Biological Forum – An International Journal 16(3): 250-256(2024)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Comparative Bio-efficacy of Herbicides for Weed Management in Garlic

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(Received: 15 January 2024; Revised: 03 February 2024; Accepted: 23 February 2024; Published: 15 March 2024)
(Published by Research Trend)

ABSTRACT: Since, weed are the most important biotic constraints in garlic cultivation, it is necessary to have the strategy for the use of proper herbicide mixtures at right time, in right dose, by right method to attain target yield and economic benefit. In this view, field experiment was conducted on medium black calcareous soil at Junagadh (Gujarat) during *Rabi* season of 2021-22 to study the comparative bio-efficacy of herbicides for weed management in garlic. The trial comprising 14 treatments was arranged in randomized block design with 3 replications. The outcomes revealed that next to weed-free treatment, tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha as pre-emergence (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 days after sowing (DAS), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS and pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS enhanced various growth parameters *viz*., plant height, leaves per plant; yield attributes *viz*., equatorial diameter of bulb, polar diameter of bulb, bulb weight, number of cloves/bulb and ultimately gave higher bulb and stover yields. These treatments also reduced density as well as dry matter of weeds and had less reduction in yield due to the better control of weeds, less crop weed competition, higher weed control efficiency and herbicide bio-efficacy. Effective control of complex weed flora with profitable yield of garlic can be secured by application of tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS, pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS, oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS, tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* hand-weeding (HW) at 30 DAS or tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS.

Keywords: Economics, garlic, growth, herbicide mixtures, weed indices, yield.

INTRODUCTION

India has been recognised as "*Home of Spices*" from ancient eras. Among the spices, Garlic (*Allium sativum* L.) is one of the important spice crops of *Alliaceae* family. It is the second most widely cultivated crop after onion. Its origin is linked to central Asia. Garlic as a whole is called either head or else knob. However, the individual part is known as the clove. It is grown for its pungent flavoured bulbs world-wide to season foods. It involves of an underground bulb and above ground vegetative part, which also contains a flat as well as slender leaves. It having fibrous root system and is frost resilient. Garlic bulb encompasses alliin, volatile oil and allinase. Volatile oil contains diallyl thiosulphinate, an active aroma principle of garlic. Due to its pungent smell, garlic is commonly known as stinking rose (Sethi *et al*., 2014). In India, key garlic cultivating states are Gujarat, Madhya Pradesh, Rajasthan, Uttar Pradesh, Assam and Odisha. In Gujarat, major garlic growing areas are Rajkot, Bhavnagar, Gondal, Dhoraji, Upleta and Junagadh. In India, the average garlic area, production and productivity is about 3,52,663 ha, 29,26,095 tonnes and 8.30 t/ha, respectively. While in Gujarat, average area, production and productivity is about 12,180 ha, 94,555 tonnes and 7.76 t/ha, respectively (Anon., 2021).

Supply of garlic is still below the actual needs of the people due to its high demand and low production. Garlic is highly susceptible to weed infestation due to its slow emergence and slow initial growth, shallow root system, non-branching habit, sparse foliage, frequent irrigation and high fertilizer application (Lawande *et al*., 2009; Rahman *et al*., 2012). Weeds compete for nutrients, soil, moisture, space and light considerably reducing the yield, quality and value through increased production and harvesting costs (Gohil *et al.,* 2014). Weed incursion in garlic is one of the major factors for loss in yield and bulb loss to the tune of 30-60% (Adekpe *et al*., 2007; Lawande *et al*., 2009). Weed reduces the bulb yield to the degree of 40 to 80% (Verma and Singh, 1996; Ahirwar *et al*. (2021a). Critical period for weed control in garlic is assessed to be from 21 to 49 days after crop emergence. This critical period is the time interval during which crops should be free from weed interference to avoid yield losses.

Emergence of weed seedlings differs every year in timing, intensity and extent. Hence forth, herbicides have as a big advantage to farmers in zones where the labour availability is limited and remunerations are high. Herbicides are the most efficacious weed control know-how ever advanced as they are selective, cost effective, easy to apply, have persistence that can be succeeded and offer flexibility in application time (Gohil *et al.,* 2020; Kadivar *et al.,* 2023). Most of the experiments conducted on weed management in garlic using the herbicides showed significant effect on bulb yield (Sandhu *et al*., 1997; Vora and Mehta 1998; Vora and Mehta 1999; Mahmood *et al*., 2002). Hence, present investigation was conducted to investigate comparative bio-efficacy of herbicides for weed management in garlic.

MATERIALS AND METHODS

A field experiment was carried out during *Rabi* season of 2021-22 at Weed Control Research Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh (Gujarat) at 21.5°N latitude and 70.5°E longitude with an altitude of 60 m above the mean sea level. The climate is typically subtropical characterized by fairly cold and dry winter, hot and dry summer and warm and moderately humid monsoon. The soil of the experimental plot was clayey in texture, high in organic carbon (0.96%) and alkaline in reaction with pH 8.03 and EC 0.57 dS/m. The soil was medium in available nitrogen (406.00 kg/ha), high in available phosphorus (88.23kg/ha) and available potassium (322.00 kg/ha).

The experiment having 14 treatments *viz*., pendimethalin 0.90 kg/ha as pre-emergence(PE) *fb* hand-weeding (HW) at 30 days after sowing (DAS) (T_1), oxyfluorfen 0.24 kg/ha (PE) *fb* HW at 30 DAS (T_2), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS (T_3), oxadiargyl 75 g/ha as early post-emergence at 7 DAS *fb* HW at 30 DAS (T_4), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop 40 g/ha at 30 DAS (T_5), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* propaquizafop 62.5 g/ha at 30 DAS (T_6), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_8), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha(PE)*fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_{10}), pre-mix quizalofop + oxyfluorfen 100 g/ha as post-emergence (PoE) at 25 DAS (T_{11}), pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha (PoE) at 25 DAS (T_{12}), weed-free check (HW at 15, 30 and 45 DAS) (T_{13}) and unweeded check (T_{14}) were laid out in RBD design with 3 replications. The gross and net plot size were 4.0 m × 2.4 m and 3.0 m × 1.8 m, respectively.

The garlic (*cv*. GJG-5) was sown with a standard package of practices. By following the recommended seed rate of 500-600 kg cloves/ha, the sowing was done on 25th November, 2021 by keeping 15 × 10 cm spacing at a depth of 5 cm. Garlic was fertilized with recommended dose of 50-50-50 N-P_2O_5-K_2O kg/ha along with FYM 10 t/ha. The herbicides were sprayed as per treatments using a knapsack sprayer with a spray volume of 500 L/ha. The growth parameters of the plants were documented at harvest and finally, the yield attributes and yield were documented after harvest. The major weed flora or different weed species observed in the experimental plots were recorded at 20, 40, 60 DAS and at harvest by quadrate count method in each plot. The quadrate (0.5 m × 0.5 m) was placed randomly in each net plot. The data thus obtained were transformed and expressed in no./m^2. Weeds present in an iron quadrate measuring 0.5 m × 0.5 m area were collected and permitted to sun-dry. The dry weight of total weeds g/m^2 was recorded at 20, 40, 60 DAS and at harvest from respective treatments and weed dry weight for total weeds was expressed in kg/ha at harvest. Weed control efficiency was measured as the competence to control the weed in term of dry matter accumulation in treated plots compared to unweeded control plot and expressed in percent. Weed control efficiency (WCE) was calculated as per formula suggested by Kondap and Upadhyay (1985). The weed index (WI) was estimated as per formula suggested by Gill and Kumar (1969). The data were subjected to statistical analysis by implementing appropriate analysis of variance as suggested by Gomez and Gomez (1984). Wherever the F values were observed significant at 5% level of probability, the CD values/DNMRT was calculated for making comparison among the treatment means.

RESULTS AND DISCUSSION

A. Effect on growth parameters

A close check of data on plant height (Table 1) revealed that the diverse weed management treatments showed their significant influence on plant height. The next to weed-free check (T_{13}), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha as pre-emergence (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 days after sowing (DAS) (T_9), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_8), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS (T_3), pendimethalin 0.90 kg/ha (PE) *fb* hand-weeding (HW) at 30 DAS (T_1) and tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE)*fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_{10}) recorded significantly highest plant height. However, significantly lowest plant height (36.93 cm) was reported in unweeded check (T_{14}).

An appraisal of data (Table 1) pointed out that different treatments produced their significant level on the number of leaves/plant. Significantly, highest number of leaves/plant (11.93) was recorded with weed-free check (T_{13}), followed by tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_8) and pendimethalin 0.90 kg/ha (PE)*fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7). In contrast, significantly lowest number of leaves per plant (7.73) was registered under unweeded check (T_{14}).

The highest plant height and number of leaves per plant at harvest under above mentioned treatments might be due to they had lesser crop weed competition for nutrient, moisture, space and light due to lower weed density. The lesser values of growth parameters were recorded under the unweeded check (T_{14}) owing to severe competition by weeds with the crop for resources, which made the crop plant ineffectual to take up adequate moisture, nutrients and light, consequently growth was suppressed due to reduced photosynthesis and breakdown of photosynthates. The examination of data showed that statistically there was no significant effect of different weed management treatments on neck thickness of bulb after harvest (Table 1). Therefore, it is specified that there was no any adverse effect of weed management treatments on neck thickness of the bulb of garlic. These findings on growth parameters are in close conformity with those of Patil *et al.* (2016); Aghabeigi and Khodadadi (2017); Sahoo *et al.* (2018); Ganapathi *et al.* (2020).

B. Effect on yield attributes

A scrutiny of data (Table 1) revealed that the different weed management treatments exerted their significant effect on the equatorial diameter of the bulb. The next to weed-free check (T_{13}), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_8), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS (T_3), pendimethalin 0.90 kg/ha (PE) *fb* HW at 30 DAS (T_1) and tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_{10}) recorded significantly highest equatorial diameter of bulb. Conversely, significantly lowest equatorial diameter of bulb (27.43 mm) was observed under the treatment pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha (PoE) at 25 DAS (T_{12}).

Table 1: Effect of different weed management treatments on plant height, no. of leaves/plant, neck thickness and equatorial diameter of bulb of garlic.

	Treatments	Plant height (cm)	No. of leaves/plant	Neck thickness (mm)	Equatorial diameter of bulb (mm)
T_1	Pendimethalin 0.90 kg/ha (PE) *fb* HW at 30 DAS	40.13 abcd	9.50 bc	4.48	29.67 abcd
T_2	Oxyfluorfen 0.24 kg/ha (PE) *fb* HW at 30 DAS	38.30 bcd	8.23 cd	4.33	28.07 bcd
T_3	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS	40.33 abcd	9.77 b	4.49	29.73 abcd
T_4	Oxadiargyl 75 g/ha(early PoE) at 7 DAS *fb* HW at 30 DAS	38.00 bcd	8.13 d	4.32	27.90 bcd
T_5	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop 40 g/ha at 30 DAS	38.77 abcd	8.87 bcd	4.46	28.57 abcd
T_6	Pendimethalin 0.45 + oxyfluorfen 0.12 kg/ha (PE) *fb* propaquizafop 62.5 g/ha at 30 DAS	38.53 abcd	8.27 cd	4.43	28.27 bcd
T_7	Pendimethalin 0.90 kg/ha (PE)*fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	40.77 abc	10.93 a	4.52	30.60 abc
T_8	Oxyfluorfen 0.24 kg/ha (PE) *fb* propaquizafop + oxyfluorfen 43.75+105 g/ha 30 DAS	40.40 abcd	11.33 a	4.52	30.73 ab
T_9	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	41.33 ab	11.67 a	4.61	30.80 ab
T_{10}	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE)*fb* propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS	39.67 abcd	9.00 d	4.46	29.57 abcd
T_{11}	Pre-mix quizalofop + oxyfluorfen 100 g/ha (PoE) at 25 DAS	37.40 cd	8.07 d	4.02	27.77 cd
T_{12}	Pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha (PoE) at 25 DAS	37.17 cd	7.80 d	3.95	27.43 cd
T_{13}	Weed-free check	42.00 a	11.93 a	4.63	31.23 a
T_{14}	Unweeded check	36.93 d	7.73 d	3.74	27.63 d
	SEm±	1.09	0.40	0.19	0.86
	CD(P=0.05)	3.18	1.15	NS	2.51
	CV (%)	4.83	7.33	7.41	5.13

PE = Pre-emergence, PoE = Post-emergence, HW = Hand-weeding, DAS = Days after sowing

A scrutiny of data furnished in Table 2 indicated that diverse weed management treatments employed their significant effect on the polar diameter of the bulb. Among the different weed management treatments, next to weed-free check (T_{13}), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_8), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS (T_3), pendimethalin 0.90 kg/ha (PE) *fb* HW at 30 DAS (T_1) and tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_{10}) recorded maximum polar diameter of bulb. On the other hand, the significantly minimum polar diameter of bulb (24.57 mm) was registered under unweeded check (T_{14}).

An analysed data (Table 2) revealed that the different weed management treatments exerted their significant effect on bulb weight. The highest bulb weight was recorded with the weed-free check (T_{13}), followed bytank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_8), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS (T_3), and tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_{10}). However, the significantly lowest bulb weight (4.38 g) was obtained underunweeded check (T_{14}).

The data revealed that the various weed management treatments exerted their significant influence on the number of cloves/bulb (Table 2). The next to weed-free check (T_{13}), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7), oxyfluorfen 0.24 kg/ha(PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_8), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS (T_3), pendimethalin 0.90 kg/ha (PE) *fb* HW at 30 DAS (T_1) and tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_{10}) recorded significantly highest number of cloves/bulb. Whereas, significantly lowest number of cloves/bulb (7.33) was recorded under unweeded check (T_{14}).

Table 2: Effect of various weed management treatments on polar diameter of bulb, number of cloves/bulb, bulb weight, bulb yield and stover yield of garlic.

	Treatments	Polar diameter of bulb (mm)	Number of cloves/ bulb	Bulb weight (g)	Bulb yield (kg/ha)	Stover yield (kg/ha)
T_1	Pendimethalin 0.90 kg/ha (PE) *fb* HW at 30 DAS	27.43 abcde	12.67 ab	8.02 bcde	5215 bcd	1443 b
T_2	Oxyfluorfen 0.24 kg/ha (PE) *fb* HW at 30 DAS	26.33 bcdef	10.47 bcd	7.48 de	4774 d	1325 b
T_3	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS	27.60 abcde	12.73 ab	9.42 abc	6173 ab	1481 b
T_4	Oxadiargyl 75 g/ha (early PoE) at 7 DAS *fb* HW at 30 DAS	26.20 cdef	9.73 de	7.15 de	4618 d	1311 b
T_5	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop 40 g/ha at 30 DAS	26.83 abcde	10.07 d	7.75 cde	5029 cd	1343 b
T_6	Pendimethalin 0.45 + oxyfluorfen 0.12 kg/ha (PE) *fb* propaquizafop 62.5 g/ha at 30 DAS	26.37 bcdef	9.93 d	7.65 cde	4914 d	1326 b
T_7	Pendimethalin 0.90 kg/ha (PE) *fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	27.90 abc	13.93 a	9.98 a	6537 a	2067 a
T_8	Oxyfluorfen 0.24 kg/ha (PE) *fb* propaquizafop + oxyfluorfen 43.75+105 g/ha 30 DAS	27.80 abcd	13.67 a	9.68 ab	6427 a	2262 a
T_9	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	28.17 ab	14.27 a	10.05 a	6612 a	2090 a
T_{10}	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE)*fb* propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS	26.90 abcde	12.60 abc	9.05 abcd	5981 abc	1343 b
T_{11}	Pre-mix quizalofop + oxyfluorfen 100 g/ha (PoE) at 25 DAS	25.97 def	9.67 de	7.06 e	4383 d	1307 b
T_{12}	Pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha (PoE) at 25 DAS	25.87 ef	9.60 de	7.03 e	4420 d	1304 b
T_{13}	Weed-free check	28.47 a	14.60 a	10.68 a	6753 a	2362 a
T_{14}	Unweeded check	24.57 f	7.33 e	4.38 f	2932 e	915 c
	SEm±	0.56	0.72	0.58	316	104
	CD(P=0.05)	1.63	2.10	1.69	920	302
	CV (%)	3.61	10.85	12.24	10.26	11.49

The increase in yield attributing characters like equatorial diameter of bulb, polar diameter of bulb, bulb weight and number of cloves/bulb under above mentioned treatments might be due to there were decreased crop weed competition thus protected a substantial amount of nutrients for crop that directed to profuse growth allowing the crop to exploit more soil moisture and nutrients from deeper soil layers. The lowest values of yield attributes except equatorial diameter of bulb were recorded under the unweeded check (T_{14}) due to severe competition by weeds for resources, which made the crop plant unable to take up satisfactory moisture and nutrients, therefore growth was unfavourably affected. These findings on yield attributes are in the vicinity of those reported by Mohite *et al.* (2015); Saravaiya *et al.* (2016); Patel *et al.* (2018); Ganapathi *et al.* (2020); Ahirwar *et al.* (2021a).

C. Effect on crop yield

A glimpse of concerned data (Table 2) indicated that different weed management treatments exerted their remarkable effect on bulb yield. The highest bulb yield was registered in weed-free check (T_{13}), followed by tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7), oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS (T_8), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS (T_3) and tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_{10}). However, significantly the lowest bulb yield (2932 kg/ha) was found underunweeded check (T_{14}).

The scrutiny of data (Table 2) indicated that various weed management treatments unveiled their significant effects on stover yield. The next to weed-free (T_{13}) treatment, oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 +105 g/ha at 30 DAS (T_8), tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9) and pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7) recorded maximum stover yield. However, significantly lowest stover yield (915 kg/ha) was registered under unweeded check (T_{14}).

The higher bulb and stover yields under these treatments could be attributed to better control of weeds and might have favoured higher uptake of nutrients and water. The present findings on crop yield are within the close vicinity of those testified with diverse weed management treatments by Patil *et al.* (2016); Patel *et al.* (2018).

D. Weed studies

The weed flora in the experimental site was monocot weeds *viz*., *Echinochloa colona* (11.47%), *Brachiaria ramose* (10.19%), *Eluropus villosus* (8.92%), *Dactyloctenium aegyptium* (8.81%), *Asphodelus tenuifolius* (5.10%) and; dicot weeds *viz*., *Indigofera glandulosa* (8.92%), *Chenopodium album* (7.64%), *Commelina nudiflora* (7.01%) *Eclipta alba* (5.73%), *Digera arvensis* (2.54%), *Parthenium hysterophorus* (1.28%), *Euphorbia hirta* (0.63%), *Tridax procumbens* (0.63%), *Portulaca oleracea* (0.63%); and sedge weed *viz*., *Cyperus rotundus* (20.39%).

Table 3: Effect of diverse weed management treatments on weed dry weight at harvest, weed control efficiency and weed index of garlic.

	Treatments	Weed dry weight (kg/ha)	WCE (%)	WI (%)
T_1	Pendimethalin 0.90 kg/ha (PE) *fb* HW at 30 DAS	285	75.30	22.78
T_2	Oxyfluorfen 0.24 kg/ha (PE) *fb* HW at 30 DAS	330	71.39	29.31
T_3	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS	292	74.70	8.59
T_4	Oxadiargyl 75 g/ha (early PoE) at 7 DAS *fb* HW at 30 DAS	479	58.43	31.62
T_5	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop 40 g/ha at 30 DAS	365	68.37	25.53
T_6	Pendimethalin 0.45 + oxyfluorfen 0.12 kg/ha (PE) *fb* propaquizafop 62.5 g/ha at 30 DAS	382	66.87	27.23
T_7	Pendimethalin 0.90 kg/ha (PE) *fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	174	84.94	3.20
T_8	Oxyfluorfen 0.24 kg/ha (PE) *fb* propaquizafop + oxyfluorfen 43.75+105 g/ha 30 DAS	188	83.73	4.83
T_9	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	125	89.16	2.08
T_{10}	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS	306	73.49	11.43
T_{11}	Pre-mix quizalofop + oxyfluorfen 100 g/ha (PoE) at 25 DAS	455	60.54	35.10
T_{12}	Pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha (PoE) at 25 DAS	503	56.33	34.55
T_{13}	Weed-free check	35	97.00	0.00
T_{14}	Unweeded check	1153	0.00	56.58
	SEm±	46	-	-
	CD(P=0.05)	133	-	-
	CV (%)	21.91	-	-

WCE = Weed control efficiency, WI = Weed index, PE = Pre-emergence, PoE = Post-emergence, HW = Hand-weeding, DAS = Days after sowing

A glance of data (Table 3) clearly indicated that significantly lowest weed dry weight (34.55 kg/ha) was registered under the weed-free check (T_{13}). The next superior treatments in this regard were tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9), pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7) and oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75 + 105 g/ha at 30 DAS (T_8). Conversely, significantly the highest weed dry weight (1152.78 kg/ha) was noted under the unweeded check (T_{14}). This might be attributed to the effective control of weeds under these treatments through hand-weeding as well as combination and pre-mixed formulation of pre-emergence and post-emergence herbicides, which resulted in lower weed density and finally reduced the weed biomass. In addition to this, dense crop canopy might have inhibited weed growth and ultimately less biomass was found. The unweeded check (T_{14}) noted significantly higher dry weight of weeds due to the uncontrolled condition, which favoured luxurious weed growth leading to increased weed dry matter. These findings are in line with those of Chaudhari *et al.* (2019); Patel *et al.* (2020).

Weed control efficiency (WCE) indicated as the efficiency to control the weed in terms of dry matter accumulation in the treated plot compared to unweeded control plot and expressed in percent. The concerned data on WCE (Table 3) revealed that highest WCE (97.00 %) was recorded under weed-free check (T_{13}), followed by tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9) and pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7).

The highest (56.58%) weed index (WI) was observed with unweeded check (T_{14}), which indicates that unrestricted weed growth reduced garlic yield (Table 3). The next to weed-free (T_{13}) treatment, lower WI (2.08%) was recorded under tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9) followed by pendimethalin 0.90 kg/ha(PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_7) with 3.20% WI.

E. Economics

The data depicted in Table 4 showed that the maximum gross returns (₹ 406366/ha) and cost of cultivation (₹ 146089/ha) were obtained with weed-free check (T_{13}). The higher gross returns under this treatment could be due to better bulb and stover yields and higher cost of cultivation under this treatment was owing to higher cost of manual weeding. Maximum net returns (₹ 269651/ha) and higher B:C ratio (3.10) was achieved with tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS (T_9). This could be due to efficient control of weeds by combination of pre-and post-emergence herbicides. The higher benefits gained under these treatments were also due to comparatively less cost of herbicides than manual weeding as well as higher bulb and stover yields of garlic. However, unweeded check recorded the lowest gross returns, net returns, cost of cultivation and B:C ratio. These results corroborate with the findings of Patel *et al.* (2018); Siddhu *et al.* (2018); Chaudhari *et al.* (2019).

Table 4: Effect of different weed management treatments on economics of garlic.

	Treatments	Gross returns (₹/ha)	Cost of cultivation (₹/ha)	Net returns (₹/ha)	B:C ratio
T_1	Pendimethalin 0.90 kg/ha (PE) *fb* HW at 30 DAS	313610	134371	179239	2.33
T_2	Oxyfluorfen 0.24 kg/ha (PE) *fb* HW at 30 DAS	287107	137160	149947	2.09
T_3	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* HW at 30 DAS	371111	131889	239223	2.81
T_4	Oxadiargyl 75 g/ha (early PoE) at 7 DAS *fb* HW at 30 DAS	277730	132748	144982	2.09
T_5	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop 40 g/ha at 30 DAS	302412	126548	175864	2.39
T_6	Pendimethalin 0.45 + oxyfluorfen 0.12 kg/ha (PE) *fb* propaquizafop 62.5 g/ha at 30 DAS	295515	126161	169354	2.34
T_7	Pendimethalin 0.90 kg/ha (PE) *fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	393256	127760	265496	3.08
T_8	Oxyfluorfen 0.24 kg/ha (PE) *fb* propaquizafop + oxyfluorfen 43.75+105 g/ha 30 DAS	386761	128590	258171	3.01
T_9	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* quizalofop + oxyfluorfen 100 g/ha at 30 DAS	397785	128134	269651	3.10
T_{10}	Pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS	359560	128216	231345	2.80
T_{11}	Pre-mix quizalofop + oxyfluorfen 100 g/ha (PoE) at 25 DAS	263616	125195	138422	2.11
T_{12}	Pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha (PoE) at 25 DAS	265837	125276	140561	2.12
T_{13}	Weed-free check	406366	146089	260277	2.78
T_{14}	Unweeded check	176383	121603	54780	1.45

CONCLUSIONS

Based on the results obtained from the present investigation, it could be concluded that effective management of complex weed flora with higher yield and profitability of garlic can be obtained by either application of tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha as pre-emergence (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 days after sowing (DAS) or pendimethalin 0.90 kg/ha (PE) *fb* pre-mix quizalofop + oxyfluorfen 100 g/ha at 30 DAS or oxyfluorfen 0.24 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS or tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* hand-weeding at 30 DAS or tank-mix pendimethalin 0.45 kg/ha + oxyfluorfen 0.12 kg/ha (PE) *fb* pre-mix propaquizafop + oxyfluorfen 43.75+105 g/ha at 30 DAS.

FUTURE SCOPE

Garlic is grown for its pungent flavoured bulbs world-wide to season foods. It is also well known for having valuable medicinal properties. Gujarat is among the major garlic growing states in India. Supply of garlic crop is still below the actual needs of the people due to its high demand and low production. Garlic is highly susceptible to weed infestation and early infestation of weeds in garlic crop is one of the major constraints limiting the establishment of crop and thereafter its production. Under the present condition of non-availability of labour for timely weeding and high costs involved therein, it has become very difficult to maintain garlic crop free from complex weed flora particularly in the initial stage of growth. Hence, herbicidal control of weeds could assume greater significance. For effective and economical weed management in garlic, use of proper herbicide mixtures at right time, in right dose, by right method in addition to manual hand-weeding should be adopted according to the availability of labours.

Authors' contributions. This research work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Acknowledgment. We are thankful to all the staff members of the Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh for providing all the necessary facilities as well as guidance during the research work.

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How to cite this article: K.B. Sangani, B.S. Gohil, R.M. Muchhadiya, M.R. Kadivar and R.R. Donga (2024). Comparative Bio-efficacy of Herbicides for Weed Management in Garlic. *Biological Forum – An International Journal, 16*(3): 250-256.