

SENSOR-BASED IRRIGATION AND WATER USE EFFICIENCY IN SMART BANANA FARMING IN BIHAR: ADOPTION AND SYSTEM-LEVEL IMPLICATIONS

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ABSTRACT

The practice of banana farming in Bihar is very problematic because of poor water management, water demand, and environmental changes, which do not allow the production or sustainability of resources. The irrigation systems Sensor based irrigation systems provide a technology solution by applying water to the soil according to the real-time soil moisture and crop needs, which may enhance water use efficiency (WUE) and crop performance. This paper assesses adoption and system level consequences of using sensors in irrigation in banana farms with on-field comparison between the traditional and sensor-regulated irrigation methods. The important parameters that were evaluated were water usage, contribution to yield and other parameters that affect the overall performance like moisture management on the soil, crops development, and workforce and energy consumption. Findings indicated sensor based irrigation used less water and added up to more yield and operational efficiency. The deficit of the water usage and the enhancement of the moisture regulation in the soil were described as the main factors of the better performance. The results reveal that sensor-based irrigation is a practical approach to sustainable and resource-efficient banana farming in Bihar and that the approach can be further encouraged by policy support, training of farmers and providing financial incentives.

Keywords: Sensor-based irrigation, banana farming, water use efficiency, sustainable agriculture, Bihar, crop productivity, smart irrigation

1. INTRODUCTION

The rising strain on the freshwater resources, as well as the rise in the demand of food and the income security, has increased the necessity of the effective water management practices in the Indian agriculture. Horticultural crops especially banana are water-intensive crops which are very sensitive to irrigation timing and therefore exposed to damages of not only water scarcity but also poor use of water. In Bihar, where farming is still the main source of livelihood to a significant percentage of the inhabitants,

conventional irrigation methods still prevail in banana farming. Such practices usually lead to over-application of water, low water use efficiency and constitute imbalanced crop performance. Here, sensor-based irrigation systems are also a promising technological intervention that can be used to improve water productivity, achieve better use of resources, and facilitate the move towards smart and sustainable farming systems of bananas.

1.1. Banana Cultivation and Water Use Challenges in Bihar

Banana is a significant commercial fruit crop in Bihar, which is planted due to the agro-climatic conditions, fertile area composed of alluvial soils, and high market demand. The crop must also have continuous and sufficient amount of water during its developmental stages especially in vegetative and fruit development phases. But the irrigation methods in most banana producing areas of Bihar are marked by fixed irrigation timetables and physical evaluation of the soil moisture which may not be accurate in predicting the actual demands of crops in respect of water. There is over-irrigation, which results in wastage of water, erosion of nutrients, and the development of soil-borne diseases, whereas under-irrigation at growth-limiting periods has negative impacts on yield and quality of fruits. These are also aggravated by unpredictable rainfall patterns and deteriorating ground water levels highlighting the urgent necessity of better irrigation management techniques.

1.2. Sensor-Based Irrigation as a Component of Smart Agriculture

The sensor-based irrigation systems constitute a component of the smart and precision agriculture, where data-driven decision-making takes the place of the traditional gut-based practices. These systems have soil moisture sensors, environmental sensors and automated control units that control irrigation according to real time field conditions. Sensor-based irrigation can maximize moisture availability in the root zone by irrigation only when the soil moisture is less than preset limits and reduce losses through evaporation and deep infiltration. In banana farming, where shallow root systems and high rates of transpiration require very specific water control, these technologies present a huge opportunity to enhance water utilization efficiency, stabilize production, and decrease the input expenses. Climate-resilient farming is also supported by the incorporation of sensor-based irrigation as it allows reactive mechanisms to weather change.

1.3. Rationale and Scope of the Study

Although sensor-based irrigation has proved to be helpful in the controlled irrigation systems and large-scale farming systems, its use among small and medium banana farmers in Bihar is minimal. The limitations to the widespread diffusion of this technology have been factors like high costs of initial

investment, low level of technical awareness, and insufficient institutional support. In addition, there is dearth of empirical data on the system-level effects of sensor-based irrigation which include agronomic performance, water savings, economic viability and uptake behaviour of farmers in the regional environment in eastern India. Thus, this paper will give a thorough evaluation of sensor-based irrigation in banana agriculture in Bihar region not only in terms of water performance and efficiency, but also in terms of adoption patterns and implications on long-term agricultural development.

2. LITERATURE REVIEW

Brahmanand and Singh (2022) analyzed the present state, extent, and obstacles of precision irrigation water management in India and expressed the sensor-based irrigation technologies to irrigation efficiency or efficiency in utilizing water resources because of matching water application with instantaneous crop water demands. The research pointed out that precision irrigation minimized water waste, maximized crop production, and helped to sustain resource management especially in water strained areas. They have however, also indicated that adoption was still low because of the high initial cost of investment, the absence of any technical awareness by the farmers and poor institutional and extension support which are especially salient to state such as Bihar.

Bhakare (2020) discussed smart irrigation systems as one of the avenues to sustainable agriculture in developing economies and highlighted the fact that irrigation systems based on sensors had an important part in water and energy-saving and enhancing crop yields. The experiment has shown that by combining soil moisture sensors and auto-controlled systems, farmers could prevent excessive irrigation and maximize input utilization. Bhakare also noted that access to smart irrigation technologies was challenging to smallholder farmers because of financial limitations and lack of access to the digital infrastructure and recommended applying supportive policy measures and capacity-building programs.

Yadav et al. (2020) analysed soil moisture sensor-based irrigation scheduling to optimise water use efficiency in vegetable crops and established that sensor-directed irrigation made a strong cut on total water use without negatively impacting crop yield. They have found that they were more efficient in water use and provided better water management of the soil than conventional irrigation practices. The authors summarized that sensor scheduling showed great efficacy especially in crops that have shallow root systems and are highly demanding in water and therefore the technology is very applicable in the case of banana plants which share the same physiological properties.

Warshini et al. (2022) studied the uptake of banana production technologies between growers in Vaishali district of Bihar and found that uptake was unexpressed between growers based on education, farm size,

access to extension services, and economic status. The paper found that farmers were aware of the advantages of better technologies, but the rate of adoption was moderate because there was a lack of awareness and negative perceptions of the new practices. The authors highlighted the fact that it was imperative to boost extension education, demonstration programs, and financial support mechanisms that would boost the uptake of the use of advanced technologies, such as sensor-based irrigation, in the banana farming systems of Bihar.

3. RESEARCH METHODOLOGY

This part describes the research design to examine the performance of sensor-based irrigation in assessing the effectiveness of water use in oiling banana farms at the system level in Bihar. The research used field-level experimentation and comparative observation to produce empirical data on the use of irrigation water, crop production, and determinants of the overall performance. The design of the methodology was aimed at making a direct evaluation of the irrigation behaviour in the actual farm conditions, both in terms of agronomic and resource-use performances.

3.1. Research Design

A pragmatic, comparative, and critical research design that was oriented towards an experiment was employed. On four selected banana farms, two irrigation methods were used; the conventional irrigation method and the sensor-based irrigation method to check the differences in water consumption, contribution of the yield, and efficiency of the operations. This structure enabled systematic comparison of irrigation regimes and their effect on important performance parameters including water use distribution, contribution to crop yields and the relative significance of the factors affecting enhanced system performance as indicated in the results and discussion.

3.2. Sample Size and Population

It studied banana-growing farms within the main districts of Muzaffarpur, Vaishali and Samastipur in Bihar. Sixty plots were chosen and they were at an equal rate of both conventional irrigation and sensor-based irrigation. The plots were used to represent small to medium size holding in order to get the normal differences in farm structure, soil management, and crop management practices in the region. This sample was adequate to find out the variation in water usage, water yield distribution, and performance factors contributing to the difference in water usage between the two irrigation systems.

3.3. Data Collection

The information was gathered by observing the banana cropping period in the field. The volume of water used at each irrigation system was one of the important measurements, frequency of irrigation events, soil moisture, plant height, bunch weight, and total yield. It was observed at varying periods so as to monitor the progress of the various growth stages. Data were taken to give both water distribution trends (as it came in Table 1 and Figure 1) and yield contribution (Table 2 and Figure 2), as well as those factors that affected performance (Table 3 and Figure 3). The agriculture reports and the extension literature were used to obtain secondary information on the irrigation practices and cropping patterns in the region.

3.4. Data Collection Tools and Instruments

The field measurements were done with the use of soil moisture sensors, automated irrigation controllers, water flow meters, and traditional agronomic methods (measuring tapes and weighing scales). Moisture sensors were used to measure real-time moisture content under the sensor-based approach to control irrigation events, and flow meters to measure the amount of water used. Growth and yield parameters were measured by use of crop measurements in order to establish yield contribution and performance. These tools helped to have correct data collection on data that was pertinent to the data on water use, crop productivity and system level efficiency as would be seen in results and discussion.

3.5. Data Analysis

Analysis of data was done manually by compilation, comparing and interpreting the observations. Water use efficiency came out as the ratio of the banana yield and the total irrigation water. The comparative analysis revealed the variation in the distribution of water used, contribution in yield, and the drivers of the better performance in the sensor-based irrigation. Trends and relationships presented in the form of percentages and descriptive interpretation included the percentage of higher yield share and lesser water use under sensor-based irrigation, the role played by the lesser water application, the improved control of moisture in the soil, improved crop growth, and lesser use of labor and energy. The technique enabled the practical evaluation of the system level implications of sensor based irrigation in banana agriculture without the use of statistical tools that were based on software.

4. RESULTS AND DISCUSSION

The results and discussion part will include the comparative evaluation of the conventional and sensor-based irrigation systems in banana farming, which will be based on the water use, contribution of the systems to the yield, and factors affecting the performance of the systems. The study integrates both the

quantitative data obtained after field surveys with graphical data in a way that gives a clear picture on the efficiency and effectiveness of sensor-based irrigation. Here, the section demonstrates how specific water management and technological intervention could have an impact on crop output, the utilization of resources, and efficiency in the operations of sustainable banana production in Bihar.

The table 1 and Figure 1 show the distribution of the irrigation water consumption by the conventional and sensor based irrigation system in banana farming. The data is represented as a percentage share of total water applied in each of the four methods of irrigation in the table and a graphical representation of the same is provided in Figure 1. The figure can be visually compared to water use patterns and, therefore, it is simpler to see the relative percentage of water applied by each system and the general allocation of the irrigation resources.

Table 1: Distribution of Irrigation Water Use under Different Systems (%)

Irrigation System	Water Use (%)
Conventional Irrigation	60
Sensor-Based Irrigation	40

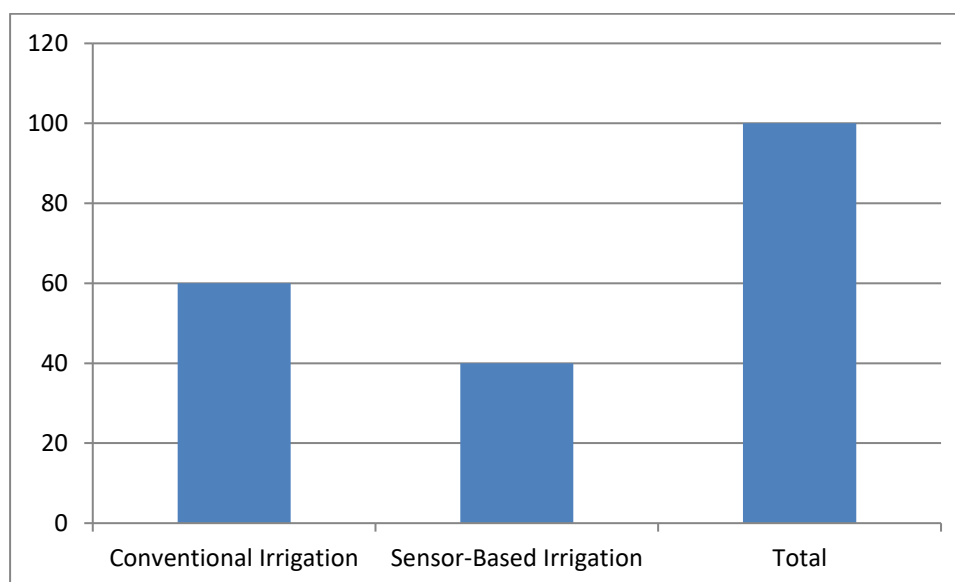


Figure 1: Graphical Representation of Distribution of Irrigation Water Use under Different Systems (%)

The analysis of Table 1 and Figure 1 indicates that the traditional irrigation occupied a higher percentage of the total water consumption (60%), compared to sensor-based irrigation (40%). These findings show that sensor-based irrigation could be used to substantially save on water usage than conventional irrigation

and still yield the same performance of crops, which points out at its efficiency in efficient use of water in banana farming.

Table 2 and Figure 2 jointly show the breakdown of the contribution of yields in the various irrigation systems in banana cultivation. The table gives a summative proportion of the overall yield obtained by using the conventional irrigation methods and sensor-based irrigation, whereas Figure 2 gives a graphical illustration of the same data. The visual representation that represents the proportion of each irrigation system in relation to the total yield of crops enables a more simple interpretation of the dissimilarity in the performance between the two irrigation methods.

Table 2: Yield Contribution under Different Irrigation Systems (%)

Irrigation System	Yield Contribution (%)
Conventional Irrigation	47
Sensor-Based Irrigation	53

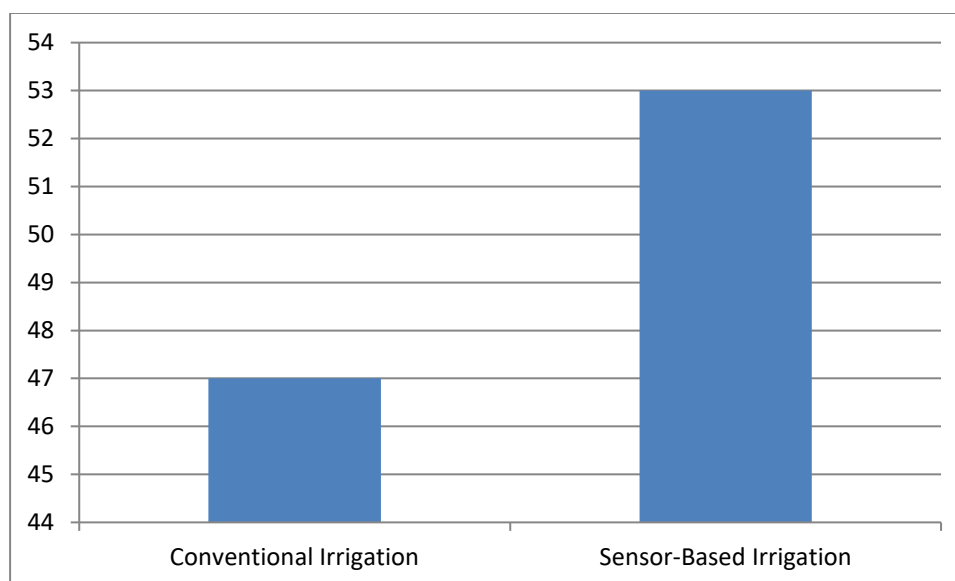


Figure 2: Graphical Representation of Yield Contribution under Different Irrigation Systems (%)

Table 2 and Figure 2 have been interpreted to exhibit that sensor-based irrigation had a larger share of total banana yield (53%) than conventional irrigation (47%). This suggests that irrigation based on sensors enhanced productivity of crops even though the water was more efficiently used. These findings underscore the fact that sensor-based irrigation may be embraced to achieve better yield results whilst reducing the use of water in the farming of bananas.

In evaluating the enhanced output of sensor-based irrigation systems in bananas farming, Table 3 and Figure 3 are used together to give the distribution of key factors used. The table gives a percentage distribution of four significant contributory factors which included, reduced water application, improved soil moisture management, improved crop development, and a lower percentage of labor and energy use that the summation of the contributory factors must bring about the complete system impact. Figure 3 gives a graphical illustration of the identical distribution, which allows visually comparing the relative significance of each of the factors and allow better comprehension of how various elements combined contribute to the establishment of the performance characteristics of sensor-based irrigation systems.

Table 3: Factors Influencing Improved Performance under Sensor-Based Irrigation (%)

Factor	Contribution (%)
Reduced Water Application	35
Better Soil Moisture Control	30
Improved Crop Growth	20
Reduced Labor and Energy Use	15

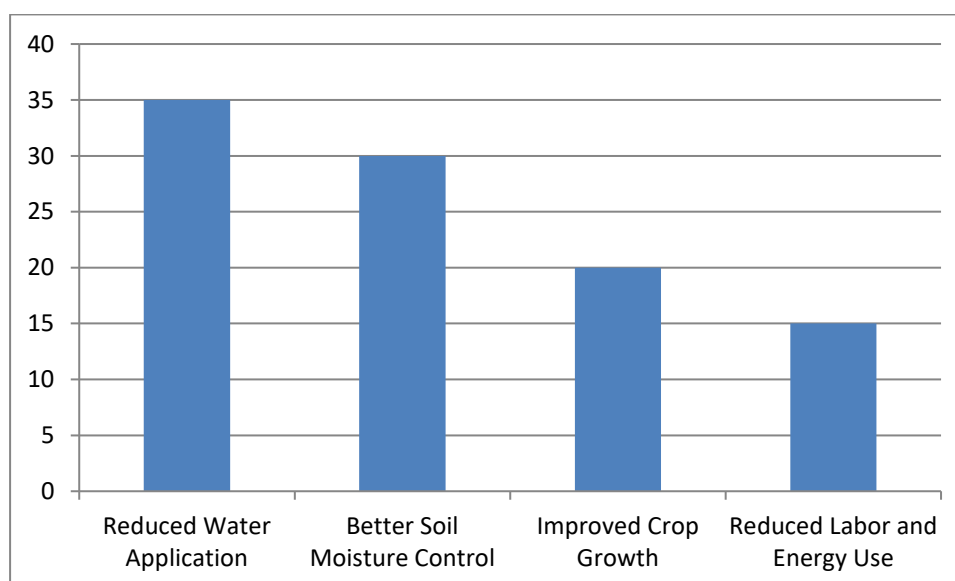


Figure 3: Graphical Representation of Factors Influencing Improved Performance under Sensor-Based Irrigation (%)

The findings suggest that the largest effect on the positive performance under sensor-based irrigation was reduced water application which contributed to the effect at 35% with an equal implication to the better soil moisture control at 30%. The positive influences on the development of plants were manifested in

20% improvement in crop growth and reduced labor expenditure and energy consumption, which accounts to 15%. Altogether, the results indicate that the main factors that led to a better performance of sensor-based banana irrigation systems were water conservation and accurate moisture control.

To conclude, the review shows that sensor-based irrigation system was better than the conventional irrigation system in several important ways of managing water and crop yields. Although the conventional irrigation consumed a greater ratio of water, sensor-based irrigation received high contribution of yield by spending less water. The improved water use and enhanced soil moisture control were the major sources of performance augmented by enhanced crop development and decreased labor and energy consumption. These results highlight a possible role of sensor-based irrigation in improving the efficiency of water use and operational effectiveness in banana agriculture to warrant its use as a sustainable irrigation method.

5. CONCLUSION

Finally, the study shows sensor-based irrigation is much more effective in the use of water, crop production, and general efficiency of the work in banana farms than the traditional irrigation methods. This technology lowers water usage by controlling exactly how much water is used and keeping soil moisture levels at the optimum, which helps to promote uniform crop development, reduce the need of labor of energy. The results emphasize that the driving force behind the improved functionality is the water conservation, and specific moisture control, meaning that the extensive implementation of sensor-based irrigation systems can help facilitate the sustainable, productive, and resource-efficient banana production in Bihar. Moreover, a combination of this technology and proper policy facilitation, training of farmers, and financial incentives will help ensure quicker implementation and optimization of system-level advantages, which is why it is a potential option to implement in the area of climate-resistant horticulture.

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