

Research Article

Comparative Evaluation of Automatic and Manual Drip Irrigation Control Systems Under Variable Valve Opening Levels

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Article info: -

- Received: 18 August 2025

- Revised: 6 October 2025

- Accepted: 18 October 2025

- Published: 23 October 2025

Keywords:

Automatic drip irrigation, Manual control, Hydraulic performance, Distribution uniformity, Maize yield, Irrigation scheduling, Valve opening levels, Water use efficiency

Abstract:

This study compared the hydraulic performance of manual and automatic drip irrigation control systems under three valve opening levels full (Q1), half (Q2), and quarter (Q3) at a constant operating pressure of 1.0 bar. Performance indicators, including coefficient of variation (CV), distribution uniformity (DU), and emission uniformity (EU), were calculated from emitter discharge measurements at four points along the lateral (0, 5, 15, and 25 m). The automatic system consistently outperformed the manual system, maintaining higher DU and EU values, especially under reduced valve openings. This stability was attributed to integrated pressure regulation and solenoid-based control, while the manual system exhibited greater performance declines and flow losses at downstream emitters. To assess agronomic implications, the automatic system was applied to irrigate maize (*Zea mays* L.) under three irrigation strategies: T1: full water requirement in one dose, T2: two equal doses, and T3: three equal doses, all at full valve opening. T3 enhanced early plant height and leaf surface area, indicating improved vegetative growth with more frequent irrigation. However, grain yield was highest under T1 (24.0 ton/ha), followed by T2 (21.3 ton/ha) and T3 (20.2 ton/ha), suggesting that less frequent but deeper irrigation favored reproductive development and yield formation. The findings confirm that automatic drip irrigation systems deliver superior hydraulic stability and uniform water application compared to manual systems. Moreover, coupling automatic control with optimized scheduling such as single-dose full water application can enhance maize yield potential and water use efficiency, contributing to more sustainable irrigation practices in large-scale agricultural production.

1. Introduction

Efficient irrigation is critical in the face of growing water scarcity, particularly in arid and semi-arid regions such as Egypt's Nile Delta. In such environments, agriculture can consume up to 75–85% of total freshwater resources, advancing the need for precise irrigation strategies to optimize usage and maintain crop productivity (Mishari et al., 2022). Drip irrigation systems have emerged as a highly effective solution, offering exceptional water conservation by supplying water directly to plant root zones and minimizing evaporation and runoff losses (Yang et al., 2023). Despite its advantages, system performance heavily depends on the control mechanism used. Manual drip systems, while economically favorable on installation, often exhibit significant variability in water delivery due to human error and inconsistent valve operation. In contrast, automatic systems equipped with solenoid valves, control panels, and pressure regulation provide scheduled irrigation, sensor-based adjustments, and enhanced uniformity (Kunt et al., 2025). Studies indicate that automatic systems may reduce water waste by 30–45% compared to manual schedules (FarmstandApp, 2023).

An essential metric for drip system evaluation is emission uniformity (EU), which measures water distribution consistency across emitters. EU typically reflects the ratio of discharge from the lowest quartile of emitters to the overall average, and is closely related to

the coefficient of variation (CV), a statistical measure of flow variability. Research standards (ASAE, 1996a) suggest that EU values above 80% represent good performance, whereas values below 70% indicate potentially problematic distribution (University of California Irrigation Guidelines, 2022). While existing literature documents the improved uniformity of automated systems under varying pressures, limited attention has been given to comparing system performance under consistent pressure but differing valve settings. Valve opening level can significantly alter internal pressure dynamics, thereby affecting emitter discharge rates even when inlet pressure remains constant. Understanding these implications is key to assessing the resilience and flexibility of control systems. The main objective of this study is to clarify how the method of opening and closing the drip irrigation system affects the hydraulic stability of the drip line, and to provide evidence-based recommendations for irrigation management under field conditions.

Therefore, this study examines the hydraulic performance of automatic versus manual drip irrigation systems, at three levels of valve opening (full, half, quarter) at a constant operating pressure of 1.0 bar. The evaluated scales include: Coefficient of variation (CV), distribution uniformity (DU), emission uniformity (EU) and water productivity (WP) of corn crop, as well as emitter discharges in multiple lateral positions.

2. Materials and Methods

2.1. Study Area Description

The field experiment was conducted in a privately owned agricultural farm in the Sidi Salem District, Kafr El-Sheikh Governorate, which is located in the northern Nile Delta area of Egypt, during the winter of 2023–2024, from November 2023 to May 2024. The study site is located at precise coordinates of 31° 20'

16.17" N latitude and 30° 52' 23.70" E longitude.

The site's clay-textured soil, which is typical of the area and is renowned for its poor permeability and high-water retention capacity, and flat terrain define it, Table (1) explains the physical properties of study site soil. To prevent problems with waterlogging or unequal distribution, such soil characteristics necessitate careful water management techniques.

Table 1. Some physical properties of soil experimental site.

Soil Depth (cm)	Particle size distribution %			Texture	Bulk density Mg/m ³	Field capacity %	PWPW %	Available Water W%
	clay	silt	sand					
0-15	65.97	18.85	15.18	Clay	1.09	47.2	25.38	21.82
15-30	66.30	13.80	19.90	Clay	1.15	40.5	21.85	18.85
30-45	66.94	16.97	16.59	Clay	1.24	39.0	21.19	17.81

An adjacent canal, a subsidiary branch of the Nile River, supplied the irrigation water directly, offering a steady and dependable supply of water fit for farming. Table (2) shows the chemical properties of irrigation water in study site. The setting offers realistic field

conditions for assessing the effectiveness of pressured drip irrigation systems on clay soils under typical canal-based irrigation scenarios. Fig. (1) shows the study area location.

Table 2. Some chemical properties of irrigation Water at the experimental site.

Soil Depth (cm)	EC (ds/m)	pH	Soluble cations, mole/kg soil				Soluble anions, mole/kg soil		
			Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Hco ₃ ⁼	Cl ⁻	So ₄ ⁼
0-15	1.50	8.15	0.30	0.10	0.76	0.02	0.55	0.21	0.46
15-30	1.57	8.00	0.31	0.10	0.79	0.02	0.57	0.22	0.48
30-45	1.65	8.00	0.34	0.10	0.89	0.02	0.65	0.23	0.50

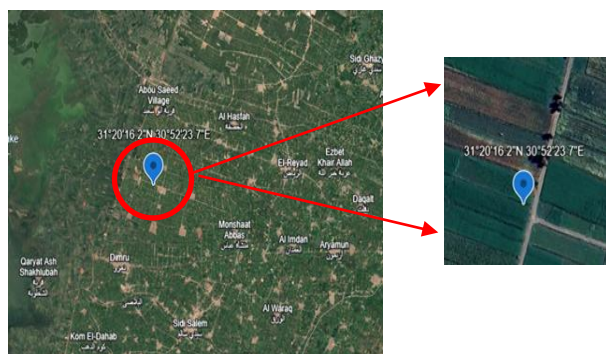


Figure1. Study area.

2.2. Experimental Design

Two identical drip irrigation networks were designed and constructed for comparison: one equipped with an automatic control system, and the other operated manually. Both systems consisted of a main line and sub-main line fabricated from 32 mm diameter UPVC pipes. Each network was connected to 12 drip laterals, each 25 meters in length, with lateral spacing of 30 cm. Emitters were installed at 30 cm intervals along each lateral, providing consistent layout between systems.

- Automatic system: Included a Rain Bird solenoid valve, an integrated control panel, and necessary electrical wiring, powered by a 220V generator. The valve assembly incorporated an internal pressure regulator

designed for low-pressure operation and a built-in filter to prevent clogging. Which converts the current from 220V to 24V and it is a pre-set control unit. The solenoid valve is calibrated three times at each valve opening rate, and this is easy because it contains a handle that can be easily calibrated in a standard way.

- Manual system: Maintained the same hydraulic configuration but required manual opening and closing of valves. It did not include any electronic components, filters, or regulators.

A pressure gauge was installed upstream of the control valve in both systems to monitor and maintain the operating pressure at a constant 1.0 bar. A schematic representation of this system is provided in Figure 2.

Each network was equipped with 12 drip laterals, each measuring 25 meters in length. The spacing between laterals was maintained at 30 cm, with emitters spaced at 30 cm intervals along the laterals. This configuration ensured uniform coverage and allowed for accurate comparison of hydraulic performance under controlled and replicable conditions.

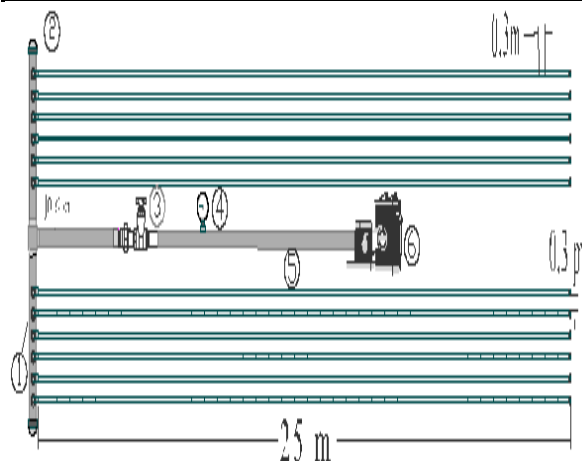


Figure 2. Schematic diagram of the manual drip irrigation control system. 1-Sub main line, 2- Lateral's line and The emitters,3- Manual valve, 4-Pressure gauge, 5- Main line, and 6- Pump and Source of water.

2.3. Control System Components and Operational Characteristics

The automatic drip irrigation system was equipped with a commercially available Rain Bird solenoid valve, integrated with a pre-programmed control panel and a set of electrical connection cables to facilitate automated scheduling and operation. The system was powered by a 220V electrical generator, which supplied sufficient energy to operate both the control unit and the water pumping system. Notably, the solenoid valve and control panel were fitted with an internal pressure regulator, specifically designed to stabilize flow under low-pressure conditions. Additionally, the solenoid valve incorporated an internal filtration unit, which served to prevent emitter clogging and ensure consistent water delivery throughout the network. In contrast, the manual control system operated entirely through direct human intervention, requiring the operator to manually open and close the valves and determine irrigation durations without the assistance of automated components.

Both systems were tested under three main valve opening levels: Full opening (Q_1), Half opening (Q_2), Quarter opening (Q_3). The operating pressure was fixed at 1.0 bar throughout all experiments. For each valve opening level, the system pressure was initially calibrated at full opening and maintained unchanged during subsequent reductions to half and quarter openings. This allowed the experiment to capture the internal hydraulic effects caused by the change in valve aperture, without altering the external pressure input from the pump.

2.4. Data Collection and Evaluation

Emitter discharge measurements were taken at four points along the length of each lateral: 0 m, 5 m, 15 m, and 25 m. At each point, five replicates were collected by capturing discharged water in graduated containers, and the volume was measured using a graduated cylinder to determine the emitter flow rate (L/h). The average of the five replicates per location was used to calculate the following performance indicators:

2.4.1. Coefficient of Variation (CV)

A statistical measure used to evaluate the variability of emitter discharge rates. A lower CV value indicates more consistent performance across emitters. CV was calculated using equations 1, and 2 (Keller and Karmeli, 1974).

$$cv = \frac{S_q}{\bar{q}} * 100 \dots \dots \dots (1)$$

$$S_q = \sqrt{\frac{\sum_{i=1}^n (q_i - \bar{q})^2}{n-1}} \dots \dots \dots (2)$$

Where:

S_q = standard deviation of emitters flow rate.

Evaluation of CV value as was mentioned by ASAE (1996a). The evaluation of CV is different from point source emitters like A and M emitters and line source emitters like G emitter as shown in Table 3.

Table 3. CV values and its corresponding classification.

Emitter type	CV range, %	Classification	Abbreviation
Point source	<5	Good	Gd
	5 to <10	Average	Av
	10 to 15	Marginal	Mg
	>15	Unacceptable	Un
Line source	<10	Good	Gd
	10 to 20	Average	Av
	>20	Marginal to Unacceptable	M

2.4.2. Distribution Uniformity (DU)

An indicator reflecting the uniformity of water distribution within the network, calculated based on the lowest quartile of emitter flow rates. DU is particularly relevant for assessing potential under-irrigation zones. The following equation was used to calculate distribution of uniformity (DU) according to Anon (1978).

$$DU = \left(\frac{\bar{q}_1}{\bar{q}} \right) \times 100 \dots \dots \dots (3)$$

Where:

DU = distribution uniformity in %.

$\bar{q}_1$ = mean of lowest one-fourth of emitter flow rates in L/h.

$\bar{q}$ = average emitter flow rates L/h.

2.4.3. Emission Uniformity (EU)

A widely adopted metric representing the ratio of minimum emitter flow to the average emitter flow rate. EU accounts for both variability and system design characteristics and is crucial for evaluating the system's efficiency in delivering water evenly calculated by the following formula (Karmeli and Keller, 1975).

$$EU = 100 \left(1 - \frac{1.27 CV}{N^{0.5}} \right) \frac{q_{min}}{q'} \dots \dots \dots (4)$$

Where:

EU: design emission uniformity, %

q_{min} = minimum observed flow rate, l/h, and

N p: number of emitters per emission point and it was 1 under the experiment conditions.

Evaluation of EU was referring to criteria of ASAE, (1996b). The evaluation of EU was as follows: $EU \geq 90\%$ is excellent (Ex), 80 to 90% good (Gd), 70 to < 80% fair (Fr), and < 70% Poor (Pr). These metrics are essential for comparing the functional performance of different irrigation control systems, especially under fluctuating pressure and flow regimes typical of field conditions.

Table 2. Performance indicators of automatic and manual drip irrigation systems under different valve opening levels (1.0 bar pressure).

System Type	Valve Opening	CV (%)	DU (%)	EU (%)	SD
Automatic	Full (Q1)	11.73	87.39	81.84	0.36
Automatic	Half (Q2)	12.04	87.14	81.60	0.37
Automatic	Quarter (Q3)	18.81	80.93	75.79	0.50
Manual	Full (Q1)	12.23	85.68	80.24	0.60
Manual	Half (Q2)	14.96	82.49	77.25	0.71
Manual	Quarter (Q3)	18.45	77.52	72.60	0.60

3.2. Coefficient of Variation (CV)

As expected, CV increased with decreasing valve opening in both systems, indicating greater variability in emitter flow rates at lower flow conditions. The automatic system consistently outperformed the manual system, particularly at full and half valve openings, with CV values of 11.73% and 12.04%, respectively. Although both systems exhibited similar variability at quarter opening ($CV \approx 18.5\%$), the slightly higher value for the automatic system (18.81%) may reflect sensitivity to low-pressure flow dynamics despite the presence of internal regulation.

3.3. Distribution Uniformity (DU)

Distribution uniformity followed a downward trend with decreased valve opening. The automatic system-maintained DU values above 80% across all settings, peaking at 87.39% for full opening. In contrast, the manual system showed a notable decline, dropping to 77.52% at quarter valve opening. These findings confirm the superior capacity of the automatic system to regulate flow and maintain even water distribution under varying hydraulic conditions.

3.4. Emission Uniformity (EU)

The emission uniformity results further emphasize

2.6. Statistical Analysis

No complex statistical analysis was employed for the data. Instead, a direct analysis of the efficiency indicators (CV, DU, EU) was relied upon, comparing their performance under different operational conditions, in addition to presenting the results in illustrative graphical representations.

3. Results and Discussion

3.1. System Performance under Varying Valve Opening Levels

The performance of both drip irrigation systems automatic and manual was evaluated under three valve opening levels (full, half, quarter), while maintaining a constant operating pressure of 1.0 bar. Key performance indicators, including the coefficient of variation (CV), distribution uniformity (DU), and emission uniformity (EU), were calculated to assess system uniformity and flow consistency. Table 2 summarizes the average values of the performance indicators obtained from five replicates per treatment.

the performance gap. At full and half valve openings, the automatic system achieved EU values exceeding 81%, while the manual system followed closely but remained slightly lower. At the quarter opening, the manual system's EU dropped to 72.60%, entering the "fair" performance range according to ASAE standards (1998), while the automatic system retained a better value of 75.79%.

3.5. Interpretation and Implications

Overall, the results clearly demonstrate that automatic control enhances system performance, especially at lower valve openings where manual systems are prone to greater variability and inefficiency. The integration of solenoid valves, pressure regulators, and control panels in the automatic setup helped stabilize flow and reduce variability across emitters. Conversely, the manual system's dependence on operator input and lack of internal regulation led to less consistent performance as flow conditions became more restrictive.

These results are particularly relevant for field conditions where manual systems dominate due to cost or availability. The findings support a shift toward automation to improve water use efficiency and reduce operational variability, particularly in large-scale or high-value crop production systems.

3.6. Emitter Discharge along the Lateral – Manual Control System

Figure 3 illustrates the emitter discharge distribution along the lateral line under the manual drip irrigation system at three different valve opening levels: full (Q_1), half (Q_2), and quarter (Q_3). The emitter discharge values show a consistent decline in flow rate from the beginning of the lateral (0 m) to its end (25 m), with the rate of decline varying according to the valve opening setting.

Under full valve opening (Q_1), the emitter discharge started at approximately 5.7 L/h at the inlet (0 m) and gradually declined to around 4.4 L/h at 25 m. A similar pattern was observed under half opening (Q_2), with slightly lower discharge values across the lateral, ranging from about 5.8 L/h at 0 m to 4.5 L/h at 25 m. Interestingly, Q_2 began with a slightly higher discharge than Q_1 at the inlet, which may be attributed to fluctuations in manual valve regulation or localized pressure surges. The quarter valve opening (Q_3) exhibited the most significant decline in emitter discharge along the lateral, starting at approximately 4.0 L/h at 0 m and dropping to 3.2 L/h at 25 m. This represents a 20% reduction in discharge along the line, indicating increased hydraulic losses and pressure decay when flow is restricted manually.

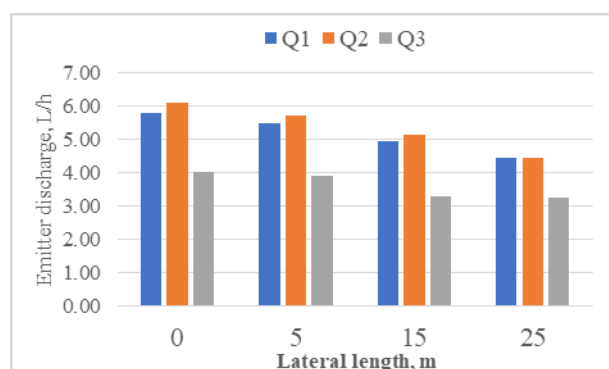


Figure 3. The emitter discharge distribution along the lateral line under the manual drip irrigation system at three different valve opening levels.

3.7. Emitter Discharge along the Lateral – Automatic Control System

Figure 4 displays the emitter discharge profile along the length of the lateral line under the automatic control system at three different valve openings: full (Q_1), half (Q_2), and quarter (Q_3). Unlike the manual system, the automatic system demonstrated notably improved flow uniformity, with relatively smaller reductions in discharge rate from the inlet to the end of the lateral.

Under full valve opening (Q_1), emitter discharge began at approximately 3.6 L/h at 0 meters and declined to about 2.8 L/h at 25 meters a drop of only ~22%, which is modest compared to the manual system. A similar pattern was observed under half opening (Q_2), with emitter discharge starting around 3.5 L/h and reducing slightly to 2.8 L/h by the end of the line.

At quarter valve opening (Q_3), the discharge ranged from 3.2 L/h at the start of the lateral to 2.3 L/h at the end. Although this represents the largest drop among the three settings, the reduction remained relatively moderate, indicating the stabilizing effect of the pressure regulator and internal control components within the automatic system. The consistent performance of the automatic system across the lateral line particularly under reduced valve openings highlights the benefits of integrated regulation mechanisms, such as the solenoid valve and internal pressure control. These components help to buffer internal pressure fluctuations and reduce frictional losses along the pipe, resulting in higher distribution uniformity and more reliable irrigation performance.

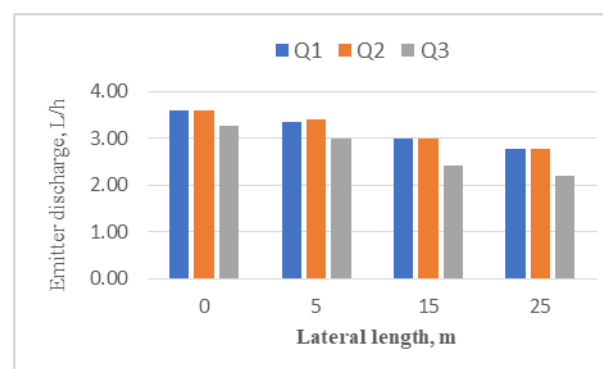


Figure 4. The emitter discharge profile along the length of the lateral line under the automatic control system at three different valve openings.

3.8. Comparative Analysis of Emitter Discharge along the Lateral Line

Figures 3 and 4 present the emitter discharge profiles along the length of the lateral line (0 m, 5 m, 15 m, and 25 m) for both the manual and automatic drip irrigation control systems, under three valve opening levels: full (Q_1), half (Q_2), and quarter (Q_3), all tested at a fixed operating pressure of 1.0 bar. In the manual control system (Figure 3), emitter discharge showed a clear decline with increasing distance from the main line, particularly under reduced valve openings. At full opening (Q_1), discharge decreased from approximately 5.7 L/h at 0 m to 4.4 L/h at 25 m, indicating moderate hydraulic losses. The half opening (Q_2) treatment exhibited a similar trend, although it began with slightly higher initial flow (5.8 L/h) and showed a comparable decrease. The quarter opening (Q_3) condition exhibited the steepest decline, dropping from 4.0 L/h to 3.2 L/h, reflecting the compounded effects of restricted flow and lack of pressure compensation. These patterns underscore the manual system's sensitivity to internal pressure variations, particularly at lower flow rates.

Conversely, the automatic control system (Figure 4) demonstrated greater stability in emitter discharge across all valve settings. At full and half valve openings (Q_1 and Q_2), emitter discharge started at around 3.5–3.6 L/h and decreased only slightly to 2.8 L/h at 25 m. Even under quarter valve opening (Q_3), the flow dropped from 3.2 L/h to 2.3 L/h, indicating better pressure regu-

lation compared to the manual system. The relatively uniform discharge values across the lateral confirm the superior performance of the automatic system in maintaining consistent flow, largely due to the integration of a solenoid valve, internal pressure regulator, and filtration components. This comparative analysis highlights that the automatic system significantly outperforms the manual system in terms of emitter discharge uniformity along the lateral, particularly under constrained flow conditions. The manual system's lack of automated regulation leads to higher frictional losses and pressure variation, resulting in uneven water distribution, especially at the downstream end of the lateral.

-Implications for Field Practice

The observed differences in hydraulic performance suggest that automated drip irrigation systems are more suitable for precise water management, especially in settings where valve modulation is frequent or where maintaining uniform discharge is critical. While manual systems may be adequate under full valve opening and small plot conditions, their performance diminishes noticeably when operated under restricted flow, potentially compromising irrigation efficiency and crop uniformity.

-Effect of irrigation-dose splitting using the automatic system on maize (*Zea mays* L.)

The automatic system demonstrates remarkable stability in performance across a wide range of pressures and valve opening degrees so can we add a part to apply the automatic system with the corn (*Zea mays* L.) crop with using 3 different methods for irrigation water application (add the water requirements at one dose T₁, adding the water requirements on two doses T₂, adding the water requirements on four doses T₃) at full opening of irrigation valve. All treatments receive the same seasonal irrigation volume, only the temporal distribution (dosing pattern) differs.

All plots use the automatic drip system. Three irrigation application methods:

- T₁: One dose (single application per irrigation event): apply the full calculated irrigation depth for the event in one continuous irrigation.
- T₂: Two doses: split the same irrigation depth into two equal sub-applications separated by a defined interval (12 hours).
- T₃: Four doses: split the same irrigation depth into four equal sub-applications separated by defined intervals.

Note: Irrigation event scheduled every 3 days.

-Effect of the irrigation application methods on the corn plants height

Fig. (5) illustrates maize plant height at four growth stages (30, 67, 93, and 107 days after sowing) under three irrigation application methods: T₁: Full water requirement in one dose, T₂: Water requirement split into two doses, T₃: Water requirement split into three doses.

At 30 days, differences among treatments were minimal, with plant height ranging between ~20 and 30 cm, suggesting that early vegetative growth was not markedly influenced by the irrigation splitting pattern. By 67 days, T₃ (four doses) recorded the highest plant height (~165 cm), surpassing T₁ (~138 cm) and T₂ (~140 cm). This suggests that more frequent water applications during the rapid growth stage may have enhanced vegetative development through improved soil moisture stability and nutrient uptake. At 93 days, T₃ maintained its growth advantage (~195 cm), with T₁ slightly lower (~180 cm) and T₂ lagging (~150 cm). The advantage of T₃ at this stage indicates that split applications likely reduced water stress during critical leaf expansion and reproductive initiation phases.

Interestingly, at 107 days (physiological maturity), T₁ reached the tallest height (~200 cm), followed by T₃ (~185 cm) and T₂ (~145 cm). This shift could be attributed to differences in plant water use patterns near the end of the season; in T₁, the larger, less frequent irrigations may have promoted deeper root development, supporting final stem elongation.

Overall, the results highlight that irrigation splitting affects maize growth dynamics, with T₃ favoring earlier height gains and T₁ achieving maximum final plant height. The optimal strategy may depend on whether the production goal prioritizes early canopy development or final biomass accumulation.

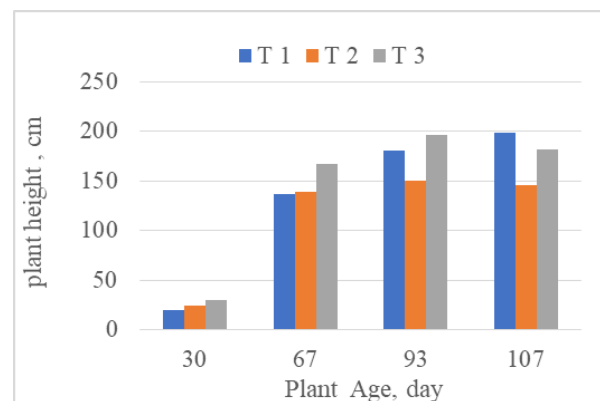


Figure 5. Effect of Irrigation Dose Splitting on Maize (*Zea mays* L.) Plant Height at Different Growth Stages under Automatic Drip Irrigation.

-Effect of the irrigation application methods on Plant leaves Surface area plant

Fig. 6 shows changes in maize leaf surface area (cm² per plant) at four growth stages (30, 67, 93, and 107 days after sowing) under three irrigation application methods. At 30 days, leaf surface area was minimal across treatments (<500 cm²), reflecting early vegetative development. T₃ recorded a slightly larger area than T₁ and T₂, indicating a marginal benefit of more frequent irrigation in promoting early leaf expansion.

By 67 days, T₂ showed the largest leaf surface area (~4,050 cm²), closely followed by T₃ (~3,850 cm²), with T₁ lagging (~3,000 cm²). This suggests that splitting irrigation into two or three doses improved

mid-season canopy development, likely due to reduced short-term water stress and enhanced stomatal conductance.

At 93 days, T₃ achieved a notable increase in leaf area (~5,300 cm²), surpassing T₁ (~4,700 cm²) and T₂ (~3,800 cm²). The advantage of T₃ at this stage may reflect improved leaf retention and delayed senescence under more stable soil moisture conditions.

By 107 days, T₃ maintained the highest leaf surface area (~7,200 cm²), far exceeding T₁ (~3,900 cm²) and T₂ (~3,400 cm²). This extended canopy duration in T₃ could enhance photosynthetic capacity during grain filling, potentially leading to higher yields and improved water productivity.

Overall, the data indicate that splitting the irrigation into four doses (T₃) promotes greater and more sustained leaf area development, which could translate into higher biomass accumulation and yield potential.

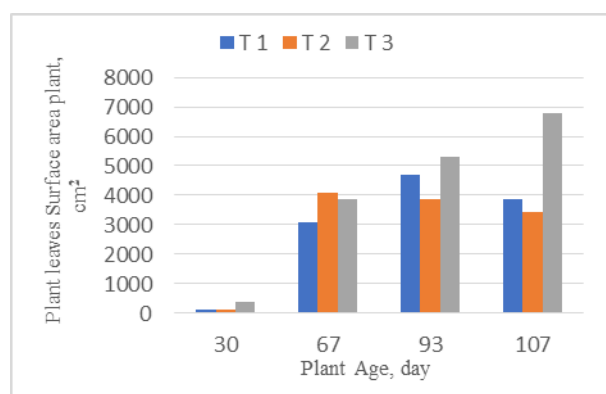


Figure 6. Effect of Irrigation Dose Splitting on Leaf Surface Area of Maize (*Zea mays* L.) at Different Growth Stages under Automatic Drip Irrigation.

-Effect of the irrigation application methods on Grain Yield

Fig. 7 illustrates the effect of three irrigation application strategies on maize grain yield (ton/ha) under an automatic drip irrigation system at full valve opening.

The results indicate a clear decreasing trend in yield with increased irrigation dose splitting. The highest yield (24.0 ton/ha) was achieved under T₁, followed by T₂ (21.3 ton/ha) and T₃ (20.2 ton/ha) suggests a strong negative linear relationship between the number of irrigation doses per application and grain yield. This decline in yield despite higher leaf area and early growth under T₃ (as seen in the leaf surface area and plant height charts) may be attributed to several factors:

1. Reduced deep soil moisture recharge in split applications, leading to shallower rooting systems and lower water availability during grain filling.
2. Possible nutrient leaching or uneven nutrient distribution with frequent irrigation, which could limit nutrient uptake at critical stages.
3. Physiological stress during reproductive stages, as T₁'s less frequent but deeper irrigation may have supported better kernel set and grain filling.

Overall, while T₃ enhanced vegetative growth, T₁ provided the most favorable conditions for final grain yield, highlighting that optimal irrigation scheduling should balance vegetative vigor with reproductive efficiency.

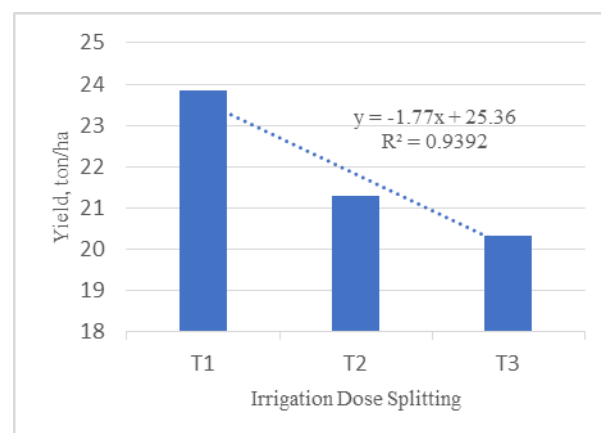


Figure 7. Effect of Irrigation Dose Splitting on Maize (*Zea mays* L.) Grain Yield under Automatic Drip Irrigation.

4. Conclusion

This study evaluated and compared the hydraulic performance of manual and automatic drip irrigation control systems under three valve opening levels (full, half, and quarter) at a constant operating pressure of 1.0 bar. Performance indicators coefficient of variation (CV), distribution uniformity (DU), and emission uniformity (EU) were assessed alongside emitter discharge rates at four positions along the lateral line. The results clearly showed that the automatic control system consistently outperformed the manual system, particularly at reduced valve openings. While both systems exhibited acceptable performance at full valve opening, the manual system experienced a notable decline in discharge uniformity and emitter flow at half and quarter openings. In contrast, the automatic system maintained stable flow rates along the lateral due to its built-in pressure regulation and solenoid-based control, achieving higher DU and EU values across all conditions. Emitter discharge measurements further confirmed that the manual system was more susceptible to pressure variation and frictional losses, particularly at the downstream end (25 m). To explore its agronomic impact, the automatic system was applied in maize (*Zea mays* L.) irrigation under three water application strategies: T₁ (full water requirement in one dose), T₂ (two equal doses), and T₃ (three equal doses), at full valve opening. Growth observations revealed that T₃ promoted greater early plant height and larger leaf surface area, indicating enhanced vegetative development under more frequent irrigation. However, yield results showed a clear advantage for T₁ (24.0 ton/ha), followed by T₂ (21.3 ton/ha) and T₃ (20.2 ton/ha). This suggests that while frequent water applications may benefit vegetative growth, less frequent but deeper irrigations better supported reproductive development and final grain production. In practical terms, these findings highlight that automatic drip irrigation systems not only ensure supe-

rior hydraulic performance and uniform water distribution but also provide the flexibility to tailor irrigation schedules to crop-specific growth dynamics. For maize production under similar field conditions, applying the full water requirement in a single irrigation event with an automatic system may optimize both water use efficiency and yield potential, contributing to more sustainable and productive agricultural practices.

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