The effect of smart sprinkler irrigation and traditional fixed sprinkler irrigation on water use efficiency and some physical properties

Shahad Adnan Sadoon[1], Mohammed Ali Abood[2] and Haidar N. Al-Anbagi[3]

University of Diyala – College of Agriculture – Department of Soil Science and Water Resources.

[3]University of Diyala- College of Engineering for Artificial Intelligence Technology

Email: [1] shahadsadoon216@gmail.com , [2] Mohammed.Ali.Abood@uodiyala.edu.iq,

[3] haidar.najim@uodiyala.edu.iq

Abstract

Water scarcity is one of the most serious challenges facing the sustainability of agriculture in Iraq. This is a result of climate change and the declining efficiency of traditional irrigation networks. This study aimed to compare the effect of smart sprinkler irrigation and traditional fixed sprinkler irrigation on total water consumption, water use efficiency, and some soil physical properties in regular and irregularly shaped gardens planted with turfgrass. The field experiment was conducted during the 2025-2026 growing season in the experimental gardens of the College of Agriculture, University of Diyala. Water consumption was measured by using a flow meter across ten irrigation cycles, and water efficiency was estimated as the ratio between the standard vegetation cover index and the amount of water consumed. Some physical properties were also measured using field and laboratory methods. The results also showed that smart irrigation significantly reduced total water consumption compared to traditional irrigation, with greater stability and narrower fluctuation range in successive readings under smart irrigation, while Conventional irrigation showed wide and irregular fluctuation. Smart irrigation also significantly improved water use efficiency and the green growth index compared to traditional irrigation, while the shape of the garden alone did not have a significant effect on water use efficiency. Conventional irrigation recorded an expressively higher penetration resistance than smart irrigation, while no substantial differences appeared between the two irrigation methods in the soil moisture stability index and total porosity, although the regular shape of the garden recorded a significantly higher porosity than the irregular shape. These results confirm that smart irrigation represents a more efficient and precise alternative to Conventional irrigation in rationalizing water consumption, as well as the results also exhibited that the smart irrigation system achieved extraordinary savings in water consumption, averaging about 65.2% compared to the conventional irrigation system, with the savings ratio among the four agricultural plots ranging from 52.9% to 70.9%. As it enhancing the physical conditions such as Soil penetration resistance, porosity, soil moisture stability and green growth density for the soil under water scarcity in Iraq.

Keywords: Smart irrigation, traditional sprinkler irrigation, turfgrass, water use efficiency**.**

Introduction:

ISSN 2072-3857

and total porosity), and determine which is more efficient.

Methodology

Experiment Site

The field experiment was carried out throughout the 2025–2026 growing season in the experimental gardens of the College of Agriculture, University of Diyala, Diyala Province, Iraq (44°35′40.800″ E, 33°41′15.209″ N) in a soil with a silty mash texture categorized as a subgroup of the Greater group Torrifluvent according to the American classification Soil Survey Staff (1975). These are newly formed river soils with physical properties appropriate for studying the behavior of water in the soil.

Preparation of Experimental Field

Four experimental plots planted with Turfgrass were selected, all of the same age but varying in size and shape (regular and irregular). The first plot was 200 m², the second 100 m², the third 200 m², and the fourth 400 m². The plots were cleaned and prepared to ensure uniform growing conditions and minimize the impact of external factors. Measurements of the turf grass were taken after irrigation had been completed.

Allocation of irrigation treatments

First: Irrigation method:

1. AI-based smart sprinkler irrigation.

2. Conventional sprinkler irrigation (CI).

Second: Garden shape:

1. Regular, denoted as S1

2. Irregular, denoted as S2. The treatments were randomly allocated

Iraq suffers from an increasing scarcity of water resources due to hydrological projects in upstream countries and climate change. The efficiency of current irrigation systems does not exceed 30% as a result of reliance on conventional irrigation methods with high water loss [2]. In light of this reality, smart irrigation systems based on artificial intelligence and the Internet of Things have emerged as a promising solution. These systems enable real-time analysis of soil moisture and climate data to make precise irrigation decisions that adapt to the actual needs of the plants, unlike traditional fixed sprinkler irrigation, which operates according to pre-set schedules [13]. A recent systematic review has shown that these systems have achieved water savings ranging from 30% to 50% compared to traditional methods [14]. The impact of smart irrigation is not limited to water use efficiency; it extends to some physical properties. Hence, this study compares smart sprinkler irrigation systems with traditional fixed sprinkler irrigation systems in terms of their impact on water use efficiency and certain physical properties.

Study Objectives:

1- Compare the impact of smart irrigation and conventional irrigation on water consumption and water use efficiency.

2- Study the impact of the two irrigation systems on some physical properties of the soil.

3- Demonstrate the impact of the agricultural plot design (regular and irregular) on the efficiency of water usage and some soil physical properties (moisture stability index

ISSN 2072-3857

8. Steel Mounting Bracket: Mounts to the ground or a wall/post/fence, with screws and mounting hardware.

9. Internal Controller: Controls water on/off, spray direction, operating time, and range according to zones defined in the app.

10. Smart Weather Scheduling System: Adjusts or stops irrigation based on rain, wind, humidity, and temperature to minimize waste.

11. Unlimited Irrigation Zones: Allows the creation of point, line, or area irrigation zones, which is essential for irregular spaces.

12. Internal Rechargeable Battery: Works with the solar panel and supports operation in low light conditions.

13. Water Meter.



Figure 1. The smart sprinkler used in the smart irrigation method.

Components of a fixed sprinkler irrigation system: A fixed sprinkler irrigation system consists of the following components

1. Water Source: (Ground or elevated water tank), well (with

thus the number of experimental plots was (12).

Smart Irrigation System

The OTO Smart Sprinkler system was used, which represents one of the modern systems based on smart technologies. The smart system consists of the following components:

1. A smart sprinkler with a 360° spray angle, programmable to irrigate designated areas only.

2. A precision nozzle: Controls the direction and range of the spray, ideal for irregular spaces as it allows for the creation of custom irrigation zones.

3. The OTO Lawn App: Used for mobile control and programming, this app allows you to map irrigation zones, set schedules, manually start irrigation, and monitor the system's status.

4. Wi-Fi connectivity: The system requires a 2.4 GHz Wi-Fi network for control and synchronization with the app.

5. Water supply: Connect the system to a standard garden hose with suitable water pressure; the company recommends a minimum pressure of 50 psi for a range of approximately 12.2 m / 40 ft.

6. Hose and GHT copper fittings: A hose with a minimum diameter of 5/8 inch and good quality fittings is recommended to prevent leaks. 7. Power Source: Built-in solar panel requires approximately 3 hours of direct sunlight daily, or an electrical inverter with a 50-foot cable in shaded areas.

ISSN 2072-3857

water consumed was also measured using a water flow meter for each treatment, noting that smart irrigation works according to the weather.

Total Water Consumption

The smart and conventional irrigation systems were programmed to operate on a standardized schedule, with each irrigation cycle lasting 30 minutes and a 48-hour interval. The conventional irrigation system consistently adhered to this schedule, regardless of prevailing weather conditions. In contrast, the smart irrigation system incorporated an additional feature based on weather forecasting. Irrigation was automatically suspended when cloudy or rainy weather was detected or predicted. As it resumed when weather conditions improved. Consequently, the irrigation frequency in the smart system was subject to the same basic parameters as in the conventional system, particularly the irrigation duration and the established interval cycles. The role of weather forecasting in the smart system was limited to temporarily suspending irrigation when unfavorable weather conditions were predicted, without creating a separate schedule or requiring periodic rescheduling of irrigation cycles.

Water Use Efficiency (NDVI m^{-3})

Water use efficiency was calculated according to the following equation

$$\boldsymbol{WUE} = \left\{\frac{\boldsymbol{NDVI}}{\boldsymbol{Wt}}\right\} - - - - - - - (\mathbf{17})$$

This index embodies the converting consumed water efficiency into vegetative growth, as expressed by NDVI values [14].

submersible pump), public water network

2. Pumping Unit: Centrifugal or multistage pump with suitable pressure (usually 2–4 bar).

3. Piping Network: The system consists of a series of lines, including the main line, sub-main lines, and lateral lines, made of PVC.

4. Sprinklers: Fixed spray sprinklers with a coverage radius of 3–15 m were used.

5. Valves: Manual valves were used to divide the system into zones.

6. Water Control Tap

7. Filters: Mesh filters were used to prevent sprinkler clogging.

8. Pressure Regulators: Pressure regulators (2–4 bar) were used to stabilize water pressure within the network, protect the sprinklers, and improve distribution. 9. Connections and Accessories: The system consists of a set of accessories, most importantly elbows, tees, couplings, air valves, and drain points.

10. Water Flow Meter: Used to measure the amount of water consumed in each irrigation.

This system operates on a constant principle without direct response to climatic and environmental conditions.

Irrigation Program

The irrigation systems were operated under a uniform irrigation schedule to ensure a fair comparison between the two systems. Each irrigation event lasted 30 min, with 48-hour intervals between irrigations to ensure a fair comparison between the two systems. The amount of

ISSN 2072-3857

Wilting Point (WP): Permanent wilting point (lowest moisture usable by the plant) (%)

Field Capacity (FC): (maximum usable moisture after excess drainage) (%)

Available Water Capacity (AWC): FC − WP (Available Water Capacity) (%).

Soil penetration resistance

The E-280 Pocket Penetrometer, with a cylindrical shaft and a flat end, with a diameter of 0.05 square inches and a penetration depth of 0.6 cm from the surface, was used according to the method proposed in [8]. Afterwards, the soil penetration resistance was estimated, the moisture content was directly estimated, and Equation [13] was adopted to calculate the soil penetration resistance as follows:

$$\mathbf{QP} = \mathbf{a}\mathbf{y}^{b}\boldsymbol{\theta}^{c} - - - - - - (\mathbf{13})$$

Where:

QP = Soil penetration resistance (kPa)

Y = Soil bulk density (Mg/m³)

θ = Soil volumetric moisture content (cm³/cm³)

a = Constants of c, b, and a = -4.65

Porosity

The porosity was estimated from the apparent and true density values according to the following equation [4]:

$$\mathbf{f} = \left\{\mathbf{1} - \frac{\boldsymbol{\rho_b}}{\boldsymbol{\rho_s}}\right\} \times \mathbf{100} - - - - - - (\mathbf{7})$$

Where:

f = Soil porosity (%)

Green Growth Density Index

[11] Indicated that the Normalized Difference Vegetation Index (NDVI) is one of the most widely used remote sensing indices for assessing Green Growth Density Index and health. The index is based on the relative difference between the reflection of near-infrared (NIR) and red light. Healthy plants absorb red light during photosynthesis and reflect near-infrared light to a high degree. The NDVI index is calculated via the following equation:

$$\boldsymbol{NDVI} = \frac{\boldsymbol{NIR} - \boldsymbol{R}}{\boldsymbol{NIR} + \boldsymbol{R}} - - - - - - - - - - (\mathbf{15})$$

Since:

NIR = Near-infrared reflectance

R = Red reflectance

Soil moisture stability index

[17] Soil moisture (SM) is defined as the actual amount of water present in the soil column at specific depths, measured in the field (based on the difference between the actual available moisture and wilting capacity). The Soil Moisture Index (SMI) equation is used to measure moisture depletion in agriculture based on the soil moisture condition and is calculated according to the following equation:

$$\boldsymbol{SMI} = \left\{\frac{\mathbf{5}(\boldsymbol{SM}-\boldsymbol{WP})}{(\boldsymbol{FC}-\boldsymbol{WP})}\right\} - - - - - - - - (\mathbf{16})$$

Where:

SMI: Measured soil moisture content.

ISSN 2072-3857

most important means of achieving sustainable water resource management, as it leads to increased productivity per unit of water and reduced water consumption, especially in areas suffering from limited water resources. [1] He also pointed out that smart irrigation systems based on sensors and artificial intelligence contribute to increasing water use efficiency by making real-time irrigation decisions based on the actual needs of the crop. As for the effect of the garden shape, the irregular shape (S2) recorded the highest average water use efficiency of 0.003 NDVI m-3 compared to the regular shape (S1) which recorded 0.002 NDVI m-3, but the differences between them were not statistically significant .This indicates that the shape of the garden alone was not a direct factor influencing the efficiency of water use, but rather its effect depends on the method of irrigation management and the efficiency of water distribution within the field, which explains why no significant differences appeared between the two garden shapes despite the numerical difference between the averages. As for the interaction between the irrigation method and the shape of the garden, the AIS2 treatment recorded the highest value for water use efficiency of 0.005 NDVI m-3, and significant differences appeared compared to all other interaction treatments, while the CIS2 treatment recorded the lowest value of 0.001 NDVI m-3. This result confirms that smart irrigation was most efficient when applied in irregular fields, as it was able to compensate for the spatial variation in water distribution through precise control of irrigation quantities and timing, which led to a

ρb = Apparent density (megagrams m^{-3})

ρs = Actual density (megagrams m^{-3})

Results and discussion

Water Use Efficiency Based on NDVI (NDVI m^{-3})

The results in Table (4-10) presented the effect of smart and conventional irrigation methods and the regular and irregular garden shape on water use efficiency values. The statistical analysis showed significant differences between the study treatments for this trait. The smart irrigation (AI) treatment recorded the highest average water use efficiency of 0.004 kg m-3, a significant difference compared to the conventional irrigation (CI) treatment, which recorded 0.001 NDVI m-3, indicating that the application of smart irrigation technology led to a significant improvement in water use efficiency compared to conventional irrigation. This superiority is attributed to the fact that smart irrigation systems rely on scheduling irrigation according to the actual needs of the plant based on soil moisture data and climatic factors, which reduces losses resulting from evaporation, surface runoff and deep seepage, as well as it increases the amount of water invested in growth and production processes. Adding water in the appropriate quantities and at the right time also helps to maintain root zone moisture within optimal limits, which increases the efficiency of water and nutrient absorption and increases the efficiency of water use. [9] it has been explained that careful irrigation management is one of the

ISSN 2072-3857

highest water use efficiency when they rely on continuous monitoring of soil moisture and plant needs, which contributes to increasing the productivity of a unit of water and improving the sustainability of water resources. In general, the results of this study confirm that smart irrigation is the most influential factor in improving water use efficiency compared to the form of the garden, and that its integration with micro-irrigation management techniques provides effective solutions to raise water use efficiency, especially in irregular fields, which enhances the possibility of adopting this technology in smart agriculture programs and the sustainable management of water resources.

reduction in water losses and improved utilization of added water. Conventional irrigation, on the other hand, was more affected by the irregular shape of the garden, as a result of the decrease in the uniformity of water distribution and the increase in water losses, which negatively affected the efficiency of water use. These results are consistent with what [19] concluded, who explained that integrating artificial intelligence technologies into irrigation management leads to raising the efficiency of water use and reducing its consumption while maintaining agricultural productivity, especially in fields with spatial variation or irregular shapes. [15] also showed that micro-irrigation systems achieve the

Table (4-10). Influence of Smart and Conventional Irrigation Methods and Regular and Irregular Garden Shapes on Water Use Efficiency Values

Irrigation Method	**Garden Shape**		**Irrigation Method Mean**	
AI	S1	S2		
CI	0.004 a	0.005 a	0.00 A	
Garden Shape Mean	0.001 b	0.001 b	0.001 B	
	0.002 A	0.003 A		

Means sharing the similar letter within each factor are not significantly different according to Duncan's multiple range test ($P \leq 0.05$).

Note: The symbols in the table indicate: AI = Smart Irrigation, CI = conventional Irrigation, S1 = Regular Garden Shape, and S2 = Irregular Garden Shape. AIS1 represents the smart irrigation method for a regular garden shape, AIS2 represents the smart irrigation method for an irregular garden shape, CIS1 represents the traditional irrigation method for a regular garden shape, and CIS2 represents the conventional irrigation method for an irregular garden shape.

Water consumption

The water consumption data for conventional irrigation shown in Table (4-13) across the four gardens shows a clear and significant variation, both between the gardens themselves and across different

ISSN 2072-3857

successive readings from the same experimental plot is a characteristic feature of conventional irrigation, which relies on a fixed schedule or an approximate estimate of water quantity rather than a precise response to the plant's actual needs or soil moisture at the time of irrigation. These results suggest that conventional irrigation lacks accuracy and consistency in water distribution across different agricultural plots and over time. This is leading to significant variations in the amount of water applied without a direct correlation to the plant's actual requirements.

irrigation dates during the study period (14/8/2025 – 28/9/2025). Garden 2 recorded the highest cumulative consumption (1520) m3 hectare-1 with a wide fluctuation between successive readings ranging between (90 and 200) m3 hectare-1, while Garden 4 recorded the lowest consumption (510) with almost complete stability in all irrigation times between approximately (50 and 55) m3 hectare-1. Gardens 1 and 3 recorded average consumption (955 and 1135) m3 hectare-1 respectively with moderate fluctuation. This pattern of large and irregular variation between

Table (4-13). Water consumption under conventional irrigation (m^3 ha^{-1})

No.	Date	Garden 1	Garden 2	Garden 3	Garden 4
1	2025/10/12	90	150	100	50
2	2025/10/17	110	140	85	50
3	2025/10/22	100	160	100	55
4	2025/10/27	75	90	95	50
5	2025/11/1	130	200	100	50
6	2025/11/6	120	150	90	50
7	2025/11/11	130	120	100	55
8	2025/11/16	100	160	95	50
9	2025/11/21	150	200	100	50
10	2025/11/26	130	150	90	50
Total		1135	1520	955	510

between successive readings for each garden was more localized and relatively more stable (for example, Garden 1, which ranged from 20-50 units), unlike the sharp fluctuations previously seen in some conventional irrigated gardens (for example, Garden 2, which reached 200 units). This pattern reflects the relative stability in the quantities of water applied and the ability of the

The water consumption data for smart irrigation, presented in Table (4-14), shows a clear decrease in the quantities consumed compared to the conventional irrigation schedule discussed earlier. Readings here generally ranged between 15 and 50 units per garden, compared to a much wider range of 50-200 units in the case of conventional irrigation. It is also observed that the fluctuation

ISSN 2072-3857

system, which relies on an approximate schedule not linked to actual needs.

smart irrigation system to supply the plant with its actual needs more accurately,

rather than large and fluctuating quantities as in the conventional

Table (4-14). Water consumption under smart irrigation (m^3 ha^{-1})

No.	Date	Garden 1	Garden 2	Garden 3	Garden 4
1	2025/12/1	50	40	20	15
2	2025/12/6	20	50	50	20
3	2025/12/11	20	40	30	25
4	2025/12/16	25	40	50	20
5	2025/12/21	20	40	50	20
6	2025/12/26	50	50	25	25
7	2026/1/1	30	50	40	25
8	2026/1/6	25	40	30	20
9	2026/1/11	50	40	50	30
10	2026/1/16	40	50	40	40
Total		330	480	385	240

Green Growth Density Index

photosynthetic efficiency. In contrast, conventional irrigation follows a fixed schedule that does not account for daily variations in the crop's actual water requirements. As well as, the same table also showed a significant effect of the regular garden shape (S1), which recorded a significantly higher value of (0.2855) compared to the irregular garden (S2), which reached (0.1771). However, there is no significant difference seemed between the two shapes under conventional irrigation (0.0110 versus 0.0118). This indicates a clear overlap between the irrigation method and the garden shape in affecting the green growth index.

Table (4-11) shows the effect of the irrigation method, the shape of the garden, and the interaction between them on the green growth density index. The results showed a clear and significant superiority of smart irrigation method (AI) over conventional irrigation (CI), as the overall average of the green growth density index under AI irrigation was 0.23128 compared to only 0. 1142 under conventional irrigation. This reflects a positive effect of precise irrigation scheduling and its ability to respond to actual weather conditions, thus improving the plant's physiological status and

ISSN 2072-3857

[16], who found that level of irrigation and irrigation scheduling expressively impacted the Normalized Difference Vegetation Index (NDVI) and the physiological status of plants. Contrasting conventional irrigation, which relies on fixed irrigation schedules, smart irrigation dynamically responds to variations in crop water need. This supports the validity of the pattern shown by the results of current studies, which indicate a clear and significant superiority of the smart irrigation system over the conventional system in the green growth index. This can be explained by the fact that the smart irrigation system, being more sensitive to water distribution within the boundaries of the agricultural plot, benefits more from the regularity of the geometric shape in achieving a homogeneous distribution of irrigation water and thus more regular vegetative growth. Meanwhile, the garden shape does not make a significant difference under conventional irrigation, as it's already low performance, as shown by the results of other growth indicators, limits the emergence of any significant variation related to the shape. The current results are in agreement with those reported by

Table (4-11). Influence of smart and conventional irrigation on the Green Growth Density Index.

Irrigation Method	Garden Shape		Irrigation Method Average
	S1	S2	
AI	0.2855 a	0.1771 b	0.23128 A
CI	0.0110 c	0.0118 c	0. 1142 B
Garden Shape Average	0.14824 A	0.09446 B	

Means that followed by the similar le

tter within each factor or their interaction are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test.

Note: The symbols in the table indicate: AI = Smart Irrigation, CI = conventional Irrigation, S1 = Regular Garden Shape, and S2 = Irregular Garden Shape. AIS1 represents the smart irrigation method for a regular garden shape, AIS2 represents the smart irrigation method for an irregular garden shape, CIS1 represents the conventional irrigation method for a regular garden shape, and CIS2 represents the conventional irrigation method for an irregular garden shape.

Soil moisture stability index

Table (4-12) shows that there are no significant differences in the soil moisture index between the smart irrigation method and the conventional irrigation method, as their values reached (0.04123 versus 0.05970) respectively, as well as

ISSN 2072-3857

distribution, as in the results of contour maps.

This result is consistent with what was found in [7], which compared the quality and moisture of grass soil under different smart and conventional irrigation systems. No significant differences were recorded in the quality of the grass or its moisture state between the treatments, despite the smart irrigation systems achieving a clear abundance of water. This indicates that the efficiency of water use is not necessarily related to apparent differences in the general indicators of moisture or quality, but is more clearly reflected in the amount of water consumed and its spatial distribution patterns.

between the regular and irregular garden shapes, as their values reached (0.04862 versus 0.05240), and all the means carried the same letter according to Duncan's test. This statistical convergence, despite the difference in the water application mechanism between the two systems, can be explained by the fact that the measurement of the soil moisture index was taken after a sufficient period of time after irrigation (to achieve a relative moisture balance), which reduces the appearance of instantaneous differences in the amount of water applied between the two systems at the level of the general index for the garden as a whole. Although these differences appear more clearly when analyzing the detailed spatial

Table (4-12). Smart irrigation and conventional irrigation Impact on soil moisture stability index

Irrigation Method	Garden Shape		Irrigation Method Average
	S1	S2	
AI	0.04149 a	0.04115 a	0.04123 A
CI	0.05575 a	0.06365 a	0.05970 A
Garden Shape Average	0.04862 A	0.05240 A	—

conventional irrigation method for a regular garden shape, and CIS2 represents the conventional irrigation method for an irregular garden shape.

Means that followed by the similar letter within each factor or their interaction are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test.

shapes and the interaction between them on Soil-Penetration-Resistance. The results of the statistical analysis showed significant differences between the treatments in this

Note: The symbols in the table indicate: AI = Smart Irrigation, CI = conventional Irrigation, S1 = Regular Garden Shape, and S2 = Irregular Garden Shape. AIS1 represents the smart irrigation method for a regular garden shape, AIS2 represents the smart irrigation method for an irregular garden shape, CIS1 represents the

Soil Penetration Resistance (kg cm^{-2})

The results in Table (4-8) show the effect of irrigation methods, garden

ISSN 2072-3857

relative increase in soil cohesion compared to the irregular shape, which was reflected in the form of increased penetration resistance. It is known that Soil Penetration Resistance does not depend on apparent density alone, but is also affected by the degree of soil moisture at the time of measurement, as resistance increases with decreasing moisture even if the apparent density is relatively low. Therefore, the interpretation of this result should take the soil moisture status during the measurement into account, which was confirmed by [6] and [10], who explained that moisture content is one of the most influential factors in soil penetration resistance.

As for the interaction between irrigation method and garden shape, the CIS1 treatment displayed the highest soil penetration resistance (1.3533 kg cm^{-2}), which was meaningfully higher than those documented for the AIS1, AIS2, and CIS2 treatments (0.9100, 0.9767, and 1.0117 kg cm^{-2}, respectively).These results indicate that the combination of conventional and regular irrigation resulted in the highest degree of soil penetration resistance, while smart irrigation contributed to reducing this characteristic regardless of the shape of the garden. This reflects smart irrigation ability to provide more stable moisture conditions, reducing soil particle cohesion and increasing root penetration of the soil, and improving the movement of water and air within the root zone, which positively impacts plant growth and the efficiency of water and nutrient absorption. These results are consistent with what [3] found, who showed that a decrease in soil penetration resistance is an characteristic. Conventional irrigation (CI) treatment recorded the highest average soil penetration resistance of 1.18250 kg cm-2, a significant difference compared to smart irrigation (AI) treatment, which recorded 0.94333 kg cm-2. These results indicate that applied of smart irrigation contributed to reducing soil penetration resistance compared to conventional irrigation. This is attributed to the ability of smart irrigation systems to regulate irrigation scheduling and quantities in accordance with the actual needs of the soil and plants. this why it is maintaining an appropriate moisture content and limiting the soil's exposure to repeated cycles of severe drought or oversaturation, which both are among the principal factors responsible for increasing soil cohesion and soil penetration resistance. [9] explained that precise irrigation management contributes to maintaining the physical condition of the soil and improving the root growth environment by reducing water stress and compaction resulting from poor water management. [18] also indicated that Soil-Penetration-Resistance is closely related to moisture content and bulk density, as it decreases with increasing soil moisture content and improved soil structure.

As for the effect of the garden shape, the regular shape (S1) recorded the highest value of soil penetration resistance of 1.16500 kg cm-2, while the irregular shape (S2) recorded 0.96083 kg cm-2, and a significant difference appeared between them. This result can be explained in light of the experimental conditions; it appears that the regularity of water distribution in the regular garden led to a decrease in moisture content at the time of measurement or to a

ISSN 2072-3857

management contributes to reducing soil resistance and improving root system growth, especially when using precision irrigation techniques.

Table (4-8). Impact of irrigation methods, garden shapes, and their interaction on soil penetration resistance.

Irrigation Method	Garden Shape		Irrigation Method Mean
	S1	S2	
AI	0.9767 b	0.9100 b	0.94333 B
CI	1.3533 a	1.0117 b	1.18250 A
Garden Shape Mean	1.16500 A	0.96083 B	

conventional irrigation (CI) treatments was 43.667% for the two treatments, with no noteworthy differences observed between them. This refers that the irrigation method had no significant weight on the total soil porosity during the experimental duration. This can be explained by the fact that porosity is a structural physical property that is related to the degree of compaction of soil particles and the distribution of pores. These are properties that do not change rapidly as a result of a change in the irrigation method, but rather require a longer period of time or clear changes in the structural composition of the soil in order such that significant differences were detected. Regarding the effect of garden shape, the regular shape (S1) recorded the highest average porosity (44.8333%), a significant difference compared to the irregular shape (S2), which recorded (42.500%). This result can be explained by the fact that a regular garden shape leads to a more uniform distribution of irrigation water, reducing variations in wetting and drying cycles between different parts of the field. This helps maintain soil structure stability and reduces compaction, thus preserving important indicator of improved soil physical environment and increased root penetration and spread. [9] also confirmed that improved irrigation

Note: The symbols in the table indicate: AI = Smart Irrigation, CI = conventional Irrigation, S1 = Regular Garden Shape, and S2 = Irregular Garden Shape. AIS1 represents the smart irrigation method for the regular garden shape, AI S2 represents the smart irrigation method for the irregular garden shape, CIS1 represents the conventional irrigation method for the regular garden shape, and CIS2 represents the conventional irrigation method for the irregular garden shape.

Note that the averages or means that take the same letter for each factor or the overlap between them do not differ significantly ($p \leq 0.05$) according to Duncan's multiple coefficient test S.D±.

Porosity%

The outcomes presented in Table (4-6) show the influence of irrigation method, garden shape, and their interaction on soil porosity. Statistical analysis indicated important differences among some of the treatments with respect to this property. The outcomes exhibited that the mean soil porosity for the smart irrigation (AI) and

ISSN 2072-3857

adequate to induce significant alterations in soil porosity. It is also noted that the porosity values in smart irrigation treatments were more similar between the regular and irregular shapes, which may reflect the ability of smart irrigation systems to achieve a more homogeneous distribution of water. As well as reduce spatial variation in moisture content, which limits the occurrence of local compaction and maintains the stability of the porous structure of the soil. However, this trend did not reach statistical significance, indicating that the porosity response remained more closely linked to the original soil properties and garden shape than to the irrigation method during the study period. These results are consistent with the well-established inverse relationship between bulk density and porosity, as higher bulk density in irregular shapes was accompanied by a significant decrease in porosity. This confirms that increased soil particle compaction leads to a decrease in total pore volume, which aligns with the findings of [6] and [18]. a higher porosity. Conversely, an irregular shape leads to uneven water distribution, with areas experiencing repeated saturation and others experiencing drought. This increases the likelihood of soil particle compaction and reduces the effective pore size, thus decreasing the overall porosity. These findings are consistent with those of [18], who explained that uniform moisture distribution is a key factor in maintaining the stability of the soil's pore structure and reducing compaction. [5] also demonstrated that consistent moisture conditions contribute to maintaining porosity and improving the physical properties of the soil. With respect to the interaction between irrigation method and garden shape, the CIS1 treatment showed the highest soil porosity (45.167%), while the lowest value (42.167%) was observed in the CIS2 treatment. However, no important alterations were noticed among the interaction treatments. These outcomes refer that garden shape had a greater impact on soil porosity than irrigation method. Furthermore, variation in the irrigation system alone was not

Table (4-6). Impact of irrigation method, garden shapes, and their interaction on the porosity values.

Irrigation Method	Garden Shape		Irrigation Method Mean
	S1	S2	
AI	44.500 a	42.833 a	43.667 A
CI	45.167 a	42.167 a	43.667 A
Garden Shape Mean	44.8333 A	42.5000 B	

Note: The symbols in the table indicate: AI = Smart Irrigation, CI = conventional Irrigation, S1 = Regular Garden Shape, and S2 = Irregular Garden Shape. AIS1 represents the smart irrigation method for the regular garden shape,

ISSN 2072-3857

5- The study recommends the adoption of smart irrigation systems for the management of green spaces because of their demonstrated water-saving benefits. It also recommends conducting long-term studies to appraise their cumulative effects on soil physical properties at greater depths.

References

1- **Abioye**, E. A., Abidin, M. S. Z., Mahmud, M. S. A., et al. (2022). A review on monitoring and advanced control strategies for precision irrigation. Computers and Electronics in Agriculture, 173, 105441.

2- **Al-Ansari**, N. et al. (2023). Causes of water resources scarcity in Iraq and possible solutions. *Engineering*, 15(9), 467–496.

3- **Bengough**, A. G., McKenzie, B. M., Hallett, P. D., & Valentine, T. A. (2021). Root elongation, water stress, and mechanical impedance: A review of limiting stresses and beneficial root tip traits. Journal of Experimental Botany.

4- **Black**, C. A. 1965. Methods of Soil Analysis. Am. Soc. Agron. No. 9 Part 1. Madison, Wisconsin. USA. PP. 374 – 390

5- **Blanco-Canqui**, H., & Ruis, S. J. (2020). Cover crops and soil physical properties: A review. Soil Science Society of America Journal, 84, 1527–1576.

6- **Brady**, N. C., & Weil, R. R. (2023). The Nature and Properties of Soils (16th ed.). Pearson.

AIS2 represents the smart irrigation method for the irregular garden shape, CIS1 represents the conventional irrigation method for the regular garden shape, and CIS2 represents the conventional irrigation method for the irregular garden shape.

Note that the averages or means that take the same letter for each factor or the overlap between them do not

differ significantly ($p \leq 0.05$) according to Duncan's multiple coefficient test S.D±.

Conclusion:

1- Smart irrigation has achieved significant savings in total water consumption compared to conventional irrigation, with clearer regularity and stability in the quantities of water added across irrigation schedules.

2- 2- Smart irrigation was significantly superior in water use efficiency and the green growth index, while the shape of the gardens did not have a significant independent effect on use efficiency.

3- Smart irrigation significantly reduced soil penetration resistance compared to conventional irrigation, while no significant differences appeared between the two irrigation methods in the soil moisture stability index or total porosity.

4- The results indicate that the management of the irrigation system is the decisive factor in water use efficiency, not the design of the agricultural unit itself.

ISSN 2072-3857

DOI: 10.1016/j.still.2020.104611.

14- **Nsoh**, B. et al. (2024). Internet of Things-based automated solutions utilizing machine learning for smart and real-time irrigation management: A review. *Sensors*, 24, 7480.

15- **Oğuztürk**, G. E. (2025). AI-driven irrigation systems for sustainable water management. *Smart Agricultural Technology*, 11, 100982.

16- **Pereira**, L. S., Paredes, P., Melton, F., Johnson, L., Wang, T., López-Urrea, R., Cancela, J. J., & Allen, R. G. (2021). Prediction of crop coefficients from fraction of ground cover and height. Background and validation using ground and remote sensing data. Agricultural Water Management, 241, 106197. https://doi.org/10.1016/j.agwat.2020.106197

17- **Singh,** A., Verdi, A., Haver, D., Sapkota, A., & Iradukunda, J. C. (2024). Using a soil moisture sensor-based smart controller for autonomous irrigation management of hybrid bermudagrass with recycled water in coastal Southern California. *Agricultural Water Management*, *299*, 108906.

18- **Sridhar,** V., Hubbard, K. G., You, J., & Hunt, E. D. (2008). Development of the soil moisture index to quantify agricultural drought and its "user friendliness" in severity-area-duration assessment. *Journal of Hydrometeorology*, *9*(4), 660-676.

19- **USDA-NRCS**. (2022). Soil Health Technical Note: Bulk Density and Soil Physical Properties. United States Department of Agriculture.

7- **Cardenas**, B., Migliaccio, K. W., Dukes, M. D., Hahus, I., & Kruse, J. K. (2020). *Irrigation Savings from Smart Irrigation Technologies and a Smartphone App on Turfgrass*. **Transactions of the ASABE**, 63(6), 1697–1709. DOI: 10.13031/trans.13903.

8- **Donald**, T. D. 1965. Pentrometer.. In Black, C. A ., D.D. Evans, L. E, Ensminger, J. L. White, and F. E . Clark (eds.). Methods of Soil Analysis . Part 1 . Agronomy 9 . Am . Soc . of . Agron . Madison, Wisconsin U.S. A.

9- **FAO**. (2023). The Status of the World's Land and Water Resources for Food and Agriculture – SOLAW 2023. Food and Agriculture Organization of the United Nations.

10- **Hillel**, D. (2022). Introduction to Environmental Soil Physics (2nd ed.). Academic Press.

11- **Huang**, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *Journal of forestry research*, *32*(1), 1-6.

12- **Marín**, J., Yousfi, S., Mauri, P. V., Parra, L., Lloret, J., & Masaguer, A. (2020). RGB vegetation indices, NDVI, and biomass as indicators to evaluate C3 and C4 turfgrass under different water conditions. Sustainability, 12(6), 2160.

13- **Moraes,** M.T.; Debiasi, H.; Franchini, J.C.; Mastroberti, A.A.; Levien, R.; Leitner, D.; Schnepf, A. (2020). *Soil Compaction Impacts Soybean Root Growth in an Oxisol from Subtropical Brazil*. **Soil and Tillage Research**, 200, 104611.

ISSN 2072-3857

A Systematic Review. Agronomy, 13(2), 342

20- **Vallejo-Gómez**, D., Osorio, M., & Hincapié, C. A. (2023). Smart Irrigation Systems in Agriculture: