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DEVELOPING AND TESTING A SMART AND PRECISE SYSTEM FOR PLANT FERTILIZATION

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ABSTRACT

The objective of this study was to increase nutrient efficiency and decrease the detrimental effects on the environment. Using automation, sensing technologies and data analysis to control the optimum distribution of fertilizers and water based on real-time crop requirements. So, sensors to determine soil nutrients (nitrogen, phosphorus and potassium), as well as specific parameters like pH, moisture content and temperature were developed to create a smart system. Upon detection of nutrient deficiency, fertilizers are applied automatically or remotely using the Internet. It was conducted using three fertilization systems (automated, semi-automated and traditional) and three different types of drippers (GR, T-TAPE, EOLOS D2000). Results showed that the automated system achieved the highest crop yield (20.71 tons/hectare) and the lowest fertilizer consumption (86.67 kg) compared to the traditional system (17.39 tons/hectare and 158.96 kg). Nutrient levels in the soil also improved, enhancing soil fertility. The findings confirm that smart fertilization enhances crop productivity, reduces fertilizer waste, and improves soil fertility, making it a sustainable and efficient option for modern agriculture.

Key words: **automated fertigation, drippers, intelligent fertilization, iot fertigation.**

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INTRODUCTION

Agriculture has recently witnessed the adoption of advanced technologies, most notably the Internet of Things (IoT), which relies on interconnected devices that enhance the efficiency of agricultural operations by improving resource management and accurate data analysis (Sinha & Dhanalakshmi, 2022). This technology allows farmers to apply precision agriculture reducing overuse of fertilizers and water and enhancing resource and yield efficiency (Rehman et al., 2022). IoT technologies are also contributing to improved soil management and aquatic nutrient monitoring which is vital to address challenges such as soil moisture and temperature and fertilizer application, enabling better fertilization and increased yields (Sharma* et al., 2020). This information allows systems to be dynamically adjusted to ensure optimal water and nutrients are provided at critical growth stages without direct human intervention, and the application of IoT technologies provides continuous monitoring and remote control, giving farmers the ability to manage irrigation and fertilization practices (Imbernón-Mulero et al., 2023; Karim & Karim, 2017; Sharma* et al., 2020). Sensors embedded in the soil collect data on moisture, pH, temperature, and nutrient content, and this information is used in sophisticated algorithms to accurately adjust the composition and amount of fertilizer, and this ensures the provision of nutrients necessary for plants during their different stages of growth (Ahn & Son, 2011; Domingues et al., 2012; Anis et al., 2023; Idris et al., 2024). Drip irrigation contributes to maintaining soil moisture and reducing evaporation which improves crop quality and reduces the use of excess fertilizer

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(Jia & Fu, 2020). This technology also allows the integration of water supply and nutrients into a single system, enhancing resource efficiency and improving productivity (Yang et al., 2023). Recent studies suggest that smart fertilization powered by AI and IoT technologies can significantly reduce fertilizer and water use without negatively impacting yield, for example research has shown that smart fertilization has reduced the use of nitrogen, phosphorus, potassium, and water compared to traditional methods while maintaining productivity (Idris et al., 2024). According to a recent study, the average production of crops using smart fertilization was 9.0 tons/hectare compared to 7.2 tons/hectares obtained in the traditional way. Note not only increases the levels of nutrients inside the soil, but the concentration of the application makes the plant use the nutrients more efficiently and reduces the nutrients that are wasted in the soil and enhances the balance of nutrients with soil health for a long time (Rogger et al., 2024). On the other hand, increasing the efficiency of water and fertilizer use through smart irrigation and fertilization techniques is one of the basic strategies to increase yields and achieve higher returns in agricultural production, these strategies contribute to improving the efficiency of the use of agricultural resources, leading to increased productivity and crop quality (Karaşahin et al., 2018). Through smart composting systems, fertilizers can be distributed more efficiently, achieving similar or better results by using less fertilizer than traditional methods, and this not only helps reduce the cost, but also contributes to reducing the environmental impact of overuse of fertilizers (Hu et al., 2021; Bao et al., 2023). Although many researchers in Iraq have conducted studies related to fertilization (Mnagd & Algailany, 2018) and the development of agricultural machinery and the use of technology (Jabbar & Jasim, 2021; Jasim et al., 2022), the topic of smart fertilization has not been explored. Fertilizer management in agriculture is a major challenge in modern farming, as traditional soil nutrient analysis methods are complex and costly, limiting their effective use. Some fertilization techniques rely on sensors that measure pH and electrical conductivity (EC), but these provide aggregate data without specifying individual ion concentrations, which reduces the accuracy of agricultural decisions (Ko et al., 2013; Scoggins, 2005). In contrast, chemical sensors offer an alternative solution that provides precise and immediate measurements at moderate costs, thus contributing to improved irrigation and fertilization management efficiency (Artigas et al., 2001). Some fertilization systems need technologies like spectroscopic analysis and image processing. These things are often expensive. That is why they are not used a lot in farming. In Iraq people do not use fertilizers in the way. This leads to crop productivity and high costs. The fertilizers are not given in the amount they are not distributed well and the wrong type of fertilizer is used for the plants. The old ways of doing things also cost a lot of money because the soil analysis is expensive and the irrigation and fertilization systems get clogged. This study wants to make cost smart fertilization systems. These systems will measure the soil and plant needs in time to make sure the fertilizers are used well. The study will help farming in Iraq, where not a lot of research has been done on these kinds of technologies. The study uses Internet of Things and Artificial Intelligence to make fertilizer use reduce costs for farmers and use resources in a sustainable way. Smart fertilization systems will also help agriculture become more digital make sure people have food and make the local economy stronger. This is important for science and, for use.

MATERIALS AND METHODS

The field experiment was conducted using a completely randomized block design with split-plot arrangements to evaluate the impact of the type of fertilization system and the type of drippers used on the performance of the smart fertilization system. The experiment included two main factors: the fertilization systems, which consisted of traditional fertilization, automated fertilization, and semi-automated fertilization, and the types of drippers, which included GR drip tubes, T-Tape, and Eolos D2000. The experiment involved 9 treatments, each with three

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replications, and the results were analysed using COSTAT software. Comparisons between means were made using the least significant difference (LSD) at a 0.05 probability level. The study was conducted during the 2024 agricultural season at a field located at the Abu Ghraib Research Station, within the Horticulture Department of the Ministry of Agriculture, 20 km west of Baghdad. The soil was classified as silty clay loam.

Fertigation system components

All fertilization systems share main components, differing primarily in the fertilization unit. These components include a main control unit, pumping unit, irrigation pipes and accessories, a water filter, and a fertilization unit, ensuring precise water and nutrient delivery.

Fertilization unit: Fertilization systems differ in their fertilization units in terms of design and operational mechanisms. Therefore, each type of fertilization unit will be explained separately and in detail.

1.Traditional fertilization system

The system comprises a 100-liter metal fertilizer tank with an inlet and outlet for irrigation water mixed with fertilizers, as shown in Figure (1). It operates on pressure differentials to dissolve and distribute fertilizers, though nutrient application remains imprecise (Shirgure, 2013).

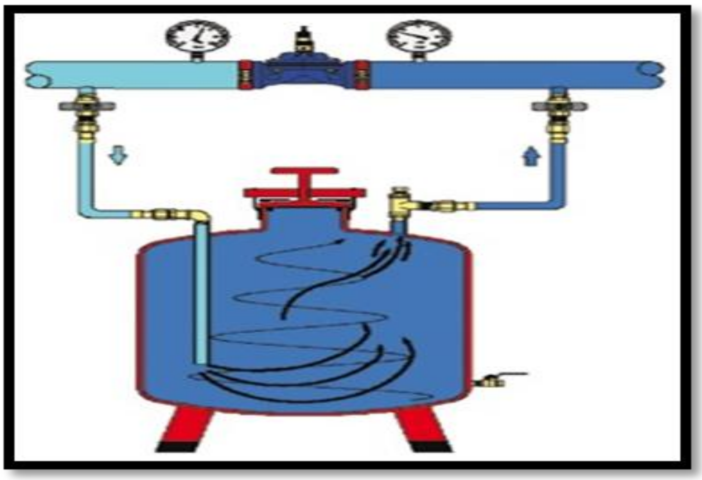

Figure 1. Fertilization Unit in the Traditional Irrigation Fertilization System

2. Automated fertilization system

The fertilization unit in the automated irrigation system consists of an intelligent device known as the smart fertilization and monitoring system, as shown in Figure (2). This system monitors and analyses soil conditions, including nitrogen, phosphorus, and potassium levels, pH, electrical conductivity, temperature, and moisture, using sensors placed at three different locations. The data is sent to a programmed electronic controller, which makes decisions based on the results. When a nutrient deficiency is detected, the controller sends commands to the execution unit, which includes electronic valves connected to fertilizer tanks. The designated valves open to release the required fertilizer, and the injection pump is activated to inject the fertilizing solution into the irrigation pipes. This system ensures automatic and precise nutrient delivery to plants in synchronization with the irrigation process.

1. control unit 2. Electric valve 3. Soil sensor 4. Fertilizer injection pump 5. Fertilizer tank 6. Irrigation water inlet

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Figure 2. Fertilization unit in the automated and semi-automated irrigation fertilization system

3. Semi-automated fertilization system

The IoT-based fertilization and monitoring system, shown in Figure (2), relies on an intelligent device that remotely monitors soil conditions, including nitrogen, phosphorus, and potassium levels, pH, electrical conductivity, moisture, and temperature, through distributed sensors. The data is transmitted to an electronic controller, which displays the results via the IoT platform and the Blynk application on smart devices, enabling real-time monitoring and remote control of fertilization for each nutrient. The execution unit includes electric valves connected to fertilizer tanks, which operate based on commands from the controller. Fertilizers are automatically pumped through an injection pump into the irrigation pipes, ensuring synchronized nutrient delivery with irrigation.

Components of automated and semi-automated systems: The fertilization unit in automated and semi-automated fertilization systems consists of interconnected components that ensure precise control of the fertilization process. The system is based on the ESP32 electronic controller (Espressif Systems Co., China), which supports secure communication protocols and NFC technology (Al-Mashhadani & Shujaa, 2022). To ensure power stability, the XL4015 DC-DC Step Down 5A voltage regulator (GNS COMPONENTS LIMITED Co., China) is used, along with a 12V, 5A power supply. The control system includes an ESP32 Shield expansion board and a TTL to RS485 converter (Shenzhen Ruised Technology Co., China) for efficient signal transmission, as well as a four-channel relay operating at 5V and 10A (Shenzhen TCT Electronics Co., China). The system features a 12V solenoid valve (Zhejiang TMOK Plumbing Co., China) and a 60W fertilizer injection pump with a flow rate of 4 L/min and a pressure of 0.6 MPa (Fujian Aidi Electric Co., China). It incorporates a multifunctional soil sensor (Hondetechco Co., China) to measure moisture, temperature, electrical conductivity, salinity, pH, and nitrogen, phosphorus, and potassium levels, with data displayed on an LCD screen (Shenzhen Goldeleway Electronics Technology Co., China). The system supports manual operation via a toggle on/off switch with 12V LED indicators, while fertilizers are stored in designated tanks. The system is controlled through the Blynk platform, enabling remote device management and real-time notifications (Othman & Zakaria, 2020). Programming is based on C++ for data collection, analysis, and operational command execution. Table (1) presents the technical specifications of the soil sensor used. Table (1) shows the technical specifications of the soil sensor used.

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Table 1. Some Technical Specifications of the Soil Sensor Used

Parameter	Specification
Product Name	8-in-1 Soil Sensor for Moisture, Temperature, EC, pH, Salinity, NPK
Probe Type	Electrode probe
Measurement Parameters	Soil Temperature, Moisture, Electrical Conductivity (EC), pH, Salinity, Nitrogen (N), Phosphorus (P), Potassium (K)
Soil Moisture Range	0 ~ 100% (V/V)
Soil Temperature Range	-40 ~ 80°C
Soil EC Range	0 ~ 20000 µS/cm
Soil Salinity Range	0 ~ 1000 ppm
Soil NPK Range	0 ~ 1999 mg/kg
Soil PH Range	3 ~ 9 pH
Soil Moisture Accuracy	±2% (0-50%), ±3% (53-100%)

1.Soil Sensor 2. Electric Valve 3. Fertilizer Injection Pump 4. Voltage Regulator 5. Signal Converter 6. Microcontroller ESP32 7. Sensor Shield 8. Relay 9.LCD Screen

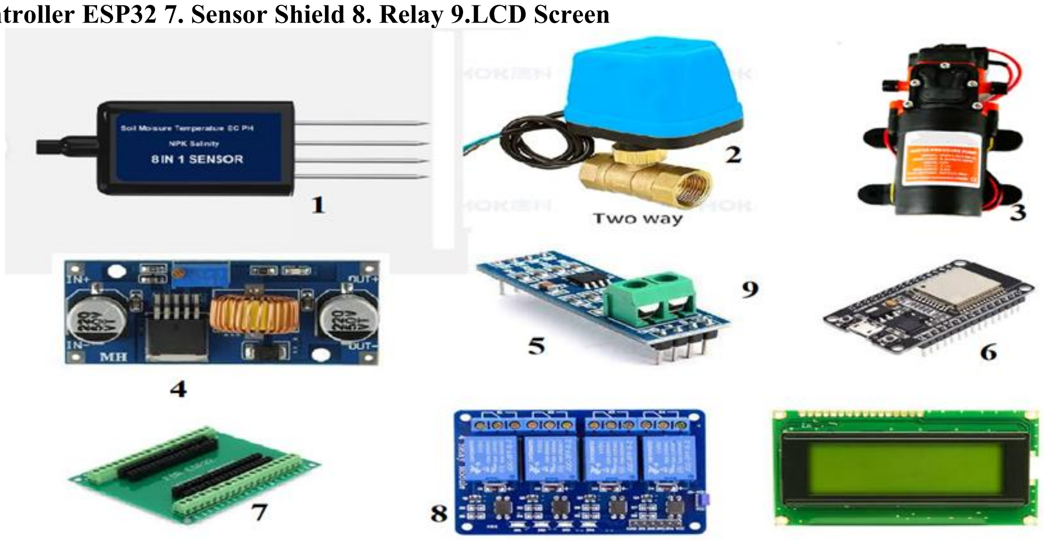

Figure 4. Components of the Smart Fertilization System Device

RESULTS AND DISCUSSION

The data in Table (2) illustrate the significant impact of fertilization system type on yield. The automated and semi-automated fertilization systems got the results with 20.71 and 20.16 tons per hectare. The manual fertilization system did the worst with 17.39 tons per hectare. This is because the automated and semi-automated fertilization systems put the amount of nutrients in the soil at the right time. This helps the crops grow better and produce more. The fertilization system is important for crop growth and productivity. These results are similar, to what other people have found in the past when they studied fertilization systems and crop growth and productivity. These results align with previous studies (Othman & Zakaria, 2020; Rogger et al., 2024). The type of dripper used did not really make a difference in how much we got. The GR dripper gave us the most on average which was 20.62 tons per hectare. The Eolos dripper gave us the least, which was 18.76 tons per hectare. When we looked at how the GR dripper worked with a machine that gives fertilizer, we got the most, which was 22.48 tons per hectare. When we used the Eolos dripper with a regular system we got the least, which was 17.28 tons, per hectare. The GR dripper and the Eolos dripper did not really make a difference though.

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Table 2. Effect of the type of fertilization system, the type of dripper, and their interaction on the yield

Traits Treatment	Yield (t/ha)
Fertilization system	
Traditional	17.39
Automated	20.71
Semi-automated	20.16
LSD (0.05)	1.158
Dripper	
T-Tape	18.89
EOLOS	18.76
GR	20.62
LSD (0.05)	N. S
Fertilization system × Dripper	
Traditional×T-Tape	17.31
Traditional× EOLOS	17.28
Traditional ×GR	17.58
Automated ×T-Tape	19.96
Automated × EOLOS	19.68
Automated × GR	22.48
Semi-automated × T-Tape	19.39
Semi-automated × EOLOS	19.30
Semi-automated × GR	21.80
LSD (0.05)	N. S

Nutrient content in the Soil

The results in Table (3) illustrate the impact of fertilization system type, dripper type, and their interaction on soil macronutrient (N.P.K) concentrations. The study found that automated fertilization systems and semi-automated fertilization systems increase nutrient levels a lot compared to fertilization systems. The highest nitrogen concentration was found in the automated fertilization system with 89.26 mg/kg of nitrogen then the semi-automated fertilization system with 86.65 mg/kg of nitrogen and the traditional fertilization system had the concentration with 61.66 mg/kg of nitrogen. The automated fertilization system and the semi-automated fertilization system also had phosphorus levels with 47.89 mg/kg and 46.21 mg/kg respectively compared to the traditional fertilization system with 39.5 mg/kg. This is because modern fertilization systems like the automated fertilization system and the semi-automated fertilization system give nutrients to plants in a precise way so plants can use them well and we do not lose a lot of nutrients. Regarding potassium levels in the soil the automated fertilization system had 180.78 mg/kg, the semi-automated fertilization system had 176.33 mg/kg and the traditional fertilization system had 149.88 mg/kg. The GR dripper was the best for nitrogen concentration with 82.83 mg/kg then the T-Tape dripper with 78.61 mg/kg and the Eolos dripper was the worst with 76.13 mg/kg. The phosphorus levels were the same for all dripper types. When we combine the GR dripper with the automated fertilization system, we get the macronutrient concentrations with 94.43 mg/kg of nitrogen 49.13 mg/kg of phosphorus and 188.88 mg/kg of potassium. On the hand the Eolos dripper with the traditional fertilization system had the lowest values with 58.89 mg/kg of nitrogen 47.28 mg/kg of phosphorus and 179.78 mg/kg of potassium. These results show that modern fertilization systems like the automated fertilization system and the semi-automated fertilization system and the right choice of dripper type are very important, for managing nutrients and increasing agricultural productivity.

Fertilizer quantity used: The results in Table (4) illustrate the impact of fertilization system type, dripper type, and their interaction on fertilizer consumption. We found that the fertilization system has an impact. The automated and semi-automated systems use a lot fertilizer. They use 86.67 kg/ha and 85.47 kg/ha of fertilizer. The traditional system uses the fertilizer at 158.96 kg/ha. The reason for this is that the automated and semi-automated fertilization systems put the amount of fertilizer in the soil. They give the plants a fertilizer often. This helps the plants use the fertilizer better and reduces waste. We also looked

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at the type of dripper used. The Eolos dripper uses the amount of fertilizer at 108.97 kg/ha. The GR dripper uses the most at 112.20 kg/ha. These differences are not really important. When we combined the Eolos dripper with the automated fertilization system we got the result. It used 84.653 kg/ha of fertilizer. These results align with previous studies (Karaşahin et al., 2018; Rogger et al., 2024). When it comes to the type of dripper the Eolos dripper used the amount of fertilizer at 108.97 kg/ha. On the hand the GR dripper used the most fertilizer at 112.20 kg/ha. The difference, between these two was not big enough to matter. The Eolos dripper and the automated fertilization system worked together to use the amount of fertilizer at 84.653 kg/ha. However, this combination did not make an enough difference either. The Eolos dripper and fertilizer usage is a combination. The automated fertilization system and the Eolos dripper together had a fertilizer usage. The Eolos dripper is a type of dripper that can be used with the automated fertilization system to reduce fertilizer usage.

Table 4. Effect of the type of fertilization system, the type of dripper, and the interaction between them on the quantity of fertilizer used

Traits Treatment	Nitrogen (mg/kg)	Phosphorous (mg/kg)	Potassium (mg/kg)
Fertilization system			
Traditional	61.66	39.5	149.88
Automated	89.26	47.89	180.78
Semi-automated	86.65	46.21	176.33
LSD (0.05)	14.61	6.07	N. S
Dripper			
T-Tape	78.61	44.62	168.54
EOLOS	76.13	44.15	163.73
GR	82.83	44.82	174.73
LSD (0.05)	N. S	N. S	N. S
Fertilization system × Dripper			
Traditional×T-Tape	61.33	40.06	144.06
Traditional× EOLOS	60.26	39.3	154.6
Traditional ×GR	4.63	39.13	151
Automated ×T-Tape	87.46	47.28	182.68
Automated × EOLOS	85.89	47.28	170.78
Automated × GR	94.43	49.13	188.88
Semi-automated × T-Tape	87.05	46.54	178.87
Semi-automated × EOLOS	82.24	45.87	165.80
Semi-automated × GR	90.67	46.22	184.33
LSD (0.05)	N. S	N. S	N. S

Table 4. Effect of the type of fertilization system, the type of dripper, and the interaction between them on the quantity of fertilizer used

Traits Treatment	The amount of fertilizer (kg/ha)
Fertilization system	
Traditional	158.96
Automated	86.67
Semi-automated	85.47
LSD (0.05)	20.34
Dripper	
T-Tape	109.92
EOLOS	108.97
GR	112.20
LSD (0.05)	N. S
Fertilization system × Dripper	
Traditional×T-Tape	158.96
Traditional× EOLOS	158.96
Traditional ×GR	158.96
Automated ×T-Tape	86.16
Automated × EOLOS	84.65
Automated × GR	89.21
Semi-automated × T-Tape	84.64
Semi-automated × EOLOS	83.32
Semi-automated × GR	88.45
LSD (0.05)	N. S

CONCLUSION

Smart fertilization systems really make a difference in how well crops grow. They help use fertilizer in a way and make the soil healthier. When we used these systems, which can work on their own or with a help we got a lot more crops. We got 20.71 tons of crops per area and 20.17 tons per area. This is a lot more than when we did it by hand and only got 17.39 tons per area.The smart fertilization systems also helped us use fertilizer in a way. We used 86.67 kilograms of fertilizer per area and 85.47 kilograms of fertilizer per area. This is a lot less than the 158.96 kilograms of fertilizer per area we used when we did it by hand. This means we did not waste much fertilizer and the crops were able to use the nutrients they needed. Smart fertilization systems also made the soil healthier by putting good things like nitrogen and phosphorus and potassium into it. These results show that using fertilization systems is a good idea for farming. It helps us grow crops and use resources in a better way. It also makes the soil healthier. Based on what we found out we think it is an idea to use automated and semi-automated fertilization systems. These systems help crops grow better and use resources in a way. If we connect these systems to the water supply it could help spread the nutrients around. We should do research to see how these systems work with different crops and, in different environments.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHOR/S DECLARATION

We confirm that all Figures and Tables in the manuscript are original to us. Additionally, any Figures and images that do not belong to us have been incorporated with the required permissions for re-publication, which are included with the manuscript

Author/s signature on Ethical Approval Statement.

Ethical Clearance and Animal welfare

Funds:

AUTHOR'S CONTRIBUTION STATEMENT

Tahseen Allawi Al-Shajari conceived, designed, and implemented the smart fertilization system and conducted the field experiments, data collection, and statistical analysis. Alaa Kamel Subr supervised the research work, contributed to the experimental design, interpreted the results, and reviewed and revised the manuscript. Both authors contributed to writing the manuscript and approved the final version for publication.

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تطوير واختبار نظام ذكي ودقيق لتسميد النباتات

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المستخلص

يهدف البحث لتحسين كفاءة استعمال المغذيات وتقليل التأثيرات البيئية السلبية. يعتمد على تقنيات الأتمتة والاستشعار لتحسين توزيع الأسمدة والمياه وفق احتياجات المحاصيل. تم تصميم منظومة ذكية تعتمد على مستشعرات لقياس العناصر الغذائية في التربة (النيتروجين، الفوسفور، البوتاسيوم) وخصائص أخرى كدرجة الحموضة والرطوبة. عند اكتشاف نقص المغذيات، يتم توزيع السماد تلقائيًا أو عبر التحكم عن بُعد باستخدام شبكة الإنترنت. اختبرت الدراسة ثلاثة أنظمة تسميد (آلي، شبه آلي، تقليدي) باستخدام أنواع مختلفة من المنقطات (GR، T–Tape، Eolos D2000)، أظهرت النتائج أن المنظومة الآلية سجلت أعلى إنتاجية (20.71 طن/هكتار) وأقل استهلاك للأسمدة (86.67 كغم) مقارنة بالنظام التقليدي (17.39 طن/هكتار و158.96 كغم). كما زادت نسب المغذيات في التربة، مما يعزز خصوبتها. تشير النتائج إلى أن التسميد الذكي يعزز إنتاجية المحاصيل، يقلل هدر السماد، ويحسن خصوبة التربة، مما يجعله خيارًا فعالًا ومستداما في الزراعة الحديثة.

الكلمات المفتاحية: التسميد بالري الالي، المنقطات، التسميد الذكي، التسميد باستخدام إنترنت الأشياء.