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Effects of Raised Bed Furrow Irrigation and Various Mulching Techniques on the Growth, Yield and Water Use Efficiency of Tomato Cultivation

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ABSTRACT

During the dry season (November to April), a field experiment was carried out at the Agricultural Field Research Center of the Bangladesh Open University, Gazipur. The effects of different levels of irrigation with various mulches were evaluated on the growth and yield of tomatoes. The trial comprised raised-bed furrow irrigation methods with three mulching treatments (i.e. without mulch, black polyethylene mulch and grass straw mulch) and two irrigation plans (6-day and 3-day intervals). The 6 treatments were designed in a randomized complete block (RCB) design in three replicates. In response to the 6-day and 3-day irrigation intervals, raised-bed furrow irrigation, with black polyethylene mulch, resulted in a significantly higher yield (96.46 t/ha and 102.19 t/ha) compared to the effect of no mulch on the yield (77.70 t/ha and 82.04 t/ha), respectively. The use of grass straw mulch (87.15 t/ha and 91.76 t/ha) also resulted in a significant yield, compared to no mulch. All three factors significantly influenced unit crop weight, fruit size at the age of 16, 18 and 20 weeks after transplanting, marketable fruit yield, plant water consumption and water use efficiency. The interaction between raised-bed furrow irrigation, mulching and irrigation schedule had a significant influence on the water use efficiency (WUE) of tomato production. The raised-bed furrow irrigation method in a two-row crop cultivation pattern was statistically equivalent in terms of WUE if it was mulched by black polyethylene and irrigated every 3 days.

Introduction

Tomato (*Lycopersicon esculentum*) is one of the most important vegetables, with great economic implications for its producers and consumers in the world (Lahoz et al., 2016). It belongs to the Solanaceae family and is grown in large ranges and fields because of its adaptability to a wide variety of soils and climates in Bangladesh (Islam et al., 2016). It contains about 94% water, 2.5% total sugar, 2% total fiber, 1% proteins and other nutrient compounds (e.g. acids, lipids, amino acids and carotenoids) (Koh et al., 2012). The popularity of the tomato and its product is increasing day by day for use in salads, soups, and processing into stable products such as ketchup, sauce, pickle paste, chutney and juice (Islam et al., 2016).

Water is one of the most important resources in agriculture. It becomes a limiting factor as increasing competition affects the production of industrial and urban settlement, which has resulted in a decrease in the quantity and quality of agricultural water use (Osman et al., 2001). To overcome this limitation, an efficient irrigation system with adequate mulching and irrigation levels is the most suitable option, which can save

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water and increase tomato productivity. Tomato plants are susceptible to drought stress and show a high correlation between evapotranspiration and crop yield (Nuruddin et al., 2003). The raised bed and furrow planting method enables good drainage and offers the possibility of weed control before transplanting. This method intercepts more solar radiation and, thus, helps reduce the incidence of diseases (Kumar, 2009).

In general, mulching helps maintain a uniform temperature. It assists in weed control, fertilizer draining, preserves soil moisture, improves irrigation efficiency (AVRDC, 1990; Benoit and Ceustermans, 1996), and boosts soil fertility through organic mulching (Rao and Pathak, 1998). Black plastic mulch has intense shortwave permeability and high shortwave absorption. It increases soil temperature (Ham and Kluitenberg, 1994; Tarara, 2000; Dodds et al., 2003; Heibner et al., 2005) and occasionally causes harmful effects on plant growth (Orzolek and Murphy, 1993; Perez et al., 2000). On the other hand, black plastic mulch renders soil temperatures low by preventing sunlight from reaching the soil surface, while also controlling weeds as organic mulch (Bonanno, 1996).

More than 100 years ago, Briggs and Shantz (1913) discovered that water use efficiency (WUE) is a concept that shows a relationship between plant productivity and water consumption. They introduced the term WUE as a measure of the amount of biomass produced per unit of water consumed by a plant. An increase in water productivity is particularly appropriate where water is scarce and where research can benefit sustainable uses of fertilizers, high-quality seeds, tillage, land formation, manpower, energy and machines (Sharma et al., 2015).

Water is the primary source of any dry-season cultivation, but issues such as land preparation, selection of irrigation method, timing of irrigation and types of mulching are also important factors. In this study, the combination of raised bed furrow irrigation with black polyethylene and straw mulch was considered as a research topic because growing tomatoes under drought stress is difficult (Klunklin and Savage, 2017). So far, most cases of previous research have focused on growing tomatoes using traditional furrow irrigation, mulching practices, and deficit irrigation (Banjaw et al., 2017; Xuelian et al., 2019), as well as plastic mulch with drip irrigation (Lin et al., 1983; Biswas et al., 2015). These methods differ from the raised bed furrow irrigation which can be used with combinations of mulching (e.g. straw and black polyethylene). However, the current research was an attempt to study the effects of raised bed furrow irrigation and mulching practices on tomato growth, yield, and water use efficiency in order to find an appropriate irrigation scheduling, with optimal variables, to improve tomato growth and yield.

Materials and Methods

Study location and experimental design

The experiment was carried out from November 2018 to April 2019 at the Agricultural Field Research Center of the Bangladesh Open University campus in Gazipur. The topography of the test field was uniform and level. The soil of the trial field was sandy-loam with a field capacity of 29.6%. The 'BARI Tomato-15' cultivar was grown in the experimental field and each plot was 5m×1m in size, with 20 seedlings, and the spaces between the plants were 0.50m × 0.50m.

Two levels of irrigation, viz. I_1 (6-day interval) and I_2 (3-day interval) were applied along with three mulch treatments. No mulch (NM) served as the control. Black polyethylene mulch (PM) and grass straw mulch (SM) were tested. There were six treatment combinations, i.e. T_1- irrigation with a 6-day interval + NM; T_2- irrigation with a 6-day interval + PM; T_3- irrigation with a 6-day interval + SM; T_4- irrigation with a 3-day interval + NM; T_5- irrigation with a 3-day interval + PM; and T_6- irrigation with a 3-day interval + SM. The experiment was set up in a randomized complete block design (RCBD) with three replications.

Process of field management and data collection

The 25-day old tomato seedlings (cv. 'BARI Tomato-15') were transplanted in December 11, 2018, in unitary plots of 5m×1m, with 50cm×50cm spacing. For the purpose of mulching, 10 µm-thick black polyethylene films were used at a spacing distance of 50cm×50cm and were spread over the beds. The films were perforated with holes (50 mm in diameter) and the seedlings were transplanted into these holes. The plants were watered immediately after transplanting and were watered twice thereafter, with an interval of 2-3 days, for up to 15 days, to establish the seedlings. Seven days after the transplanting, grass straw (10 t/ha) was used as straw mulch. The irrigation was carried out according to the schedules (i.e. 6- and 3-day intervals) by the raised bed and furrow irrigation method. Recommended fertilizer doses (N100, P100, K80 kg/ha) were used for all treatments, according to Biswas et al., 2015. The total amount of P in the form of Triple Super Phosphate (TSP) was applied at the time of final tillage. During the growing season, N and K were applied in the form of urea and potassium salt (MOP) in four equal portions, with a time lapse of 15 days from one instance of application to the next. The first dose of fertilizer was applied 15 days after transplanting. For the purpose of irrigation, water tanks were installed with the raised bed furrow irrigation system at a height of 1 m above the ground surface. Accordingly, this allowed the irrigation of 18 plots by gravity flow. Plant height (cm) was measured with a scale from the ground level to the tip of the shoot. The number of branches was counted manually before tomato fruits were first harvested from the plants. Ripened tomato fruits were harvested sequentially, 13 times, from March 12, 2019, to April 24, 2019. During the harvest, the number of fruits was counted per plant and recorded in a data sheet with the harvest date. The tomatoes were collected separately in a previously labeled ploy bag and brought to the laboratory for further measurements of fruit weight by digital weight scales. Also, yield-related data were recorded, i.e. yield per plant (kg) and yield per plot (kg) for each treatment group. When the gross yield and the marketable yield were recorded in kilograms per plot, the data were then converted into yield (tons) per hectare.

Water application and water use efficiency

In the open field, irrigation water was applied from the water tank, according to the method of raised bed furrow irrigation. The water was applied for a total number of 15 times in each plot throughout the whole period of the experiment, with an interval of 6 days. On the other hand, the irrigation was applied for a total number of 28 times when considering the 3-day interval regime of irrigation frequency. The water use efficiency (WUE) is usually defined as the amount of yield that can be generated from a certain amount of water. WUE was calculated using the following formula and was expressed in kg/ha-mm.

$$\mathrm{WUE} = \frac{\text{Yield of tomato (kg/ha)}}{\text{Total water use (mm)}}$$

Statistical analysis

All data were statistically analyzed using the 'R-3.6.2' software to determine significant variations in the results, regarding various irrigation and mulching practices in the treatments. The mean values in each treatment group were compared by the Least Significance Difference (LSD) test at a significance level of 1% and 5%, i.e. ($P \leq 0.01$) and ($P \leq 0.05$).

Results

Effects of irrigation levels and mulches on total yield and yield components

The growth, total yield and yield components of tomato were significantly influenced by different levels of irrigation and mulching (Table 1). While considering the effect of irrigation only, substantial variations were observed in plant height, number of branches, number of fruits per plant, and unit weights of fruit and yield. With the exception of fruit count per plant, maximum values of all other traits resulted from the 3-day interval, whereas minimum values resulted from the 6-day interval of irrigation. Regarding the effect of mulching, the tallest plants were observed in the non-mulch (NM) treatment group, whereas the longest branches occurred in the grass straw mulch (SM) treatment group. On the other hand, significant variations were observed in the number of fruits per plant and in the unit weight of fruits and yields when the plants were treated with black polyethylene mulch.

Regarding the interactive effects of irrigation and mulching, the plant height was highest in the no mulch (NM) group. In the 6-day interval regime, a similar number of branches was observed in response to polyethylene (PM) and straw mulch (SM). Compared to PM, however, SM caused higher branches in association with the 3-day interval regime. Regarding the effects of black polyethylene mulch, different irrigation levels led to significant differences in the number of fruits per plant, the unit fruit weight and the yields.

The raised bed furrow irrigation with black polyethylene mulch resulted in significantly higher yields (96.46 t/ha and 102.19 t/ha), compared to the effect of no mulch (77.70 t/ha and 82.04 t/ha) in response to the irrigation regime of 6-day and 3-day intervals, respectively. Similarly, using grass straw mulch resulted in significant yields, compared to no mulch. The PM treatments (T_2 and T_4) resulted in higher yields (29.28% and 30.14%), respectively, compared to the corresponding irrigation treatments without mulch. Even when compared to treatments T_3 and T_6, the yields were 14.27% and 14.36% higher than the analogous treatments without mulch.

Effect of irrigation and mulching on the time of fruit harvest after planting

The fruit number and unit weight, at 16, 18 and 20 weeks after transplanting (WAT), showed a significant effect on irrigation and mulching (Table 2). For the effect of irrigation, a higher number of fruits and a higher unit weight were observed in response to the 6-day irrigation interval by 16 and 18 weeks after transplanting, but after 20 weeks the fruit number and unit weight became higher in response to the 3-day irrigation interval. For the effect of mulching, the total number of harvested fruits varied in response to 16, 18 and 20 weeks after transplanting. In those cases, a higher unit weight was observed in plants that were treated with the black polyethylene mulch (PM). For the interactive effects of irrigation and mulching, the 6-day irrigation interval resulted in greater fruit counts, compared to the 3-day interval, but the fruit unit weight was higher as a result of the 3-day interval.

Table 1. The plant height, number of branches, fruits per plant, units of fruit weight and yield of tomato, as influenced by different irrigation and mulching practices

Factors /Treatments	Plant height (m)	Branch /plant (number)	Fruit/ plant (number)	Unit fruit weight (g)	Yield (kg/plant)	Yield (kg/plot)	Gross Yield (t/ha)	Marketable yield (t/ha)	Marketable yield increase over corresponding control (%)
Furrow Irrigation									
I_1	0.89	7.67	35.11a	61.83b	2.18b	43.55b	87.10b	78.89b	-
I_2	0.90	8.00	34.67b	66.13a	2.30a	46.00a	91.99a	84.15a	-
CV (%)	2.080	13.984	1.002	0.653	1.068	1.090	1.082	0.775	-
LSD	ns	Ns	0.37*	0.44***	0.025***	0.51***	1.018***	0.663***	-
Mulches									
NM	0.915a	7.00b	34.17b	58.42c	2.00c	39.93c	79.87c	71.09c	-
PM	0.885b	8.00ab	36.33a	68.13a	2.49a	49.67a	99.32a	92.22a	-
SM	0.885b	8.50a	34.17b	65.40b	2.24b	44.73b	89.45b	81.26b	-
CV (%)	2.080	13.984	1.002	0.653	1.068	1.090	1.082	0.775	-
LSD	0.024*	Ns	0.45***	0.54***	0.031***	0.628***	1.246***	0.813***	-
Interaction of irrigation and mulches									
T_1	0.91ab	7b	34bc	56.57f	1.94f	38.84f	77.70f	68.89f	-
T_2	0.88b	8ab	36a	65.92c	2.41b	48.23b	96.46b	89.06b	29.28
T_3	0.88b	8ab	35b	63.00d	2.18d	43.57d	87.15d	78.72d	14.27
T_4	0.92a	7b	34cd	60.00e	2.05e	41.02e	82.04e	73.28e	-
T_5	0.89ab	8ab	36a	70.35a	2.55a	51.10a	102.19a	95.37a	30.14
T_6	0.89ab	9a	34d	67.80b	2.29c	45.88c	91.76c	83.80c	14.36
CV%	2.08	13.98	1.00	0.65	1.07	1.09	1.08	0.78	-
LSD	0.03**	1.99*	0.64**	0.76***	0.04***	0.89***	1.76***	1.15***	-

Abbreviations: I_1- 6-day interval; I_2- 3-day interval; NM- no mulch; PM- black polyethylene mulch; SM- grass straw mulch; T_1- irrigation at 6-day interval + NM; T_2- irrigation at 6-day interval + PM; T_3- irrigation at 6-day interval + SM; T_4- irrigation at 3-day interval + NM; T_5- irrigation at 3-day interval + PM; and T_6- irrigation at 3-day interval + SM.
All mean values, followed by different letters, relate to the same parameter and are statistically different at the 5% level using the LSD test. ns= Non-significant; * = 5% Level of significance; **= 1% Level of significance; *** (0.1% level of significance)

Water application and water use efficiency

Significant differences were caused by the application of variations in irrigation regime, crop water use and water use efficiency as influenced by raised bed furrow irrigation and different mulches (Table 3). When irrigation was applied by the 6- and 3-day intervals, the plants in the non-mulched plots consumed more water (935 mm), compared to those in the mulched plots (535 mm) in the growing season. The values of crop water use were 416 mm and 866 mm in response to the 6- and 3-day intervals, respectively.

Table 2. Fruit count and unit average weight, according to the time of fruit harvest after transplanting, as influenced by different levels of furrow irrigation and mulches

Factors/Treatments	Fruit count and unit weight at harvest age weeks after transplanting (WAT)					
	16 WAT		18WAT		20WAT	
	Fruits (number)	Unit fruit weight (g)	Fruits (number)	Unit fruit weight (g)	Fruits (number)	Unit fruit weight (g)
Furrow Irrigation						
I_1	332.89b	74.19b	281.33b	48.73b	69.11a	38.62a
I_2	354.11a	76.23a	324.89a	52.99a	57.22b	36.07b
CV (%)	0.695	0.979	0.794	0.503	1.939	1.705
LSD	2.51***	0.77***	2.53***	0.26***	1.29***	0.67***
Mulches						
NM	348.83a	70.94c	296.33b	48.20c	59.33c	35.89b
PM	335.67b	79.83a	330.00a	52.44a	64.00b	38.31a
SM	346.00a	74.86b	283.00c	51.93b	66.17a	37.84a
CV (%)	0.695	0.979	0.794	0.503	1.939	1.705
LSD	3.071***	0.95***	3.10***	0.33***	1.58***	0.82***
Interaction of irrigation and mulches						
T_1	363b	70.63c	251f	47.12d	68b	36.64b
T_2	296f	80.08a	340b	50.01b	68b	39.53a
T_3	339d	71.85c	253e	49.06c	71a	39.70a
T_4	334e	71.25c	342a	49.29c	51d	35.14c
T_5	375a	79.57a	320c	54.88a	60c	37.09b
T_6	353c	77.87b	313d	54.80	61c	35.98bc
CV%	0.70	0.98	0.79	0.51	1.94	1.71
LSD	4.34***	0.95***	4.38***	0.47***	2.23***	1.16***

Abbreviations: I1- 6-day interval; I2- 3-day interval; NM- no mulch; PM- black polyethylene mulch; SM- grass straw mulch; T_1- irrigation at 6-day interval + NM; T_2- irrigation at 6-day interval + PM; T_3- irrigation at 6-day interval + SM; T_4- irrigation at 3-day interval + NM; T_5- irrigation at 3-day interval + PM; and T_6- irrigation at 3-day interval + SM.
All mean values followed by different letters are statistically different at the 0.1% level using the LSD. *** (0.1% level of significance)

In plants of the NM group, the water consumption was 866 mm in response to the 3-day irrigation regime. Nonetheless, the values were significantly higher, i.e. 680 mm and 726 mm, in the treatment groups of PM and SM, respectively.
In using both levels of irrigation, the polyethylene mulch required less irrigation than the straw mulch and non-mulched groups. In response to the 6-day and 3-day irrigation intervals, the highest water use efficiencies were 261 kg/ha-mm and 150 kg/ha-mm, respectively, in plants of the black polyethylene mulch group. Among the mulches, the maximum water use efficiency was measured in plants of the black polythene mulch (205.50 kg/ha-mm), followed by those of the grass straw (188.50 kg/ha-mm), whereas the lowest WUE was recorded in the non-mulched group (141.00 kg/ha-mm).

Discussion

Tomato yields increased parallel to the increase in the water supply. This observation was true in both mulch and non-mulch cultivations. The higher yield from mulching treatments could be due to one of the beneficial effects on weed control. Weeds were completely eradicated as a result of black polyethylene mulch, whereas the weeds in non-mulch plots had to be removed manually, 15 days after the beginning of the field trial. A similar study on complete weed eradication was conducted earlier, using black polyethylene (Chakraborty et al., 1994; Singh, 2005). In the current research, a higher fruit yield was observed when black polyethylene mulch was used, which can be attributed to an increase in tomato yield because of a better WUE, a greater nutrient uptake and an optimal soil-water-plant relationship, thereby confirming previous results by Ashworth and Harrison (1983), Chakraborty et al. (1994) and Singh (2005). On the other hand, black plastic mulch had an intensive short-wave permeability and high short-wave absorption

(Heibner et al., 2005), while having the capability of lowering the soil temperature by preventing sunlight from reaching the soil surface (Bonanno, 1996). Irrigating with a constant amount of water, without mulch, resulted in the lowest yield. Mulching had a greater impact on tomato yield, compared to the effect of raised bed furrow irrigation without mulch. Many researchers have reported promising results on how vegetable crops respond to mulch in terms of growth and yield (Asiegbu, 1991; Shrivastava et al., 1994; Tiwari et al., 1998).

Table 3. Irrigation events, water application, crop water use and water use efficiency (WUE) for tomato cultivation as influenced by different irrigation and mulching practices

Factors/Treatments	Irrigation events (number)	Water applied (mm)	Crop water use (mm)	Water use efficiency (WUE) (kg/ha-mm)
Furrow Irrigation				
I_1	15	477b	378.33b	233.00a
I_2	28	819a	757.33a	123.67b
CV (%)	-	1.031	1.268	3.025
LSD	-	7.02***	7.56***	5.67***
Mulches				
NM	-	735a	641a	141.00c
PM	-	579c	507.50c	205.50a
SM	-	630b	555.00b	188.50b
CV (%)	-	1.031	1.268	3.025
LSD	-	8.60***	9.26***	6.94***
Interaction of irrigation and mulches				
T_1		535d	416d	187c
T_2	15	420f	335f	261a
T_3		476e	384e	251b
T_4		935a	866a	95f
T_5	28	738c	680c	150d
T_6		784b	726b	126e
CV%	-	1.04	1.27	3.02
LSD	-	12.20***	13.12***	9.80**

Abbreviations: I_1- 6-day interval; I_2- 3-day interval; NM- no mulch; PM- black polyethylene mulch; SM- grass straw mulch; T_1- irrigation at 6-day interval + NM; T_2- irrigation at 6-day interval + PM; T_3- irrigation at 6-day interval + SM; T_4- irrigation at 3-day interval + NM; T_5- irrigation at 3-day interval + PM; and T_6- irrigation at 3-day interval + SM.
All mean values followed by different letters are statistically different at the 1.0% level using the LSD. ** (1% level of significance), *** (0.1% level of significance)

PM had the same performance in association with any level of irrigation, whereas SM performed significantly better when the irrigation requirement was met by the raised bed furrow system with the 6-day interval regime. The loss of water from the soil surface through evaporation was much lower in PM than in SM. It created poor ventilation with a high humidity under the PM, which is sometimes not optimal for achieving higher yields.

A higher number of fruits and a larger unit weight were measured with the 6-day irrigation interval for 16 and 18 weeks after transplanting, but they reached a higher level after 20 weeks in the 3-day interval. A higher unit weight was observed in response to the effects of black polyethylene mulch (PM). Tomato cultivation without mulch showed a lower average weight than polyethylene and grass straw mulch throughout the harvest period. The dryness of the soil, as represented by

suction levels, led to a decrease in fruit unit weight, thereby confirming a previous research by Ramalan and Nwokeocha (2000).
Significant differences occurred as a result of variations in water application, crop water use and water use efficiency when the tomatoes were grown in raised bed furrow irrigation with various mulches. The water consumption varied in the plants per treatment group, notably in response to the different mulches which reduced evaporation from the soil surface (Tindall et al., 1991). The water use efficiency (WUE) in tomatoes was significantly affected by the raised bed furrow irrigation in non-mulched and mulched conditions. A higher water use efficiency was recorded with the black polyethylene mulch, compared to the condition without mulch, which suggested that the polyethylene mulch considerably improved the water use efficiency of tomatoes (Berihun, 2011). This finding was similar to those on water use efficiency, reported by Biswas et al. (2015), that all mulch and non-mulch treatments work similarly for WUE. The use of black polyethylene mulch resulted in a higher WUE than the condition of using organic mulch. This was probably due to an efficient weed control, along with the efficient use of water and nutrients by the plants (Mukherjee et al., 2012). The highest level of WUE occurred in response to the lowest irrigation level, which indicated a comparatively more efficient use of irrigation water by the plants (Dunage et al., 2009).

Conclusion

From the present study and other similar works in the literature, it is understood that the marketable yield and water use efficiency of tomatoes can be significantly affected by irrigation levels and mulching. Non-mulched plots displayed a higher water consumption by the plants, compared to the mulched ones, due to greater evaporation loss. The results conclusively indicated that the 3-day irrigation interval was more effective in increasing the yields and the WUE, compared to the 6-day irrigation interval. The raised bed furrow irrigation method with the two-row cultivation pattern was superior to the conventional furrow irrigation method. The interactions between the raised bed furrow irrigation method and the two-row cultivation system, along with different mulches and irrigation regimes, had a significant impact on the water use efficiency (WUE) of tomato plants. In order to achieve the highest tomato yield in Bangladesh, our farmers are therefore advised to use the raised bed furrow irrigation technique, with black polyethylene mulch, and an irrigation schedule that leaves a 3-day interval from one irrigation session to the next.

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Conflict of interest

The authors stated no conflict of interest in this research.

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