Indian Journal of Agricultural Sciences **85** (3): 437–41, March 2015/Article

Planting method and tank-mix herbicides effects on weed management in garlic (*Allium sativum*)

ABDOLHAMID HAJEBI[1], T K DAS[2], A K VYAS[3] and D S RANA[4]

Indian Agricultural Research Institute, New Delhi 110 012

Received: 27 July 2014; Revised accepted: 15 January 2015

ABSTRACT

A field experiment was carried out at the Indian Agricultural Research Institute during 2012 and 2013 to investigate the effect of planting method and tank-mix herbicide application on weeds, and growth, yield and nutrient uptake of garlic (*Allium sativa* L.). It was observed that the flat (FB) and raised (Furrow-irrigated raised bed system; FIRBS) beds were comparable with each other on the density and dry weight of weeds, and plant height, yield and bulb diameter of garlic during both years. The pre-emergence tank-mix application of pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha was superior to all other herbicide treatments in reducing weed competition as well as the uptakes of N, P and K by weeds. The uptakes of N, P and K, and the bulb yield of garlic were considerably higher in weed-free check and the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha compared to other treatments. The pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha and weed-free check brought about increases in two-year mean garlic bulb yield by 244.4% (~2.4 times) and 264.2% (~2.6 times), respectively over weedy check.

Key words: Garlic, Nutrients, Planting methods, Tank-mix herbicide, Weed, Yield

Garlic (*Allium sativum* L.) is the second important bulb crop grown after onion in the world. It is grown widely in the world over 11.99 lakh hectares with a production of 176.75 lakh tonnes, having productivity of 14.73 tonnes/ha. China has the highest area (55%) and production (77%) in the world, followed by India (5%). India, although ranks second in area and production, the productivity of garlic (5.29 tonnes/ha) is the lowest (Srivastava *et al*. 2002). Weed infestation is the largest single limiting factor, severely affecting garlic yield. Weeds compete with garlic for nutrients, soil moisture, space, and light, and considerably reduce the yield, quality and value of crop. Due to smaller leaf size and canopy coverage, garlic cannot compete well with weeds, resulting in 30-60% yield losses (Lawande *et al.* 2009). Limited studies conducted in garlic showed a significant effect of herbicides on weed control and garlic bulb yield. Planting methods play a key role in the emergence and establishment of crop seedlings besides affecting soil aeration, temperature, root development and water use. FIRBS and bed plantings have been shown to be more efficient in relation to water and nutrient use in other field crops. Flat planting method produced the highest dry matter, fresh herbage and essential oil yield of Japanese mint than ridged and trench planting methods (Kaur 2001). Applying a single herbicide may not provide desired level of broad-spectrum weed control. Combinations of herbicides with different mechanisms of action not only control a broad-spectrum of weeds but also may prevent shift in weed flora and delay herbicide resistance. Besides, mixing two herbicides together can enhance herbicide activity resulting in reduction of the dose of the component herbicides of the tank-mixes (Das 2008, Younesabadi *et al.* 2013). Application of post-emergence herbicides sometimes has a deleterious effect not only on undesirable weeds but also on the main crop. Therefore, this study was designed to evaluate the effect of herbicides applied pre-emergence, alone or as tank-mix, under different planting methods on weed management in garlic.

MATERIALS AND METHODS

Field experiments were conducted in 2012 and 2013 at the Indian Agricultural Research Institute, New Delhi to investigate the effect of planting methods and tank-mix herbicide applications on weed control, yield and nutrient uptake of garlic. Soil of the experimental field was alluvium (Typic Ustochrepts; Order Inceptisol) and sandy-loam (62.1% sand, 16.5% silt and 19.8% clay) with 0.54% organic carbon and pH 7.6. The available P (18.5 kg P/ha) and K (191.5 kg K/ha) were medium, but available N (272.5 kg N/ha) was low. The experiment, comprising of two methods

Based on part of the Ph D thesis of the first author submitted to IARI, New Delhi 110 012 during 2014 (Unpublished)

[1]Scientist (Medicinal Plant & Agronomy) (e-mail: hamid_hajebi@yahoo.com), Department of Natural Resources, Agricultural & Natural Resources Research Center of Hormozgan Province, Iran; [2,4]Principal Scientist, Division of Agronomy, IARI, New Delhi; [3]Assistant Director-General (HR), Krishi Bhawan, ICAR, New Delhi

Table 1 Weed density and dry weight in garlic as influenced by planting method and herbicide application

Treatment	Weed density (no. /m^2) (30 DAS)			Weed dry weight (g/m^2) (30 DAS)		
	2012	2013	pooled	2012	2013	Pooled
First year (2012)			6.83(62.3)			4.80(34.51)
Second year (2013)			6.35(54.4)			4.47(30.19)
SEm ±			0.17(2.47)			0.15(1.50)
LSD(P=0.05)			NS			NS
Planting method (P)						
Flat bed	7.1(65.9)	6.6(56.7)	6.8(61.3)	5.02(37.57)	4.66(31.95)	4.84(34.76)
Raised bed (FIRBS)	6.6(58.8)	6.2(52.0)	6.4(55.4)	4.59(31.44)	4.29(28.43)	4.44(29.94)
SEm ±	0.15(2.27)	0.17(3.00)	0.17(2.47)	0.14(1.60)	0.13(1.11)	0.15(1.51)
LSD(P=0.05)	NS	NS	NS	NS	NS	NS
Weed control treatment (W)						
Pendimethalin 1.0 kg/ha pre-em	6.6(44.0)	6.05(37.0)	6.3(40.5)	3.91(15.50)	3.53(12.26)	3.72(13.88)
Pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha pre-em tank-mix	7.1(50.0)	6.8(46.2)	6.9(48.1)	4.13(17.24)	3.97(16.16)	4.05(16.70)
Pendimethalin 0.75 kg/ha+imazethapyr 0.075kg/ha pre-em tank-mix	5.4(29.3)	4.5(20.3)	5.0(24.8)	3.53(12.15)	2.93(8.44)	3.23(10.30)
Pendimethalin 0.75 kg/ha followed by quizalofop-p-ethyl 0.025 kg/ha at 30 DAS	6.8(46.7)	6.6(43.7)	6.7(45.2)	4.78(22.70)	4.64(21.65)	4.71(22.18)
Pendimethalin 0.75 kg/ha + oxyfluorfen 0.2 kg/ha pre-em tank-mix	6.0(35.3)	5.6(31.2)	5.8(33.3)	3.96(15.19)	3.75(14.01)	3.85(14.60)
Weedy check (WC)	15.2(231.0)	14.2(202.1)	14.72(216.58)	12.60(158.77)	11.80(138.81)	12.20(148.79)
Weed-free check (WFC)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)
SEm ±	0.24(3.28)	0.32(4.57)	0.20(2.81)	0.19(2.25)	0.22(1.86)	0.147(1.46)
LSD (P=0.05)	0.69(9.58)	0.92(13.35)	0.56(8.00)	0.57(6.56)	0.65(5.41)	0.42(4.14)

*Figures in parentheses are original values. Original values were transformed through square-root [$\sqrt{(x + 0.5)}$] method

of planting, viz. flat bed (FB) and FIRBSd bed (RB) in main plots, and 7 weed management treatments (Table 1) in sub-plots, was laid out in a split plot design with 3 replications. Pre-emergence application of herbicides alone or as tank-mix combinations was made two days after planting and one post-emergence herbicide was sprayed 30 days after planting with knapsack sprayer fitted with a flat fan nozzle using 400 l water/ha. Weed-free check was kept free from weeds all through the growing season by manual weeding. Garlic cloves cv. G 41, weighing between 4 and 5 g was planted on 9 November 2012 and 2013. Row to row and plant to plant distances were kept at 20 cm and 15 cm, respectively with a plot size of 3.0 m × 2.8 m. The recommended cultural practices and plant protection measures were adopted to raise a healthy crop. Crop was fertilized with 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha through urea, diammonium phosphate (DAP), and muriate of potash, respectively. Half dose of N and full dose of P_2O_5 and K_2O were applied at the time of sowing and remaining N was top-dressed in two equal splits at 45 and 60 days of sowing (DAS).

Weed population and dry weight were recorded at 30 DAS by placing a quadrat of 50 cm×50 cm randomly in each plot. Garlic plant height and dry weight were recorded at 30 and 60 DAS, and garlic bulb yield at harvest from the net plots (2.0 m×1.4 m). Nitrogen concentration in garlic bulbs and stalks, and weeds at harvest was determined by modified Kjeldahl method; P concentration by vanadomolybdophosphoric acid yellow colour method using spectrophotometer; and K concentration by flame photometer (Prasad *et al.* 2006). Data on weed population and dry weight were transformed through square-root [$\sqrt{(x + 0.5)}$] method before analysis of variance (ANOVA). All data on weed and garlic were subjected to ANOVA by using MSTAT C software (CIMMYT, Mexico City, Mexico) to evaluate differences among treatments, and interactions between the main and sub-plot treatments. The significance was tested by variance ratio (i.e. F value) at $P \leq 0.05$ (Gomez and Gomez 1984). Standard error (SEm±) and least significant difference (LSD) were worked out for each parameter of weed and garlic for comparing the treatment means.

RESULTS AND DISCUSSION

Weed competition

Eight weed species, three monocotyledons (monocots) and five dicotyledons (dicots) belonging to six botanical families were present in garlic. The share of monocots and dicots weeds in the total weed population at 30 DAS were 53% and 47%, respectively (mean of 2 years). The monocots

weeds were: *Phalaris minor* Retz., *Avena sterilis* ssp *ludoviciana* Dur. (Nym.) (Poaceae) and *Cyperus rotundus* L. (Cyperaceae), and the dicots weeds were: *Melilotus alba* (L.) Desf. (Fabaceae), *Coronopus didymus* (L.) Smith (Brassicaceae), *Chenopodium album* L. and *Chenopodium murale* L. (Chenopodiaceae), and *Convolvulus arvensis* L. (Convolvulaceae).

Pooled analysis of the density and dry weight of weeds at 30 DAS (Table 1) showed that there was no significant variation in weed density and weed dry weight between the years (2012 and 2013) and planting methods. The weed population and weed dry weight, however, were significantly reduced due to weed control treatments. Lowest weed density and dry weight were recorded in the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha, excluding weed-free check. This tank-mix pre-emergence herbicide treatment was superior to all other treatments on the reduction in weed competition (density and dry weight) during both years. Younesabadi *et al*. (2013) reported similar results in soybean. Arnold *et al*. (1993) observed an efficient broad-leaved weed control in Pinto beans by imazethapyr applied as pre-plant incorporation or post-emergence. They highlighted that barnyard grass [*Echinochloa crus-galli* (L.) Beauv.] control by imazethapyr ranged from 58 to 96%, and was increased to 98% when imazethapyr was combined with metolachlor, pendimethalin, trifluralin or EPTC. The dose played a role in this experiment, too. The dose of pendimethalin was reduced to 0.75 kg/ha (by 25%) in the tank-mixture compared to 1.0 kg/ha as usually recommended (Das 2008). Similarly, the dose of imazethapyr was reduced by 25%, considering its 0.100 kg/ha dose recommended for soybean. No studies on imazethapyr alone or in combination with pendimethalin are reported in garlic. We observed that the effect of pendimethalin when tank-mixed was slightly affected due to lower dose of pendimethalin, but its mixture with imazethapyr 0.075 kg/ha could compensate this, might be due to synergistic action upon tank-mixing. The reduction in efficacy was also observed in pre-emergence application of pendimethalin 0.75 kg/ha + HW in which weed dry weight was the second highest in both years. This necessitated the tank-mix application of pendimethalin and imazethapyr for better weed control in garlic. Qasem (1996) claimed that post-emergence application of oxyfluorfen and oxadiazon at 3-4 leaf stage gave better crop yield than that in weed-free crop. In this study, oxyfluorfen was tank-mixed with pendimethalin and proved to be almost similar with the tank-mix application of pendimethalin and imazethapyr on weed control in garlic. Vora and Mehta (1998) observed the highest bulb yield of garlic in weed-free control, while herbicide application alone did not control weeds effectively.

Growth, yield attributes and yield of garlic

Pooled analysis of garlic plant dry weight and height at 30 and 60 DAS (Table 2) showed a significant difference between the years, the second year (2013) registered significantly higher garlic growth over that in the first year (2012). Favourable environmental conditions (mainly, temperature in the early November), leading to better germination and subsequent growth of plants contributed to this in the latter year than in the former year. The garlic growth (dry weight and height) was not significantly influenced due to planting methods, except the dry weight at 60 DAS, which indicates that both flat bed (FB) and raised bed (RB) were similar in their effects on garlic. However, having recorded higher values of these two growth parameters, the raised bed was superior to flat bed. Dry matter accumulation and plant height of garlic varied significantly due to planting methods and weed control treatments at 60 DAS. Among the weed control treatments, pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha resulted in better garlic plant dry weight and plant height (Table 2) compared to others. The planting methods and weed control treatments interacted significantly for garlic dry weight and plant height at 60 DAS.

Table 2 Dry matter and plant height of garlic at 30 and 60 DAS (pooled data of two years)

Treatment	Plant dry matter (g/m^2)		Plant height (cm)	
	30 DAS (pooled)	60 DAS (pooled)	30 DAS (pooled)	60 DAS (pooled)
First year (2012)	1.23	1.67	26.0	42.3
Second year (2013)	1.36	1.88	28.6	47.2
SEm ±	0.02	0.029	0.39	0.68
LSD(P=0.05)	0.09	0.11	1.52	2.67
Planting method (P)				
Flat bed	1.26	1.68	27.1	43.4
Raised bed (FIRBS)	1.34	1.87	27.5	46.1
SEm ±	0.02	0.03	0.39	0.76
LSD(P=0.05)	NS	0.11	NS	NS
Weed control treatment (W)				
Pendimethalin 1.0 kg/ha pre-em	1.35	2.01	27.8	46.9
Pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha pre-em tank-mix	1.10	1.37	25.68	40.8
Pendimethalin 0.75 kg/ha + imazethapyr 0.075kg/ha pre-em tank-mix	1.46	2.17	29.9	48.0
Pendimethalin 0.75 kg/ha followed by quizalofop-p-ethyl 0.025 kg/ha at 30 DAS	1.17	1.69	26.3	42.3
Pendimethalin 0.75 kg/ha + oxyfluorfen 0.2 kg/ha pre-em tank-mix	1.26	1.84	27.1	43.6
Weedy check (WC)	0.99	0.81	23.3	36.9
Weed -free check (WFC)	1.76	2.53	31.0	54.9
SEm ±	0.04	0.05	0.67	1.18
LSD (P=0.05)	0.10	0.13	1.90	3.35

Garlic yield and bulb diameter were not significantly influenced by planting method during both years (Table 3). However, these parameters were significantly influenced

Table 3 Yield and bulb diameter of garlic as influenced by planting method and herbicide application

Treatment	Yield (tonnes/ha)			Bulb diameter(cm)		
	2012	2013	pooled	2012	2013	Pooled
First year (2012)			7.67			3.76
Second year (2013)			8.12			4.12
SEm ±			0.13			0.06
LSD(P=0.05)			NS			0.24
Planting method (P)						
Flat bed	7.30	7.75	7.52	3.76	4.11	3.94
Raised bed (FIRBS)	8.04	8.50	8.27	3.76	4.13	3.94
SEm ±	0.16	0.20	0.134	0.08	0.09	0.062
LSD(P=0.05)	NS	NS	0.53	NS	NS	NS
Weed control treatment (W)						
Pendimethalin 1.0 kg/ha pre-em	8.52	9.12	8.82	3.91	4.30	4.10
Pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha pre-em tank-mix	6.85	7.69	7.27	3.65	3.93	3.79
Pendimethalin 0.75 kg/ha +imazethapyr 0.075kg/ha pre-em tank-mix	9.40	9.67	9.54	4.01	4.45	4.23
Pendimethalin 0.75 kg/ha followed by quizalofop-p-ethyl 0.025 kg/ha at 30 DAS	7.81	8.15	7.98	3.72	4.03	3.88
Pendimethalin 0.75 kg/ha + oxyfluorfen 0.2 kg/ha pre-em tank-mix	8.63	9.00	8.82	3.89	4.27	4.08
Weedy check (WC)	2.62	2.92	2.77	2.77	3.00	2.88
Weed -free check (WFC)	9.87	10.32	10.09	4.37	4.85	4.61
SEm ±	0.28	0.27	0.192	0.15	0.16	0.111
LSD (P=0.05)	0.71	0.77	0.55	0.44	0.48	0.32

by weed control treatments in both year, and weed-free-check resulted in highest values of yield and bulb diameter, followed by the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha in both years. Weedy check gave the lowest garlic yield and bulb diameter and all weed control measures exhibited higher garlic yield and bulb diameter than weedy check. Vora and Mehta (1998) and Mahmood *et al*. (2002) found

Table 4 Total N, P and K uptake by weed as influenced by planting method and herbicide application

Treatment	N (kg/ha)		P (kg/ha)		K (kg/ha)	
	2012	2013	2012	2013	2012	2013
Planting method (P)						
Flat bed	30.3	28.0	3.3	3.2	23.9	23.3
Raised bed (FIRBS)	23.3	19.5	3.3	3.0	18.7	17.0
SEm ±	0.65	0.62	0.08	0.08	0.49	0.46
LSD(P=0.05)	3.95	3.76	NS	NS	3.00	2.82
Weed control treatment (W)						
Pendimethalin 1.0 kg/ha pre-em	9.9	9.7	1.2	0.7	9.6	9.3
Pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha pre-em tank-mix	15.6	13.2	2.2	2.2	12.0	12.6
Pendimethalin 0.75 kg/ha +imazethapyr 0.075kg/ha pre-em tank-mix	8.9	6.8	0.5	0.9	6.2	5.6
Pendimethalin 0.75 kg/ha followed by quizalofop-p-ethyl 0.025 kg/ha at 30 DAS	20.9	16.4	2.9	2.7	15.6	14.2
Pendimethalin 0.75 kg/ha + oxyfluorfen 0.2 kg/ha pre-em tank-mix	11.8	11.1	0.8	0.7	8.6	7.5
Weedy check (WC)	120.3	108.8	15.3	14.3	97.1	91.7
Weed -free check (WFC)	0.0	0.0	0.0	0.0	0.0	0.0
SEm ±	1.19	1.12	0.14	0.13	0.88	0.69
LSD (P=0.05)	3.48	3.28	0.41	0.38	2.58	2.00

Table 5 Total N, P and K uptake by garlic crop as influenced by planting method and herbicide application

Treatment	N (kg/ha)		P (kg/ha)		K (kg/ha)	
	2012	2013	2012	2013	2012	2013
Planting method (P)						
Flat bed	84.7	95.2	18.9	20.1	38.1	41.0
Raised bed(FIRBS)	103.1	117.2	24.2	25.8	56.4	60.7
SEm ±	1.50	1.91	0.40	0.56	0.88	1.06
LSD(P=0.05)	9.19	11.62	2.41	3.42	5.37	6.46
Weed control treatment (W)						
Pendimethalin 1.0 kg/ha pre-em	116.2	130.0	25.7	27.6	55.7	60.6
Pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha pre-em tank-mix	76.5	88.6	17.9	19.9	30.1	32.8
Pendimethalin 0.75 kg/ha +imazethapyr 0.075kg/ha pre-em tank-mix	141.9	156.1	25.9	26.6	50.4	53.7
Pendimethalin 0.75 kg/ha followed by quizalofop-p-ethyl 0.025 kg/ha at 30 DAS	81.9	99.3	26.1	27.4	60.0	63.6
Pendimethalin 0.75 kg/ha + oxyfluorfen 0.2 kg/ha pre-em tank-mix	94.3	104.3	26.3	27.7	62.6	67.1
Weedy check (WC)	25.2	29.4	7.3	8.2	17.5	19.2
Weed -free check (WFC)	121.5	135.5	22.0	23.3	54.3	58.9
SEm ±	2.41	3.10	0.64	0.86	1.60	1.84
LSD (P=0.05)	7.06	9.04	1.86	2.50	4.67	5.36

that pendimethalin and oxadiazon application alone did not control weeds effectively in garlic crop. The highest bulb yield of garlic was recorded when pendimethalin was followed by mechanical weeding or hoeing.

Nutrients uptake

Weeds had lower N, P and K uptake than that by garlic plants (Tables 4 and 5). Highest N, P and K uptake by weeds was observed in weedy check, and the lowest uptake, excluding weed-free check, in the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ ha in both years (Table 4). Barring P uptake, the N and K uptakes by weeds varied significantly due to planting methods. Weeds under flat beds extracted significantly higher amount of N and K from soil, which indicates the superiority of raised bed over flat bed towards weed management in garlic. This resulted in significantly higher uptake of N, P and K by garlic crop in raised beds compared to those in flat beds (Table 5). Nitrogen, P and K uptake by garlic crop was higher in the pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha treatment than in other herbicides treatments in both years.

This two-year study shows that the raised bed (FIRBS) was superior to flat bed towards weed management in garlic. Similarly, the pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha through greater reduction in weed dry weights and N, P and K uptake by weeds resulted in higher garlic bulb yield. Therefore, a combination of the raised bed with tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.075 kg/ha may be recommended for higher bulb yield of garlic through better weed management.

REFERENCES

Arnold R N, Murray M W, Gregory E J and Smeal D. 1993. Weed control in Pinto beans (*Phaseolus vulgaris*) with imazethapyr combination. *Weed Technology* **7**: 361–4.

Das T K. 2008. *Weed Science: Basic and Applications*, pp 119–25, 1st Edn. Jain Brothers Publishers, New Delhi.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, Second Edition, pp 97–130. John Wiley & Son publication.

Kaur J. 2001. Effect of planting methods and row spacings on yield and quality of Japanese mint (*Mentha arvensis* L.). M Sc thesis, Punjab Agricultural University, Ludhiana.

Lawande K E, Khar A, Mahajan V, Srinivas P S, Sankar V and Singh R P. 2009. Onion and garlic research in India. *Journal of Horticultural Sciences* **4**(2): 91–119.

Madan S P, Jassal S and Saimbhi M S. 1994. Herbicidal control of weeds in garlic. *Punjab Vegetable Growers* **29**: 1–2.

Mahmood T, Hussain S I, Khokhar K M, Jeelani G and Hidayatullah M. 2002. Weed control in garlic drop in relation to weedicides. *Asian Journal of Plant Sciences* **1**(4): 412–3.

Prasad R, Shivay Y S, Kumar D and Sharma S N. 2006. *Learning by Doing Exercises in Soil Fertility.* Division of Agronomy, Indian Agricultural Research Institute, New Delhi.

Qasem J R. 1996. Weed competition in garlic (*Allium sativum* L.). *Journal of Horticultural Sciences* **71**:41–8.

Srivastava S C, Sharma U C, Singh B K and Yadav H S. 2012**.** A profile of garlic production in India: facts, trends and opportunities. *International Journal of Agriculture, Environment and Biotechnology* **5**(4): 477–82.

Vora V D and Mehta D R. 1998. Integrated weed management in winter garlic. *Agricultural Science Digest,* Karnal **18**: 237–9.

Younesabadi M, Das T K and Sharma A R. 2013. Effect of tillage and tank-mix herbicide application on weed management in soybean (*Glycine max*). *Indian Journal of Agronomy* **58**(3): 372–8.