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COMPARATIVE ANALYSIS OF YIELD AND PROFITABILITY OF MAIZE (*Zea mays* L..) PRODUCTION USING PRECISION AGRICULTURE IN THE SEMI-ARID REGION OF NIGERIA

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ABSTRACT

Maize (*Zea mays* L.) is a crucial staple crop in Nigeria, particularly in the semi-arid region where productivity is constrained by erratic rainfall, low soil fertility, and inefficient use of inputs. Precision Agriculture (PA), particularly Internet of Things (IoT) enabled nutrient management, offers a potential solution to enhance maize yield and profitability. However, empirical evidence on its effectiveness remains limited in Nigeria. This study conducted a dual-locational field trial at Dutsin-Ma and Malumfashi in Katsina State during the 2023/2024 rainy season to compare maize yield and profitability across four fertilization strategies (IoT-assisted nutrient application, recommended agronomic practice, farmers' conventional methods, and a control) laid out in a Randomized Complete Block Design (RCBD) and replicated four (4) times. Results showed that the recommended agronomic practice consistently produced the highest yields at both study sites (3458 kg/ha in Dutsin-Ma and 4963 kg/ha in Malumfashi), followed by IoT-based application, which outperformed farmers' conventional methods in Malumfashi but not in Dutsin-Ma. Partial budgeting analysis revealed that while the recommended practice had the highest net returns, IoT-based fertilization showed promising economic benefits, particularly in more favourable agro-ecological conditions. The findings highlight the potential of PA in optimizing input use and improving maize productivity, but also underscore the need for site-specific calibration and farmer adaptation strategies. Scaling up digital agriculture will require targeted investments in infrastructure, training, and policy support to enhance adoption among smallholder farmers in Nigeria's dry lands.

Keywords: Maize, Precision agriculture, IoT, Yield, Profitability

INTRODUCTION

Maize (*Zea mays* L.) is a staple crop and a vital source of food, feed, and income in Nigeria, particularly in the semi-arid region where agricultural production is increasingly vulnerable to erratic rainfall, low soil fertility, and unsustainable farming practices. The crop occupies an essential position in Nigeria's agricultural economy, contributing significantly to household food security and national Growth Domestic Products (GDP) (FAOSTAT, 2023). However, maize yields in many parts of sub-Saharan Africa, including Nigeria, remain significantly below their potential due to sub-optimal agronomic practices, poor input use efficiency, and climate-induced stresses (AGRA, 2022).

Recent innovations in Precision Agriculture (PA) particularly the deployment of Internet of Things (IoT) enabled systems offer promising opportunities to enhance the productivity, profitability, and sustainability of maize production. These technologies support real-time monitoring of soil nutrients, water availability, and plant health, thereby enabling data-driven decision-making and efficient input use (Wolfert *et al*., 2017; Parameswaran *et al*., 2020). Despite these potential benefits, the adoption of PA remains low in most parts of rural Nigeria due to infrastructural limitations, lack of awareness, and insufficient empirical evidence on the cost-benefit outcomes of such technologies (Nnadi *et al*., 2022).

This study focuses on a comparative analysis of maize yield and profitability under different fertilization strategies, including IoT-assisted nutrient application, recommended agronomic practices, farmers' conventional methods, and a control. The study leverages site-specific soil data and yield outcomes to evaluate the effectiveness of precision agriculture in the semi-arid zone.

Materials and Methods

A dual-locational field trial for the production of maize using Internet of Thing (IoT) was conducted in two locations in Katsina State. The chosen locations are: Dutsin-Ma 12° 25.776N, 7° 27.812' E and 512m above sea level and Malumfashi, 11° 41.30' N 7° 30.863' E and 647m above sea level. The treatments were laid out in Randomized Complete Block Design (RCBD) and replicated four (4) times. The treatments consisted of: T1:

Internet of Thing (IoT), T2: Recommended Practice (RR), T3: Farmers' Method (FP) and T4: Control. The (IoT) treatment involves using an IoT device to determine soil nutrient availability prior to the application of fertiliser. Subsequently, the shortfall in terms of the recommended rate is then augmented to meet crop requirements. The recommended rate is the actual rate for Maize in Savannah Zone of Nigeria. The farmers' practice refers to the practice of applying inorganic fertiliser to crops without any prior soil test and also not based on recommended rates established for a specific crop.

The lands intended for this research were manually cleared using cutlass. All stumps of previous plants were removed. The lands were demarcated, layout and properly labelled respectively. Each plot measured 5 m x 4.5 m with 0.5 m as discard between plots and replications. SAMMAZ 53 an early maturing (85 days) was planted at an inter and intra row spacing of 75 cm x 25 cm with an expected plant population of 53,333 plants per hectare. Prior to planting, seeds were dressed with Dress Force (Imidaclorpid 20%+M20% a +Tebuconazole2% WS) at the rate of 1 sachet/4 kg. Three (3) seeds were planted in a hole of 3-5 cm deep. Immediately after planting, the land was sprayed with a mixture of Atrazine containing 80% WP (containing 800g/kg Atrazine powder) as pre-emergence and systemic herbicide and Paraquat as, a non-selective herbicide consisting of Paraquat Dichloride (276g/l).

The recommended rate of NPK, 120kg N ha^{-1}:60kg P_2O_5:60kg K_2O ha^{-1}, was used for the experiment, where the N rate was applied in split doses. NPK (20:10:10) was used for the experiment while urea (46 % N), single super phosphate (18% P_2O_5) and murate of potash (60% K_2O) were equally used to supplement where necessary to meet the recommended rate. The first application of 60kg N ha^{-1}:60 kg P_2O_5 :60kg K_2O ha^{-1} was done at 2 week after sowing (WAS). The second dose of N was applied at 5 WAS using urea (46 % N) at the rate of 60kg N ha^{-1}. The needed N, P and K were added to the Internet of Things (IoT) plots based on nutrients contained in the soil to meet the recommended rate of 120kg N ha^{-1}:60 P_2O_5:60kg K_2O ha^{-1}. For farmers' practice, the quantity of fertilizer applied was determined after a key informant interview (KII) with some maize farmers in the two study areas. The KII revealed that 4 bags of NPK and 1 bag of urea are generally applied. The control plots were without fertilizer application. The data on grain yield were measured at harvest and the total grain weight per plot was expressed in kilogram hectare (kg ha^{-1}).

Grain yield data were subjected to statistical analysis of variance (ANOVA) as described by Gomez and Gomez (1984). The differences among treatment means were separated using Duncan's Multiple Range Test (Duncan, 1955)

Description of the IoT system deployed

Microcontroller (ESP32*):* The core processing unit, responsible for controlling sensors, displaying data, and transmitting information which supports WiFi connectivity and multiple sensor inputs.

Sensor Suite: A 7-in-1 sensor capable of measuring humidity, temperature, electrical conductivity, pH, nitrogen (N), phosphorus (P), and potassium (K).

LCD Display: 16x4 I2C LCD to provide real-time visualization of the collected data.

Power Supply: A 5V power source is used to power the ESP32 microcontroller, the sensor and the router.

The two locations used for the trial have different soil profiles, providing an opportunity to test the system under varying conditions. Readings were taken from different point in the two locations at varying times.

Partial Budgeting Analysis

The profitability analysis was based on the formula developed by CIMMYT (1988) and given as follows.

Estimation of the gross returns: Gross returns were calculated by multiplying the unit price of a Kg of Maize (Pq) by the adjusted yield.

Gross returns = $Pq \ast$ Adjusted yield

CIMMYT (1988) also recommended reducing experimental yields by a percentage ranging from 5 to 30%, in order to approach those obtainable by farmers on their farms. As such,

Adjusted yield = Experimental yield $\ast$ (1 – adjustment ate). An adjustment rate of 10 per cent was adopted in the study.

Estimation of net returns: These were obtained by subtracting from the gross returns, the costs that vary (CVi).

Net returns = Gross returns $- CVi$

CVi is the costs that vary. This is obtained by multiplying the unit prices of the relevant inputs by their levels of use in each treatment and then summing up. Only the costs associated with the decision to use or not to use a treatment are taken into account. These are the costs that make it possible to differentiate one treatment from the other and they are called "Costs that Vary", and they are so called because they vary from one treatment to another. The remaining costs are not affected by the decision to use a particular treatment, and remain constant (Reyes-Hernández, 2001). The costs of NPK, UREA, SSP and MOP are the ones that vary in this study.

RESULTS AND DISCUSSION

Some physico-chemical properties of soils in the experimental sites are presented in Table 1. Dutsin-Ma has higher organic carbon, nitrogen, and potassium, indicating stronger immediate nutrient content. Malumfashi has higher phosphorus, CEC, and a more favorable pH, suggesting better nutrient retention and availability in the long run. In terms of long-term fertility and nutrient availability, Malumfash***i*** slightly edges out Dutsin-Ma in overall soil fertility status.

Table 1: Some physico-chemical properties of soils in the experimental sites

	Experimental site	
Parameter	**Dutsin-Ma**	**Malumfashi**
Soil texture (%)		
Sand	66.48	56.75
Silt	28.89	33.01
Clay	4.63	10.24
Textural class	**Sandy loam**	**Sandy loam**
Organic carbon (%)	1.03	0.36
Nitrogen (mg/kg)	0.06	0.05
Phosphorus (mg/kg)	0.89	4.70
$Potassium^{+}$ (cmol/kg)	0.22	0.13
Cation Exchange capacity	3.39	5.24
pH (1:1)	5.93	6.11

Soil analysis as conducted in the laboratory of Centre for Dryland Agriculture, Bayero University Kano, Nigeria.

The grain yield of maize under four fertilizer application methods is presented in Table 2 across two semi-arid locations in Katsina State**:** Dutsin-Ma**,** and Malumfashi**.** In Dutsin-Ma, the recommended fertilizer rate yielded the highest grain output (3458 kg/ha), significantly outperforming all other methods ($P< 0.05$). The IoT method (1748 kg/ha) and Farmers' Practice (1769 kg/ha) performed similarly and were both substantially better than the control (514 kg/ha). This pattern reflects the known efficiency of following site-specific recommended nutrient management protocols**,** which are designed to match crop nutrient requirements and maximize uptake efficiency (Vanlauwe *et al*., 2015).

Table 2: Influence of fertilizer application methods on grain yield of maize

	Grain Yield (kg ha^{-1})	
Treatments	**Dutsin-Ma**	**Malumfashi**
Fertilizer Application Methods		
Control	514^{c}	2056^{c}
Farmers' Practice	1769^{b}	3611^{b}
Recommended Rate	3458^{a}	4963^{a}
Internet of Thing (IoT)	1748^{b}	3982^{b}
SE (±)	208.50	122.20

Means followed by the same superscript within the same treatment are not significantly different at 5% level of probability using Duncan's Multiple Range Test (DMRT).

At Malumfashi, the recommended rate again produced the highest yield (4963 kg/ha), followed by IoT-based application (3982 kg/ha) and Farmers' Practice (3611 kg/ha). Interestingly, the IoT method outperformed the farmers' approach, indicating that real-time soil monitoring and nutrient matching using IoT tools can result in better nutrient use efficiency and potentially improved yield outcomes under favourable agro-ecological conditions. These findings are in line with the work of Gebbers and Adamchuk (2010), who highlighted how precision agriculture technologies enhance productivity by tailoring input applications to crop and site needs.

Comparing IoT vs Farmers' Methods

The IoT-based fertilizer application method, although technologically advanced, did not always outperform the traditional farmers' practice, particularly in Dutsin-Ma. This may be attributed to technical limitations in sensor calibration, timing of application, or a learning curve associated with deploying IoT in real-world field conditions. As suggested by Zhang et al. (2021), while IoT in agriculture holds transformative potential, its success depends on contextual calibration, user adaptation, and ecological suitability**.** However, in Malumfashi, where soil conditions (Table 1) and rainfall was more favourable, IoT-based application provided a measurable advantage. This finding aligns with Raza *et al*. (2019), who reported that digital farming tools are most effective when used in conjunction with good agronomic practices and enabling environmental factors.

Generally, across the two locations, recommended fertilizer rates consistently yielded the highest grain output, reaffirming the effectiveness of agronomic best practices in maize cultivation (Adediran *et al.*, 2020). The IoT system showed promise, particularly in more fertile and better-watered conditions, but its performance was inconsistent across sites

Partial Budgeting Analysis

At Dustin-Ma, the highest gross return was under RR (₦1,774,125) due to its higher yield, followed by FP and IoT. The Net returns were also highest for RR (₦1,116,537), despite its high fertilizer cost (₦657,588) (Table 3). FP and IoT had similar net returns but were significantly lower than RR. The control had the lowest net return (₦263,682) since it had no fertilizer cost. However, at Malumfashi, the RR again had the highest gross returns (₦2,546,019), followed by IoT (₦2,042,766) and FP (₦1,841,043**)**. The Net returns followed the same trend, with RR producing the highest (₦1,962,054), followed by IoT and FP. The control treatment performed much better in Malumfashi than in Dutsin-Ma, with a net return of ₦1,054,956, showing that natural soil fertility might be higher in Malumfashi. The RR is the most profitable in both locations despite its high fertilizer cost. The higher yield compensates for the cost. The IoT-based application performs better than FP in Malumfashi but slightly worse in Dutsin-Ma. This suggests location-specific efficiency differences.

Table 3: Partial budgeting analysis for different application methods on grain yield of maize

Treatments	Adjusted Yield (Kg)	Gross returns (₦)	Cost of fertiliser (₦)	Net returns ₦)
Dutsin-Ma				
Control	462.6	263682.00	0.00	263682.00
FP	1592.1	907497.00	174000.00	733497.00
RR	3112.2	1774125.00	657588.00	1116537.00
IoT	1573.2	896724.00	200038.00	696686.00
Malumfashi				
Control	1850.8	1054956.00	0.00	1054956.00
FP	3229.9	1841043.00	174000.00	1667043.00
RR	4466.7	2546019.00	583964.80	1962054.20
IoT	3583.8	2042766.00	195464.00	1847302.00

NOTE: ₦570 was adopted as the Price per kg of Maize
FP=Farmers practice, RR =Recommended rate, IoT, Internet of things based application

CONCLUSION

The results of this study demonstrate that fertilizer application methods significantly influenced maize grain yield across different agro-ecological zones in Katsina State, Nigeria. The recommended fertilizer rate consistently produced the highest yields and net returns across all sites, validating the efficacy of agronomic best practices tailored to specific crop nutrient requirements. The IoT-based precision agriculture approach showed promising results, especially in more favourable locations like Malumfashi, where it outperformed traditional farmers' methods, indicating the potential of digital technologies to improve input efficiency and yield outcomes. Overall, the findings support the scaling up of precision agriculture tools as a complementary strategy to existing recommended practices. For this to be successful, further investment in farmers' training, system calibration, and infrastructure is required to ensure effective adoption and adaptation of digital technologies in resource-constrained, semi-arid environments.

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REFERENCES

Adediran, J. A., Adekiya, A. O., & Ajayi, A. O. (2020). Site-specific nutrient management for sustainable maize production in Nigeria. *Journal of Plant Nutrition*, 43(14), 2200–2212.

AGRA (2022). *Africa Agriculture Status Report 2022: Accelerating African Food Systems Transformation*. Nairobi, Kenya. https://agra.org

CENTRO INTERNACIONAL DE MEJORAMIENTO DE MAÍZ Y TRIGO (CIMMYT). (1988). La Formulación de Recomendaciones a partir de Datos Agronómicos: Un manual 25 metodológico de evaluación económica. Edición Completamente Revisada. México: CIMMYT.

Duncan, D.B.(1955). Multiple Range and Multiple F-test. *Biometrics* 11:1-42.

FAO (2021). *The State of the World's Land and Water Resources for Food and Agriculture – Systems at Breaking Point*. Food and Agriculture Organization of the United Nations. https://www.fao.org

FAOSTAT (2023). *Food and Agriculture Data*. Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/faostat/

Gebbers, R., & Adamchuk, V. I. (2010). Precision Agriculture and Food Security. *Science*, 327(5967), 828–831.

Gomez, K.A. and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research.* 2nd Edition, John Willey and Sons, New York, 680pp

Nnadi, F. N., Okoroafor, A. C., & Ukwuaba, S. I. (2022). Adoption and constraints of precision agriculture technologies among farmers in Nigeria. *Nigerian Journal of Agricultural Extension*, 23(1), 45–56.

Parameswaran, L., Selvan, G., & Rajendran, P. (2020). IoT and Smart Agriculture: A Review. *Materials Today: Proceedings*, 33, 1121–1125.

Raza, M., Tripathi, N. K., & Rehman, A. (2019). Integration of Remote Sensing and IoT for Precision Agriculture: A Review. *Remote Sensing Applications: Society and Environment*, 15, 100249.

Reyes-Hernández, M. (2001) Economic analysis of agricultural experiments with partial budgets: Re-teaching the use of this approach.

Vanlauwe, B., Wendt, J., & Giller, K. E. (2015). A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, 155, 10–13.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big Data in Smart Farming. A Review. *Agricultural Systems*, 153, 69–80.

Zhang, C., Walter, M. T., & Niyogi, D. (2021). Smart farming and the future of agriculture: The role of IoT and AI. *Computers and Electronics in Agriculture*, 189, 106408.