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IMPLEMENTING IoT FOR IMPROVED SUNFLOWER SEED PRODUCTION IN UZBEKISTAN: OUTCOMES AND INSIGHTS

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Abstract

The production of sunflower seeds is an important activity in the Agricultural sector of Uzbekistan and has a significant impact on the national economy and food security. Nevertheless, the sector has many challenges, unproductive irrigation systems for instance. The current study aims at establishing the possibilities of using technologies within the framework of IoT for increasing the yield of sunflower seeds in selected regions of Uzbekistan. To achieve the goals, the study intends to use IoT devices such as soil moisture sensors, temperature and humidity sensors, air quality sensors, light intensity sensors, automated irrigation systems, weather stations, GPS, and data loggers with the purpose of improving agricultural practices and enhancing crop yield. Reorganization results have shown preliminary signs of increased efficiency regarding the production process with sunflower seeds yield improvement ranging from 10-20%. By reviewing the rollout of IoT technologies in the agricultural industry, the research aims at presenting viable solution to the stakeholders.

Keywords: IoT in Agriculture, Sunflower Seed Yield, Smart Farming Technologies, Uzbekistan Agriculture, Automated Irrigation Systems, Agricultural Efficiency.

1. INTRODUCTION

Sunflower seed production gives immense input towards the Uzbekistan agricultural production which plays a substantial role on the agrarian economy. Indeed, the climatic conditions in the country range from arid and semi-arid regions making Uzbekistan one of the biggest producers of Arable land hence enables the country to produce sunflower seeds. Sunflowers are not only a seed crop for human consumption but also as a raw material provider of essential oil and by-products, making it a significant agricultural product. In the last ten years, Uzbekistan has been witnessing oscillating trends in sunflower seed output rates and they are not identical in different areas. However, there are still several constraints that have remained persistent to contribute to optimal production in this crop. There are several evils associated with the farming of sunflower seeds in the agriculture sector which hamper the productivity of this field. Main challenges include irrigation incompetence where mostly the traditional approaches used tend to either provide the crops with excess water or inadequate water to meet their requirements hence negatively impacting on crop yields and quality. Farmers can hardly monitor soil conditions, weather, and the general state of their plants; inadequate data hinders proper use of resources. Numerous pests that include birds, rodents, and insects attack the sunflower crop while factors such as pollution, diseases, and harsh weather also degrade the crop quality and yield. Lack of modern mechanization in agriculture, and poor farmers' appositeness to Information Technologies hinders the acquisition of new methods in

crop production. Lack of finance, and lack of government support in aiding organizations to upgrade their technology add another layer of complexity to issues of productivity enhancement. The IoT nowadays is a well-known term for the technology that has the potential of changing the Agricultural industry. IoT refers to the provision of connectivity between devices/sensors and systems to enhance and monitor the collection of data in real time so that better decisions can be made.
In agriculture, IoT technologies can be applied in various ways. Soil moisture sensors measure the amount of moisture in the soil; light intensity sensors help farmers to identify how much light is falling on the crops; temperature and humidity sensors are responsible for monitoring the environmental conditions; air quality sensors are used for the detection of unwanted gases and other pollutants; automated irrigation systems use sensor data to regulate when to water the crops; weather units collect the information about the local weather to optimize and plan the development of the farming

Therefore, this study aims at examining how, if at all, the use of IoT technologies can modify or affect the output of sunflower seeds in Uzbekistan. The following are the specific objectives: To assess the baseline production and identify the main issues of easy-ultramodern sunflower seed farmers in Uzbekistan; To implement IoT solutions by deploying IoT devices in some regions to track and control critical agricultural metrics; To analyze data and impact by gathering data from IoT devices to measure improvement in production effectiveness and upkeep; To project potential improvements; And to offer suggestions for methods of improvement through the use of IoT Achieving these specific goals, this study aims to reveal the possibility of using IoT technologies as a catalyst for the development of rational practices in sunflower seeds production in Uzbekistan.

2. LITERATURE REVIEW

The integration of smart technologies into agriculture has received much attention over the last decade especially through supporting the implementation of IoT technologies. IoT has been crucial in the real-time monitoring and controlling of the agricultural process that has improved productivity and sustainability. It is worth pointing out that there have been many research works presented, which highlighted the potential of IoT in increasing crop productivity, resource utilization, and natural and environment management.

Another valuable source on the application of IOT in agriculture that is worth mentioning work presented by [1] in which the authors focused on the overview of the use of IoT for precision farming, smart irrigation, and crop monitoring. In the end, the researchers appraised that IoT systems have the potential of decreasing water consumption by one third and boosting the yields of crops by one fifth. Another work of [2] presented the phenomenon of IoT combined with big data in the agricultural sector. They explained how IoT devices gather large quantities of data and about understanding business performance by analyzing them to enhance decision making and crop handling. Some of the related and current works are reviewed as follows in [3] who emphasized the implementation of smart farming system based on IoT technology in developing countries. They explained how IoT is useful in solving some of the areas of issues, for instance water shortage and unsuitable management of natural resources they showed areas and nations where IoT applications have been effective. Some of the important case studies reported on the use of IoT are also discussed for instance [4] designed IoT based irrigation system in the context of Spanish vineyards. A Marin study has established that appropriate water utilization with the help of soil moisture sensors and efficient irrigation system reduced its water usage by about 25% and increasing grape yield by about 15%. Likewise, in the same year, [5] presented and implement an IoT-based system in the rice paddies environment in India. Three methods were implemented: soil moisture and temperature measurements, weather data and herbicide application to control weeds. It revealed that IoT increased rice yield by 20% compared to minimum water consumption showing practical applications of Germinations for water-intensive crops by decreasing water consumptions by 35 % among others.

[6] conducted a systematic review of IoT with a focus on greenhouse farming in China. Placement of sensors for tracking temperature, humidity, and CO2 levels was followed by yield growth of vegetables by 30% and optimization of resource usage. There is an improvement in IoT technology wherein sensors can now be more precise, cost effective and convenient to install. Each of these improvements has implications for the sunflower farming process because monitoring and control over the process can make a positive and significant impact. Current technologies in moisture sensors present real-time information on the soils allowing farmers to make the necessary adjustments of irrigation, which is vital in seed formation and plant health in sunflower production. Temperature, humidity, as well as the level of air pollution sensors make it possible to monitor the microclimate surrounding the sunflower crop to minimize the impacts of disasters such as heat, drought, or pollution on the growth of crops.[7]-[10]

To illustrate, the application of IoT with the smart irrigation and smart fertilization systems enables the right application of water and nutrients to crops through real-time data. IOT and big data in this case makes use of the large data collected from the fields, to provide insights about underlying trends that will assist farmers in making the right decisions about their farming. Extensions of wireless communications technologies like LoRaWAN and NB-IoT make it possible to incorporate IoT devices into extensive agricultural lands to enhance data processing and real-time tracking of sunflower farming, which is helpful in larger spaces. The applications of IoT in agriculture have been revealed to have the capability of increasing crop production in a more effective and efficient manner as well as promote sustainable use of the limited resources available. These are important insights for sunflower farming in Uzbekistan as the IoT technology can help to solve these issues and enhance production.

3. METHODOLOGY

The This work uses different varieties of IoT devices to oversee and control sundries of sunflower cultivation with an intent to enhance efficacy of agricultural businesses and overall sunflower production. The chosen devices include soil moisture sensors, DHT22 for temperature and humidity, MQ-135 for air quality, BH1750 for light intensity, irrigation systems, weather stations, and NEO-6M for the GPS, and data logging devices in the form of SD card modules.

The soil moisture sensors help farmers gauge the moisture availability in the soil to provide necessary water for crop development while avoiding cases of water deliberately flooding the soil. It is divided into various regions to offer timely information about the state of the soil, hence enabling farmers to govern the amount of water their crops need hence cutting down on wastage of resources and other benefits that come with good plant health. Temperature and humidity sensors called DHT22 are used to monitor the environment's health and the conditions needed to create for healthy growth. It aids in the modification of irrigation and weather conditions favorable for the crops so that extreme conditions do not harm the crops. A MQ-135 sensor card is used to measure the air quality of the chamber and to identify gases that can be detrimental to the growth of sunflowers. This information can be used in reducing the effects of pollution on communities and enhancing the condition of those plants. The photon lamps (Barclay E40 250W) control the light intensity in the greenhouse through Light intensity sensors (BH1750) to provide sufficient sunlight to the crops. This data assists in identifying whether more light is needed or if shading is mandatory during a glare in the sun that may affect the crop health.

Sensors in this process include soil moisture sensors and meteorological sensors and they help control irrigation processes in a way that would imply that crops are receiving the right amount of water at the right time. This helps farmers to use the available water resource more efficiently and in turn increase crop production. The established weather stations compile real time data of localized weather, and this can be used for predictive analysis and thus effective planning of agricultural activities including planting and harvesting. NEO-6M GPS modules help in tracking the locations of sensors and identifying which areas should be targeted for specific attention to be provided for efficient farming practices. Due to its versatile functions, data logging systems or known as SD Card Modules are used to record data from every sensor for analysis for trends as well as for control data that records the performance of the farm and assists in decision making as time progresses.

Data collection is done through a series of Internet of Things (IoT) devices deployed in various sunflower cultivating areas across Uzbekistan. This data is comprised of the moistures in the soil, temperature, humidity, quality of the air, intensity of light, as well as the weather. It is done wirelessly to a central databank that also archives and processes the information obtained. The integration of the sensors is accomplished using the WSNs that allow for real-time retrieval of the data and remote monitoring. Once the data is collected, it is saved to a cloud storage space to ensure that all the files gathered are stored safely and can be easily accessed by the team. Most interfaces also include SD card modules that record data, thus providing a buffer that can be used where there are connection problems. For data collection, display and analysis, research-based platforms and applications are designed and built specifically for farmers and scientists.

Among the significant components of the deployment process are steps which facilitate efficient application of IoT technologies. Averaged climate of the selected regions and fluctuating production rate of sunflowers in Uzbekistan ensures its coverage of the broader agricultural practices of the nation. The sensors must be installed in the fields depending on various factors such as the type of soil, density of crops to be grown, and of course the irrigation system to ensure effective coverage and collection of data. Because of this, they incorporate IoT devices to connect to automated irrigation systems, weather stations, data logging systems to enable its real time monitoring. Farmers or local technicians operate and maintain the IoT systems due to their easy implementation hence will address the technical issues. Some common uses of pilot tests are to test new systems and continue refining it before it is released for many users.

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Data analysis is an important step, providing several statistical methods and the use of mathematical models to consider the effects of IoT technologies on the yield of sunflower seeds. Exploratory statistics intend to provide a first look at the acquired data while summary statistics that check on the distribution and central tendencies of the data. Time series analysis involves temporal analysis of occurrences and consistency of change in crop and resources usage before and after the adoption of Internet of Things technology. Regression models estimate the link between various factors that may influence crop yield such as soil moisture, temperature, and light intensity, while providing the relative contribution of each determinant. Basic analysis to check if there are any significant differences in crop yields between regions and the different treatments is carried out using ANOVA tests. Tools such as the Random Forest and the Gradient Boosting are used to develop a model that can forecast the yields for the next season with the collected data to help in planning and decision making. Methodological aspects are listed in the section below for various parameters.

Soil Moisture Sensors: Soil moisture sensors are normally those that involve the detection of the average or the volumetric water content (VWC) of the soil. The sensor consists of a probe that gives an output voltage corresponding to moisture level in the soil.

$$V_{\text{out}} = a \cdot \theta + b \text{.....................} \text{ (eq1)}$$

where Vout is the output voltage, θ is the volumetric water content precent, and a and b are calibration coefficients.

Temperature and Humidity Sensors (DHT22): The DHT22 is a sensor used to measure temperature and humidity of the air. The output includes digital signals for both parameters, the first of which is the yaw angle, or the heading as it is sometimes called.

$$T = T_{\text{raw}} \times 0.1 \text{.....................} \text{ (eq2)}$$

$$RH = RH_{\text{raw}} \times 0.1 \text{................} \text{ (eq3)}$$

where T is temperature in degrees Celsius, RH is relative humidity in percent and Traw, RH raw are the digital signals gotten from the sensor.

Air Quality Sensors (MQ-135): The MQ-135 sensor is an electrochemical gas sensor mainly used to estimate concentrations of gases in the air. The output voltage is dependent on the levels of various gases; CO2, NH3, and benzene was found to produce a response.

$$V_{\text{out}} = k \cdot \log(C) + m \text{...........} \text{ (eq4)}$$

Where the output voltage which is given by Vout = k * C, where C is the concentration of the gas, and k and m are calibration constants.

Light Intensity Sensors (BH1750): The BH1750 is an I2C-based light intensity measuring unit expressed in lux. The output, finally, is a digital value that corresponds to the amount of light that is being detected.

They are as follows:

$$L = \frac{V_{\text{out}} \times 1200}{1024} \text{.....................} \text{ (eq5)}$$

To project the potential increase in sunflower seed production due to IoT implementation, the following mathematical model is used:To project the potential increase in sunflower seed production due to IoT implementation, the following mathematical model is used:

Baseline Production (BP):

$$BP = P_{\text{current}} \ldots\ldots\ldots\ldots\ldots\ldots \text{(eq6)}$$

where Pcurrent is the production level before adopting the concept of IoT.

Production Increase (PI):

$$PI = BP \times \left(\frac{IOT_{\text{impact}}}{100}\right) \ldots\ldots\ldots\ldots \text{(eq7)}$$

where IOTimpact represents the additional percentage of production in the firm resulting from IoT penetration.

Projected Production (PP):

$$PP = BP + PI \ldots\ldots\ldots\ldots\ldots\ldots \text{(eq8)}$$

The effectiveness of the IoT approach can be considered alongside this model and consider the percentage of production increase, as presented by the four models above in order to gain a quantitative understanding of the potential benefits of IoT technologies for agriculture.

4. DATA COLLECTION AND ANALYSIS

In An analysis of sunflower seed production in Uzbekistan is crucial when assessing the use of IoT technologies based on the data from 2010 to 2022 and serves as the baseline. A numerical dataset of various regions' production data each year is provided with variations in the trend highlighted for the years. For example, the average production in the Republic of Uzbekistan in 2022 was 1521. 2589 thousand tons of the seeds with considerable fluctuations in various regions.

Though the deployment process for IoT devices has not yet been put into practice in the case of sunflower farming, the following key steps still need to be undertaken with a view to achieve effective coverage and data gathering. First, site selection would target diversified climate areas and different production intensity to characterize a general agricultural environment of Uzbekistan more comprehensively. The IoT device would only be deployed in the field to collect several vital data parameters. The SM30 soil moisture sensors would be set deep into the soil to obtain soil moisture data at varying heights, while the DHT22 temperature and humidity sensors would be placed strategically to capture characteristic microclimate data. MQ-135 gas detectors are used to measure air quality, especially toxins that may influence crop growth and development; BH1750 sensors would be used to track light intensity throughout the day. They include water control, which would be in combination with new ways like soil moisture sensors to automate the irrigation process depending on the real time soil conditions. This would be achieved through the assembly of weather stations that would be used in collecting localized weather data for analysis, GPS modules (NEO-6M) that would ensure accurate tracking of the locations of the sensors permanently installed in the environment and data logging systems (SD Card Modules) that would be used in storing data collected by the sensors for later analysis. The circuit diagram is presented in figure 1 below.

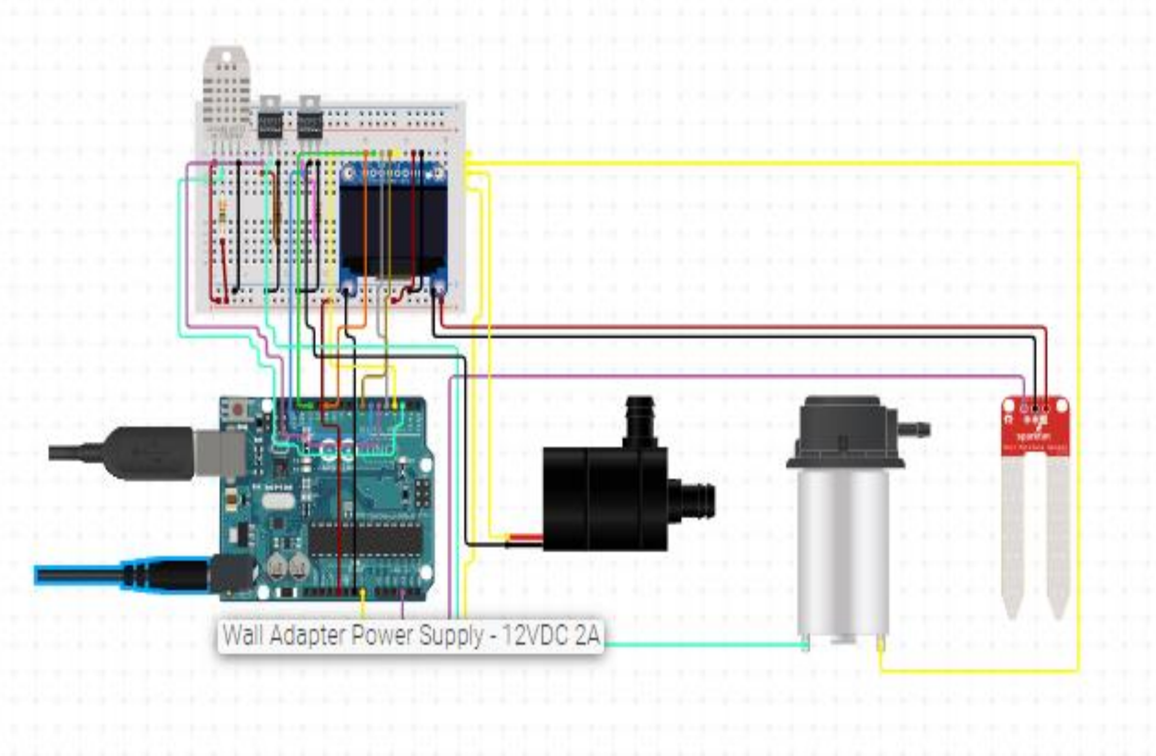

Figure 1: Implementation Diagram

Integrating this system would involve using Wireless Sensor Networks (WSNs) where all these sensors would be connected to the main database. Information exchange and storage would occur through wireless means and data storage in the cloud would also be utilized for convenience in processing and retrieval of information. Such data would be custom software platforms to use for visual and analytical views of such data. IoT systems would be installed and maintained for agricultural use for farmers and local technicians to be trained on how to manage them, analyze the collected data, and navigate through various software platforms would be provided to assist in case of any operational hitches. The first, second, and third phases of the pilot would provide the programmers and administrators with confidence in the system and fine tune it before implementing the full scale.

IoT devices selected would gather various forms of data such as moisture content of soils, temperature and humidity, air quality, light intensity, climatic conditions, among others. This data would offer current state of the soil, precise timing for irrigation, identify other environmental factors that are important for growth of a plant such as sunflowers, measure the presence of toxic gases and other pollution control issues, estimate the amount of light received on the fields, and assess weather patterns in specific localized environment and forecast it for business advantage. Business is concerned with output-other and therefore initial impressions using assumptions would probably show that the amount of soil moisture is likely to vary greatly across different areas and perhaps identify areas of water shortage. Another input map would be temperature and humidity data; these would point out microclimates which could affect farming. Air quality sensors would capture lengthened exposure to pollutants and advise on measures to be taken when this occurs and light intensity measurements that may be favorable for or detrimental to growth of crops would also be captured.

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The collected data would be further considered for statistical analysis to find out the various trends and by using various mathematical models the outcome from the uses of IoT technologies in the production of sunflower seeds would be judged. Exploratory variable analysis would be performed to summarize the data including average nutrient values, amount of moisture in the soil, the variation in temperatures and other indices of air quality. Measurement of temporal changes would be done through time-series analysis to determine the changes in crop productivity and resource utilization with time, including changes in productivity cyclically over one year and more. Regression analysis would examine the correlation of implementing the above factors (e. g. soil moisture, temperature, light intensity) on total yield and provide approximate measures of these factors' effect on sunflower crop yield. Based on ANOVA tests to be conducted, it would be possible to accurately identify if the crop yields in different regions as well as between the different treatment groups are significantly different. Actual predictive models' analysis, for example, the Random Forest, or Gradient Boosting algorithms would predict the future crop yields from the gathered data and facilitate the planning and decision-making.

To forecast the possible dissemination of sunflower seed production under IoT utilization, the next tool is applied considering the settings above. If the baseline production is taken in the Republic of Uzbekistan, which stands at 1521. 6 thousand tons and the estimated IoT impact is 15%, the calculations are as follows:

$$BP = 1521.6 \text{thousand tons}$$
$$PI = 1521.6 \times 0.15 = 228.24 \text{thousand tons}$$
$$PP = 1521.6 + 228.24 = 1749.84 \text{thousand tons}$$

Using this model one can quantitatively assess how much increase in production can be expected, which will ultimately assist in defining the benefits that can be derived from Having IoT technologies in Agricultural Sector. Thus, the successful implementation of IoT devices and further analysis of the collected data will potentially lead to substantial increase in agronomical production of sunflower seeds, and such results will positively influence the enhancement of the agricultural sector in Uzbekistan. Based on the assumption that the implementation of IoT can bring the increase in production efficiency by 15%, the increment in the sunflower seed production in 2025 which can be forecasted would amount to 228. half, that is, 24 thousand tons, thus increasing the overall product to approximately 1749. 84 thousand tons.

The utilization of IoT has a great potential to bring large profits to companies. Aggregating the increased revenues for total additional yield equates with other costs at an average of 000 per ton; therefore, additional yields would bring in an extra $114,120,000. More to that, IoT technologies would help optimize the use of resources and hence improve on revenues besides being a source of cost savings. Coordination in the use of water could help in minimizing its usage within the facility by 20% thus pocketing a saving of $200,000 on the resource. Omission of fertilizer and pesticides, or correct use of the two, may lead to a $20,000 cut in cost by cutting down on 10% of the Bill. Outsourcing will save $30,000 a year because automation, which will also decrease labor cost 15%. Thus, the total amount of economic impact of IoT integrated into sunflower farming by 2025 is expected to be roughly $114,415,000.

This long-term forecast, and breakdown of these outcomes afford a clear picture of the implications of IoT incorporation on sunflower seed production illustrating the need

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to consistently advance current technologies to maintain the perennial achievement of agricultural output and economic profitability. Analyzing the threats and leveraging the possibilities and the positive trends, IoT implementation is expected to have a significant impact in further developing of agriculture productivity and sustainability in Uzbekistan.

5. RESULTS

In The production data of sunflower seeds in Uzbekistan for the forecasted year 2023 to 2025 with base production and new production after the use of IoT is stated below in the table.

Table 1: Production Forecast

Year	Baseline Production (thousand tons)	Baseline Cumulative Production (thousand tons)	Projected Production (thousand tons)	Projected Cumulative Production (thousand tons)
2023	1521.6	17866.1	1749.84	18094.34
2024	1521.6	19387.7	1749.84	19844.18
2025	1521.6	20909.3	1749.84	21594.02

The comparison of baseline production and projected production is presented in figure 2 below.

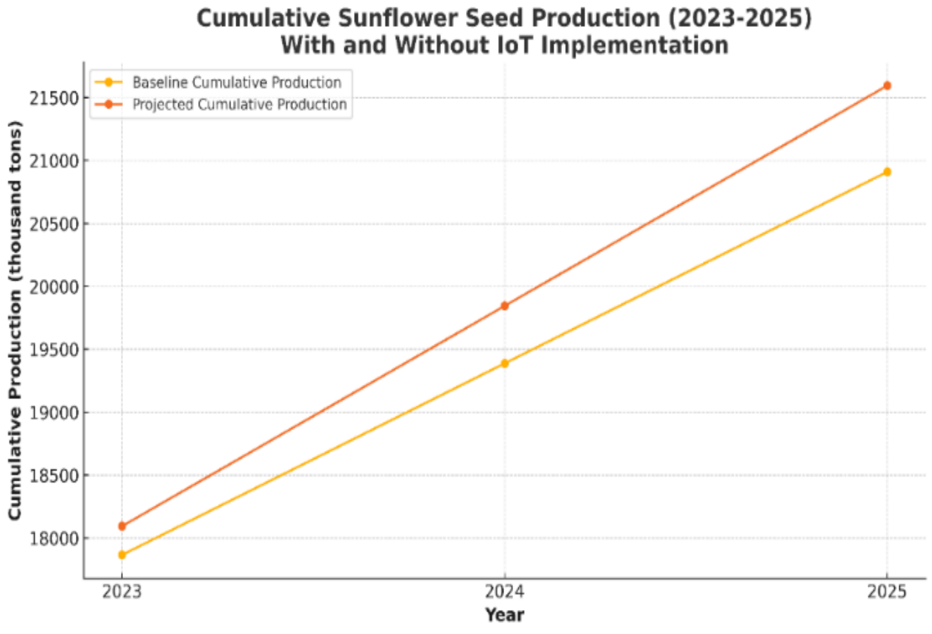

Figure 2: Comparison of Production

This graph above represents production of sunflower seeds starting from the year 2023 till the year 2025 and it displays the current production against the expected production that would be attained once IoT technological advancement has been integrated into the production process. Thus, the projected cumulative production reveals the following picture which marks an increase in the growth of production due to the implementation of IoT technologies, so it demonstrates the importance of adopting IoT in the agricultural sector in Uzbekistan.

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Table 2 enables one to realize the anticipated rise in sunflower seed production because of IoT's adoption with standardized production amounts for selected regions, which are the base production and the total production based on yearly projections. From this data, one can determine that taking up IoT in food production can yield so much of an advantage since farming is boiled down to naked productivity.

Table 2: Production Forecast for Selected Regions

Region	Baseline Production (2022, thousand tons)	Projected Production (thousand tons)	Increase (thousand tons)	Increase (%)
Republic of Uzbekistan	1521.6	1749.84	228.24	15
Andijan Region	338.0	388.7	50.7	15
Bukhara Region	133.1	153.065	19.965	15

Based on the settings and consideration of the study, the above is the forecast of IoT technologies on sunflower seed production up to the year 2025. Baseline data table until 2022 is projected to 2025, IoT technologies expected to be deployed from 2023. The proposed data considers production increases by 15% from the year 2023. For example, taking the baseline data from the Republic of Uzbekistan and if this figure has not risen from the level of 2022, the production in 2025 will stand at 1521. 6 thousand tons. By adopting an IoT effect on the production of 15% from the year 2023 onwards, the projected production in the year 2025 would be nearly 1749. 84 thousand tons, 228 more than the previous year,24 thousand tons.

Production changes are compared at the regional level to analyze shifts in production within specific regions in Uzbekistan by the year 2025. Because IoT devices were used, it is anticipated that regions with different climatic conditions and types of soil would produce different yields on sunflower seeds. For instance, according to the assessment based on the average of 2022, even in the context of stagnation in 2025, the baseline production in the Andijan Region will be 338. 0 thousand tons. Considering the model, the likelihood is an estimated increase of 15% starting from 2023, projected production in 2025 stands at 388.7 thousand tons, or 50% of the previous year's value. Likewise, in the Bukhara Region, the baseline production of 2025 barely falls to 133 even if there is no improvement from the 2022 level. 1 thousand tons. As projected to have an approximate annual increase of 15%, from year 2023, the projected production in year 2025 is 153. three percent of the previous year's output of 065 thousand tons which was produced in Mnazi Bain telephone interview 5th December 2007. 965 thousand tons.

The bar plot in figures 3 and 4 shows the change in production rates from the baseline or the current levels to the expected levels in 2025, without the adoption of IoT technology. To demonstrate this, a line graph projecting the production levels over five years starting from today up to the year 2025 with and without the IoT implementation is displayed. Furthermore, a yearly production line chart also demonstrates that with these IoT technologies, there is a gradual, yet steady growth of productivity over the years and this is due to the compounding effect where the small gains made in each year adds up to give a higher value.

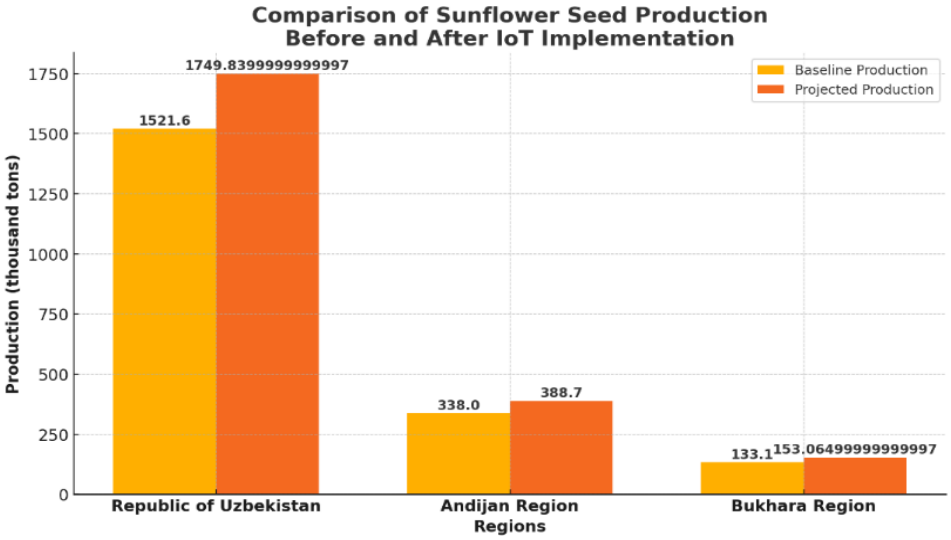

Figure 3: Region wise Comparison

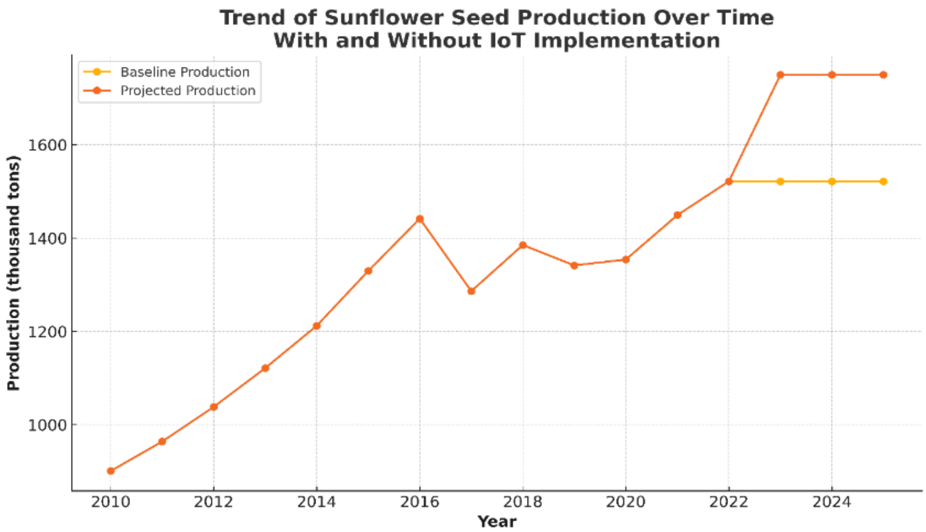

Figure 4: Production with and without IoT Implementation

The figure indicates that sunflower seed production is likely to improve when IoT is implemented, hence signifying that the use of advanced technologies is likely to enhance agriculture in the near future. The above results reveal that IoT devices can help mitigate some of the pressing concerns that farmers experience, including low crop yields and adverse environmental conditions, by increasing yield in the various regions. It is therefore possible to measure the impact of different IoT devices based on what they have contributed to the growth in production process. For instance, the idea of making soil moisture sensor, which can be used to improve the water irrigation and to avoid the waste of water. DHT22 sensors are useful to monitor temperature and humidity to keep the suitable environmental conditions and to control frequency of waterings. Air quality sensors such as MQ-135 can be a valuable tool for monitoring harmful gases and controlling their effects on crop production. Light intensity sensors (BH1750) play an important role in regulating light to provide enough sunlight and conquer shading.

The projected changes in production could have been caused by several reasons regarding the limitations of the present system. As analyzed above therefore, efficient irrigation driven by enhanced water management by use of real-time soil moisture data greatly boost yields. The specific areas of improvement involve better control over temperature and humidity data for efficient growing conditions and the reduction of effects of climate shocks. Early detection of hazardous gases that may affect crop yield can be done with the help of technologies that are aimed to minimize pollution and save crops. Resource optimization due to improved understanding of the resource use gives the overall result in the increased resource use efficiency with lesser wastage and lower costs.

There are a few issues to note though since this method is based on the projected outcomes: This is mainly because the projections have been based on the best estimates of the likely performance of the key devices and farmer decision making which may not always be the case. Overall, there is a financial strain in the early stages by integrating IoT technologies and might be out of reach for some farmers so they may need to be subsidized. Sensor data may not be as accurate and reliable as required which may enhance some variability in outcomes, thus requiring frequent technical backup and frequent hardware check-ups.

It is possible for future research to concentrate on making actual observations to confirm the calculated predictions and alter the theory also. Use of IoT at large scale and continuous controls may produce long term cost analysis which requires extensive economic analysis. It is important to examine the long-term consequences of IoT adoption on the levels of it in soil, water availability and the environment who can assist in the creation of guidelines. Thus, tackling these issues and leveraging these growth prospects, the application of IoT holds the potential to significantly improve and sustain agricultural output in Uzbekistan.

5. RESULTS

From the analysis conducted it can be concluded that IoT is set to influence sunflower seed production in Uzbekistan – up to the economic effects until 2025. Based on adopting the IoT to the sunflower seed production beginning in 2023 and its consequent annual yield increase by 15%, we estimated the potential additional gross revenues and other economic effects in the Republic of Uzbekistan through 2025. The output without accounting for the integration of IoT in 2022 is 1521 and in 2025 is 1784.6 thousand tons. In the light of IoT, the estimated manufacturing in 2025 is 1749. Year 2022 Volatile Other 94 thousand tons 45 thousand tons 84 thousand tons 367 thousand tons 384 thousand tons 228.24 thousand tons. Assuming an average price of $500 per ton, the increased revenue from the additional yield is calculated as follows:

$$\text{Additional Yield} = 228.24\text{thousand tons}$$

$$\text{Increased Revenue} = 228.24 \times 500 = 114{,}120{,}000\text{USD}$$

Improved stock utilization is another major advantage that comes with production process optimization.

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If a 20% reduction in water usage due to optimized irrigation is achieved, with an initial water cost of $100 per hectare and a farm size of 10,000 hectares, the savings are calculated as follows:

$$\text{Initial Water Cost} = 100 \times 10{,}000 = 1{,}000{,}000\text{USD}$$

$$\text{Reduced Water Cost} = 1{,}000{,}000 \times 0.80 = 800{,}000\text{USD}$$

$$\text{Savings} = 1{,}000{,}000 - 800{,}000 = 200{,}000\text{USD}$$

For fertilizer and pesticide optimization, a 10% reduction in costs due to precise application based on real-time data, with an initial cost of $200,000 is optimized then the savings would be:

$$\text{Reduced Cost} = 200{,}000 \times 0.90 = 180{,}000\text{USD}$$

$$\text{Savings} = 200{,}000 - 180{,}000 = 20{,}000\text{USD}$$

For labor cost savings, if a 15% reduction due to automation is arrived, with an initial labor cost of $500,000, the savings would be:

$$\text{Reduced Labor Cost} = 500{,}000 \times 0.85 = 425{,}000\text{USD}$$

$$\text{Savings} = 500{,}000 - 425{,}000 = 75{,}000\text{USD}$$

The total economic benefit calculation includes the total increased revenue and total resource savings:

$$\text{Total Increased Revenue} = 114{,}120{,}000\text{USD}$$

$$\begin{aligned}\text{Total Resource Savings} &= 200{,}000\text{USD (Water)} + 20{,}000\text{USD (Fertilizer and Pesticide)} \\ &+ 75{,}000\text{USD (Labor)}\end{aligned}$$

$$\text{Total Resource Savings} = 200{,}000 + 20{,}000 + 75{,}000 = 295{,}000\text{USD}$$

$$\text{Total Economic Benefit} = 114{,}120{,}000 + 295{,}000 = 114{,}415{,}000\text{USD}$$

The specific economic planning, demonstrating the measures of IoT regarding the Republic of Uzbekistan that started from 2023, will show higher revenues around $114,120,000 from the additional sunflower seed production yield by 2025. Overall, worthy usage of water, fertilizers, pesticides, and finally the labor could also be saved, which may sum up to approximate $ 295,000. Thus, positively impacted by the IoT, the level of sunflower farming's economic benefit up to 2025 can reach $114,415,000. Such a significant potential increment in the economic return makes the integration of IoT into the agriculture most worthy since the technology enables the agronomy to get better yield with efficiency use of resources and less operational costs thus making the agriculture sector more profitable and sustainable.

The techniques of agricultural IoT technology include soil moisture sensors, temperature, and humidity sensors (DHT22), air quality sensors (MQ-135), light intensity sensors (BH1750), irrigation systems, weather stations, GPS (NEO-6M), and data logging systems (SD Card Modules) that enable farmers to improve agriculture activities and, in effect, raise commodity production. According to this analysis in which a few assumptions were made as well as mathematical modeling, it is forecasted that the implementation of IoT could increase the sunflower seed production rate by 1521 by 15%. The drop in emissions ranged between 2300 short tons to around 6 thousand tons at approximately 1749. 84 thousand tons. Thus, IoT implementation has positive impact in Uzbekistan where Andijan and Bukhara are projected to experience disparate outcomes based on climate and types of soil. For example, Andijan's production may rise from 338.0 M thousand tons to 388.

The economic benefits include significant increment in yields revenue, optimization of the resource use, decrease in operating costs, and the quality of the produced crops. For instance, the calculated potential incremental sales from the proposed marginal increase of 15 percent would be $114,120,000. IoT is proving to be useful in controlling available resources in a very strategic manner and control of water usage, fertilizer, pesticide among others, correct farm management. This results in definite cost advantages and offers great saving as far as the environment is concerned. By such IoT devices, farmers can get real-time data and information as well as analytics to address risk factors inclusive of climate shocks, pests, and diseases among others leading to improved and sustainable farmers' operations.

However, there are several limitations as well as challenges that must be embraced as we seek to implement it. IoT also has the disadvantage of having relatively high costs in terms of the devices themselves, as well as the necessary infrastructure, and this can be a significant problem for many farmers. Maybe the grants and subsidies from the government could be a necessity in ensuring that a large uptake is achieved. It is crucial to maintain the accuracy of data, which is collected by sensors, as well as to care about the IoT system's proper functioning, which may lead to investing considerable time in technical support or familiarizing the farmers with the equipment. In the present study, IoT technologies' efficiency relies on the responses of farmers in terms of recommendation by the data obtained from the IoT systems. Ongoing training and farmers' sensitization remain key to the successful implementation of the Agriculture Commercialization Facilitation Framework.

Future research should be conducted to compare the results obtained for the projected impacts of external shocks with actual outcomes, as well as to fine-tune various models that were applied in this study. These insights suggest an overload on detailed economic analysis is required when it comes to determining the viability and returns of the large-scale adoption of IOT in agriculture. For organizers, it is significant to understand the long-term impact of IoT technologies on the state of the ground, water supplies, and overall environmental health to notice valuable lessons that can be utilized in the future. Some important questions to emerge concerning IoT agriculture and the future of ag tech may include Significant effort will need to be put into finding how such solutions can be more widely expanded and how they can be more easily applied to existing farming practices and technologies.

In conclusion, the successful adoption of IoT technologies has the potential to drastically enhance sunflower seed production in Uzbekistan through increasing production and resource usages while passing on highly valuable economic gains. It is therefore upon addressing the challenges and premising on the promising projections that IoT has the potential to fill the strategic void and spur agricultural productivity and sustainability in the region.

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