.

However, from fig. 2, an architecture design was done which entails the input layer, hidden layer and output layer.

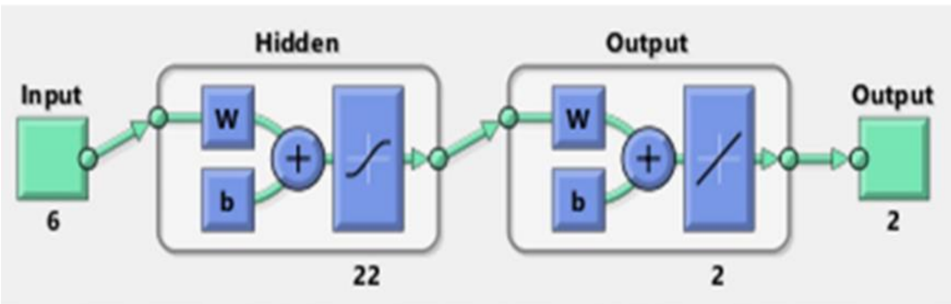

Figure 2. ANN Architecture, [1].

Model Performance Evaluation

The performance of the developed ANN model was evaluated to affirm its ability to estimate or predict the response parameters with an acceptable degree of accuracy. To validate the performance of the ANN model, a multiple linear regression (MLR) model was developed as a benchmark. The performance metrics used for evaluation is Root Mean Squared Error (RMSE). Root mean squared error measures the square root of the average of the squared difference between actual and predicted values. It gives a higher weight to larger errors, making it sensitive to outliners. Mathematically, it is expressed as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(E_i - M_i)^2}{n}} \quad \text{……… (1)}$$

Where is:
E_i, the actual value,
M_i , the predicted value,
n, the data point [11], [12].

Experimental Database

The derived data from the questionnaire and survey were systematically sorted and organized to facilitates a comprehensive evaluation of the factors affecting cost control challenges in construction projects within Calabar Municipal.

A total of 199 response was gotten from the questionnaire and survey and was analyzed using MATLAB. The experimental database was structured into multiple tables to organize the data effectively, the main table contained on each construction project including all input and output variables, [1].

RESULTS AND DISCUSSION

Demographical characteristics.

From table 1, the gender distribution of respondent reveals a significant disparity, with males comprising the majority (80%) of the sample and females representing 20%. This gender in balance may reflect the gender demographics within the construction industry in Calabar Municipal.

The age indicates that the majority of respondent 60% fall with the 20-35 years age group, suggesting that younger professionals are heavily represented in the construction sector.

The 36-45 years age group is the second most common, accounting for 31.3% of respondent. This distribution suggests that the industry also has a substantial number of mid-career professionals. The representation of older age group 46-60 years and 60 years is significantly lower, which could be due to retirement or a lower presence of senior professionals actively participating in project management and fieldwork. 71.5%, 4.4%, 7.9%, 3% and of 13.2% of the respondents are civil engineers, builders, contractors, clients, and other team players involved in construction industry respectively. The years of experience of the respondents showed 80.7% for 1-20 years, 14.7% for 21-30 years, 3.6% for 31-45 and 1% for people above 45 years as recorded by, [13].

Table 1. Respondents' Demographical Characteristics

S/N	Variables	Division	Percentage %	Frequency
1.	Sex	Male	80	159
		Female	20	40
		Total	100	199
2.	Age	20-35	60	119
		36-45	31.3	62
		46-60	7.3	15
		60 >	1.6	3
		Total	100	199
3.	Occupation	Civil Engineer	71.5	142
		Builder	4.4	9
		Contractor	7.9	16
		Client	3	6
		Others	13.2	26
		Total	0	0
			100	199
4.	Years of experience	1-20	80.7	161
		21-30	14.7	29
		31-45	3.6	7
		Others	1	2
		Total	100	199

Statistical Functions

Table 2 presents the Statistical functions for output and input variables. The standard deviation of Actual cost (Ac), 1.3575 and sample variance of 1.8427 indicates a moderate spread of data points around the mean. These measures reflect the variability in the responses concerning cost control method, the average value of cost control method is 1.8598, suggesting that, on average, respondent rated cost control methods relatively low, with median of 14809 indicates the middle value of the dataset is significantly a skewed distribution, the predicted cost (Pc) shows a large value of the median. The actual duration (Ad) has a standard deviation of 223.93 and a variance of 5.0147 indicating a wide range of actual duration and showing significant variability in the responses. The various mean result gave a central tendency of the dataset, these values can be used as a benchmark for comparing other variables as suggested by [14] and [15].

Table 2. Statistical functions for output and input variables

Parameters	Standard deviation	Sample variance	Median	Mean
Actual Cost	1.3575	1.8427	14809	1.8598
Actual duration	223.93	5.0147	442	499.43
Economic condition	0.7215	0.5206	2	1.6025
Planned cost	9.5951	9.2666	10958	1.5348
Planned duration	214.45	4.599	41880	464.86
Resources availability	0.5345	0.2857	1	1.4503
Construction method	0.523	0.1346	1	1.2206

Multiple Linear Regression (MLR) Result

From table 3.0, with R =0.669757 and R^2 = 0.448574, the model explains only 4.48% 0f the variability in the dependent variable, which is quite low. This suggest that the independent variables in the model are not very effective at explaining the variation in the dependent variable in MLR. The adjusted $R^{2\,=}$ 0.43 is even lower, indicating that when the number of predictors is considered, the model's explanatory power decreases further. This could be due to overfitting.

The standard error of 98269 represent the average distance that the observed values fall from the regression line, providing a measure of model's accuracy as obtained by [16] [17].

Table 3. Regression Model Summary

Regression Statistics	
Multiple R	0.669757
R Square	0.448574
Adjusted R Square	0.431342
Standard Error	98269009
Observations	199

Artificial Neural Network (ANN) Model Development

From the survey data results, the factors which effects the cost control challenges were sorted as the independent variables which consists of, cost control method, actual duration, planned cost, planned duration, economic conditions, resources availability and Project budget. The model framework is designed as seven-input variables and one-output target response (Actual cost). The processing parameter settings for the neural network model is presented in Fig. 3 which showed a 7-35-1 two-layer feed-forward network with tensig hidden neurons and linear output neurons, can fit multi-dimensional mapping problems arbitrarily well, given consistent data and enough neurons in its hidden layer. In order to determine the best performing n-neurons, mean squared error (MSE) and R-value's evaluation criteria were used in this analytical study.

From the performance test, at 35 number of neurons produced the optimal generalization results in terms the test criteria result with respect to training, validation and testing of the network as shown in figure 3,7. This is in agreement with the observations of [18] and [19].

Model Summary

Train a neural network to map predictors to continuous responses.

Data

Predictors: data - [199x7 double]

Responses: Ac - [199x1 double]

data: double array of 199 observations with 7 features.

Ac: double array of 199 observations with 1 features.

Algorithm

Data division: Random

Training algorithm: Levenberg-Marquardt

Performance: Mean squared error

Training Results

Training start time: 28-Jul-2024 23:25:10

Layer size: 35

	Observations	MSE	R
Training	139	7.5557e+14	0.9930
Validation	30	9.4892e+14	0.9850
Test	30	7.3950e+14	0.9922

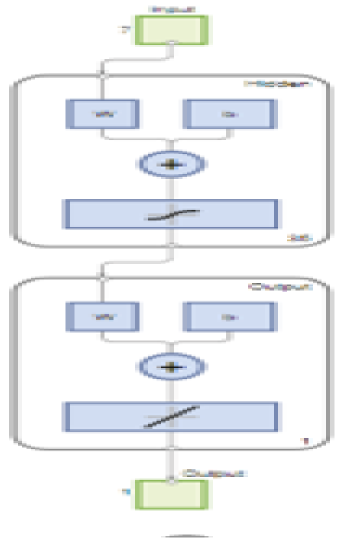

Figure 3. ANN Architecture

Training State of the ANN

The provided training results for ANN model indicate the state of a gradient at 7.0860 in figure 4, with specific observations about the epochs and the onset of overfitting. The gradient value of 7.0860 suggest the magnitude of the gradient during training, if this value is relatively large, it could indicate that the model is learning significantly from the data and has not reached convergence yet. Monitoring gradient values helps in understanding the training dynamics and whether the learning rate needs adjustment. The model performance on the validation set start to degrade at epoch 1, suggesting that the optimal performance on validation data was achieved at this point. After epoch 1.5, the model's ability to generalize to new data begins to decline. From epoch 3 onwards, the model start overfitting. This means that while the model continues to improve on the training data, it performs worse on the validation data. This is in accordance with the findings of [20].

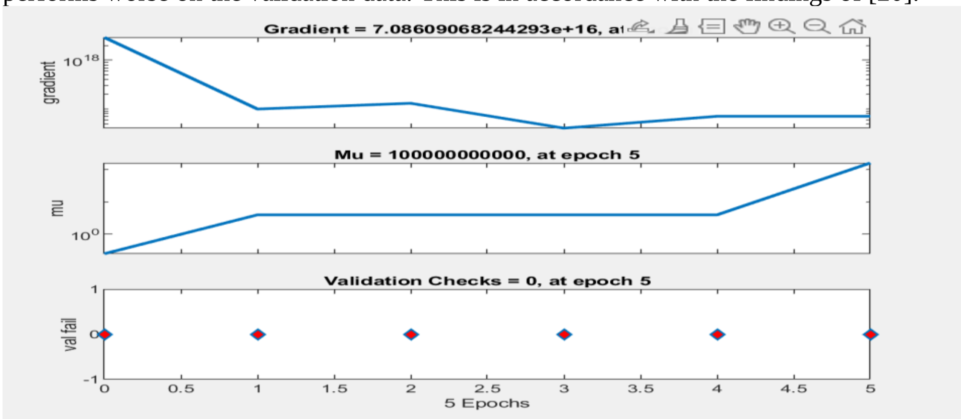

Figure 4. Training State of the ANN

Validation Performance of the ANN

MSE which was the loss function parameter used to evaluate the model performance for validation of the ANN network developed as shown in Fig. 5 presenting the best validation performance of 124932260 at Epoch 2 for the optimized network (7-35-1). The result indicated satisfactory model performance with the smart model capable of predicting the target output parameters accurately generalizing the sets of complex input variables with minimum error as noted by [21].

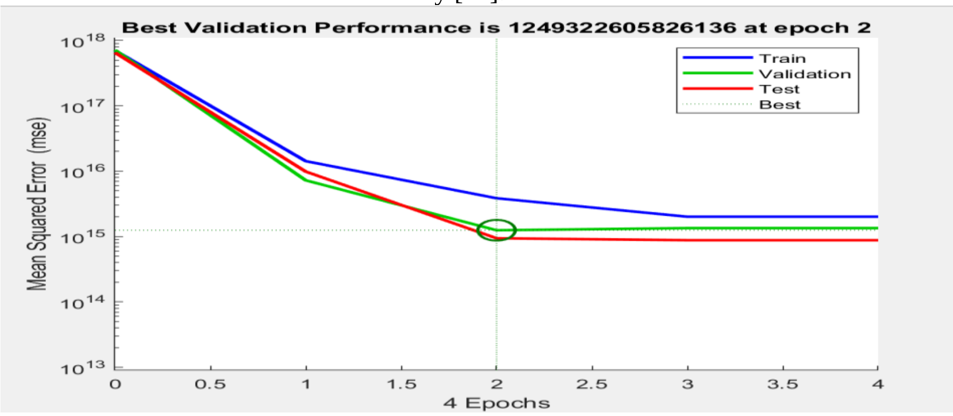

Figure 5. Validation Performance of the ANN

Error Histogram of the ANN

Figure 6 shows how the error histogram is a useful tool for visualizing the distribution of distribution of prediction errors in a model. In this case, you have an error histogram with 20 bins for training, test, and validation data, with an overall error mean of 1.74. The error histogram provides a graphical representation of the difference between predicted and actual values. The errors are divided into 20 bins, allowing us to see how the errors are spread across the data. A mean of 1.74 indicates a slight bias in the model's predictions. This value being close to zero suggest that, on average, the model's predictions are slightly lower than the actual values which agrees with the observations of [22].

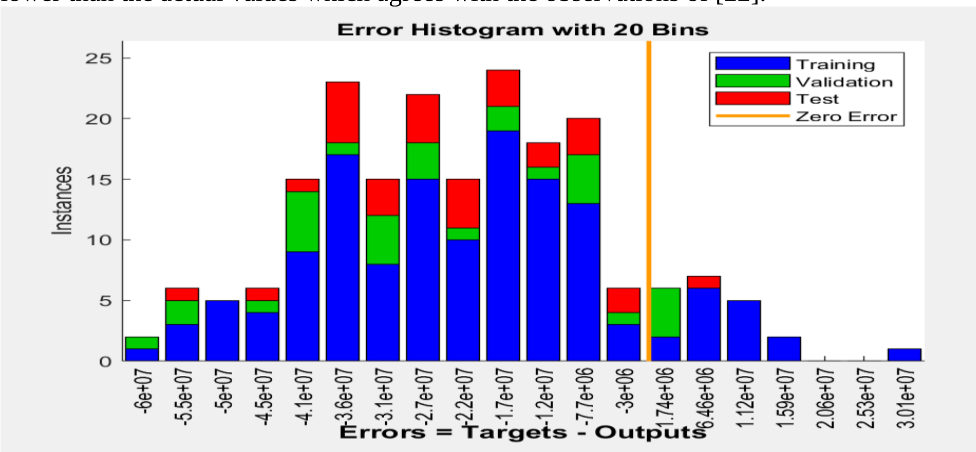

Figure 6. Error Histogram of the ANN

Regression Plot of the ANN

The regression results for the ANN model indicate the performance of the regression on different data subset: training, test, validation and all combined Figure 7). The training R with value of 0.993, this R value represents the correlation between the predicted and actual values on the training data. An R value of 0.993 is relatively high, suggesting that the model fits the training data well and captures most of the underlying patterns. The test R value is slightly lower than the training R value, at 0.99221. this indicates that the model generalizes fairly well to unseen data, although it performs slightly less effectively on the test data compared to the training data. The decrease is minor, suggesting that there is no significant overfitting. However, the validation R value of 0.98499 is close to the training R value, which implies that the model the model maintains its performance on validation data. This is a good indication of model stability and consistency. Finally, the combined R values for all data is 0.99216, which consolidates the performance across the entire dataset. This value being close to the training and validation R values further reinforces that the model has a good overall fit and is reliable. In conclusion the regression results for ANN model are very promising. The high and consistent R values across training, test, and validation sets indicate a well-balanced model with strong predictive capabilities and good generalization to new data. This model can be considered reliable for practical applications where accurate predictions are required. This is in line with the findings of [22] and [23].

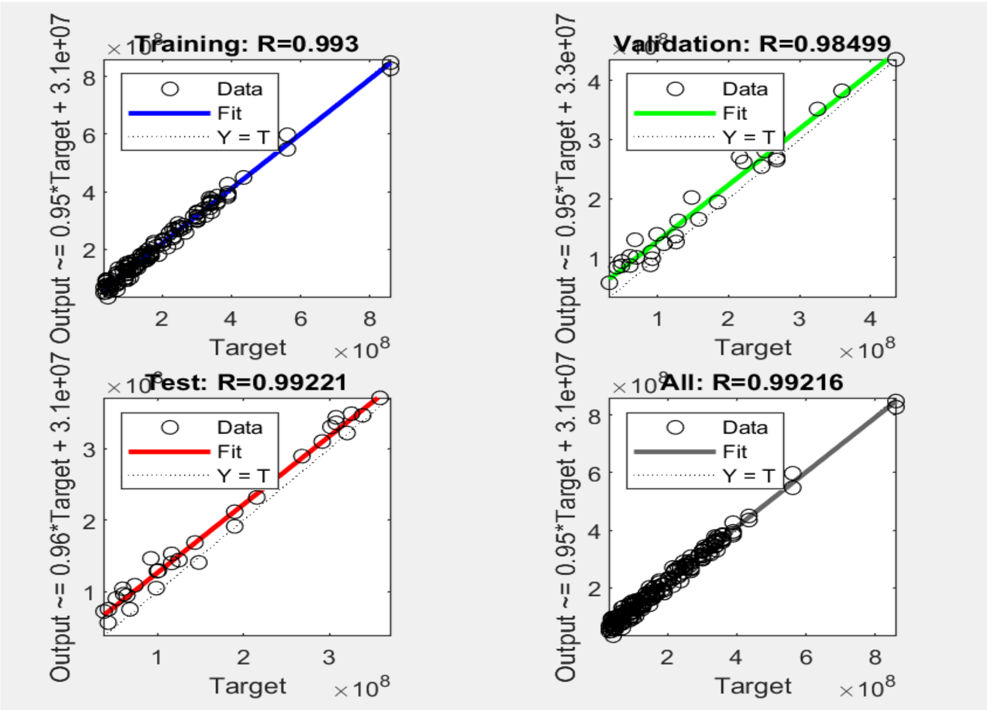

Figure 7. Regression Plot of the ANN

Functions Fit for Output Layers

Figure 8 shows an output function is a function that an optimization function calls at each iteration of its algorithm. Typically, you use an output function to generate graphical output, record the history of the data the algorithm generates, or halt the algorithm based on the data at the current iteration. The function fit shows an error of 6 and inputs of 5.7 while the outputs and target show high training targets and low training outputs.

However, the training outputs falls below 0 to -3 and same results is achieved for the test outputs. This result shows a good performance for the function of fit.

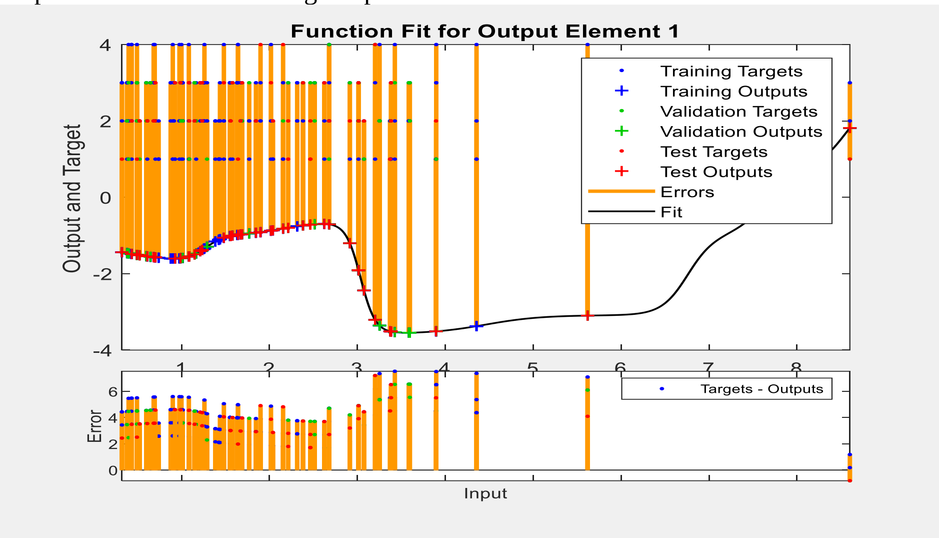

Figure 8. Functions Fit for Output Layers

CONCLUSIONS

This study has demonstrated the significant advantages of employing Artificial Neural Network (ANN) models over traditional multiple linear regression (MLR) in predicting construction cost and addressing cost control challenges within the construction industry. By analyzing a dataset of 199 responses using MATLAB, this dataset was used in comparing the performance of the ANN model with the traditional multiple linear regression (MLR), the ANN's ability to handle complex non-linear relationships within the dataset enables more accurate and reliable cost forecasts. The MLR analysis, with its R value of 0.669757 and R^2 value of 0.448574, revealed its limitations in explaining the variability in construction cost. In contrast, the ANN model, designed with a 7-35-1 architecture, achieved substantially better results, with training, testing, and validation R values indicating robust predictive capabilities. The optimal training state, with a gradient of 7.0860at epoch 9 and a validation performance of 124932260 at epoch 2, further shows the ANN model's effectiveness.

In conclusion, the findings of this study advocate for the integration of machine learning techniques, particularly ANN, in the construction industry's cost control practices.

The superior performance of the ANN model over MLR suggest that adopting such advanced predictive models can lead to more accurate cost forecast, improved resources allocation, and enhanced overall project management. Future research could explore the application of other machine learning algorithms and expand the dataset to further validate these findings and enhance the model's predictive accuracy. By leveraging these innovative techniques, the construction industry can achieve more efficient cost management, ultimately contributing to more successful project outcomes.

RECOMMENDATIONS

i. The construction industry should invest in developing and implementing machine learning techniques, like ANN, to enhance project management and cost control practices

ii. Future research should explore the application of ANN to other construction project management challenges, such as schedule prediction and risk management.

iii. Integrating ANN models with existing project management software can streamline the cost estimation process and provide real-time insights. This integration can facilitate better decision making and allow project managers to respond swiftly to cost variations and project changes

REFERENCES

[1] Jesam, A. U., Mbadike, E. M. and Alaneme, G. U. 2022. Prediction of cost and duration of building construction using artificial neural network. Asian J. Civ. Eng. https://doi.org/10.1007/s42107-022-00474-4.

[2] Elhegazy, A. H. *et al.*2022. Artificial intelligence for developing accurate preliminary cost estimates for composite flooring systems of multi-storey buildings. J. Asian Archit. Build. Eng. 21(1). pp.120–132. https://doi.org/10.1080/13467581.2020.1838288

[3] Kerzner, H.2000. Project Management: A systems approach to planning, scheduling, and controlling, John Wiley, 7th Ed.

[4] Mohd S, Mazianah R, Nurdiana A, Mohd H. 2022. challenges of cost management technique implementation during pre – tender in Klang Valleyconstruction project, https/doi.rg/10.1051/e3sconf/202234705009.

[5] Rajguru, A. and Mahatme P. 2016. Effective techniques in cost optimization of construction projects. Int J Inf Future Res. 3(5):1646–1658. http://ijifr.com/searchjournal.aspx.

[6] Lewis, J.P.2011. Project Planning, Scheduling & Control; a hands-on guide to bringing projects in time and on budget, 5th edition, MacGraw-Hill, New York, USA.

[7] Shanmugapriya S. and Subramanian D. K. 2013. Investigation of significant factors influencing time and cost overruns in Indian construction projects. International Journal of Emerging Technologies, 3(10). pp.734–740.

[8] Sunjka B. P. and Jacob U. 2013. Significant causes and effects of project delays in the Niger delta region Nigeria. SAIIE25 Proceedings: Stellenbosch South Africa. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.882.9428&rep=rep1&type=pdf.

[9] Mahamid, I., and Amund, A.2010. Analysis of cost diverge in road construction projects. In: *Proceedings of the 2010 Annual Conference of the Canadian Society for Civil Engineering*, 9–12 June 2010, Winnipeg, Manitoba, Canada.

[11] Ritter, A., and Munoz-Carpena, R. 2013. Performance evaluation of hydrological models: Statistical significance for reducing subjectivity in goodness-of-fit assessments. *Journal of Hydrology, 480*(1). pp.33–45. https:// doi. org/ 10. 1016/j. jhydr ol. 2012. 12. 00.

[12] Alaneme, G.U., Mbadike, E.M., Attah, I.C., and Udousoro, I. M. 2022. Mechanical behaviour optimization of saw dust ash and quarry dust concrete using adaptive neuro-fuzzy inference system. *Innovative Infrastructure Solutions., No7*, p.122. https://doi. org/10. 1007/ s41062-021- 00713-8.
[13] AlSehaimi, A., & Koskela, L. 2008. What Can be Learned from Studies on Delay in Construction ?. Proceedings for the 16th Annual Conference of the International Group for Lean Construction, pp.95–106.
[14] Onyelowe, K. C., Fazal, E. J., Michael, E. O., Ifeanyichukwu, C.O., Alaneme, G.U.,&Chidozie,I. (2021). Artificial intelligence prediction model for swelling potential of soil and quicklime activated rice husk ashblend for sustainable construction. Journal Kejuruteraan., 33(4), pp.845–852.
[15] Rofooei, F.R., Kaveh, A., & Masteri-Farahani, F. 2011. Estimating the vulnerability of concrete moment resisting frame structures using artificial neural networks. International J. of Operational Research, 3(1), pp.433–448.
[16] Okonkwo, U. N., Agunwamba, J. C., & Iro, U.I. 2016. Geometric models for lateritic soil stabilized with cement bagasse ash. Nigerian Journal of Technology, 35(4), pp.769–777.
[17] Okonkwo, U. N., Arinze, E. E., & Ubochi, S.U. 2021. Predictive model for elapsed time between mixing operation and compaction of lateritic soil treated with lime and quarry dust for sub-base of low-cost roads. International Journal Pavement Research Technology. https://doi.org/10.1007/s42947-021-00022-4.
[18] Çelik, S., & Tan, Ö. 2005. Determination of preconsolidation pressure with artificial neural network. Civil Engineering and Environmental Systems, 22, pp. 217–231. https:// doi. org/10. 1080/ 10286 600500383923.
[19] Sobhani, J., Najimi, M., Pourkhorshidi, A. R., & Parhizkar, T. 2010. Prediction of the compressive strength of no-slump concrete: A comparative study of regression, neural network and ANFIS models. Construction of Building Materials, 24, pp.709 –718.
[20] Erzin, Y., Gumaste, S. D., Gupta, A.K., & Singh, D.N. 2009. ANN models for determining hydraulic conductivity of compacted fine grained soils. Canadian Geotechnical Journal, 46, pp. 955–968.
[21] Erzin, Y., Rao, B.H., Patel, A., Gumaste, S.D., Gupta, A.K., & Singh, D. N. 2010. Artificial neural network models for predicting of electrical resistivity of soils from their thermal resistivity. Inter national Journal of Thermal Sciences, 49, pp.118–130.
[22] Shahmansouri, A. A., Akbarzadeh Bengar, H. & Jafari, A. 2020. Modeling the lateral behavior of concrete rocking walls using multi objective neural network. J. Con. Struct. Mater. 5(2), pp.110–128. https://doi.org/10.30478/jcsm.2021.272480.1192.
[23] Ambrule, V. R., & Bhirud, A. N.2017. Use of artificial neural network for pre design cost estimation of building projects. Interational Journal on Recent and Innovation Trends in Computing and Communication, 5(2), pp.173–176.

ANALIZA PROCENE KONTROLE TROŠKOVA U GRAĐEVINSKOJ INDUSTRIJI, KORIŠĆENJEM VEŠTAČKE NEURONSKE MREŽE

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Apstrakt. Građevinska industrija se često susreće sa značajnim izazovima procene kontrole troškova koji mogu uticati na efikasnost i profitabilnost projekata. Rešavanje ovih problema zahteva napredne modele predviđanja koji mogu precizno predvideti troškove izgradnje i identifikovati uticajne faktore.
Ovo istraživanje ima za cilj da iskoristi model ANN-Artificial Neural Network , Veštačke Neuronske Mreže-VNM, za predviđanje i procenu predpostavke troškova izgradnje koristeći parametre funkcije gubitka, upoređujući njegove performanse sa performansama MLR -Multiple Linear Regression, (Višestruka Linearna Regresija-VLR).
Sveobuhvatan skup podataka od 199 odgovora iz upitnika i rezultata ankete izveden je iz različitih građevinskih projekata.
Rezultat višestruke linearne regresije (VLR) je dao R vrednost od 0.669757, R^2 vrednost od 0.448574 i prilagođenu vrednost R^2 od 0.43, što ukazuje na ograničenu moć objašnjenja ili slabu prediktivnu sposobnost i ukazuje da model ne uzima u obzir veći deo promenljivih parametara.
Ovi rezultati naglašavaju ograničenja MLR (Multiple Linear Regression) u rukovanju složenim, nelinearnim odnosima unutar podataka. Nasuprot tome, VNM, (ANN), prema arhitekturi 7-35-1 je implementirana i analizirana u programu MATLAB, korišćenjem širenja povratnog protoka sa funkcijom Levenberg-Markuardt.
Nasuprot tome, model ANN je pokazao superiorne performanse, sa R vrednostima obuke, testiranja i validacije od 0.993, 0.99221 i 0.98499, respektivno, i ukupnom vrednošću R^2 od 0.99216. Stanje -VNM, (eng. ANN-Artificial Neural Network) je pokazalo najbolji gradijent od 7.0860 u epohi 2, dok je performansa validacije dostigla vrhunac na 124932260 u epohi 5. Dobijeni su parametri funkcije gubitka, prosečna kvadratna greška (RMSE-Root Mean Square Error) od 0,81.
Istraživanja i rezultati sugerišu da je VNM, (eng. ANN- Artificial Neural Network) pokazuje tačniji i pouzdaniji pristup za predviđanje procene troškova izgradnje u poređenju sa MLR (Multiple Linear Regression), ističući potencijal naprednih tehnika mašinskog učenja u rešavanju procene kontrole troškova u građevinskoj industriji i takođe ukazujući na snažnu sposobnost predviđanja u različitim podskupovima podataka.

Ključne reči: *Konstrukcija, cena, MATLAB, optimizacija, predviđanje.*

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EFFECTS OF DEFICIT IRRIGATION AND MANURE APPLICATION ON GROWTH, YIELD AND WATER USE EFFICIENCY OF ONION (*Allium cepa L.*)

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Abstract: With increasing municipal and industrial demands for water, its allocation for agriculture is decreasing steadily. Irrigated agriculture, both now and in the future, will occur in areas with limited water resources. Insufficient water supply for irrigation will become the norm rather than the exception, and irrigation management will move from prioritizing production per unit area to optimizing production per unit of water consumed. To deal with limited resources, deficit irrigation is an integral strategy for minimizing irrigation water consumption. In this study, the growth, yield, water use efficiency, and nutritional content of onion (*Allium cepa L.*) were evaluated, as well as the interacting effects of deficit irrigation and manure treatment on these factors. The research was carried out utilizing a factorial design that was arranged in split plots and included three replications from each group. Treatments consisted of three irrigation levels (ETc 100%, ETc 75% and ETc 50%) and two manure levels (with and without manure application).

When compared to deficit irrigation alone, the results showed that the combination of deficit irrigation with the application of manure resulted in a considerable increase in plant height, stem diameter, number of leaves, bulb weight, bulb diameter, and nutrient content.

The treatment with manure and 50% ETc had the highest water use efficiency of all the treatments. Under conditions when there is a limited supply of water, the study demonstrates that a combination of deficit irrigation and the use of manure can improve onion yield.

***Key words**: Onion, deficit irrigation, manure, water use efficiency, yield, nutrient content.*

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INTRODUCTION

Water scarcity has emerged as one of the most pressing global challenges of the 21st century, with far-reaching implications for food security, economic development, and environmental sustainability, [1,2]. The agricultural sector, which accounts for approximately 70% of global freshwater withdrawals, stands at the forefront of this crisis [3,4]. As the world's population continues to grow and climate change exacerbates water stress in many regions, there is an urgent need to develop and implement water-efficient agricultural practices that can maintain crop productivity while significantly reducing water consumption [5-8]. The scale of the water scarcity problem is staggering. According to recent estimates by the United Nations, over 2 billion people live in countries experiencing high water stress, and this number is projected to increase dramatically in the coming decades [9]. Climate change is expected to intensify water scarcity through altered precipitation patterns, increased evapotranspiration rates, and more frequent and severe droughts in many parts of the world [10-12]. These changes pose significant threats to agricultural production, particularly in arid and semi-arid regions that are already struggling with limited water resources.

In response to these challenges, researchers and practitioners have been exploring innovative approaches to improve water use efficiency in agriculture. One such approach that has gained significant attention in recent years is deficit irrigation, often combined with sustainable soil management practices such as organic manure application [13-14]. This integrated approach seeks to optimize water use while maintaining soil health and crop productivity, offering a promising pathway towards more sustainable agricultural systems. Deficit irrigation is an optimization strategy in which crops are deliberately exposed to a certain level of water stress, either during specific growth stages or throughout the entire growing season, without causing significant yield reduction [15-16]. This approach is based on the principle that maximizing water productivity – the amount of crop produced per unit of water consumed – may be more profitable for farmers than maximizing yields, especially in water-scarce regions [17].

The concept of deficit irrigation challenges the conventional wisdom that crops should always be fully irrigated to achieve maximum yields. Instead, it recognizes that plants have varying sensitivities to water stress at different growth stages and that moderate water deficits can sometimes trigger beneficial physiological responses, such as improved root growth or increased fruit quality [15, 18].

By carefully managing the timing and extent of water stress, farmers can potentially achieve substantial water savings with only minimal impacts on yield. However, the successful implementation of deficit irrigation requires a nuanced understanding of crop-specific responses to water stress at different growth stages, as well as the potential interactions with other agronomic practices [19-22]. This complexity underscores the need for robust scientific research to guide the development of effective deficit irrigation strategies for different crops and environments. While deficit irrigation offers significant potential for improving water use efficiency, it is not without challenges. One of the primary concerns is the risk of yield reduction if water stress is too severe or poorly timed. Additionally, deficit irrigation may affect crop quality parameters, which can be particularly important for high-value horticultural crops, [23-25].

These risks highlight the importance of combining deficit irrigation with other agronomic practices that can help mitigate the negative impacts of water stress.

This is where the application of organic manures comes into play. Organic amendments, such as farmyard manure, compost, and green manures, have long been recognized as beneficial practices in sustainable agriculture [26]. These materials can improve soil physical properties, enhance water retention capacity, increase nutrient availability, and promote beneficial soil microbial activity [27]. In the context of deficit irrigation, the potential of organic manures to mitigate the negative impacts of water stress on crop growth and yield has garnered increasing attention from researchers and practitioners alike [28]. The benefits of organic manures in agriculture are multifaceted. From a water management perspective, organic amendments can significantly improve soil structure and water-holding capacity, allowing crops to access stored soil moisture more effectively during periods of water stress [29]. This can be particularly beneficial in deficit irrigation systems, potentially extending the intervals between irrigation events and reducing overall water consumption. Furthermore, organic manures provide a rich source of nutrients that are released slowly over time, improving nutrient use efficiency and reducing the risk of nutrient leaching [26]. This steady supply of nutrients can help support crop growth and development even under water-limited conditions. Organic amendments also stimulate soil microbial activity, which can enhance nutrient cycling, improve soil structure, and potentially increase plant resistance to stress [27].

The combination of deficit irrigation and organic manure application represents a holistic approach to sustainable water management in agriculture. By simultaneously addressing water use efficiency and soil health, this integrated strategy has the potential to enhance crop resilience to water stress while maintaining or even improving soil fertility and overall agroecosystem health [28].

In this context, the study of crops that are both economically important and sensitive to water stress becomes particularly relevant. Onion (Allium cepa L.) is one such crop that fits this description perfectly. As a globally important vegetable, onion is valued for its culinary versatility and medicinal properties [30]. It is cultivated in a wide range of climatic conditions and plays a significant role in both local consumption and international trade [31].

The global importance of onion is reflected in its production statistics. According to the Food and Agriculture Organization (FAO), global onion production reached approximately 102 million tonnes in 2020, with China, India, and the United States being the top producers [31].

Onions are not only a staple food item in many cuisines worldwide but also a valuable cash crop for many smallholder farmers in developing countries. However, onion production faces several challenges, particularly in the context of water scarcity and climate change. Onions are known for their sensitivity to water stress, especially during the bulb formation stage [32]. This sensitivity is compounded by the crop's relatively shallow root system, which limits its ability to access water from deeper soil layers during dry periods. These characteristics make onion an interesting and important subject for studying the effects of deficit irrigation and potential mitigation strategies. The water requirements of onion crops vary depending on the climate, soil type, and cultivation practices, but they are generally considered to be moderate to high. In many production systems, onions receive frequent irrigation to maintain optimal soil moisture levels throughout the growing season.

However, as water resources become increasingly scarce, there is a growing need to develop more water-efficient production methods for this important crop.
Research on deficit irrigation in onion production has shown mixed results, highlighting the complexity of the crop's response to water stress. Some studies have demonstrated that moderate deficit irrigation can be applied without significant yield losses, particularly if the timing of water stress is carefully managed (Shock et al., 2005). Other research has shown that deficit irrigation can even improve certain quality parameters, such as pungency and soluble solids content, [33]. However, severe or poorly timed water stress can lead to significant reductions in bulb size and marketable yield, [32]. The potential of organic manures to mitigate the negative impacts of water stress in onion production is an area of growing research interest. Several studies have demonstrated that the application of organic amendments can improve soil water retention, enhance nutrient availability, and promote better root development in crops, [34-40). These benefits could potentially help onion plants better tolerate periods of water stress under deficit irrigation regimes. Moreover, the use of organic manures in onion production aligns with the growing consumer demand for sustainably produced foods. Organic and low-input production systems for onions have gained popularity in many markets, driven by concerns about pesticide residues and environmental sustainability, [41]. The integration of deficit irrigation and organic manure application could potentially contribute to the development of more sustainable onion production systems that meet these consumer preferences while addressing water scarcity challenges.
The study of the interactive effects of deficit irrigation and manure application on onion growth, yield, water use efficiency, and nutrient content addresses a critical knowledge gap in sustainable onion production. By investigating how these two practices interact, researchers can potentially identify synergistic effects that could lead to more effective water management strategies for onion crops. This research is particularly timely and relevant given the growing global concerns about water scarcity, food security, and sustainable agricultural practices, [9]. As the world grapples with the challenges of feeding a growing population under increasingly water-constrained conditions, the development of water-efficient production methods for staple crops like onions becomes ever more crucial. The potential implications of this research extend beyond onion production.
The insights gained from studying the interactions between deficit irrigation and organic amendments in onions could inform similar research in other crops, contributing to the broader development of sustainable agricultural practices. Furthermore, by demonstrating the potential for significant water savings in a water-sensitive crop like onions, this research could encourage wider adoption of water-efficient practices across the agricultural sector.
The study therefore sought to address a critical knowledge gap by investigating the interactive effects of deficit irrigation and manure application on onion growth, yield, water use efficiency, and nutrient content. This research is particularly timely and relevant given the growing global concerns about water scarcity, food security, and sustainable agricultural practices, [9].

MATERIAL AND METHODS

The experiment was conducted at the School of Agriculture Teaching and Research Farm, University of Cape Coast, Ghana. The soil at the site is classified as a sandy clayey loam. The study used a factorial design laid out in split plots with three replications. The main plots consisted of three irrigation levels 100% ETc (Crop Evapotranspiration), 75% ETc, and 50% ETc. The sub-plots comprised two manure levels with manure application and without manure application. The experimental field was cleared, leveled and divided into plots of 1.5 m x 2 m (3 m²). Four-week-old onion seedlings were transplanted at a spacing of 0.60 m x 0.60 m, with 12 plants per plot. Irrigation was applied every two days using watering cans. The crop water requirement (ETc) was calculated as:

ETc = ETo x Kc …………………...(1)

Where:
ETo = Reference evapotranspiration (measured using US Class A evaporation pan)
Kc = Crop coefficient (FAO values used for different growth stages)

ETo = Epan x Kp …………………...(2)

Where;
Epan = Pan evaporation
Kp = Pan co-efficient

Table 1 below outlines the key parameters measured and the methodologies used in assessing various plant characteristics and water use efficiency. These measurements were taken to evaluate the growth, yield, and nutrient content of plants under different treatment conditions.

The parameters include plant height, stem diameter, number of leaves, bulb weight, bulb diameter, number of rings, water use efficiency, and nutrient content, each determined using specific methods to ensure accurate and consistent data collection.

Table 1. Measurement Methods and Parameters for Plant and Bulb Characteristics

Key Parameters	Methodology
Plant height	Measured using a 1m ruler Six plants selected from each treatment replication for measurement
Stem diameter	Determined using a digital caliper
Number of leaves	Obtained by counting
Bulb weight	Six bulbs selected from each treatment and weighed to determine average bulb weight per plant
Bulb diameter	Measured as an indicator of bulb size Measured using calipers
Number of rings	Counted visually after cutting bulbs
Water use efficiency	Calculated as yield (g) divided by total water applied (mm)
Nutrient content	Protein was determined using Micro-Kjeldahl method for nitrogen content Phosphorus was determined using Bray No. 1 method. Carbohydrate content was determined using the phenol-sulfuric acid method. Dried and ground onion samples were extracted with hot water. The extract was reacted with 5% phenol solution and concentrated sulfuric acid, producing a golden-yellow color. The absorbance was measured spectrophotometrically at 490 nm. Carbohydrate concentration was calculated using a glucose standard curve.

Data collection and statistical analysis:

Plant height, Stem diameter, Number of leaves, Bulb weight, Bulb diameter, Number of rings, Water use efficiency, and Nutrient content (Protein, Phosphorus, Carbohydrates) were the parameters measured. Data were analyzed using analysis of variance (ANOVA) in GenStat statistical software (2020 version). Treatment means were compared using least significant difference (LSD) at $p<0.05$.

RESULTS AND DISCUSSION

Deficit irrigation and manure application on onion yield components

Table 2 presents the interactive effects of deficit irrigation and manure application on onion yield components, specifically bulb weight, bulb diameter, and number of rings.

Table 2. Interactive effects of deficit irrigation and manure application on onion yield components

Treatment	Deficit Irrigation	Bulb weight (g)	Bulb diameter (mm)	Number of rings
Manure	100% ETc	71.9a	63.4a	7.33a
	75% ETc	43.6b	58.2b	6.67ab
	50% ETc	39.5b	46.6c	6.47bc
No Manure	100% ETc	35.0b	57.1b	6.33bc
	75% ETc	25.8c	50.4c	5.67cd
	50% ETc	22.1c	44.9d	5.67cd
LSD (0.05)		25.58	4.55	1.546

Means followed by the same letter within a column are not significantly different at $p<0.05$

The results show that bulb weight was significantly affected by both irrigation levels and manure application. The heaviest bulbs (71.9 g) were produced in the treatment combining 100% ETc with manure application. This finding is consistent with the research of Nandle et al. [42] and Pejić et al. [43], who reported that increasing irrigation levels resulted in higher average bulb weights in onion. A clear trend of decreasing bulb weight is observed as the irrigation level decreases, both with and without manure application. This response to water stress aligns with the findings of Kumar et al. [32], who observed reduced onion bulb weights under deficit irrigation. However, it is notable that at each irrigation level, bulbs from plants receiving manure were consistently heavier than those without manure. For instance, at 50% ETc, bulbs with manure weighed 39.5 g compared to 22.1 g without manure. This suggests that manure application can significantly mitigate the negative effects of water stress on bulb weight, possibly due to improved soil water retention and nutrient availability [44,45].

The bulb diameter showed a similar pattern to bulb weight. The largest bulb diameter (63.4 mm) was observed in the 100% ETc with manure treatment. This result supports the findings of Shock et al. [46], who reported that onion bulb size increased with higher irrigation thresholds. The bulb diameter decreased with reducing irrigation levels, but the decline was less pronounced in treatments receiving manure. For example, at 50% ETc, bulbs were 3.8% larger in diameter with manure (46.6 mm) compared to without manure (44.9 mm). This indicates that manure application can help maintain bulb size under water-limited conditions, which is crucial for marketable yield. These results are in line with the observations of Dhaker et al. [47], who reported that organic manure application improved yield attributes in onion.

The number of rings per bulb, an indicator of bulb quality, also showed significant differences among treatments. The highest number of rings (7.33) was observed in the 100% ETc with manure treatment. This aligns with the findings of Madoli et al. [48], who reported that yield attributes of onion were significantly improved with organic manure application. The reduction in ring number was more pronounced under deficit irrigation without manure.

For instance, at 50% ETc, bulbs from plants with manure had 38.5% more rings (6.47) compared to those without manure (4.67). This suggests that manure application can help maintain bulb quality under water stress, which is important for both market value and storage life of onions.

Deficit irrigation and manure application on water use efficiency and nutrient content of onion

Table 3 presents the interactive effects of deficit irrigation and manure application on water use efficiency (WUE) and nutrient content of onion.

Table 3. Interactive effects of deficit irrigation and manure application on water use efficiency and nutrient content of onion

Treatment	Deficit Irrigation	WUE (g/mm)	Protein (%)	Phosphorus (μg/g)	Carbohydrate (%)
Manure	100% ETc	0.20b	22.10a	5927.33a	19.30a
	75% ETc	0.21b	22.36a	5934.34a	19.48a
	50% ETc	0.25a	21.33a	5930.38a	19.08a
No manure	100% ETc	0.11c	16.47b	4640.55b	14.97b
	75% ETc	0.13c	16.22b	4499.28b	14.43b
	50% ETc	0.14c	14.30b	4636.14b	14.37b
LSD (0.05)		0.023	2.87	97.42	2.14

Means followed by the same letter within a column are not significantly different at $p<0.05$

The results in Table 2 show that WUE was significantly affected by both irrigation levels and manure application. The highest WUE (0.25 g/mm) was achieved in the 50% ETc treatment with manure application. This finding supports the concept that deficit irrigation can improve water productivity in crop production, as proposed by Zhang & Oweis [49]. The increase in WUE under deficit irrigation is likely due to the plant's ability to maintain relatively high yield levels while consuming less water [16]. Interestingly, manure application enhanced WUE across all irrigation levels. For instance, at 50% ETc, WUE increased from 0.14 g/mm without manure to 0.25 g/mm with manure. This improvement can be attributed to the positive effects of organic matter on soil structure and water-holding capacity, as suggested by Yavitt et al. [50] and Nath [51]. The enhanced WUE with manure application indicates that organic amendments can play a crucial role in optimizing water use in onion production under water-limited conditions.

Protein content in onion bulbs was significantly higher in treatments receiving manure application across all irrigation levels. The highest protein content (22.36%) was observed in the 75% ETc treatment with manure. This aligns with findings by Jayathilake et al. [44], who reported increased nutrient uptake and content in onion with organic manure application.

Notably, even under deficit irrigation (50% ETc), manure application maintained higher protein levels (21.33%) compared to full irrigation without manure (16.47%). This suggests that manure can help sustain crop nutritional quality under water-limited conditions.

The phosphorus content showed a similar trend to protein content. Manure application significantly increased phosphorus levels in onion bulbs across all irrigation treatments. The highest phosphorus content (5934.34 µg/g) was observed in the 75% ETc treatment with manure. This corroborates with the findings of Gnanasundari et al. [52], who reported improved nutrient uptake in onion with organic manure application. The ability to maintain high phosphorus levels even under deficit irrigation (5930.38 µg/g at 50% ETc with manure) is particularly noteworthy, as phosphorus plays a crucial role in energy transfer and root development [53-54].

Carbohydrate content in onion bulbs was also significantly enhanced by manure application. The highest carbohydrate content (19.48%) was observed in the 75% ETc treatment with manure. This is consistent with the research of Abdelrasheed et al. [55], who found that organic amendments improved the quality parameters of onion, including carbohydrate content. The maintenance of high carbohydrate levels even under deficit irrigation with manure application (19.08% at 50% ETc) suggests that organic amendments can help sustain the nutritional and flavor qualities of onion under water stress conditions.

Effect of deficit irrigation and manure application on plant height of onion

Figure 1 illustrates the interactive effects of deficit irrigation and manure application on onion plant height over a 6-week period after transplanting. For both manure and no-manure treatments, plant height consistently increases with higher irrigation levels (50% ETc < 75% ETc < 100% ETc). This aligns with the findings of Kumar et al. [32], who observed reduced onion plant growth under deficit irrigation conditions. The 100% ETc treatments show the steepest growth curves, indicating that full irrigation promotes optimal plant height development. At each irrigation level, treatments with manure application consistently outperform those without manure in terms of plant height. This supports the findings of Dhaker et al. [47], who reported that farm yard manure was effective in increasing the growth of onion. The positive effect of manure is particularly pronounced in the later weeks of growth. The graph clearly demonstrates that manure application mitigates some of the negative impacts of deficit irrigation on plant height. For instance, the 75% ETc with manure treatment achieves similar plant heights to the 100% ETc without manure treatment by week 6. This interaction suggests that manure application can partially offset the effects of water stress on onion growth, likely due to improved soil water retention and nutrient availability [56]. All treatments show a general trend of increasing plant height over time, but with varying rates.

The steepest growth curves are observed for the 100% ETc with manure treatment, while the flattest curve is seen for the 50% ETc without manure treatment. This illustrates how both water and nutrient availability affect the rate of plant growth. The differences between treatments become more pronounced as time progresses. This suggests that the cumulative effects of irrigation and manure treatments on plant growth increase over the growing period, as noted by Jayathilake et al. [44] in their study on organic manure effects on onion. Figure 1 suggests that in water-limited conditions, applying manure could be an effective strategy to maintain reasonable plant growth. For instance, the 75% ETc with manure treatment achieves better plant height than 100% ETc without manure by week 6, indicating potential for water savings without compromising growth.

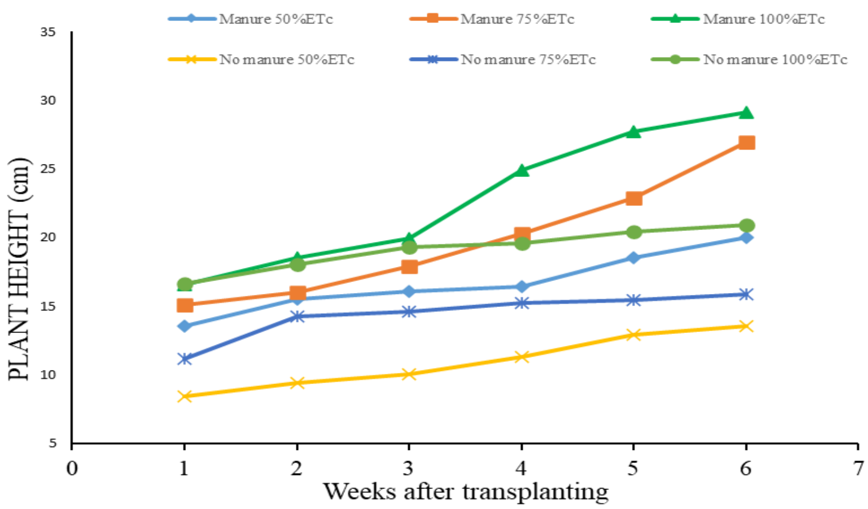

Figure 1. Interactive effect of deficit irrigation and manure application on plant height of onion

Effects of deficit irrigation and manure application on onion stem diameter

Figure 2 illustrates the interactive effects of deficit irrigation and manure application on onion stem diameter over a 6-week period after transplanting. For both manure and no-manure treatments, stem diameter generally increases with higher irrigation levels (50% ETc < 75% ETc < 100% ETc). This aligns with the findings of Kumar et al. [32], who observed that water stress negatively impacts onion growth parameters. The 100% ETc treatments, especially with manure, show the steepest growth curves, indicating that full irrigation promotes optimal stem development. At each irrigation level, treatments with manure application consistently outperform those without manure in terms of stem diameter, particularly in the later weeks.

This supports the findings of Jayathilake et al. [44], who reported that growth parameters of onion, including stem girth, were significantly increased with the application of organic manures. The positive effect of manure becomes more pronounced as the growing period progresses. The graph clearly demonstrates that manure application mitigates some of the negative impacts of deficit irrigation on stem diameter. For instance, by week 6, the 75% ETc with manure treatment achieves similar stem diameters to the 100% ETc without manure treatment. This interaction suggests that manure application can partially offset the effects of water stress on onion growth, likely due to improved soil water retention and nutrient availability [56]. All treatments show a general trend of increasing stem diameter over time, but with varying rates. The steepest growth curve is observed for the 100% ETc with manure treatment, while the flattest curve is seen for the 50% ETc without manure treatment. This illustrates how both water and nutrient availability affect the rate of stem thickening, which is crucial for supporting the developing onion plant and bulb. The differences between treatments become more pronounced as time progresses, particularly after week 3. This suggests that the cumulative effects of irrigation and manure treatments on stem growth increase over the growing period, as noted by Mandoli et al. [48] in their study on organic manure effects on onion growth traits. Figure 2 suggests that in water-limited conditions, applying manure could be an effective strategy to maintain reasonable stem growth. For instance, the 75% ETc with manure treatment achieves better stem diameter than 100% ETc without manure by week 6, indicating potential for water savings without compromising this important growth parameter.

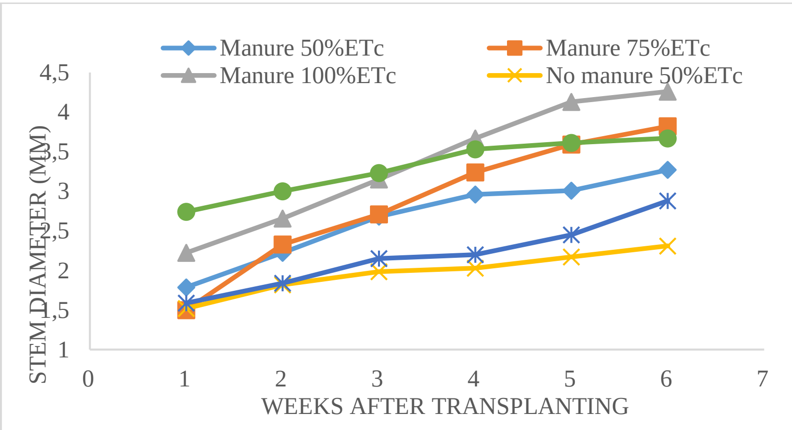

Figure 2. Interactive effect of deficit irrigation and manure on stem diameter of onion

Effects of deficit irrigation and manure application on the number of leaves

Figure 3 illustrates the interactive effects of deficit irrigation and manure application on the number of leaves per onion plant over a 6-week period after transplanting. The number of leaves per plant followed a trend similar to plant height and stem diameter.

Plants receiving 100% ETc with manure produced the highest number of leaves (8.7), which is in line with the observations of Mandoli et al. [48], who reported that growth traits such as number of leaves were significantly higher with organic manure application. For both manure and no-manure treatments, the number of leaves generally increases with higher irrigation levels (50% ETc < 75% ETc < 100% ETc). This aligns with the findings of Kumar et al. [32], who observed that water stress negatively impacts onion growth parameters, including leaf development. The 100% ETc treatments, especially with manure, show the steepest growth curves, indicating that full irrigation promotes optimal leaf production. At each irrigation level, treatments with manure application consistently outperform those without manure in terms of leaf number, particularly in the later weeks. This supports the observations of Mandoli et al. [48], who reported that growth traits such as number of leaves were significantly higher with organic manure application. The positive effect of manure becomes more pronounced as the growing period progresses. The reduction in leaf number was more pronounced under deficit irrigation without manure. This suggests that manure application can help maintain leaf production under water stress, which is crucial for photosynthetic capacity and overall plant productivity. Figure 3 clearly demonstrates that manure application mitigates some of the negative impacts of deficit irrigation on leaf production. For instance, by week 6, the 75% ETc with manure treatment achieves similar leaf numbers to the 100% ETc without manure treatment. This interaction suggests that manure application can partially offset the effects of water stress on onion leaf development, likely due to improved soil water retention and nutrient availability [56]. All treatments show a general trend of increasing leaf numbers over time, but with varying rates. The steepest growth curve is observed for the 100% ETc with manure treatment, while the flattest curves are seen for the 50% ETc and 75% ETc without manure treatments. This illustrates how both water and nutrient availability affect the rate of leaf production, which is crucial for photosynthetic capacity and overall plant productivity. The differences between treatments become more pronounced as time progresses, particularly after week 3. This suggests that the cumulative effects of irrigation and manure treatments on leaf development increase over the growing period, as noted by Jayathilake et al. [44] in their study on organic manure effects on onion growth. Figure 3 suggests that in water-limited conditions, applying manure could be an effective strategy to maintain reasonable leaf production.

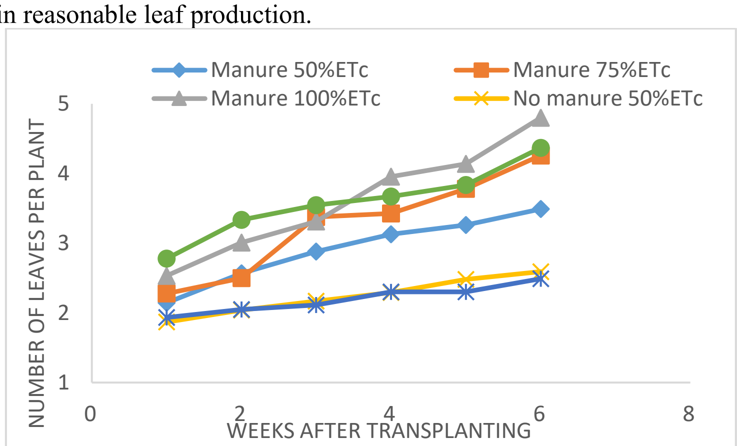

Figure 3. Interactive effect of deficit irrigation and manure on number of leaves of onion

CONCLUSIONS

Farmers in water-scarce regions should consider adopting deficit irrigation strategies combined with manure application to improve water use efficiency in onion production. This study demonstrated that combining deficit irrigation with manure application can significantly improve onion growth, yield and water use efficiency compared to deficit irrigation alone. While full irrigation (100% ETc) with manure produced the highest yields, moderate deficit irrigation (75% ETc) with manure maintained acceptable yields while improving water productivity. The 50% ETc treatment with manure achieved the highest water use efficiency, suggesting potential for water savings in water-scarce regions. Manure application also helped maintain nutrient content in onion bulbs under deficit irrigation. Hence authors recommend that manure application should be promoted as a complementary practice to deficit irrigation, as it helps mitigate the negative impacts of water stress on crop growth and nutrient uptake. These findings provide valuable insights for developing sustainable irrigation and fertilization strategies to optimize onion production under water-limited conditions. However, further research is needed to refine recommendations for different environments and assess long-term impacts on soil health and crop productivity.

REFERENCES

[1] Zhang, D., Sial, M. S., Ahmad, N., Filipe, A. J., Thu, P. A., Zia-Ud-Din, M., & Caleiro, A. B. 2020. Water Scarcity and Sustainability in an Emerging Economy: A Management Perspective for Future. Sustainability, 13(1), p.144. https://doi.org/10.3390/su13010144

[2] Tzanakakis, V. A., Paranychianakis, N. V., & Angelakis, A. N. 2020. Water Supply and Water Scarcity. Water, 12(9), p. 2347. https://doi.org/10.3390/w12092347

[3] FAO. 2023. Water Use in Agriculture. Food and Agriculture Organization of the U.N.

[4] Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. 2010. Groundwater use for irrigation – a global inventory. Hydrology and Earth System Sciences, 14(10), pp.1863–1880. https://doi.org/10.5194/hess-14-1863-2010.

[5] IPCC. (2022). Climate Change 2022. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

[6] Liu, X., Liu, W., Tang, Q., Liu, B.,Wada, Y., & Yang, H. 2022. Global agricultural water scarcity assessment incorporating blue and green water availability under future climate change. Earth's Future, 10, e2021EF002567. https://doi.org/10.1029/2021EF002567

[7] Boretti, A., Rosa, L. Reassessing the projections of the World Water Development Report. npj Clean Water 2, 15. 2019. https://doi.org/10.1038/s41545-019-0039-9.

[8] Iglesias, A., & Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. Agricultural Water Management, 155, pp.113–124. https://doi.org/10.1016/j.agwat.2015.03.014.

[9] UN Water. 2023. The United Nations World Water Development Report 2023: Accelerating Change. UNESCO.

[10] Bolan, S., Padhye, L.P., Jasemizad, T., Govarthanan, M., Karmegam, N., Wijesekara, H., Amarasiri, D., Hou, D., Zhou, P., Biswal, B.K., Balasubramanian, R., Wang, H., Siddique, K. H.M., Rinklebe, J., Kirkham, M. B., Bolan, N. 2024. Impacts of climate change on the fate of contaminants through extreme weather events. Science of The Total Environment, 909, 2024, 168388.

[11] Caretta, M.A., A. Mukherji, M. Arfanuzzaman, R.A. Betts, A. Gelfan, Y. Hirabayashi, T.K. Lissner, J. Liu, E. Lopez Gunn, R. Morgan, S. Mwanga, and S. Supratid, 2022. Water. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp.551–712, https://doi.org/10.1017/9781009325844.006.

[12] Rijsberman, F. R. 2006. Water scarcity: Fact or fiction? Agricultural Water Management, 80(1-3), pp.5–22. https://doi.org/10.1016/j.agwat.2005.07.

[13] Selie A.H. 2022. The Essentials of Deficit Irrigation for Crop and Water Productivity in Ethiopia: A Review, European J. of Agriculture and Forestry Research, 10 (3) pp. 23-34.

[14] Geerts, S., & Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural Water Management, 96(9), pp.1275-1284. https://doi.org/10.1016/j.agwat.2009.04.009

[15] Costa, J. M., Ortuño, M. F., & Chaves, M. M. 2007. Deficit Irrigation as a Strategy to Save Water: Physiology and Potential Application to Horticulture. Journal of Integrative Plant Biology, 49(10), 1421–1434. https://doi.org/10.1111/j.1672-9072.2007.00556.x

[16] Fereres, E., & Soriano, M. A. 2007. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany, 58(2), pp.147–159. http://dx.doi.org/10.1093/jxb/erl165.

[17] Li, M., Zhang, Y., Ma, C., Sun, H., Ren, W., Wang, X. 2023. Maximizing the water productivity and economic returns of alfalfa by deficit irrigation in China: A meta analysis. Agricultural Water Management, 287, 108454. https://doi.org/10.1016/j.agwat.2023.108454.

[18] Mubarak, I. & Hamdan, A. 2018. Onion crop response to regulated deficit irrigation under mulching in Dry Mediterranean Region. Journal of Horticultural Research, 26(1): 87–94 https://doi.org/10.2478/johr-2018-0010.

[19] Chand, J. B., Hewa, G., Hassanli, A., & Myers, B. 2021. Deficit Irrigation on Tomato Production in a Greenhouse Environment: A Review. Journal of Irrigation and Drainage Engineering, 147(2), 04020041. https://doi.org/10.1061/(asce)ir.1943-4774.0001529.

[20] Darko, R.O., Yuan, S., Kumi, F., Quaye, F. 2019. Effect of deficit irrigation on yield and quality of Eggplant. International Journal of Environment, Agriculture and Biotechnology, 4(5). pp.1325-1333.

[21] Chai, Q., Gan, Y., Zhao, C., Xu, H.-L., Waskom, R. M., Niu, Y., & Siddique, K. H. M. 2015. Regulated deficit irrigation for crop production under drought stress. A review. Agronomy for Sustainable Development, 36(1). https://doi.org/10.1007/s13593-015-0338-6.

[22] Owusu-Sekyere, J. D., & Annan, E. 2010. Effect of deficit irrigation on growth and yield of okro (abelmoscus esculentus). Journal of Science and Technology, 30(2), pp.128-134.

[23] Abdelkhalik, A., Pascual, B., Nájera, I., Domene, M. A., Baixauli, C., & Pascual-Seva, N. 2019. Effects of deficit irrigation on the yield and irrigation water use efficiency of drip-irrigated sweet pepper (Capsicum annuum L.) under Mediterranean conditions. Irrigation Science. https://doi.org/10.1007/s00271-019-00655-1.

[24] Yang, B., Fu, P., Lu, J. et al. 2022. Regulated deficit irrigation: an effective way to solve the shortage of agricultural water for horticulture. Stress Biology 2, p.28. 2022. https://doi.org/10.1007/s44154-022-00050-5.

[25] Sam-Amoah, L.K., Willie, W.K.T., & Owusu-Sekyere, J.D. 2016. Effects of Deficit Irrigation and Chicken Manure Interactions on the Growth and Yield of Okra in a Pot Experiment. Asian Journal of Agricultural Research, 10 (1), pp.47-55. https://doi.org/10.3923/ajar.2016.47.55

[26] Diacono, M., & Montemurro, F. 2011. Long-Term Effects of Organic Amendments on Soil Fertility. Sustainable Agriculture Volume 2, pp.761–786. http://dx.doi.org/10.1007/978-94-007-0394-0_34

[27] Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., de Goede, R., … Brussaard, L. 2018. Soil quality – A critical review. Soil Biology and Biochemistry, 120, 105–125. https://doi.org/10.1016/j.soilbio.2018.01.030.

[28] Ding, Y., Liu, Y., Liu, S., Li, Z., Tan, X., Huang, X., … Zheng, B. (2016). Biochar to improve soil fertility. A review. Agronomy for Sustainable Development, 36(2),36 http://dx.doi.org/10.1007/s13593-016-0372-z.

[29] Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677), 1623-1627. http://dx.doi.org/10.1126/science.1097396.

[30] Brewster, J. L. 2015. Onions and other vegetable alliums (2nd ed.). CAB

[31] FAO. 2022. FAOSTAT Statistical Database. Food and Agr. Org. of the United Nations

[32] Kumar, S., Imtiyaz, M., Kumar, A., & Singh, R. 2007. Response of onion (*Allium cepa L.*) to different levels of irrigation water. Agricultural Water Management, 89(1-2), pp.161-166. http://dx.doi.org/10.1016/j.agwat.2007.01.003.

[33] Ghazouani, H.; Rallo, G.; Mguidiche, A.; Latrech, B.; Douh, B.; Boujelben, A.; Provenzano, G. 2019. Effects of Saline and Deficit Irrigation on Soil-Plant Water Status and Potato Crop Yield under the Semiarid Climate of Tunisia. Sustainability 2019, 11, 2706. https://doi.org/10.3390/su11092706.

[34] El-Ghamrya, A. E., Ghazia, D.A., El-Sherpinyb, M.A., Kassema, M.A, Kassemb, A.A., & Helmya. A.A. 2024. Enhancing onion growth and yield quality via soil amendments and foliar nutrition under deficit irrigation. Egypt. J. Soil Sci., 64 (2), pp.523 – 542.

[35] Lee, J. 2010. Effect of application methods of organic fertilizer on growth, soil chemical properties and microbial densities in organic bulb onion production. Scientia Horticulturae, 124(3), 299–305. https://doi.org/10.1016/j.scienta.2010.01.004.

[36] Showler, A.T. 2022. Effects of compost on onion quality, yield, and thrips infestation. Environ Syst Res 11, 22. https://doi.org/10.1186/s40068-022-00268-2.

[37] Naghman, R., Bhatti, M. T., Najabat, Z., Hyder, S., Rizvi, Z. F., Gondal, A. S., Zafar, Z., Malik, S., Iqbal, R., Hafeez, A., Ali, B., & Marc, R. A. 2023. Organic amendments: A natural way to suppress phytopathogens: a sustainable approach to go green. Turkish Journal of Agriculture and Forestry. 47(5), 2. https://doi.org/10.55730/1300-011X.3113.

[38] Khaitov, B., Yun, H.J., Lee, Y., Ruziev, F., Le, T.H., Umurzokov, M., Bo Bo, A., Cho, K.M., Park, K.W. 2019. Impact of Organic Manure on Growth, Nutrient Content and Yield of Chilli Pepper under Various Temperature Environments. Int J Environ Res Public Health,16(17), p. 3031. https://doi.org/10.3390/ijerph16173031.

[39] Urra, J.; Alkorta, I.; Garbisu, C. 2019. Potential Benefits and Risks for Soil Health Derived From the Use of Organic Amendments in Agriculture. Agronomy 2019, 9, p.542. https://doi.org/10.3390/agronomy9090542.

[40] Scavo, A., Fontanazza, S., Restuccia, A. et al. 2022. The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. Agron. Sustain. Dev. 42, p.93. https://doi.org/10.1007/s13593-022-00825-0.

[41] Reeve, J. R., Hoagland, L. A., Villalba, J. J., Carr, P. M., Atucha, A., Cambardella, C., Davis D.R. & Delate, K. 2015. Organic farming, soil health, and food quality: Considering possible links. Advances in Agronomy, 137, pp. 319-367. http://dx.doi.org/10.1016/bs.agron.2015.12.003.

[42] Nandle, N., Sharma, R. K., Kushwah, S. S., & Gallani, R. 2018. Effect of Irrigation Regimes and Varieties on Growth, Bulb Yield and Quality of Onion (*Allium cepa L.*). Int. J. Curr. Microbiol. App. Sci, 7(5), pp.1104-1111. https://doi.org/10.20546/ijcmas.2018.705.135.

[43] Pejić, B., Gvozdanović-Varga, J., Milić, S., Ignjatović, Ćupina, A., Krstić, D., & Ćupina, B. 2011. Effect of irrigation schedules on yield and water use of onion (*Allium cepa L.*). African Journal of Biotechnology, 10(14), pp.2644-2652.

[44] Jayathilake, P.K.S., Reddy, I.P., Srihary, D., Reddy, K.R., Neeraja, G., (2003). Integrated nutrient management in onion (Allium cepa L.). Trop. Agric. Res., 15: 19.

[45] Mohanty, A., Behera, P., Harichandan, S. 2024. Effect of nutrient management on the growth and productivity of onion. Agricultural Science Digest. 35(3), pp.241-243. https://doi.org/10.5958/0976-0547.2015.00056.7.

[46] Shock, C. C., Feibert, E. B. G., & Saunders, L. D. 2000. Irrigation criteria for drip-irrigated onions. HortScience, 38(6), pp.1188-1191.

[47] Dhaker, B., Sharma, R.K., Chhipa, B.G., Rathore, R.S. 2017. Effect of different organic manures on yield and quality of onion (Allium cepa L.). International Journal of Current Microbiology and Applied Sciences. 6(11), pp. 3412-3417. http://dx.doi.org/10.20546/ijcmas.2017.611.400.

[48] Mandoli, K.S., Bose, U.S., Deshmukh, K.S. 2008. Effect of organic manures and inorganic fertilizers on growth and yield of onion (*Allium cepa L.*) The Asian Journal of Horticulture. 3(2), pp.238-240.

[49] Zhang, H., & Oweis, T. 1999. Water–yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agricultural Water Management, 38(3), pp.195-211. http://dx.doi.org/10.1016/S0378-3774(98)00069-9

[50] Yavitt, J.B., Pipes, G.T., Olmos, E.C., Zhang, J., Shapleigh, J.P. 2021. Soil organic matter, soil structure, and bacterial community structure in a post-agricultural landscape. Front. Earth Sci. 9, 1–15. https://doi.org/10.3389/feart.2021.590103

[51] Nath, T.N. 2014. Soil texture and total organic matter content and its influences on soil water holding capacity of some selected tea growing soils in Sivasagar district of Assam, India. International Journal of Chemical Sciences. 12(4), pp.1419–1429.

[52] Gnanasundari, K., Srivignesh, S., Rama Krishna, K., pelte, M., Kumar, A.R. 2022. Integrated nutrient management in onion-a review. Ecology Environment & Conservation, 28 (November Suppl. Issue), S182-S192.http://doi.org/10.53550/EEC.2022. v28i07s.030

[53] Khan, F., Siddique, A.B., Shabala, S., Zhou, M., Zhao, C. 2023. Phosphorus Plays Key Roles in Regulating Plants' Physiological Responses to Abiotic Stresses. Plants (Basel). 12(15): p.2861. http://doi.org/10.3390/plants12152861.

[54] Malhotra, H., Vandana, Sharma, S., & Pandey, R. (2018). Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. Plant Nutrients and Abiotic Stress Tolerance, pp.171–190. http://doi.org/10.1007/978-981-10-9044-8_7.

[55] Abdelrasheed, K.G.; Mazrou, Y.; Omara, A.E.-D.; Osman, H.S.; Nehela, Y.; Hafez, E.M.; Rady, A.M.S.; El-Moneim, D.A.; Alowaiesh, B.F.; Gowayed, S.M. 2021. Soil Amendment Using Biochar and Application of K-Humate Enhance the Growth, Productivity, and Nutritional Value of Onion (*Allium cepa L.*) under Deficit Irrigation Conditions. Plants 2021, 10, p. 2598. https://doi.org/10.3390/plants10122598.

[56] Pelter, G. Q., Mittelstadt, R., Leib, B. G., & Redulla, C.A. 2004. Effects of water stress at specific growth stages on onion bulb yield and quality. Agricultural Water Management, 68(2), pp.107–115.

EFEKTI DEFICITARNOG NAVODNJAVANJA I PRIMENE STAJNJAKA NA RAST, PRINOS I EFIKASNOST KORIŠĆENJA VODE KOD LUKA (*Allium cepa L.)*

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Apstrakt. Povećanjem opštih i industrijskih potreba za vodom, izdvajanja vode za poljoprivredu se stalno smanjuju. Navodnjavanje u poljoprivredi, kako sada, tako i u budućnosti, biće potrebno u područjima sa ograničenim vodnim resursima.

Nedovoljno (deficitarno) snabdevanje vodom za navodnjavanje, postaće pre norma nego izuzetak. Upravljanje navodnjavanjem, mora imati prelaz sa davanja prioriteta proizvodnje po jedinici površine, na optimizaciju proizvodnje po jedinici potrošene vode.

Da bi se suočili sa ograničenim resursima, deficit navodnjavanja je integralna strategija za minimiziranje potrošnje vode za navodnjavanje.

U ovoj studiji, procenjeni su rast, prinos, efikasnost korišćenja vode i nutritivni sadržaj luka (*Allium cepa L.*), kao i interakcijski efekti navodnjavanja, deficita i tretmana sa stajnjakom na navedene faktore.

Istraživanje je sprovedeno korišćenjem faktorskog dizajna koji je raspoređen u podeljene dijagrame, i uključuje tri ponavljanja iz svake grupe. Tretmani se sastoje od tri nivoa navodnjavanja (ETc 100%; ETc 75% i ETc 50%) i dva nivoa primene stajnjaka (sa i bez primene).

U poređenju sa samo deficitarnim navodnjavanjem, rezultati su pokazali da je kombinacija deficitarnog navodnjavanja sa primenom stajnjaka rezultirala značajnim povećanjem visine biljke, prečnika stabljike, broja listova, težine lukovice, prečnika lukovice i sadržaja hranljivih materija. Tretman stajnjakom i 50% ETc imao je najveću efikasnost korišćenja vode od svih tretmana. U uslovima kada postoji ograničena zaliha vode, studija pokazuje da kombinacija deficitarnog navodnjavanja i upotrebe stajnjaka može poboljšati prinos luka.

Ključne reči: Luk (*Allium cepa L.*), deficitarno navodnjavanje, stajnjak, efikasnost korišćenja vode, prinos, sadržaj hranljivih materija

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ODREĐIVANJE ČVRSTOĆE PLODA U PROCENI ZRELOSTI VOĆA

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Sažetak: Određivanje zrelosti plodova i vremena berbe voća je jedan od činilaca od kojeg zavisi kvalitet i uspešnost berbe. U radu su prikazane mehaničke, senzorne i metode za utvrđivanje stepena zrelosti voća na osnovu čvrstoće plodova. Za potrebe istraživanja korišćen je uređaj sa aplikacijom za utvrđivanje čvrstoće voća direktnom metodom probijanja ploda. U proizvodnim zasadima voća u okolini Čačka (R.Srbija), ubrani su uzorci za ispitivanje čvrstoće plodova višnje (Cigančica), šljive (Čačanska rodna) i borovnice (Duke). Metodom probijanja površine ploda utvrđeno je da je najveću prosečnu čvrstoću ploda imala šljiva 11,74 N, zatim višnja 2,32 N i najmanju brovnica 1,23 N. Granične vrednosti čvrstoće ploda šljive su značajno veće u odnosu na čvrstoću višnje i borovnice, sa vrednostima od minimalnih 7,68 N do maksimalnih vrednosti od 14,92 N. Vrednosti čvrstoće ploda višnje bile su u rasponu od 1,69 N do 2,94 N, a čvrstoća ploda borovnice bila je niža i kretala se u granicama od 0,95 N do 1,56 N.

Prema istraživanju Autora o klasiranju voća, a na osnovu izmerenih rezultata graničnih vrednosti čvrstoće plodova utvrđene metodom probijanja, plodovi šljive, višnje i borovnice po stepenu zrelosti su klasirani u kategoriju mekih plodova.

Ovi rezultati graničnih vrednosti sile probijanja plodova mogu se koristiti za određivanje stepena zrelost voća. Ujedno bi se vršila i klasifikacija voća po čvrstoći plodova u kategorije koje bi mogle biti u upotrebi kao prihvaćeni univerzalni standard. Takođe dobijeni rezultati mogu se koristiti pri predviđanju dužine trajanja transporta i skladištenja voća, a mogu imati primenu pri projektovanju mašina za ubiranje, transportovanje, klasiranje i preradu voća, a sve u cilju smanjenja gubitaka u toku i posle berbe.

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Ključne reči: *zrelost plodova, metode za određivanje čvrstoće voća, sila probijanja ploda, borovnica, višnja, šljiva*

UVOD

Jedna od najvažnijih agrotehničkih mera u proizvodnji voća je određivanje vremena berbe plodova, jer od toga zavisi kvalitet, dužina transporta, čuvanja i trajanja plodova. U širokoj proizvodnoj praksi vreme berbe voća namenjeno tržištu se najčešće određuje na osnovu boje pokožice, a plod je zreo kada je cela površina pokožice potpuno iste boje. Vreme berbe i zrelost voća, određena na osnovu indeksa boje ploda, nije dovoljno pouzdana metoda, jer plodovi na istoj grani stabla i sličnom bojom mogu se razlikovati po fiziološkoj zrelosti i kvalitetu. Berač tokom berbe ne može da uoči razliku u boji između plodova, i bere nedovoljno zrele plodove. Već više decenija u upotrebi su različiti instrumenti i metode za brzo i precizno utvrđivanje vremena i početka berbe.

Nažalost, i pored velikog angažovanja naučnika, stručnjaka, komercijalista, menadžera, potrošača, još uvek ne postoji usvojen jedinstven metod za ocenjivanje kvaliteta voća na osnovu čvrstoće ploda. Potrebno je odabrati metodu za utvrđivanje vremena berbe ploda, na osnovu koje će se najbrže i najbolje proceniti kvalitet voća, kako bi se zadovoljili ukusi potrošača i potrebe naučnih radnika istraživača.

U radu su opisane metode za utvrđivanje vremena berbe i zrelosti voća na osnovu čvrstoće plodova koje su do sada primenjivane u praksi i nauci. Ukazano je i na projektovanje i primenu merno akvizicionog uređaja za utvrđivanje graničnih vrednosti čvrstoće voća (višnje, borovnice i šljive) na osnovu testa probijanja plodova.

METODE ZA ISPITIVANJE ČVRSTOĆE PLODA

U naučnim i stručnim istraživanjima poznato je nekoliko mehaničkih metoda za utvrđivanje kvaliteta i zrelosti voća na osnovu čvrstoće ploda, od najednostavnije senzorne metode gnječenja plodova između prstiju, do softerskih mehaničkih metoda kompresije i probijanja, gde se koriste najsavremeniji instrumenti i oprema za testiranje. U zavisnosti od raspoložive opreme i pribora, same težine i vremena izvođenja testa i analize rezultata, zavisi koja će se metoda za utvrđivanje čvrstoće ploda primeniti u praksi i u naučnim istraživanjima.

Ocenjivanje zrelosti i kvaliteta voća na osnovu čvrstoće ploda određuje se primenom: subjektivnih senzornih i instrumentalnih mehaničkih metoda.

Senzorne metode za određivanje čvrstoće voća

U upotrebi su dve senzorne metode pomoću kojih se zrelost i kvalitet voća određuje i to: na osnovu osećaja u ustima žvakanjem ploda i na osnovu dodira prstiju ruke. Ocena kvaliteta voća na osnovu dodira prstiju ruke obavlja se nežnim stiskanjem ili kotrljanjem ploda između kažiprsta i palca. Na osnovu osećaja dodira i inteniziteta pritiskanja prstima, subjektivno se procenjuje čvrstoća i rangiranje plodova voća.

Autori [1,2] su ovom metodom pritiskanjem ploda između palca i kažiprsta, i intenziteta otpora koji pruža plod određivali čvrstoću ploda borovnice.

Prema čvrstoći plod je rangiran u kategoriji od najmekšeg – mekog; do najčvršćeg - čvrstog. Ova senzorna metoda se najviše koristi u komercijalne svrhe, gde se brzo, jednostavno i jeftino određuje kvalitet na terenu gde nema instrumenata za merenje čvrstoće ploda. Zbog jednostavnog utvrđivanja zrelosti ploda i kvaliteta, koji zadovoljava ukuse potrošača, metoda dodira prstiju ima širu primenu u snabdevanju tržišta svežim voćem.

Senzornu ocenu zrelosti i kvaliteta voća na osnovu osećaja ukusa u ustima tokom žvakanja poloda izvodi veći broj ocenjivača, predhodno obučenih ili neobučenih. Ocenjivanje kvaliteta i zrelosti voća vrši se na osnovu navedenih parametara:

- Čvrstoće voća i sile potrebne da zubima odgrizu i usitne mezokar ploda (od mekog do čvrstog);
- Hrskavosti i jačine zvuka prilikom odgrizanja i žvakanja ploda (kašasta do hrskava ili kruta);
- Sočnosti i količine soka koja se odvaja u ustima prilikom žvakanja (nije sočno do sočno sa sokom);
- Zrnastosti kamenih ćelija ili semena (bez zrnastosti - glatko do zrnasto);
- Osećaja brašnjavosti i suvoće u ustima (brašnjavo i nije brašnjavo);
- Čvrstoće i količine pokožice preostale u toku žvakanja (nežna i tvrda pokožica);
- Ukusa teksture mezokarpa (ocenjivanje na skali).

Prema navedenim autorima [1,3,4], ocenjene karakteristike voća dobijene metodom osećaja u ustima boduju se na osnovu doživljenih subjektivnih osećaja u toku različitih faza procesa žvakanja pri konzumiranju plodova na skali od 0 do 10 ili od 0 do 100.

Senzorne metode ocene kvaliteta voća su direktne metode, ali mogu biti neprecizne i nepouzdane, jer se zasnivaju na subjektivnom osećaju i zavise od obučenosti i iskustva ocenjivača.

Instrumentalne mehaničke metode za merenje čvrstoće voća

Prema dosadašnjim istraživanjima, za određivanja zrelosti i kvaliteta voća merenjem čvrstoće ploda najviše je korišćen metod kompresije, zatim metod probijanja, a najmanje metod udara i smicanja. Merenje čvrstoće plodova navedenim metodama (testovima) vrši se sa odgovarajućim priborom (penetrometrom), instrumentima i uređajima koji su dosta skupi.

Metod kompresije

Ispitivanje čvrstoće voća metodom kompresije, sastoji se u tome, da se sondom poznatih dimenzija, deluje normalno u odnosu na peteljku i čašicu ploda, to jest na ekvatorijalnu ravan ploda. U istraživanjima mehaničkih osobina kvaliteta voća primenom testa kompresije najviše je ispitivana maksimalna sila deformacije i čvrstoća ploda, a manje granica elastičnosti. Tokom testiranja, snimaju se deformacije nastale na plodu i beleže podaci o maksimalnoj sili deformacije pucanja i čvrstoće ploda trešnje i višnje [5] i borovnice [1,3,4].

Nedostatak metoda kompresije je u tome što je razarajući, pa prilikom merenja čvrstoće voća dolazi do delimične ili do potpune deformacije, narušavanja i oštećenja strukture ploda, i nemogućnosti praćenja promene kvaliteta istog ploda u toku skladištenja i čuvanja posle berbe.

Za ocenjivanje kvaliteta voća merenjem maksimalne čvrstoće, sile pucanja i gnječenja ploda koriste se ravne pločaste sonde prečnika od 15-75 mm ili cilindrične sonde prečnika 20-40 mm. Male cilindrične sonde su manjeg prečnika imaju manju kontaktnu površinu sa plodom u odnosu na pločaste sonde. Zbog toga se u toku merenja sa cilindričnim sondama dobijaju niže vrednosti sile probijanja u odnosu na izmerene vrednosti sile kompresije sa pločastim sondama na istim plodovima.

Metod probijanja

Utvrđivanje vrednosti čvrstoće plodova sa mekim mezokarpom obavlja se metodom probijanja, primenom penetrometra kod kojih se sondom prvo probije pokožica, a zatim prodre u mezokarp. Ovaj metod je korišćen za utvrđivanje kvaliteta grožđa [6], maline [7], borovnice [1,2,3,4], šljive [8,9,10,12,13], višnje [5], trešnje [14,15] i plodova drugog voća.

Određivanje čvrstoće plodova metodom probijanja vrši se instrumentima i uređajima, gde se za merenje maksimalne sile probijanja pokožice i mezokarpa koriste cilindrično igličaste sonde prečnika od 2 mm do 6 mm sa izoštrenim ili ravnim vrhom..

Merenje zrelosti i kvaliteta voća na osnovu čvrstoće ploda primenom instrumentalnih metoda je pouzdanije od drugih metoda, jer su dobijeni rezultati konkretni, tačni, precizni i provereni.

Svakako je interes proizvođača voća, trgovaca, menadžera, izvoznika i potrošača da imaju objektivnu i pouzdanu instrumentalnu metodu za određivanje zrelosti i kvaliteta voća na osnovu čvrstoće ploda.

MATERIJAL I METOD RADA

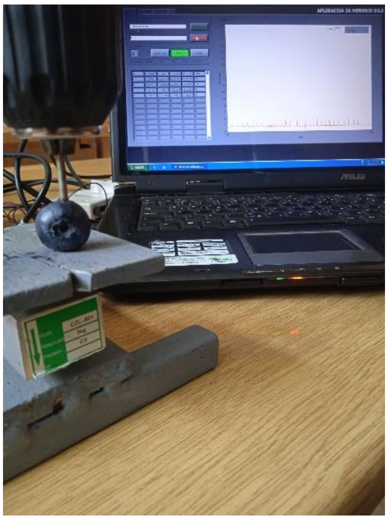
U proizvodnim zasadima u okolini Čačka odabrana su stabla voća i ubrani plodovi višnje (Cigančica), šljive (Čačanska rodna) i borovnice (Duke). Ukupno je za analizu čvrstoće ploda na osnovu sile probijanja uzeto po 10 plodova u 3 ponavljanja za svaku voćnu vrstu.

Uređaj za merenje čvrstoće voća primenom direktne metode probijanja ploda konstruisan je u Laboratoriji za mehatroniku Fakulteta tehničkih nauka u Čačku, a primenjen na Agronomskom fakultetu. Pored merenja čvrstoće plodova različitih voćnih vrsta, uređaj se može koristiti za merenje sile pucanja plodova (uljane repice, soje, pasulja, graška, žutog zvezdana i dr.) i čvrstoće ljuske jaja [16, 17,18].

Detaljan opis merno akvizicionog sistema za merenje mehaničkih osobina, pre svega čvrstoće, sile probijanja, kompresije i rezanja plodova prikazan je u radu [19].

Postupak određivanja čvrstoće voća primenom direktne metode probijanja ploda voća vrši se na taj način što se plod postavi na oslonu ploču u horizontalnom položaju (po dužini) upravno na pravac dejstva sile (Slika 1). Sondom od nerđajućeg čelika sa ravnim vrhom prečnika od 2-5 mm vrši se probijanje pokožice i prodiranje u mezokarp ploda, vodeći računa da ne dođe do kontakta sonde i košpice višnje i šljive.

U momentu probijanja pokožice registruje se sila probijanje koja predstavlja maksimalnu čvrstoću, odnosno silu probijanja voća prikazanu u N. Uređaj registruje i prikazuje u Exel tabeli i grafikonu podatke o izmerenim vrednostima maksimalne sile probijanja ploda, (Slika 1). U tabelarnom izveštaju dati su podaci o maksimalnim silama probijanja ploda sa osnovnim statističkim podacima (prosečna vrednost, maksimum, minimum, kojeficijent varijacije, standardna devijacija).



Slika 1. Uređaj za merenje čvrstoće ploda metodom probijanja
Figure 1. Device for measuring fruit firmness using the method of puncture

REZULTATI ISTRAŽIVANJA I DISKUSIJA

Osnovni cilj berbe je da se u optimalnom roku zrelosti uberu zdravi plodovi odgovarajućeg kvaliteta sa najmanje oštećenja, gubitaka, i ekonomski prihvatljive tržišne vrednosti. Jedan od činilaca od koga u mnogome zavisi uspešnost berbe je pravilno određivanje zrelosti plodova i vremena berbe.

Čvrstoća plodova voća borovnice, šljive i višnje je sposobnost ploda da se odupre dejstvu spoljašnih sila koje mogu da oštete i razore pokožicu i mezokarp. Od čvrstoće plodova voća zavisiće dužina čuvanja, transporta i vreme upotrebe voća u svežem stanju.

Prosečna čvrstoća ploda izmerena je silom probijanja i za borovnicu je iznosila 1,23 N, sa variranjem u granicama od 0,95- 1,56 N (Tabela 1, Grafikon 1.)

U poređenju sa sličnim istraživanjima, autori [2] su na kraju berbe borovnice sorte Duke izmerili prosečnu čvrstoću ploda od 1,38 N, što je u opsegu približnih rezultata prikazanih u radu. Minimalne vrednosti sile probijanja borovnice od 0,95 N (Tabela 1), se podudaraju sa vrednostima 1,00 N koje navode [4]. U istraživanjima autora [3] dobijene vrednosti sile probijanja ploda borovnice sorte Duke su 1,89-2,07 N.

Autori [3,4] su ustanovili odnos između vrednosti čvrstoće borovnice izmerene instrumentalnom metodom sa vrednostima utvrđene senzorskom metodom, pri čemu čvrstoća ploda manja od 1,4 kN/m odgovara bobicama „meke“ kategorije.

Prema graničnim vrednostima čvrstoće ploda koju su utvrdili navedeni autori plodovi borovnice u našim istraživanjima pripadaju kategoriji mekih plodova.

Tabela 1. Prosečna čvrstoća (sila probijanja) plodova šljive, višnje i borovnice

Table 1. Average firmness (puncture force) of plum, sour cherry and blueberry fruits

Sila probijanja Puncture force	Šljiva Plum	Višnja Sour cherry	Borovnica Blueberry
1	7,68	2,94	1,12
2	14,92	1,87	1,01
3	8,89	2,3	0,95
4	10,52	1,69	1,47
5	9,9	2,85	1,33
6	12,63	1,98	1,19
7	12,94	2,21	1,24
8	14,92	2,37	1,17
9	13,69	2,56	1,56
10	11,29	2,44	1,28
Prosečno / Average	11,74	2,32	1,23
Minimum	7,68	1,69	0,95
Maximum	14,92	2,94	1,56
Stand. Dev.	2,49	0,40	0,19
CV (%)	21,24	17,40	15,38

Izmerene vrednosti za čvrstoću ploda šljive sorte Čačanska rodna su se kretale od 7,68-14,92 N (Tabela 1). Do sličnih rezultata došli su i autori [9] pri merenju čvrstoće ploda šljive sorte Stanley od 6,66 N, kao i autori [12] za plod divlje šljive 7,85 N. Rezultati navedenih autora o prosečnoj čvrstoći ploda utvrđene metodom probijanja su manji u odnosu na prosečnu vrednost čvrstoće ploda šljive od 11,74 N u Tabeli 1. Autori [8] su kod sorte šljive Yanzhi, Taoli, Oishiwase, Furong i Jinmi izmerili prosečnu silu probijanja pokožice ploda nižu od 10 N.

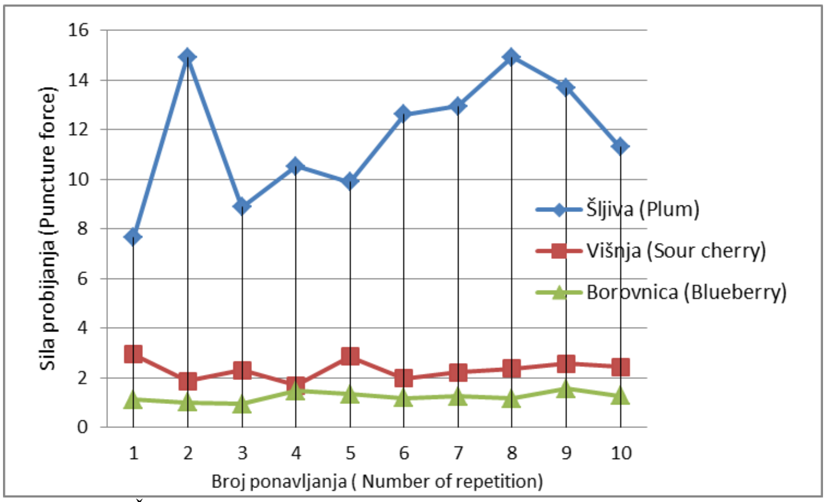
Prosečno izmerena sila probijanja u radu je približna čvrstoći ploda od 10,94 N kod sorte šljive Frenze 90 [9]. Više srednje vrednosti čvrstoće plodova šljive od navedenih u radu utvrdili su i autori [10] kod sorte Valjevka 16,66 N.

Minimalna vrednost čvrstoće ploda šljive od 7,68 N izmerena u radu je kao i kod sorte Oishiwase 7,34 N [8]**,** viša je od 5,0 N kod ukrasne šljive [13], a niža od 12,7 N od sorte Ruth Gerstetter [10].

Maksimalna čvrstoća ploda šljive prikazana u radu od 14,92 N je manja od vrednosti sile za sorte Santa Rosa 39,16 N [11] i sorte Fengtang (44.89 N), Cuimi (41.50 N) i Dabai (40.50 N) [8].

Na osnovu čvrstoće plodova utvrđene merenjem sile probijanja, autori [8] su po stepenu zrelosti plodove šljive klasirali u tri kategorije: jako tvrde, tvrde i meke.

Prema istraživanjima prikazanim u radu i prosečnim vrednostima čvrstoće ploda, šljive pripadaju kategoriji mekih plodova.



Grafikon 1. Čvrstoća ploda šljive, višnje i borovnice utvrđena metodom probijanja
Chart 1. The firmness of plum, sour cherry and blueberry fruit obtained by the method of puncture

Čvrstoća plodova višnje određena metodom sile probijanja varirala je u granicama od 1,69 do 2,94 N, što su niže vrednosti u odnosu na nemačku sortu višnje od 7,01 N do 16,67 N prema istraživanju [5]. Izmerena prosečna vrednost čvrstoće višnje od 2,32 N (Tabela 1) niža je u odnosu na rezultate od 4,34 N koje su dobili za trešnju sorte Regina autori [15] i za sorte Fabiola 8,25 N, Kordia 8,29 N i Jacinta 4,26 N [14].

Rezultati čvrstoće plodova borovnice, šljive i višnje prikazani u Tabeli 1 i Grafikonu 1, razlikuju se od istraživanja drugih autora, zbog agroekoloških uslova gajenja voća, primenjenih agrotehničkih mera, perioda sazrevanja plodova, vremena berbe, različitih sorti, upotrebne namene voća i same metodike ispitivanja.

ZAKLJUČAK

U proizvodnoj praksi se za određivanje zrelosti voća na osnovu čvrstoće ploda koristi više metoda od kojih su u radu opisane: senzorne (metoda valjanja plodova između prstiju ruke i na osnovu osećaja u ustima žvakanjem ploda) i instrumentalne mehaničke metode (metoda kompresije i metoda probijanja plodova). U radu je za određivanje zrelosti šljive, borovnice i višnje na osnovu čvrstoće voća primenjena metoda probijanja ploda.

Iako je u nauci i praksi poznat veliki broj različitih metoda za merenje zrelosti voća na osnovu čvrstoće ploda, ipak još uvek ne postoji jedinstvena standardna metoda koja je opšte prihvaćena. U praksi se za utvrđivanja zrelosti voća na osnovu čvrstoće ploda, najviše koristi metoda probijanja, jer je jednostavna, precizna i brža u odnosu na druge.

Čvrstoća voća utvrđena metodom probijanja plodova kod šljive imala je najveće vrednosti sile probijanja i varirala je u rasponu 7,68 N od 11,74 N, zatim višnje od 1,69 N do 2,94 N i kod borovnice od 0,95 N do 1,56 N.

Na osnovu graničnih vrednosti čvrstoće šljive, višnje i borovnice plodovi su prema stepenu zrelosti klasifikovani u meke plodove. Utvrđene granične vrednosti sile probijanja plodova mogu se koristiti za određivanje stepena zrelosti i klasiranje plodova po čvrstoći voća u 3 standardne kategorije, dobijene na osnovu poređenja senzornih i instrumentalnih metoda, a prema predlogu navedenih autora.

Poznavanje vrednosti čvrstoće ploda pored određivanja zrelosti i kvaliteta plodova, mogu se primeniti u predviđanju dužine trajanja, transporta i čuvanja voća, kao i projektovanju mašina za ubiranje, transportovanje, klasiranje i preradu. Pri tome bi se smanjili gubici voća u toku i posle berbe kao i tokom skladištenja.

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LITERATURA

[1] Rivera, S., Giongo, L., Cappai, F., Kerckhoffs, H., Sofkova-Bobcheva, S., Hutchins, D., East, A. 2022. Blueberry firmness-A review of the textural and mechanical properties used in quality evaluations. *Postharvest Biology and Technology*, *192*, 112016. https://doi.org/10.1016/j.postharvbio.2022.112016

[2] Moggia, C., Graell, J., Lara, I., Schmeda-Hirschmann, G., Thomas-Valdes, S., Lobos, G.A. 2016. Fruit characteristics and cuticle triterpenes as related to postharvest quality of highbush blueberries. *Scientia Horticulturae*, 211, pp. 449–457. https://doi.org/10.1016/j.scienta.2016.09.018

[3] Lobos, G.A., Bravo, C., Valdes, M., Graell, J., Ayala, I.L., Beaudry, R.M., Moggia, C., 2018. Within-plant variability in blueberry (*Vaccinium corymbosum* L): maturity at harvest and position within the canopy influence fruit firmness at harvest and postharvest. *Postharvest Biology and Technology*, 146, 26–35. https://doi.org/10.1016/j.postharvbio.2021.111815

[4] Blaker, K. M., Plotto, A., Baldwin, E. A., Olmstead, J. W. 2014. Correlation between sensory and instrumental measurements of standard and crisp-texture southern highbush blueberries (*Vaccinium corymbosum L. interspecific hybrids*). *Journal of the Science of Food and Agriculture*, *94*(13), pp.2785–2793.

[5] Sharoba, A. M., Bahlol, H., El-Mansy, H. A., Senge, B. 2005. Effect of varieties, heat treatment and storage at different conditions on mechanical properties of cherry fruits. In *3rd International Conference for Food Science and Technology "Modernizing Food Food Science and Technology "Modernizing Food Industries" February*. pp. 22–24.

[6] Letaief, H., Rolle, L., Gerbi, V., 2008. Mechanical behavior of winegrapes under compression tests. *American Journal of Enology and Viticulture*, 59, pp.323–329. https://www.ajevonline.org/content/59/3/323.article-info

[7] Giongo, L., Ajelli, M., Poncetta, P., Ramos-Garcia, M., Sambo, P., Farneti, B., 2019. Raspberry texture mechanical profiling during fruit ripening and storage. *Postharvest Biology and Technology*, 149, 177–186. https://doi.org/10.1016/j.postharvbio.2018.11.021

[8] Qiu, X., Zhang, H., Zhang, H., Duan, C., Xiong, B., & Wang, Z. 2021. Fruit textural characteristics of 23 plum (*Prunus salicina* Lindl) cultivars: Evaluation and cluster analysis. *HortScience*, *56*(7), pp.816–823.

[9] Ertekin, C., Gozlekci, S., Kabas, O., Sonmez, S. A. H. R., Akinci, I. 2006. Some physical, pomological and nutritional properties of two plum (*Prunus domestica* L.) cultivars. *Journal of Food Engineering*, *75*(4), pp.508–514.

[10] Blažek, J., Pištěková, I. 2009. Preliminary Evaluation Results of New Plum Cultivars in a Dense Planting. *Horticultural Science*, *36*(2): pp. 45–54.
[11] Altuntas, E., Yaldiz, M. (2016). Physical, mechanical and chemical properties of plums (cv. Santa Rosa) affected by aminoethoxyvinylglycine applications. *African Journal of Traditional, Complementary and Alternative Medicines*, *13*(1), pp.128–133.
[12] Calisir, S., Haciseferogullari, H., Ozcan, M., Arslan, D. 2005. Some nutritional and technological properties of wild plum fruits in Turkey. *Journal of Food Engineering*, 66, pp.233–237.
[13] Ersoy, H., Altuntaş, E. 2022. Determination of Some Biotechnical Characteristics of Ornamental Plum (*Prunus cerasifera var. atropurpurea*) Fruit. *Eurasian Journal of Agricultural Research*, *6*(2), pp.74–82.
[14] Szpadzik Eva, Krupa Tomasz, Molska-Kawulok Karolina, Przybyłko Sebastian. 2022. Fruit Quality and Contents of Some Bioactive Compounds in Selected Czech Sweet Cherry (*Prunus avium* L.) Cultivars under Conditions of Central Poland. *Agriculture,* 12 (11), pp. 1–18. https://doi.org/10.3390/agriculture12111859.
[15] Göksel, Z., Aksoy, U. (2014). Sofralık bazı kiraz çeşitlerinin fizikokimyasal özellikleri. *Türk Tarım ve Doğa Bilimleri Dergisi*, *1*(Özel Sayı-2), pp.1856–1862.
[16] Koprivica, R., Veljković, B., Rakonjac, S., Božić, M., Vujičić, V., Radivojević, D., Marković, D., Topisirović, G. 2021. Direct methods for determination of the egg shell strength. *Journal of Agricultural Engineering*, *46*(2), 1–10. http://dx.doi.org/10.5937/POLJTEH2102001K
[17] Koprivica, R., Veljkovic, B. 2021. Determination of hen eggshell strength by the puncture method. *Journal on Processing and Energy in Agriculture*, *25*(3), pp.82–85.
[18] Koprivica, R., Rakonjac, S., Veljković, B., Radivojević, D., Petrović, M. D., Petrović, M. Ž., Mladenović, J. 2021. Determination of external, internal and eggshell quality parameters. *Book of Proceedings of the XII International Scientific Agricultural Symposium "Agrosym 2021"*, Kovačević D. (ed), pp.1204-1209. East Sarajevo, Bosnia and Herzegovina: Faculty of Agriculture.
[19] Božić, M., Koprivica, R., Bošković, N., Veljković, B. 2014. Merno akvizicioni sistem za merenje sile otvaranja plodova poljoprivrednih kultura. Traktori i pogonske mašine. 19(4), pp.98–106.

DETERMINATION OF FRUIT FIRMNESS IN ASSESSING THE FRUIT MATURITY

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Abstract: Determining the maturity of the fruits and the time of fruit harvesting is one of the factors on which the quality and success of the harvest depend. The paper presents mechanical sensory and instrumental methods for determining the degree of ripeness of fruit based on the firmness of fruit.

For research purposes, a device with an application was used to determine the firmness of the fruit by direct puncture in the fruit.

In the fruit plantations around Čačak (Republic of Serbia), samples were collected to test the firmness of the fruits of sour cherry (Cigančica), plum (Čačanska rodna) and blueberry (Duke).
The Method of puncture determined that the highest average fruit firmness, 11.74 N was plum, followed by the sour cherry, 2.32 N, and the least blueberry, 1.23 N. Limit values of plum fruit firmness are significantly higher compared to sour cherry and blueberry, with values from a minimum of 7.68 N to a maximum of 14.92 N. Sour cherry fruit firmness values ranged from 1.69 N to 2.94 N, and blueberry fruit firmness was lower and ranged from 0.95 N to 1.56 N.

According to the Author's research on fruit classification, and based on the measured results of the limit values of fruit strength determined by the Method of puncture, plum, sour cherry and blueberry fruits are classified according to the degree of maturity into the category of soft fruits.

These results of the limit values of the puncture force fruit can be used to determine the degree of fruit ripening. At the same time, the classification of fruits according to the firmness of the fruits would be carried out into categories that could be used as an accepted universal standard. Also, these obtained results can be used to predict the duration of transportation and storage. They can also be applied in the design of machines for picking, transporting, classifying and processing fruit, all to reduce losses during and after harvesting.

Keywords: *Fruit maturity, methods for determining fruit firmness, force of puncture fruit, blueberry, sour cherry, plum.*

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DEVELOPMENT AND EVALUATION OF TWO-ROW HAND HELD MANUAL PLANTER FOR BLACK PEPPER SEEDS

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Abstract. The study focused on the development of a portable low-cost planter for black pepper (*Piper nigrum L.*). The physical attributes of Tellicherry black and Malabar black variety of black pepper seed in terms of tri-axial dimensions, angle of repose, roundness and test weight were used to select the design values of individual components of planter. The mean tri-axial dimensions and angle of repose of Tellicherry black pepper and Malabar black ranged as 4.33 – 4.35 mm, 27° and 4.42 – 4.45 mm, 25°, respectively. The roundness was recorded as 1.06 mm – 1.07 mm and 1.04 – 1.14 mm under similar conditions. The test weight of 1000 seeds, used to design the hopper was recorded as 38.6 g and 42.1 grams, respectively.

The black pepper planter (H x h x W x w = 1000 x 920 x 300 x 150 mm) comprised of seed hopper, fulcrum-based seed metering device, handle, adjustable row to row distance and seed tubes. The developed planter was evaluated in terms of seed spacing (15, 20 and 25 cm) and two black pepper varieties (Tellicherry black and Malabar black). The performance parameters of missing percentage, multiple percentage and field capacity (ha h^{-1}) and economic parameters of operating cost, breakeven point, benefit-cost ratio and payback period were recorded.

The optimization of the results through Design-Expert 13.0 revealed 31% missing percentage and 24.6% multiple percentage at 15 cm seed spacing with field capacity of 0.03 ha per hour. The operational cost (Rs h^{-1}), benefit cost ratio, breakeven point (ha) and payback period (hours) was calculated as 84.97, 1.30, 16.36 and 58.85, respectively. The cost of operation of the hand held two row planter was found be Rs. 2832 per hectare.

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Abbreviations:
H = Maximum height, mm
h = Minimum height, mm
W = Maximum width, mm
w = Minimum width, mm

***Keywords**: Planter, pepper, design, portable, performance, spacing, variety, efficiency, breakeven point, payback.*

INTRODUCTION

Piper nigrum (*Black pepper L.*) from family *Piperaceae* is cultivated in the tropical regions of Brazil, Vietnam, Indonesia and India, contributing about 72% of the global production [1]. It possesses rich nutrient composition in terms of 37.4 % carbohydrate, 25.5%, 23.6% fibers and 5.3% fat content [2]. It also contains potassium, calcium, phosphorus and magnesium to the tune of 0.66%, 0.20%, 0.16% and 0.16 percent [3].

The origin of the crop can be traced from the Western Ghats region of India, particularly in the states of Kerala, Tamil Nadu, Karnataka, Konkan, Pondicherry, Andaman and Nicobar Islands. India has the privilege to occupy the top slot in terms of production, consumption and export of black pepper with an annual production of 61000 tons from 1,37,378 hectares from the total global production of 546 million tones [4]. Black pepper has helped India to stay afloat in international trade in terms of export earnings from foreign exchange, thereby, earning the title of 'black gold'. Geographically, it is known as Kali Mirch in Urdu and Hindi; Pippali in Sanskrit; Milagu in Tamil and Peppercorn, White pepper, Green pepper, Black pepper, Madagascar pepper in English. It is widely believed that *Karimunda* is most popular in the series comprising of *Kottanadan*, *Narayakodi*, *Aimperian*, *Neelamundi*, *Kuthiravally*, *Balankotta* and *Kalluvally* from a total of 75 cultivars grown in Indian subcontinent.

Black pepper is perceived as 'king of spices' with broad spectrum of applications in pharmaceuticals, preservative, food industry, perfume enterprises and households [5]. Black pepper contains major pungent alkaloid Piperine (1-peperoyl piperidine) essential in pharmacology and traditional Ayurvedic and Unani System of medicines. Piperine possesses multiple properties like antihypertensive and antiplatelets, antioxidant [6], neurodegeneration [2], anti-bacterial [7], antidiarrheal [8], analgesic [9], anti-depressant [10], insecticidal and larvicidal characteristics [11], anti-fungal [12], anti-protozoal [13] properties.

Piperine enhances the therapeutic efficacy of drugs, vaccines and nutrients by increasing oral bioavailability and inhibiting metabolizing enzymes [14]. It also enhances the cognitive action and fertility among mammals.

The piperine has a stimulating effect on pancreatic and intestinal enzymes responsible for digestion process. Besides that, black pepper is used in flour enhancer [15], herbal medicines, preservative and biocontrol agent [7].

The propagation of black pepper is carried out through pepper cuttings and seeds. The pepper cutting is ready for transplantation in the main field in about 3-4 months. This time creates obstruction in terms of time and land.

On the other hand, the plantation of black pepper seeds is still carried through broadcasting method, which is manifested with high time consumption, uneven seed spacing, exorbitant seed rate and drudgery [16]. The efficiency of the broadcasting method rests exclusively on the skill of the operator. The non-availability of appropriate planter for black pepper has rendered the system unsustainable. This has prompted the farmers to rely extensively on broadcasting method for planting purpose. Moreover, the cultivation of black pepper in polyhouses demand small portable planter.

The designers and researchers have already utilized engineering parameters to design and develop agricultural machinery related to sowing vegetables [17], pea [18], seed metering [19]; extraction chilly [20], maize [21], mixing [22], peeling [23], grading [24], cracking [25] and harvesting [26]. The involvement of the engineering parameters in design has the propensity to develop an efficient machine with drilling mechanism, resulting in uniform seed spacing, proper root growth, better crop management, thereby, reduction in cost of production and increase in crop yield. The uniformity of seed establishment and plant distribution are dependent on the type of planting tools and techniques employed, that have the direct bearing with the crop yield. The importance of hand-held planters has started gaining traction due to the consciousness of conservation agriculture dubbed minimum tillage. This study focused on the design and development of low-cost portable planter for black pepper on the basis of engineering properties of black pepper seeds. It also encompasses the evaluation at field level to ascertain the variation in seed deposition efficiency.

MATERIALS AND METHODS

The development of the individual components of the hand held two row planters demanded the measurement of the physical and engineering properties of the black pepper seeds to arrive at logical conclusion for selecting the design parameters.

Procurement of materials

The black pepper seed varieties (*Tellicherry Black, Malabar Black*) were purchased from the local market and moisture content was determined by gravimetric method. The moisture content was found to be 12 % for both the varieties. The physical and engineering parameters of the two varieties of black pepper (Tellicherry Black, and Malabar Black) essential to select the design values includes:

I. **Size**: The size was represented by tri-axial dimensions, measured using digital Vernier Caliper possessing 0.01 mm accuracy, Fig. 1. It was desired to decide the diameter of the hole in the metering mechanism to accommodate the seeds of different varieties of black pepper.
II. **Angle of repose (**θ): The smooth flow of the seeds from the seed hopper towards the metering mechanism was decided on the basis of angle of repose. The angle of repose was measured by placing the seeds (heap) on the tilting box and raising the platform till the seeds start rolling down.

$$\theta = \tan^{-1}\left[\frac{2\,h}{D}\right]$$

Where,
h = Height of the heap, mm
D = Diameter of plate, mm

III. **Roundness**: The smoothness of the metering hole defines the efficiency of the metering mechanism. The roundness of the seeds was determined by the ratio of the polar diameter to equatorial diameter. The design value for the roughness of the metering hole was decided based on roundness value.

$$\text{Roundness} = \frac{Dp}{De}$$

Where,
D_p = Polar diameter, mm
D_e = Equatorial diameter, mm

IV. **Test weight**: The volume of the seed hopper was determined by measuring the test weight of 1000 seeds on electronic weighting balance with a least count of 0.01 g, Fig. 2. The procedure involves the random selection of 1000 black pepper seeds from Tellicherry Black and Malabar Black variety and placing them on weighing balance at a time. It was imperative to decide the volume of seeds that should be placed in the seed hopper at one time. It helped to decide the live load on the planter during operation.

Conceptualization and development of planter

The planter for black pepper was conceptualized and sketch using Creo 2.0 design software, Fig 3(a). The design values were selected from the measured values. The whole intention was to keep the design simple and provide adjustments to reduce the overall cost of fabrication and allow the farmer to adjust the planter for different varieties with different sowing practices, Fig 3(b). The metering mechanism of the planter was designed separately to allow uniform metering of individual black pepper seeds. The planter comprised of main frame, seed hopper, handle, seed tube, clutch, adjustable handle and width accessories, Fig. 3(c).

The seed metering mechanism consists of a clutch, clutch wire, fulcrum lever, spring and an inward depressed washer. A seed hopper was mounted on top of each vertical pipe along with fulcrum to open or close the metering hole. The opening size of the vertical tube was reduced to accommodate the black pepper seed with the help of washer. The washer allowed only a specific size of the seed to pass through the hole. The movement of the fulcrum up and down was controlled by a wire connected with clutch.

The compression of the clutch generates a pull to lift the fulcrum from the metering hole, allowing the seed to pass from the seed hopper to the metering hole. The loosing of the clutch pulls the fulcrum to the original position with the help of springs and blocks the metering hole. This prevents the movement of the seed from the seed hopper to the seed tube.

Evaluation of the developed prototype

The evaluation of the developed prototype of hand-held tow row planter was carried out to check the efficacy of the seed metering mechanism, uniformity of seed distribution, seed damage and multiplicity/missing of the seeds in the row. The procedure involved estimation of its performance under two levels of black pepper varieties (Tellicherry black, Malabar black) and seed spacing (15, 20 and 25 cm). The response parameters were measured in terms of missing percentage, multiple seed index and field capacity, Table 1.

Fig.1. Measurement of size of black pepper seeds by digital Vernier Caliper

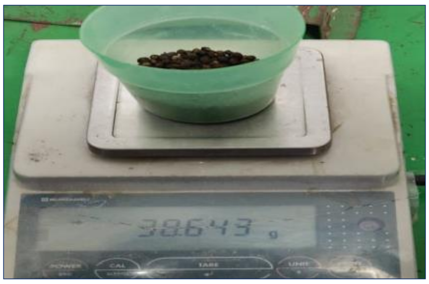
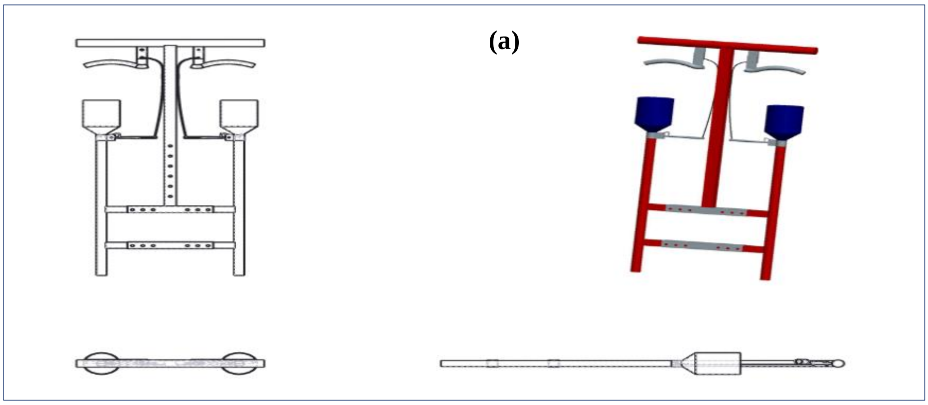
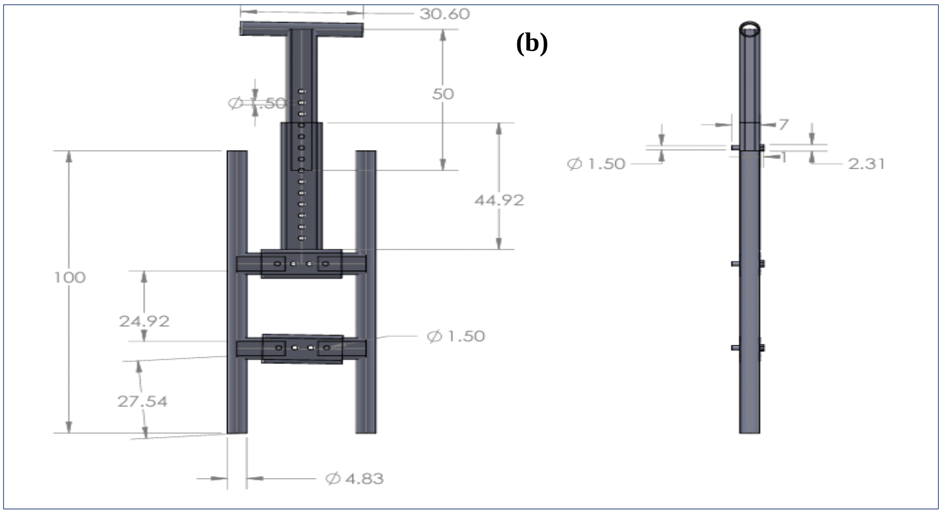


Fig.2. Determination of test weight by electronic weighing balance





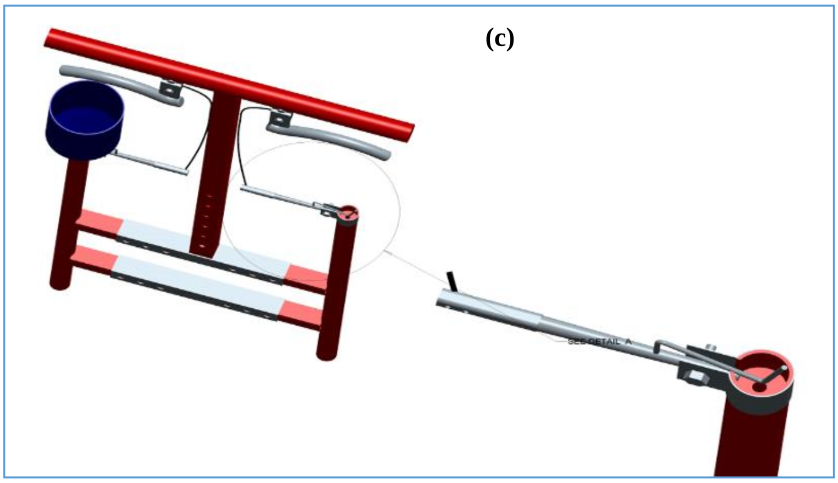


Fig. 3(a)-Conceptual view, (b)-Working components, (c)-Metering Mechanism

Table 1. Plan of experiment for evaluation of hand held two row planter

Type	Parameters	Levels`	Response
Performance evaluation	Varieties	2 (Tellicherry Black, Malabar Black)	• Missing index (%) • Multiple index (%) • Field capacity, ha h^{-1}
	Seed spacing	(15 cm, 20 cm and 25 cm)	
Economic evaluation	• Cost of the planter, Rs. • Operating cost, Rs. ha^{-1} • Benefit-cost ratio • Breakeven point, ha • Payback period, hours		

Measurement of response parameters: The parameters that ultimately defines the efficiency of the planter were considered to arrive at a logical conclusion. The parameters of missing index and multiple index indicates the uniformity of the seed distribution at the field level.

A.Missing index: The missing of the seeds in a particular row was calculated by counting the number of seeds dropped to the total number of seeds that should have been dropped in that particular length of the strip, [27].

$$\text{Missing Index, \%} = \frac{N}{M} \times 100 \qquad \text{……………………..(1)}$$

Where,
N = number of seeds missing during operation into seed tube
M = number of seed dropped if no missing occurred

B.Multiples index: It is the representative of multiple droppings at one single point. It refers to the percentage of spacing that is less than or equal to half of the set plant distance [27].

$$\text{Multiple Index, \%} = \frac{n}{M} \times 100 \qquad \text{……………………..(2)}$$

Where,
n = number of multiple seeds during operation into seed tube
M = number of seed dropped if no multiple seed drop occurred

C.Field efficiency: The field efficiency defines the percentage of useful work. It is calculated by the ratio of actual field capacity to theoretical field capacity [28].

$$\text{Field efficiency, \%} = \frac{AFC}{TFC} \times 100 \qquad \text{… …………………..(3)}$$

Where,
AFC = Actual field capacity, ha h^{-1}
TFC = Theoretical field capacity, ha h^{-1}

Development of plater for black pepper seed

The planter comprised of mainframe, seed hopper, handle, seed tube and clutch**.** The main frame served as the foundation for supporting the individual components of the planter. It held the components in place and provided base for mounting handle, seed metering mechanism and seed tube. The main frame consists of two vertical pipes attached with the help of two horizontal adjustable square pipes. The main frame was provided with square having holes on the entire surface to allow the width adjustment. A funnel shaped seed hopper was fabricated with the involvement of angle of repose to allow the smooth flow of the seed towards the metering mechanism. It served as repository of seeds.

The handle of manually operated hand held planter was designed to allow maximum number of people to operate it. The middle finger palm diameter of Indian workers was considered for deciding the diameter of the handle of the planter. The vertical adjustment of the handle was intended to reduce the drudgery associated with bad posture and inability to operate the planter efficiently. The handle was made from galvanized iron flat bars each of 600 mm long and circular bars of 19 mm diameter fastened to the frame. The inner circular bar slides inside the outer bar to extend the height of the planter with the help of nuts and bolts. The seed tubes were meant to carry the metered seeds from the seed hopper to the hole made in the seed bed.

The conical shaped pointers at the bottom of the vertical tubes were designed to penetrate in the soil and allow the metered seed to flow into it. The clutch was attached with the handle for ease of operation. The wire of the clutch was fastened to the fulcrum of the metering mechanism to open or close the metering hole. The compression and relaxation of the clutch was transmitted to the fulcrum by means of a wire to open or close the metering hole. Two clutches were provided on extreme end of the handle for seed sowing in two rows.

The fabrication of the hand held two row planter was carried out at workshop, College of Agricultural Engineering and Technology (COAET), SKUAST – K, Kashmir, J&K. The planter consists of main frame, seed hopper, handle, seed tube and clutch. The design values were selected based on the physical parameters and review of literature. The main frame of the machine (Table 2.) was 1000 x 300 mm.

Table 2. Specifications and design values of hand held two row planter

S. No.	Components	Material	Functions	Design parameter	Design value
1.	Main frame	Galvanized Iron	To provide the support to the planter	-	100 × 30 cm
2.	Seed hopper	LDPE	To store the seeds	Angle of repose, Test weight, Roundness	500 g capacity
3.	Handle	Galvanized Iron	For operating the machine	Anthropometric data (Middle finger palm diameter)	41 cm length, ¾ inch diameter
4.	Seed Tube	Mild Steel	To pass the seeds to the hole made in the seed bed	Size, Roundness,	62 cm length, ¾ inch diameter
5.	Clutch	Mild Steel	For operating the metering mechanism	-	8 mm diameter
6.	Fulcrum	Mild Steel	To block and pass the seeds into seed tube	-	2 mm diameter

RESULT AND DISCUSSION

Physical characteristics of black-pepper seed varieties relevant to design of planter

The physical properties of the seeds viz. size, roundness, angle of repose and test weight were determined to select the design values of individual components of the machine.

I.Size: The dissimilarity in the size of the seeds provided an opportunity to select an average value that will be the representative of the size for black pepper seed varieties. This helped to accommodate maximum size variation.

The mean and standard deviation of Tellicherry black pepper was found to vary from 4.33 mm – 4.35 mm and 0.33 – 0.45, respectively. In case of Malabar seeds (Table 3.) the mean and standard deviation ranged from 4.42 mm to 4.45 mm and from to 0.20 – 0.35.

Table 3. Variation in the size of black pepper varieties

Variety	R_1, mm	R_2, mm	R_3, mm
Tellicherry black	4.74	4.7	4.61
	3.64	4.62	3.85
	4.85	4.62	4.28
	4.59	4.66	4.37
	4.16	3.8	3.85
	4.09	4.51	4.45
	3.68	4.43	5.07
	4.17	4.14	4.17
	4.43	4.07	4.44
	4.9	3.94	4.26
Mean ± SD	4.33 ± 0.45	4.35 ± 0.33	4.34 ± 0.36
Malabar black	4.21	4.1	4.28
	4.59	4.52	4.56
	4.71	4.49	4.32
	4.97	4.39	4.45
	4.42	4.31	4.13
	4.58	4.28	4.38
	3.68	4.33	4.27
	4.28	4.84	4.98
	4.66	4.41	4.49
	4.36	4.55	4.61
Mean ± SD	4.45 ± 0.35	4.42 ± 0.20	4.45 ± 0.24

II.Angle of Repose: The angle of repose measurement was required to ensure the fabrication of seed hopper of the hand-held planter prompting smooth flow of the seeds towards the metering mechanism. The angle of repose of Tellicherry black and Malabar black was found to be approx. 27° and 25° with standard deviation (Table 4.) of 1.18 ad 1.72, respectively.

Table 4. Measurement of angle of repose for Tellicherry and Malabar black variety

Angle of repose	Tellicherry Black	Malabar Black
R_1	27.6	24.28
R_2	25.5	22.69
R_3	27.5	26.13
Mean ± SD	~27 ± 1.18	~25 ± 1.72

*Each replication is an average of 50 random samples

III.Roundness: The measurement of roundness of the seed was essential to decide the diameter of the size in the metering mechanism for smooth flow.

The roundness of the seed of Tellicherry black and Malabar black variety ranged (Table 5.) from 1.06 mm to 1.07 mm and 1.04 – 1.14 mm

Table 5. Roundness of Tellicherry black and Malabar black variety

	R_1	R_2	R_3
Tellicherry black	1.04	1.05	1.06
	1.11	1.05	1.06
	1.04	1.04	1.03
	1.12	1.15	1.11
	1.04	1.05	1.02
Mean ± SD	1.07 ± 0.04	1.07 ± 0.05	1.06 ± 0.03
Malabar Black	1.04	1.07	1.12
	1.03	1.07	1.08
	1.05	1.07	1.11
	1.06	1.17	1.30
	1.02	1.02	1.07
Mean ± SD	1.04 ± 0.01	1.08 ± 0.06	1.14 ± 0.09

Test Weight: The test weight determines the size and the type of material to be used for the fabrication of the seed hopper. The test weight of 1000 seeds of Tellicherry black and Malabar black variety of black pepper (Table 6.) were found to be 38.6 g and 42.1 g

Table 6. Test weight of 1000 seeds of Tellicherry and Malabar black

Variety	Test weight (g)
Tellicherry black	38.64
	38.64
	38.64
Mean	38.64
Malabar black	42.19
	42.19
	42.19
Mean	42.19

	1.05	1.07	1.11
	1.06	1.17	1.30
	1.02	1.02	1.07
Mean ± SD	1.04 ± 0.01	1.08 ± 0.06	1.14 ± 0.09

Evaluation procedure for uniformity of seed distribution

The evaluation was carried out in 5 m length strip constituting an area of 0.0025 ha. The prototype of the hand held two row planter for black pepper was operated by pressing the clutch to operate the metering mechanism and deliver the seeds through the seed tube at variable seed spacing. The seed spacing in between the rows was controlled by shifting the inner rectangular bar out and fixing the distance by nut and bolt. The number of seeds dropped was observed for missing and multiple percentage to check the distribution of the seeds.

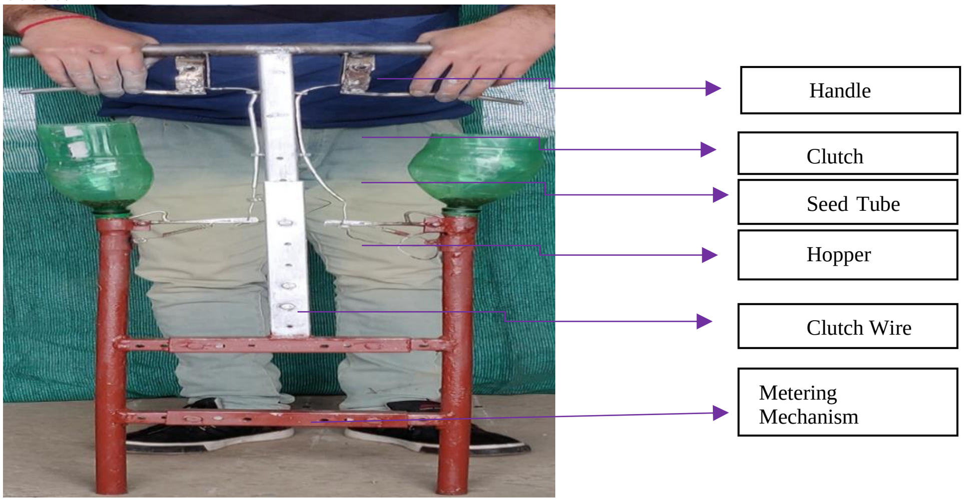
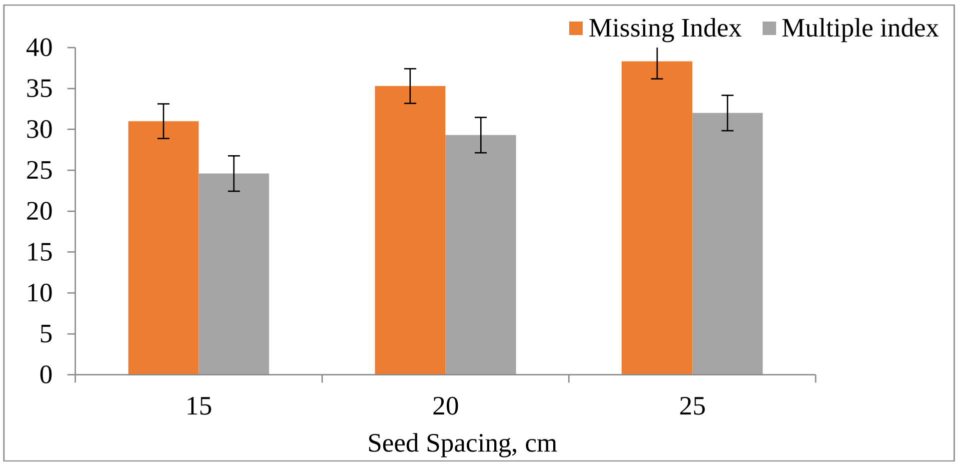


Fig.4. Prototype of hand held two row planter for black pepper

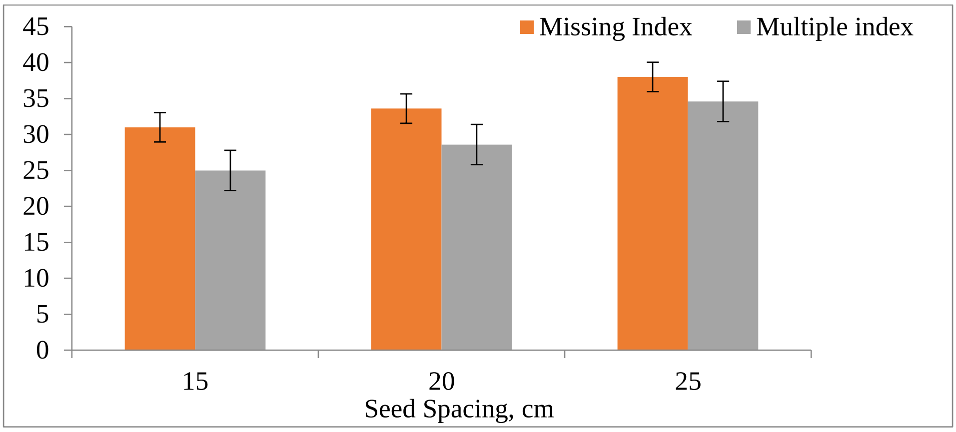
Fig. 5. Measurement of missing and multiple percentage

A. Effect of seed spacing on missing percentage and field capacity

The variation in missing percentage was observed for seed spacing, Fig. 6. At 15 cm, the missing percentage was observed to be 31 % for both Tellicherry and Malabar black pepper. The higher percentage was due to higher moisture content of the black pepper seeds resulting in blockage of metering hole. At higher seed spacing of 20 cm, the missing percentage increased to 35.3 % and 33.6 % and further to 38.3 % and 38 % at 25 cm for Tellicherry and Malabar black pepper, Fig. 6 (a). The field capacity ranged from 0.02 – 0.03 ha h^{-1} in all the experiments. The increase in missing percentage at 20 cm and 25 cm was mainly due to the increase in distance between clutch and metering hole. This tends to increase the force required to operate the clutch.



(a)



(b)

Fig. 6. Missing and multiple percentage (a) Tellicherry, (b) Malabar black pepper variety

Variation in multiple percentage and field capacity

At certain occasions, it was observed that more than one seed was dropped. This was mainly due to the fault in metering mechanism, high moisture content of black pepper seeds, prolonged clenching of clutch lever and inappropriate spring tension. At speed spacing of 15 cm, the multiple percentage was 24.6 % and 25 % for Tellicherry and Malabar black pepper variety with field capacity of 0.03 ha h^{-1}, Fig. 6 (b). When main frame was extended to increase the spacing between seeds to 20 cm, the multiple percentage was found to be 29.3 % and 28.6 %, respectively. The highest multiple seed percentage of 32 % and 34.6 % was found to be associated with the seed spacing of 25 cm. The distance between the clutch and metering mechanism defined the intensity of seed metering and multiple seed percentage index.

Cost economics of developed two row hand held planter

The economic feasibility is one among the prime factors that defines the acceptance of the machine among the farming community. The total cost incurred in the development of prototype of two row hand held planter was about Rs. 1500. The economic analysis revealed the operating cost as Rs. 84.97 per hour, benefit cost ratio of 1.30, breakeven point 16.36 ha and payback period of 58.85 hours, Table 7. The cost of operation obtained by the ratio of operating cost and field capacity as Rs. 2832 per hectare.

Table 7. Economic analysis of two row black pepper planter

S. No.	Item	Value
1.	Total operating cost, Rs h^{-1}	84.97
2.	Benefit-cost ratio	1.30
3.	Break-even point, ha	16.36
4.	Payback period, hours	58.85

CONCLUSIONS

A low-cost portable planter for black pepper was designed, developed and evaluated at field conditions. The planter comprised of handle, clutch, seed hopper, metering mechanism and seed tubes. The evaluation of the planter at field conditions revealed a missing percentage of 31% and multiple percentage of 24.6% at 0.03 ha h^{-1} field capacity. The cost of the two-row black pepper planter was calculated as Rs. 1500.

The operating cost, benefit-cost ratio, breakeven point and payback period was calculated as Rs. 84.97 per hour, 1.30, 16.36 ha and 58.85 hours, respectively. The cost of operation of the hand held two row planter was found be Rs. 2832 per hectare. The planter can be useful for small land holdings and small farmers.

Conflict of Interest: The authors declare that no conflict of interest exists in any manner.

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REFERENCES

[1] Sawe, B. E. 2019. The world’s top black pepper producing countries, Vol. 2020. WoldAtlas.com.

[2] Lee, JG., Chae, Y., Shin, Y. and Kim, Y. 2020. Chemical composition and antioxidant capacity of black pepper pericarp.*Appl Biol Chem* **63**, 35.https://doi.org/10.1186/s13765-020-00521-1

[3] Al-Jasass, F.M. and Al-Jasser, M. S. 2012. Chemical composition and fatty acid content of some spices and herbs under Saudi Arabia conditions. Sci World J. https://doi.org/10.1100/2012/859892

[4] Subha, S. P. and Balamurugan, S. 2020. Economic analysis of pepper cultivation in India. International Journal of Economics and Management Studies, pp. 1-5.

[5] Spence, C. (2024). The king of spices: on pepper’s pungent pleasure. International Journal of Gastronomy and Food Science. 35, 100900. https://doi.org/10.1016/j.ijgfs.2024.100900

[6] Gorgani, L., Mohammadi, M., Najafpour, G.D. and Nikzad, M. (2017). Piperinethe bioactive compound of black pepper: from isolation to medicinal formulations. Compr Rev Food Sci F. 16(1): pp.124–140

[7] Ahmad, N., Fazal, H., Abbasi, B.H., Farooq, S., Ali, M. and Khan, M. A. 2012. Biological role of *Piper nigrum* L. (Black pepper): a review. Asian Pac J Trop Biomed. 2: S1945–S1953

[8] Bajad, S., Bedi, K.L., Singla, A.K. and Johri R.K. 2001. Antidiarrheal activity of piperine in mice.*Planta Med.* **67**: pp.284–287.

[9] Costa, R., Machado, J. and Abreu, C.2016. Evaluation of analgesic properties of *Piper nigrum* essential oil: a randomized, double-blind, placebo-controlled study. World Journal of Traditional Chinese Medicine 2(2): pp.60–64. https://doi.org/10.15806/j.issn.2311- 8571.2015.0032.

[10] Khan, M., 2015. Comparative physicochemical evaluation of fruits and antidepressant potential of volatile oils of fruits of local *Piper* species. Orient. J. Chem. 31, pp. 541–545. https://doi.org/10.13005/ojc/310167.

[11] Okumura, Y., Narukawa, M., Iwasaki, Y., Ishikawa, A., Matsuda, H., Yoshikawa, M., Watanabe, T., 2010. Activation of TRPV1 and TRPA1 by black pepper components. Biosci. Biotechnol. Biochem. 74, pp. 68–72.

[12] Gasparetto, A., Cruz, A.B., Wagner, T.M., Bonomoni, T.J., Correa, R. and Malheiros, A. 2017. Seasonal variation in the chemical composition, antimicrobial and mutagenic potential of essential oils from *Piper cernum*. Ind Crops Prod 95: pp.256–263.

[13] Sauter, I. P., Rossa, G. E., Lucas, A. M., Cibulski, S. P., Roehe, P. M., da-Silva, L. A. A., Rott, M. B., Vargas, R. M. F., Cassel, E. and von-Poser, G.L.2012. Chemical composition and amoebicidal acitivity of *Piper hispidinervum* (Piperaceae) essential oil. Ind Crops Prod 40: pp.292–295.

[14] Chonpathompikunlert, P., Wattanathorn, J. and Muchimapura, S.2010. Piperine, the main alkaloid of Thai black pepper, protects against neurodegeneration and cognitive impairment in animal model of cognitive deficit like condition of Alzheimer's disease. Food Chem Toxicol 48: pp.798–802.

[15] McNamara, F. N., Randall, A. And Gunthorpe, M. J. 2005. Effects of piperine, the pungent component of black pepper at the human vanilloid receptor. Br J Pharmacol. 144(6): pp.781-790.

[16] Alan, O. and Ilbi, H. 2023. Effect of cutting treatment on seed yield and seed quality of dill. *Journal of Tekirdag Agricultural Faculty,* 20(1): pp.94-103. https://doi.org/10.33462/jotaf.1073356

[17] Malla, U. M., Khan, A. R., Muzamil, M., Mohiuddin, M., Rashid, S., Banday, R. and Kumar, R. 2022. Development and evaluation of four-row seeder for vegetable crops in the temperate region of Jammu and Kashmir. SKUAST Journal of Research, 24(1): 71-79. http://dx.doi.org/10.5958/2349-297X.2022.00016.2.

[18] Wani, M. H., Muzamil, M., Dixit, J., Faisal, S. and Khan, A. A. 2024. Development of a low-cost portable two row pea planter for Hilly terrain of Kashmir Valley. Journal of Tekirdag Agricultural Faculty 21(3): pp.561-577.

[19] Jadhav, M. L., Din, M., Nandede, B. M. and Kumar, M. 2020. Engineering properties of paddy and wheat seeds in context to design of pneumatic metering devices. *Journal of the Institution of Engineers (India): Series A,*101: pp. 281-292. https://doi.org/10.1007/s40030-019-00430-7.

[20] Mohiuddin, M., Muzamil, M., Dixit, J., Faisal, S. and Khan, I. 2022. Engineering properties of Chilli fruit relevant to the design and evaluation of Chilli seed extractor for hilly region of Kashmir valley. Journal of Institution of Engineering (India): Series A 103: pp. 433-443. https://doi.org/10.1007/s40030-022-00617-5.

[21] Magray, M. A., Fayaz, A., Muzamil, M., Rasool, S., Nath, S., Banday, R. and Faisal, S. 2023. Development and performance evaluation of low-cost cylinder type maize sheller for small farmers of Jammu and Kashmir. SKUAST Journal of Research 25(1): pp. 22-33. http://dx.doi.org/10.5958/2349-297X.2023.00003.X

[22] Muzamil, M., Mani, I., De, D. and Lande, S. 2013. Influence of operational parameters of windrow turner for mass production of compost. International journal of agricultural and statistical science, 9(1): pp. 19 – 28.

[23] Malik, M.A., Faisal, S., Muzamil, M., Langoo, B. A., Shukla, R. M., Reshi, M., Dhekale, B. and Hussain, S. Z. 2023. A Low-Cost Portable Willow Wicker Peeling Machine: An Innovative Mechanical Intervention in the Wickercraft Industry of Kashmir. *J. Inst. Eng. India Ser. A* 104, pp. 271–280. https://doi.org/10.1007/s40030-023-00726-9.

[24] Muzamil, M., Wani, J., Mustafa, A., Mohiuddin, M., Mir, A., Faisal, S. and Nirbhavane, S. 2018. A Low-Cost Divergent Type Apple Grader for Kashmiri Apples. International Journal of Current Microbiology and Applied Sciences 7(4): p.p.3561-3569. https://doi.org/10.20546/ijcmas.2018.704.401.

[25] Rashid, Z., Faisal, S., Muzamil, M., Dixit, J., Shukla, R. M. and Khan, I. 2023. Development of an innovative universal walnut cracking and separating machine for farmers and walnut industry of Kashmir Valley. Journal of Institution of Engineering (India): Series A 104: pp. 355-365. https://doi.org/10.1007/s40030-023-00718-9.

[26] Kumar, A., Muzamil, M. and Dixit, J. 2022. Smart vermicomposting bin for rapid transformation of Dal Lake aquatic weed into fortified vermicompost. Internal Journal of Recycling of Organic waste in Agriculture 12(2). https://doi.org/10.30486/ijrowa.2022.1955835.1445.

[27] Yasir, S. H., Liao, Q., Yu, J. and He, D. 2012. Design and test of a pneumatic precision metering device for wheat. *Agricultural Engineering International: CIGR Journal*, 14(1): pp.16–25.

[28] Bamgboye, I. A. and Mofolasayo, S. A. 2006. Performance evaluation of two row okra planter. *Agricultural Engineering International: CIGR e-Journal*, 8(7). Manuscript PM 06002.

RAZVOJ I EVALUACIJA DVOREDNE RUČNE SEJALICE ZA SEME CRNOG BIBERA

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Apstrakt. Studija se fokusirala na razvoj prenosive jeftine dvoredne sejalice za crni biber (*Piper nigrum L.*). Fizički atributi za seme crnog bibera Tellicherri i i Malabar u smislu tri-aksijalnih dimenzija, ugla trenja, zaobljenosti (sferičnosti) semena i težine 1000 semena, korišćeni su za određivanje projektovanih vrednosti pojedinih komponenti sejalice. Srednje vrednosti tri-aksijalnih dimenzija i ugao trenja Tellicherri crnog i Malabar crnog bibera, kretale su se u rasponu od 4.33 – 4.35 mm, 27° i 4.42 – 4.45 mm, 25°, respektivno. Sferičnost (zaobljenost) semena je 1,06 mm – 1,07 mm i 1,04 – 1,14 mm u sličnim uslovima. Težina 1000 semena, korišćenih za projektovanje rezervoara za seme je 38,6 g i 42,1 grama, respektivno.

Ručna sejalica crnog bibera (H x h x W x w = 1000 x 920 x 300 x 150 mm) ima: rezervoar za seme, uređaj za doziranje semena, ručku, podesiv (promenljiv) razmak između redova, sprovodne cevi za seme. Razvijena sejalica ima razmak redova 15, 20 i 25 cm, za dve sorte crnog bibera (*Piper nigrum L.*). (Tellicherri crni i Malabar crni).

Zabeleženi su parametri performansi procenta greški, višestruki procenat greški i učinka na polju (ha h^{-1}) i ekonomskih parametara troškova eksploatacije, tačke rentabilnosti, odnosa koristi i troškova i perioda otplate.

Optimizacija rezultata kroz program Design-Expert 13.0 je prikazala 31% nedostatka i 24,6% višestrukih greški kod razmaka semena od 15 cm sa poljskim učinkom od 0,03 ha na čas.

Operativni trošak (Rs h^{-1}), odnos troškova i dobiti, tačka rentabilnosti (ha) i period otplate (časova), izračunati su kao 84.97, 1.30, 16.36 and 58.85, respektivno. Utvrđeno je da je cena rada ručne dvoredne sejalice Rs. 2832 po hektaru.

Skraćenice:
H = Maksimalna visina, mm
h = Minimalna visina, mm
W= Maksimalna širina, mm
w = Minimalna širina, mm

Ključne reči: *Sejalica, biber, dizajn, prenosivi, performanse, razmak, raznolikost, efikasnost, tačka rentabilnosti, isplativost.*

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UNIFORMNOST DISTRIBUCIJE VODE KOMBINOVANOG SAMOHODNOG AUTOMATSKOG UREĐAJA ZA NAVODNJAVANJE U TOKU LINEARNOG KRETANJA

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Sažetak. Kombinovani samohodni automatski uređaj za navodnjavanje namenjen je za kombinovano linearno i kružno kretanje. Ispitivanje uniformnosti distribucije vode izvedeno je u režimu linearnog kretanja, prilikom redovnog korišćenja uređaja. Pritisak vode na ulasku u uređaj iznosio je od 1,8 do 1,9 bar, a prema preporuci proizvođača treba da bude 4 bar. Utvrđeno je kontinualno opadanje visine vodenog taloga, udaljavanjem od mesta priključka za vodu. Ispitivani uređaj je nov, ali zbog neodgovarajućeg korišćenja i podešavanja, utvrđene su relativno niske vrednosti za Christiansen koeficijent (CUc=81,11%) i za koeficijent ujednačenosti distribucije (DUlq=0,73), uz visoku vrednost koeficijenta varijacije (CV=25,71%). Ostvarene vrednosti koeficijenata ujednačenosti distribucije vode i koeficijenta varijacije, nalaze se na granici prihvatljivosti sa stanovišta korišćenja vodnih i zemjišnih resursa, kao i uticaja na prinos.

Ključne reči: *Navodnjavanje, uniformnost distribucije, korišćenje, podešavanje i održavanje.*

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UVOD

Poljoprivreda danas koristi oko 70% vode za piće, a očekuje se usled klimatskih promena, potrošnja vode porasti za 70-90% do 2050. godine, [1]. Između savremene poljoprivredne proizvodnje i dostupnosti vode postoji snažna zavisnost. Ukupna navodnjavana površina u Republici Srbiji iznosi oko 207.000 ha, što čini 8,3% korišćenog poljoprivrednog zemljišta, od toga se 41% navodnjava metodom kap po kap.

U regionu Vojvodine navodnjava se približno 144.000 ha što iznosi 9,6% korišćenog poljoprivrednog zemljišta, [2]. Od toga, najveći deo površine navodnjava se veštačkom kišom korišćenjem samohodnih automatskih uređaja za navodnjavanje, pri čemu je zastupljenost mašina tipa center pivot oko 90%, ostalo su mašine linear ili rendžer tipa.

U zemljama u razvoju od ukupne količine vode koja se koristi za navodnjavanje, oko 40% se gubi isparavanjem, izlivanjem ili apsorpcijom dubokih slojeva zemljišta izvan dometa korenovog sistema gajenih biljaka, [3].

Uniformnost distribucije vode samohodnih automatskih uređaja ima značajan uticaj na količinu utrošene vode i angažovane energije, odražava se na prinos i ima potencijalni uticaj na životnu sredinu, [4]. Na samohodnim automatskim uređajima danas se koriste odbojni (tanjirasti) rasprskivači niskog pritiska, čija je primena energetski manje zahtevna, a ostvaruju se i niže vrednosti gubitaka vetrom, kao i evaporacije, [5]. Ujednačenost rada rasprskivača najčešće se ocenjuje preko Christiansen koeficijenta uniformnosti, (CU), [6].

Kvalitet rada se ocenjuje na onovu izmerenih vrednosti koeficijenta uniformnosti distribucije i kažemo da je "exellent >90%", "good 85-90%", "fair 80-85%" i "poor" <80%" [7].

Samohodni automatski uređaji za navodnjavanje mogu da se koriste i za hemigaciju (đubrenje i hemijska zaštita) zajedno sa navodnjavanjem samo u slučaju kada je vrednost CU > 85%. Vrednost CU > 80% obezbeđuje zadovoljavajuću ujednačenost prinosa [8]. Najčešći faktori koji utiču na uniformnost aplikacije vode su izbor, raspored i razmak rasprskivača, varijacija pritiska u lateralu za distribuciju vode i brzina vetra, [9; 10; 11].

Na osnovu izmerenih vrednosti uniformnosti distribucije u zavisnosti od vrste korišćenih rasprskivača i ostvarenog prinosa može se preporučiti optimalna vrsta rasprskivača, [12]. I ako je navodnjavanje veštačkom kišom samohodnim mašinama najviše zastupljeno u poljoprivredi Republike Srbije, ne postoji dovoljno relevantnih studija vezanih za uniformnost aplikacije vode (WAU), uniformnost fertigacije (FU), efikasnost korišćenja vode za navodnjavanje (WUE) i efikasnost korišćenja azota (NUE), [13; 14].

MATERIJAL I METOD RADA

Ispitivan je samohodni automatski uređaj za navodnjavanje, koji može da se koristi kombinovano, za pravolinijsko (linear tipa) i kružno (center pivot tip) kretanje. Svi tornjevi na mašini su pokretni. Prvi toranj se oslanja na četiri točka, na njemu se nalaze: kontrolni panel, uređaj za navođenje pomoću brazde i ima dva priključka za fleksibilnu cev za vodu i električnu energiju. Voda potrebna za rad mašine obezbeđuje se preko hidranata i fleksibilnih cevi.

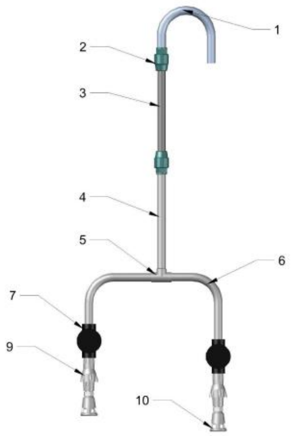
Ukupna dužina mašine iznosi 385,85 m i sastoji se od pet raspona dužine 54,55 m, dva raspona dužine 47,90 m i prepusta dužine 16,5 m. Preporučeni radni pritisak na ulazu u mašinu iznosi 4 bar, pri čemu se ostvaruje protok sistema od 301,6 m^3/h. Vođenje mašine po pravcu izvodi se uz pomoć kanala (brazda) kojom se kreće vođica.

Celom dužinom mašine ide galvanizovana razvodna cev prečnika $6^{5/8}$"(168 mm). Izlazna cev prema rasprskivaču deli se na dva toka na kojima se nalaze hidraulični ventili, i preko kojih se bira režim rada, linear ili center pivot (sl. 1). U produžetku cevi postavljen je regulator pritiska UNI-FLO 20 PSI SS REG 3/4" FNPT x SQUARE THD koji daje izlazni pritisak 1,4 bar (20 PSI), a konačna dezintegracija mlaza vode ostvarena je pomoću rasprskivača Nelson R3000 sa crvenim diskom. Tamno smeđa dizna (3TN #31) postavljena je na 1, 2, 19, 20 i 23 rasprskivač, ljubičasta (3TN #37) na poslednji 166 rasprskivač, a na svim ostalim rasprskivačima postavljena je narandžasta dizna (3TN #32). Prvi rasprskivač postavljen je na rastojanju od 8,4 m a ostali na rastojanju 2,3 m, sa izuzetkom početka svakog raspona, kao i na prepustu, koji su postavljeni na rastojanju 2,4 m. Na osnovu vrste dizni, kao i razmaka i broja rasprskivača dobija se 2,6% veći protok u odnosu na nominalni.

Maksimalna radna brzina mašine iznosi 1,9 m/min, pri čemu ostvaruje visina vodenog taloga 7,03 mm. Podešavanjem procentualnog programatora koji je smeštem u kontrolnom panelu podešava se radna brzina, a time i visina vodenog taloga. Cilj navodnjavanja je bilo da se postigne visina vodenog taloga od oko 30 mm. Radi kontrole pravilnog rada procentualnog programatora i podešavanja visine vodenog taloga, merena je radna brzina mašine na klasičan način pomoću pantljike, vizir motki i štoperice.

Ispitivanje kombinovanog samohodnog automatskog uređaja izvedeno je prilikom pravolinijskog kretanja u režimu rada linear na osnovu procedura i postupaka utvrđenih standardom (ASAE S436.1) [15]. Ispitivanje je izvedeno dana 09.07.2024. godine u ataru sela Ratkovo, prilikom navodnjavanja useva krompira, položaj parcele 45°28'57,1"N 19°2122,1"E.

Merenje uniformnosti distribucije visine vodenog taloga po širini radnog zahvata mašine, izvedeno je postavljanjem posuda prečnika 88 mm i visine 135 mm, koje su postavljene na metalne nosače iznad površine zemljišta, tako da lisna masa navodnjavanog useva ne zaklanja posude (sl. 2). Korišćenjem mernih posuda poznate površine, utvrđena je stvarna primenjena visina vodenog taloga, na pojedinim delovima parcele. Prema standardu [15], razmak između posuda treba da iznosi 3 do 5 m u zavisnosti od vrste korišćenih rasprskivača. Merne posude su postavljene na rastojanju 3 do 3,5 m. Ispitivanje je izvedeno u dva ponavljanja (1x, 2x).



Slika 1. Dvostruki izlaz sa dva hidraulična ventila (7) i dva seta rasprskivača (9 i 10) za režime rada linear i center pivot
Figure 1. Double outlet with two hydraulic valves (7) and two sets of sprinklers (9 and 10) for linear and center pivot operating modes

Slika 2. Merenje uniformnosti distribucije vode
Figure 2. Measuring the uniformity of water distribution

Na uniformnost distribucije vode, veliki uticaj imaju vremenski uslovi u kojma je izvedeno ispitivanje. Merena je brzina i pravac vetra u odnosu na mašinu, kao i temperatura i relativna vlažnost vazduha. Za merenje brzine vetra korišćen je anemometar proizvođača Merni uređaj Testo, model 416, sa malom turbinom prečnika 16 mm (0,63") čiji stepen očitavanja iznosi 0,1 m/s, i klasa tačnosti ±0,2 m/s +1% izmerene vrednosti. Za merenje pravca položaja mašine, kao i pravca i smera vetra korišćena je aplikacija za mobilni telefon "kompas" sa stepenom očitavanja 5°. Za merenje temperature i relativne vlažnosti vazduha (RH) korišćen je merni instrument proizvođača Testo model 635 uparen sa senzorom ("Testo sensor %rF/RH/HR 0420.0023"), sa preciznosti očitavanja 0,1°C i 0,1% RH, uz klasu tačnosti ±0,2°C i ±2%RH.

Za merenje pritiska vode na ulasku u mašinu, korišćen je manometar čija preciznost očitavanja iznosi 0,1 bar. Za merenje zapremine tečnosti zahvaćene u posudama, korišćena je plastična menzura 1000 ml, sa podeocima na 10 ml. U toku merenja postignuta je klasa tačnosti 5 ml.

Za izračunavanje vrednosti uniformnosti distribucije vode korišćen je Christiansen koeficijent uniformnosti [6; 15]:

$$CU_C = 100\left[1 - \frac{\sum_{i=1}^{n}\left|V_i - \overline{V}\right|}{\sum_{i=1}^{n} V_i}\right] \qquad \text{(1)}$$

gde je:

CU_C - Christiansen koeficijent uniformnosti,
n - broj kolektora korišćenih u analizi podataka,
V_i - zapremina (ili masa) vode sakupljene u i-tom kolektoru,
$\overline{V}$ - aritmetička sredina zapremine ili mase vode sakupljene u svim kolektorima.

Uniformnost distribucije vode može da se odredi i preko koeficijenta ujednačenosti distribucije (DUlq - the low quarter Distribution Uniformity) (DUlq) [16], koji se računa iz jednačine:

$$DU_{lq} = \frac{\overline{V_{lq}}}{\overline{V}} \qquad \text{(2)}$$

gde je:

$\overline{V_{lq}}$ - aritmetička sredina jedne četvrtine najnižih izmerenih vrednosti u mernim posudama (kolektorima).
$\overline{V}$ - aritmetička sredina svih izmerenih vrednosti u mernim posudama (kolektorima).

Koeficijent varijacije (CV) je izračunat na osnovu poznate jednačine iz statistike:

$$CV = \frac{S}{\overline{V}} \cdot 100 \qquad \text{(3)}$$

gde je:
S - standardna devijacija.

REZULTATI ISPITIVANJA I DISKUSIJA

Ispitivanje je izvedeno u prepodnevnim satima, pri čemu su izmerene vrednosti za temperaturu vazduha od 29,1 do 33,9°C i vlažnost vazduha 66,1–55,8%. Vremenski uslovi u kojima je izvedeno ispitivanje bili su u granicama predviđenim standardom ASAE S436.1, prvenstveno brzina vetra koja je na početku merenja imala vrednost 2,55 a na kraju ispitivanja 1,75 m/s. Pravac vetra je na početku merenja bio jug jugo-zapad, pomerenost za 210° u odnosu na sever, a na kraju merenja zapad jugo-zapad, pomerenost za 250° u odnosu na sever. Pravac mašine za navodnjavanje bio je približno sever-jug sa odstupanjem od -(5–10°). Pogonski toranj je postavljen sa severne strane mašine i kreće se po dobro izravnatom zemljanom putu (sl. 3).

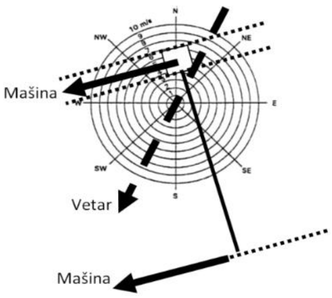
Nakon prolaska mašine izmerena je norma navodnjavanja, merenjem zapremine vode u posudama. S obzirom da je za merenje 117 uzoraka bio potreban vremeski period od 20 minuta, usled isparavanja vode iz mernih posuda, došlo bi do greške u merenju. Ova greška merenja otklonjena je merenjem zapremine vode i na početku i na kraju merenja prvih pet mernih posuda.

Izmerena razlika između merenja na početku i kraju merenja bila je 7 ml i posledica je isparavanja vode iz merne posude. Usvojeno je da brzina isparavanja vode iz mernih posuda ima linearnu zavisnost u toku vremena, i izvedena je korekcija izmerenih vrednosti zapremine vode.

Merenjem radne brzine utvrđeno je da se mašina kreće brzinom 0,24 m/min. Programator smešten u kontrolnom panelu, podešen je da se kretanje odvija 15% vremena, tako da očekivana radna brzina iznosi 0,28 m/min uz normu navodnjavanja od 46,84 mm. Obzirom da postoji razlika između podešene i ostvarene radne brzine mašine usled klizanja pogonskih točkova, očekuje se norma navodnjavanja od 51,10 mm.

Izmerene vrednosti norme navodnjavanja znatno odstupaju od podešenih, i posledica su rada mašine sa nižim pritiskom od projektovanog. Na ulazu u mašinu treba da se obezbedi pritisak od 4 bar, i usled linijskih gubitaka i gubitaka usled više izlaza na glavnoj razvodnoj cevi, njegova vrednost opadne za 1,1 bar.

Obzirom da je na ulazu u mašinu u toku ispitivanja izmeren pritisak od svega 1,8 do 1,9 bar (sl. 4), cela mašina nije radila u predviđenom režimu rada, i ostvarena je niža norma od podešene, kao i povećana varijacije norme navodnjavanja po površini parcele usled neodgovarajućih vrednosti pritiska vode za kvalitetan rad rasprskivača i ujednačeno pokrivanje površine zemljišta.



Slika 3. Pravac i smer kretanja mašine i vetra
Figure 3. The route and direction of movement of the machine and the wind

Slika 4. Radni pritisak na ulazu u mašinu
Figure 4. Working pressure at the machine inlet

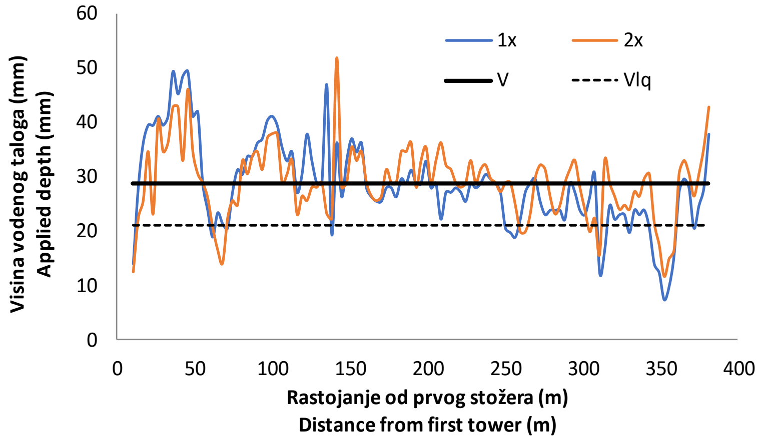
Ispitivanje je izvedeno u dva ponavljanja (1x i 2x) i izračinate su vrednosti za aritmetičku sredinu, standardnu devijaciju i koeficijent varijacije (tab. 1).

Tab. 1. Ostvarene vrednosti visine vodenog taloga
Tab. 1. Realized values of applied depth irrigation

Parametar Parameter	1x	2x	Srednje Averge
Aritmetička sredina V (mm) Average V (mm)	28,54	28,83	**28,7**
Standardna devijacija S (mm) Standard deviation S (mm)	8,06	6,65	**7,37**
Koeficijent varijacije CV (%) Coefficient of variation CV (%)	28,23	23,08	**25,7**

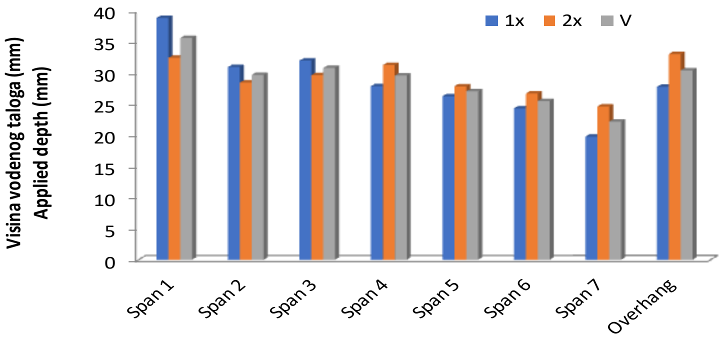
Između merenja ostvarene su minimalne razlike, čime je potvrđena preciznost merenja. Ostvarena visina vodenog taloga pri radnoj brzini od 0,24 m/min i radnom pritisku 1,8–1,9 bar bila je 28,7 mm, a podešena preko procentualnog programatora 51,10 mm. Visoke vrednosti standardne devijacije i koeficijenta varijacije posledica su rada rasprskivača pri pritisku nižem od predviđenog, usled čega dolazi do neravnomerne raspodele vode po površini parcele, i značajnog smanjenja norme navodnjavanja za više od 40%.

Na osnovu izmerenih vrednosti visine vodenog taloga u mernim posudama, formirana je distribucija visine vodenog taloga od prvog stožera (sl. 5). Ukupno je izvedeno 117 merenja po jednom ponavljanju, i prema ispitivanom standardu (ASAE S436.1) ispitivanje je izvedeno u dva ponavljanja, a da rastojanje između ponavljanja ne bude veće od 50 m.



Sl. 5. Distribucija visine vodenog taloga od prvog stožera u dva ponavljanja (1x, 2x), aritmetička sredina svih merenja (V) i aritmetička sredina četvrtine minimalnih vrednosti (V_{ql})
Sl. 5. Distribution of applied depth of water width of the working area for two repetitions (1x, 2x), average of all measurements (V) and average of quarter of minimum values (Vql)

Izmerene vrednosti visine vodenog taloga od prvog stožera, po širini radnog zahvata, za oba ponavljanja pokazuju istu zakonitost koja se ogleda u činjenici da je na prvom rasponu ostvarena visina vodenog taloga, čije se vrednosti približavaju zadatim vrednostima podešenim preko procentualnog programatora. Horizontalna linija predstavlja aritmetičku sredinu svih merenja, a isprekidana horizontalna linija, aritmetičku sredinu četvrtine najnižih izmerenih vrednosti. Znatno niže vrednosti u odnosu na podešenu vrednost visine vodenog taloga (51,10 mm), uz izrazito izraženu varijaciju između mernih mesta utvrđene su na svim rasponima. Na prvom rasponu ostvarena je najviša vrednost norme navodnjavanja od 35,7 mm, a najniža vrednost je ostvarena na sedmom rasponu i iznosi 22,2 mm (sl. 6). Usled nedovoljne vrednosti pritiska na ulazu u mašinu, došlo je do kontinualnog pada norme navodnjavanja udaljavanjem od mesta na kojem se nalazi priključak za vodu.



Slika 6. Visina vodenog taloga po rasponima
Figure 6. Applied depth of water per spans

Uniformnost distribucije vode ispitivane mašine ocenjena je preko Christiansen-ovog koeficijenta (CUc), koeficijenta ujednačenosti distribucije (DUlq) i koeficijenta varijacije (CV), za prvo merenje (1x), drugo merenje (2x), kao i za oba merenja zajedno (tab. 2).

Tabela 2. Izmerene vrednosti koeficijenata uniformnosti distribucije visine vodenog taloga
Table 2. Measured values of water distribution uniformity coefficients

Koeficijent (%) - Coefficient (%)	1x	2x	Prosek - Average
Christiansen-ov koeficijent uniformnosti (CUc) Christiansen's uniformity coeficijent, (CUc)	79,11	83,10	**81,11**
Koeficijent ujednačenosti distribucije (DUlq) Coefficient of distribution uniformity (DUlq)	66,88	79,85	**73,40**
Koeficijent varijacije (CV) - Coefficient of variation (CV)	28,23	23,08	**25,71**

Izmerene vrednosti za Christiansen koeficijent (CUc), koeficijent ujednačenosti distribucije (DUlq) i koeficijent varijacije (CV) imaju vrednosti koje se nalaze nagranici između zadovoljavajućeg (fair) i lošeg (poor). Ispitivana mašina je nova, nema curenja, postavljeni su novi rasprskivači i ima sve preduslove da bude ocenjena kao odlična prema svim parametrima za ocenu uniformnosti distribucije, ali nepravilnim korišćenjem dovedena je do granice prihvatljivosti rada sa stanovišta uniformnosti distribucije i korišćenja vodnih i zemjišnih resursa.

Mašina za navodnjavanje je u toku ispitivanja postigla površinski učinak od 0,55 ha/h. Pri radu sa odgovarajućim pritiskom vode, ostvarile bi se približno dva više vrednosti za učinak, uz racionalniju upotrebu vode, hraniva i ostalih zemljišnih rasursa.

ZAKLJUČAK

Prilikon ispitivanja ujednačenosti distribucije vode za kombinovani samohodni automatski uređaj u režimu rada linear, utvrđena je nedovoljna vrednost pritiska vode na ulasku u mašinu od 1,8 do 1,9 bar, a prema preporuci proizvođača treba da bude 4 bar.

Posledica niskog pritiska i nedovoljnog protoka vode na samohodnom automatskom uređaju dovela je do kontinualnog pada visine vodenog taloga, udaljavanjem od mesta priključka za vodu. Na prvom rasponu, koji se nalazi najbliže priključku za vodu, ostvarena je najviša vrednost visine vodenog taloga od 35,7 mm, a najniža vrednost je ostvarena na sedmom rasponu i iznosi 22,2 mm. Usled rada samohodnog automatskog uređaja za navodnjavanje sa nedovoljnom količinom i pritiskom vode, ostvarene su relativno niske vrednosti za Christiansen-ov koeficijent (CUc) i koeficijent ujednačenosti distribucije (DUlq), uz visoku vrednost koeficijenta varijacije (CV). Ostvarene vrednosti koeficijenata ujednačenosti distribucije vode nalaze se na granici prihvatljivosti sa stanovišta korišćenja vodnih i zemjišnih resursa, kao i uticaja na prinos.

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LITERATURA

1. Tsakmakis et al, 2017. Operational Precise Irrigation for Cotton Cultivation through the Coupling of Meteorological and Crop Growth Models. Water Resour Manage, 31: pp.563–580.
2. Popis poljoprivrede 2023. https://popispoljoprivrede.stat.gov.rs/media/31092/brosura-srpski-sa-koricom.pdf
3. Zhu X.Y, Chikangaise P, Shi W.D, Chen W.H, Yuan S.Q. 2018. Review of intelligent sprinkler irrigation technologies for remote autonomous system. Int J Agric & Biol Eng, 11(1): pp.23–30.
4. Louis M, Selker J. 2000. Sprinkler head maintenance effects on water application uniformity. Journal of Irrigation and Drainage Engineering, 126, pp. 142–148.
5. Sourell H, Faci J M, Playan E. 2003. Performance of rotating spray plate sprinklers in indoor experiments. Journal of Irrigation and Drainage Engineering, 129, pp.376–380.
6. Christiansen, J.E. 1942. Irrigation by Sprinkler, California Agricultural Experimental Station Bull; No. 670; University of California at Davis: Davis, CA, USA.
7. Harrison, K; Perry, C. 2013. Evaluating and Interpreting Application Uniformity of Center Pivot Irrigation Systems, Circular 911; University of Georgia Cooperative Extension: Athens, GA, USA.
8. Ortiz, J.N; De Juan, J.A; Tarjuelo, J.M. 2010. Analysis of water application uniformity from a centre pivot irrigator and its effect on sugar beet (Beta vulgaris L.) yield. Biosyst. Eng. 105, pp. 367–379.
9. Playán, E.; Salvador, R.; Faci, J.M.; Zapata, N.; Martínez-Cob, A.; Sánchez, I. 2005. Day and night wind drift and evaporation losses in sprinkler solid-sets and moving laterals. Agric. Water Manag. 76, pp.139–159.
10. Al-Ghobari, H.M. 2010. The performance of the center pivot irrigation systems under Riyadh region conditions in Saudi Arabia. J. Saudi Soc. Agric. Sci. 9, pp.55–68.
11. Zhang, L.; Merkley, G.P.; Pinthong, K. 2013. Assessing whole-field sprinkler irrigation application uniformity. Irrig. Sci. 31, pp. 87–105.
12. CAI Dong-yu et al, 2020. Effects of water application uniformity using a center pivot on winter wheat yield, water and nitrogen use efficiency in the North China Plain. Journal of Integrative Agriculture, 19(9): pp. 2326–2339.

13. Ponjičan O, Bugarin R, Sedlar A, Turan J, Višacki V, Stanić N. 2017. Stanje i pravci razvoja navodnjavanja u svetu i kod nas. *Savremena poljoprivredna tehnika*, *43*(4), 147-157. https://doi.org/10.5937/SavPoljTeh1704147P .
14. Ponjičan, O., Učur, S., Vučinić, Ž., Samardžić, B., Sedlar, A., Turan, J., Višacki, V., & Vasić, F. 2022. Automatsko upravljanje sistemima za navodnjavanje. *Poljoprivredna tehnika*, *47*(1), pp. 1-14. https://doi.org/10.5937/PoljTeh2201001P
15. ASAE Standards, 48th ed. 2001. S436.1. Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles. St. Joseph, Mich.: ASAE.
16. Al-Ghobari, H.; Dewidar, A.Z. 2021.A Comparative Study of Standard Center Pivot and Growers-Based Modified Center Pivot for Evaluating Uniformity Coefficient andWater Distribution. Agronomy, 11, 1675.https:// doi.org/10.3390/agronomy11081675.

UNIFORMITY OF WATER DISTRIBUTION OF A COMBINED SELF-PROPELLED AUTOMATIC IRRIGATION DEVICE DURING LINEAR MOVEMENT

Ponjičan Ondrej

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Abstract. The combined self-propelled automatic irrigation device is intended for combined linear and circular movement. The uniformity of water distribution test was performed in the linear movement mode, during regular use of the device. The water pressure at the entrance to the device was from 1.8 to 1.9 bar, and according to the manufacturer's recommendation it should be 4 bar. A continuous decrease in the height of the applied water was determined, moving away from the water connection point. The tested device is new, but due to inappropriate use and adjustment, relatively low values were determined for the Christiansen's coefficient (CUc = 81.11%) and for the distribution uniformity coefficient (DUlq = 0.73), with a high value of the coefficient of variation (CV = 25.71%). The achieved values of the water distribution uniformity coefficients and the variation coefficient are at the limit of acceptability from the point of view of the use of water and land resources, as well as the impact on yield.

Key words: *Irrigation, uniformity of distribution, use, adjustment and maintance*

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PRIMENA MAŠINSKOG UČENJA U POLJOPRIVREDI

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Sažetak: Mašinsko učenje (eng. ML – Machines Learning), kao podskup veštačke inteligencije, igra ključnu ulogu u modernizaciji poljoprivrede, jer omogućava analizu velikih količina podataka i donošenje brzih i tačnih odluka u poljoprivrednoj proizvodnji. ML je korišćen u različitim fazama poljoprivrednog ciklusa, uključujući analizu zemljišta, kvalitet semena, detekciju bolesti useva, kontrolu korova, prepoznavanje biljnih vrsta i optimizaciju berbe. Različite metode ML, kao što su nadzirano učenje, nenadzirano učenje, polunadzirano učenje i pojačano učenje, koriste se u cilju poboljšanja tačnosti predviđanja i odluka u poljoprivredi. Veštačke neuronske mreže (eng. ANN - Artificial Neural Networks), posebno duboke neuronske mreže (eng. DNN - Deep Neural Networks) i konvolutivne neuronske mreže (eng. CNN - Convolutional Neural Networks), pokazale su se kao najefikasniji alati za analizu podataka, kao što su slike i numerički podaci, čime se omogućava precizno upravljanje poljoprivrednim praksama. Ove tehnologije omogućavaju optimizaciju resursa i smanjenje negativnog uticaja na životnu sredinu, čime se povećava održivost poljoprivredne proizvodnje.Primena mašinskog učenja u poljoprivredi predstavlja ključnu komponentu u razvoju precizne poljoprivrede, koja omogućava efikasno upravljanje proizvodnjom u realnom vremenu, smanjenje upotrebe resursa (kao što su voda, đubrivo i pesticidi), i povećanje prinosa. Iako su postignuti značajni napreci, postoji prostor za dalja istraživanja u razvoju novih modela ML koji će obuhvatiti sve faze poljoprivrednog ciklusa.

Ključne reči: *Precizna poljopriveda, mašinsko učenje, veštačke neuronske mreže, obrada slike*

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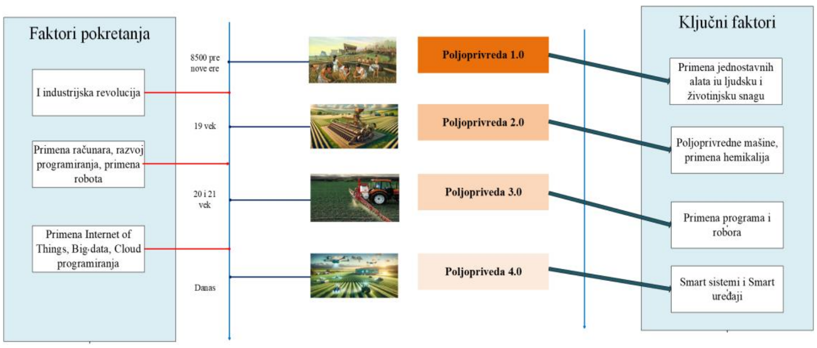
UVOD

Prema projekcijama na osnovu rasta stanovništva u poslednjih nekoliko decenija, očekuje se da će svetska populacija dostići broj i do 10 milijardi do 2050 [1]. Uporedo sa rastom stanovništva menja se i njegova struktura. Krajem 20 veka preko 60% stanovništva živelo je u ruralnim područjima, dok danas oko 54% stanovništva živi u velikim gradovima koji se sve više šire.

Porast stanovništa neminovno dovodi i do porasta potražnje za hranom, vodom i energijom koje su međusobno spregnute. FAO predviđanja za period u narednih trideset godina podrazumevaju porast svetske proizvodnje hrane za 60 do 70% [2]. Savremena poljopriveda, kao osnovni stub ekonomija svih država mora ne samo da odgovori na ovaj zadatak, nego ujedno da se suoči i sa trajnim klimatskim promenama [3], neprekidnim iscrpljivanjem prirodnih resursa [4], kao i sa savremenim zahtevima po pitanju proizvodnje zdrave i bezbedne hrane kao posledice promena životnih navika savremenog stanovništva.

Poljoprivreda je jedina privredna grana čiji rast i razvoj prati evoluciju čovečantsva [5], kao što je prikazano na Slici 1. Poljoprivreda 1.0 odnosi se na period primene ljudske i životinjske snage, uz primenu relativno jednostavnih poljoprivrednih oruđa. I industrijska revolucija uvela je značajne promene i u poljoprivredi koja se može definisati kao Poljopriveda 2.0.



Slika 1. Faze razvoja poljoprivrede, [5].
Figure 1. Stages of agricultural development, [5].

Razvoj poljoprivrednih mašina, kao i primena zaštitnih sredstava u biljnoj proizvodnji sa jedne strane, prouzorkovao je značajan porast poljoprivredne proizvodnje, ali na žalost sa druge strane, doveo i do zagađenja zemljišta i voda, prekomernog trošenja prirodnih resursa i preterane potrošnje energije. Ovi problemi su prilagođeni u Poljoprivredi 3.0 do kraja 20 veka, a nastali su pre svega kao posledica naglog rasta IT industrije koja je svoje mesto našla i u poljoprivredi. Racionalno gazdovanje poljoprivrednom tehnikom, ograničena upotreba hemijskih sredvstava u primarnoj poljoprivrednoj proizvodnju, unapređeni sistemi navodnjava, pokazali su da se poljoprivredna proizvodnja lako može prilagoditi savremenim izazovima i trendovima koji su pred njom.

Danas je evolucija poljoprivredne proizvodnje došla do faze Poljoprivreda 4., koja se prema Ujedinjenim nacijama naziva i Digitalna poljoprivredna revolucija, [6].

Zahvaljući primeni savremenih tehnologija kao što su Internet of Things, Big Data, Cloud Computing, Remoting Sensing Artificial Intelligence, efikasnost poljoprivredne proizvodnje može se značajno unaprediti, a da se pri tome proces proizvodnje bazira na održivom razvoju uz što je mogue manji negativan uticaj na životnu sredinu, trenutne prirodne resurse i potencijalno smanjenje efeksta staklene baste, [7-9].

Poljoprivreda 4.0 može se takođe definisati kao i složen sistem sakupljanja informacija daljinskom detekcijom, satelitkim snimcima, primenom dronova i sl. Ove informacije se moraju prikupiti u realnom vremenu i veoma brzo obraditi kako bi farmerima bile dostupne za brzo donošenje odluka. Treba imati na umu, da se količina ovih informacija neprekidno uvećava tokom procesa proizvodnje, pa je stoga potrebno ustanoviti šablone u obradi informacija, kako bi se proces odluke sveo na najkraći vremenski period. Mašinsko učenje (eng. Machine Learning –ML) razvilo se upredo sa naprednim računarskim tehnologijama i računarima visokih performansi kako bi se proces obrade podataka, detektovanje šablona i na kraju razumevanje procesa u obradi velikog broja podataka moglo primeniti. Od svojih početaka, polovinom prološ veka do danas, ML je našlo primenu gotovo u svim sferama industrije u kojima se proces odlučivaja zasniva na obradi podataka, a svoju primenu našlo je uspešno ne samo u primarnoj poljoprivrednoj proizvodnji, nego i u prehrambenoj industriji, [10].

PRINCIP I TEHNIKE MAŠINSKOG UČENJA

Kao podskup veštačke inteligencije, ML se može definisati najjednostavnije kao tehnika kojom se omogućuje računaru da uspostavi veze i šablone iz velikog broja podataka i da odgovarajuća predviđanja [11]. U tradicionalnom programiranju, računaru se zadaju instrukcije preko napisanog koda, koje računar sekvencijalno izvršava. ML podrazumeva da računar sam pronađe odgovarajuće veze između ulaznih podataka, da "nauči" model i izvrši predviđanja izlaznih podataka. S obzirom na činjenicu da ML modeli rade sa velikim brojem podataka, nisu zavisni od skladištenja na računarima, već upravo imaju sposobnost da podatke skladište na mreži (Cloud computing) i da ih pozivaju sa mreže. Sa druge strane, ML modeli zahtevaju jake procesore za obradu podataka, pa je kvaliter računara jedan od dorеđujućih faktora takođe. Generano, kreiranje ML agoritama i modela ne zahteva posebna teorijska znanja iz oblasti za koje se formiraju, već samo dobra programerska znanja softvera koji se koristi.

Slika 2. Shematski prikaz ML modela, [12].
Figure 2. Schematic representation of the ML model, [12].

Model se obično trenira do zadate tačnosti, ili što manjih gubitaka – razlika između predviđenih i realnih podataka. Proces se ponavlja više puta, uz modifikaciju vrednosti hiperparametara – veličina kojima se upravlja modelom, dok se ne dobije što je moguće bolje poklapanje i na podacima za treniranje, ali i na podacima za validaciju modela [12].

U praksi se međutim pokazalo, da bez obzira na formalno postizanje matematičke konvergencije u treniranju modela, teorijska znanja su od izuzetne važnosti radi što je mogućeg kvalitetnijeg tumačenja dobijenih vrednosti, koja u nekim primena ML mogu imati veliki i finansijski, ali i životni uticaj. Primera radi, ukoliko postoji samo jedna izlazna veličina iz ML modela, analiziraju se tzv. "False pozitive" i "False negative" vrednosti. "False positive" ili lažno tačne vrednosti u sličaju primene ML u navodnjavanju ili primeni odgovarajućih pesticida mogu upravo putem netačne informacije da farmera navedu da primeni više zaštitnog sredstva nego što je potrebno ili da pojača sistem za navodnjavanje preko granice koja je potrebna biljakama. "False negative" ili lažno netačna informacija može da manji sadržaj azota u biljaka zameni sa pojavom bolesti, i da na taj način farmera navede da donese poptuno pogrešnu odluku. U drugim granama primene ML modela, npr u finansijama, ovakve vrednosti mogu dovesti do pogrešnih procesa u poslovanju i velikih finansijskih gubitaka, a u najoštrijem slučaju u medicini, do pogrešnog dijagnostifikovanja bolesti [13]. U najširoj klasifikaciji ML može se podeliti u četiri grupe:

- Nadzirano učenje (eng. Supervised Learning)
- Nenadzirano učenje (eng. Unsupervised Learning)
- Polunadzirano učenje (eng. Semisupervised Learning)
- Pojačano učenje (eng. Reinforcement Learning)

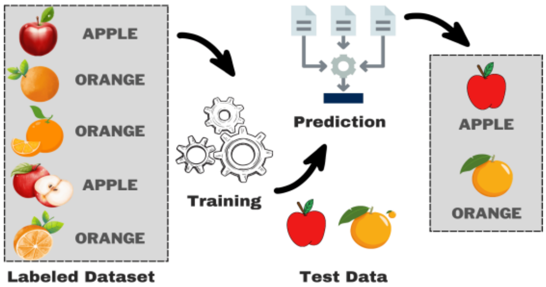
Bez obzira koja se grupa ML primenjuje, postupak fomiranja algoritma, modela i treniranja modela je identičan. Ulazni podaci se moraju prvo obraditi, tako što će se normalizovati, kao i izlazni podaci. U slučaju slika, one se prevode u tenzore, a svaki tenzor ima svoju oznaku. Neki ML modeli mogu da rade i sa podacima koji nedostaju, dok se kod nekih modela mora izvršiti prilagođavanje i isključiti ulazi sa nedostajućim vrednostima. Normalizovani podaci se dele na podatke za treniranje modela i validaciju (odnos 80:20 %), ili na podatke za treniranje, test i validaciju (80:10:10 %) ukoliko opstoji veliki broj podataka. Ne postoji precizan algoritam na koji se može pozvati u formiranju modela. Izborom hiperparametara, u većini slučajeva treniranje modela svodi se na model proba – test.

Nadzirano učenje

Nadzirano učenje je podkategorija ML u kojoj računar uči na osnovu seta označenih ulaznih i izlaznih podataka. U većini slučajeva, kao što je prikazano na Slici 3, ovi algoritmi i modeli se vezuju za prepoznavanje slika. Računar uči tako što povezuje naziv, kao izlaznu veličinu sa odgovarajućom slikom, kao ulaznom veličinom. Kada računar dobije novi nepoznati ulazni podatak da ga analizira, prvo ga deli na odgovarajuće osobine: oblik, tekstura, boja i sl, a zatim ove osobine upoređuje sa podacima iz kojih je učio. Kada pronađe da osobine se u najvećem procentu poklapaju sa nekom od označenih veličima, ulaznom podatku dodeljuje tu oznaku.

Ovi ML algoritmi koriste se u modelima klasifikacije i regresije. Inicijalno, većina ML modela koristi ovaj tip, mada su danas neki drugi modeli popularniji.

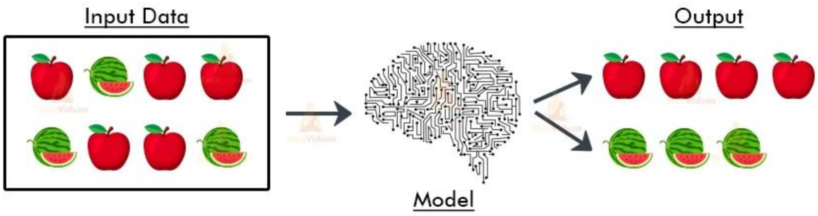
U većini slujačeva, primena nekog drugog tipa ML, na kraju se svodi na analizu nadziranim učenjem.



Slika 3. Shematski prikaz nadziranog učenja, [14].
Figure 3. Schematic representation of supervised learning, [14].

Nenadzirano učenje

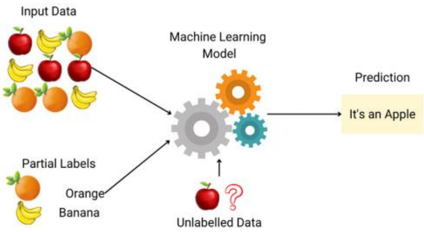
Nenadzirano učenje je podkategorija Ml koja obrađuje neoznačene podatke. Značavanje podataka može se tumačiti kao inicijalni ML algoritam, gde se podaci klasifikuju u odgovarajuće kategorije. U slučaju da podaci nisu označeni, nenadzirano učenje podrazumeva da računar sam mora da nauči da izvrši klasifikaciju podataka na osnovu njihovih polaznih parametara, kao što su na primer, boja, oblik, dimenzije i sl. Podacima se svakako na izlazu mogu dodeliti oznake ako je to neophodno.



Slika 4. Shematski prikaz nenadziranog učenja, [15].
Figure 4. Schematic representation of unsupervised learning, [15].

Polunadzirano učenje

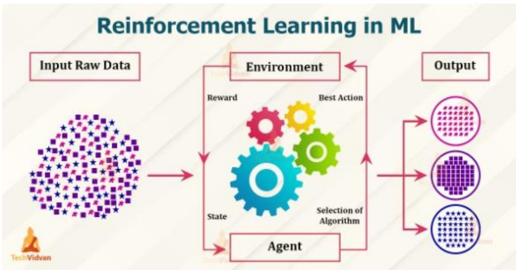
Polunadziranon učenje je specijalna kombinacija prethodna dva tipa ML, u kom se ulazni podaci dele u dve grupe: veliku grupu neobeleženih podatakam i malu grupu obeleženih podataka. Kako je na Slici 4 prikazano, računaru se dodeljuju podaci koji nnisu obeleženi i manji deo podataka koji je obeležen. Njegov zadatak je da za novi ulaz prepozna da nije ni jedan od podataka koji su obeleženi, pa da ovaj podatak klasifikuje u tačno odgovarajuću kategoriju.



Slika 5. Shematski prikaz nenadziranog učenja, [16].
Figure 5. Schematic representation of unsupervised learning, [16].

Pojačano učenje

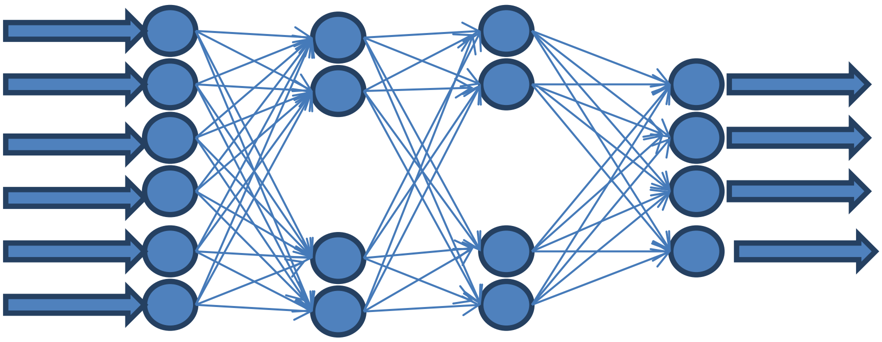
Pojačano učenje je još jedan tip kombinacije nadziranog i nenadziranog učenja, ali za razliku od polunadziranog učenja, u ovom učenju daje se nagrada za povrtane informacije algoritmu da uči i poboljša buduće rezultate. Pojačano učenje u mnogome liči na princip odlučivanja ljuskog mozga, pa se može koristiti u u mrežama sa veštačkim neuronima (eng. Artificial Neural Networks – ANN). Prednost ovih modela je što u slučaju pojave greške u početnim fazama učenja, upravo sistem u kom sebe algoritam koriguje može značiti da kasnije do iste greške neće uopšte ni dolaziti. Sa druge strane, mana modela je što zahtevaju mnogo podataka za treniranje u cilju dobijanja modela koji predviđa sa visokom tačnošću.



Slika 6. Shematski prikaz nenadziranog učenja, [17].
Figure 6. Schematic representation of unsupervised learning, [17].

Veštačke neuronske mreže (ANN), koje su se pokazale kao mreže koje daju najboloje rezultate u primeni u poljoprivredi [18]. Koncipirani da simuliraju rad ljudskog mozga, ovi modeli su sposobni da uče iz reprezentativnog skupa podataka. Pogodne su za širok dijapazon problema, pa čak i situacijama kada klasični modeli regresije ne daju očekivane rezultate. U osnovi se sastoje iz tri sloja: ulaznog, "skrivenog sloja" i izlaznog sloja, kao što je prikazano na Slici 7. Ulazni sloj sadrži set podataka koji treba da se obrade, i između kojih se funkcijama aktivacije u "skrivenim slojevima" pronalaze međusobne zavisnosti, da bi se na kraju u izlasnom sloju dobili očekivani podaci. Duboke neuronske mreže (eng. Deep Neural Networks - DNNs) kao podskup ANN modela koriste višestruke "skrivene slojeve" između ulaznih i izlaznih podataka, a moguće je ih primeniti i u nadziranom i nenadziranom učenju, [19].

Poseban tip DNNs-a su konvolutivne neuronske mreže (eng. Convolution Neural Networks - CNN) koje za razliku od tradicionalni mogu da organizuju neurone u mrežama u tri dimenzije [20]. Posebno je izražena njihova primena u obradi slika, gde mogu da postignu izuzetno visoku tačnost. Pored ovih mreža, postoji veliki broj mreža koje se mogu koristiti, a koje su manje zastupljene u analizama u poljoprivredi [21,22].



Slika 7. Primer DNNs modela u sušenju prehrambenih proizvoda
Figure 7. Example of DNNs model in drying food products

MAŠINSKO UČENJE U POPLJOPRIVREDI: PREGLED PRIMENE

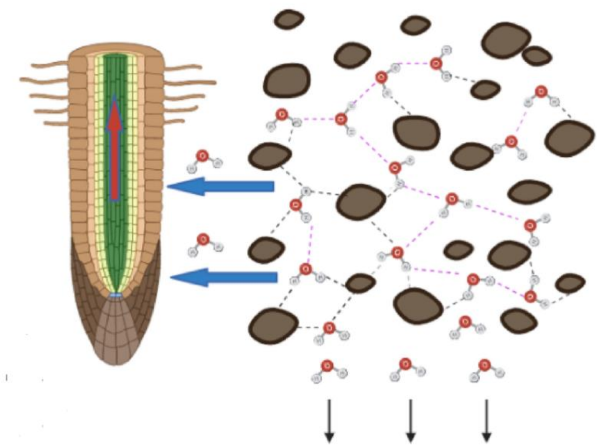
U okviru jednog proizvodnog ciklusa, farmeri moraju da izvrše odgovarajuće zadatke, bilo da je reč o ratarskoj, povrtarskoj ili voćarsko-vinogradarskoj proizvodnji, kao što je prikazano na Slici 6. Uopšteno, neophodna je priprema semena, priprema zemljišta, sejanje, navodnjavanje i đubrenje, održavanje useva primenom pesticida ili obrezivanje, proces branja ili žetve i na kraju primena post-žetvenih tehnologija kako bi proizvodi u dužem vremenskom periodu pre svega ostali mikrobiloški ispravni i kao takvi plasiran krajnjem potrošaču.

Slika 8. Faze u poljoprivrednoj proizvodnji, [23].
Figure 8. Stages in Agricultural production, [23].

Precizna poljoprivredna treba da obuhvati sve faze i korake u proizvodnji i da primenom odgovarajuće obrade prikupljenih popdataka u realnom vremenu na osnovu prethodnih saznanja pruži farmeru tačne informacije na osnovu kojih može da primeni adekvatne agrotehničke mere. ML upravo tu pruža velike mogućnosti za pravilnu obradu podataka. Bilo da je reč o modelima selektovanja, regresije, stabla odluke ili širokog spektra veštačkih neuronskih mreža koje mogu da vrše obradu slika, numeričkih i kategorijskih veličina, ML je u mogućnosti da za svaki pojedinačni segment kvantifikuje odgovarajuće parametre.

Upravljanje zemljištem

Upravljanje zemljištem je od izuzetne važnosti u početnim fazama ratarske i voćarske proizvodnje. Tradicionalne tehnike analiza zemljišta podrazumevaju uzorkovanje i laboratorijske analize koje mogu biti skupe, a zahtevaju i mnogo rada. Mapiranje zemljišta, u cilju detektovanja problema erozije, neravnoteže hranljivih materija izazvane prekomernnim đubrenjem i degradacijom zemljišta, tekstura, organska materija i na kraju sadržaj hranljivih materija veoma pristupačno se mogu rešiti primenom ML. Sa druge strane, baze podataka koje se obrađuju u modelima mogu biti i regionalno poveznane, pa se na taj način mogu uspostaviti zajednički modeli na izuzetno velikim površinama. Metod primene zavisi od tipa podataka koji su na raspolaganju, a mogu biti numerički podaci, gde je najlakše primeni ANN, ili ukoliko je mapiranje izvršeno fotografisanjem, mogu se primeniti CNN [24-32].

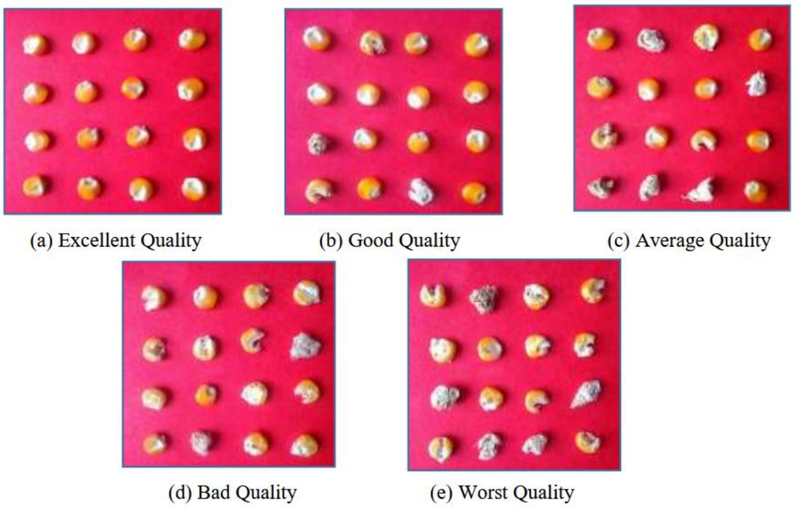


Slika 9. AI model kretanja vode kroz zemljište, [34].
Figure 9. AI model of water movement through soil, [34].

Seme

Kvalitet semena je od izuzetne važnosti za predviđanje prinosa i određivanje kvaliteta proizvodnje. U industrijskoj proizvodnji semena, klafikacija se uglavnom obavlja ručno, što daje mogućnost češće pojave greške i povećanje otpada.

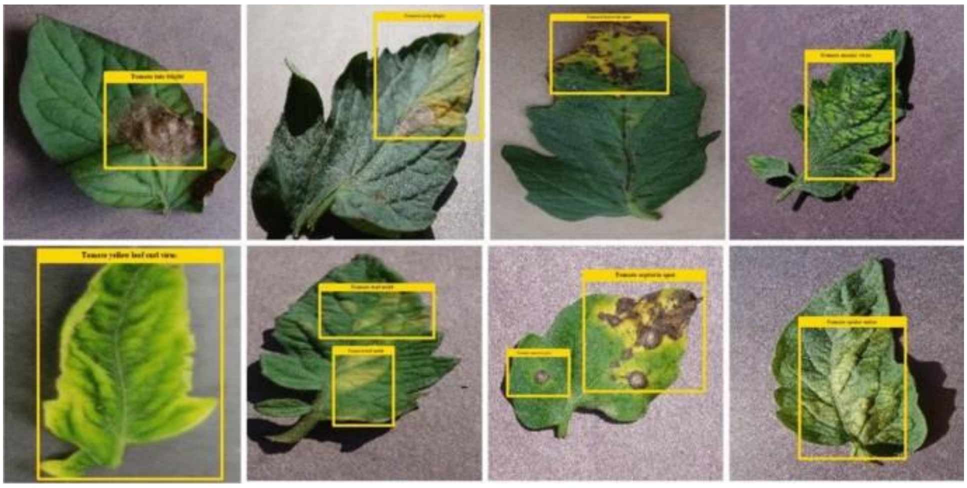
Automatizovano selektovanje semena moguće je obezbediti primenom različitih ML modela, koji u osnovi imaju korišćenje komjuterskog vida, tj. obradu slike. Iako su i ranije zabeleženi primeri obrade slike u cilju detekcije, a zatim i klasterovanja semena CNN mreže su se pokazale kao najpraktičnije i najpreciznije rešenje u ovom slučaju [34-38]



Slika 10. Određivanje kvaliteta semena primenom CNN modela, [39].
Figure 10. Seed quality assessment using CNN model, [39].

Bolesti useva

Bolesti useva su još jedan važan faktor za predviđanje kvaliteta prinosa, s obzirom na činjenicu da ukoliko se ne detektzuju na vreme ili ne primeni odgovarajuće zaštino sredstvo mogu značajno smanjiti ukupan prinos. Klasična poljoprivreda podrazumevala je obučene agronome koji su vizuleno detektovali bolesti i donosili odluke koji pesticid i kada terba primeninti. Današnja precizna poljoprivreda upravo pomaže da se razvoj bolesti otkrije na vreme, primeni pravi pesticid i u odgovarajućoj količini. I ovde je detektovanje zasnovano na vizulenoj promeni, kao što je promena boje lista, uvenuće, pojava pega na listovima i plofdovima, ujvijanje lista i sl. Tehnološki napredak je omogućio da se detektovanje promena senzorima, ali isto tako i slikanje pogotovo autonomnim vozilima u realnom vremenu kako bi se otkrila vrsta promene i površina koja je zahvaćena promenom, pa se mogu praviti i prostorne mape distribucije bolesti. I u ovom slučaju obrada slike se pokazala kao najbolje rešenje, a različiti tipovi ML modela su pokazali dobra predviđanja. Za dobar model u ovom slučaju neophodno je obezbediti veliki broj slika zdravih biljaka i veliki broj biljaka zahvaćenih odgovarajućom bolešću u različitim fazama razvijanjna bolesti. Slike se prvo klasteruju prema nazivima, a modeli treba da budu trenirani da sa dovoljnom preciznošću na osnovu slike daju pouzdanu informaciju na osnovu koje se kasnije odlučuje o primeni odgovarajućeg pesticida [40-52].

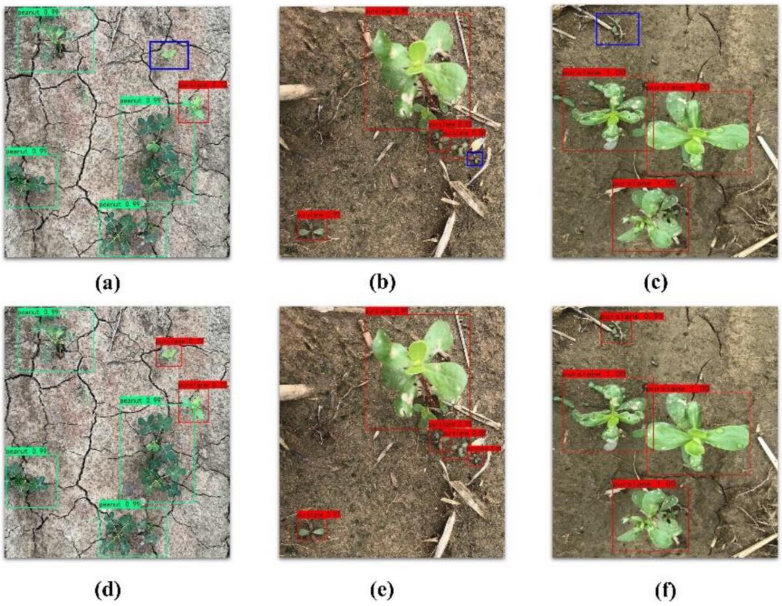


Slika 11. Detektovanje bolesti vizualizacijom i klasifikacijom, [53].
Figure 11. Disease detection by visualization and classification, [53].

Detekcija korova

Korovi se relativno lako i invazivno šire po površinama polja pre svega zbog svoje proizvodnje semena i dugovečnosti. Može se reći da se oni takmiče sa usevima za resurse kao što su prostor, svetlost, hranljive materije i dostupnost vode, a uglavnom izbijaju ranije od useva.

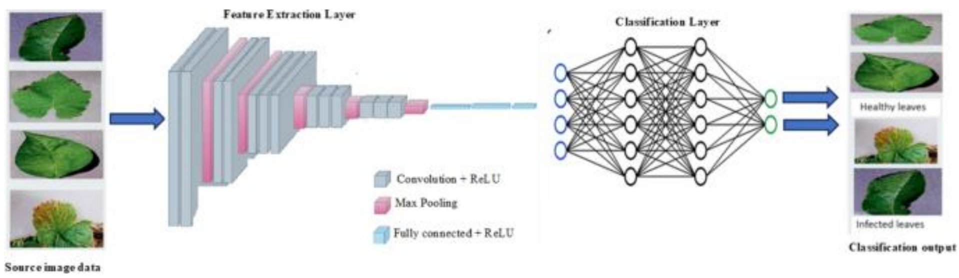
Kontrola korova može da se vrši dvojako, mehaničkim tretiranjem i primenom herbicida. Često je mehanički tretman težak za izvođenje, i neefikasan, pa je primena herbicida mnogo češća u praksi. Velika upotreba herbicida u dužem vremenskom peridou na žalost dovodi do otpornosti korova, a sa druge strane opasna je i po životnu sredinu. Primena dronova u ovom slučaju za fotografisanje, a zatim obrada slike različitim ML metodama može u mnogome da smanji primenu herbicida. ML model može da pruži informacije o trenutnoj fazi rasta korova, rasprostranjenosti na polju i da se na osnovu toda donese odluka o primeni odgovarajućeg herbicida u doziranoj količini [54-61].



Slika 12. Detekcija korova snimanjem i obradom slike, [62].
Figure 12. Weed detection by recording and image processing, [62].

Prepoznavanje useva

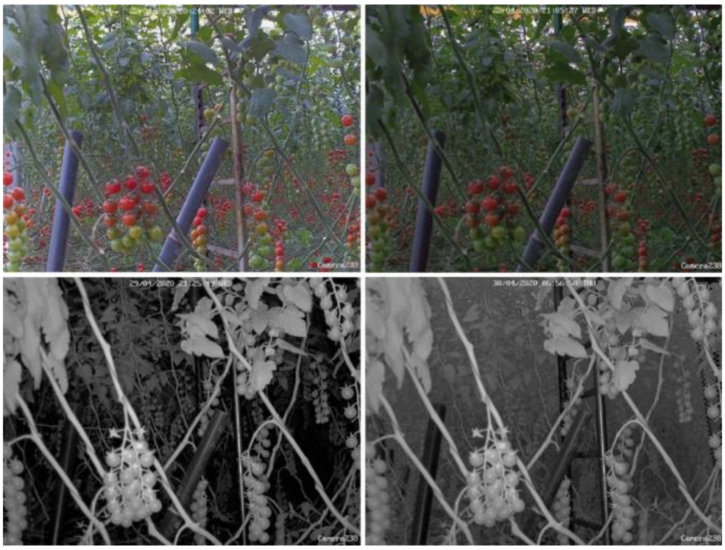
Biljne vrste mogu se identifikovati i klasifikovati ispitivanjem zaličitih organa kao što su koren, stabljike, listovi, cvetovi, plodovi, seme. Ova tehnika je poslednjih godina veoma popularna u taksonomiji bijaka i otkrivanju novih vrtsa. Najčešći metod koji se primenjuje je prepoznavanje biljke na osnovu lista. Primena dronova i ovde je od velike važnosti za otkrivanje svojstava biljaka, a kasnija obrada slika i velika baza podaka primenom ML mogu da obezbedu dobru klasifikaciju [63-67].



Slika 13. Detekcija useva CNN modelima, [68].
Figure 13. Crop detection with CNN models, [68].

Kvalitet useva

Kvalitet useva ima značaj uticaj za kasnije plasiranje na tržištu. Rezultat je primene svih agrotehničkih mera od setve žetve, i ubiranja plodova u optimalnoj fazi zrelosti. Najčešći indeksi na osnovu kojih se određuje optimalno vreme berbe su čvrstoća mesa, sadržaj rastvoriljivih materija, boja kože. U praksi se često primenjuje i selektivna berba kako bi se poboljšao kvalitet. Ovi podaci se neophodni i u kasnijim fazama skladištenja i čuvanja poljoprivrednih proizvoda na odgovarajućim uslovima. Podaci koji se mogu dobiti iz ove faze proizvodnje mogu biti numerički, kategorički ili slike. U zavisnosti od podataka mogu se primenjivati klasični ANN modeli, a mogu i kombinovani obradom slike i ostalih podataka. Značaj optimalne berbe može se sagledati i sa smanjivanjem nepotrebnog bacanje hrane, ili propadanja proizvoda u toku procesa skladištenja, [69-73].



Slika 14. Detekcija kvaliteta plodova paradajza obradom slike, [74].
Figure 14. Detection of tomato fruit quality by image processing, [74].

ZAKLJUČAK

Brojni radovi koji su poslednjih godina objavljeni na temu primene ML u poljoprivredi pokazuju da je ova tema u vrhu istraživanja. Obzirom na multidisciplinarost teme, zahteva anagžovanje stručnjaka širokog spektra, što joj takođe daje na aktuelnosti. Iako u radu nisu pokriveni svi aspekti primene ML u ratarskoj, voćarskoj i vinogradarskoj proizvodnji, a posebno u stočarskoj, iz pregleda se može videti da još postoje nerešena pitanja koja daju prostor za istraživanje i sa strane detekcija problema, načina prikupljanja i obrade podataka, a posebno modifikovanja i pronalađenja novih modela ML koji bi u budućnosti mogli da obuhvate čitav proizvodni proces.

Precizna poljoprivreda u osnovi uključuje uoptrebu algoritama ML, kako bi se u realnom vremenu donele važne i tačne odluke o upravljanju proizvodnjom.
Cilj ML modela je da na osnovu prkipljenih podataka mogu da daju realno predviđanje uz maksimalni ujčinak u prinosu, a uz minimiziranje ulaznih parametara, kao što su navodnjavanje, đubrenje i primena pesticida.

U većini primera su prikazani ML modeli koji uključuju obradu slike su među najčešćim, što se poklapa sa tehnikama precizne poljoprivrede i načinom uzorkovanja podataka. Ovi modeli i dalje mogu da se razvijaju, posebno u namenskoj primeni u poljoprivredi, a otvoren je prostor za modele koji kombinuju numeričke i grafičke podatke, što otvara vrata za projektovanje složenih biotehničkih informacionih sistema u budućnosti.

LITERATURA

[1] Food and Agriculture Organization. 2017. The Future of Food and Agriculture—Trends and Challenges. Food and Agriculture Organization of the United Nations: Rome, Italy.

[2] Powell, N., Ji, X., Ravash, R., Edlington, J., Dolferus, R. 2012. Yield stability for cereals in a changing climate. Functional Plant Biology, 39(7), pp. 539-552. https://doi.org/10.1071/FP12078.

[3] Thayer, A.W., Vargas, A., Castellanos, A.A., Lafon, C.W., McCarl, B.A., Roelke, D.L., Winemiller, K.O., Lacher, T.E. 2020. Integrating agriculture and ecosystems to find suitable adaptations to climate change. Climate, 8(10), pp. 1-12. https://doi.org/10.3390/cli8010010.

[4] Nassani, A.A., Awan, U., Zaman, K., Hyder, S., Aldakhil, A.M., Abro, M.M.Q. 2019. Management of natural resources and material pricing: Global evidence. Resources Policy, 64, pp. 101500. https://doi.org/10.1016/j.resourpol.2019.101500.

[5] Tekinerdogan, B. 2018. Strategies for technological innovation in Agriculture 4.0. Wageningen University, Wageningen, The Netherlands.

[6] Rose, D.C., Chilvers, J. 2018. Agriculture 4.0: Broadening responsible innovation in an era of smart farming. Frontiers in Sustainable Food Systems, 2, pp. 87.https://doi.org/10.3389/fsufs.2018.00087.

[7] Kovács, I., Husti, I. 2018. The role of digitalization in the agricultural 4.0—How to connect the industry 4.0 to agriculture? Hungarian Agricultural Engineering, 33, pp. 1-7.https://doi.org/10.17676/HAE.2018.33.38 .

[8] Bakkari, M., Khatory, A. 2017. Industry 4.0: Strategy for more sustainable industrial development in SMEs. Proceedings of the IEOM 7th International Conference on Industrial Engineering and Operations Management, Rabat, Morocco, April 11-13, pp. 43-49.

[9] Lee, J., Bagheri, B., Kao, H.-A. 2015. A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, pp. 18-23. https://doi.org/10.1016/j.mfglet.2014.12.001.

[10] Tambakhe, M.D., Gulhane, V.S., Karnewar, J.S. 2019. Machine learning application in the field of agriculture: A review. International Journal of Research in Advent Technology, 7(4), pp. 274-276.10.32622/ijrat.732019123.

[11] Venkatasubramanian, V. 2018. The promise of artificial intelligence in chemical engineering: Is it Here, Finally?. *AIChE Journal*, 65. No.2., pp. 466–478. https://doi.org/10.1002/aic.16489.

[12] Müller, A.C., Guido, S. 2016.*Introduction to Machine Learning with Python – A Guide for Data Scientists*. O'Reilly Media.

[13] Siqueira, V.S., Borges, M.M., Furtado, R.G., Dourado, C.N., Costa, R.M. 2021. Artificial intelligence applied to support medical decisions for the automatic analysis of echocardiogram images: A systematic review. *Artificial Intelligence in Medicine*, 120(5), 102165.https://doi.org/10.1016/j.artmed.2021.102165.

[14] K. Dnuggets. Understanding supervised learning: Theory and overview. Dostupno na: https://www.kdnuggets.com/understanding-supervised-learning-theory-and-overview.[Pristupljeno 29.11.2024.].

[15] TechVidvan. Unsupervised learning. Dostupno na: https://techvidvan.com/tutorials/unsupervised-learning [Pristupljeno 29.11.2024.].].

[16] Sharma, G. A gentle introduction to semi-supervised learning. *Medium*. Dostupno na:https://medium.com/@gayatri_sharma/a-gentle-introduction-to-semi-supervised-learning-7afa5539beea.[Pristupljeno 29.11.2024.].].

[17] TechVidvan. Reinforcement learning. Dostupno na: https://techvidvan.com/tutorials/reinforcement-learning. [Pristupljeno 29.11.2024.]..

[18] Chen, Y.Y., Lin, Y.H., Kung, C.C., Chung, M.H., Yen, I.H. 2019. Design and implementation of cloud analytics-assisted smart power meters considering advanced artificial intelligence as edge analytics in demand-side management for smart homes. *Sensors*, 19(9), 2047.https://doi.org/10.3390/s19092047.

[19] LeCun, Y., Bengio, Y., Hinton, G. 2015. Deep learning. *Nature*, 521(7553), pp. 436–444. https://doi.org/10.1038/nature14539.

[20] De Oliveira, M.A., Monteiro, A.V., Vieira Filho, J. 2018. A new structural health monitoring strategy based on PZT sensors and convolutional neural network. *Sensors*, 18(9), 2955. https://doi.org/10.3390/s18092955.

[21] Anagnostis, A., Benos, L., Tsaopoulos, D., Tagarakis, A., Tsolakis, N., Bochtis, D. 2021. Human activity recognition through recurrent neural networks for human–robot interaction in agriculture. *Applied Sciences*, 11(5), 2188. https://doi.org/10.3390/app11052188.

[22] Pisner, D.A.; Schnyer, D.M. Support Vector Machine; Mechelli, A., Vieira, S.B.T.-M.L., Eds.; Academic Press: Cambridge, MA, USA, 2020; Chapter 6; pp. 101–121. ISBN 978-0-12-815739-8

[23] Tripathi, P., Kumar, N., Rai, M., Shukla, P.K., Verma, K.N. 2023. Applications of Machine Learning in Agriculture. In: M. Khan, B. Gupta, A. Verma, P. Praveen, & C. Peoples (Eds.), *Smart Village Infrastructure and Sustainable Rural Communities*, IGI Global Scientific Publishing, pp. 99-118. https://doi.org/10.4018/978-1-6684-6418-2.ch006.

[24] Lampridi, M., Sørensen, C., Bochtis, D. 2019. Agricultural sustainability: A review of concepts and methods. *Sustainability*, 11, 5120.https://doi.org/10.3390/su11185120.

[25] Suchithra, M.S., Pai, M.L. 2020. Improving the prediction accuracy of soil nutrient classification by optimizing extreme learning machine parameters. *Information Processing in Agriculture*, 7(1), pp. 72–82. https://doi.org/10.1016/j.inpa.2019.06.001.

[26] Nahvi, B., Habibi, J., Mohammadi, K., Shamshirband, S., Saleh Al Razgan, O. 2016. Using self-adaptive evolutionary algorithm to improve the performance of an extreme learning machine for estimating soil temperature. *Computers and Electronics in Agriculture*, 124, pp. 68–79. https://doi.org/10.1016/j.compag.2016.03.025.

[27] Johann, A.L., de Araújo, A.G., Delalibera, H.C., Hirakawa, A.R. 2016. Soil moisture modeling based on stochastic behavior of forces on a no-till chisel opener. *Computers and Electronics in Agriculture*, 121, pp. 420–428. https://doi.org/10.1016/j.compag.2015.12.020.

[28] Gebbers, A.V.I. 2010. Precision agriculture and food security. *Science*, 327(5967), pp. 828–831. https://doi.org/10.1126/science.1183899.

[29] Chakravarti, A., Joshi, N., Panjiar, H. 2015. Rainfall runoff analysis using artificial neural network. *Indian Journal of Science and Technology*, 8(14), pp. 1–7. https://doi.org/10.17485/ijst/2015/v8i14/54370.

[30] Besalatpour, A., Hajabbasi, M.A., Ayoubi, S., Gharipour, A., Jazi, A.Y. 2012. Prediction of soil physical properties by optimized support vector machines. *International Agrophysics*, 26(2), pp. 121–129. https://doi.org/10.2478/v10247-012-0017-7.

[31] Azizi, A., Gilandeh, Y.A., Mesri-Gundoshmian, T., Saleh Bigdeli, A.A., Moghaddam, H.A. 2020. Classification of soil aggregates: A novel approach based on deep learning. *Soil and Tillage Research*, 199, 104586. https://doi.org/10.1016/j.still.2020.104586.

[32] Zema, D.A., Nicotra, A., Mateos, L., Zimbone, S.M. 2018. Improvement of the irrigation performance in water users associations integrating data envelopment analysis and multi-regression models. *Agricultural Water Management*, 205, pp. 38–49. https://doi.org/10.1016/j.agwat.2018.04.032.

[33] Sawarkar, M., Rode, S.V. 2017. Digital image processing applied to seed purity test. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, 5(5). https://doi.org/10.17148/IJIREEICE.2017.5539.

[34] Awais, M., Naqvi, S.M.Z.A., Zhang, H., et al. 2023. AI and machine learning for soil analysis: An assessment of sustainable agricultural practices. *Bioresources and Bioprocessing*, 10(90). https://doi.org/10.1186/s40643-023-00710-y.

[35] Belsare, P.P., Dewasthale M.M. 2013. Application of image processing for seed quality assessment: A survey. *International Journal of Engineering Research & Technology (IJERT)*, 2(2), Paper ID IJERTV2IS2152.

[36] Sivakumar, D., SuriyaKrishnaan, K., Akshaya, P., Anuja, G.V., Devadharshini, G.T. 2019. Computerized growth analysis of seeds using deep learning method. *International Journal of Recent Technology and Engineering*, 7(6S5). Paper ID F13380476S519/2019©BEIESP.

[37] Huang, S., Fan, X., Sun, L., Shen, Y., Suo, X. 2019. Research on classification method of maize seed defect based on machine vision. *Journal of Sensors*, 2019, Article ID 2716975. https://doi.org/10.1155/2019/2716975.

[38] Young, J., Se, J.K., Dayeon, K., Keondo, L., Wan, C.K. 2018. Super-high-purity seed sorter using low-latency image-recognition based on deep learning. *IEEE Robotics and Automation Letters*, 3(4), pp. 2377–2382. https://doi.org/10.1109/LRA.2018.2849513.

[39] Bhurtel, M., Shrestha, J., Lama, N., Bhattarai, S., Uprety, A., & Guragain, M. K. 2019. Deep learning based seed quality tester. In Science, Engineering and Technology (SET) Conference, pp. 1-10.

[40] Alagumariappan, P., Dewan, N.J., Muthukrishnan, G.N., et al. 2020. Intelligent plant disease identification system using machine learning. *Engineering Proceedings*, 2, 49. https://doi.org/10.3390/ecsa-7-08160.

[41] Savary, S., Ficke, A., Aubertot, J.-N., Hollier, C. 2012. Crop losses due to diseases and their implications for global food production losses and food security. *Food Security*. https://doi.org/10.1007/s12571-012-0200-5.

[42] Sujatha, R., Chatterjee, J.M., Jhanjhi, N.Z., Brohi, S.N. 2021. Performance of deep learning vs machine learning in plant leaf disease detection. *Microprocessors and Microsystems*, 80. https://doi.org/10.1016/j.micpro.2020.103615.

[43] Karadag, K., Tenekeci, M.E., Tasaltı, R., Bilgilic, A. 2018. Detection of pepper fusarium disease using machine learning algorithms based on spectral reflectance. *Sustainable Computing: Informatics and Systems*, 8. https://doi.org/10.1016/j.suscom.2019.01.001.

[44] Pandya, I.Y. 2018. Pesticides and their applications in agriculture. *Asian Journal of Applied Science and Technology (AJAST)*, 2(2), pp. 894–900. ISSN: 2456-883X.

[45] Arsenovic, M., Karanovic, M., Sladojevic, S., Anderla, A., Stefanovic, D. 2019. Solving current limitations of deep learning-based approaches for plant disease detection *Symmetry (Basel)*, 11, 939. https://doi.org/10.3390/sym11070939.
[46] Barbedo, J.G.A. 2019. Plant disease identification from individual lesions and spots using deep learning. *Biosystems Engineering*, 180, pp. 96–107. https://doi.org/10.1016/j.biosystemseng.2019.02.002.
[47] Saleem, M.H., Potgieter, J., Arif, K.M. 2019. Plant disease detection and classification by deep learning. *Plants*, 8, 468. https://doi.org/10.3390/plants8110468.
[48] Harvey, C.A., Rakotobe, Z.L., Rao, N.S., Dave, R., Razafimahatratra, H., Rabarijohn, R.H., Rajaofara, H., MacKinnon, J.L. 2014. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1639), 20130089, https://doi.org/10.1098/rstb.2013.0089.
[49] Wu, H., Wiesner-Hanks, T., Stewart, E.L., DeChant, C., Kaczmar, N., Gore, M.A., Nelson, R.J., Lipson, H. 2019. Autonomous detection of plant disease symptoms directly from aerial imagery. *The Plant Phenome Journal*, 2(1), pp. 1–9, https://doi.org/10.2135/tppj2019.03.0006.
[50] Abdu, A.M., Mokji, M.M., Sheikh, U.U. 2020. Automatic vegetable disease identification approach using individual lesion features. *Computers and Electronics in Agriculture*, 176, 105660. https://doi.org/10.1016/j.compag.2020.105660.
[51] Picon, A., Alvarez-Gila, A., Seitz, M., Ortiz-Barredo, A., Echazarra, J., Johannes, A. 2019. Deep convolutional neural networks for mobile capture device-based crop disease classification in the wild. *Computers and Electronics in Agriculture,* 161, pp. 280–290, https://doi.org/10.1016/j.compag.2018.04.002.
[52] Wiesner-Hanks, T., Wu, H., Stewart, E., DeChant, C., Kaczmar, N., Lipson, H., Gore, M.A., Nelson, R.J. 2019. Millimeter-level plant disease detection from aerial photographs via deep learning and crowdsourced data. *Frontiers in Plant Science*, 10, 1550, https://doi.org/10.3389/fpls.2019.01550.
[53] Nawaz, M., Nazir, T., Javed, A., et al. 2022. A robust deep learning approach for tomato plant leaf disease localization and classification. *Scientific Reports*, 12, 18568. https://doi.org/10.1038/s41598-022-21498-5.
[54] Su, W.H. 2020. Advanced Machine Learning in Point Spectroscopy, RGB- and Hyperspectral-Imaging for Automatic Discriminations of Crops and Weeds: A Review. *Smart Cities*, 3, pp. 767–792, https://doi.org/10.3390/smartcities3030039.
[55] Ahmad, J., Muhammad, K., Ahmad, I., Ahmad, W., Smith, M.L., Smith, L.N., Jain, D.K., Wang, H., Mehmood, I. 2018. Visual features based boosted classification of weeds for real-time selective herbicide sprayer systems. *Computers in Industry*, 98, pp. 23–33, https://doi.org/10.1016/j.compind.2018.02.005.
[56] Bah, M.D., Hafiane, A., Canals, R. 2018. Deep learning with unsupervised data labeling for weed detection in line crops in UAV images. *Remote Sensing*, 10(11), 1690. https://doi.org/10.3390/rs10111690.
[57] Barrero, O., Perdomo, S.A. 2018. RGB and multispectral UAV image fusion for Gramineae weed detection in rice fields. *Precision Agriculture*, 19(5), pp. 809–822, https://doi.org/10.1007/s11119-017-9558-x.
[58] Sabzi, S., Abbaspour-Gilandeh, Y. 2018. Using video processing to classify potato plants and three types of weed using hybrid of artificial neural network and particle swarm algorithm. *Measurement*, Volume 126, pp. 22–36. https://doi.org/10.1016/j.measurement.2018.05.037.
[59] Teimouri, N., Dyrmann, M., Nielsen, P.R., Mathiassen, S.K., Somerville, G.J., Jorgensen, R.N.2018. Weed growth stage estimator using deep convolutional neural networks. *Sensors*, 18(5), 1580. https://doi.org/10.3390/s18051580.

[60] Partel, V., Kakarla, S.C., Ampatzidis, Y. 2019. Development and evaluation of a low-cost and smart technology for precision weed management utilizing artificial intelligence. *Computers and Electronics in Agriculture*, 157, pp.339–350, https://doi.org/10.1016/j.compag.2018.12.048.

[61] Kamath, R., Balachandra, M., Prabhu, S. 2020. Paddy crop and weed discrimination: A multiple classifier system approach. *International Journal of Agronomy*, 2020, https://doi.org/10.1155/2020/6474536.

[62] Zhang, H., Wang, Z., Guo, Y., Ma, Y., Cao, W., Chen, D., Yang, S., Gao, R. 2022. Weed Detection in Peanut Fields Based on Machine Vision. *Agriculture*, 12(10), 1541. https://doi.org/10.3390/agriculture12101541.

[63] Ji, S., Zhang, C., Xu, A., Shi, Y., Duan, Y. 2018. 3D convolutional neural networks for crop classification with multi-temporal remote sensing images. *Remote Sensing*, 10(1), 75, https://doi.org/10.3390/rs10010075.

[64] Nemmaoui, A., Aguilar, M.A., Aguilar, F.J., Novelli, A., Garcia Lorca, A. 2018. Greenhouse crop identification from multi-temporal multi-sensor satellite imagery using object-based approach: A case study from Almería (Spain). *Remote Sensing*, 10(11), 1751, https://doi.org/10.3390/rs10111751.

[65] Piedelobo, L., Hernandez-Lopez, D., Ballesteros, R., Chakhar, A., Del Pozo, S., Gonzalez-Aguilera, D., Moreno, M.A. 2019. Scalable pixel-based crop classification combining Sentinel-2 and Landsat-8 data time series: Case study of the Duero river basin. *Agricultural Systems*, 171, pp. 36–50, https://doi.org/10.1016/j.agsy.2019.01.005.

[66] Sun, C., Bian, Y., Zhou, T., Pan, J. 2019. Using of multi-source and multi-temporal remote sensing data improves crop-type mapping in the subtropical agriculture region. *Sensors*, 19(10), 2401, https://doi.org/10.3390/s19102401.

[67] Wei, S., Zhang, H., Wang, C., Wang, Y., Xu, L. 2019. Multi-temporal SAR data large-scale crop mapping based on U-Net model. *Remote Sensing*, 11(1), 68, https://doi.org/10.3390/rs11010068.

[68] Ngugi, H.N., Ezugwu, A.E., Akinyelu, A.A., et al. 2024. Revolutionizing crop disease detection with computational deep learning: A comprehensive review. *Environmental Monitoring and Assessment*, 196, 302. https://doi.org/10.1007/s10661-024-12454-z.

[69] Genze, N., Bharti, R., Grieb, M., Schultheiss, S.J., Grimm, D.G. 2020. Accurate machine learning-based germination detection, prediction, and quality assessment of three grain crops. *Plant Methods*, 16(1), pp. 1–11, https://doi.org/10.1186/s13007-020-00699-x.

[70] De Medeiros, A.D., Pinheiro, D.T., Xavier, W.A., da Silva, L.J., dos Santos Dias, D.C.F. 2020. Quality classification of *Jatropha curcas* seeds using radiographic images and machine learning. *Industrial Crops and Products*, 146, https://doi.org/10.1016/j.indcrop.2020.112162.

[71] Lee, J., Nazki, H., Baek, J., Hong, Y., Lee, M. 2020. Artificial intelligence approach for tomato detection and mass estimation in precision agriculture. *Sustainability*, 12(21), 9138, https://doi.org/10.3390/su12219138.

[72] Yang, B., Gao, Y., Yan, Q., Qi, L., Zhu, Y., Wang, B. 2020. Estimation method of soluble solid content in peach based on deep features of hyperspectral imagery. *Sensors*, 20(18), 5021, https://doi.org/10.3390/s20185021.

[73] Kamath, R., Balachandra, M., Prabhu, S. 2020. Crop and weed discrimination using Laws' texture masks. *International Journal of Agricultural and Biological Engineering*, 13(1), pp. 191–197, https://doi.org/10.25165/j.ijabe.20201301.4920.

[74] Perales Gómez, Á.L., López-de-Teruel, P.E., Ruiz, A., et al. 2022. FARMIT: Continuous assessment of crop quality using machine learning and deep learning techniques for IoT-based smart farming. *Cluster Computing*, 25, pp. 2163–2178. https://doi.org/10.1007/s10586-021-03489-9.

APPLICATION OF MACHINE LEARNING IN AGRICULTURE

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Abstract. Machine learning (ML) is a key technology driving the modernisation of agriculture. It enables large data sets to be analysed and precise decisions to be made at all stages of agricultural production.

ML is used for soil analysis, plant disease detection, weed control, crop species identification and harvest optimisation. Various techniques such as supervised, unsupervised and reinforcement learning help to improve the accuracy of predictions and decisions. Artificial neural networks (ANN), in particular deep neural networks (DNN) and convolutional neural networks (CNN), efficiently analyse images and numerical data and enable precise management of agricultural practises. These technologies contribute to sustainability by reducing the negative impact on the environment and optimising the use of resources.

While significant progress has already been made, there is still potential for further development of ML models that cover all phases of the agricultural cycle and make precision agriculture more efficient and safer

Key words: *Precision agriculture, machine learning, artificial neural networks, image processing.*

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