MATHEMATICAL APPLICATIONS FOR SUSTAINABLE AGRICULTURAL DEVELOPMENT: A REVIEW

ABSTRACT

This review article explores the pivotal role of mathematics in fostering sustainable development within the realm of agriculture. Drawing upon diverse sources, the paper investigates the multifaceted applications of mathematical principles in various facets of agricultural practices. These applications, from soil analysis to financial decision-making, crop modeling, and statistical approaches for yield tests, have tangible benefits for agriculture, enhancing efficiency, productivity, and environmental sustainability. The article delves into the significance of number systems, mathematical models, and experimental designs, providing a comprehensive overview of how these mathematical applications contribute to informed decision-making and innovation in agricultural science, leading to practical benefits in the field.

Keywords: Mathematics; Agriculture; Sustainability; Mathematical models; Experimental designs; Statistical.

1. Introduction

Johnson and Rising [1] described mathematics as a creation of the human mind, concerned primarily with ideas, processes, and reasoning. The application of mathematics is critical in all spheres of life, including agriculture [2]. Mathematics is called "The Queen of Science."

Agriculture is an integral part of science, which involves cultivating land, raising and rearing animals for food production for man, feed for animals, and raw materials for industry [3]. Sustainable development in agriculture is a continuous process of generating and allocating resources more efficiently (without degradation) to achieve greater socially satisfying needs [21-23]. This concept is crucial to understanding the role of mathematics in fostering sustainability in agriculture.

2. Requirements for Sustainable Development in Agriculture

According to Adedayo [4], the following are requirements of agricultural development:

2.1 Marketing

There should be a high demand or consumption for agricultural products; marketing entails getting products from farmers to consumers. It enlarges agricultural production as well as facilitating industrial growth and bringing greater wealth to the nation. Marketing involves transportation, storage, processing, and packaging.

2.2 New Farm Technology

Agricultural development requires a research program that is continuously generating new farming techniques.

2.3 Purchasable Input

Agricultural inputs like seeds, fertilizers, etc., should be available to farmers at affordable prices and supplied at the right time and place.

2.4 Incentives to Farmers

Farmers should be motivated towards producing more through price subsidies, fair sharing of farm produce in case of sharecropping, and the goods and services required by farmers, which should be made available to improve their standard of living.

2.5 Production Credit

"Credit is necessary for farmers to procure and adapt essential technologies. A significant source of credit for farmers is government and commercial banks, but these are usually not available to farmers because of a lack of collateral security and default in repayment.

These requirements demand one form of mathematics application or the other, especially in the area of new farm technology, known as the springboard of agricultural development. While acknowledging this fact, Ajai and Imoko pointed out that without mathematics, there is no science; without science, there is no modern technology, and without modern technology in our farms and farming activities, society stands to suffer greatly" [5-6].

3. Role of Mathematics in the Sustainable Development of Agriculture

Mathematics plays a crucial role in the sustainable development of agriculture by providing valuable tools and techniques for analyzing data, making informed decisions, and optimizing various aspects of agricultural practices. To be a farmer, it is critical to have problem-solving, decision-making, and money-management abilities. They use advanced mathematical technology to calibrate machines and irrigation pumps. The areas in agriculture where mathematical skill is vital include:

3.1 Soil Analysis

One of the fundamental aspects of sustainable agriculture is understanding the properties and characteristics of soil. Mathematics facilitates soil analysis by enabling precise measurements and calculations. Mathematical models interpret soil composition, texture, nutrient levels, and pH values, helping farmers determine optimal fertilization and irrigation practices. Through data analysis and statistical methods, mathematicians can identify soil patterns, predict nutrient deficiencies, and recommend appropriate soil amendments, thus maximizing crop yield and minimizing resource wastage.

Mathematical skill is needed in soil analysis to assist the agriculturalist in the following:

a. Calculation of the existing amount of soil nutrient;

b. Calculation of the amount of soil nutrients to be added to the soil;

3.2 Evaluation of Retailer Performance

Mathematics plays a vital role in evaluating the performance of retailers in the agricultural sector. Mathematical tools use statistical analysis and data modeling techniques to assess factors such as supply chain efficiency, inventory management, pricing strategies, and customer demand. Farmers and policymakers can use these mathematical models to identify inefficiencies, optimize distribution channels, reduce post-harvest losses, and improve overall profitability while minimizing environmental impact. "Mathematics plays a role in investments and advertisement, revenue calculation, and sales made as a percentage of sales" [7].

3.3 Application Rates

Determining the appropriate application rates for fertilizers, pesticides, and other agricultural inputs is crucial for sustainable farming. Mathematics provides the necessary framework for optimizing application rates, considering soil fertility, crop type, growth stage, and environmental considerations. Mathematical models, such as regression analysis and optimization algorithms, help calibrate application rates to ensure optimal resource utilization, minimize negative impacts on ecosystems, and reduce the risk of over-application or under-application. Mathematics is involved in fertilizer compounding and applications, and its application to the field must be calculated as under- and over-applications that are counterproductive. It will enable the agriculturist to calculate the nozzle size needed, the amount of pressure, the flow rate, and the quantity of water required. A lot of simple mathematics is involved in the chemical control of pests, diseases, and weeds. This is to avoid the loss of crops that might occur during preparation (mixing) and application of such chemicals. A wrongly mixed and applied chemical could cause damping-off, burning, and killing of the crop foliage. The feeding area is calculated through a mathematical equation given below:

$$\text{Feeding area} = \text{Intra} \times \text{Inter row spacing}$$

3.4 Finance Decision

Effective financial management is essential for the sustainability of agricultural operations. Mathematics assists in financial decision-making processes by providing tools for budgeting, risk analysis, and investment planning. Farmers can use mathematical models to evaluate the profitability of different crops, assess the impact of market fluctuations on their revenue, and make informed decisions about resource allocation. Additionally, mathematical techniques like linear programming can optimize resource allocation and production planning, maximizing profitability and minimizing resource waste. Mathematics skills will assist the agriculturist in evaluating investment in trucks, storage tanks, and manufacturing.

3.5 Crop Modeling and Yield Prediction

Mathematics plays a crucial role in developing crop models and predicting yields. Mathematical models can simulate crop growth and predict yields under different scenarios by incorporating various factors such as weather patterns, soil characteristics, crop genetics, and management practices. These predictive models assist farmers in making informed decisions regarding planting dates, irrigation schedules, and pest management strategies. These models contribute to sustainable agricultural practices and ensure food security by optimizing resource allocation and reducing yield variability.

3.6 Optimization of Resource Use

Mathematics enables the optimization of resource utilization in agriculture, promoting sustainable practices. Farmers can determine the optimal allocation of resources such as water, land, and fertilizers through mathematical techniques like linear programming, considering economic, environmental, and social constraints. This optimization process helps farmers achieve higher productivity while minimizing resource waste, improving resource efficiency, and reducing the ecological footprint of agricultural operations.

3.7 Number System

Number systems and related concepts are crucial in driving sustainable development in agriculture. They provide a foundation for accurate measurements, efficient resource allocation, and informed decision-making. Table 1 highlights the importance of various number system components in sustainable agriculture, including conversions, number concepts, percentage measurements, and linear programming.

3.8 Others

Farmers use numbers daily for various tasks, from measuring and weighing to landmarking.

Field experimentation is another core area where mathematics applications are used. According to Adedayo [4], it is a systematic and logical process of comparing two or more factors in the field to identify the best in specific characteristics. It is an organized agricultural research endeavor to gain new facts and knowledge to increase productivity and agricultural development. It involves the conduct of field experiments where the fieldwork is carried out, and the application of statistical methods for collecting, organizing, presenting, analyzing, and interpreting data are employed. Here, the effects of different fertilizers on crops for optimum yields and plant population implications are studied. Soil suitability for crops and other soil tests are conducted using field experimentation. All these are realizable through complete mathematics applications.

“More recent advances in the mathematical sciences have helped improve our ability to predict the weather, measure the effects of environmental hazards, and study the universe's origin” [8]. “This is very important in the current climate change trend in the entire world.

Akissani and Muntari pointed out that overpopulation on the farm causes overcrowding, poor ventilation, and reduction in yield as a result of competition for environmental resources and that low population densities are not desirable as there is the emergence of weeds”.[9] The plant's population is calculated using the formula:

Plant population = Area of land/Feeding area

Amodu and Okpanachi [10] underscore the relevance and usefulness of various mathematical models. For instance, the Malthusian model on population growth against growth in food production is still a guide for decisions on food security today. Likewise, a mathematical model of economic growth against agricultural development can spur government policy and action on agriculture. Again, mathematical models on world population growth against food security have placed agriculture on the top list of global affairs.

Table 1 Importance of Various Number Systems in Agriculture

Number system and concept	**Importance of sustainable development in agriculture**
Conversion	Facilitates conversion of units for accurate measurements, e.g., converting acres to hectares or pounds to kilograms. Enables efficient resource allocation and planning by converting quantities into standardized units. Allows for comparing data from different sources by converting measurements to a standard scale. Supports data integration and analysis across systems or regions by converting diverse formats or units.
Number Concept	Helps analyze and interpret agricultural data, such as crop yield, livestock population, or land area, to make informed decisions. Supports forecasting and predictive modeling by understanding trends and patterns in agricultural data. Enables effective budgeting and financial planning based on numerical information. Facilitates risk assessment and management through statistical analysis of agricultural data.
Percentage Measurement	Assists in assessing agricultural productivity and efficiency by calculating growth rates, yield improvements, or resource utilization percentages.

	Quantifying the percentage change facilitates monitoring and evaluating sustainable agricultural practices, such as reducing water or energy consumption. Helps understand market dynamics, pricing, and profit margins by calculating percentage markups or discounts. Supports benchmarking and goal setting by comparing performance against targets or industry standards.
Linear Programming	Optimizes resource allocation and utilization in agriculture, such as determining the most efficient combination of crops, livestock, and land to maximize output. It helps identify the optimal allocation of resources, such as fertilizers, water, or pesticides, to minimize waste and environmental impact. Supports decision-making in supply chain management, such as determining the most cost-effective transportation routes or storage capacities. Enables scenario analysis and simulation modeling for evaluating the potential impact of various agricultural strategies.

Nworah [3] revealed that in agricultural mechanics, calculus is used to adjust aircraft that apply spray material to crops. It can also calculate amounts when the application has multiple variables.

Mathematics is also used to measure discharge in irrigation. According to Uguru [11], the discharge of water from a pipe or a channel is the volume of water flowing per second, measured in cubic meters per second (m^3/s).

$$\text{Discharge } (m^3/s) = \text{area } (m^2) \times \text{velocity of flow } (m/s).$$

Fadare *et al*. [12] "pointed out the use of mathematics for the following agricultural activities: plotting the demand and supply schedule and curve for decision making, amount of fertilizers to be applied per area of land and stand of a crop, oestrus cycle, incubation period and gestation periods in livestock, loss and profit accounts and percentages, the diameter of soil components, interest on agricultural loans and credit facilities, number of eggs laid by fowls, liters of honey harvested in a bee box, making of in-let and out-let in a fish pond and their correct depth and height, quantity of water to be used for vaccine, etc".

These are just a few specific examples of mathematics applications for sustainable development in agriculture.

4. Statistical Approaches for Yield Tests

Field plot techniques are widely used in various scientific disciplines, such as agriculture, ecology, forestry, and environmental science, to gather data and analyze patterns and trends in natural or experimental settings. Field plots involve establishing predefined sampling areas where measurements, observations, and experiments are conducted to collect data on specific variables of interest. Field plot techniques provide valuable insights into the distribution, abundance, composition, and dynamics of organisms or physical features in their natural habitats. These techniques often involve standardized protocols to ensure consistency and comparability of data across different studies. The commonly used field plot techniques are given in Table 2.

The choice of field plot technique depends on the specific research objectives, the characteristics of the study area, and the variables being measured [13]. Careful planning and design of field plots, considering plot size, shape, spacing, and replication factors, is essential to ensure statistically valid and representative data collection.

Table 2 The Comparative Analysis of Different Field Plot Techniques

Technique	Key Features	Applications
Transects	Linear sampling paths: assess the spatial distribution	Vegetation surveys, animal movements, habitat mapping
Quadrats	Fixed-area frames; estimates population density and composition	Plant ecology, community structure, biomass estimation
Circular Plots	Circular sampling areas; measure vegetation attributes	Forest inventory, plant diversity assessment
Nested Plots	Multiple plots within larger plots; assess hierarchical patterns	Ecological studies, habitat heterogeneity analysis
Point Sampling	Systematically selected points; estimates cover or density.	Vegetation monitoring, soil characterization
Mark-Recapture	Capturing and marking individuals; estimates population size	Population ecology, wildlife conservation

5. Basic principles of a well-designed experiment

"It is a planned inquiry to discover new facts or confirm or deny previous investigations' results. The basic principles of a well-designed experiment are randomization, replication, and local control" [14]. These three principles are, in a way, complementary to each other in trying to increase the accuracy of the experiment and to provide a valid test of significance, retaining at the same time the distinctive features of their roles in any investigation.

"Before conducting an experiment, an experimental unit is to be defined, e.g., a leaf, a tree, or a collection of adjacent trees may be an experimental unit. An experimental unit is sometimes called a plot" [15]. "A collection of plots is termed a block" [15]. Observations made on experimental units vary considerably. These variations are partly produced by manipulating certain variables of interest, generally called treatments, built-in and manipulated deliberately in the experiment to study their influences. Besides the variations produced in the observations due to these known sources, the variations are also made by many unknown sources, such as uncontrolled variation in extraneous factors related to the environment, genetic variations in the experimental material other than that due to treatments, etc. They are there, unavoidable, and inherent in the very process of experimentation. Because of their undesirable influences, these variations are called experimental errors, meaning not arithmetical errors but variations produced by a set of unknown factors beyond the experiment's control. The experimental observations by extraneous factors may be systematic or random in their incidence mode. The errors arising due to equipment or the errors due to observer fatigue are examples of systematic errors. On the other hand, the unpredictable variation in the number of leaves collected in litter traps under a particular treatment in a related experiment is random. Any number of repeated measurements would not overcome systematic error, whereas it is very likely that random errors would be canceled out with repeated measurements.

5.1 Randomization

Randomization is a fundamental principle that helps eliminate bias and ensure the validity of experimental results [16]. It involves assigning subjects or treatments randomly to different experimental conditions. By doing so, researchers minimize the effects of confounding variables and create balanced groups, thus enhancing the study's internal validity. Randomization can be achieved through various methods, such as simple, block, and stratified. Simple randomization involves assigning subjects randomly to different groups, whereas block randomization ensures that each treatment appears an equal number of times within blocks of subjects with similar characteristics. Stratified randomization, conversely, involves dividing subjects into subgroups based on specific factors and then randomly assigning treatments within each subset.

5.2 Replication

Replication involves experimenting multiple times with different samples or subjects to assess the consistency and reliability of the results [17]. It enhances the study's external validity by increasing the generalizability of the findings beyond the specific sample used in the experiment. Replication can be performed through two main approaches: exact and conceptual. Exact replication involves reproducing the entire study with an independent sample and attempting to obtain the same results. Conversely, conceptual replication focuses on testing the same research question using different methods, measures, or populations.

5.3 Local control (error control)

Local control refers to the control of extraneous variables within the experimental setting. It involves manipulating and monitoring the variables likely to affect the study's outcome, allowing researchers to establish a cause-and-effect relationship between the independent and dependent variables. Local control can be achieved through various techniques, including random assignment, blocking, matching, and statistical control. Random assignment distributes potential confounders evenly across treatment groups. Blocking involves grouping subjects based on specific characteristics (e.g., age, gender) and randomly assigning treatments within each block. Matching involves pairing subjects with similar characteristics and assigning them to different treatments. Statistical control, often achieved through techniques like analysis of covariance (ANCOVA), includes confounding variables as covariates. The replication is used with local control to reduce the experimental error.

6. Field plot experimental designs

There are different methods of field plot experiments for evaluating promising materials in the field. The method depends upon the size of the test materials and the availability of land for experiments, among other factors. The most commonly used field plot experimental designs are RCBD [18], ARCBD [19], and LSD (Table 3).

Table 3 The critical differences between Randomized Complete Block Design (RCBD), Augmented Randomized Complete Block Design (ARCBD), and Latin Square Design (LSD)

Property	**RCBD**	**ARCBD**	**LSD**
Structure	The experimental units are grouped into homogeneous blocks, and treatments are	It's similar to RCBD, but additional treatments (controls or standards) are included	Treatments are arranged in a square grid, with each treatment appearing

	randomly assigned within each block.	in each block alongside the main treatments.	once in each row and column.
Blocking	Blocks are formed based on a relevant blocking factor, which helps account for variation within the experimental units.	Similar to RCBD, blocks are formed based on a blocking factor. Each block contains both the additional treatments and the main treatments.	It does not use blocking in the traditional sense. Instead, it controls for both row and column effects by arranging treatments in a square grid.
Treatment Replication	Each treatment appears once within each block, allowing for comparisons within homogeneous groups.	Each block contains the additional and main treatments, ensuring all treatments are represented within each block.	Each treatment appears once in each row and column, providing a balanced representation across the entire design.
Objective	They are designed to reduce the effect of variation by accounting for known sources of variability through blocking.	Extends RCBD by including additional treatments to improve efficiency and statistical power, particularly when compared against control or standard treatments.	Controls for both row and column effects to investigate the combined influence of two factors simultaneously.
Applicability	It is suitable when there is a known or expected source of variability that can be controlled through blocking.	Applicable when it is essential to include additional treatments alongside the primary treatments to improve experimental design.	Appropriate when the primary interest lies in investigating the combined effects of two factors that can be arranged in a square grid.

6.1 Randomized complete block design

If many treatments are to be compared, many experimental units are required. This will increase the variation among the responses. In such a case when the experimental material is not homogeneous, and there are v treatments to be compared, then it may be possible to:

•Group the experimental material into blocks of sizes v units.

•Blocks are constructed such that the experimental units within a block are relatively homogeneous and resemble each other more closely than those in the different blocks.

•If there are b such blocks, we say that the blocks are at b levels. Similarly, if there are v treatments, we say that the treatments are at v levels. The responses from the b levels of blocks and v levels of treatments can be arranged in a two-way layout. The observed data set is positioned as shown in Figure 1:

		Treatments (Factor B)						Block totals
		1	2		j		v	
Blocks (Factor A)	1	y_{11}	y_{12}	…	y_{1j}	…	y_{1v}	B_1
	2	y_{21}	y_{22}	…	y_{2j}	…	y_{2v}	B_2
	⋮	⋮	⋮		⋮		⋮	⋮
	i	y_{i1}	y_{i2}	…	y_{ij}	…	y_{iv}	B_i
	⋮		⋮		⋮		⋮	⋮
	b	y_{b1}	y_{b2}	…	y_{bj}	…	y_{bv}	B_b
Treatment totals		T_1	T_2	…	T_j	…	T_v	Grand total (G)

Figure 1. XXXXXXX

A two-way layout is called a randomized block design (RBD) or a randomized complete block design (RCBD) if, within each block, the v treatments are randomly assigned to v experimental units such that each of the $v!$ ways of assigning the treatments to the units has the same probability of being adopted in the experiment and the assignment in different blocks are statistically independent.

6.2 Augmented Randomized Complete Block Design (ARCBD)

Augmented RCBD is a function that analyzes the variance of an augmented randomized block design and generates and compares the adjusted means of the treatments/genotypes. ARCBD has both replicated and unreplicated treatments. The replicated treatments are tested in each block as in an RCBD, but unreplicated treatments occur in only one block, so each block has a different set of unreplicated treatments. It has the advantage of flexibility with large numbers of treatments.

6.3 Latin Square Design (LSD)

In Latin square design (LSD), the experimental material is divided into rows and columns [20], each having the same number of experimental units equal to the number of treatments. The treatments are allocated to the rows and columns such that each treatment occurs once and only once in each row and column.

A Latin square of order p is an arrangement of p symbols in 2 p cells arranged in p rows and p columns such that each symbol occurs once and only once in each row and each column. For example, to write a Latin square of order 4, choose four symbols, i.e., A, B, C, and D. These letters are Latin letters used as symbols. Write them in a way such that each of the letters out of A, B, C, and D occurs once and only once in each row and each column. For example, as shown in Figure 2.

A	B	C	D
B	C	D	A
C	D	A	B
D	A	B	C

Figure 2. XXXXXXX

7. Conclusion

This comprehensive review underscores the importance of mathematical applications in advancing sustainable development within the agricultural domain. The myriad applications of mathematics, ranging from soil analysis and financial decision-making to crop modeling and experimental designs, collectively contribute to optimizing resource utilization, enhancing productivity, and mitigating environmental impact. The integration of statistical approaches, such as randomized complete block designs and Latin square designs, further strengthens the reliability of agricultural experiments and ensures the validity of results. As the global agricultural landscape confronts challenges like climate change and increasing population, adopting mathematical tools becomes imperative for informed decision-making and innovative solutions. Moving forward, the harmonious integration of mathematics with agricultural science is indispensable for achieving and maintaining sustainable farming practices worldwide.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.
2.
3.

COMPETING INTERESTS

The authors have declared that no competing interests exist.

References

[1] Johnson DA, Rising GR. Guidelines for teaching mathematics. (2nd ed). *Belmont, Wardsworth Publishing Company*. 1972.

[2] Enemali IA, Adah OC. Empowering individuals and communities through agricultural education: The role of mathematics education. *Journal of Vocational and Technical Educators.* 2015a; **4**(4): 46-50.

[3] Nworah FC. Mathematics application for agricultural development in Nigeria. **In** Sadiku, J. S (ed.) *Proceedings of September 2015 Annual National Conference of Mathematical Association of Nigeria (M.A.N.).* 2015; pp: 72-77.

[4] Adedayo RO. Agricultural economics for colleges and secondary schools. *Ado-Ekiti, Adedayo Printing Nigeria Limited.* 1999; pp: 65-171.

[5] Ajai IJ, Imoko TB. Mathematics as a tool for sustainable national development and addressing Nigerian challenges in the 21st century. *Nasher Journal.* 2011, **9**(2): 95-101.

[6] Enemali IA, Adah OC. Quality assurance in educational administration teaching farm mathematics for national integration in Nigeria. *Journal of Education and Practice.* 2015b; **6**(23): 52-56.

[7] Malami B, Ayyub MH, Halilu A. Mathematics education as a tool for national development. *A paper presented at the 50th Annual National Conference of*

Mathematical Association of Nigeria (M.A.N.) held at St. Patrick's College, Asaba, Delta State. 31st August-5th September. 2013.
[8] Aguele LI, Usman KO. Mathematics education for dynamic economy in Nigeria in the 21st century. 2007; Retrieved from http://www.krepublishers.com/02.
[9] Akissani I, Muntari I. The role mathematics in agricultural development. **In** Sadiku, J. S (ed.) *Proceedings of September 2015 Annual National Conference of Mathematical Association of Nigeria (M.A.N.)*. 2015; pp: 317-324.
[10] Amodu A, Okpanachi D. Effect of mathematical applications on agricultural development in Kogi State, Nigeria. **In** Sadiku, J.S (ed.) *Proceedings of September 2015 Annual National Conference of Mathematical Association of Nigeria (M.A.N.)*. 2015; pp: 296-303.
[11] Uguru MI. Crop production: Tools, techniques and practice. *Nsukka, Fulladu Publishing Company*. 1996; pp: 2432.
[12] Fadare AO, Ayeni AA. Enhancing the teaching and learning of commercial mathematics for entrepreneurship skills development. *A paper presented at the 5th Annual National Conference of School of Sciences, Federal College of Education (Special).7th-10th April*. 2015.
[13] Song N, Shen X, Wang J, Wang P, Yi R. Plot layout method of field experiment for wheat with border irrigation based on soil water content heterogeneity. *Agronomy*. 2023, 13: 2267. https://doi.org/10.3390/agronomy13092267
[14] Borges A, González-Reymundez A, Ernst O, Cadenazzi M, Terra J, Gutiérrez L. Can spatial modeling substitute for experimental design in agricultural experiments? *Crop Science*. 2019, 59: 44-53. https://doi.org/10.2135/cropsci2018.03.0177
[15] Piepho HP, Edmondson RN. A tutorial on the statistical analysis of factorial experiments with qualitative and quantitative treatment factor levels. *J Agro Crop Sci*. 2018, 204: 429-455.
[16] Baghbaninaghadehi F, Armijo-Olivo S, Woodhouse L. 2016. Fundamentals of randomization in clinical trial. *International Journal of Advanced Nutritional and Health Science*. 2016, **4**(1): 174-187.
[17] Santos A, Vegas S, Uyaguari F, Dieste O, Turhan B, Juristo N. Increasing validity through replication: an illustrative TDD case. *Software Qual J*. 2020, 28: 371–395. https://doi.org/10.1007/s11219-020-09512-3
[18] Kutubi HSAL. On Randomized Complete Block Design. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*. 2021, **53**(2): 230-243.
[19] Hoefler R, González-Barrios P, Bhatta M, Nunes JAR, Berro I, Nalin RS, Borges A, Covarrubias E, Diaz-Garcia L, Quincke M, Gutierrez L. Do spatial designs outperform classic experimental designs?. *JABES*. 2020, 25: 523–552. https://doi.org/10.1007/s13253-020-00406-2
[20] Arumugam R, Preethi SS, Rajathi M. application of Latin Square Design in the analysis of the effectiveness of four different traffic violation on road accidents: a study. *Compliance Engineering Journal*. 2021, **12**(2): 18-27.

21. Mellaku MT, Sebsibe AS. Potential of mathematical model-based decision making to promote sustainable performance of agriculture in developing countries: A review article. Heliyon. 2022 Feb 1;8(2).

22. Adah OC, Enemali IA, Adejoh SO, Edoka MH. Mathematics applications for agricultural development: Implications for agricultural extension delivery. Journal of Natural Sciences Extension delivery. 2015;5:20.

23. Shaimardanovich DA, Rustamovich US. Economic-mathematical modeling of optimization production of agricultural production. Asia Pacific Journal of Research in Business Management. 2018 Jun;9(6):10-21.