PLANT SPACING AND MULCHING TOGETHER AFFECT THE PHENOLOGY AND YIELD OF TOMATO CROP

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ABSTRACT

Field trials were carried out in the farm of the University of Agriculture, Peshawar Pakistan in the years 2012 and 2013 in order to investigate the effect of line spacings, mulching materials, and herbicides on phenology of the tomato crop. The design of the experiments was RCBD, with split-plot arrangement. Three various line spacings viz. 40, 60, and 80 cm between the adjacent tomato lines were maintained in main plots; whereas the mulches and herbicides were arranged in the sub-plots. The mulches of polyethylene (white), polyethylene (black), wheat straw at the rate of 1.0 kg, saw dust (1.0 kg), paper mulch at the rate of 0.5 kg m^{-2}, and the herbicides of Puma super 7.5 EW (fenoxaprop-p-ethyl) @ 2 kg, Dual Gold 960 EC (s-metolachlor) @ 1.5 kg, and Stomp 330 EC (pendimethalin) @1.44 kg a.i ha^{-1}, a hand weeding (weed free) and a weedy check (control) treatments were used. The data recording parameters were fresh weed biomass (kg ha^{-1}), days to flowering, and fruiting, leaf area (LA), leaf area index (LAI), and yield of tomato fruit (t ha^{-1}). All the treatments significantly affected the studied parameters. The line spacing of 40 cm among the tomato lines had the lowest weed biomass and that of 80 cm spacing had the highest weed biomass. The number of days to first flowering and first fruiting was declined in 40 cm line spacing and enhanced in 80 cm line spacing plots. The leaf area and leaf area index were the uppermost in 40 cm line spacing and lower most in 80 cm spacing. Finally, the highest total fruit yields were 12.12 and 15.15 t ha^{-1} during 2012 and 2013, respectively in 60 cm line spacing. Among the subplot treatments, the control plots showed maximum weed biomass while minimum in the weed free plots. However, number of days to flowering and fruiting were highest in hand weeded treatments followed by pendimethalin and polyethylene-white plots which were statistically at par in both the years. Similarly, the LA, LAI and total fruit yield of tomato were best in the plots of hand weeding in comparison with the lowest values in weedy check plots. In conclusion, line spacing of 60 cm, the application of pendimethalin herbicide as pre-emergence, once manual weeding, and black plastic mulch proved to be the best integrated weed management strategy for enhancing the phenology of tomato crop.

Keywords: Herbicides, mulches, row spacing, tomato, weed biomass

INTRODUCTION

Tomato ranks second after potato crop in global vegetable crops production and is a key source of antioxidants and minerals like carotenoids, lycopene, vitamin C and E, along with some phenolic compounds (Adalid *et al*., 2004). It helps in preventing some of cardiovascular and cancer diseases (Frusciante *et al*., 2007). Tomato cultivation in Pakistan is done on a very large scale. Tomato was grown on an area of 0.0574 million ha with a total production of 0.5779 million tons in Pakistan, with the average yield of 10.1 tons ha^{-1} (Anonymous, 2013). The yields of tomato in the country are quite lower than the advanced countries which are mainly due to the weed menace. Weeds reduce crop yield, quality, value and increases cost of production. They do weaken the tomato crop stand and reduce the harvest efficiency. Moreover, weeds function as the alternate hosts for other crop pests. During the first 40-50 days after sowing weeds removal is must, as the weeds presence during this period decline tomato yield by 70% (Garvey *et al*., 2013; Portugal *et al*., 2015; Chaudhary *et al*., 2016); however the impact depends on the stage and duration of weed competition.

Herbicide use is one of the most common weed control method. The germinating seeds of weeds are easily killed by spraying the pre-emergence herbicides; though the herbicide use needs specific equipment and experience to properly apply at recommended rates with special measures to protect human health. As the herbicide use is discouraged worldwide there is a dire need for alternate methods of weed control which must be environment friendly and good substitute for the herbicides application. Mulching is one of such methods which prevents soil erosion, adds organic matter, retains soil moisture and gives weed suppression. Thus, mulches could be a better practice to replace herbicides application or the two methods can be integrated for achieving profitable results. Another alternate technique is the manipulation of the plant population (row-spacing). Increasing row spacing results in decline of the seed rates or of the plant population of the crop, and vice-versa. Thus, row spacing influences the branching ability of the crop and other parameters like flowering and fruiting of the crop plants (Bakht and Khan, 2014). It is therefore very necessary to assess the collective effect of various mulching materials and row spaces in order to generate an effective and eco-friendly strategy for weed management.

The present study was therefore planned aimed at evaluating the effect of varying mulching materials, different herbicides and row spacing on phenology of tomato crop plants under weed competition regimes.

MATERIALS AND METHODS

Study area and agronomic practices: Field experiments were carried out in the University of Agriculture Peshawar, Pakistan during 2012 and 2013 to find out the effect of varying spaces among tomato lines, different mulching materials, and herbicidal treatments on phenology of tomato plants. The experiments were laid out in Randomized Complete Block (RCB) design during both the years with split plot arrangement keeping three replications with the treatments re-randomized in the second experiment. Line spacings were kept in main plots and the mulching materials and herbicides in the sub-plots. Tomato seedlings were transplanted 40 days after germination in both the experiments followed by immediate irrigation. Mulching materials were applied three days after the irrigation. Tomato seedlings were planted with the constant plant-to-plant distance of 10 cm uniformly on the ridges.

Treatments: The treatments included line spacings of 40, 60, and 80 cm distributed in the main plots, whereas the mulch treatments of polyethylene (white), polyethylene (black), wheat straw at the rate of 1 kg m^{-2}, saw dust at rate of 1 kg m^{-2}, paper mulch treatment at rate of 0.5 kg m^{-2}), herbicides of Puma super 7.5 EW @ 2 kg a.i., Dual gold 960 EC @ 1.5 kg a.i., and Stomp 330 EC @ 1.44 kg a.i. ha^{-1}, along with a weed free treatment (hand weeding) and a control (weedy check) in subplots. The data were documented on weed fresh biomass (kg ha^{-1}), no. of days to flowering and fruiting, LA (cm^2), LAI and total fruit yield of tomato (t ha^{-1}).

The data recorded for each parameter were individually analyzed for the ANOVA (ANOVA Table given below) using Statistix 8.1 computer software and MS-Excel 2007. The design used was Split Plot design with the row spacings (Factor A) having three levels were kept in the main plots and 10 different weed control treatments (Factor B) were placed in the subplots. The means were separated through Fisher's protected LSD test (Steel *et al*., 1997).

ANOVA Table for split plot design.

Sources of Variation	Degrees of Freedom
Replication	r-1
Row spacing (Factor A)	a-1
Error-I	(r-1) (a-1)
Weed control treatments (Factor B)	b-1
A x B	(a-1) (b-1)
Error-II	a (r-1) (b-1)
Total	rab-1

RESULTS AND DISCUSSION

Fresh weed biomass (kg ha^{-1}): The year effect was significant on the fresh weed biomass which could be due to the variations in the weather conditions. The line spacing and the varying mulch and herbicide treatments and the interaction of these treatments all had significant effect on weed fresh biomass in both the years. The fresh weed biomass (1219 kg ha^{-1}) recorded in the 80 cm row spacing plots was the highest, followed by the biomass of 929 kg ha^{-1} in the row spacing of 60 cm and the lowest value was 658 kg ha^{-1} observed in plots of 40 cm row spacing. In 2013, the respective values for row spacing of 80, 60 and 40 cm were 1524, 1161 and 522 kg ha^{-1}, respectively.

The higher competition did not permit the flow of resources towards the weeds in the narrow row spacing. Samedani *et al*. (2006) mentioned that weeds in narrow spacing are a bit suppressed in comparison with the wide row spacing. The biomass of weeds in a crop field corresponds to the respective decline in biomass of crop (Rao, 2000; Barker and Bhowmik, 2001). Hand weeding treatment had the least weed biomass of 510.0 kg and 638.0 kg ha^{-1}; while highest weeds biomass of 1603 and 2004 kg ha^{-1} were recorded in control plots in 2013 and 2014, respectively. Bakht *et al*. (2014) reported significant effect of mulches and herbicides on weed biomass. Masiums *et al.* (2003) had reported similar interaction effects as achieved in this research.

Days to first flowering: The influence of the row spacing and the weed control treatments was significant on the phonological parameter of days to first flowering of tomato plants in the two years study. Similarly, the year effect was also significant statistically. In 2012, the 40 cm row spacing took a minimum of 36.48 days to flowering, which was closely followed by the 60 cm (38.74) and 80 cm (40.21 days to first flowering).

In narrow row spacing, the intra-specific and inter-specific competition is always greater which result into stressful environment and thus the flowering stage is affected (Sanchez *et al*., 2008; Rahman *et al.,* 2012; Amare *et al*., 2015). The treatments had a significant effect on days to first flowering in both the years, and days to flowering was maximum in pendimethalin treated plots with 39.7 and 45.0 days in years of 2012 and 2013, respectively. The weedy check showed minimum days to flowering (37.10 and 42.43, respectively). Thus the highest number of days to first flowering in plots of weedy check indicated that weed competition with crop plants resulted in higher no. of days to flowering initiation. There was a significant effect of interaction on days to flowering in both the experiments.

Days to first fruiting: The combined analysis of the data indicated a significant effect of the year effect and the effect of row spacings and weed management methods on the no. of days to fruiting initiation. A linear surge in no. of days to fruiting initiation was found as shown in Table 1. The results showed that days taken in first fruiting increased with increase in the row spacing among tomato plants. Thus, increase in spaces among crop plants rows improved vegetative growth of the crop instead of its reproductive growth.

The trend in days to first fruiting was similar to the days to first flowering. Jelonkiewiez and Borowy (2000) stressed that early flowering and fruiting is resulted by a poor weed control and also by narrowing the spaces. The reason for the highest no. of days to fruiting in the row spacing of 80 cm could be the highest competition for space among the individual tomato plants and with the weed plants. Moreno and Moreno (2008) stressed that increase in row spacing had an incremental trend. Therefore, a good weed control treatment together with a narrow row-spacing required less days in getting to fruiting stage, as compared to wider row spacing and vice-versa. The interaction effect was also significant statistically. Adigun (2002) is of the view that chemical weed control treatment together with wider spacing of rows increased the no. of days to fruiting initiation. The no. of days to fruiting stage was from 49.43 to 51.61 among the treatments in 2012 and the range was from 51.43 to 53.61 in 2013. The no. of days to fruiting was lowest in the weedy check plots.

Leaf area of tomato (cm^2): A general concept is that the photosynthesis increases with higher leaf area. The 2-years combined data indicated a significant effect of the years, spacing among rows and the treatments (weed control) on tomato leaf area. The LA declined with rise in the spacing among rows from 40cm up to 80cm in both of the experiments.

The increase in leaf area therefore might be a result of greater vegetative growth because of severe weed competition due to larger spaces present between the adjacent rows of tomato crop plants. This reason was presented by Decotea (2007) as well. Among weed control treatments, the highest leaf area was found in the manual weeding plots and in the plots of black polyethylene plastic. The LA was however lowest in the weedy check. The other treatments of weed control were however at par statistically. Hanna (2000) is of the view that the mulching of black plastic is quite favorable for improvement in leaf area of the crop. In both years, the interaction effect was found significant as well. Thus mulching of black plastic can prove to be a best alternative for manual weeding where there is sufficient manpower at home (Decoteau 2007).

Leaf area index: Row spacing and weed control treatments presented a significant effect on LAI in both of the years. Increase in spacing between rows linearly decreased the LAI in the two years experimentations. The highest LAI of 2.14 was calculated in 40 cm spacing among crop rows which might be because of the greatest population density of tomato plants. The trend was analogous in both the years. Actually the no. of leaves increases when there is an increase in the number of plants per unit area, which eventually results in an increase in the LAI. Manley *et al*. (2000) reported that LAI is always higher with increase in plant canopy which increases the process of photosynthetic in the crop plants. Maximum LAI of 3.05 and 3.42 were recorded in hand weeding in 2012 and 13, respectively. The minimum values of 2.20 and 2.57 were obtained in control plots (weedy check) in year 2012 and 13, respectively. The LA $plant^{-1}$ was improved due to highest weed control (weed free situation) in the plots of hand weeding that eventually enhanced the LAI. There was also a significant effect of the interaction on LAI. As the tomato plants population was largest in the plots of row spacing of 40 cm, the LAI was therefore biggest. Thus, the decreasing trend in LAI was linear from 40cm row spacing to 80cm row spacing. Sajadian *et al.* (2010) are of the view that with the surge in the row spacing a decline in the plant population occurs which decreases the ultimate LAI of the plots.

Fruit yield (t ha^{-1}): There was a significant effect of row spacing on total fruit yield of tomato in 2012 and 2013 both as given in Table 2. The fruit yield was highest (12.12 t ha^{-1}) in 2012 in plots of 60 cm row spacing which was an indication of optimum conditions for tomato plants. However, there was a decrease in the fruit yield in 40 cm plots (10.23 t ha^{-1}) followed by plots of 80 cm row spacing with yield of 7.76 t ha^{-1}. During 2013, the respective values of total fruit yield were 12.79 t, 15.15 t and 9.70 t ha^{-1} in treatments of row spacings of 40 cm, 60 cm, and 80 cm, respectively.

Mudarres *et al*. (1998) is of the view that at higher plant populations, the individual yield of plants is always decreased. George *et al*. (2013) and Sobkowicz and Tendziagolska (2005) stated that the lower tomato fruit yields are because of limited availability of the soil resources in spite of reducing the spacings among the crop rows. The treatments of weed control also had a significant effect on the fruit yield of tomato. The treatment of hand weeding gave significantly the highest tomato fruit yield i.e. 13.73 t ha^{-1} in 2012, followed by polyethylene black (plastic mulch) with 11.99 t ha^{-1} yield, Stomp 330 EC with 11.82 t ha^{-1}, Dual gold with 11.76 t ha^{-1}, and white plastic (white mulch) with 11.26 t ha^{-1} yield, as mentioned in the Table 2 below. The fruit yield that was lowest (6.75 t ha^{-1}) was obtained in the control plots. In 2013, the trend was similar to that of 2012 regarding tomato fruit yield. The decrease in yield corresponds to the increase in weeds density (George *et al*. 2013). Rao (2000) described that one kilogram weed biomass corresponds to 1 kg loss in yield of crop. The interaction of spacing of rows and the different weed control measures also had a significant effect in the two years. Mamolos and Kalburtji (2001) indicated that yield losses in crops occur due to biomass and density of weeds.

Table 1. Fresh weed biomass (kg ha^{-1}), days to first flowering and days to first fruiting of tomato crop as affected by row spacing, weed control techniques and their interaction during 2012 and 2013.

	Fresh weed biomass (kg ha^{-1})		Days of first flowering		Days to first fruiting	
	2012	2013	2012	2013	2012	2013
ROW SPACING(cm)						
40	658.0 c	822.5 c	36.483 b	41.483 b	46.483 c	50.483 b
60	929.4 b	1161.8 b	38.743 ab	44.743 a	50.743 b	53.743 a
80	1219.3 a	1524.2 a	40.217 a	45.217 a	55.217 a	54.217 a
$LSD_{0.05}$	96.74	120.94	2.541	2.451	3.421	2.415
TREATMENTS						
Polyethylene (white)	709.7 cd	887.2 cd	39.278 a	44.611 a	51.611 a	53.611 a
Polyethylene (black)	573.5 de	716.8 de	38.567 ab	43.900 ab	50.9 ab	52.900 ab
Wheat straw	1118.9 b	1398.6 b	38.567 ab	43.900 ab	50.9 ab	52.900 ab
Saw dust	1205.4 b	1506.7 b	37.467 b	42.800 b	49.8 b	51.800 ab
Paper mulch	1252.4 b	1565.5 b	38.633 ab	43.967 ab	50.967 ab	52.967 ab
fenoxaprop-p-ethyl	736.6 c	920.3 c	38.222 ab	43.556 ab	50.556 ab	52.556 ab
s-metolachlor	795.0 c	993.7 c	38.633 ab	43.967 ab	50.967 ab	52.967 ab
Pendimethalin	850.6 c	1063.3 c	39.722 a	45.056 a	52.056 a	54.056 a
Hand weeding	510.6 e	638.2 e	38.622 a	43.956 ab	50.956 ab	52.956 ab
Weedy check	1603.5 a	2004.3 a	37.100 b	42.433 b	49.433 b	51.433 b
$LSD_{0.05}$	151.66	189.58	1.754	1.800	1.670	1.574
INTERACTION of RS x T	*	*	*	*	*	*
YEAR effect	*	*	*	*	*	*

Means of the same category followed by different letters are significantly different at P≤0.05 level using LSD test.
RS = Row Spacing, T = Treatments, NS = Non Significant, *Significant at P≤0.05

Table 2. Leaf area (cm^2), LAI and total fruit yield (t ha^{-1}) of tomato crop as affected by row spacing, weed control techniques and their interaction during 2012 and 2013.

	Leaf area (cm^2)		Leaf area index		Tomato yield	
	2012	2013	2012	2013	2012	2013
ROW SPACING(cm)						
40	577.68	686.68 a	3.140 a	4.610 a	10.234 b	12.792 b
60	480.83	583.83 b	2.612 b	3.007 b	12.124 a	15.155 a
80	387.18	483.18 c	2.170 c	2.420 c	7.762 c	9.704 c
LSD Values	16.809	16.809	0.151	0.231	0.457	0.575
TREATMENTS						
Polyethylene (white)	485.11 abc	587.78 abc	2.730 ab	3.100 ab	11.260 b	14.077 b
Polyethylene (black)	497.04 a	599.70 a	2.827 ab	3.197 ab	11.991 b	14.990 b
Wheat straw	476.64 bcd	579.31 bcd	2.438 bc	2.808 bc	7.938 de	9.921 de
Saw dust	474.19 bcd	576.86 bcd	2.506 bc	2.876 bc	7.334 ef	9.166 ef
Paper mulch	490.74 ab	593.41 ab	2.646 ab	3.016 ab	8.342 d	10.429 d
Fenoxaprop-p-ethyl	470.97 cd	573.63 cd	2.728 ab	3.098 ab	9.466 c	11.833 c
s-metolachlor	484.3 abc	586.97 abc	2.714 ab	3.084 ab	11.761 b	14.702 b
Pendimethalin	480.32 abcd	582.98 abcd	2.564 bc	2.934 bc	11.826 b	14.782 b

Hand weeding	494.97 a	597.64 a	3.054 a	3.424 a	13.733 a	17.167 a
Weedy check	464.69 d	567.35 d	2.200 c	2.570 c	6.750 f	8.437 f
LSD Values	17.169	17.169	0.4352	0.5243	0.865	1.0814
Interaction of RS x T	*	*	*	*	*	*
Year effect	*	*	*	*	*	*

Means of the same category followed by different letters are significantly different at P≤0.05 level using LSD test

Conclusion: The crop phenology is significantly affected by the varying line spacing, herbicides and mulches. Among the weed control treatments, the manual weeding gave optimum results in the parameters of weeds and the crop. The impact of the herbicides used and that of the mulches applied was at par statistically for almost all the parameters studied which indicated that dependence on herbicides needs to be minimized. Hence, in light of study results the 60 cm spacing among tomato rows is recommended along with its integration with the black or white plastic mulch and the herbicide Stomp 330 EC pendimethalin) or Dual gold 960 EC (s-metolachlor) as pre-emergence application in order to achieve efficient weed control for obtaining a potential crop yield.

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