RESEARCH ARTICLE

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Development of Automated Water Delivery System for Microirrigation in Bangladesh for Okra Cultivation

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ABSTRACT

Okra is a well-known and economically important vegetable grown in Bangladesh for consumption and seed production. The yield of okra is low compared to developed countries that can be increased using irrigation water efficiently. Traditional irrigation methods are used for okra cultivation in the developing countries, resulting in significant water loss. One of the options that appears to be promising for reducing this water loss is drip irrigation since it applies water directly to the plant's root zone. However, farmers frequently complain about manual inspection and water wastage from the overhead tanks in small-scale microirrigation systems. An automated microirrigation system can help to solve this problem. This approach was developed at Bangabandhu Sheikh Mujibur Rahman Agricultural University to evaluate the performance of okra in terms of plant growth, seasonal water usage, and yield factors. For a better understanding of specialist crop irrigation management, the effectiveness of water utilization was also investigated. The experimental field was set up in a Randomized Complete Block Design (RCBD) from March to May 2021, with three different treatments such as T_1 (Conventional irrigation), T_2 (Drip irrigation) and T_3 (Timer drip irrigation), for comparing the treatments with four replications. To construct an automated microirrigation system, a pump controller with sensing probes to regulate the water level in the irrigation tank and irrigation timers for watering the okra field depending on scheduling were used. According to the data, only the length of the pod varied significantly, whereas the other factors were non-significant. The yield components, such as the weight of pod per plant and yield, did not varied significantly among the treatments. The highest (12.95 kg/m^3) and the lowest (10.47 kg/m^3) water use efficiency were obtained in T_3 (Timer drip irrigation) and T_1 (Conventional irrigation) respectively. The study reveals that automated microirrigation technology can save 11% more irrigation water than conventional irrigation.

Keywords: controlled timer, microirrigation, okra, pump controller, water use efficiency.

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I. INTRODUCTION

Okra, often known as lady's finger, is one of the most common summer vegetables grown in Bangladesh [1], which is also considered economically important vegetable crop grown in tropical and sub-tropical parts of the world [2], [3]. It is grown for immature pods, which can be eaten as a fried or cooked vegetable, or added to salads, soups, and stews [4]. The substantial amount of okra is produced each year in Bangladesh, and about 70242 metric tons of okra was produced in 2020–21 from 12189 ha of land with an average yield of 5.7 ton/ha [5]. However, Okra production is mainly limited from February to July [6] which has fallen in the Kharif-1 season. During this season, water is scarce because of the high rate of evaporation and low intensity of the rain. This can lead to water deficits during the flowering and fruiting stages, which are the most delicate periods of okra's entire growing season, which can also reduce yield [7], [8]. Since okra requires adequate water and moderately moist soil during the growing season to provide a better yield [9], an efficient irrigation system can increase okra productivity by more effectively using the water available at that time.

Traditionally, the surface flood irrigation method along with strip and furrow methods are most commonly used in South Asia [10] and particularly in Bangladesh [11]. Such methods result in excessive irrigation water use, which reduces water use efficiency by increasing surface runoff, deep percolation, and water stagnation [12]. These ultimately lead to a water scarcity problem, and to address this issue, it is necessary to reconsider the conventional irrigation systems coupled with modern methods and technologies in the field of irrigation that increase the productivity of water volume units by reducing water gates during irrigation processes [13], [14]. Experiments at different places showed that a uniform application of water at or near field capacity of the soil should be applied all over the field for a higher yield [15], [16]. This condition can be achieved through microirrigation system, which appears to be the only promising method for dryland horticultural crops in Bangladesh [11].

Drip irrigation is a very efficient microirrigation system at maintaining the desired range of soil moisture for plant growth because it provides water to the plant's root zone directly [17]. The adoption of drip irrigation increases water use efficiency (60–200%), saves water (20–60%), reduces fertilization requirement (20–33%) through fertilization, produces better quality crop, and increases crop yield (7–25%) as compared with conventional irrigation system [18], [19]. However, waste of water from small-scale microirrigation overhead tanks is a common problem for farmers in Bangladesh. Such unnecessary wastage due to overflowing of water is also prevalent in many residential buildings [20]. This is because it is not always possible to monitor the water filling process and manually stop the motor when the reservoir is completely filled. Literature also [21] suggests that such settings result in significant water waste. This problem, however, can be solved by utilizing a suitable smart controller system with automatic water level indicators in the tank [22], since it requires minimal or no human interference. In recent years, several monitoring systems integrated with water level detection have been introduced by the scientific community for particular problems [23], [24]. These automatic water level controllers are designed based on the concept reported by Jamal [25]. Additionally, an irrigation timer is a device that can automatically operate irrigation systems such as lawn sprinklers and drip irrigation systems that can use water more efficiently than any other means when combined with a pump control system. Most controllers have a means of setting the frequency of irrigation, the start time, and the duration of watering. Some controllers have additional features such as multiple programs to allow different watering frequencies for different types of plants, rain delay settings, input terminals for sensors such as rain and freeze sensors, soil moisture sensors, weather data and remote operation [26]–[28]. To address the problem of wastage of water from overhead tank and manual intervention for maintaining irrigation scheduling in the field, an efficient water delivery system for microirrigation purposes should be developed for horticultural crops such as okra in Bangladesh.

In this research, an automated water delivery system for microirrigation has been developed for controlling the water waste from overhead tanks and minimizing human interference during okra production. The water level in the irrigation tank is controlled automatically. When the water level in the tank drops below a certain level, the pump starts automatically, and when the tank fills completely, the pump stops. An automatic pump controller unit has been used in this regard, and the irrigation timers have also been set on the drip irrigation water delivery line to operate the irrigation scheduling. Therefore, the system is surely effective for the proper utilization of available water in Bangladesh.

II. MATERIALS AND METHODS

A. *Components of Automated Microirrigation System*

1) *Automated pump controller and Sensing probes*

The pump controller (12V) is an essential component in the study and was used to control the pump start and stop concerning the water level in the tank by using sensor probes (Fig. 1). Three sensor probes were connected with that pump controller, which were used to detect water levels regarding to low (L), common (C) and full (F) in the water tank. As depicted on Fig. 1, the blue and white probes were used to indicate the lowest and highest water level of the tank respectively. The red probe was used as a common or reference level.

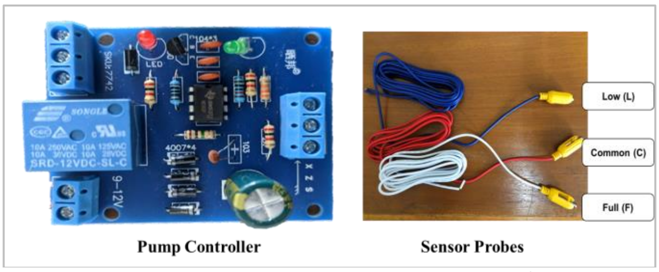

Fig. 1. Automated pump controller board and sensor probes for indicating water level.

2) *Water pump*

Pumps are mechanical or electromechanical devices designed to move water through a pipe or hose that creates pressure difference. For this study two pumps were selected, one of which was used for laboratory tests and another one was used in the experimental field. A mini pump (Model: 0B60 0.5 HP, Max flow rate: 50 L/min, Max suction: 8m and Max head: 35m) was used for the laboratory condition, and a single-phase pump (Model: TJSW-15M 1.5 HP, Max flow rate: 55 L/min, Max suction: 9m and Max head: 70m) was used in the field.

3) *Irrigation controlled timers*

Three types of irrigation timers were used, one of which was mechanical timers, and the other two were automated timers. Mechanical timer has the advantage of simplicity. They do not use electricity, so they do not run out of battery power in the middle of the watering cycle. These options usually have a control dial that is easy to use and understand. The timer used for the study was a green colored plastic timer having a (14x6x8.3 cm) dimension (Fig. 2(a)). The running time can be set simply by turning the dial to any desired value within 5–120 minutes. When the time comes, the water will automatically stop. There is no need for batteries for such timers. Automated timers can be programmed with a basic watering schedule that allows the timer to operate in its own way, watering once or twice a day at scheduled times and stopping the flow of water when the allotted watering time is complete. Two types of automated timers were used, and one of them was a BN-link timer (Fig. 2(b)) with 3 separate watering programs to set different start times (P1/P2/P3) per day, including customized irrigation frequency and duration. The runtime can be set from 1s to 99min 59s, and every 1 hour to 15 days interval, which will fully align the watering schedule with the rules of plant growth. It is an (86x56x160 mm) dimensional timer with a LCD screen. Another (86x56x 160 mm) dimensional digital screened timer was also used for the study (Fig. 2(c)), in which a 9 (Nine) groups of programming timing can be set by this particular timer. The watering time is adjustable from 5s to 60 minutes in every 1 to 30 days intervals. To select the run time a dial pointer is used and by pressing the (+/-) buttons the schedule is set. Both of these timers are waterproof and working under 1.12-1.8 MPa water pressure. Two 1.5V AA alkaline batteries are needed to run the water timer for over 6 months.

Fig. 2. Mechanical and automated timer controller.

4) *Drip Irrigation Set*

Through a set of pipes, the water is delivered to wherever it is needed from a water tank that was used for the study. Depending on the availability of different sized water tanks in the market, two tanks were selected for this study. For the laboratory test, a mini water tank with maximum capacity of 200-300 liter was used, and a large tank with maximum capacity of 1000 liter was used in the field. From the water source to the field, water was delivered through ¾ inches diameter of the main pipe, and such pipes were used because they could minimize evaporation and percolation losses. Lateral pipes connected with main pipelines deliver water directly to the crop root zone by means of droplets through emitters. The usual diameter of such lateral pipe is ½ inches. T-joints were used for partitioning water flow from one pipe to another. End caps were used to stop the water flow at the end of the drip lines, reducing water waste. One end of the irrigation timer was connected with the main pipeline through a ball valve to control the water flow, and the other end was connected with the sub main line through a thread pipe which could prevent leakage.

B. *Overall Working Procedure of Automated Water Delivery System for Microirrigation*

The overall working procedure of this experiment (Fig. 3) was carried out in two distinct phases. One of which was the control of the water level of the microirrigation tank using a pump controller. This process was first carried out in the laboratory (Fig. 4(a)) and then implemented in the experimental field (Fig. 4(b)). The second phase was to control the drip irrigation scheduling using an irrigation timer, and it was carried out in the field for okra production. The overall working procedure is as follows.

Phase 1- The automated pump controller unit has three single stranded wires used as sensing probes namely full (F), low (L) and common (C) (Fig. 5) which were dipped in water at various levels to sense the level of water in the tank. The probe C was connected as common to the other two, which should be at the bottom most part of the water tank which also acts as a reference level. The probes F and L were set as fully filled (Level-1) and minimum or slightly filled (level-2) respectively. A red led indicator was connected for alarming the water level in the tank. A single-phase pump was connected to the relay module (Fig. 4(a)). A 12V adapter was also associated with the power supply of 12V for providing current to the controller circuit. There were two main cases of this automated pump controlling system and those were.

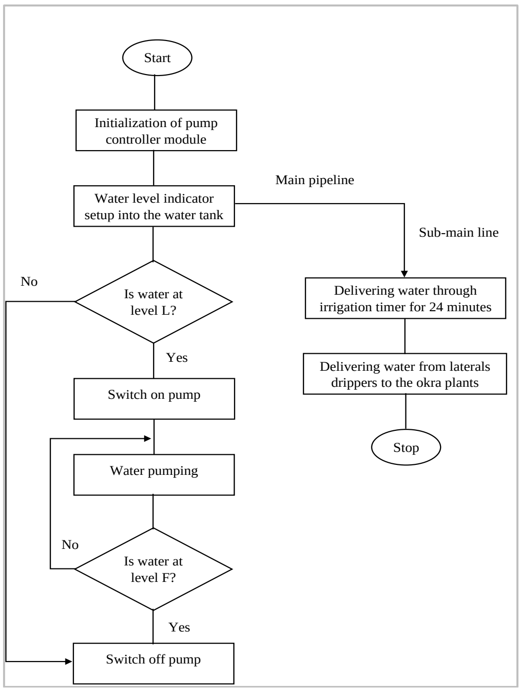

Fig. 3. Flow chart of automated water delivery system for microirrigation.

Case 1: When the water level was dropped below the sensing probe L, the indicator was blinked, and probe L was sent the signal to the relay module, which start the pump.

Case 2: When the water level was reached the highest level of the tank, which was on probe F, the indicator was blinked again, and probe F was sent the signal to the relay module, which automatically stopped the pump from running.

Fig. 4. Pump automation system.

Phase 2- As mentioned earlier, for controlling the irrigation schedule, three types of irrigation timers were used (Fig. 2). The main features of those timers are when, how long, and how often water will deliver to the field. The timer was placed between the main pipeline and sub-mainline (Fig. 5). After installation, the calibration of the irrigation timer was done by adjusting the current time of the first irrigation day (7th March 2021). For doing that, the timer dial was turned on the set clock option and selected the time, which was 11 am, by adjusting the (+/-) buttons. After setting the time, the starting time for irrigation of that day was selected (11:30 am) by turning the timer dial on the start time option. A similar manner was followed for setting the start time. For setting the irrigation frequency, the dial of the timer was turned to the how often option, and four days interval was set by adjusting the (+/-) buttons, and again the dial was turned to the how long option where 24 minutes was set for watering the plants. This schedule was continued until the first harvesting day (28 April 2021).

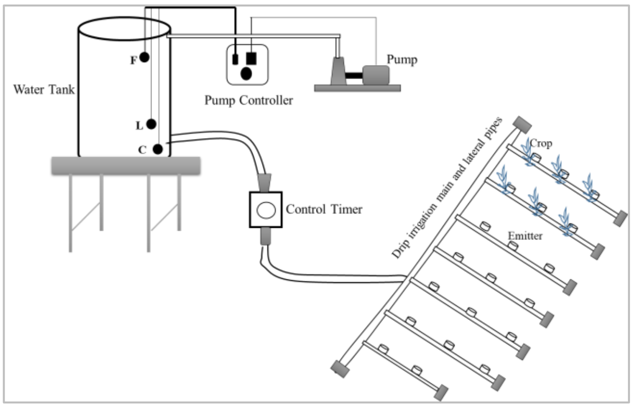

Fig. 5. Schematic diagram of the automated water delivery system for microirrigation using pump controller and irrigation timer.

C. *Experimental Design*

Fig. 6 shows the overall experimental layout for automated water delivery system for microirrigation system. The experiment was conducted in a Randomized Complete Block Design (RCBD) containing four replications with three treatments viz. T_1=Conventional irrigation (CI), T_2=Drip irrigation (DI), and T_3=Timer Drip Irrigation (TDI). The field was divided into four blocks to represent four replications of these treatments. The spacing between the adjacent block was designed to be 61 cm. Each block was divided into three treatments plot and the size of each plot was maintained to 200 cm×220 cm. An adjacent 10 cm buffer zone was also maintained between the plots.

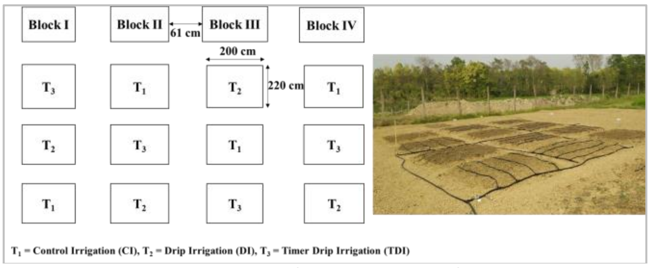

Fig. 6. Layout of the experimental field.

D. *Experimentation*

The study was conducted in the research field of Agricultural Engineering Department, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) during the period of 7 March 2021 to 31 May 2021. The experiment plots were located at an altitude of 8.4 m above mean sea level with latitude of 24°.09′ N and Longitude of 90°.26′ E (Anon,1989). Meteorological data such as rainfall, air temperature, relative humidity, evaporation in the study area were collected from the meteorological station located at BSMRAU campus (Table I).

TABLE I: METEOROLOGICAL DATA FOR OKRA CULTIVATION DURING THE STUDY PERIOD (MARCH 2021–MAY 2021)

Location	Climatic Parameter			
	Rainfall (mm)	Evaporation (mm/day)	T_{avg} (°C)	Humidity (%)
BSMRAU meteorological station	225	4.68	29.42	81.45

The experimental field was terrace soil, which was also under the Madhupur tract having silty clay loam soil within 50 cm from the surface. The field capacity (FC) and permanent wilting point (PWP) of that soil were recorded at about 28% and 13%, respectively. The experiment field was prepared by ploughing and cross ploughing with a tractor, by removing weeds and crop residues from the field, and by adding extra well-decomposed cow dung. The individual plots were also raised about 10 cm by making ridges from the soil surface. Hybrid okra (Kanchan) which is a high yield variety of okra developed by United Seed Store of Bangladesh, was sowed manually on 7th March 2021 in each plot, and the germination time was 5 days. One seed per hole was maintained for each plot contained 16 holes, and the row to row and plant to plant were considered at 60 cm and 40 cm, respectively. In the research field, a low-head drip watering system was established with a 1000-liter water tank. The main line was 3/4 inches diameter, while the sub main and laterals were 1/2 inches. A control timer was coupled with the timer drip irrigation (TDI) treatment section whereas a control valve was also used to regulate the flow of water only into the drip irrigation (DI) treatment section. Recommended fertilizer doses viz. Urea (120-150 Kg/ha), TSP (120-150 Kg/ha) and MoP (120-150 Kg/ha) were applied during the experiment. Weeds were controlled with manual weeding as well as application of herbicides until the last harvesting. In addition, a liquid pesticide which is usually mixed with 5-6 liters of water was sprayed over the okra plant to get rid of pests at maturity stage of the plant.

E. Drip Performance Evaluation

1) Flow measurement

The discharge rate of emitters was obtained from 500 ml catch can (Fig. 7) which was placed under the laterals to receive water for 3 minutes. This equivalent volume of collected water was converted to obtain the hourly flow rate of an emitter expressed as liters per hour. Evaporation rate was also synthesized with the flow rate while the weight was measured.

Fig. 7. Catch can measurement in the experimental field.

2) Uniformity indices of drippers

Uniformity is important for appropriate microirrigation systems maintaining a higher crop yield and reduces the initial investment of the system. This experiment was carried out regarding the evaluation of uniformity indices for the drip irrigation system [29]. On the other hand, lower quarter distribution uniformity ($DU_{1/4}$) is also considered as an important parameter for evaluating microirrigation system, and it can be expressed by the following formula (1) [30].

$$DU_{1/4}=100\left(\frac{\bar{D}_{1/4}}{D_{total}}\right) \quad (1)$$

where:
$\bar{D}_{1/4}$ – Lowest quarter average of a group of catch-can measurement
D_{total} – Total average of a group of catch-can measurements.
The desirable value for DU is 94% or more.

Another uniformity coefficient usually adopted by researchers for the evaluation is emission uniformity. The following equation (2) as suggested by ASABE [33] was used to calculate emission uniformity of emitters.

$$SU=100(1-CV)=100\left(1-\frac{SD_q}{\bar{q}}\right) \quad (2)$$

where:

CV – Coefficient of variation of emitter flow
SD_q – Standard deviation
$\bar{q}$ – Average flow rate.

F. Harvesting and Data Analysis

Harvesting was done from each plot, and data was collected based on plant characters and yield contributing characters. The parameters viz. plant height (cm), number of leaves per plant, days for first flowering, number of pods per plant, length of pods (cm), number of seeds per pod, weight of pod (g) and yield (t/ha) were calculated from the data obtained from the first harvesting done on 28 April 2021 to last one. Up to seven harvestings were considered for the collection of plant characters and yield data in this experiment. Application of irrigation water was also obtained for determining the water saving as well as water use efficiency for the irrigation treatments. The collected data were analyzed statistically with the help of the "Statistix10" program. The mean values for all the treatments were calculated, and analysis of variance for each of the characters was performed. Mean differences among the treatments were also compared by Tukey's Honestly Significant Difference (Tukey's HSD at 0.05).

1) Application of irrigation water

Regarding cost and labor, 3 to 5 days of irrigation frequency were considered, which turned out to be 4 days, ideal for horticulture crops. Total seasonal crop water use (SCWU) was calculated as the sum of the total irrigation water applied (I), effective rainfall (Pe), and soil water contribution (SWC) between sowing and final harvest and expressed by the following formula (4). Effective rainfall was estimated by using the USDA soil conservation method [31].

$$SWC=\frac{M_p-M_h}{100}\times As\times D \quad (3)$$

where:
M_p – Soil moisture percentage at sowing,
M_h – Soil moisture percentage at harvesting,
A_s – Bulk density, (g/cc)
D – Crop rootzone depth, (cm)

Total seasonal crop water use,

$$SCWU=FIW+Pe+SWC \quad (4)$$

The quantity of water saving was calculated by following formula (5),

$$\text{Water Savings (\%)}=\frac{\text{SWU in CI-SWU in DI or TDI}}{\text{SWU in CI}} \quad (5)$$

where:
CI, DI, and TDI represent conventional irrigation, drip irrigation, and timer drip irrigation, respectively.

2) Water use efficiency

Water use efficiency (WUE) of each irrigation treatment was calculated according to the following formula (6) [32].

$$WUE = \frac{Total\ marketable\ yield\ (kg)}{Total\ water\ used\ (m^3)} \quad (6)$$

III. RESULTS AND DISCUSSION

A. Performance Evaluation of Drip Irrigation System

The distribution uniformity ($DU_{1/4}$) of drip irrigation system was calculated for 16 emitters from each block, and the results are shown in Fig. 8. The emitter distribution uniformity for drip irrigation ranged from 93.5% to 86.87% for four blocks which falls into the 'Excellent' category. The distribution uniformity for timer drip irrigation, on the other hand, was determined from 90.84% to 84.85% for four blocks, which falls into the 'Very Good' category. The average distribution uniformity for drip systems was 90.5%, which is excellent, while the distribution uniformity for timer drip irrigation was 87.7%, which is very good. The system's total lower quarter distribution consistency was 89.1%, which is considered as 'Excellent' category [33].

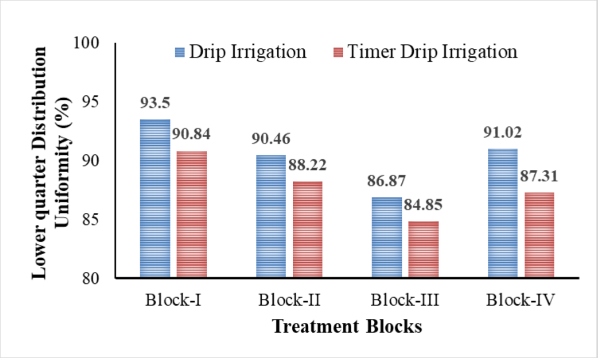

Fig. 8. Lower quarter Distribution Uniformity for four blocks.

Emission uniformity (EU) was determined for each of the four blocks, which determines the uniformity of discharge from each emitter or the uniform distribution of water for each crop and is presented in Table II. The emission uniformity for drip irrigation for the four blocks was determined from 80.77% to 87.08%, which falls into the 'Good' category, and the average (83.82%) also falls into the 'Good' category, on recommendation of ASABE [33]. On the other hand, the emission uniformity (EU) of timer drip irrigation system ranged from 81.20 to 87.99%, which indicates the 'Good' category as well as the average (83.81%) was in the 'Good' category. Emission uniformity (EU) was 83.8% for the whole system, which can also be termed as 'Good' regarding to ISO9261.

B. Impact of Automated Water Delivery System on Plant Growth and Yield Components

Height is an index of plant growth, which is influenced by environmental and crop management practices. The data on mean plant height (cm) of okra for different treatments are presented in Table III. The highest average plant height (91.22 cm) was obtained in the treatment of T_3 and the lowest height (85.47 cm) was found in the treatment of T_1. Although the plant heights varied to some extent, it did not exhibit any significant difference between the treatments. Because the water was discharged directly to the root of the plants to the field capacity, the result justified the fact that supplied water was available for okra plants under timer drip irrigation to utilize maximally, which helped to avoid a water shortage for the physiological functions of the plants [34]. Leaf numbers are one of the important parameters for measuring yield performance of Okra. The number of leaves per plant was recorded during the matured stage of plant, and the mean leaves number per plant for different irrigation treatments are shown in Table III. The highest average number of leaves (33.38) per plant was obtained in the treatment of T_3 while the lowest number of leaves (32.31) per plant was recorded in the treatment of T_1. Similar results were reported by Singh *et al.* [35] that the number of branches and leaves of plants grown under drip irrigation was higher than that of surface irrigated plant, and this could be because of carbon dioxide exchange rates which varied considerably under the drip irrigation methods with proper irrigation timings and quantity of water applied [36].

TABLE II: EMISSION UNIFORMITY (EU) FOR FOUR BLOCKS

Block	Drip Irrigation				Timer Drip Irrigation			
	Flowrate, (L/h)	Coefficient of variation of flow (CV)	EU%	Aver-age EU%	Flowrate, (L/h)	Coefficient of variation of flow (CV)	EU%	Aver-age EU%
I	3.32±0.45	0.13	86.53	83.82	3.10±0.37	0.12	87.99	83.81
II	3.16±0.50	0.16	84.17		3.31±0.61	0.18	81.67	
III	3.28±0.63	0.19	80.77		3.20±0.60	0.18	81.20	
IV	3.21±0.42	0.13	87.08		3.29±0.51	0.16	84.37	

TABLE III: IMPACT OF AUTOMATED WATER DELIVERY SYSTEM ON PLANT GROWTH AND YIELD COMPONENTS

Treatments	Plant Height (cm)	No. of leaves/Plant	Days of First Flowering	No. of Pod/ Plant	Length of Pod (cm)	No. of Seed/ Pod	Yield (Ton/ha)
T_1	85.47^a	32.31^a	44.10^{ab}	2.62^a	13.28^b	36.5^a	15.57^a
T_2	87.81^{ab}	32.44^a	45.25^a	2.87^a	14.48^a	40.5^a	16.46^a
T_3	91.22^a	33.38^a	43.40^b	3.10^a	14.72^a	37.7^a	16.7^a
CV	4.5224	2.2817	1.2890	0.7801	0.7480	7.1489	0.1772
HSD (0.05)	NS	NS	NS	NS	S	NS	NS

CV–Critical value for comparison; NS= No significant pairwise differences among the means at 0.05 level using Tukey's HSD test;
S–Significant pairwise differences among the means at 0.05 level using Turkey's HSD test.

In Table III, there were no significant pairwise differences among the means except the means of length of pods using Tukey’s HSD test. The minimum days to first flowering (43.4 days) was obtained in treatment T_3 (Timer Drip Irrigation) while the maximum days to first flowering (45.25 days) was recorded in treatment T_2 (Drip irrigation). Flowers could be propagated by avoiding water stress in plant canopies [37], and the results mentioned that timer drip irrigation system can reduce water stress of plants. The results of the average number of pods per plant for seven days of pod picking showed that there were no significant pairwise differences among the means as shown in Table IV. The highest average number of fresh pods per plant (3.10) was obtained in the treatment of T_3 among other treatments. On the other hand, the highest average length of pods (14.71 cm) was obtained from the treatment T_3 (Timer Drip Irrigation), and the lowest average (13.28 cm) was recorded for the treatment T_1 (Conventional Irrigation). There was no significant difference found between the treatments T_3 (Timer Drip Irrigation), and T_2 (Drip Irrigation), but the average lengths of pod obtained from both of these treatments were significantly different from the treatment T_1 (Conventional Irrigation) as shown in Table III. The average number of seeds (40.5) per pod was also obtained under the treatment T_2 (Drip Irrigation) which was little bit higher than the average seeds per pod for the treatments T_3 (Timer Drip Irrigation) and T_1 (Conventional Irrigation). The results showed that the seeds per pod on different irrigation techniques had no significant pairwise differences among the means. In Table III, the highest yield (16.70 Ton/ha) was obtained from the treatment T_3 (Timer Drip Irrigation), while the lowest yield (15.57 Ton/ha) was obtained from the treatment T_1 (Conventional Irrigation). The pod yields on different irrigation treatment showed that the means were not significantly different from one another. This result also supports the findings of Jayapiratha *et al.* [37] who reported the yield of plants under drip irrigation with various treatments was higher than those under conventional irrigation. This could be because using drip irrigation maintains moisture content in the root zone of the crop, which increases the availability of water and plant nutrients [39].

C. Seasonal Water Use and Water Use Efficiency of Okra

The data regarding seasonal water use/contribution (SWC) of okra under the treatments are presented in Table IV. The amount of water used by plants varied among the treatments due to variation in water application technique. The highest water savings were obtained from the treatment T_3 (Timer Drip Irrigation) as compared to the treatments T_2 (Drip Irrigation) and T_1 (Conventional Irrigation). Water savings under treatments T_3 and T_2 were calculated from 12-10% and 9-8%, respectively. Water saved more at the timer drip irrigation than drip irrigation due to watering stops whenever the plants received the desired amount of water.

TABLE IV: SEASONAL WATER USE OF OKRA UNDER THREE TREATMENTS FOR 7 MARCH 2021–31 MAY 2021

Treatment	Block	Total FIR (mm)	Effective Rainfall (mm)	SWC (mm)	SCWU (mm)	Water Savings (%)
T_1	I	50	200	-105	145	-
	II	50		-104	146	-
	III	50		-104	146	-
	IV	50		-106	144	-
T_2	I	38		-106	132	9
	II	36		-104	132	9
	III	37		-104	133	8
	IV	37		-105	132	8
T_3	I	35		-108	127	12
	II	38		-108	130	11
	III	36		-106	130	10
	IV	37		-107	130	10

TABLE V: EFFECT OF THREE TREATMENTS ON WATER USE EFFICIENCY (WUE)

Treatment	Total water used (mm)	Pod Yield (t/ha)	Water Use Efficiency (kg/m^3)	Water savings (%)
T_1	145	15.57	10.74	-
T_2	132	16.46	12.47	9
T_3	129	16.70	12.95	11

Effective and safe use of agricultural water is essential to positively affect production and crop yields. In Table V, the highest water use efficiency (WUE) was found 12.95 kg/m^3 under the treatment T_3 (Timer Drip Irrigation) while the lowest was recorded 10.47 kg/m^3 under the treatment T_1 (Conventional Irrigation). From the treatment of T_2 (Drip Irrigation), water use efficiency (WUE) was found to be 12.47 kg/m^3. These results indicated that the water productivity of timer drip irrigation system was better than that of drip and conventional irrigation. Considering the whole system, the treatment of T_3 (Timer Drip Irrigation) and T_2 (Drip Irrigation) saved 11% and 9% of water respectively as compared to the treatment of T_1 (Conventional Irrigation). Ibragimov *et al.* [38] reported that 18-42% of irrigation water was saved under drip irrigation with different treatments in comparison of conventional irrigation in cotton cultivation. It was due to under drip irrigation soil preserves moisture by preventing deep percolation and evaporation from the soil surface [34]. However, the overall water savings under timer drip irrigation were lower than what the literature suggests. One of the reasons behind this could be an excessive rainfall of

225 mm during the whole growing season of okra cultivation (March 2021-May 2021). Moreover, the soil type of the experimental area was silty clay loam, which usually contains 50% clay and is rich in organic matter [40], both of which increase the holding capacity of the soil [41].

IV. CONCLUSIONS

The experimental evidence indicates that timer drip irrigation systems can be developed for okra production. The system requires an automatic pump controller unit with a continuous power source to control the water level of the irrigation tank, which was also combined with an irrigation timer and drip components, both of which were used for water delivery on the field. It is a feasible, precise, and protected irrigation system for okra production since it minimizes manual interference. This timer drip irrigation system provided also satisfactory plant development. The results determined from plant height, leaf number, days to first flowering, and quantity of fruits per plant, showed that the conventional irrigation and drip irrigation techniques did not show any significant difference. As compared to conventional and drip irrigation methods, yield components including pod weight, yield performance and pod quantity were derived to be optimal with timer drip irrigation. This could be because timer drip irrigation system utilizes water more precisely than the other two treatments. Among the three treatments, the highest water use efficiency (12.95 kg/m^3) was obtained from the timer drip irrigation system, and the lowest was found (10.74 kg/m^3) for conventional irrigation. However, timer drip irrigation could also save 11% of irrigation water for okra production.

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CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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