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Weed management in garlic (*Allium sativum* L.)

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Abstract
Three herbicides (Pendimethalin @ 0.75 and 1.0 kg/ha, Oxyfluorfen @ 0.125 and 0.150 kg/ha and Quizalofop ethyl @ 0.025 and 0.50 kg/ha) alone and in combinations were compared with weedy check (untreated) and weed free check during *rabi* season 2015-16 for controlling weeds in garlic crop. The herbicide treatment T_{10} - Oxyfluorfen 0.150 kg/ha + Quizalofop ethyl 0.050 kg/ha found significantly superior and recorded minimum weed density at stages of crop growth, dry weight and yield (155.60 q/ha). Similarly the same herbicide treatment registered the maximum Weed control efficiency (84.17%), Herbicide efficiency index (5.41%), Weed management index (0.91%), Gross monetary returns and net monetary returns as well as highest B:C ratio (2.70). The minimum weed index (5.12%) and agronomic management index (1.11%) were noticed in same herbicide treatment. This clearly indicates that the application of Oxyfluorfen 0.150 kg/ha + Quizalofop ethyl 0.050 kg/ha as post emergence found effective in controlling weeds and increasing bulb yield of garlic crop.

Keywords: Garlic, Herbicide, weed index, weed control efficiency, Weed management indices, economics

Introduction
Garlic is highly vulnerable to weed infestation due to its slow emergence and slow initial growth, non-branching habit, sparse foliage, shallow root system (Rahman *et al.*,2012, Lawande *et al*., 2009) [12, 6], frequent irrigation and high fertilizer application. Weeds compete for nutrients, soil, moisture, space and light considerably reducing the yield, quality and value through increased production and harvesting costs. Garlic is closely planted crop with very small canopy. Due to smaller leaf size it cannot compete with the weeds. Their competition with the plants starts at very early growth stage because immediately after planting the cloves, the weed emergence occurs that competes with the tender seedlings. Weeds also harbor insect pests and disease-causing organisms. The losses caused by weeds have been estimated to be much higher than those caused by insect pest and diseases.
Weed infestation in garlic is one of the major factors for loss in yield and bulb loss to the tune of 30-60% (Lawande *et al*., 2009) [6]. Weed reduces the bulb yield to the extent of 40 to 80% (Verma and Singh, 1996) [21]. In garlic shallow root system make mechanical method of weed control difficult and sometimes causes damage to developing bulbs (Lawande *et al*., 2009) [6]. The predominant weed flora that hampers the growth and yield of crop vary with soil type, moisture, and other climatic factors.
Garlic is closely planted and shallow rooted bulbous crop. Therefore, intercultural practices are very difficult to undertake and manual weeding during the establishment stage of crop causes physical damage to crop plant. A most of troublesome problem faced by garlic grower is the control of weeds during early stage of crop growth. Because of higher plant density and slow growth of plant, interculturing is practically difficult and crop suffers heavily from weed competition during establishment of plant. The weeds compete for moisture, space, nutrients and light which affects growth and development of crop. Therefore, it is essential to keep field weed free during critical period of crop growth. However, manual hand weeding is a very tedious and labour expensive method of weed control. Sometimes due to shortage of labour and unexpected rains, hand weeding or mechanical weed operations are delayed or left altogether. The chemical weed control in garlic has received little attention and weeds are mostly managed manually. In such situation, herbicides offer the most practical, more effective and economical method of weed control for increasing bulb yield of garlic. Hence, present investigation was conducted to find out suitable herbicide for controlling weed growth and enhancing the bulb yield of garlic.

Materials and Methods
The present study Weed management in garlic (*Allium sativum* L.) was carried out at All India Coordinated Research Project on Vegetable Crops, Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri. (Maharashtra State).

The experiment was laid out in Randomized block design with 12 treatments replicated thrice having 4.05 X 2.0 m plot size spaced at 15 X 10 cm during 2015-16 *rabi* season. The recommended cultural practices and plant protection measures were followed during growing period of crop for better growth and controlling disease and pest. The treatments consisted of three herbicides (Pendimethalin, Oxyfluorfen and Quizalofop ethyl) and their combinations along with weedy check and weed free check. Pendimethalin was applied as pre emergence (2 DAP) whereas, Oxyfluorfen and Quizalofop ethyl were applied as post emergence (20 DAP). The total twelve treatments comprised of T_1: Pendimethalin 30% EC PE @ 0.75 kg a.i. ha^{-1} T_2 :Pendimethalin 30% EC PE @ 1.00 kg a.i. ha^{-1} T_3 : Oxyfluorfen 23.5% EC PoE @ 0.125 kg a.i. ha^{-1} T_4 :Oxyfluorfen 23.5% EC PoE @ 0.150 kg a.i. ha^{-1} T_5 :Quizalofop ethyl 5% EC PoE @ 0.025 kg a.i. ha^{-1} T_6 :Quizalofop ethyl 5% EC PoE @ 0.050 kg a.i. ha^{-1} T_7 :Oxyfluorfen 23.5% EC PoE @ 0.125 kg a.i. ha^{-1} + Quizalofop ethyl 5% EC PoE@ 0.025 kg a.i. ha^{-1} T_8 :Oxyfluorfen 23.5% EC PoE @ 0.125 kg a.i. ha^{-1} + Quizalofop ethyl 5% EC PoE @ 0.050 kg a.i. ha^{-1} T_9 :Oxyfluorfen 23.5% EC PoE @0.150 kg a.i. ha^{-1}+ Quizalofop ethyl 5% EC PoE@ 0.025 kg a.i. ha^{-1}T_{10}:Oxyfluorfen 23.5% EC PoE @ 0.150 kg a.i. ha^{-1}+ Quizalofop ethyl 5% EC PoE @ 0.050 kg a.i. ha^{-1} T_{11} : Weedy check T_{12} : Weed free check. The crop was harvested on 15th March, 2016. The observations were recorded on the periodical weed weed density (no/0.5m^2) at 30, 60, 90, 120, at harvest, dry weight of weeds (60 DAP and at harvest), bulb yield, weed control efficiency (%), weed index (%), herbicide efficiency index (%), agronomic management index (%). The weed density was recorded by placing 50 X 50cm quadrates at two random places in each plot. After drying samples in hot air oven (70 $\pm$ 1 ^{o}C for 72 hour) weed dry weights was recorded. The different weed indices were worked out as per metod suggested by Walia (2003) [24].

Results and Discussion

Effects on weed density

The total weed density 0.5m^{-2} as influenced by different weed management practices is presented in Table 1. The mean total weed density differ significantly due to different weed management practices. Weed free check treatment recorded significantly the lowest total weed density as compared to rest of the treatments, except the treatments T_{10}, T_9, T_8, T_7, T_4 and T_3 at 30 DAP, T_{10}, T_9, T_8, T_7 and T_4 at 60 DAP, T_{10}, T_9, T_8, T_7, T_4 and T_3 at 90 DAP, T_{10}, T_9 and T_8 at 120 DAP and T_{10} and T_9 at harvest which are at par with each other. Significantly the highest total weed density was noticed in weedy check treatment at all the stages of observation. The reduction in total weed density in herbicide weed control treatments might be due to broad spectrum herbicidal effect of post emergence herbicides *viz*., Oxyfluorfen and Quizalofop ethyl which have controlled most of monocot (Grassy) and dicot (Broad leaf) weeds emerged in the experimental plot. These findings are in accordance with Mehmood *et al.* (2007), Ramani and Khanpara (2010), Sampat *et al.* (2014) and Mohite *et al.* (2015) [9, 13, 16, 10] in garlic crop.

Dry weight of weeds

The data presented in Table 1 revealed that various weed control treatments were significantly influenced dry weight of weeds. At 60 DAP and at harvest the weedy check treatment (T_{11}) recorded significantly highest dry weight of weeds (38.20 g) and (366.67 g) respectively. The weed free check recorded the lowest dry weight of weeds (0 g) due to it was kept weed free upto 60 days and (19.00 g) respectively. Among the herbicidal weed control treatments T_{10}- Oxyfluorfen 0.150 kg/ha+ Quizalofop ethyl 0.050 kg/ha recorded lowest weed dry weight (10.07 and 52.67 g). This might be due to fact that maximum number of monocotyledonous and dicotyledonous weeds in weedy check treatment and less number of monocot and dicot weed population in herbicide treatment indicate that herbicide treatments were effective for weed control than other. Similar results are also reported by Mehmood *et al.* (2007), Mohite *et al.* (2015), Sampat *et al.* (2014) and Mahmood *et al.* (2002) in garlic [9, 10, 16, 7]. Whereas Manjunath *et al.* (1989), Warade *et al.* (2006), Sable *et al.* (2013), Shinde *et al.* (2013), Kalhapure and Shete (2013) and Anarase (2014) [8, 15, 18, 13, 1] in onion crop.

Bulb Yield

The data on bulb yield presented in table 1, revealed that the weed free check treatment (T_{12}) recorded significantly the highest bulb yield over rest of the treatments (163.96 q/ha). However, it was at par with T_{10}- Oxyfluorfen 0.150 kg/ha + Quizalofop ethyl 0.050 kg/ha (155.60 q/ha). Maximum yield in weed free treatment seems to be due to favourable environment created by clean crop culture resulting in more absorption of solar radiation and plant nutrients resulting in more photosynthetic rates and more dry matter accumulation in cloves following the good cultural practices in weed free treatment. While the weedy check recorded significantly the lowest bulb yield (87.79 q/ha). This may be due to low chlorophyll content and photosynthetic rates due to unchecked weed growth there by reducing availability of moisture, light and nutrients to the crop and resulted in loss of yield in unweeded (weedy check) control. These results are in accordance with Mahmood *et al.* (2002), Mehmood *et al.* (2007), Turk and Tawaha (2002), Ramani and Khanpara (2010) and Sampat *et al.* (2014) [7, 9, 20, 10, 16] in garlic and Anarase (2014), Verma and Singh (1996) [1, 21] in onion crop.

Weed Indices

The results on different weed indices like weed control efficiency, weed index, herbicide efficiency index, weed management index and agronomic management index are presented in table 2.

Weed control Efficiency

The treatment T_{12}-weed free check recorded significantly maximum WCE over rest of the treatments at the harvesting stage. Among the herbicide weed control treatments, application of Oxyfluorfen 0.150 kg a.i. ha^{-1}+ Quizalofop ethyl 0.050 kg a.i. ha^{-1} (T_{10}) registered maximum and significantly higher WCE at the harvesting stages. However, it was at par with T_9 and T_8 at harvest. The highest weed control efficiency in the treatment T_{12}- weed free check (97.16%) attributes to frequent removal of weeds as and when seen resulted in less weed density compared to the treatment T_{11}- weedy check. In herbicide weed management treatments *viz.*, T_{10}, T_9, T_8, T_7 and T_4 showed the better WCE might be due to herbicidal effect of post emergence herbicides. The Oxyfluorfen acts as a broad spectrum contact herbicide whereas Quizalofop ethyl functions systematically, get translocated into the plant system thus restricting the weed growth and yielding significant weed control efficiency after weed free treatment. Similar results were recorded by Tewari

et al. (1999) and Warade *et al.* (2006) in onion. Ghadge *et al.* (2012) and Ramani and Khanpara (2010) [19, 2, 13] in garlic.

Weed Index

Weed index was significantly influenced by the different weed control treatments. Among the herbicidal treatments application of Oxyfluorfen 0.150 kg a.i. ha^{-1} + Quizalofop ethyl 0.050 kg/ha recorded the lowest weed index (5.12%). It was at par with T_9- Oxyfluorfen 0.150 kg/ha + Quizalofop ethyl 0.025 kg a.i. ha^{-1} (6.63%), T_8- Oxyfluorfen 0.125 kg/ha + Quizalofop ethyl 0.050 kg/ha (7.45%), T_7- Oxyfluorfen 0.125 kg/ha + Quizalofop ethyl 0.025 kg/ha (10.06%), T_4- Oxyfluorfen 0.150 kg/ha (11.64%) and T_3- Oxyfluorfen 0.125 kg/ha (13.18%). Weed free treatment recorded the lowest weed index (0%) indicating that there is no reduction in bulb yield in this treatment due to weed infestation. The highest weed index (46.46%) was recorded in weedy check due to prominent weed competition, suppression of crop plants by emerging weeds and more utilization of nutrients and moisture by weed canopy, hence giving the lowest yield. Lower weed index resulting in higher bulb yield in the corresponding treatments and vice versa. Similarly, maximum weed index was recorded by Rahman *et al.* (2012) and Ghadge *et al.* (2012) in garlic, Patel *et al.* (1986), Tewari *et al.* (1999), Warade *et al.* (2006), Kathepuri *et al.* (2007), Sharma *et al.* (2009) and Anarase (2014) in onion [12, 2, 11, 19, 4, 17, 1].

Herbicide efficiency index

Herbicide efficiency index was significantly influenced by the different weed control treatments. Among the herbicidal treatments application of Oxyfluorfen 0.150 kg/ha + Quizalofop ethyl 0.050 kg/ha (T_{10}) recorded the highest herbicide efficiency index (5.41%). This indicates weed killing potential and no phytotoxicity on crop and results in higher herbicide efficiency index of these treatments. These results are in accordance with Kumar *et al.* (2013) [5] while studying integrated weed management in garlic. Sharma *et al.* (2009) and Anarase (2014) [17, 1] reported similar findings in onion.

Weed management index

Weed management index was significantly influenced by the different weed control treatments. The highest WMI was recorded with treatment T_{12}- weed free check (0.92%). The lowest weed management index was recorded in weedy check treatment. Similar findings are in conformity with Kumar *et al.* (2013) [5] in garlic.

Agronomic management index

The agronomic management index was significantly influenced by the different weed control treatments. The highest AMI was recorded with treatment T_6- Quizalofop ethyl 0.050 kg a.i. ha^{-1} (1.21%). However, it was at par with all the treatments except T_{12}- weed free check. These results are in close agreement with those of Kumar *et al.* (2013) [5] in garlic crop.

Benefit: Cost ratio

Benefit cost ratio was worked out by considering the cost of cultivation and gross monetary returns. The B:C ratio was higher in the treatment T_{10}- Oxyfluorfen 0.150 kg a.i. ha^{-1} + Quizalofop ethyl 0.050 kg a.i. ha^{-1} (2.70). This could be attributed to lower cost of cultivation in these herbicide treatments as compared to weed free treatment. In the treatment T_{12}- weed free check total bulb yield and gross monetary returns was noticed maximum, the net monetary returns and B:C ratio was minimum as compared to the treatment T_{10}- Oxyfluorfen 0.150 kg a.i. ha^{-1} + Quizalofop ethyl 0.050 kg a.i. ha^{-1}. This could be due to more cost of cultivation increased remarkably due to frequent weeding operations followed by clean cultivation. It increased the cost of manual weeding thus corresponding towards total output cost. Moreover, unweeded control (weedy check) recorded significantly lesser B:C ratio (1.91) due to lower bulb yield owing to more crop weed competition. Similar findings were recorded by Vermani *et al.* (2001) and Sampat *et al.* (2014) in garlic. Rameshwar *et al.* (2002), Warade *et al.* (2006), Kalhapure and Shete (2013) and Anarase (2014) [22, 16, 14, 1] in onion crop.

Table 1: Periodical total weed density (no./0.5m^2) at different stages and yield of garlic as influenced by different weed management treatments

Treatments	Total weed density (no./ 0.5m^2)					Dry weight (g)/ 0.5m^2		Yield (q/ha)
	30 DAP	60 DAP	90 DAP	120 DAP	At harvest	60 DAP	At Harvest	
T_1	7.63 (2.85)	15.65 (4.01)	26.29 (5.17)	38.96 (6.28)	49.30 (7.06)	20.07 (4.53)	123.00 (11.11)	120.08
T_2	6.64 (2.67)	14.96 (3.93)	24.62 (5.01)	36.63 (6.09)	48.96 (7.03)	19.07 (4.42)	112.00 (10.61)	121.70
T_3	2.98 (1.86)	5.31 (2.41)	12.62 (3.62)	20.98 (4.63)	35.30 (5.98)	15.33 (3.96)	94.00 (9.72)	142.33
T_4	2.31 (1.68)	4.98 (2.34)	11.32 (3.43)	19.97 (4.52)	32.97 (5.78)	14.40 (3.84)	84.67 (9.23)	144.94
T_5	5.97 (2.54)	10.98 (3.38)	18.96 (4.41)	31.30 (5.64)	44.30 (6.69)	18.67 (4.37)	72.67 (8.55)	135.48
T_6	5.31 (2.41)	9.65 (3.18)	17.62 (4.25)	30.63 (5.58)	42.95 (6.60)	18.33 (4.33)	72.00 (8.51)	138.83
T_7	1.99 (1.57)	4.98 (2.34)	10.65 (3.33)	19.30 (4.45)	29.96 (5.52)	13.67 (3.75)	65.33 (8.11))	147.40
T_8	1.65 (1.46)	4.33 (2.19)	10.31 (3.28)	18.31 (4.33)	29.31 (5.45)	12.17 (3.55)	63.33 (7.99)	151.75
T_9	1.65 (1.46)	3.99 (2.11)	9.64 (3.18)	16.64 (4.14)	25.97 (5.14)	11.10 (3.39)	54.00 (7.38)	153.10
T_{10}	1.32 (1.34)	3.31 (1.95)	8.98 (3.07)	14.65 (3.89)	23.97 (4.95)	10.07 (3.24)	52.67 (7.29)	155.60
T_{11}	32.33 (5.73)	58.96 (7.71)	86.62 (9.33)	122.62 (11.10)	151.31 (12.32)	38.20 (6.22)	366.67 (19.16)	87.79
T_{12}	0.00 (0.71)	0.00 (0.71)	1.32 (1.34)	2.31 (1.67)	4.32 (2.20)	0.00 (0.71)	19.00 (4.41)	163.96
S.E ±	0.77	0.63	1.40	1.26	1.19	0.17	0.10	5.13
C.D at 5%	2.26	1.86	4.12	3.71	3.48	0.51	0.27	15.04

Figures in the parenthesis are square root transform (√X+0.5) values. The figures outside the bracket are original values.

Table 2: Weed indices and economics of weed management treatments in garlic

Treatments	WCE (%) at harvest	WI (%)	HEI (%)	WMI (%)	AMI (%)	Gross monetary returns (₹./ha.)	Net monetary returns (₹./ha.)	B:C Ratio
T_1	67.44	26.76	1.12	0.57	1.04	960640	548839	2.33
T_2	67.62	25.77	1.29	0.56	1.06	973600	559461	2.35
T_3	76.69	13.18	2.45	0.84	1.12	1138640	696837	2.58
T_4	78.24	11.64	2.81	0.84	1.10	1159520	714028	2.60
T_5	70.72	17.36	2.79	0.69	1.20	1083840	651287	2.51
T_6	71.62	15.30	2.98	0.73	1.21	1110640	672868	2.54
T_7	80.21	10.06	3.81	0.83	1.10	1179200	729885	2.62
T_8	80.69	7.45	4.26	0.89	1.16	1214000	758132	2.66
T_9	82.87	6.63	5.07	0.87	1.11	1224800	767675	2.68
T_{10}	84.17	5.12	5.41	0.91	1.11	1244800	783589	2.70
T_{11}	0.00	46.46	-	0.00	-	702320	334107	1.91
T_{12}	97.16	-	-	0.92	0.93	1311680	815407	2.64
S.E ±	0.62	3.13	0.32	0.07	0.08	-	-	-
C.D at 5%	1.82	9.17	0.95	0.22	0.24	-	-	-

T_1: Pendimethalin 30% EC PE @ 0.75 kg a.i. ha^{-1} **T_2**: Pendimethalin 30% EC PE @ 1.00 kg a.i. ha^{-1}
T_3: Oxyfluorfen 23.5% EC PoE @ 0.125 kg a.i. ha^{-1} **T_4**: Oxyfluorfen 23.5% EC PoE @ 0.150 kg a.i. ha^{-1}
T_5: Quizalofop ethyl 5% EC PoE @ 0.025 kg a.i. ha^{-1} **T_6**: Quizalofop ethyl 5% EC PoE @ 0.050 kg a.i. ha^{-1}
T_7: Oxyfluorfen 23.5% EC PoE @ 0.125 kg a.i. ha^{-1} + Quizalofop ethyl 5% EC PoE@ 0.025 kg a.i. ha^{-1}
T_8: Oxyfluorfen 23.5% EC PoE @ 0.125 kg a.i. ha^{-1} + Quizalofop ethyl 5% EC PoE @ 0.050 kg a.i. ha^{-1}
T_9: Oxyfluorfen 23.5% EC PoE @0.150 kg a.i. ha^{-1}+ Quizalofop ethyl 5% EC PoE@ 0.025 kg a.i. ha^{-1}
T_{10}: Oxyfluorfen 23.5% EC PoE @ 0.150 kg a.i. ha^{-1}+ Quizalofop ethyl 5% EC PoE @ 0.050 kg a.i. ha^{-1}
T_{11}: Weedy check **T_{12}**: Weed free check
WCE - weed control efficiency; WMI - weed management index; AMI – agronomic management index; HEI - Herbicide efficiency index; WI - weed index; B:C ratio- benefit: cost ratio

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