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Surface and Subsurface Drainage Systems in Mitigating Waterlogging and Improving Crop Yield in Flood-Prone Agricultural Lands in Cross River State, Nigeria

Abstract

Agriculture is the mainstay of the rural economy in Cross River State, Nigeria, but productivity is often constrained by poor drainage and recurrent waterlogging in flood-prone areas. High annual rainfall, low-lying topography, hydromorphic soils, and inadequate drainage infrastructure have led to seasonal crop losses, reduced soil fertility, and food insecurity among farming households. Despite the recognised role of drainage in agricultural production, there is limited documentation on the effectiveness of surface and subsurface drainage systems in the ecological context of Cross River State. This study examined the role of surface and subsurface drainage systems in mitigating waterlogging and improving crop yield in flood-prone agricultural lands in Cross River State. The study specifically assessed the causes and effects of waterlogging, evaluated the role of drainage in improving crop yield, identified challenges to drainage infrastructure development, and proposed strategies for effective drainage management. Data for the study were obtained from relevant literature, government reports, and empirical studies on drainage and agricultural production. From the study, it was seen that waterlogging in Cross River State is primarily caused by high rainfall intensity, poor topography, impermeable soils, flooding from rivers, and poor farm-level drainage. The effects include reduced crop yield, soil degradation, delayed planting, increased pests and diseases, and loss of farm income. Surface drainage helps to remove excess runoff and prevent ponding, while subsurface drainage lowers the water table and improves root zone aeration, thereby increasing crop yield by 20% to 50% in waterlogged areas. However, the development of drainage infrastructure is hindered by inadequate funding, lack of technical expertise, poor policy implementation, low farmer awareness, and climate change impacts. The study concludes that effective drainage management is essential for sustainable agricultural production in Cross River State. It recommends increased government investment in drainage infrastructure, strengthening of agricultural extension services, promotion of community participation, integration of drainage into agricultural policies, and adoption of climate-smart drainage strategies. Implementing these measures will reduce waterlogging, improve crop yield, enhance food security, and promote sustainable rural development in the state.

Research Article

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Introduction

Agriculture remains the backbone of Nigeria's economy and the primary source of livelihood for over 70% of the

rural population, particularly in states like Cross River State where farming is both a cultural and economic activity [1]. The sector contributes significantly to food supply, employment generation, foreign exchange earnings, and poverty reduction. However, agricultural productivity in Nigeria has remained below potential due to a combination of biophysical and socio-economic constraints. Among these constraints, poor drainage and recurrent waterlogging in flood-prone agricultural lands have emerged as critical factors limiting crop production and rural development [2]. Cross River State, located in the Niger Delta region of Nigeria, is characterized by high rainfall, low-lying topography, and hydromorphic soils. The state experiences an average annual rainfall of between 2,000mm and 3,000mm, with peak periods between March and October [3].

The persistent flooding of farmlands during the rainy season has become a major threat to the livelihoods of smallholder farmers who depend on agriculture for survival. Many farmers in these areas report partial or total loss of crops annually, which directly affects household income and food availability.

Waterlogging occurs when the soil becomes saturated with water to the extent that air spaces in the soil are filled, thereby limiting oxygen availability to plant roots [4]. This condition negatively affects soil physical, chemical, and biological properties. It leads to reduced nutrient uptake, root rot, stunted growth, delayed planting, and ultimately low crop yield [5]. In Cross River State, farmers often experience seasonal losses of staple and cash crops such as cassava, yam, maize, plantain, and vegetables due to prolonged flooding and poor drainage [6]. Apart from direct crop losses, waterlogging also encourages the proliferation of pests and diseases, increases labour costs for land preparation, and discourages farmers from cultivating low-lying areas. Fields that remain waterlogged for long periods become unsuitable for cultivation, forcing farmers to abandon fertile lands. The problem is further compounded by climate change, which has increased the frequency and intensity of extreme rainfall events in the region (Intergovernmental Panel on Climate Change [7]. Without adequate intervention, the trend threatens to undermine efforts aimed at achieving food security and sustainable agricultural development in the state.

Drainage is therefore a fundamental component of sustainable agricultural land management. It refers to the removal of excess water from the soil surface and subsurface to create favourable conditions for crop growth [8]. Two major types of drainage systems are recognised in agricultural practice: surface drainage and subsurface drainage. Surface drainage involves the removal of excess water from the soil surface through open drains, canals, ridges, and graded fields. It is particularly effective in areas with heavy rainfall and low infiltration rates [9]. Subsurface drainage, on the other hand, involves the removal of excess groundwater through buried pipes, tile drains, or mole drains. It lowers the water table and improves soil aeration and root zone conditions [10]. Both systems are complementary and their effectiveness depends on soil type, topography, rainfall pattern, and the crops being cultivated. In flood-prone areas, a combination of both is often required to achieve optimal results.

The role of effective drainage systems in enhancing agricultural productivity has been well documented in the literature. Studies have shown that well-designed drainage can increase crop yield by 20% to 50% in waterlogged areas by improving soil structure, reducing salinity, and extending the growing season [11]. By removing excess water, drainage improves soil aeration, enhances microbial activity, facilitates root development, and increases the availability of plant nutrients. It also allows for timely land preparation and planting, thereby reducing the risk of crop failure. In Asia and Europe, large-scale investment in drainage infrastructure has transformed flood-prone areas into highly productive agricultural zones [12]. In Africa, however, drainage development has received limited attention compared to irrigation, even though excess water is as damaging as water scarcity [13]. This imbalance has left many productive lands in sub-Saharan Africa underutilised, with farmers bearing the cost of annual flood losses.

In Nigeria, and specifically in Cross River State, drainage infrastructure remains largely inadequate, poorly maintained, and farmer-driven. Most smallholder farmers rely on traditional methods such as mound making, ridging, and local channels, which are often insufficient to cope with heavy rains [14]. These methods are labour-intensive and provide only temporary relief. During peak rainfall, the local channels are easily blocked by silt and vegetation, leading to overflow and flooding of adjacent farms. The absence of coordinated government

intervention, technical support, and proper planning has left many flood-prone agricultural lands underutilised or abandoned during the rainy season. This situation directly affects crop yield and farm income. It also limits the ability of farmers to engage in all-season production and to diversify into high-value crops that require well-drained soils such as vegetables and spices.

The implications of poor drainage extend beyond the farm level to food security and rural development. Food security, defined as physical, social, and economic access to sufficient, safe, and nutritious food [15], is threatened when agricultural systems are unable to withstand climatic shocks such as flooding. In Cross River State, food insecurity is evident in rural communities where farming households lose a significant portion of their harvest annually to waterlogging [16]. Reduced output leads to higher food prices, increased dependence on food imports, and greater vulnerability among low-income households. Women and youth who constitute a large proportion of the farming population are disproportionately affected because they often lack the resources to recover from flood losses. Enhancing agricultural productivity through effective drainage is therefore not only an agronomic necessity but also a strategy for ensuring household and national food security.

Beyond productivity and food security, drainage infrastructure plays a vital role in sustainable rural development. Sustainable rural development entails improving the quality of life of rural dwellers through increased income, better infrastructure, and environmental sustainability [17]. When drainage systems are in place, farmers can cultivate their lands throughout the year, reduce post-harvest losses, and access markets more reliably [18]. This stimulates rural economies, creates employment opportunities, and reduces rural-urban migration. Reliable drainage also encourages private investment in agriculture, including agro-processing and storage facilities. In Cross River State, where over 60% of the population lives in rural areas and depends on agriculture, investment in drainage can serve as a catalyst for inclusive growth [19]. It can also support the state's drive toward agricultural commercialisation and agro-industrial development by making more land available for productive use.

Despite the recognised benefits, several challenges hinder the development and adoption of drainage systems in Cross River State. These include inadequate funding, lack of technical expertise, poor policy implementation, and low awareness among farmers [20]. Many farmers lack knowledge of modern drainage techniques and cannot afford the cost of installation and maintenance. Government programs on drainage are often fragmented and poorly coordinated, with little involvement of local communities. Land tenure issues and lack of proper land use planning further complicate drainage development. Additionally, there is limited research and documentation on the specific impact of surface and subsurface drainage on crop yield in the ecological context of Cross River State. Most existing studies have focused on irrigation or general flood control, with little emphasis on agricultural drainage as a productivity-enhancing strategy [21]. This gap in knowledge makes it difficult to design appropriate interventions that address the unique drainage problems of the state.

Given this background, it is imperative to examine the role of surface and subsurface drainage systems in mitigating waterlogging and improving crop yield in flood-prone agricultural lands in Cross River State. Understanding the current state of drainage, its impact on crop performance, and the socio-economic implications for farmers will provide evidence for policy formulation and investment decisions. Such evidence is critical for guiding government, development partners, and farmers toward sustainable drainage solutions that can enhance agricultural productivity and rural livelihoods. Addressing drainage challenges will require a collaborative approach involving government agencies, research institutions, farmers' organisations, and the private sector. With proper planning and investment, drainage can transform flood-prone areas from zones of risk into zones of agricultural opportunity in Cross River State.

Concept of Drainage Systems in Agriculture

Drainage in agriculture refers to the controlled removal of excess surface and subsurface water from farmland to create favourable conditions for crop growth and soil health [8]. The concept is based on the understanding that although water is essential for plant growth, excess water in the soil is harmful. When the soil becomes saturated, air spaces are filled with water, leading to oxygen deficiency in the root zone. This results in poor root respiration, reduced nutrient uptake, and ultimately low crop yield [4].

The core idea of agricultural drainage is to maintain a

balance between water retention and water removal. It seeks to prevent waterlogging by lowering the water table, improving soil aeration, and ensuring that plant roots have access to both moisture and oxygen [5]. Without drainage, excess rainwater, irrigation water, and seepage accumulate in the soil profile, causing anaerobic conditions that affect crop physiology and soil biological activity.

Agricultural drainage systems are designed to manage two forms of excess water: Surface water - water that accumulates on top of the soil due to heavy rainfall or poor infiltration. Subsurface water - groundwater that rises close to the root zone and saturates the soil [10]. The concept therefore encompasses both engineering and agronomic principles. From an engineering perspective, drainage involves the construction of channels, pipes, and structures to convey excess water away from the field. From an agronomic perspective, it involves creating soil conditions that support root development, microbial activity, and nutrient availability [9]. In essence, the concept of drainage systems in agriculture is about transforming waterlogged and unproductive lands into productive farmland. It is a key strategy for sustainable land and water management, particularly in high-rainfall and flood-prone areas where excess water is a major constraint to crop production [11]. By controlling soil moisture, drainage enhances productivity, extends the growing season, and supports year-round farming.

Causes and effects of waterlogging on agricultural lands in cross river state

Waterlogging refers to the condition where the soil becomes saturated with water to the extent that air spaces in the soil pores are filled, thereby limiting oxygen supply to plant roots [4]. In agricultural lands, this condition persists for hours, days, or weeks depending on rainfall intensity, soil type, and drainage. In Cross River State, waterlogging is a recurring problem due to the humid tropical climate and low-lying topography [22]. Causes of Waterlogging in Cross River State Several natural and human-induced factors contribute to waterlogging of agricultural lands in Cross River State:

i. High Rainfall Intensity and Duration Cross River State experiences an average annual rainfall of between 2,000mm and 3,000mm, with peak periods from March to October (Nigerian Meteorological Agency [3]. The prolonged and heavy rainfall exceeds the infiltration capacity of many soils, leading to surface ponding and saturation of the root zone.

ii. Low-lying Topography and Poor Natural Drainage: Much of the agricultural land in LGAs such as Calabar South, Bakassi, Akpabuyo, Odukpani, and Akamkpa lies in coastal plains, floodplains, and river valleys [22]. The flat terrain and poor natural gradient prevent quick runoff, causing water to accumulate on farmlands.

iii. Hydromorphic and Clayey Soils The predominant soils in the state are hydromorphic, gleyic, and clayey soils with low permeability [6]. These soils retain water for long periods and have poor internal drainage, making them highly susceptible to waterlogging.

iv. Flooding from Rivers and Coastal Inundation: Overflow from the Cross River, Calabar River, and other tributaries during peak rainfall often inundates adjoining farmlands. Coastal communities also experience tidal flooding and saltwater intrusion which worsens waterlogging [7].

v. Poor Farm-Level Drainage Infrastructure Most smallholder farmers rely on traditional methods such as ridging and local channels which are inadequate and poorly maintained [14]. Blocked natural waterways, lack of field drains, and absence of engineered drainage systems further aggravate the problem.

vi. Climate Change and Extreme Weather Events: Climate variability has increased the frequency and intensity of extreme rainfall in the Niger Delta region [7]. This has led to more frequent and prolonged flooding of agricultural lands in the state.

Effects of waterlogging on agricultural lands in cross river state

Waterlogging has both direct and indirect effects on crop production, soil health, and farmer livelihoods:

i. Reduced crop yield and crop failure: Excess water limits oxygen availability to roots, leading to root rot, stunted growth, chlorosis, and eventual death of plants [5]. In Cross River State, farmers

report significant losses of cassava, yam, maize, plantain, and vegetables during the rainy season due to prolonged waterlogging [6].

ii. **Poor soil physical and chemical properties**: Waterlogged soils become compacted, reducing porosity and soil structure. Anaerobic conditions lead to the accumulation of toxic substances such as ferrous iron, manganese, and hydrogen sulfide, which are harmful to crops [8]. Nutrient leaching and denitrification also reduce soil fertility.

iii. **Delayed land preparation and planting**: Fields that remain waterlogged cannot be accessed for ploughing, ridging, or planting until the excess water recedes. This shortens the growing season and forces farmers to plant late, reducing yield potential [11].

iv. **Increased incidence of pests and diseases**: Wet conditions favour the development of fungal diseases, bacterial wilt, and pests such as nematodes and snails. Crops like cocoyam and vegetables are particularly affected in waterlogged areas of the state [16].

v. **Reduced farm income and food insecurity**: Crop losses translate directly into reduced income for farming households. With less food produced, households experience food shortages and are forced to buy food at higher prices [23]. This worsens poverty and food insecurity in rural communities.

vi. **Land degradation and abandonment**: Repeated waterlogging leads to soil degradation and loss of productive land. Some farmers abandon low-lying plots and migrate to upland areas, reducing the total area under cultivation [20].

Role of surface and subsurface drainage in improving crop yield

Drainage systems play a critical role in improving crop yield in flood-prone agricultural lands by removing excess water and creating favourable soil conditions for plant growth. In Cross River State where heavy rainfall and poor natural drainage are common, both surface and subsurface drainage contribute directly to increased agricultural productivity. Surface drainage functions by removing excess water from the soil surface through open channels, field drains, ridges, and graded land. In areas of Cross River State that experience intense rainfall between March and October, surface drainage prevents water from ponding on farmlands for long periods [3].

By quickly conveying runoff to natural outlets, surface drains reduce the duration of saturation in the root zone. This allows crops such as maize, yam, cassava, and vegetables to establish properly without suffering from oxygen deficiency. Surface drainage also enables timely land preparation and planting, which is essential for maximizing the growing season. Farmers who practice ridging and furrow drainage report fewer cases of seed rot and better crop establishment compared to flat, undrained fields [14]. In addition, surface drainage reduces soil erosion and nutrient loss, thereby maintaining soil fertility and supporting higher yields over time.

Subsurface drainage works by lowering the groundwater table and removing excess water from within the soil profile through tile drains, mole drains, or vertical drainage systems [10]. This is particularly important in low-lying areas of Cross River State where the water table remains high during the rainy season. By improving soil aeration, subsurface drainage enhances root respiration and nutrient uptake, leading to healthier plant growth and better yield [5]. It also reduces the accumulation of toxic substances such as ferrous iron and hydrogen sulfide that develop under anaerobic conditions. Studies have shown that well-designed subsurface drainage can increase crop yield by 20% to 50% in waterlogged areas by extending the growing season and improving soil structure [11]. For crops that are sensitive to excess moisture, such as plantain and vegetables, subsurface drainage creates a more stable root environment and reduces crop failure.

Both surface and subsurface drainage systems also support sustainable crop production by improving soil biological activity. Aerated soils promote beneficial microbial activity that enhances nutrient cycling and organic matter decomposition [8]. Well-drained soils are easier to work with mechanized tools, which reduces labour costs and allows farmers to cultivate larger areas. Furthermore, effective drainage reduces the incidence of pests and diseases associated with wet conditions, such as root rot and fungal infections, which are common in waterlogged fields in Cross River State [6]. Overall, the role of surface and subsurface drainage in improving crop yield lies in their ability to control soil moisture, prevent

waterlogging stress, and create optimal conditions for crop growth. When properly implemented, drainage transforms marginal and flood-prone lands into productive agricultural areas, thereby contributing to increased food production and improved livelihoods for farmers in Cross River State [18].

Challenges of drainage infrastructure development in cross river state

Despite the recognized benefits of drainage, the development of effective drainage infrastructure in Cross River State faces several challenges. These challenges limit the ability of farmers and government to address waterlogging and improve agricultural productivity.

One major challenge is inadequate funding and investment. Drainage infrastructure, especially subsurface drainage, requires significant capital for construction, materials, and maintenance. Government budgetary allocation to agricultural drainage in the state has been limited, and most drainage works are left to individual farmers [20]. Smallholder farmers who constitute the majority lack the financial capacity to construct modern drainage systems, and as a result rely on rudimentary methods that are often ineffective during peak rainfall.

Another challenge is the lack of technical expertise and inadequate planning. The design and installation of drainage systems require knowledge of soil properties, hydrology, and engineering principles. However, there is a shortage of trained personnel and extension agents in Cross River State who can provide technical guidance to farmers [19]. Many drainage projects are poorly designed and fail to consider soil type, slope, and rainfall pattern, leading to siltation, collapse, or poor performance.

Poor policy implementation and weak institutional coordination also hinder drainage development. While policies exist to support agricultural infrastructure, there is often poor coordination between the Ministry of Agriculture, Ministry of Works, and local government authorities [21]. This results in fragmented projects and lack of maintenance culture. Drainage channels constructed by government are frequently blocked by silt, weeds, and solid waste due to absence of regular desilting.

Low awareness and limited adoption among farmers constitute another challenge. Many farmers in Cross River State are not fully aware of the benefits of modern drainage systems or lack knowledge on how to construct and maintain them [14]. Traditional practices such as mound making are still widely used, even though they provide only temporary relief. The perception that drainage is costly and labour-intensive also discourages adoption.

Land tenure and land use issues further complicate drainage development. In many rural communities, farmlands are fragmented and communally owned, making it difficult to implement coordinated drainage projects that cut across multiple farms. Conflicts over drainage outlets and water flow paths are also common, especially in floodplains and coastal areas [22]. Finally, climate change and environmental factors pose additional challenges. The increasing intensity of rainfall and flooding in the state often damages existing drainage structures and overwhelms their capacity [7]. Coastal erosion and saltwater intrusion in areas like Bakassi and Calabar South also affect the functionality of drainage systems.

Strategies for effective drainage management in flood-prone agricultural areas

Effective drainage management is essential for reducing waterlogging and sustaining crop production in flood-prone areas of Cross River State. Several strategies can be adopted by government, extension agencies, and farmers to improve drainage and enhance agricultural productivity.

First, integrated drainage planning and design is critical. Drainage systems should be planned at both farm and watershed levels, taking into consideration soil type, topography, rainfall pattern, and cropping system [8]. Government and relevant agencies should conduct drainage surveys and develop master plans for flood-prone LGAs such as Bakassi, Calabar South, Akpabuyo, and Odukpani. Combining surface and subsurface drainage where necessary will ensure comprehensive water control.

Second, promotion of farmer-based drainage practices can improve drainage at the field level. Farmers should be trained and encouraged to adopt improved surface drainage techniques such as broad bed and furrow systems, contour drains, and proper ridging [14]. These methods are low-cost and can be implemented with local materials. Group farming and cooperative drainage projects can also help farmers share costs and manage communal drains more effectively.

Third, government investment in drainage infrastructure is necessary. This includes the construction and maintenance of primary and secondary drains, canals, and outfalls that serve large agricultural areas [18]. Public-private partnerships can be explored to fund large-scale drainage projects. Regular desilting and clearing of blocked waterways should be institutionalized to ensure functionality.

Fourth, capacity building and extension services should be strengthened. Agricultural extension agents need to be trained on modern drainage design and management so they can educate farmers [20]. Demonstration farms showing the impact of drainage on crop yield can help increase awareness and adoption among farmers in Cross River State.

Fifth, integration of drainage with other water and land management practices is important. Drainage should be linked with soil conservation, irrigation, and flood control measures to maximise benefits [9]. Agroforestry and cover cropping can also be used to improve soil structure and infiltration, thereby reducing runoff.

Finally, policy support and community participation are key. Government policies should prioritise drainage in agricultural development plans and provide incentives such as subsidies and technical support [19]. Community involvement in planning, construction, and maintenance will ensure sustainability and ownership of drainage projects.

Summary

Agriculture remains the mainstay of livelihood in Cross River State, but productivity is severely constrained by waterlogging caused by high rainfall, poor topography, and inadequate drainage infrastructure. Waterlogging leads to reduced crop yield, soil degradation, delayed planting, increased pests and diseases, and food insecurity among farming households. Drainage systems, both surface and subsurface, play a vital role in removing excess water, improving soil aeration, and creating favourable conditions for crop growth. While surface drainage is effective for removing runoff, subsurface drainage is essential for controlling the water table and improving root zone conditions. Despite these benefits, drainage development in Cross River State faces challenges such as inadequate funding, lack of technical expertise, poor policy implementation, low farmer awareness, and climate change impacts. To address these problems, there is a need for integrated planning, government investment, farmer training, and community participation in drainage management. Implementing effective drainage strategies will transform flood-prone lands into productive agricultural areas and contribute to food security and sustainable rural development in the state.

Relevance of the study to modern day agricultural education

The study on the role of surface and subsurface drainage in mitigating waterlogging and improving crop yield in flood-prone areas of Cross River State is highly relevant to modern-day agricultural education. Agricultural education today emphasises climate-smart practices, sustainable land management, and problem-solving approaches that address real field challenges faced by farmers. 1. Curriculum Development and Practical Knowledge

Modern agricultural education curricula are shifting from theory-based instruction to practical, problem-based learning. This study provides current, location-specific data on drainage problems and solutions in Cross River State that can be integrated into courses on Soil and Water Conservation, Irrigation and Drainage, and Crop Production [1]. Students will gain practical knowledge on how to identify waterlogged soils, design surface and subsurface drains, and assess their impact on crop performance. This bridges the gap between classroom teaching and field realities.2. Training of Agricultural Extension Agents

Extension agents are the link between research and farmers. The findings of this study will equip extension personnel with evidence-based strategies to train farmers on drainage management [20]. In modern agricultural education, extension training now focuses on climate adaptation and resilience. Knowledge from this study will enable agents to demonstrate to farmers how proper drainage can reduce crop losses during heavy rainfall, which is increasing due to climate change [7].3. Promotion of Climate-Smart Agriculture

Modern agricultural education emphasises climate-smart agriculture to build resilient food systems. Waterlogging is a direct effect of climate variability and extreme rainfall. This study highlights drainage as a major adaptation strategy [18]. By teaching students and farmers about drainage, agricultural education institutions will be contributing to

the development of climate-resilient farming systems in Cross River State and similar agro-ecological zones.4. Skill Acquisition and Entrepreneurship

With growing interest in commercial agriculture and agribusiness, there is demand for skilled personnel in land development and water management. This study provides content for training students in drainage design, installation, and maintenance as a viable agri-service business [19]. Graduates of agricultural institutions can offer drainage consultancy and construction services to farmers and government agencies.5. Research and Innovation

The study identifies research gaps in agricultural drainage in Nigeria, particularly in the humid tropics [21]. For universities and colleges of agriculture, this provides a basis for student projects, theses, and further research. It encourages innovation in low-cost drainage technologies suitable for smallholder farmers, which is a major focus of modern agricultural education.6. Food Security and Sustainable Development Education

Modern agricultural education also teaches students about the link between agriculture, food security, and sustainable development goals [17]. This study demonstrates how poor drainage contributes to food insecurity and how improved drainage can increase productivity, income, and rural development. It therefore serves as a case study for teaching the role of infrastructure in achieving SDG 2: Zero Hunger.

Conclusion

Agriculture remains the backbone of livelihoods in Cross River State, yet its potential is greatly undermined by persistent waterlogging in flood-prone agricultural lands. This study has established that waterlogging in the state is largely driven by high rainfall intensity, low-lying topography, hydromorphic and clayey soils, river flooding, and the absence of functional drainage infrastructure. The consequences are severe and multi-dimensional: reduced crop establishment and yield, deterioration of soil physical and chemical properties, delayed farm operations, increased incidence of pests and diseases, and ultimately loss of income and food insecurity among rural households. The study further confirms that both surface and subsurface drainage systems play a vital role in mitigating these challenges. Surface drainage provides a quick and cost-effective means of removing excess runoff and preventing ponding, thereby enabling timely land preparation and crop establishment. Subsurface drainage, on the other hand, addresses excess soil water within the root zone, improves aeration, reduces toxicity, and creates a more stable environment for root growth and nutrient uptake. Together, these systems can transform marginal, waterlogged lands into productive areas and increase crop yields by a significant margin. However, the development and adoption of drainage infrastructure in Cross River State is constrained by inadequate funding, limited technical expertise, weak policy implementation, low awareness among farmers, and the increasing impacts of climate change. These challenges have slowed down efforts to address waterlogging despite its known effects on agricultural productivity. In light of these findings, it is evident that effective drainage management is not an option but a necessity for sustainable agricultural development in Cross River State. Investment in well-planned, community-driven, and climate-resilient drainage systems will not only improve crop yield and farmers' income but also contribute to food security and rural development. Therefore, concerted efforts by government, research institutions, extension agencies, and farming communities are required to prioritise drainage in agricultural planning. When this is adequately done, Cross River State can build a more resilient agricultural sector capable of withstanding climate variability and meeting the food demands of its growing population.

Recommendations

Based on the findings discussed, the following recommendations are made:

i. The Cross-River State Government, in collaboration with federal agencies and development partners, should allocate adequate funds for the construction and maintenance of drainage systems in flood-prone agricultural areas [19].

ii. Extension workers should be trained and deployed to educate farmers on the design, construction, and maintenance of both surface and subsurface drainage systems [20].

iii. Farmers and rural communities should be involved in the planning and management of drainage projects to ensure sustainability and proper maintenance.

iv. Drainage should be given priority in state agricultural policies and rural development programmes. Incentives such as subsidies and grants should be provided to farmers who adopt improved drainage practices.

v. Research institutions should conduct location-specific studies on drainage and establish demonstration plots to show farmers the benefits of drainage on crop yield [21].

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