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Effects of Irrigation and Application of Phosphorus Fertilizer on the Yield and Water Use of Tomato Grown on a Clay Terrace Soil of Bangladesh

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A field experiment was conducted in the rabi (dry) season of 1998–99 on a clay terrace soil of Bangladesh to study the effects of irrigation and P fertilization on the yield, total water use, and water use efficiency of tomato. Five levels of irrigation and four levels of P application were involved. Irrigation, P application, and the interaction of irrigation and P application had a significant impact on the yield of tomato. In the individual effects of irrigation and P application, the yield was significantly high in the three and four irrigations and at the P level of 120 kg P_2O_5 ha^{-1}. As the interaction effect, the highest yield of 38.7 Mg ha^{-1} with the maximum net benefit was obtained under the combination of three irrigations at 15, 35, and 55 days after transplantation of seedlings and P application at the level of 120 kg P_2O_5 ha^{-1}. Its total water use was 169 mm, giving the reasonably high water use efficiency of 229 kg ha^{-1} mm^{-1}. The highest range of water use efficiency was noted in non-irrigation treatments, but the yield and net benefit were about half of those of the highest yield. The treatment with three irrigations along with P application at the level of 120 kg P_2O_5 ha^{-1} was concluded to be the best combination for the sustainable tomato cultivation in Shallow Red–Brown Terrace Soil of Bangladesh.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is a popular vegetable crop in Bangladesh. Its cultivation in 1996–97 was 12,600 ha of land of the country, producing approximately 93,000 Mg of fruits (Bangladesh Bureau of Statistics, 1997). An average yield of 7.4 Mg ha^{-1} is, however, poor compared to other tropical countries (FAO, 1988). This poor yield is due to the use of low–yielding varieties, improper cultural practices including insufficient supply of nutrients and water, and poor disease control (Ali *et al.*, 1994).

Tomato is grown in the rabi (dry) season (November through March) in Bangladesh, when lack of water becomes a serious constraint to crop production. Around 80 to 90% of the annual rainfall occurs during the premonsoon and rainy season (April through October), leaving less than 10% for the rabi season. Rainfall in the rabi season is so variable and unpredictable that cultivation of crops becomes risky under the rainfed condition (Karim and Egashira, 1994). Irrigation becomes indispensable for successful

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cultivation of rabi crops but the facility is limited. Therefore, it is important to estimate the water requirement of crops to avoid over– and under–irrigation for them.

Tomato has been reported to be sensitive to water (Bose and Som, 1986). Both over–watering and insufficient irrigation are detrimental to its growth. It was found in Italy that relatively high soil moisture regime (75 to 100% of evapotranspiration (ET)) gave the best yield of tomato but both excess and minimum moisture regimes, 125% and 50% of ET, respectively, led to the reduction in yield (Hamdi, 1992).

Like other fruit crops, tomato is responsive to P application, and the optimum dose depends largely on soil types, growing conditions, and environmental factors. A balanced fertilization of P and other fertilizers together with judicious application of irrigation water may result in the substantial yield increase of tomato.

Information on the interaction effect of irrigation and application of P fertilizer on the cultivation of tomato is lacking in Bangladesh. It is evident that a good interaction of these two inputs leads to higher yield of tomato. The present study was undertaken to determine the water and P requirements of tomato for achieving the maximum yield potential on a clay terrace soil of Madhupur Tract, Bangladesh.

MATERIALS AND METHODS

Location and soil

The experiment was conducted at the experimental farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh, during December 1998 to April 1999. It is located at the center of Madhupur Tract (24° 05' N latitude and 90° 16' E longitude) at an elevation of 8.4 m above MSL and is 40 km north of Dhaka, the capital.

The soil belongs to Salna series of Shallow Red–Brown Terrace Soil (Brammer, 1971; Saheed, 1984) and is equivalent to Ochrepts in Soil Taxonomy. The soil is silty clay loam in texture having the mean bulk density of 1.47 g cm^{-3} up to a depth of 30 cm from the surface. Porosity of the soil varied between 59% at the surface (0–10 cm) and 35% at the subsurface (20–30 cm). Hydraulic conductivity is 10^{-3} to 10^{-4} cm s^{-1} at the surface and 10^{-6} to 10^{-7} cm s^{-1} at the subsurface layers, indicating the impeded internal drainage condition of the soil. The pH of the soil up to the depth of 20 cm was 6.2 and the contents of organic C and total N were 9.5 and 0.76 g kg^{-1}, respectively. The amounts of available P by the Olsen method and of exchangeable K were 12 mg kg^{-1} and 0.34 $cmol_c$ kg^{-1}, respectively.

Climate

The climate of Bangladesh is dominated by the tropical and subtropical monsoons with scanty rainfall during the rabi season. The mean annual rainfall of Madhupur Tract is about 2200 mm which is higher than the annual potential ET (PET) of about 1700 mm, but PET always exceeds rainfall in the rabi season. No rainfall occurred during the cropping period of tomato at the studied area in the 1998–99 rabi season. The mean monthly air temperature for the months of December, January, February, March, and April was 22.9, 18.9, 22.4, 24.7, and 30.0 °C, respectively, and optimum for tomato cultivation.

Experimental design and treatments

The experiment was laid out in the split-plot design with three replications. Two factors of irrigation and P fertilization were involved in the experiment. Irrigation was arranged in main plots and P fertilization was distributed to subplots.

Five levels of irrigation were as follows:

I_0 : no irrigation after seedling establishment;
I_1 : one irrigation at 15 days after transplantation (DAT) of seedlings;
I_2 : two irrigations at 15 and 35 DAT of seedlings;
I_3 : three irrigations at 15, 35, and 55 DAT of seedlings;
I_4 : four irrigations at 15, 30, 45, and 60 DAT of seedlings.

Measured amounts of irrigation water were applied to bring the soil moisture to field capacity up to the rooting depth (Giriappa, 1988). This was done to avoid deep percolation loss of irrigation water.

Four levels of P application were as follows:

P_0 : no application of P;
P_1, P_2, and P_3: application of P at the rates of 90, 120, and 150 kg P_2O_5 ha^{-1}, respectively.

Triple super phosphate (TSP) was applied as the source of P fertilizer.

The dimension of unit plot was 2.4 m×3.0 m having plot-to-plot and block-to-block spacings of 1.0 m and 1.5 m, respectively. A shallow drain was made around each plot for removal of rain water. A dike was made around the plot for restricting the lateral flow of irrigation water away from the plot. Urea and muriate of potash (MP) were applied to each plot to supply 90 kg N and 100 kg K_2O per ha, respectively. The total amounts of TSP and MP along with half of urea were applied to the individual plots just after the final land preparation and construction of the plot. The remaining urea was top-dressed just before the flowering stage of tomato.

Test crop, transplantation, and cultural operations

The tomato variety used in the experiment was "Roma VF" of the determinate type. The fruits are oblong-shaped and medium- to small-sized. Forty-five-day healthy tomato seedlings were transplanted on December 15, 1998 by maintaining row-to-row and plant-to-plant spacings of 60 and 40 cm, respectively. There were five rows in a plot, having six plants in each row. Each plot was irrigated uniformly by a calibrated watering can every alternate day for 13 days after transplanting to ensure proper establishment of seedlings. The total amount of added water was 59.0 mm. The dead or ill-healthed seedlings were replaced by healthier ones. A supporting bamboo stick was placed beside each plant and tied loosely with a jute-string to keep it straight. Weeding and soil loosening were done when necessary.

Harvest of tomato

The harvest of tomato started from March 1, 1999 and continued for 55 days till April 24. Ten tomato plants were selected randomly from the middle three rows of each plot and labeled to record the data on yield and yield-components. The plants at the two ends of each of the three rows were also omitted. This was done to avoid the border effect of a plot. The plants were supervised every day to find the ripened fruit for harvest. The fruits which have turned to yellowish–red were harvested and kept beside the specific plant. The individual weight of each harvested fruit and the total number of the fruits of the specific plant were recorded. The cumulative weight of fruits of ten labeled plants throughout the season was used to determine the yield of tomato.

Soil moisture monitoring

Soil moisture was monitored gravimetrically at one out of three plots for the respective treatments once a week at three different depths (0–10, 10–20, and 20–30 cm) from transplanting to harvest of tomato. The data were used for computing irrigation requirement of the crop and soil water depletion.

Irrigation requirement (IR) was calculated as follows:

$$IR = \{(M_{FC} - M_{PI})/100\} \times A \times D$$

where M_{FC} is soil moisture at field capacity (% by weight), M_{PI} is soil moisture prior to irrigation (% by weight), A is bulk density of soil (g cm^{-3}), D is the rooting depth (cm; maximum depth of 30 cm was considered as such).

Soil moisture depleted (S) was calculated as follows:

$$S = \{(M_T - M_H)/100\} \times A \times D$$

where M_T is soil moisture at transplanting (% by weight), M_H is soil moisture at harvest (% by weight), and A and D are the same as those in the above equation.

Total water use and water use efficiency

Total water use (TWU) was determined using the water balance equation given by Rose (1966) by assuming the drainage component as zero. The TWU is the summation of measured quantities of irrigation water, seasonal rainfall, and profile water contribution. This is expressed as follows :

$$TWU = IR + ER + S$$

where IR is irrigation requirement (mm), ER is seasonal effective rainfall (mm), and S is soil water depleted (mm). Under the prescribed condition, TWU can be regarded to be nearly equal to ET. Water use efficiency (WUE) was calculated by dividing the yield by TWU.

Statistical analysis

Duncan's multiple range test was applied to the statistical analyses of yield and yield–components data of tomato.

RESULTS AND DISCUSSION

Yield–components of tomato

Number of fruits per plant and individual fruit weight were considered as the yield–components of tomato and are shown in Table 1. The effect of irrigation on both yield–components was significant. The highest number of fruits per plant and individual fruit weight were recorded under the highest frequency of irrigation in I_4. The values of

Table 1. Effects of irrigation and phosphorus application on the yield–components and yield of tomato.

Treatment	Number of fruits per plant	Individual fruit weight (g)	Yield (Mg ha^{-1})
Irrigation			
I_0	33.6 c	23.9 e	19.0 c
I_1	37.0 b	27.1 d	22.6 b
I_2	39.0 ab	28.3 c	24.9 b
I_3	40.2 a	36.2 b	33.1 a
I_4	40.5 a	37.4 a	34.0 a
P application			
P_0	37.2	26.0 d	20.9 d
P_1	38.0	31.3 c	27.2 c
P_2	38.5	33.1 a	30.3 a
P_3	38.8	31.9 b	28.5 b
Irrigation×P application			
I_0P_0	32.1 c	19.8 o	19.5 fgh
I_0P_1	32.9 bc	22.0 n	16.2 h
I_0P_2	36.3 abc	27.0 jk	20.7 efg
I_0P_3	33.0 bc	26.7 k	19.6 fgh
I_1P_0	36.9 abc	23.3 m	18.0 gh
I_1P_1	36.2 abc	28.5 i	24.5 def
I_1P_2	36.5 abc	28.9 i	24.8 def
I_1P_3	38.6 abc	27.7 j	23.4 def
I_2P_0	39.4 abc	24.7 l	18.2 gh
I_2P_1	38.9 abc	29.0 hi	25.8 def
I_2P_2	39.7 abc	30.0 fg	28.6 bcd
I_2P_3	38.0 abc	29.6 gh	27.1 cde
I_3P_0	39.7 abc	30.7 f	24.2 def
I_3P_1	39.3 abc	39.0 b	35.1 ab
I_3P_2	40.5 ab	39.2 b	38.7 a
I_3P_3	42.4 a	36.0 d	34.3 abc
I_4P_0	40.1 abc	31.5 e	24.6 def
I_4P_1	39.6 abc	38.2 c	34.5 abc
I_4P_2	40.6 ab	40.1 a	38.5 a
I_4P_3	41.9 a	39.6 ab	38.4 a

Treatments having a common letter in a column are not significantly different at 5% level.
A column having figures without letters means no significant difference between treatments.

individual components decreased significantly with decreasing the level of irrigation and came down to the minimum under the non–irrigation condition after seedling establishment in I_0. It was found that water stress created adverse effects on the yield–components of tomato and that the effect was more distinct for individual fruit weight than for number of fruits per plant.

Phosphorus application had a significant impact on the individual fruit weight of tomato (Table 1). It was highest under P application at the level of 120 kg P_2O_5 ha^{-1} in P_2 and significantly decreased with decreasing or increasing the level of P. Phosphorus application could not create any significant impact on the number of fruits per plant.

The interaction effect of irrigation and P application was significant on both the number of fruits per plant and individual fruit weight (Table 1). However, the highest value of the number of fruits per plant noted in I_3P_3 was statistically similar to those in other treatments except for the three treatments of I_0P_3, I_0P_1, and I_0P_0 under the non-irrigation condition. This result reveals that P application and maintenance of optimum soil moisture are not the key factors for the significant increment in the number of fruits in tomato, which may be more strongly dependent on the duration of harvest time or the physiological nature of the tomato variety. On the other hand, the individual fruit weight increased significantly with the increment of both factors. The highest fruit weight was recorded under the highest level of irrigation along with the P application at the level of 120 kg P_2O_5 ha^{-1} in I_4P_2. It is evident from the findings that both irrigation and P application have favored to make the plants capable of producing larger fruits, through proper extraction of nutrients from soil probably due to accelerating the root growth. The individual fruit weight was found to control mainly the yield of tomato.

Yield and water use of tomato

Irrigation and P application individually created a significant impact on the yield of tomato (Table 1). The highest yield of 34.0 Mg ha^{-1} was recorded under four irrigations in I_4, which was statistically similar to the yield of 33.1 Mg ha^{-1} under three irrigations in I_3. The initial common watering of 59.0 mm enabled the plants to survive in the non-irrigation condition and to produce an yield of 19.0 Mg ha^{-1}. The yields in I_1, I_2, I_3, and I_4 were higher by 19, 31, 74, and 79%, respectively, than the yield in I_0, thus revealing that irrigation is indispensable and higher frequency of irrigation is required for obtaining the higher yield of tomato in the clay terrace soil of Bangladesh. Due to the significant difference in the yield between I_2 and I_3, irrigation frequency up to 3 irrigations after seedling establishment is necessary for obtaining the satisfactory high yield of tomato, beyond which the yield increase may not be proportional to the supply of irrigation water.

Concerning the P application (Table 1), the highest yield of 30.3 Mg ha^{-1} was recorded at the level of 120 kg P_2O_5 ha^{-1} in P_2, and above and below that level the yield decreased significantly. The yields in P_1, P_2, and P_3 were higher by 30, 45, and 37%, respectively, than the yield in P_0. Phosphorus application up to the level of 120 kg P_2O_5 ha^{-1} is indispensable to get the satisfactory high yield of tomato in the clay terrace soil of Bangladesh. Comparatively low yield of tomato under the P level of 150 kg P_2O_5 ha^{-1} may be due to P toxicity in tomato (Jones, 1998), although Faria *et al.* (1999) harvested 56.5 and 69.4 Mg ha^{-1} of tomato in northeastern Brazil by applying P at the levels of 143 and 182 kg P_2O_5 ha^{-1}, respectively.

The interaction effect of irrigation and P application on the yield of tomato was significant (Table 1). Both of these two costly inputs combinedly favored increase in the yield. The highest yield of 38.7 Mg ha^{-1} was recorded in I_3P_2 which was followed by I_4P_2 (38.5 Mg ha^{-1}), I_4P_3 (38.4 Mg ha^{-1}), I_3P_1 (35.1 Mg ha^{-1}), I_4P_1 (34.5 Mg ha^{-1}), and I_3P_3 (34.3 Mg ha^{-1}). There was no significant difference in the yield among these treatments, suggesting a major influence of irrigation on the yield of tomato.

The TWU for the treatments of I_3P_2, I_4P_2, I_4P_3, I_3P_1, I_4P_1, and I_3P_3 was 169.1, 194.7, 200.5, 177.1, 203.3, and 168.0 mm with the WUE of 229, 198, 192, 198, 170, and 204 kg ha^{-1} mm^{-1}, respectively (Table 2). In I_3P_2, the TWU was considerably lower than that of the other treatments except for I_3P_3. This has led to attaining the highest WUE of 229 kg ha^{-1} mm^{-1} in I_3P_2 among the treatments giving the highest and statistically similar yield.

Table 2. Soil water depleted, irrigation water, total water use, and water use efficiency under different levels of irrigation and phosphorus application.

Treatment	Soil water depleted (mm)	Irrigation water (mm)	TWU (mm)	WUE (kg ha^{-1} mm^{-1})
I_0 P_0	12.2	59.0	71.2	274
P_1	16.9	59.0	75.9	213
P_2	15.3	59.0	74.3	279
P_3	13.3	59.0	72.3	271
I_1 P_0	16.5	115.4	131.9	136
P_1	14.4	115.4	129.8	189
P_2	18.6	115.4	134.0	185
P_3	17.1	115.4	132.5	177
I_2 P_0	3.3	129.7	133.0	137
P_1	6.2	130.2	136.4	189
P_2	17.2	131.8	149.0	192
P_3	12.6	128.5	141.1	192
I_3 P_0	5.3	160.5	165.8	146
P_1	6.5	170.6	177.1	198
P_2	4.0	165.1	169.1	229
P_3	7.0	161.0	168.0	204
I_4 P_0	−0.5	191.7	191.2	129
P_1	−3.6	206.9	203.3	170
P_2	−4.2	198.9	194.7	198
P_3	1.2	199.3	200.5	192

Initial common watering (59.0 mm) which is included in irrigation water was considered for computing TWU.

In each irrigation level, WUEs of P_1, P_2, and P_3 were remarkably higher than that of P_0, indicating the effect of P application on the increment of WUE under the irrigated condition. The level of P application which gives the highest WUE depended on the irrigation level, and the WUE was highest for P_1 in the I_1 treatment while for P_3 in I_3 and I_4 treatments. Under the specified level of P, the WUE was always greater for I_3 treatment than for I_1, I_2, and I_4 treatments. Appropriateness of three irrigations after seedling establishment and of P application at the level of 120 kg P_2O_5 ha^{-1} in the three irrigations was evaluated from WUE. Over–application was suggested for four irrigations and the P level of 150 kg P_2O_5 ha^{-1}.

The highest WUE of around 275 kg ha^{-1} mm^{-1} was recorded under the non–irrigation condition of I_0P_0, I_0P_2, and I_0P_3, but the yield was in the unacceptably low range of 19.5 to 20.7 Mg ha^{-1}. Selection of an appropriate combination of the treatments should not merely depend on the higher values of yield per unit use of the inputs. Acceptable yield of the crop for getting the maximum return of the inputs should also be considered. From the viewpoint of crop yield and its water use, the treatment with three irrigations coupled with P application at the level of 120 kg P_2O_5 ha^{-1} may be judged to be superior for achieving the highest yield of tomato in Shallow Red–Brown Terrace Soil of Madhupur Tract.

Table 3. Partial budget analysis for different levels of irrigation and phosphorus application in tomato cultivation.

Treatment	Gross return (Tk. ha^{-1})	Variable cost (Tk. ha^{-1})	Net benefit (Tk. ha^{-1})
I_0 P_0	146,325	2,919	143,406
P_1	121,725	5,734	115,991
P_2	155,325	6,670	148,655
P_3	146,700	7,607	139,093
I_1 P_0	135,000	2,924	132,076
P_1	183,525	5,736	177,789
P_2	185,625	6,675	178,950
P_3	175,200	7,652	167,548
I_2 P_0	136,650	2,924	133,726
P_1	193,275	5,739	187,536
P_2	214,800	6,682	208,118
P_3	203,250	7,616	195,634
I_3 P_0	181,650	2,940	178,710
P_1	263,250	5,758	257,492
P_2	290,025	6,692	283,333
P_3	257,325	7,629	249,696
I_4 P_0	184,425	2,952	181,473
P_1	258,525	5,771	252,754
P_2	288,750	6,711	282,039
P_3	287,625	7,642	279,983

Rates used: tomato, Tk. 7.50 kg^{-1}; urea, Tk. 8.00 kg^{-1}; triple super phosphate, Tk. 15.00 kg^{-1}; muriate of potash, Tk. 14.00 kg^{-1}; irrigation, Tk. 40 h^{-1} (discharge = 10 L s^{-1}).

Economic aspect

Partial budget analysis on the yield of tomato was done to evaluate the economic acceptability of the treatment by the farmers (Table 3). Maximum net benefit of Tk. 283,333 ha^{-1} was obtained in I_3P_2 which was followed by Tk. 282,039 ha^{-1} in I_4P_2 and Tk. 279,983 ha^{-1} in I_4P_3. Although the non-irrigation treatment with or without P application achieved the maximum WUE, the net benefit values were as low as 50% of those noted under the higher levels of irrigation and P application, due to their poor yield. The treatment of three irrigations together with application of 120 kg P_2O_5 ha^{-1} was supported as the most economically acceptable combination of irrigation and P levels from calculation of the net benefit.

CONCLUSIONS

The highest and the most economically acceptable yield of tomato of about 39 Mg ha^{-1} was obtained by the treatment of three irrigations after seedling establishment and P application at the level of 120 kg P_2O_5 ha^{-1}, on the clay terrace soil of Bangladesh in the 1998–99 rabi (dry) season where no rainfall occurred during the cropping period. Total water use of this treatment was 169 mm and the water use efficiency was 229 kg ha^{-1} mm^{-1}.

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