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Eco-Adaptive Bioring for Flood and Drought Management in Agriculture: A Sustainable Root-Zone Water Management Approach

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Abstract- Agriculture is increasingly affected by irregular rainfall patterns, prolonged droughts, intense rainfall events, surface runoff, and temporary flooding. Conventional agricultural water-management practices generally address excess water and water scarcity as separate problems, requiring drainage during wet conditions and irrigation during dry conditions. This study proposes an Eco-Adaptive BioRing as a sustainable, decentralized root-zone water management approach designed to address both conditions using a single localized system. The proposed BioRing is positioned around the crop root zone and is designed to facilitate controlled water collection, temporary retention, gradual infiltration, and excess-water drainage. During heavy rainfall, the system is intended to reduce prolonged water accumulation around the crop by directing surplus water through a controlled overflow pathway while allowing a useful portion of the incoming water to infiltrate into the surrounding soil. During dry periods, the retained soil moisture can gradually become available to the crop roots, potentially extending the duration of root-zone moisture availability and reducing unnecessary irrigation demand. The methodology includes sustainable material selection, BioRing fabrication, field installation, soil-moisture monitoring, flood-condition evaluation, drought-condition evaluation, water-balance assessment, and comparison with conventional root-zone management. The proposed approach integrates water conservation, localized infiltration, controlled drainage, and sustainable material utilization within a single agricultural intervention. The system has potential applications in rainfed farming, irrigated agriculture, drought-prone regions, and areas experiencing irregular rainfall and temporary flooding. The proposed Eco-Adaptive BioRing provides a promising low-complexity approach for improving root-zone water regulation and increasing the effective utilization of available agricultural water resources.

Keywords— Eco-Adaptive BioRing, Flood Management, Drought Management, Root-Zone Water Management, Soil Moisture, Sustainable Agriculture, Water Conservation, Controlled Infiltration.

I. INTRODUCTION

Agriculture is highly dependent on the availability of water, and proper water management is essential for healthy crop growth and productivity. However, changing climatic conditions and irregular rainfall have increased the occurrence of both excessive rainfall and prolonged dry periods. Heavy rainfall can cause flooding, waterlogging, soil erosion and nutrient loss, whereas drought conditions can reduce soil moisture and create water stress for plants. These extreme conditions can negatively affect root development, crop growth and overall agricultural productivity. Conventional irrigation, drainage and rainwater harvesting techniques provide useful solutions for managing agricultural water, but they may require additional infrastructure, continuous maintenance or external water supply. Drip irrigation improves the efficiency of water delivery, while drainage systems help remove excess water. However, there is a need for a simple approach that can manage both excess water and insufficient moisture directly around the plant root zone. Maintaining a suitable moisture level near the roots is important because both excessive and insufficient water can affect plant development. To address this challenge, the proposed Eco-Adaptive BioRing is designed as a sustainable root-zone water-management system. The BioRing is placed around the plant root zone using suitable eco-friendly and water-absorbing materials. During heavy rainfall or excess irrigation, the ring is intended to absorb and temporarily retain a portion of the available water. During dry conditions, the retained moisture can gradually move into the surrounding soil, thereby providing additional moisture near the roots. This dual-function mechanism aims to reduce water loss and maintain a more balanced root-zone moisture condition. The proposed Eco-Adaptive BioRing provides a simple and environmentally friendly approach for improving agricultural water management under changing climatic conditions. Its performance can be evaluated by monitoring soil moisture, water retention, drainage, water consumption and plant growth under wet and dry conditions. By combining temporary water storage with gradual moisture release, the system has the potential to support water conservation, reduce plant water stress and improve climate resilience in agriculture. Further experimental and field-level studies can help validate its effectiveness for different crops and soil conditions.

Objectives

The primary objective of the Eco-Adaptive BioRing is to develop a sustainable and localized water management system for agricultural crops under changing climatic conditions. The proposed system aims to collect and temporarily retain excess water during heavy rainfall and flood conditions, while gradually supplying the stored moisture to the root zone during dry periods. It also aims to maintain stable soil moisture around plant roots, reduce water wastage and runoff, minimize water stress, and improve the efficient use of available rainfall and irrigation water. Overall, the system is intended to provide a simple, eco-friendly, low-cost, and climate-resilient solution for sustainable agricultural water management.

II. RELATED WORK

Agricultural water management mainly focuses on irrigation, rainwater harvesting, and soil-moisture conservation. These methods help improve water availability and reduce water wastage, but their effectiveness can vary under changing rainfall and drought conditions. Rainwater harvesting and water-storage techniques are useful for collecting excess rainfall and providing water during dry periods. However, many existing systems require separate storage structures and maintenance. A localized root-zone water management approach can reduce this dependency. Soil-moisture conservation methods such as mulching, improved soil management, and efficient irrigation help maintain moisture near plant roots. These methods mainly reduce water loss but may not directly address excess water during heavy rainfall. Climate-resilient agricultural practices aim to protect crops from both water scarcity and extreme rainfall. The Eco-Adaptive BioRing is proposed as a simple approach that can temporarily retain excess water and gradually release moisture during dry conditions, supporting balanced root-zone moisture management.

III. METHODOLOGY

1. Problem Identification and System Concept

The proposed methodology begins with identifying the major problems caused by irregular water availability in agriculture. Excessive rainfall can result in waterlogging, runoff and soil erosion, whereas prolonged dry conditions can reduce soil moisture and cause water stress to plants. To address both conditions using a single sustainable approach, the Eco-Adaptive BioRing is designed as a root-zone water management system. The basic concept is to temporarily retain excess water during wet conditions and gradually make the stored moisture available to the surrounding soil during dry conditions.

2. Site and Soil Preparation

A suitable agricultural site is selected for evaluating the proposed system. The soil is prepared uniformly to minimize variations in the experimental conditions. Important soil characteristics such as texture, drainage behaviour and moisture-holding capacity are considered during the preparation stage. The selected area is divided into suitable experimental units for BioRing and control conditions. Similar soil and environmental conditions are maintained for both setups to obtain a reliable comparison.

3. Crop and Plant Selection

Healthy plants belonging to the same crop variety and similar growth stage are selected for the study. The plants are maintained under similar sunlight, temperature and cultivation conditions. This helps ensure that the differences observed during the evaluation are mainly associated with the BioRing system rather than variations in plant growth conditions.

4. Selection of Eco-Friendly Materials

The BioRing is developed using environmentally friendly and biodegradable materials with suitable water-absorbing and water-retaining properties. The material should be capable of absorbing excess moisture without causing harmful effects to the soil or plant. The selection process considers water absorption capacity, moisture-release behaviour, durability, biodegradability and availability. Using sustainable materials supports the environmental objective of the proposed system.

5. BioRing Design and Fabrication

The BioRing is designed as a circular structure surrounding the plant root zone. The dimensions of the ring can be modified according to the crop type, root-zone size and soil characteristics. The structure is designed to allow water to enter and be temporarily retained within the absorbent layer. At the same time, it should permit gradual movement of moisture towards the surrounding soil. The circular arrangement provides relatively uniform moisture distribution around the plant.

6. Installation of the BioRing

The prepared BioRing is installed around the selected plant at an appropriate distance from the stem. The ring is positioned so that it covers the effective root-zone region without damaging the existing roots. The surrounding soil is maintained properly to ensure good contact between the BioRing and soil. After installation, the system is allowed to stabilize before starting the wet- and dry-condition evaluation.

7. Water Absorption and Temporary Storage

During rainfall or irrigation, water reaches the BioRing and its surrounding soil. The absorbent material within the ring captures and temporarily stores a portion of the available water. This stored water acts as a temporary moisture reserve. The mechanism reduces the rapid loss of water from the root-zone region and allows the captured moisture to remain available for later use.

8. Flood and Excess-Water Management

To evaluate flood-management performance, excess-water conditions can be simulated using controlled water application or observed during natural rainfall events. The response of the BioRing to increased water availability is monitored. The ring temporarily retains part of the excess moisture and regulates its movement through the surrounding soil. This approach is intended to reduce rapid runoff and excessive accumulation of water near the plant roots while improving the utilization of available rainfall.

9. Drought and Moisture-Deficit Management

For drought-condition evaluation, water input is gradually reduced or temporarily stopped after sufficient moisture has been stored in the system. As the surrounding soil becomes dry, the moisture retained within the BioRing gradually moves into the soil. This process provides additional moisture to the root-zone region and can extend the period of water availability. The gradual release mechanism is particularly useful during short periods of insufficient rainfall.

10. Root-Zone Moisture Monitoring

Soil moisture is monitored at regular time intervals throughout the experiment. Measurements can be taken before water application, during excess-water conditions and throughout the drying period. The moisture variation near the BioRing is compared with the control setup. This helps determine whether the proposed system is capable of maintaining a more stable moisture environment around the roots.

11. Control Setup and Comparative Evaluation

A control setup without the BioRing is maintained under similar soil, crop, water and environmental conditions. The BioRing-treated and control plants are monitored simultaneously. Parameters such as soil moisture, water retention, drainage, water consumption and plant growth are compared. This comparative approach helps determine the contribution of the BioRing to improved root-zone water management.

12. Plant Growth and Performance Monitoring

Plant growth is monitored throughout the evaluation period. Parameters such as plant height, number of leaves, root development and general plant health can be recorded at regular intervals. Water consumption and moisture availability are also considered while assessing the performance of the system. The combined observations help determine whether improved root-zone moisture management contributes to better plant development.

13. Data Collection and Analysis

All observations obtained during wet and dry conditions are systematically recorded. The collected data are analysed to identify changes in soil moisture, water retention and plant growth. The performance of the BioRing is compared with the control setup. The results can be presented using graphs and statistical analysis to determine the effectiveness and reliability of the proposed system.

V. MAIN RESULTS

1. Improved Water Retention

The proposed Eco-Adaptive BioRing is expected to improve the temporary retention of water around the plant root zone. During heavy rainfall or excess irrigation, the absorbent layer captures a portion of the available water and prevents it from being immediately lost through runoff or rapid drainage. This retained moisture acts as a temporary water reserve. As a result, the system can improve the effective utilization of naturally available rainfall and irrigation water.

2. Effective Flood and Excess-Water Management

Under excessive-water conditions, the BioRing provides a controlled region for temporary water retention. Instead of allowing large quantities of water to accumulate rapidly around the plant or move away as surface runoff, the system helps regulate water movement through the soil. This can potentially reduce the negative effects associated with waterlogging and uncontrolled runoff. Therefore, the BioRing provides a simple approach for managing excess water close to the crop root zone.

3. Gradual Moisture Release During Dry Conditions

One of the major functional outcomes of the proposed system is gradual moisture release during dry conditions. The water retained within the BioRing is slowly transferred to the surrounding soil as soil moisture decreases. This creates a localized moisture reserve near the roots. The mechanism can extend the availability of water between rainfall or irrigation events and reduce the sudden decline of soil moisture during short dry periods.

4. Improved Root-Zone Moisture Stability

The BioRing is designed to act as a moisture buffer between wet and dry conditions. During periods of excessive rainfall, it retains part of the excess water, while during dry conditions it gradually supplies moisture to the soil. This dual behaviour can reduce sudden fluctuations in root-zone moisture. Maintaining a more stable moisture environment is beneficial because plant roots require adequate moisture without prolonged exposure to excessive water.

5. Reduction of Plant Water Stress

The gradual availability of stored moisture can help reduce water stress during periods of insufficient rainfall. When the surrounding soil begins to lose moisture, the BioRing can provide additional moisture close to the root zone. This may help plants maintain normal physiological activity for a longer period under moisture-deficit conditions. The system therefore has potential to improve crop resilience against short-term drought conditions.

6. Improved Water-Use Efficiency

The proposed system can contribute to improved water-use efficiency by retaining water that may otherwise be lost. Instead of depending completely on frequent irrigation, the system attempts to utilize available rainfall more effectively. The stored water is gradually made available to the soil according to moisture conditions. This approach can reduce unnecessary water wastage and support more sustainable agricultural water management.

7. Support for Plant Growth

A relatively stable root-zone moisture condition can support better root activity and plant development. Adequate moisture availability can contribute to consistent plant growth, particularly when environmental conditions fluctuate. When compared with plants grown without the BioRing, the BioRing-treated plants can be evaluated for differences in plant height, leaf development, root growth and overall plant health.

8. Environmental and Agricultural Benefits

The Eco-Adaptive BioRing provides an environmentally conscious alternative to water-management methods that depend heavily on complex infrastructure. Its use of biodegradable or eco-friendly materials can reduce environmental impact. By combining water conservation, excess-water management and root-zone moisture regulation, the system supports the broader goal of climate-resilient and sustainable agriculture.

9. Overall Performance

Overall, the proposed Eco-Adaptive BioRing demonstrates a dual-function water-management concept. During wet conditions, it functions as a temporary water-retention medium, while during dry conditions, it acts as a gradual moisture-release source. This adaptive behaviour can help maintain a more balanced root-zone moisture condition, improve water utilization and reduce the impact of irregular rainfall. Therefore, the BioRing has potential to serve as a simple, eco-friendly and sustainable approach for managing flood and drought effects in agriculture.

Advantages

Dual Water Management

Manages both excess water and water scarcity.

Water Conservation

Stores available water and reduces unnecessary water loss.

Root-Zone Moisture Control

Helps maintain suitable moisture around plant roots.

Eco-Friendly Design

Uses sustainable and environmentally friendly materials.

Reduced Water Stress

Provides moisture during dry conditions and supports healthier plant growth.

Low-Cost Approach

Can be designed as a simple and affordable solution for farmers.

Future Work

Future work will focus on evaluating the Eco-Adaptive BioRing under real field conditions with different crops, soil types, and climatic environments. Experiments can be conducted to measure water absorption capacity, retention duration, moisture-release rate, soil-moisture stability, and crop growth performance. The design can also be improved by testing different biodegradable materials, ring sizes, and structural configurations to achieve better water management. In addition, sensors and automated monitoring systems can be integrated to continuously measure soil moisture and water levels. Large-scale field trials and long-term studies can further determine the economic feasibility, durability, environmental benefits, and practical suitability of the BioRing for farmers.

VI. CONCLUSION

The Eco-Adaptive BioRing is proposed as a sustainable and localized approach for managing the two major and contrasting agricultural water challenges of excess rainfall and drought. The central concept is to regulate water directly around the crop root zone through a combination of localized water collection, temporary retention, controlled infiltration, gradual moisture redistribution, and excess-water drainage. This integrated approach differs from conventional systems that generally treat flood management and drought management as separate agricultural requirements. The proposed system has the potential to reduce prolonged water accumulation around crops during heavy rainfall while retaining a useful portion of available water within the root-zone environment. During subsequent dry periods, the retained moisture can gradually support crop roots and potentially reduce the frequency of irrigation. The use of sustainable and locally available materials further increases the environmental relevance of the proposed approach. The methodology developed for the BioRing considers system design, sustainable material selection, fabrication, field installation, experimental evaluation, soil-moisture monitoring, water-balance assessment, and comparative performance analysis. These components provide a framework for systematically evaluating the proposed technology under normal, excess-water, and water-deficit conditions. Overall, the Eco-Adaptive BioRing represents a promising concept for decentralized agricultural water management. Its ability to combine water conservation and excess-water control within the root-zone environment may contribute to improved water-use efficiency and greater resilience to irregular rainfall conditions. However, extensive field experimentation and long-term validation are necessary before definitive performance claims can be established. Future research should focus on crop-specific design optimization, sustainable material evaluation, long-term durability, economic feasibility, environmental impact, and multi-season field validation. With appropriate development and testing, the Eco-Adaptive BioRing could provide a simple, scalable, and sustainable solution for improving agricultural resilience to both flood and drought conditions.

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