Approach to Minimize Loss of Water Using Containerized Seedlings and Drip Irrigation in Tomato Production

A Thesis

By

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ABSTRACT

Traditionally produced or mud-bed seedlings are not good in quality and cannot perform better afterwards. The present study aimed at identifying a suitable containerized tomato seedling production system. The experiment consisted of three growing containers viz. plastic cell tray, large plastic cup, small plastic cup following completely randomized design (CRD) with seven replications. Plant growth and other characteristics of BARI tomato-19 were significantly higher in plastic cell tray seedlings among the containers. In order to save water a modern holistic irrigation method is of prime importance where drip irrigation system approach might be an inalienable option. This research also aimed to find out the profitability and feasibility of drip irrigation above traditionally used furrow system.

This field experiment consisted of three factors, namely two irrigation management practices (Drip and furrow), three tomato varieties (BARI Tomato-16; BARI Tomato-19 and Mintoo Super) and two growing season. It was conducted to evaluate growth, yield, quality, and water productivity of tomato. The field trials were carried out in split plot design with three replications and data were collected on some selected attributes. The results showed that growth, physiological traits, yield and water productivity were significantly influenced by irrigation method and tomato cultivars in which drip irrigation significantly lowered total water input by 58% and improved water productivity by 62% over furrow irrigation. Mintoo Super (HYV) performed significantly better than other tomato cultivars in improving physiological and phenological attributes, quality parameters (pH, SI, TSS, Hue angle, Firmness) and thereby advancing tomato growth, yield (9.35 t ha^{-1}) and fruit quality. Regression analysis illustrated total fruit yield was declined by 3.96 with each unit increase of days to first flowering. Under drip irrigation, the total effectiveness of Mintoo super (HYV) tomato production was increased by Tk.1,57,542 ha^{-1}. Thus, plastic cell tray with coco-dust tomato seedling production system could be a suitable option for vegetable growers. Also, a drip irrigation system combined with the Mintoo super (HYV) tomato cultivar could be a feasible option for reducing total water input through precise irrigation with maximizing tomato yield and improving total water productivity ensuring economic viability.

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CHAPTER I

Introduction

Tomato is the popularly consumed horticultural crop with a rich sources of vitamins, minerals and antioxidants beneficial for human health but highly sensitive to soil moisture stress. Due to nutritional properties, tomato cultivation area is increasing day by day in the world including Bangladesh which is a small country where total tomato cultivation area is about 68,000 ha having an average yield of 40-50 MT ha^{-1} (Yearbook of Agricultural Statistics, 2020). Delta, Mintoo, Unnayan, Tripti-2, Mintoo Super, BARI hybrid-4 are widely cultivated tomato cultivars in which Mintoo Super cultivar was exhibited highest fruit yield over others (Islam et al., 2014). Raising healthy seedlings under good nursery management is a vital part of effective vegetable production, especially for tomato that is commonly transplanted (Lin et al., 2015, Bharathi and Ravishankar, 2018). Containerized seedling production system could be a suitable alternative of conventional mud-bed seedling production system. Containerized seedlings prevent injury to the roots and transplanting shock to the seedlings (Lin et al., 2015). In recent years, maximum tomato producing country has increased the commercial production of containerized seedlings, which do not require overhead irrigation for establishment. Also, roots of containerized seedlings are alive and active, facilitating more efficient absorption of water than bare-root seedlings. Containerized seedlings establish more quickly than bare-root seedlings under field conditions due to less early establishment stress (Lin et al., 2015). In contrast, removal from the soil, shipment and transplanting of bare-root seedlings causing injury and death of fine roots that compromises effective water uptake during establishment of the crop (Lin et al., 2015, Bharathi and Ravishankar, 2018). Additionally, seedlings grown in mud-bed suffer from root damage when the plants are pulled apart for transplanting; this can slow down subsequent growth. Tomato growers produce bare-root seedlings for tomato production and this production system involves raised beds with furrow irrigation. Therefore, containerized seedlings may have the potential to provide greater early tomato yield and thus more profit to the producer. Traditionally farmers in Bangladesh plant tomato seedlings on furrow bed system where a huge amount of water is needed. Climate change and agricultural malpractices are causing ground water depletion which is a matter of great concern globally and are more acute in the developing countries of Asia (Ahmed et al., 2014; Scott and Sharma, 2009) that results in water scarcity for crop production especially in dry seasons (Jahan et al., 2010; Hasan et al., 2018) so we cannot make waste of our water resources by doing furrow bed agriculture. Fresh water scarcity through ground water depletion is a severe environmental phenomenon threatening global food security by adversely impacting sustainable crop production (Ullah et al., 2017; Ilyas et al., 2021). Agriculture is the largest freshwater consumer globally but decreasing freshwater availability due to enormous population growth, climate change, industrialization and unproductive water loss are the main challenge for sustainable production (Chareesri et al., 2020; Das et al., 2021). Water scarcity induces down-regulation of different physiological and biochemical processes in plants causing severe oxidative damage to cellular activities resulting in a significant yield loss (Ullah et al., 2019; Panda et al., 2021). Water scarcity and food security are strongly linked because agricultural systems are probably the first and direct victims of climate change mediated ground water depletion. Future climate projection indicates more uncertainties on irrigation water availability and frequent episodes of drought will aggravate sustainable and precise application of irrigation water (Neupane et al., 2021; Gosling and Arnell, 2016; Namara et al., 2005). According to current research climate change may be exacerbating many countries' experiences of groundwater depletion, water stress, and constraining the accessibility of irrigation water (Yan et al., 2015). Conventional crop production system is water-intensive overexploiting freshwater resources and should be replaced with water-saving systems to maintain productivity and to conserve environment without compromising crop yield and quality (Ruiz-Sanchez et al., 2011). These necessitate the variation of water-efficient approaches to decrease water use in the agriculture sector, while conserving or boosting yield to assist a rising population (Rijsberman, 2006; Carrijo et al., 2017). Soil moisture is a key factor influencing the yield and quality of tomato crops and better levels of irrigation have been found to enhance yield but reduce quality attributes viz. organic acid, dry matter content, soluble sugar, in the fruit (Rolando et al., 2015). Therefore, efficient water savings irrigation management might be a feasible option for enhancing growth, yield and water productivity of tomato to ensure global food security (Guntzer et al., 2012; Chakma et al., 2021). Insufficiency irrigation has been found to increase the TSS, ascorbic acid and titratable acidity content of tomato but limit the fruit yield (Cantore et al., 2016). Hence, holistic irrigation strategies to reduce water input and enhancing sustainability of tomato production is needed.

The sustainable use of ground water resources for irrigation has risen as a key concern (Wada et al., 2010; Chen et al., 2018). Drip irrigation is a suitable option for sustainable and precise application of irrigation water (Ben-Gal and Shani, 2003; Namara et al., 2005) because of higher water use efficiency in tomato production (Musa et al., 2014). Also, drip irrigation systems maintain proper soil moisture and greatly reduce the evaporation losses compared to furrow irrigation leading to good crop response (Baye, 2011). In addition, drip irrigation aids to control soil salinity in the crop root zone and retain high soil potential (Sun et al., 2012; Wan et al., 2007; Hanson and May, 2004). On the contrary, furrow irrigation techniques require huge labor to fill out the irrigation needs of a farm and human labor does not come in free of cost resulting lowered benefit-cost ratio (Polak et al., 1997; Tiwari et al., 1998a; Hanson and May, 2004). Conventional furrow irrigation method depends on a high volume of water throughout the production period to promote successful plant growth and development where water can evaporate before it reaches the crop root zone and canopy. Tomato producers utilize as much as 22599 m^3ha^{-1} of water over the growing season using a conventional furrow irrigation system (Musa et al., 2014). However, drip irrigation system has boost up net return of tomato by \$6960 ha^{-1} over furrow irrigation in Turkey (Kuscu et al., 2009). The cost of vegetable production was raised by 33% over furrow irrigated crops in India (Jha et al., 2017). Drip irrigation system provides more efficient use of water, but its upsurge installation and maintenance cost (\$2470 ha^{-1}) prohibited the wide-scale adoption of drip irrigation system for lower income growers in many countries (Postel, 1996; Polak et al., 1997; Hanson and May, 2004). These necessitate the advancement of a steadfast effective irrigation system that matches the desires of lower income farmers of many countries (Saksena, 1995; Nir, 1995). To confront the changing environment and to conserve the surface and ground water, a holistic approach is needed to modernize the irrigation system (Malek-Mohammadi, 1998; Ben-Gal and Dudley, 2003).

To evaluate the costs and benefits of drip irrigation for tomato production, a partial budget analysis might be a good option. Partial budgeting is a useful tool for estimating the costs and benefits of a specific farm change (Cornelisse, 2017; Roy, 2018). Advancing water efficiency in crop production is getting further significance, with rising irrigation expenses and worldwide evolving water paucity. High-accuracy irrigation techniques can lower irrigation water needs with retaining high yields and quality of fruits (Kumar and Sahu, 2013). Efficient water savings irrigation is a sustainable approach to modulate growth, physiological response, quality and yield of tomato. It was assumed that containerized seedlings and drip irrigation may be effective to save significant amount of water and boost-up tomato yield by confirming affordable technology and more profit. A number of literatures are available on different aspects of tomato but limited numbers of published literatures are available on evaluation of water saving potentials between drip and furrow irrigation method for tomato cultivation. Therefore, the goal of this study was to evaluate the efficiency containerized seedlings and drip irrigation for improved tomato production. Considering the above facts, the present study was undertaken with the following specific objectives-

i. To find out a suitable containerized tomato seedlings production system.

ii. To evaluate the drip irrigation system in tomato production and

iii. To assess the costs and benefits of using containerized seedling and drip irrigation system by partial budget analysis.

Dewanto et al., 2002). Water stress is one of the most important environmental factors that regulate plant growth and development and limit plant production (Gulen and Eris, 2004). Liu et al. (2011) and Isah et al. (2015) reported that tomato responds well to fertilizer application and a heavy feeder of nitrogen (N), phosphorus (P), and potassium (K) fertilizer. Thus, it is compatible with drip irrigation, which is a very efficient means of using water and nutrients.

2.1 Tomato production and water stress

Tomato is considered as one of the most consumed vegetable crops throughout the world (Chang et al., 2019 and Hashem et al., 2018). It contains beneficial minerals, vitamins, polyphenol, lycopene and antioxidant which protects cellular lipids, protein, and DNA from free radical oxidative damage (Zhu et al., 2013 and Shariffa et al., 2017). However, tomato is extremely susceptible to water stress. In this regard Shuxue et al. (2019) conducted a study to investigate the response of tomato yield under different water stress at different growth stages. The results showed that water stress is important for the improvement of fruit quality, but fruit yield decreased due to water stress. However, the fruit quality in terms of soluble sugar, total soluble solids, vitamin C and firmness improved under water stress compared to control. Also, Kalloo and Bergh (1993) reported that water plays an important role in plant life and the amount of water was a determining factor to boost-up yield of tomato. Proper crop management practices are required for optimum and sustainable production of tomato that conserve and manage soil nutrients and maintain soil moisture (Yaffa et al., 2000). Again, it was found that the moisture shortage in the end of growing season adversely affects the quality of product even though total yields may not be affected (Wright, 2002). As tomato plants are sensitive to water stress and show a significant correlation between evapotranspiration and crop yield (Nuruddin et al., 2003) so, growth is impaired due to water stress

(Kamgar, 1980; Wolf and Rudich, 1988; Shinohara et al., 1995). Nahar et al. (2012) investigated the influence of water stress on tomato plants and fruit quality and they found that yield and dry matter production were adversely affected due to variation of moisture levels (100% and 40% of the field capacity). They also informed that irrigation frequencies and timings had significant effects on root development, tomato yield, water distribution and water use efficiency.

2.2 Effect of Container on Seedlings Performance

Container seedlings production gain popularity with nursery growers over the past 50 years because crops can be produced more rapidly and economically (Majsztrik et al., 2017; USDA, 2007) and the root zone (substrate, fertilizer, and water) is easier to modify, compared to field production (Ruter, 1993). Besides, container seedlings survive and grow better, they are often preferred, especially for species that are difficult to establish or those seedlings with a higher level of genetic value (Lin et al., 2015). Containerized seedlings have intact root system with large, fibrous, compact root with higher physiological function. This prevents injury to the roots and transplanting shock to the seedlings. Seedlings rose in individual containers or plug trays normally have a 100% establishment rate in the field since they are transplanted with the medium-root block (Lin et al., 2015). Ruter (1993) showed that under pot conditions, 27% of total biomass increased by growing *Betula nigra* compared with field conditions, which was likely due to more favorable root zone conditions. On the contrary, in seedbed method seedlings may suffer from root damage when the plants are pulled out of the seedbeds for transplanting. Damage may occur at roots which will delay growth or cause the seedlings to die (Stodels, 2019). Container-grown plants are weightless and easy to move and shipping, allowing more flexibility at an operation and improving shipping efficiency. Farmers can sell plants throughout the year regardless of soil conditions or plant growth stage, which increases productivity per unit area. Typically, lower rates of fertilizer and water per hectare are applied compared with mud-bed production (Bailey et al, 1999). In case of spacing, mud-bed plants also need wider spacing compared to both container production in nurseries and greenhouses (Majsztrik, 2011). Containers can be consolidated to make room for additional plants, while in field operations it is not possible. This greater density (number of plants per unit area) of container-grown crop results in both higher revenue and increased material and input costs compared with field production.

Container gardening is one of the best ways to save water with a smaller surface area for water loss and evaporation (Stodels, 2019). Also, Van et al (2008) found that tomato plants grown in container use less amount of water than open field or greenhouse. However, producers of containerized plants can face several challenges related to water use and runoff. Containerized production systems need more frequent irrigation compared to field soils because containers filled with soilless substrates have lower available water, which have high porosity and restricted root volumes (Allaire-Leung et al., 1999; Argo 1998; Beeson 2007; Owen and Altland 2008). Any excess water or other materials like fertilizers, pesticides and plant growth regulators applied than the capacity of the container, are unable to be utilized by the plant, and that will likely leach and run off and may affect surface water and groundwater (Cabrera, 1997). Concerning this factor, some growers capture and reuse this portion of runoff, whereas other growers allow runoff to drain from their operations to the surrounding ecosystem.

2.3 Effect of Drip Irrigation

A holistic effort is needed to modernize irrigation and drainage system to tackle the changing environment, conserve the surface and ground water and to further develop the existing facilities in order to serve various purposes like food production, water conservation, soil salinization and prevention of water logging; basically, to protect the environment (Malek-Mohammadi,1998; Ben-Gal and Dudley 2003b). Water supply will be efficient through specialized micro irrigation system such as drip irrigation (Rakibuzzaman et al., 2018). Drip irrigation has the potential to use scarce water resources most efficiently to produce vegetables (Locascio, 2005). The modern development of drip irrigation started in Great Britain during World War II and continued in Israel and other countries (Camp, 1998). There will be no water to runoff, deep percolation and evaporation if we can introduce a well-designed drip irrigation system with appropriate intervals and water amount (Rakibuzzaman et al., 2018). Shareef et al. (2019) reported that there is a lot of advantages of drip irrigation; it can irrigate only a limited patch of soil with small quantities and low pressure with limited evaporation of water; it doesn't wet the plant leaves and distribute the fertilizers with irrigation water (enriched irrigation); it can be used with the automatic techniques thus improve the quality and quantity of production. Imtiyaz et al. (2000) informed that drip irrigation has proved its superiority over other conventional method of irrigation, especially in the cultivation of fruits and vegetables due to precise and direct application of water in root zone. A considerably saving in water, increased growth, development and yield of vegetables under drip irrigation has been reported by researchers (Bhella, 1988; Bafna et al., 1993; Raina et al., 1999 and Imtiyaz et al., 2000). In addition, drip irrigation is suitable for all types of soils, water and the land shapes. Therefore, using drip irrigation system, could obtain high productivity for different crops. Zhai et al. (2010) conducted a pot experiment with tomato plants and the plants were watered with different irrigation regimes and their effects on vegetative growth, fruit yield and irrigation water use efficiency of tomato were examined. They reported that fruit yield was significantly different between irrigation frequency and water amount. In addition, when comparing with other irrigation methods to produce different crops, for example, Abubaker et al. (2006) found that there were significant differences between irrigation methods in terms of grain production and fresh weight, where the average production was better in drip than furrow but was best in sprinkler. Also, Tagar et al. (2012) reported that the drip irrigation method saved 56.4% water and gave 22% more yield as compared to that of furrow irrigation method. Pruitt et al. (1984) conducted a field experiment in USA which demonstrated that drip irrigation increased yield of tomato and water use efficiency by 19% and 20%, respectively as compared to furrow irrigation. Drip irrigation has profound effect on growth and yield also. Similarly in Bangladesh, Rakibuzzaman et al. (2018) conducted an experiment on rooftop to evaluate the performance of drip and traditional irrigation system on growth and yield of BARI-14 tomato. They revealed that the drip irrigation systems are effective in fruit yield improvement of tomato in comparison to the non-drip overhead irrigation.

2.4 Drip Irrigation, fertigation and economics of tomato cultivation

Conventional irrigation system has two problematic factors those limit its efficiency. First on is human labor and second is scarcity of water. As irrigation is a regular process it needs constant monitoring and supervision, so it requires regular labor to fill out the irrigation needs of a farm and human labor and that doesn't come in free of cost. That ultimately raises the cost of production and increases the price of the crop. Drip irrigation saves human labor substantially by reducing intercultural operations like irrigation and weeding (Rakibuzzaman et al., 2018). It is also a highly efficient method of controlling the placement and supply rate of water-soluble fertilizers. Fertigation allows precise timing and uniform distribution of applied nutrients to meet the crop nutrient demand with ensures substantial saving in fertilizer usage (Shaymaa et al., 2009). To maintain high yield, drip irrigation proved to efficiently provide water and nutrients to the roots of plants. Moreover, a drip irrigation system can easily be used for fertigation, through which crop nutrient requirements can be met accurately (Or and Coelho, 1996). Because of the way the water is applied in a drip system, fertilizers should be applied in a form that becomes available in synchrony with crop demand for maximum utilization of nutrients from fertilizers (Boyhan et al., 2001). Some fertigation experiments with tomato and brinjal gave encouraging results in terms of growth, yield, and economic return in Bangladesh (Anonymous, 2004). Besides, increased growth and yield of vegetable crops under fertigation were reported by many investigators (Bresler, 1977; Bhella, 1988 and Malik et al., 1994). Tomato responds well to additional fertilizer applied and it is reported to be a heavy feeder of NPK (Hebbar et al., 2004). Drip irrigation is an effective way to improve fertilizer use efficiency by the plants, resulting improved tomato yields (Locascio et al., 1989; Dangler and Locascio, 1990). There is a close relationship between the incidence of diseases, pests and the way water are supplied to the tomato plants. Existence of free water on the leaves, and high-water content in the soil favor the conditions of most diseases. Drip irrigation system was minimized the incidence of disease in the tomato shoots by not wetting the plants (Marouelli et al, 2005).

Jha et al. (2017) reported that the average cost-benefit (CB) of drip-irrigated crop was 33% more compared to furrow irrigated crops. They also mentioned that drip-irrigated cauliflower is more profitable in terms of net return and CB ratio. In India, the net returns and benefit-cost ratio (7:1) of tomato *cv. Arka Abha* was found higher with drip irrigation system compared to furrow irrigation system reported by Tiwari et al. (1998a). Also, Hanson and May (2004) also stated that profits of tomato cultivation under drip irrigation system were \$867 to \$1493 ha^{-1} over sprinkler irrigation system. In Turkey, the net return was elevated by \$6960 ha^{-1} under drip irrigation tomato production system (Kuscu et al., 2009).

Drip irrigation system is a relatively new technology in Bangladesh, is being used for growing vegetable crops. This system is gaining popularity because of irrigating fruit and vegetable crops owing to its precise and direct application of water in the root zone with a considerable saving in fertilizer and water (Jain et al., 2000). It also has the potential to increase the yield of crops even to reduce irrigation water needs (Yohannes and Tadesse, 1998).

From the above discussion it can be easily be understandable that there is a little amount of work have done on the effect of drip irrigation system and containerized seedlings in Bangladesh. Therefore, the present study was undertaken.

CHAPTER III

Materials and Methods

This chapter describes the materials and methods those were used in carrying out the field experiment. The details of the materials used, and methods adopted in this experiment are presented in this section.

3.1 Experimental site

The experiments were conducted at Professor Dr. Purnendu Gain field laboratory of Agrotechnology Discipline, Khulna University, Bangladesh (22°47' N; 89°34' E) during winter season of 2019-2020 (November-April) and the experiments were repeated in 2020-2021 (November-April).

3.2 Climatic and soil condition

The experimental area was under the sub–tropical climatic zone characterized by relatively scanty rainfall, high humidity, high temperature and long day period during the Kharif season (April to September) and scanty rainfall associated with moderate low temperature and short day period during the Rabi season (October to March). Temperature in the experimental field ranged from 22 to 32°C, while relative humidity ranged 70-86% throughout the growing period. The soil was collected from the research farm of Khulna University to analyze the soil properties that consisting of 16% sand, 36% silt, 51% clay and 2.4% organic matter. It was found that soil is slightly acidic (pH of 6.2) with an inherent exchangeable P, K, Ca, and Mg content were 2.1 Cmol kg^{-1}, 0.5 Cmol kg^{-1}, 15.5 Cmol kg^{-1}, and 10.5 Cmol kg^{-1} soil, respectively (Soil Resource Development Institute, 2009). Field capacity of the soil was calculated according to Datta et al. (2009) where 44.8% soil moisture content was determined at 100% field capacity and also 0 kPa soil water potential.

Experiment 1. Production of tomato (BARI Tomato-19) seedlings using plastic containers

3.3 Materials

Plastic cell trays (100-cells/tray) and one-time plastic cups large (6.0 cm × 8.2 cm × 14.2 cm) and small (6.0 cm × 8.2 cm × 12.3 cm) were used as containers for seedling growth. Locally available coco-dust was used as a growing media, and it was sterilized before use in containers. Tomato (BARI Tomato-19) seeds were used as experimental materials which were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh and the life cycle of this varieties range from 80–90 days. Seeds were surface purified with 10% H_2O_2 for 10 min, rinsed followed by washing thoroughly with purified water and then soaked in purified water before sowing (Das et al., 2021).

3.4 Treatments and design of the experiment

The experiment consisted of various growing containers viz. plastic cell tray, plastic cup (large), plastic cup (small) following completely randomized design (CRD) with seven replications. Each replication consisted of 20 plants.

3.5 Seedlings management

Irrigation was applied using a watering can (5 liters) at 7 days interval to maintain proper moisture of the growing media and in the mud-bed. The manures and fertilizers that were used in the growing media in a liquid formula using the following rates viz. Urea: 240kgha^{-1}, TSP: 260kgha^{-1}, MOP: 150kgha^{-1} and the ratio was 20:20:20. Bildor insecticide was applied @ 0.2 ml L^{-1}as and when required to control thrips of tomato.

3.6 Data collection of seedlings

The performance of tomato seedlings was evaluated. The growing medium was observed every day and the number of germinated seeds was recorded. The germination (%) was calculated using the following formula:

$$Germination(\%) = \frac{Number of seed germinated}{Total\ number\ of\ seeds\ placed\ in\ growing\ medium} \times 100$$

The number of survived seedlings was assessed at 2 and 4 weeks after sowing and those data were used to calculate the percentage of vegetable seedlings survival. Plant vigor was assessed using a modification of the procedure reported by Monfort *et al.* (2007). A scale of 0 to 10 was used with 0 being dead plants and 10 being the most vigorous plants. The number of leaves per plant was counted after 4 weeks of transplanting. The plant height was measured using measuring scale and stem diameter was measured using digital slide calipers, total biomass (root and shoot) was dried at 65°C for 72 hours and dry weights were determined after 4 weeks of sowing.

Experiment 2. Evaluation of drip irrigation system in tomato production

3.7 Experimental design and treatments

Two years field experiment consisted of three factors where main plot was irrigation methods, sub plot was tomato cultivars viz. BARI Tomato-16, BARI Tomato-19 and Mintoo Super (HYV) and growing season arranged with three replications. Each plot was considered as experimental unit for individual treatment combination.

3.8 Crop management

The BARI Tomato-16, BARI Tomato-19 and Mintoo Super (HYV) tomato cultivars were used as planting materials. The BARI Tomato-16 and BARI Tomato-19 seed were moisture content) of the highest amount of water held in the soil whereas 0 kPa refers to the highest amount of water held in the soil after gravitational water drainage stops according to Das et al. (2021). In clay loam texture soil, the drip irrigation (0.002 m^3 $min.^{-1}$ 30 m^{-1}) was run 10 min. day^{-1} (5 min. morning and 5 min. afternoon) up to December and it was increased to 20 min. day^{-1}(10 min. morning and 10 min. afternoon) from January using slightly modified protocol of Sanchez (2018). Water was delivered from an elevated water tank (500 L, Gazi tank, Bangladesh) which was filled by an electric pump.

3.9 Data collection

3.9.1 Plant height (cm)

Plant height was measured by meter scale during harvesting stage. The measurement was taken from the ground level to the tip of the largest leaf of an individual plant. Mean value of the five selected plants was calculated for each unit plot and expressed in centimeter (cm).

3.9.2 Leaf area (cm^2)

ImageJ software was used to compute leaf area (cm^2 $plant^{-1}$) which is widely used software for leaf area measurement, to compute leaf area utilizes a threshold-based pixel count procedure described by Easlon et al. (2014).

3.9.3 Shoot and root dry weight (g $plant^{-1}$)

Shoot and root dry weight were determined by measuring the oven-dried (80°C) weight of tomato shoot until constant weight was obtained.

3.9.4 Number of flowers plant^{-1}

The number of flowers was counted from the five sample plants periodically during flowering season, and average number of flower plant^{-1} was recorded.

3.9.5 Number of fruit clusters plant^{-1}

The number of fruit clusters was recorded from the five sample plants, and the average number of fruit clusters produced plant^{-1} was recorded.

3.9.6 Leaf greenness (SPAD value)

The leaf greenness was measured at full maturity stage using SPAD 502 Plus chlorophyll meter (Spectrum Technologies, Aurora, IL) and four readings from each plot were averaged to represent a single observation.

3.9.7 Leaf relative water content (LRWC) (%)

For measuring LRWC, leaf samples were collected from the fully expanded second topmost leaf of the plant and were weighed for their fresh weight (FW) as soon as after collecting the samples. After collecting FW, leaves were separated into small pieces (2 cm), immersed into purified water in test tubes, kept overnight in the laboratory and turgid weight (TW) of the leaves determined. Then turgid leaves were oven-dried at 70°C until the steady weight was reached, and dry weight (DW) was recorded. Leaf relative water content was computed using the following formula stated by Jones and Turner (1978):

$$\text{LRWC (\%)} = \frac{FW-DW}{TW-DW} \times 100$$

3.9.8 Leaf area index (LAI)

The leaf area index (LAI) was measured nondestructively using an application of smart phone (Pocket LAI) (Maneepitak, et al., 2019).

3.9.9 Canopy temperature (°C)

The canopy temperature was measured at full maturity stage using an infrared thermometer (Fluke 572-2 High-Temperature infrared thermometer, TEquipment, USA).

3.9.10 Electrolyte leakage (%)

Electrolyte leakage (EL) was computed using the following formula stated by Camejo et al. (2005) and Chakma et al. (2021). The leaf samples were sliced into six discs and washed with deionized water for couple of times to eliminate adhered debris. The discs were inserted into test tube and filled with 20 ml deionized water and kept for 20-h. The electrical conductivity (EC_1) of the solution was recorded using a conductivity meter (CON 150, Thermo Scientific, Singapore). Then the samples were boiled for 15-min and followed by room cooling and the final electrical conductivity of solution (EC_2) was measured. The electrical conductivity was computed using the following formula:

$$\text{EL (\%)} = \frac{EC1}{EC2} \times 100$$

3.9.11 Determination of pH of tomato fruit pulp

The pH of tomato fruit pulp was measured by a desktop pH meter.

Preparation of standard buffer solution

pH 7 and pH 4 buffer tablet was dissolved in water and made up the mark of 100 ml with distilled water.

Extraction of tomato fruit juice

For the determination of pulp pH, 5 g of fresh pulp was taken in a conical flask with 10 ml of distilled water. Then the pulp was crashed by using blender and extract was filtrated through two layers of cloth.

Procedure

The standard buffer solution of pH 7 was taken into a clean and dry beaker. The electrode assembly of the pH meter was dipped into the solution. The temperature correction knob was set to 28°C and the fine adjustment was made by asymmetry potential knob to pH 7. After washing with distilled water, the electrode assembly was dipped into a solution of standard pH 4 and adjusted to the required pH by fine asymmetry potential knob. The electrode assembly was raised, washed twice with distilled water then rinsed with tomato fruit juice and finally it was dipped into the juice of tomato fruit. The pH was recorded from the meter.

3.9.12 Shape index

The equatorial dimeter (D_e), polar diameter (D_p) and cross-sectional thickness (T) were measured using digital slide callipers. Equatorial diameter is the maximum width of the tomato fruits in a plane perpendicular to the polar diameter. Polar diameter is the distance between the tomato fruit crown and the point of fruit attachment to the tomato fruit. The shape index was calculated using the following equation given by Dabhi and Patel (2017).

$$\text{Shape index} = \frac{D_e}{\sqrt{D_p + T}}$$

Where, D_e= equatorial dimeter, D_p=polar diameter, T=cross-sectional thickness

The tomato fruit is considered as an oval if the shape index >1.5, on the contrary, it is deemed spherical if the shape index <1.5.

3.9.13 Determination of total soluble solids (TSS)

Equipment

Digital Brix meter (Digital/Brix/RI-Check Refractometer, Reichert Technologies, Inc. Japan) was used to measure total soluble solids.

Procedure

A drop of juice from the pulp of tomato fruit was placed on the prism of the refractometer and percentage of total soluble solid as degrees Brix was obtained from direct reading.

3.9.14 Hue angle (°h)

The surface color of the tomato was determined using a chromo meter (CR-410, Konica Minolta, USA) by calculating a*, b* values, where a* means redness, b* means yellowness, and the output was evaluated as hue angle (h). The following equation was used to assess the hue angle: $h = \tan^{-1}\left(\frac{b*}{a*}\right)$.

3.9.15 Firmness (N)

A food texture analyzer (Shimadzu EZ-SX, USA) was used to determine the firmness (F) of treated tomatoes (2 mm diameter). Each fruit was penetrated at four different equilateral locations to assess the firmness. The probe speed was 2 mm s^{-1} and the penetration depth was 5 mm. The maximum force firmness was stated in N cm^{-2}.

3.9.16 Water input (m^3)

In the case of drip irrigation, the water input was measured by the water meter (DLJ) whereas water input was measured by flow rate minute^{-1} system in case of furrow irrigation (Dash et al., 2020).

3.9.17 Fruit yield (t ha^{-1}) and water productivity (kg m^{-3})

Data on fruit yield was recorded during harvesting and total yield was calculated. The total irrigation water productivity (kg m^{-3}) was computed the total fruit yield (kg) divided by total irrigation input (m^3) as mentioned by Chakma et al. (2021).

Experiment 3. Partial budget analysis for using containerized seedlings and drip irrigation system in tomato production

The cost of containers, coco-dust and intercultural operations (land preparation, watering, weeding uplifting and tying) according to market price were included for partial budgeting. In case of drip irrigation system, plastic mulch, water tank, drip tape, dripper, end cap, water meter, tank fittings, intercultural operations were included for partial budgeting. A partial budget analysis was conducted summarizing the changes in revenue and expenses using containerized seedlings and drip irrigation system with the current tomato production system.

3.9.18 Statistical analysis

Seedling's performance evaluation data was subjected to one-way analysis of variance (ANOVA) and the field data were subjected to a three-way ANOVA the data were analyzed using the analytical software SAS following the GLM procedure and means with significant treatments effects were identified by F test and separated by conducting post-hoc analysis using Tukey's honest significant difference test at $p \leq 0.05$ (SAS software Version 9.4, SAS Institute Inc, Cary, NC). The field experiments were conducted in 2-growing seasons and replicated average mean was present for comparison. Correlation analyses were performed to judge the pattern and strength of the relationship between the different types of experimental variables. In addition, simple regression was worked out to predict the impact of predictor variable to responsible variable. The partial budget analysis was computed by Excel 2016. Partial budgeting is an efficient tool used to assess the expenses and gains associated with a specific change in a farm (Cornelisse, 2017; Roy, 2018).

number of fruit clusters plant^{-1} than furrow irrigation system whereas Mintoo super (HYV) cultivar exhibited better than tomato cultivar.

Treatments	Plant height (cm)	Leaf area (cm^2)	Shoot dry matter (g $plant^{-1}$)	Root dry matter (g $plant^{-1}$)	Number of flowers $plant^{-1}$	Number of fruit cluster $plant^{-1}$
Irrigation systems (I)						
Drip	88.7±0.6	18396±117 a	34.3±1.2 a	3.5±0.2 a	24.2±0.5 a	13.9±0.4 a
Furrow	84.6±0.5	14139±75 b	26.7±0.8 b	2.9±0.1 b	19.2±0.1 b	11.2±0.3 b
Tomato cultivars (T)						
BARI Tomato-16	84.4±0.8	15982±75 b	25.8±0.7 b	2.6±0.2 b	20.1±0.5 b	11.5±0.2 b
BARI Tomato-19	83.5±0.6	15863±63 b	25.2±0.5 b	2.5±0.2 b	19.4±0.4 b	10.9±0.3 b
Mintoo Super (HYV)	89.8±0.9	16572±97 a	32.6±0.9 a	3.2±0.3 a	23.6±0.2 a	13.3±0.6 a
Level of significance						
Irrigation systems (I)	NS	**	*	*	**	**
Tomato cultivar	NS	*	*	*	*	*

Table 1: Individual effect of irrigation systems and cultivars on growth parameters of tomato

NS-not significant; ***p*< 0.01; **p*< 0.05.

4.2.2 Physiological parameters

The drip irrigation system resulted in a higher Soil Plant Analysis Development reading than the furrow irrigation system with no seasonal statistical differences. Leaf greenness was 5.1% higher in drip irrigated plants compared with furrow irrigation and SPAD reading was the highest (56.7) at Mintoo super (HYV) tomato cultivar, whereas it was the lowest (53.2) at BARI Tomato-19 followed by statistically alike with BARI Tomato-16 (54.1). The irrigation systems and tomato cultivars had a significant (P<0.05) two-way interaction effect on leaf relative water content (LRWC) and it was reported that Mintoo Super grown under drip irrigation showed 8% higher LRWC compared to other interactions. Drip irrigation system dominated over furrow irrigation system and caused 26.32% higher leaf area index (LAI) than furrow irrigation for LAI. Mintoo super (HVY) was led for better LAI over BARI Tomato-19 and BARI Tomato-16. The two and three-way interaction did not influence LAI. Canopy temperature was maximum (32.7°C) when the plants received furrow irrigation compared to drip irrigation system (28.7°C) whereas canopy temperature was not affected by the tomato cultivars. The furrow irrigation system revealed more electrolyte leakage (EL) than drip irrigation system where tomato cultivars had no significant effect on EL

Table 2: Effect of irrigation systems and tomato cultivars on leaf relative water content, electrolyte leakage, canopy temperature and SPAD value

Treatments	Leaf greenness (SPAD value)	Leaf relative water content (%)		Leaf area index	Canopy temperature (ºC)	Electrolyte leakage (%)
Irrigation systems (I)						
Drip	57.7±0.5 a	76.5±0.87 a		5.32±0.12 a	28.7±0.3 b	20.1±0.3 b
Furrow	54.9±0.3 b	71.9±0.79 b		3.92±0.32 b	32.7±0.5 a	22.2±0.5 a
Tomato cultivars (T)						
BARI-Tomato-16	54.1±0.2 b	72.5±22 b		3.58±0.13 b	30.8±0.7	21.7±0.2
BARI Tomato-19	53.2±0.1 b	73.1±0.37 b		3.73±0.11 b	31.0±0.5	21.9±0.1
Mintoo Super (HYV)	56.7±0.2 a	75.3±0.45 a		4.93±0.22 a	30.3±0.4	21.5±0.1
IxT	-	Drip	Furrow	-	-	-
BARI-Tomato-16		75.6±0.62 b	71.9±0.55 b			
BARI Tomato-19		74.9±0.57 b	71.4±0.50 b			
Mintoo Super (HYV)		78.2±0.63 a	72.4±0.51 b			
Level of significance						
Irrigation systems (I)	**	**	**	**	**	**
Tomato cultivars (T)	**	**	*	*	NS	NS

NS-not significant; ** $p< 0.01$; * $p< 0.05$.

4.2.3 Fruit quality parameters

The fruit pH was significantly ($p < 0.05$) higher with furrow irrigation system compared to drip irrigation while no significant variation was noticed between growing year of 2019-2020 and 2020-2021. The fruit pH was maximum at Mintoo super (HYV) tomato cultivar, whereas it was the minimum in BARI Tomato-19 followed by statistically alike pH reading in BARI Tomato-16. The fruit shape index was markedly affected by individual effect of irrigation systems and tomato cultivars ($p < 0.01$). The fruits considered oval under drip irrigation system. The Mintoo super (HYV) tomato shape index belongs to oval whereas BARI Tomato-19 and BARI Tomato-16 considered as spherical. The total soluble solids content (TSS) was considerably ($p < 0.01$) impacted by the individual effect of irrigation system and tomato cultivars and the effect was found maximum under drip irrigation system over furrow irrigation. The highest TSS content was recorded from Mintoo super (HYV) whereas the lowest in BARI Tomato-19 and BARI Tomato-16. The color of tomato was significantly ($p < 0.05$) affected by irrigation system and tomato cultivars. The tomato produced bright red color fruits grown under drip irrigation system. Likewise, Mintoo super (HYV) tomato gave bright red color fruits over other cultivars tested. The individual effect of irrigation systems and tomato cultivars were significantly ($p < 0.05$) impacted by firmness. The drip irrigated plants had 8.8% higher firmness value than furrow irrigated plants. Also, Mintoo super (HYV) cultivar exhibited a better firmness value compared with other cultivars.

Table 3: Effect of irrigation systems and tomato cultivars on pH, shape index, TSS, hue angle, and firmness

Treatments	Fruit pH	Shape index	TSS (°Brix)	Hue angle (°h)	Firmness (N)
Irrigation systems (I)					
Drip	4.5±0.1 b	2.1±0.02 a	8.2±1.1 a	52.3±0.06 a	33.1±0.2 a
Furrow	5.2±0.2 a	1.6±0.01 b	7.3±0.09 b	48.7±0.04 b	30.2±0.1 b
Tomato cultivars (T)					
BARI Tomato-16	5.2±0.03 a	1.4±0.01 b	7.1±0.03 b	48.3±0.4 b	31.1±0.3 b
BARI Tomato-19	5.1±0.03 a	1.4±0.02 b	7.2±0.06 b	49.6±0.3 b	30.9±0.2 b
Mintoo Super (HYV)	4.3±0.02 b	2.2±0.01 a	8.3±0.05 a	54.7±0.2 a	33.6±0.2 a
Level of Significance					
Irrigation systems (I)	*	**	**	*	**
Tomato cultivars (T)	*	**	**	**	**

NS-not significant; ** $p< 0.01$; * $p< 0.05$.

4.2.4 Fruit yield

Fruit yield was highly (p<0.01) influenced by the individual effect of irrigation system and tomato cultivars while no statistical variation was noticed between two growing seasons. The fruit yield of drip irrigated plants produced about 13% higher than furrow irrigation system for both growing season and Mintoo super tomato cultivar produced 6% more fruit yield in comparison to the others. The drip irrigation system gave 11.5% higher fruit yield than furrow irrigation system. Fruit yield was the highest (94.37 tha^{-1}) in Mintoo super (HYV) tomato cultivar, whereas it was the lowest (88.97tha^{-1}) in BARI Tomato-16 followed by statistically alike fruit yield in BARI Tomato-19 (89.08tha^{-1}).

4.2.5 Soil moisture, water input and water productivity

More consistent soil moisture was detected with drip irrigation than with furrow irrigation system throughout the growing period (Fig. 2). Soil moistures were high in both systems due to severe rainfall in 2019-2020 season whereas almost very low rainfall in 2020-2021, except some rainfall in few days (Fig. 3). In 2019-2020, drip irrigation system (6673±542 m^3ha^{-1}) distributed more precise use of water with 7110±454 m^3ha^{-1} less water compared to furrow irrigation system (13783±996 m^3ha^{-1}). Similarly, the drip irrigation system (7,190±863 m^3ha^{-1}) supplied more effective water use with 9,782 ±802 m^3ha^{-1} less water used than the furrow irrigation system (16,972±1665 m^3ha^{-1}) in 2020-2021.

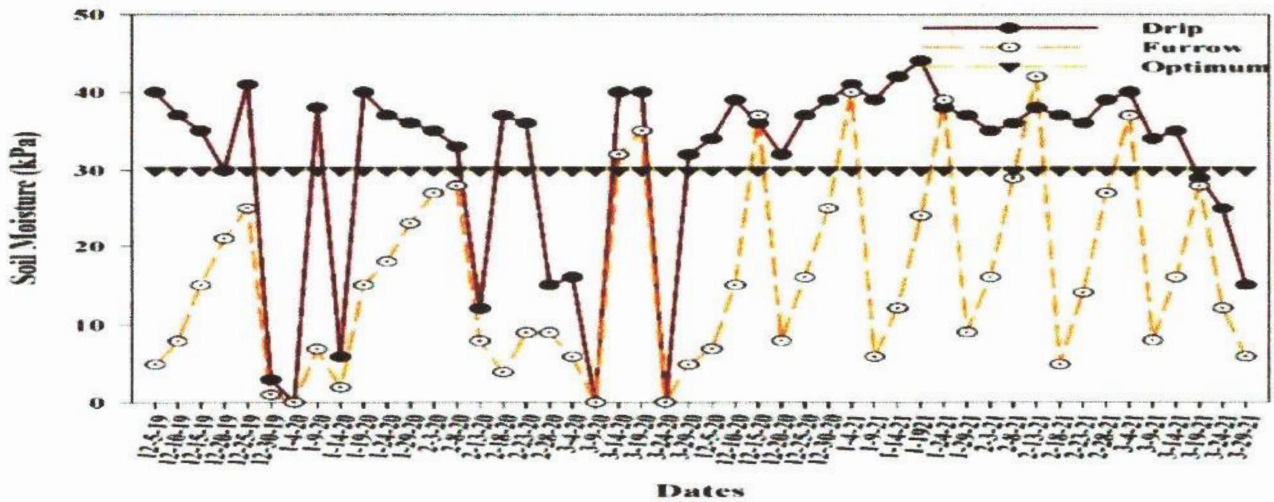

Figure 2: Soil moisture (kPa) at weekly interval in drip and furrow irrigation systems measured using tensiometers and showing optimum soil moisture level (2019-2020 and 2020-2021)

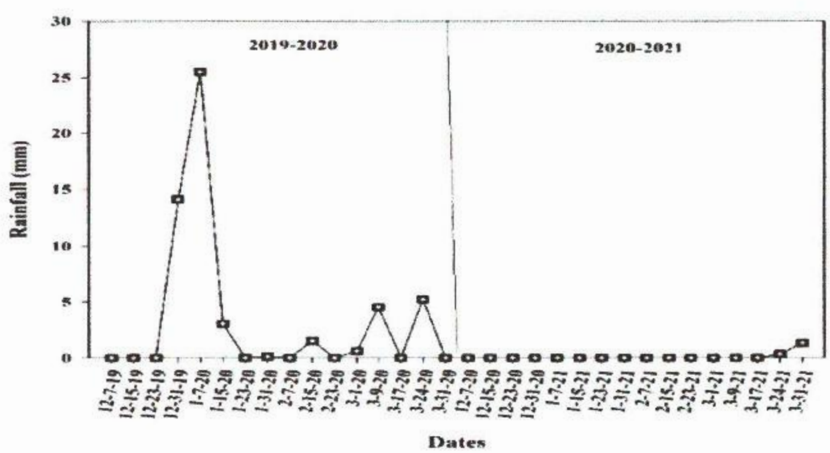

Figure 3: Rainfall (mm) data during the crop growing period in 2019-2020 and in 2020-2021

Total water input (TWI) and total water productivity (TWP) were highly significantly influenced by the individual effect of irrigation systems (p<0.01) while two and three-way interaction effect of seasons, irrigation systems and tomato cultivars were non-significant. However, total water input varied between 2019-2020 and 2020-2021 filed trials. The plots kept under furrow irrigation system showed the highest total water input in both tomato growing seasons. The drip irrigation system lowered total water input by 51.6% and 57.6% compared with furrow irrigation system in 2019-2020 and 2020-2021, respectively. The drip irrigation technique saves water by reducing total water input in both growing seasons with a subsequent upsurge of TWP. The total water productivity was significantly higher under drip irrigation than furrow irrigation in both of the years. As a result, in drip irrigation system 57.24 % and 62.22% higher TWP were recorded than furrow irrigation in 2019-2020 and 2020-2021, respectively.

Table 4: Effect of irrigation systems and tomato cultivars on water input, fruits yield and water productivity

Treatments	Total water input (m^3ha^{-1})		Fruit yield (tha^{-1})		Total water productivity (m^3ha^{-1})	
Irrigation systems (I)	2019-2020	2020-2021	2019-2020	2020-2021	2019-2020	2020-2021
Drip	6673±542 d	7190±863 b	96.87±1.32 a	97.35±2.02 a	14.5±0.5 a	13.5±0.8 a
Furrow	13783±996 c	16972±1665a	85.97±0.79 b	86.09±1.69 b	6.2±0.4 b	5.1±0.3 b
Tomato cultivars (T)						
BARI Tomato-16	10130±522	11113±987	88.10±0.58 b	88.97±1.23 b	8.7±0.2	8.0±0.3
BARI Tomato-19	10267±943	11286±1021	88.89±0.57 b	89.08±1.75 b	8.6±0.3	7.9±0.5
Mintoo Super (HYV)	11345±1002	12876±1105	93.79±0.98 a	94.37±1.85 a	8.3±0.3	7.3±0.4
Level of Significance						
Irrigation systems (I)	**	**	**	**	**	**
Tomato cultivars (T)	NS	NS	**	**	NS	NS

ns, not significant; **$p< 0.01$; *$p< 0.05$.

4.2.6 Relationship among studied variables

The Pearson correlation matrix showed that the analyzed variables had a tight relationship with one another, boosting or altering tomato yield and total water productivity (Fig. 4). Significantly positive relations were detected among number of flower cluster (NFLC) and number of fruit cluster (NFRC). On the contrary, a negative correlation was recorded alongside group in respect of leaf area (LA) and total soluble solids (TSS). Except for above-mentioned characteristics, plant height (PH), leaf area index (LAI), shoot dry matter (SDM), root dry matter (RDM), leaf relative water content (LRWC), electrolyte leakage (EL), canopy temperature (CT), SPAD, pH, shape index (SI), hue angle (HA), firmness (F), total water input (TWI), fruit yield (FY) and total water productivity (TWP) showed the most non-significant correlations with other variables.

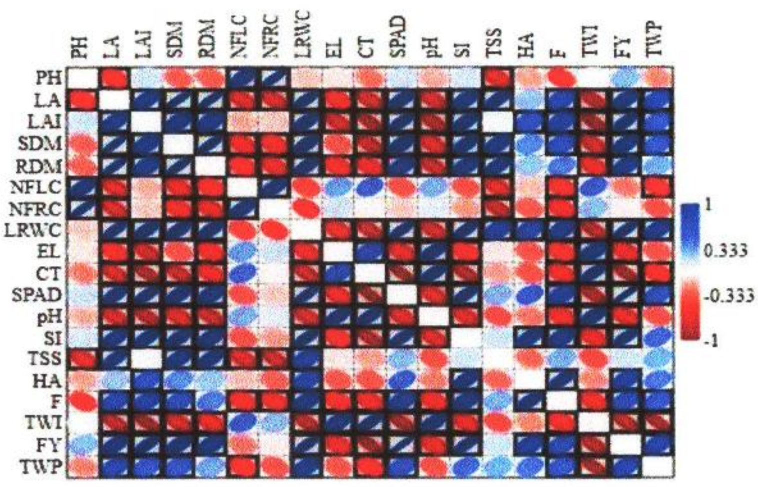

Figure 4: Pearson correlation matrix plot on studied 19 variables of 2 irrigation systems and 3 tomato cultivars, the box indicates significant ($p<0.05$) correlation

As noticed in regression analysis (Fig. 5), 72% data of illustrative variable suited the regression model ($R^2=0.71$) in linear fashion revealing that there was a little variation between the clarifying data and the fitted line. Also, the R^2 values highlighted that the studied independent variable markedly justified the variability of the dependent variable regardless of statistical significance. Negative values (b= -3.96) of the straight line represented there was a downhill pattern while other variables in the model were held constant. The plants took less time for first flowering resulted in the highest yield. Overall, the total yield declined as plants took more time for flowering.

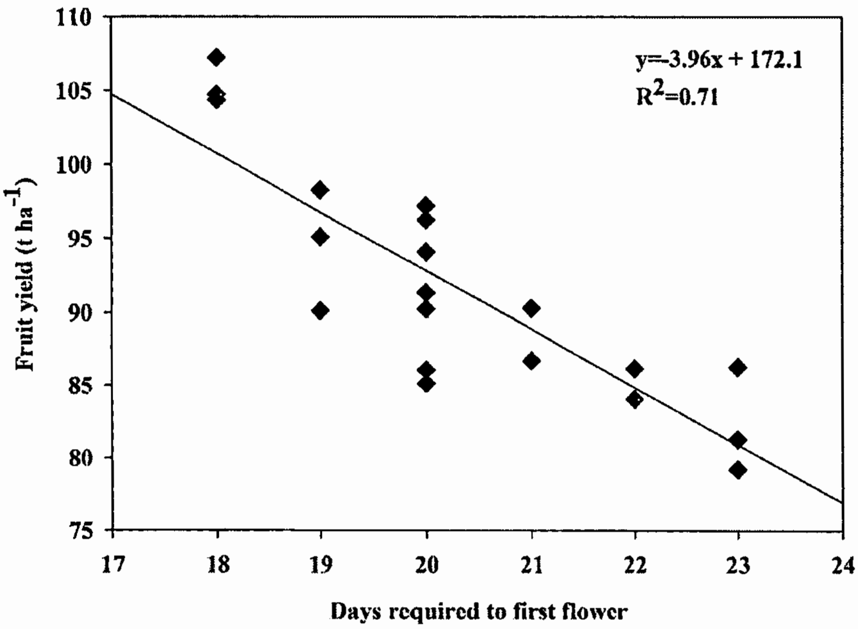

Figure 5: Linear regression between fruit yield and days required to first flower.

Experiment 3. Partial budget analysis for using containerized seedlings and drip irrigation system in tomato production

4.3.1. Economic evaluation for containerized seedlings production

The plastic cell tray tomato seedlings production system reduced significant operating cost required for labors (land preparation and sowing, weeding, seedlings uplifting and tying) but increased materials (cell tray, coo-dust) cost. The cost of production of plastic cell tray seedlings required about 72% more (Tk. 9000) than that of mud-bed seedlings (Table 6). However, the cost increase in plastic cell tray was Tk. 17500 and Tk. 1500 for purchasing plastic cell tray and coco-dust, respectively. The selling prices of plastic cell tray seedlings were increased by Tk. 75000 over mud-bed seedlings for 50000 seedlings (Table 7). During vegetable production season the individual seedling price varied from Tk. 0.5 to 2.0. The expected net profit by using the plastic cell tray was Tk. 66000/50000 seedlings.

Table 5: Cost comparison between plastic cell tray and mud-bed tomato seedlings production

Category	Cost items	Cost due to use of mud-bed seedlings (Tk.[w]/50000 seedlings)	Cost due to use of plastic cell tray seedlings (Tk./50000 seedlings)	Cost changes due to the use of plastic cell tray seedlings (Tk./50000 seedlings)
Operating	Labor for land preparation and sowing[u]	7500	2500	-5000
	Plastic cell tray cost[v]	-	17500	17500
	Coco-dust cost[x]	-	1500	1500
	Labor for weeding[y]	2500	-	-2500
	Labor for uplifting and tying[z]	2500	-	-2500
Total		12500	21500	9000

[u]Labor cost for land preparation and sowing (50000 seedlings): at 500 Tk./labor- 15 labors for mud-bed and 5-labor for plastic cell tray, [v]Plastic cell tray cost: at 35 Tk./tray- total 500 trays, [w]Tk.-Bangladeshi taka, [x]Coco-dust cost: 300/medium gunny bag-5 bags in total, [y]Labor cost for weeding: at 500 Tk./labor- 5 for mud-bed seedlings, [z]Labor cost for uplifting and tying: at 500 Tk./labor- 5 for mud-bed seedlings.

Table 6: The net effect of using plastic cell tray tomato seedlings relative to mud-bed tomato seedlings

Budget variable	Selling prices of mud-bed (Tk./50000 seedlings)[z]	Selling price of plastic cell tray (Tk./50000 seedlings)[z]	Value changes (Tk./50000 seedlings)
Revenue changes	25000	100000	75000
Cost changes	12500	21500	9000
Net effects	12500	78500	66000

[z]Selling price (50000 seedlings): at Tk. 0.5seedling^{-1} for mud-bed and Tk. 2.0 seedling^{-1} for plastic cell tray

4.3.2. Economic assessment of drip irrigation by partial budgeting

Total marketable yield and price value were higher in drip irrigation system compared to the furrow irrigation system (Table 7). The drip irrigation system (DI) reduced considerable operating cost required for pesticides, labors for spraying, weeding, irrigation (Table 8). The cost of tomato production using DI system required about 14.23 % of less operating cost (Tk. 50,962 ha^{-1}) than that of traditional furrow irrigation system (FI). However, the cost increases in DI system was Tk. 24000, 1,50,000, 5,400 and 6000 ha^{-1} for plastic mulch, drip irrigation set up, labor for mulching set up and harvesting, respectively.

Table 7: Total yield, price and cost variation, and changes in return of following drip irrigation (DI) system relative to traditional furrow irrigation (FI) tomato (Mintoo super HYV) production system

Treatments	Total yield (kg ha^{-1})	Value[a] (Tk. ha^{-1})
Drip Irrigation	97,353	1,973,530
Furrow Irrigation	86,095	1,860,950
Changes	11,258	112,580
Cost changes	-	44,962
Total return	-	1,57,542

[a]The growers selling price of tomatoes varied from Tk. 10-30 kg^{-1} during the harvesting period.

Table 8: Cost comparison between tomato following traditional furrow system (FI) and drip irrigation system (DI)

Cost category	Cost items (ha^{-1})	Total cost of cultivating tomato in FI(Tk. ha^{-1})	Total cost of cultivation for DI (Tk. ha^{-1})	Total changes in cost due to cultivation of DI (Tk. ha^{-1})
Operating	Plastic mulch[a]	-	24,000	24,000
	Drip system setup[b]	-	1,50,000	1,50,000
	Pesticide and fungicide cost[c]	5,928	4,550	-1,378
	Labor cost for mulching set up above beds[d]	-	5,400	5,400
	Labor cost for spraying fungicides	27,000	18,900	-8,100
	and pesticides[e]	1,21,500	18,000	-1,03,500
	Labor cost for weeding[f]	2,03,664	86,280	-1,17,384
	Irrigation[g]			
Total operating		3,58,092	3,07,130	-50,962
Harvesting	Labor for harvesting[h]	54,000	60,000	6,000
Total		4,12,092	3,67,130	-44,962

[a]Plastic mulch cost Tk. 24,000.(1 roll Tk. 8000), [b]Drip system (water tank, drip tape, dripper, end cap, water meter) setup: Tk. 1,50,000, [c]Pesticides and fungicides cost: Tk. 5928for furrow irrigation system (FI) and Tk. 4,550 for drip irrigation system (DI) , [d]Labor cost for mulching set up at Tk. 450 $labor^{-1}$ (12 labors) [e]Labor cost for spraying: 20 times for FI and 14 times for DI system at Tk. 450$spray^{-1}$, 3 labors/spray, [f]Labor cost for weeding: at Tk. 450 $labor^{-1}$- 6 times for FI (45 labors each time) and 4 times for L02 (10 labors each time), [g]Irrigation cost based on Tk. $12/m^3$ for 16,972 m^3ha^{-1} for furrow irrigation system and 7190 m^3ha^{-1} for drip irrigation system, [h]Labor cost for harvesting: at Tk. 200 $person^{-1}$, 10 times harvesting (30 labors each time) for DI system and 9 times harvesting (30 labor each time) for furrow irrigation system (FI).

The marketable fruit yield of DI system was 97,353 kg ha^{-1}, and similarly marketable yield of FI was 86,095 kg ha^{-1}. The drip irrigation (DI) system yield was increased by 11,258 kg ha^{-1} over FI (Table 7). During growing period tomato growers having prices for tomato were varied from Tk. 10 to 30. The expected net profit from the cultivation of the drip irrigation system was Tk. 1,57,542 ha^{-1} would be greater than traditionally cultivating tomatoes using FI system, signifying increased effectiveness potential under this specific set of assumptions.

5. Discussion

Improved plant height, vigor, leaf number and biomass of plastic cell tray of tomato seedlings are consistent with previous reports that plastic cell tray containing seedlings can protect plants from adverse weather and soilless growing medium is used instead of soil to which nutrients are added for healthy root development and seedling growth. Also, plastic cell tray seedlings have a root ball that holds moisture and ensures root integrity and enhance seedlings growth and have superior vigor (Lin *et al.* 2015, Coolong, and Boyhan, 2017). Dimsey (2009) reported that seedlings can easily detach from the cell tray and the intact root systems reduce the incidence of transplant shock and improved crop uniformity which matched to this finding. In contrast, the roots of mud-bed seedlings incur root injury when the seedlings are pulled from the beds for transplanting, adversely affecting transplant growth (Lin *et al.*, 2015). Several plant growth parameters (germination, survival, stem diameter) were not varied significantly among the containerized seedlings. It may be all containerized seedlings were grown in coco-dust media that facilitated alike environments for roots development and seedlings growth.

There must be a revenue reward for the current vegetable seedlings grower in addition to the less operating costs for the plastic cell tray. That revenue reward was provided by price premiums from more individual seedling price. The savings in operating costs (labors) would add more to this cost-effectiveness. The net profit was higher with containerized seedlings over field grown seedlings reported by Coolong and Boyhan (2017). The capacity to establish plants without soil would be a special advantage of vegetables seedlings grower in making profit from commercial or even small-scale vegetable cultivation in Bangladesh.

Precise irrigation approaches for productive use of irrigation water can be attained through improving available water resources management for sustainable crop production. It was reported that about 70% of the world's freshwater reserves are utilized for agricultural activities (Himanshu et al., 2019). Sustainable irrigation water use efficiency (IWUE) has potential to preserve inadequate water assets with achieving peak economic crop output (Abdel Gadir et al., 2012). Acceptance of water-saving irrigation systems is a necessity under the current climate change circumstances where water convenience for agriculture segment is declining and becoming challenging (Dou et al. 2016).

The irrigation system had a significant impact on growth, physiological traits of tomato, in the present study. In the furrow irrigation system, irrigation water was applied less frequently, potentially causing a water deficit in the soil. Interference in cell division and cell extension activities is one of the main effects of water deficiency (Ilyas et al., 2017; Ullah et al., 2018; Chakma et al., 2021) which might be accountable for the diminution of plant height and leaf area. Palada et al. (2003) stated that water input per hectare, and water use efficiency were higher in drip irrigation system as compared to furrow irrigation for cultivation of tomato and cucumber. Sirisuntornlak et al. (2019) mentioned a decline in growth factors, grain yield, and yield elements of maize (*Zea mays* L.) due to water deficit condition from well-watered (100 % FC) to acute water stress (50 % FC), which was ascribed to lowered cell division and cell enlargement activities. It is distinct from the current study the growth and fruit yield attributes of tomato plants were significantly reduced when they were grown in a furrow irrigation system that created a water deficit condition. These results are in deal with those of Kuscu et irrigation system resulting fruit yield reduction and vegetative growth impaired while electrolyte leakage was increased at furrow irrigation system where lower moisture regime observed. Similarly, Hayat et al. (2008) informed that electrolyte leakage was elevated in lower moisture regime, which is opposite to LRWC. These results are in complete agreement with the current study.

Tomato yield was influenced by cultivars and the present study revealed that Mintoo super (HYV) (97.4 t ha^{-1}) dominated over BARI Tomato-16 and BARI Tomato-19 for fruit yield. Antonina et al. (2020) also observed an increase in fruit yield (130.4 Mg ha^{-1}, 126.5 Mg ha^{-1}, 106.45 Mg ha^{-1}) by hybrid tomato 'Cobra 26 F1', 'Heinz 3402F1', 'Sister F1' over other tomato cultivars tested in Russia although various agrochemicals influenced tomato yield. Also, Valenzano et al. (2008) informed that tomato cultivars 'Diana F1' and 'Jama F1' 'Naomi F1' and 'Conchita F1' respond differently for fruit yield in Southern Italy. Eight BARI tomato cultivars were tested in both coastal areas (Benarpota and Kalapara) of Bangladesh, and BARI Tomato-7 outperformed other cultivars in terms of growth, development, yield contributing attributes, and yield (Naher et al., 2020). In the coastal areas of Patuakhali, Hasan et al. (2017) found that BARI Tomato-14 outperformed LE-009, TLB-130, VRT-005, VRT-007, BARI Tomato-3, BARI Tomato-8, and BARI Tomato-15 in terms of growth and yield. Five tomato cultivars showed morphological, phenological, and yield attribute differences, with BARI Tomato-12 and BARI-Tomato-14 showing better results for flower and fruit production characteristics observed by Malaker et al. (2016). Those findings are very similar to the current findings. In Tunisia, however, marketable yields of the tomato cultivars 'Perfectpeel,' 'Ri Grande,' 'Hypeel 108,' and 'Firenze' were not affected by cultivar differences, as reported by Riahi et al. (2009).

Fruit quality is an important index for determining shelf life, selling price and gross return of tomato while it was reported that an improvement of fruit quality is habitually paralleled with the undesirable yield depression under limited soil moisture supply especially small fruit size (Wu et al., 2021). In the present study, some of the quality parameters, such as TSS, firmness and shape index improved under drip irrigation. Similarly, Nangare et al. (2016) also observed a considerable progress in most of the attributes (fruit pH, TSS, and color index) of tomato in response to deficit irrigation practices. Wu et al. (2021) reported higher contents of soluble solids, ascorbic acid, and soluble sugar of greenhouse-grown tomato fruits under lowered water supply (50% and 75% FC) compared with the well-watered condition (100% FC). Irrigation system and cultivars had a significant impact on tomato fruit quality parameters. According to Vescera and Brown (2016), the sweetness of the fruit was used to determine its quality (TSS). Similarly, the chemical lycopene is responsible for the bright red color of the fruit and is considered one of the most important characteristics in determining the quality of the fruit (Hui et al., 2006; Lambelet et al., 2009). The other quality parameter, firmness, was significantly influenced by irrigation regime and regulates photo assimilate, as Zegbe et al. (2006) mentioned.

Crop yield is the final output resulted from cumulative action of all metabolic reactions of plants including photosynthesis, respiration, and transpiration, which are adversely affected by soil moisture availability (Vaghar and Ehsanzadeh, 2018). Efficient irrigation system ensures soil water availability that influence on growth, quality and fruit yield of tomato visualized in the present study. Irrigation water use was lower with drip than furrow irrigation system in both seasons, which was projected. This was because drip irrigation could be regulated more accurately than furrow irrigation. Water was supplied drop by drop in root zone of the plants at drip irrigation system resulted in a significant proportion of water saved reported by Ngouajjo et al. (2007). Over or deficit irrigation causes water logging and water shortage conditions leading to reduce water use efficiency by <30% (Ishfaq, 2002). Drip irrigation system offers several benefits over furrow irrigation system comprising higher water and fertilizer use efficiency, saves 70-80% water, and boost up fruit yield (Camp et al., 2001). The use of a drip irrigation system in strawberry fields prevented excessive water loss through infiltration and percolation (Morillo et al., 2017). In strawberry, Hoppula and Salo (2007) and Kumar et al. (2012) found that drip irrigation was more efficient than furrow irrigation in terms of water use. When compared to a surface irrigation system in strawberry, drip irrigation delivers water precisely to the root zone with minimal water loss due to evaporation and leaching (Sharma et al., 2005). In India, furrow irrigation system is widely used for vegetable cultivation as a conventional system, but the furrow system consumed more water compared to drip irrigation system. The higher application efficiency of drip irrigation water was found over conventional furrow water system reported by many researchers (Tiwari et al., 1998a; Hanson et al., 1997; Fekadu and Teshome, 1998). Drip irrigation system helps to save 67% to 80% more irrigation water in different vegetables production than surface irrigation systems informed by Sivanappan and Padmakumari (1980). Khade (1987) stated 60% more yield of okra plus water reserves of 40% under drip irrigation than furrow irrigation system in India. The drip irrigation maintains proper soil moisture along with black plastic mulch resulted in 72% more yield of okra compared to furrow irrigation system reported by Tiwari et al. (1998a). Similarly, fruit yield of tomato was higher under drip irrigation system than furrow irrigation system mentioned by different researchers (Shrivastava et al., 1998; Tiwari et al., 1998b; Malash et al., 2005; Mahajan and Sing, 2006).

Jha et al. (2017) reported that tomato yield was raised by 58.7% in drip irrigation system over furrow irrigation. The higher water productivity was obtained from drip irrigation system over conventional furrow irrigation system of vegetable crops (Singh et al., 2009). Panigrahi et al. (2012) found that adaptation and acceptance of drip system were expanded due to better water use productivity and confirmed better yield of various crops in India.

In addition to the lower input costs for the drip irrigation system, there must be a revenue incentive for the current Mintoo super (HYV) tomato grower. Price premiums from increased tomato yield provided that profit incentive. When compared to furrow irrigation and BARI tomato cultivars, increases in Mintoo super (HYV) tomato yield with drip irrigation would pay for the increased input costs (mulch, drip system installs, and labors). Input cost savings (labor, pesticides, weeding and irrigation) would contribute even more to this cost-effectiveness. Jha et al. (2017) reported that the average cost-benefit (CB) of drip-irrigated crop was 33% more compared to furrow irrigated crops. Also, they mentioned that drip-irrigated cauliflower is more profitable in terms of net return and CB ratio. In India, the net returns and benefit-cost ratio (7:1) of tomato *cv. Arka Abha* was found higher with drip irrigation system compared to furrow irrigation system reported by Tiwari et al. (1998a). Also, Hanson and May (2004) stated that profits of tomato cultivation under drip irrigation system were \$867 to \$1493 ha^{-1} over sprinkler irrigation system. In Turkey, the net return was elevated by \$6960 ha^{-1} under drip irrigation tomato production system (Kuscu et al., 2009).

CHAPTER V

Summary and Conclusions

The experiments were conducted at Professor Dr. Purnendu Gain field laboratory of Agrotechnology Discipline, Khulna University, Bangladesh during winter season of 2019-2020 (November-April) and the experiments were repeated in 2020-2021.The seedlings productions experiment consisted of three growing containers viz. plastic cell tray, large plastic cup, small plastic cup following completely randomized design (CRD) with seven replications. Plant height was higher with plastic cell tray (8.80 cm) compared to plastic cups (L and S) growing seedlings (6.13 cm and 6.20 cm respectively). At 2 and 4 weeks after sowing (WAS), vigor with plastic cell tray was higher than plastic cups (L and S) growing seedlings. Plastic cell tray containing seedlings produced more leaves relative to small size plastic cup growing seedlings. Total biomass was higher in plastic cell tray compared to plastic cups (L and S) growing seedlings.

Drip irrigated plants were about 5% taller in compared to furrow irrigation and 23.14% higher LA than furrow irrigation system while the cultivars, Mintoo super (HVY) produced the highest LA (16572 cm^2) but the lowest in BARI Tomato-19 (15863 cm^2). Shoot dry matter (SDM) was 22% higher under drip irrigation system than furrow irrigation and Mintoo super (HVY) produced 29% more SDM than others. Similar trends with 21% higher root dry matter were observed for drip irrigation in both growing seasons. It was found that plant grown under drip irrigation system resulted in 20% more flowers $plant^{-1}$, 19% number of fruit clusters $plant^{-1}$ than furrow irrigation system whereas Mintoo super (HYV) cultivar exhibited better than tomato cultivars. Leaf greenness was 5.1% higher in drip irrigated plants compared with furrow irrigation and SPAD reading was the highest (56.7) at Mintoo super (HYV) tomato cultivar. Mintoo Super grown under drip irrigation showed 8% higher LRWC compared to other interactions. Drip irrigation system dominated over furrow irrigation system and caused 26.32% higher leaf area index (LAI) than furrow irrigation for LAI. Canopy temperature was maximum (32.7 °C) when the plants received furrow irrigation compared to drip irrigation system (28.7 °C). The furrow irrigation system revealed more electrolyte leakage (EL) than drip irrigation system. However, the Mintoo super (HYV) tomato shape index belongs to oval whereas BARI Tomato-19 and BARI Tomato-16 were considered as spherical. The highest TSS content was recorded from Mintoo super (HYV) whereas the lowest in BARI Tomato-19 and BARI Tomato-16.The tomato produced bright red color fruits grown under drip irrigation system. Likewise, Mintoo super (HYV) tomato gave bright red color fruits over other cultivars tested. The drip irrigation system showed 8.8% higher firmness value than furrow irrigation system. The fruit yield of drip irrigated plants produced about 13% higher than furrow irrigation system for both growing season and Mintoo super tomato cultivar produced 6% more fruit yield in comparison to others. Fruit yield was the highest (94.37 tha^{-1}) at Mintoo super (HYV) tomato cultivar, whereas it was the lowest (88.97tha^{-1}) in BARI Tomato-16. Drip irrigation significantly lowered total water input by 58% and improved water productivity by 62% over furrow irrigation.

The total profitability of plastic cell tray tomato seedling production system was elevated by Tk. 66000 compared to traditional mud-bed seedlings. Under drip irrigation, the total effectiveness of Mintoo super (HYV) tomato production was increased by Tk.1,57,542ha^{-1}.Thus, drip irrigation system combined with the Mintoo super (HYV) tomato cultivar might be a viable option for better water productivity with maintaining maximum fruit yield in the limited water supply environment to ensure a profit premium for tomato growers.

CHAPTERVI

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Appendices

Appendix I. Significance levels in three-way ANOVA of the effect of growing season, irrigation method and cultivar on growth parameters, physiological parameters, yield components, quality attributes, fruit yield and water productivity of tomato

Items	Growing season (S)	Irrigation method (I)	Tomato cultivar (T)	S × I	I × T	T × S	S × I × T
Plant height (cm)	1.4^{ns}	5.4^{ns}	4.8^{ns}	6.3^{ns}	0.5^{ns}	5.9^{ns}	6.1^{ns}
Leaf area (cm^2)	3.1^{ns}	35.2^{**}	10.6^{*}	4.2^{ns}	1.6^{ns}	7.1^{ns}	4.9^{ns}
Shoot dry matter ($gplant^{-1}$)	1.3^{ns}	14.4^{*}	9.3^{*}	1.5^{ns}	3.1^{ns}	2.7^{ns}	3.9^{ns}
Root dry matter ($gplant^{-1}$)	1.4^{ns}	7.8^{*}	5.7^{*}	3.2^{ns}	1.3^{ns}	1.9^{ns}	1.1^{ns}
Number of flowers $plant^{-1}$	2.3^{ns}	23.4^{**}	18.2^{*}	2.8^{ns}	4.5^{ns}	3.1^{ns}	2.5^{ns}
Number of fruit cluster $plant^{-1}$	1.2^{ns}	16.4^{**}	11.6^{*}	3.3^{ns}	5.5^{ns}	4.2^{ns}	3.1^{ns}
Leaf greenness (SPAD value)	1.6^{ns}	25.7^{**}	35.5^{**}	2.8^{ns}	2.5^{ns}	3.2^{ns}	1.7^{ns}
Leaf relative water content (%)	1.3^{ns}	28.1^{**}	23.2^{**}	3.9^{ns}	7.0^{*}	2.1^{*}	3.3^{ns}
Leaf area index	5.5^{ns}	30.3^{**}	14.8^{*}	6.1^{ns}	1.3^{ns}	8.2^{ns}	6.7^{ns}
Canopy temperature (°C)	1.1^{ns}	58.2^{**}	2.4^{ns}	1.5^{ns}	1.2^{ns}	3.9^{ns}	2.5^{ns}
Electrolyte leakage (%)	1.8^{ns}	18.7^{**}	2.6^{ns}	1.7^{ns}	1.1^{ns}	2.3^{ns}	1.4^{ns}
Fruit pH	1.5^{ns}	8.1^{*}	6.0^{*}	2.1^{ns}	3.8^{ns}	1.9^{ns}	2.3^{ns}
Shape index	1.4^{ns}	21.1^{**}	20^{**}	1.3^{ns}	1.1^{ns}	1.5^{ns}	1.7^{ns}
TSS	1.1^{ns}	18.2^{**}	40.3^{**}	1.5^{ns}	1.3^{ns}	1.4^{ns}	2.2^{ns}
Hue angle (°h)	1.7^{ns}	13.1^{*}	34.5^{**}	1.8^{ns}	1.4^{ns}	1.6^{ns}	2.0^{ns}
Firmness (N)	2.6^{ns}	39.1^{**}	57.6^{**}	1.6^{ns}	1.7^{ns}	1.5^{ns}	3.1^{ns}
Water input (m^3ha^{-1})	41.1^{**}	34.5^{**}	1.1^{ns}	1.4^{ns}	1.2^{ns}	2.1^{ns}	2.7^{ns}
Fruit yield (tha^{-1})	1.1^{ns}	21.6^{**}	48.8^{**}	1.3^{ns}	0.7^{ns}	1.9^{ns}	2.4^{ns}
Water productivity (m^3ha^{-1})	2.5^{ns}	21.1^{**}	1.2^{ns}	2.2^{ns}	1.1^{ns}	2.5^{ns}	2.7^{ns}

NS-not significant; $^{**}p < 0.01$; $^{*}p < 0.0$

Appendix II. Research activities at Khulna University Field Laboratory (2019-2020 and 2020-2021)

Fig. 1. Drip irrigation installment, dripper, drip tape at field lab of Agrotechnology Discipline

Fig. 2. Mulching installment and layout of the plot and raised bed preparation before planting

Fig. 3. Tomato seedlings growing in plastic cell tray, plastic cup and mud-bed, respectively

Fig. 4. Staking in tomato filed

Fig. 5. Installation of Tensiometer to monitor soil moisture

Fig.6. Field monitoring by Dr. Prosanta K. Dash in 2019-2020 (Left) and 2020-2021 (Right)

Fig. 7. Tomato field at full blooming and fruiting stage, and data collection and intercultural operation done by Sangeeta Mukherjee (MS Student)