Indian J. Weed Sci. **40** (3 & 4) : 109-120 (2008)

Efficacy of Tribenuron-methyl Applied Alone and Tank Mix Against Broadleaf Weeds of Wheat (*Triticum aestivum* L.)

Samunder Singh, S. S. Punia, R. S. Balyan and R. K. Malik
Department of Agronomy
CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India

ABSTRACT

Field and pot studies were carried out to evaluate the efficacy of tribenuron-methyl 75% PX (paste extruded) formulation used alone and tank mixed with grassy (field conditions) and broadleaf (screen house) herbicides during 2006-07 and 2007-08 at CCS Haryana Agricultural University, Hisar. Tribenuron 15 g/ha was effective against *Chenopodium album* under field conditions and provided 85-88% control. Increasing the dose from 15 to 30 g/ha or to 45 g/ha further increased control of *C. album*, but the effect was similar at higher rates. Adding a non-ionic surfactant (0.2%) increased the efficacy of tribenuron compared to no surfactant. 2,4-D ester/amine 500 g/ha or Sodium salt 1000 g/ha provided 100% control of *C. album* and the mortality was similar to premix of mesosulfuron+iodosulfuron (Atlantis) 21.6 and 14.4 g/ha, premix of sulfosulfuron+metsulfuron (Total) 16 g/ha, metsulfuron-methyl 4 g/ha or higher rates of tribenuron (26.25, 30 and 45 g/ha with and without surfactant). Tribenuron had no adverse effect on wheat upto 45 g/ha and no residual phytotoxicity was observed on mungbean or sorghum planted after wheat harvest. Effect of carfentrazone 20 g/ha and tribenuron 15 g/ha was similar against *C. album* but lower than other treatments. All broadleaf herbicides provided significantly higher yield compared to weedy plots, but were inferior to pre- or tank-mix applications of grassy and broadleaf herbicides. Atlantis 21.6 g/ha was phytotoxic to wheat and significantly checked plant growth and produced lower yield than 14.4 g/ha application rate. Tank mix applications of pinoxaden 45 g/ha and clodinafop 60 g/ha with tribenuron 15 g/ha produced highest yield and yield attributes of wheat. Under pot studies, tribenuron 15 g/ha, carfentrazone 20 g/ha, metsulfuron 4 g/ha, 2,4-D ester 250 g/ha and their tank mix combinations were compared with 2,4-D 500 g/ha against *Anagallis arvensis, Asphodelus tenuifolius, Chenopodium album, C. murale, Lathyrus aphaca, Melilotus indica, Malva parviflora, Medicago denticulata, Rumex dentatus, R. spinosus, Silene conoidea, Sisymbrium irio* and *Vicia sativa*. Tribenuron 15 g/ha provided 73 to 100% control of *A. arvensis, A. tenuifolius, M. denticulata, V. sativa, C. murale, R. spinosus, R. dentatus, C. album, S. irio* and *S. conoidea*, but it was not effective against *M. parviflora* and *L. aphaca*. Effect was also lower on *M. indica*, but tank mix applications with carfentrazone/2,4-D or metsulfuron improved its control by 15 to 25%. The overall weed mortality by tribenuron was similar to that of carfentrazone, but better than 2,4-D 250 g/ha, though the effect was significantly less than metsulfuron or 2,4-D 500 g/ha. Tank mixing of carfentrazone with metsulfuron inflicted maximum weed mortality (data averaged over species), but it was statistically similar to all other mixtures except carfentrazone plus 2,4-D 250 g/ha which has significantly less weed mortality. Similar trend was recorded in fresh weight accumulation by weeds with different treatments. *L. aphaca* and *M. parviflora* were most difficult-to-control weeds, whereas *S. conoidea* and *S. irio* were most susceptible weeds (data averaged over herbicide treatments). Tribenuron 15 g/ha had no significant edge over metsulfuron 4 g/ha against any of the test species in the screen house, though in tank mix applications with pinoxaden and clodinafop it produced similar yield compared to recommended field herbicides, with the advantage of no residual toxicity on succeeding sensitive crops.

Key words : Herbicide mixture, weed control efficiency, residual effect, wheat, broadleaf weeds

INTRODUCTION

Wheat being the major winter season crop of India, raised in 27 m ha, competes with several grassy and broadleaf weeds in its growth period depending upon the agronomic practices followed, locations (soil types) and weed management practices adopted. Weed flora is always dynamic and weed species adapt more quickly to the management practices followed, for their survival and prevalence. Broadleaf weeds were most common in wheat before the onset of green revolution, fertilizer responsive dwarf varieties which were less competitive with grassy weeds resulting in the dominance of *Phalaris minor* and *Avena ludoviciana* (Singh *et al*., 1995). Continuous use of PS II inhibitor herbicides viz., isoproturon to control grassy weeds in N-W India resulted in resistant biotypes of *P. minor* (Malik and Singh, 1995; Singh *et al*., 1997). New herbicides (fenoxaprop-

P-ethyl, clodinafop-propargyl and sulfosulfuron) recommended in 1998 to control isoproturon resistant *P. minor* (Chhokar and Malik, 2002), were more effective against grasses and their incessant use shifted the weed flora towards broadleaf weed dominance particularly where clodinafop and fenoxaprop were used. The effective control of grassy weeds, *Rumex dentatus, Medicago denticulata, Melilotus indica, Convolvulus arvensis* and *Malva parviflora* dominated the rice-wheat rotation system. Similarly, *R. spinosus* became a serious weed of other than rice-wheat rotation areas. Not only *Rumex* species offer a stiff competition to wheat, these also interfere in crop harvesting. A population of three plants/m^2 of *R. spinosus* was found to reduce the yield of wheat by 20% (Walia *et al.*, 2004). 2,4-D does not provide effective control of tough weeds like *C. arvensis*, *Rumex* species and *M. parviflora* and can also cause developmental deformities in some wheat accessions (Gill and Walia, 1985; Yaduraju and Ahuja, 1992). Also there are compatibility issues when 2,-D is used in the mixtures with ACCase inhibitor herbicides (FOPS) resulting in decreased weed control efficacy (Gillespie and Nalewaja, 1989; Punia *et al*., 2006a).

M. parviflora, a broadleaf weed with long tap root and capacity to withstand moisture stress, has increased occurrence in minimum or no-till wheat which is posing a serious challenge as it is not effectively controlled by sulfosulfuron. Carfentrazone-ethyl is very effective against *M. parviflora, R. dentatus* and *C. arvensis* (Punia *et al*., 2006b), but its efficacy against *C. album* and *M. indica* has been found less compared to other broadleaf herbicides. Moreover, delayed application (advance growth stage of weeds) lowers the efficacy of carfentrazone. There is also temporary crop setback following the application of carfentrazone. Carfentrazone tank mixed with tralkoxydim caused greater wheat injury than carfentrazone alone, though plants recovered within three weeks without any yield loss (Howatt, 2005).

Metsulfuron has been found effective against several broadleaf weeds, but an antagonistic effect was observed when it was mixed with fenoxaprop (Singh and Singh, 2005). Field studies with several broadleaf weeds revealed that carfentrazone and triasulfuron provided similar control to that of already recommended 2,4-D (Walia and Singh, 2007); however, Yadav *et al*. (2004) reported that tank-mix application of triasulfuron with clodinafop resulted in lower weed control efficacy of clodinafop. Similar results of tank mixture of triasulfuron with fenoxaprop, sulfosulfuron, or tralkoxydim were observed where the mixture resulted in lowering the mortality of grassy weeds. Triasulfuron applied in wheat also persisted long enough to damage sorghum planted after wheat harvest (Malik *et al*., 2008). Tribenuron-methyl evaluated both under pots and field conditions found ample crop safety and satisfactory control of *C. album*, but it was not equally effective against other broadleaf weed species (Singh and Malik, 1993, 1994). Balyan and Malik (1994) reported that tribenuron alone was not effective, but its tank mix application with isoproturon resulted in satisfactory control of weeds in barley. In spring barley, tribenuron 5.5 g/ha provided effective control of *Viola arvensis* (Davies and Wilson, 1997), but poor efficacy was recorded in direct seeded spring wheat when rainfall was limiting with a tank mixture of thifensulfuron 10 g/ ha+tribenuron 5 g/ha, but reduced plant density by 82-92% when rainfall was greater (Degenhardt *et al*., 2005). Tribenuron with thifensulfuron has been effectively used for broadleaf weed control in wheat (Bailey *et al*., 2004). Two or more herbicides are commonly used in Europe and America to increase the spectrum of weed control and delay the evolution of resistance (Green, 1989; Wrubel and Gressel, 1994).

Under Indian conditions, there are only few broadleaf weed herbicides for wheat and not all of them are compatible in the mixture with grass herbicides and there is a greater need to have more candidate herbicides which can be used target specifically, alone or in tank mix application to increase the spectrum of weed control under diverse agro-climatic conditions. This is also imperative to mitigate the shifting of weed flora towards difficult-to-control weeds. A new formulation of tribenuron-methyl [75% PX (Paste Extruded)] was evaluated under field and pot studies applied post-emergence, alone and tank mix with other herbicides for effective control of different weed species infesting wheat crop.

MATERIALS AND METHODS

Field Studies

Wheat cv. PBW-343 was sown using 100 kg seed/ha on beds (two rows per bed, 70 cm spaced) on 28 November 2006 and 30 November 2007 at Agronomy

Research Farm of CCS Haryana Agricultural University, Hisar. The soil of the experimental field was sandy loam in texture, low in organic carbon and available N, medium in P_2O_5 and high in K_2O with a pH of 8.4. Basal application of P_2O_5 and half of N was applied at sowing and the remaining half of N was applied after irrigation. Herbicides were applied 40-43 DAS. The treatments included tribenuron-methyl 15, 18.75, 22.5 and 30 g/ha with 0.2% surfactant, metsulfuron-methyl 4 g/ha, 2,4-D ester and amine 500 g/ha each, 2,4-D Na 1000 g/ha, carfentrazone-ethyl 20 g/ha, premix of sulfosulfuron+ metsulfuron (Total) 16 g/ha, premix of mesosulfuron+ iodosulfuron (Atlantis), 14.4 and 21.6 g/ha, tank mix of clodinafop-propargyl+tribenuron 60+15 g/ha and pinoxaden+tribenuron 45+15 g/ha alongwith untreated weedy check. In the second year, tribenuron was compared with and without surfactant. Tribenuron 15, 18.75, 22.5, 26.25 and 45 g/ha with 0.2% surfactant; tribenuron 18.75, 22.5, 26.25 and 45 g/ha without surfactant was compared with metsulfuron 4 g/ha, 2,4-D ester 500 g, carfentrazone 20 g/ha, premix of mesosulfuron+iodosulfuron (Atlantis) 14.4 g/ha, premix of sulfosulfuron+metsulfuron (Total) 16 g/ha and tank mix of pinoxaden+tribenuron 45+15 g/ha. The field was infested with *Avena ludoviciana* Dur., *Phalaris minor* Retz., *Chenopodium album* L., *Rumex dentatus* L., *Convolvulus arvensis* L. and *Melilotus indica* (L.) All. Fl. Ped. (in decreasing order of dominance). Wheat attained 24 cm height with 5-7 tillers compared to *A. ludoviciana* 25 cm (2-8 tillers), *P. minor* 18 cm (2-8 tillers), *C. album* 14 cm (5-7 branches), *R. dentatus* 8 cm (3-7 leaves), *C. arvensis* 25 cm (3-10 branches) and *M. indica* 7 cm (3-5 leaves) at the time of spray. Herbicides were sprayed using a knapsack sprayer fitted with three flat fan nozzles delivering 500 l water/ha in a plot size of 2.1 x 6.0 m, replicated thrice. Observations were recorded on crop phytotoxicity, plant height, weed count, per cent mortality, tillers/metre row length, earhead length and crop yield. Data were subject to ANOVA using SPSS software. After wheat harvest, moongbean and sorghum were planted in the treated plots to evaluate soil residual effect of tribenuron.

Pot Studies

Screen house experiments were conducted for two years to assess the efficacy of tribenuron applied alone and tank mix with broadleaf herbicides. Seed of *A. arvensis* L. (ANGAR), *A. tenuifolius* Cav. (ASHFI), *C. album* (CHEAL), *C. murale* L. (CHEMU), *Lathyrus aphaca* L. (LTHAP), *Malva parviflora* L. (MALPA), *Medicago denticulata* Willd. (MEDDE), *M. indica* (MEUIN), *R. dentatus* (RUMDE), *R. spinosus* (L.) Campd. (RUMSP), *Silene conoidea* L. (SILCD), *Sisybmrium irio* L (SSYIR) and *Vicia sativa* L. (VICSA) was planted in pots (20 cm top diameter and height) using 5 kg soil in 2 : 1 : 1 ratio of field soil, dunal sand and vermi-compost. *M. parviflora* and *M. denticulata* had germination problems during the first year and only one year data are presented. The soil was collected from fields where no herbicides were used for the last four years. At 45-46 DAS, plants were sprayed with tribenuron 15 g, carfentrazone 20 g, metsulfuron 4 g, 2,4-D ester 250 g/ha and tank mix of tribenuron+carfentrazone 15+20 g, tribenuron+ metsulfuron 15+4 g, tribenuron+2,4-D ester 15+250 g, carfentrazone+metsulfuron 20+4 g, carfentrazone+2,4-D ester 20+250 g, metsulfuron+2,4-D 4+250 g, 2,4-D ester 500 g/ha. A non-ionic surfactant (0.2%) was used with all treatments of tribenuron. There were three replicated pots for each species and herbicide treatment. Herbicides were sprayed as in field by placing pots in 2 x 5 m area. Pots were arranged in a CRD after spraying and watered daily/as required. Observations on visual mortality (0-100 scale, where 0=no effect and 100=complete mortality) were made at weekly intervals until five weeks after treatment (WAT). Plants were harvested five WAT and fresh weight were recorded. Pooled data of two years were analyzed using ANOVA and means separated by One-Way ANOVA using Student-Newman-Keuls tests.

RESULTS AND DISCUSSION

Field Studies

The field was infested with natural weed flora dominated by *P. minor, A. ludoviciana* and *C. album*. Other weeds present, but not uniformly distributed in all plots included *R. dentatus, C. arvensis, M. indica, Coronopus didymus* (L.) Sm., *A. arvensis* L., *F. parviflora* Lamk. and *L. aphaca*. Observations were made for grasses (*P. minor* and *A. ludoviciana*) and broadleaf weeds (*C. album* and others). Broadleaf weed population ranged from 42 to 59 plants/m^2 compared to 47 to 71 plants of grassy weeds in different treatments at the time of spray; both were statistically similar (Table 1). Tribenuron was effective against *C. album*, but the effect was slow and there was no complete mortality three weeks after treatment (WAT) as evident with 2,-4 D and metsulfuron. Also weed population recorded three WAT was statistically similar with different application rates of tribenuron (Table 1). Minimum broadleaf weed population was recorded with metsulfuron and readymix of sulfosulfuron+metsulfuron (Total), which was significantly better than tribenuron alone at 22.5 g/ha. All the three formulations of 2,4-D were similarly effective against *C. album* at the used rates, but effect was lower on *R. dentatus* and *C. arvensis* compared to carfentrazone, recorded 3 WAT (Table 1). Grassy weeds were more in plots treated with broadleaf herbicides, 3 WAT compared to readymix of sulfosulfuron+ metsulfuron, mesosulfuron + iodosulfuron (Atlantis) and tank mix of tribenuron with clodinafop or pinoxaden.

Table 1. Effect of different treatments on weed population and their growth (2006-07)

Treatments	Weed population (No./m^2) at spraying		Weed population (No./m^2) 3 WAT		Plant height (cm) 3 WAT	*C. album* mortality (%) 3 WAT	Tillers (No./m.r.l.)	Wheat yield (kg/ha)
	BLW	Grasses	BLW	Grasses	Wheat			
TBN+S 15 g	57	47	25	48	36	85 (67)	73	4189
TBN+S 18.75 g	59	51	24	48	34	92 (73)	76	4244
TBN+S 22.5 g	52	60	24	52	36	95 (80)	78	4317
TBN+S 30 g	45	51	15	44	33	98 (85)	77	4352
MSM+S 4 g	47	63	8	54	34	100 (90)	80	4386
2,4-D ester 500 g	47	68	17	55	35	100 (90)	78	4322
2,4-D amine 500 g	44	64	16	60	36	100 (90)	80	4335
2,4-D Na 1000 g	41	71	19	61	34	100 (90)	77	4310
CZN 20 g	42	63	15	55	35	83 (66)	75	4357
Total 16 g	56	69	8	33	30	98 (86)	103	5591
Atlantis 14.4 g	49	52	17	33	25	97 (81)	98	5476
Atlantis 21.6 g	55	56	12	29	23	100 (90)	94	5268
CDF+TBN 60+15 g	44	71	21	33	34	90 (72)	102	5525
PDN+TBN 45+15 g	45	49	17	29	34	92 (73)	107	5647
Weedy check	49	51	83	63	36	0 (0)	58	3315
LSD (P=0.05)	NS	NS	15	29	3	8	8	387

TBN–Tribenuron, S–Surfactant, MSM–Metsulfuron, CZN–Carfentrazone, BLW–Broadleaf weeds, m. r. l.–metre row length. Arcsin transformed values in parentheses. NS–Not Significant.

Tribenuron or other broadleaf herbicides (metsulfuron, 2,4-D and carfentrazone) had no adverse effect on wheat crop after spraying as there were no injury symptoms and no reduction in wheat growth. Some spots on leaves with carfentrazone that appeared after spraying, were not visible 3 WAT. However, suppression in wheat growth was evident with Atlantis and Total herbicides (Table 1); Atlantis was more phytotoxic at higher rate. Lower wheat height was recorded with these herbicide mixtures at 3 WAT, but tank mix application of clodinafop or pinoxaden with tribenuron had no adverse effect on wheat.

Efficacy of carfentrazone was lower on *C. album*, but it was more effective on *R. dentatus* and *C. arvensis*. Tribenuron 15 g/ha with 0.2% surfactant provided 85% mortality of *C. album* as observed 3 WAT; increasing tribenuron rates increased mortality, but there was no significant difference between 22.5 and 30 g/ha of tribenuron (Table 1).

Highest tiller numbers and crop yield were recorded with tank mix of tribenuron with pinoxaden, followed by Total and premix of clodinafop+tribenuron (Table 1). Lower numbers of tillers were recorded with higher rate of Atlantis compared to other mixtures of grass and broadleaf herbicides. There were no significant differences in the tiller numbers with different broadleaf herbicides, but they were significantly higher than weedy plots. Application of broadleaf herbicides increased wheat yield by 30% compared to untreated conditions, but it was lower by 28% compared to a mixture of grass and broadleaf weed herbicides (Table 1).

Similar results were recorded during the second year on the efficacy of tribenuron against *C. album* and other broadleaf weeds (Fig. 1). Lower mortality of *C. album* was observed when tribenuron was applied without surfactant at 18.5 and 22.5 g/ha followed by tribenuron 15 g/ha with 0.2% surfactant. All other treatments provided good control of *C. album* except carfentrazone that showed 85% mortality when recorded 3 WAT during 2007-08. Highest grain yield was recorded with pinoxaden+tribenuron (45+15 g/ha) which was similar to Total and Atlantis herbicides (Fig. 1). There was no residual effect of tribenuron on sorghum and mungbean planted after wheat harvest from 15 to 45 g with and without surfactant, applied alone or tank mix with clodinafop or pinoxaden, whereas germination and growth of sorghum were significantly affected by Total and Atlantis (data not presented).

Pot Studies

***Anagallis arvensis* :** Tribenuron provided 73% mortality of *A. arvensis*; tank mixing with broadleaf herbicides increased the mortality by 15 to 27% (Fig. 2). Tank mixing of tribenuron with metsulfuron was more effective than carfentrazone or 2,4-D, though there were no statistical differences in *A. arvensis* mortality among the three mixtures. Lowest mortality was recorded with carfentrazone followed by 2,4-D and their mixture. Tank mixing of tribenuron with carfentrazone provided significantly higher mortality than their alone applications. Similarly, 2,4-D 250 g/ha alone provided only 61% mortality, but its tank mixture with tribenuron or metsulfuron had same effect to that of its double application rate (Table 2). Significantly lower fresh

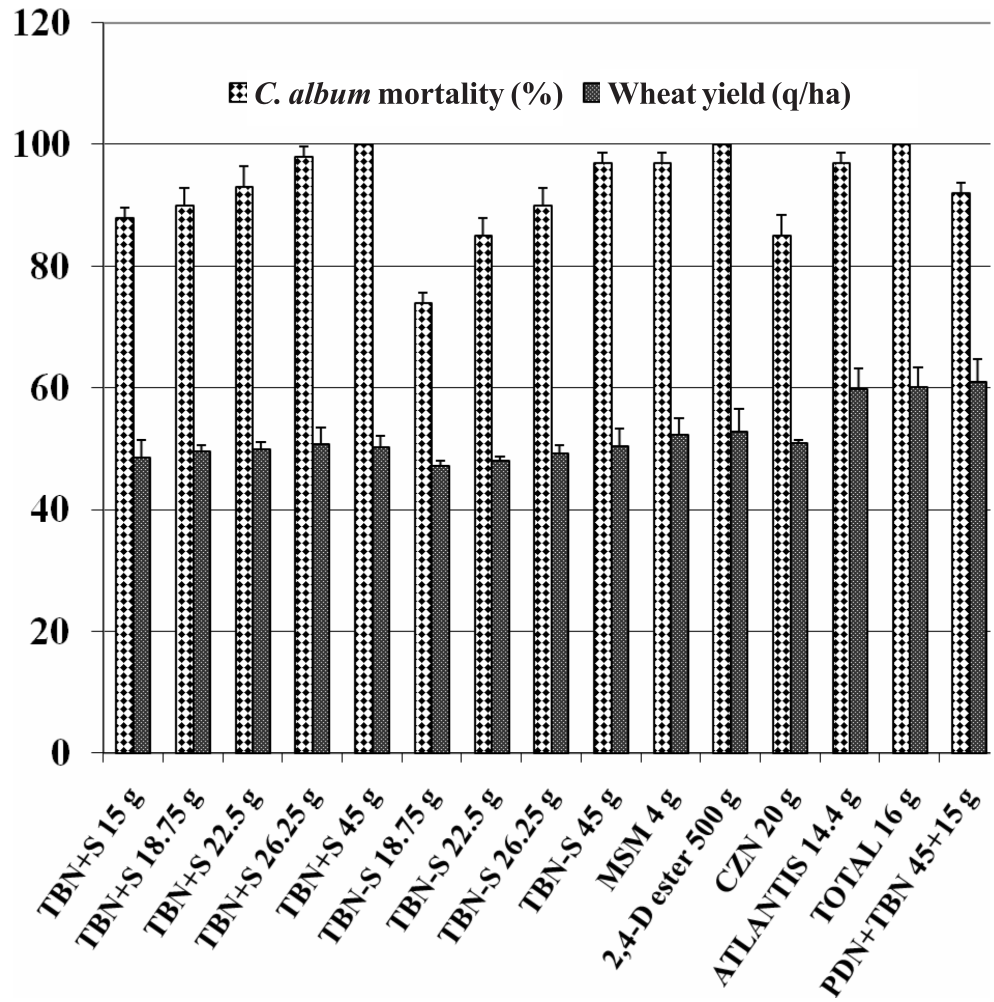

Fig. 1. Effect of tribenuron with and without surfactant on *C. album* mortality and wheat yield (2007-08), TBN–Tribenuron, S–Surfactant, MSM–Metsulfuron, CZN–Carfentrazone.

Table 2. Effect of tribenuron alone and tank mix with different broadleaf herbicides on fresh weight (g/pot) of some broadleaf weeds under pot studies

Herbicides	Weed species												
	ANGAR	ASHFI	CHEAL	CHEMU	LTHAP	MEUIN	MALPA	MEDDE	RUMDE	RUMSP	SILCD	SSYIR	VICSA
TBN 15 g	6.0	6.0	8.2	9.9	19.8	14.6	16.3	10.7	10.2	6.7	0.3	7.5	7.3
CZN 20 g	11.7	4.2	10.4	13.6	21.2	15.5	0.7	11.5	1.3	0.9	0.6	7.7	16.0
MSM 4 g	2.8	2.2	6.7	4.0	5.3	0.7	12.5	1.8	1.2	1.8	0.7	0.7	1.1
2,4-D 250 g	7.3	10.5	7.4	5.1	15.7	7.4	15.0	13.9	9.7	8.7	1.4	0.7	5.1
TBN+CZN 15+20 g	3.56	1.0	2.4	0.5	18.8	5.7	1.2	7.3	5.8	0.9	0.6	7.0	6.3
TBN+MSM 15+4 g	0.9	1.1	2.3	0.9	5.8	3.8	12.4	4.4	0.3	1.3	1.0	0.8	1.4
TBN+2,4-D 15+250 g	5.5	2.6	1.0	0.5	3.6	2.5	11.8	2.5	1.9	2.2	0.7	0.7	6.3
CZN+MSM 20+4 g	0.8	1.4	3.2	1.0	8.2	2.9	1.1	4.1	0.3	0.3	1.1	0.6	2.8
CZN+2,4-D 20+250 g	10.2	7.7	5.3	4.7	15.0	10.2	1.4	5.1	6.1	5.6	4.4	0.8	12.1
MSM+2,4-D 4+250 g	2.0	1.2	2.7	0.5	3.5	1.4	11.8	1.4	0.3	0.3	1.1	0.5	2.0
2,4-D 500 g	1.4	3.8	1.7	0.5	3.4	5.6	12.7	5.6	3.1	6.2	0.4	0.5	5.3
Control	16.5	21.5	31.9	28.2	29.2	37.2	25.6	24.4	48.3	34.0	16.9	20.3	31.4
LSD (P=0.05)	2.8	3.5	3.4	3.1	6.0	4.7	2.9	3.0	8.4	8.4	2.6	2.4	3.8

ANGAR–*Anagallis arvensis,* ASHFI–*Asphodelus tenuifolius,* CHEAL–*Chenopodium album,* CHEMU–*Chenopodium murale,* LTHAP–*Lathyhrus aphaca,* MEUIN–*Melilotus indica,* MALPA–*Melilotus parviflora*, MEDDE–*Medicago denticulata*, RUMDE–*Rumex dentatus,* RUMSP–*Rumex spinosus,* SILCD–*Silene conoidea,* SSYIR–*Sisymbrium irio,* VICSA–*Vicia sativa,* TBN–Tribenuron, CZN–Carfentrazone, MSM–Metsulfuron.

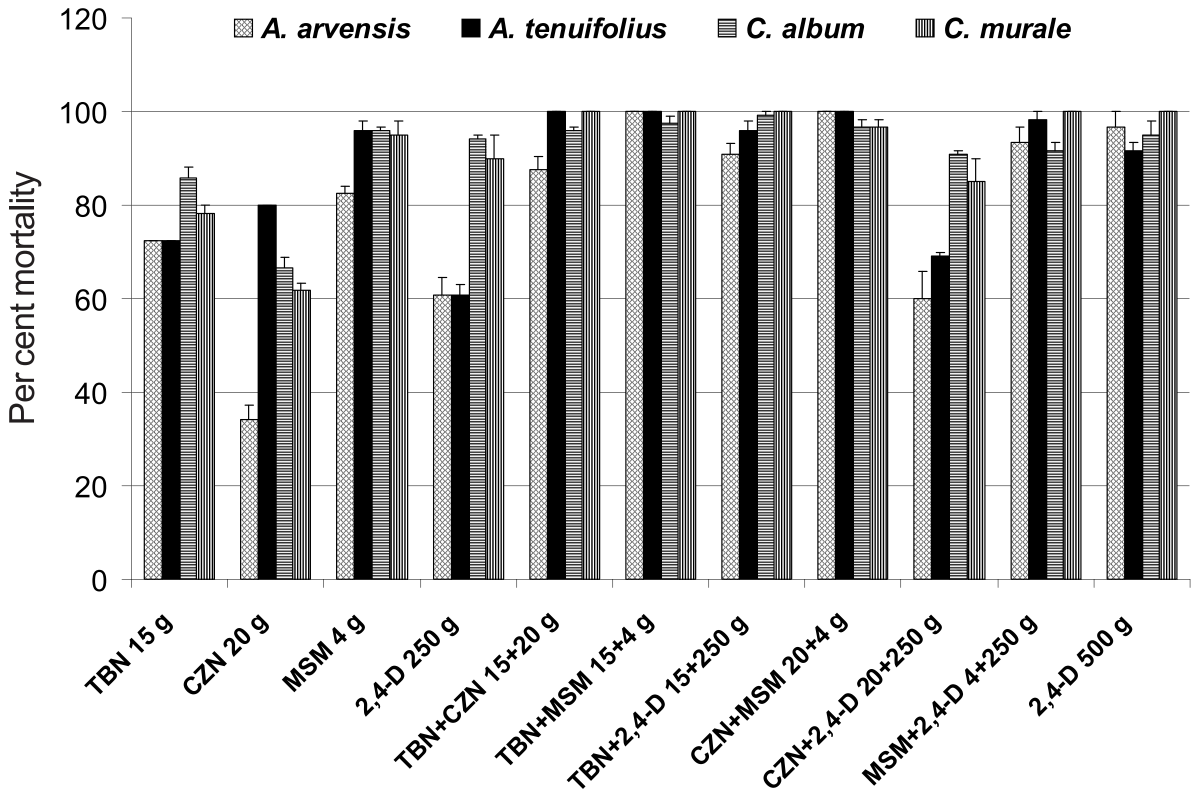

Fig. 2. Effect of tribenuron alone and tank mix with different broadleaf herbicides on mortality of *A. arvensis, A. tenuifolius, C. album* and *C. murale* under pot studies (Mean data of two years, bars indicate SEm.). TBN–Tribenuron, CZN–Carfentrazone, MSM–Metsulfuron.

weight was recorded with tribenuron and metsulfuron mixture compared to tribenuron+2,4-D 250 g/ha or tribenuron alone (Table 3). Highest fresh weight was recorded with control plants followed by carfentrazone and its tank mixture with 2,4-D, whereas minimum fresh weight was recorded with carfentrazone plus tribenuron mixture.

Asphodelus tenuifolius **:** Tribenuron alone was less effective compared to its tank mix application with carfentrazone/metsulfuron or 2,4-D (Fig. 2). Metsulfuron was more effective than carfentrazone applied alone, whereas 2,4-D 250 g/ha was less effective against *A. tenuifolius*, but increasing its dose to 500 g/ha provided 92% control. Tank mixing of 2,4-D 250 g with metsulfuron had no significant improvement on *A. tenuifolius* mortality over metsulfuron alone, and 2,4-D tank mixed with carfentrazone significantly reduced *A. tenuifolius* control compared to alone application of carfentrazone (Fig. 2). Tribenuron tank mixed with carfentrazone or metsulfuron was better than its mixture with 2,4-D in controlling *A. tenuifolius*. Highest fresh weight of *A. tenuifolius* was recorded with 2,4-D 250 g/ha (other than untreated plants), followed by tank mix of carfentrazone with 2,4-D and tribenuron alone (Table 2). All other mixtures reduced the fresh weight greatly over untreated plants.

Chenopodium album **:** All the herbicides used alone or with tank mix partners provided >90% control of *C. album* (Fig. 2), except carfentrazone (71%) and tribenuron (86%). 2,4-D 250 g/ha provided 94% mortality of *C. album*, but tank mixing with carfentrazone or metsulfuron resulted in slightly lower mortality than alone application of metsulfuron or 2,4-D. None of the treatments provided complete control of *C. album* (mean of two years), because the plant growth was more at the time of spray in the first year which lowered its mean mortality. Lowest fresh weight was recorded when tribenuron was tank mixed with 2,4-D, followed by tribenuron+metsulfuron, metsulfuron+2,4-D and 2,4-D alone at 500 g/ha (Table 2).

***Chenopodium murale* :** Except carfentrazone all herbicides used alone or in tank mix application provided more than 78% control of *C. murale* (Fig. 2). Tank mixing of carfentrazone with 2,4-D lowered the control compared to 2,4-D 250 g/ha alone which was significantly lower than other tank mix applications, 2,4-D alone at 500 g/ha, metsulfuron or tribenuron. Reduction in fresh weight of *C. album* was only 52% by carfentrazone compared to 67% reduction by tribenuron over untreated control (Table 2). Metsulfuron, 2,4-D 250 g alone and tank mixed with carfentrazone 20 g/ha reduced the fresh weight of *C. murale* by 86, 82 and 83%, respectively, whereas 2,4-D 500 g/ha and other tank mix applications reduced the fresh weight more than 96% over control (Table 2).

***Lathyrus aphaca* :** Only 2,4-D 500 g/ha and metsulfuron + 2,4-D 250 g/ha provided 85% control of *L. aphaca*, whereas tribenuron, carfentrazone and lower rates of 2,4-D failed to provide its satisfactory control (Fig. 3). Metsulfuron alone could provide only 74% control of *L. aphaca* which was similar to its tank mix application with tribenuron or carfentrazone. Tank mix application of tribenuron with metsulfuron provided 78% control of *L. aphaca*, but tribenuron or carfentrazone applied alone or in tank mix applications failed to control *L. aphaca*. Similarly, 2,4-D 250 g/ha or carfentrazone+ 2,4-D 250 g were ineffective as they could provide <45% control of *L. aphaca*. The efficacy of these herbicides applied alone and in tank mix application was similarly reflected in fresh weight accumulation by *L. aphaca* (Table 2).

***Melilotus indica* :** Metsulfuron was significantly better than tribenuron, carfentrazone and 2,4-D 250 g/ha in controlling *M. indica* (Fig. 3). Highest mortality of *M. indica* was observed with tank mix application of metsulfuron+2,4-D which was statistically similar to alone application of metsulfuron or its tank mix application with carfentrazone (Fig. 3). Carfentrazone tank mixed with 2,4-D or tribenuron exhibited lowest mortality of *M. indica* compared to

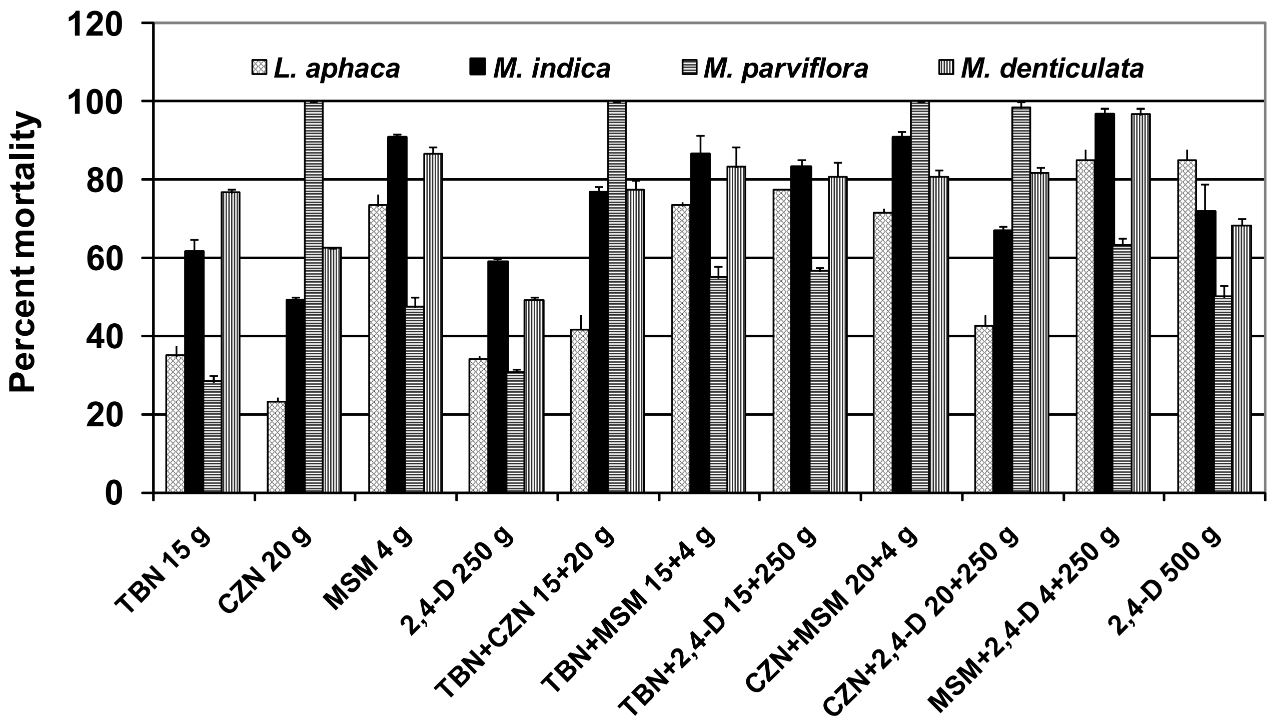

Fig. 3. Effect of tribenuron alone and tank mix with different broadleaf herbicides on mortality of *L. aphaca, M. indica, M. parviflora,* and *M. denticulata* under pot studies (Mean data of two years, bars indicate SEm.). TBN–Tribenuron, CZN–Carfentrazone, MSM–Metsulfuron.

other tank mix applications. Tribenuron tank mixed with metsulfuron did not increase *M. indica* control compared to alone application of metsulfuron. Fresh weight was more with carfentrazone, tribenuron and tank mix application of carfentrazone with 2,4-D 250 g/ha compared to other treatments (Table 2).

Malva parviflora **:** Carfentrazone was most effective against *M. parviflora*, whereas metsulfuron, 2,4-D or tribenuron failed to provide its effective control (Fig. 3). Also increasing the rate of 2,4-D to 500 g/ha could not provide >50% control. Tank mix applications of carfentrazone with tribenuron, metsulfuron or 2,4-D were effective, whereas other combinations failed to provide satisfactory control of *M. parviflora*. The poor efficacy of tribenuron and 2,4-D is also reflected in fresh weight accumulation by *M. parviflora* which was significantly more than other herbicidal treatments (Table 2). Carfentrazone alone and its tank mixtures with metsulfuron, tribenuron or 2,4-D caused more than 95% reduction in fresh weight accumulation and the effect was similar in all these treatments. Fresh weight reduction (51%) by metsulfuron was significantly more than tribenuron or 2,4-D 250 g/ha, but was similar to higher dose of 2,4-D or other tank mix applications.

Medicago denticulata **:** Carfentrazone or 2,4-D (both rates) were poor in controlling *M. denticulata* compared to metsulfuron (Fig. 3). Highest mortality was recorded with tank mix applications of metsulfuron+2,4-D, which was significantly better than other tank mix applications. Tribenuron alone provided only 77% control but none of the mixtures could provide similar control to that of metsulfuron tank mixed with 2,4-D. The fresh weight was reduced by 93 and 95% by metsulfuron alone and its tank mix application with 2,4-D compared to 43, 53 and 56% by 2,4-D 250 g, carfentrazone 20 g and tribenuron 15 g/ha, respectively (Table 2). The fresh weight of *M. denticulata* was significantly less with tribenuron+2,4-D 15+250 g/ha compared to alone application of 2,4-D 500 g/ha or tribenuron plus carfentrazone (Table 2).

Rumex dentatus **:** Tribenuron and 2,4-D were less effective against *R. dentatus* compared to carfentrazone and metsulfuron (Fig. 4). Increasing the rate of 2,4-D from 250 to 500 g/ha was also poor in controlling *R. dentatus*, but better than tank mix application of carfentrazone+ 2,4-D at 250 g/ha. Metsulfuron tank mixed with carfentrazone, tribenuron or 2,4-D provided complete mortality of *R. dentatus*, though effect was statistically similar to alone application of metsulfuron or carfentrazone (Fig. 4). Among the herbicidal treatments, highest fresh weight of *R. dentatus* was recorded with tribenuron followed by 2,4-D 250 g/ha, carfentrazone+2,4-D and tribenuron+carfentrazone and minimum with carfentrazone+metsulfuron (Table 2).

Rumex spinosus **:** Tribenuron provided significantly higher (82%) control of *R. spinosus* compared to 49 and 75% control with 2,4- D at 250 and 500 g/ha, respectively (Fig. 4). Carfentrazone 20 g/ha provided 99% control of *R. spinosus*, but tank mixing with 2,4-D significantly lowered the control (70%). Similarly, tank mix application of carfentrazone with tribenuron reduced the control of *R. spinosus* by 13% compared to carfentrazone alone. Metsulfuron tank mixed with tribenuron, carfentrazone or 2,4-D and tribenuron plus 2,4-D provided 91-100% control of *R. dentatus* (Fig. 4). All the herbicide treatments significantly reduced the fresh weight of *R. spinosus* compared to control, even the treatments with lower mortality caused more than 74% reduction in fresh weight of *R. spinosus* (Table 2).

Silene conoidea **:** Except 2,4-D 250 g/ha, all herbicides used alone or in tank mix application provided 94-100% control of *S. conoidea* (Fig. 4). Carfentrazone plus 2,4-D reduced the mortality to 94% compared to 100% by carfentrazone alone. Similarly, the fresh weight of *R. spinosus* was more in carfentrazone+2,4-D treated plants, compared to other treatments, though it was reduced by 74% compared to untreated plants (Table 2).

Sisymbrium irio **:** Lowest mortality was observed with carfentrazone (80%) followed by tribenuron (88%) and their tank mixture (85%), all other treatments provided more than 94% control of *S. irio* (Fig. 4). Similarly, the fresh weight of *S. irio* was significantly more with tribenuron, carfentrazone and their mixture compared to all other herbicides or their tank mix applications (Table 2).

Vicia sativa **:** Except metsulfuron (88%), no other herbicide used alone could provide satisfactory control of *V. sativa* (Fig. 4). Highest mortality of 95%

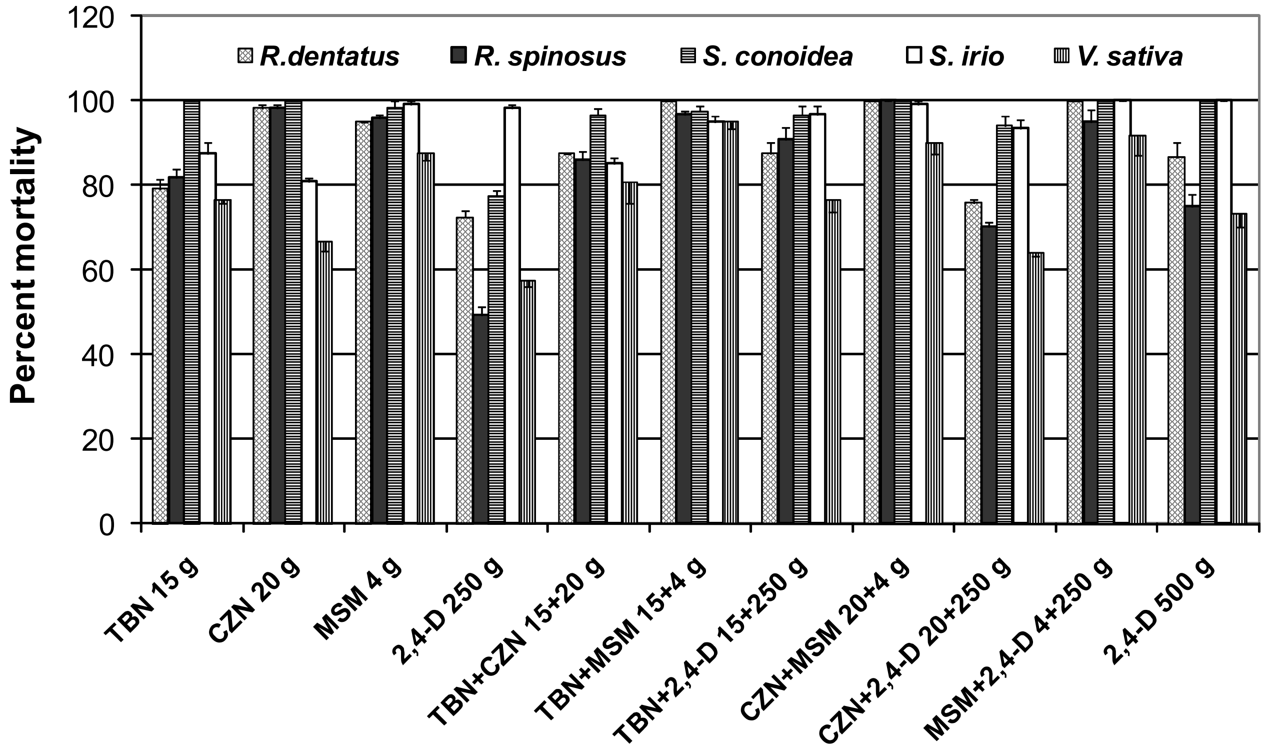

Fig. 4. Effect of tribenuron alone and tank mix with different broadleaf herbicides on mortality of *R. dentatus, R. spinosus, S. conoidea, S. irio* and *V. sativa* under pot studies (Mean data of two years, bars indicate SEm.). TBN–Tribenuron, CZN–Carfentrazone, MSM–metsulfuron.

was recorded with tank mix application of metsulfuron +tribenuron which was similar to metsulfuron+2,4-D or metsulfuron+carfentrazone, but significantly higher than tank mix application of tribenuron with carfentrazone. 2,4-D at either rate was not effective and tank mix application of 2,4-D with carfentrazone resulted in lowest weed mortality among tank mix applications. Lowest reduction in fresh weight (49%) was recorded with carfentrazone compared to untreated plants (Table 2). Tank mix application of carfentrazone with 2,4-D reduced the fresh weight by 61% over control and was better than alone application of carfentrazone. All other treatments significantly reduced the fresh weight of *V. sativa* (Table 2).

Interactions of Herbicides and Species

When data were averaged over species, highest mortality of 94, 93 and 91% was achieved by tank mixing of metsulfuron with carfentrazone or 2,4-D or tribenuron, respectively (Fig. 5). Tank mixing of carfentrazone with 2,4-D resulted in significantly lower weed mortality compared to other tank mix applications (data averaged over species). Metsulfuron and 2,4-D 500 g/ha provided 88 and 84% control of all weed species (averaged) and were significantly better than carfentrazone (72%), tribenuron (72%) and 2,4-D 250 g/ha (64%). Tribenuron tank mixed with carfentrazone or 2,4-D increased weeds mortality compared to their alone applications, but the effect was similar to metsulfuron alone (Fig. 5). Comparing among herbicides, tribenuron, 2,4-D 250 g, carfentrazone and carfentrazone plus 2,4-D had the maximum fresh weight of weed species (Fig. 5), whereas carfentrazone+metsulfuron and metsulfuron+2,4-D produced minimum fresh weight of weed species (data averaged over species). *L. aphaca* and *M. parviflora* were the toughest weeds, whereas *S. irio* and *S. conoidea* were most sensitive weeds, when data were averaged over herbicides (Table 2).

Tribenuron 15 g/ha was effective as tank mix application with pinoxaden or clodinafop under field conditions and there was no residual effect on succeeding

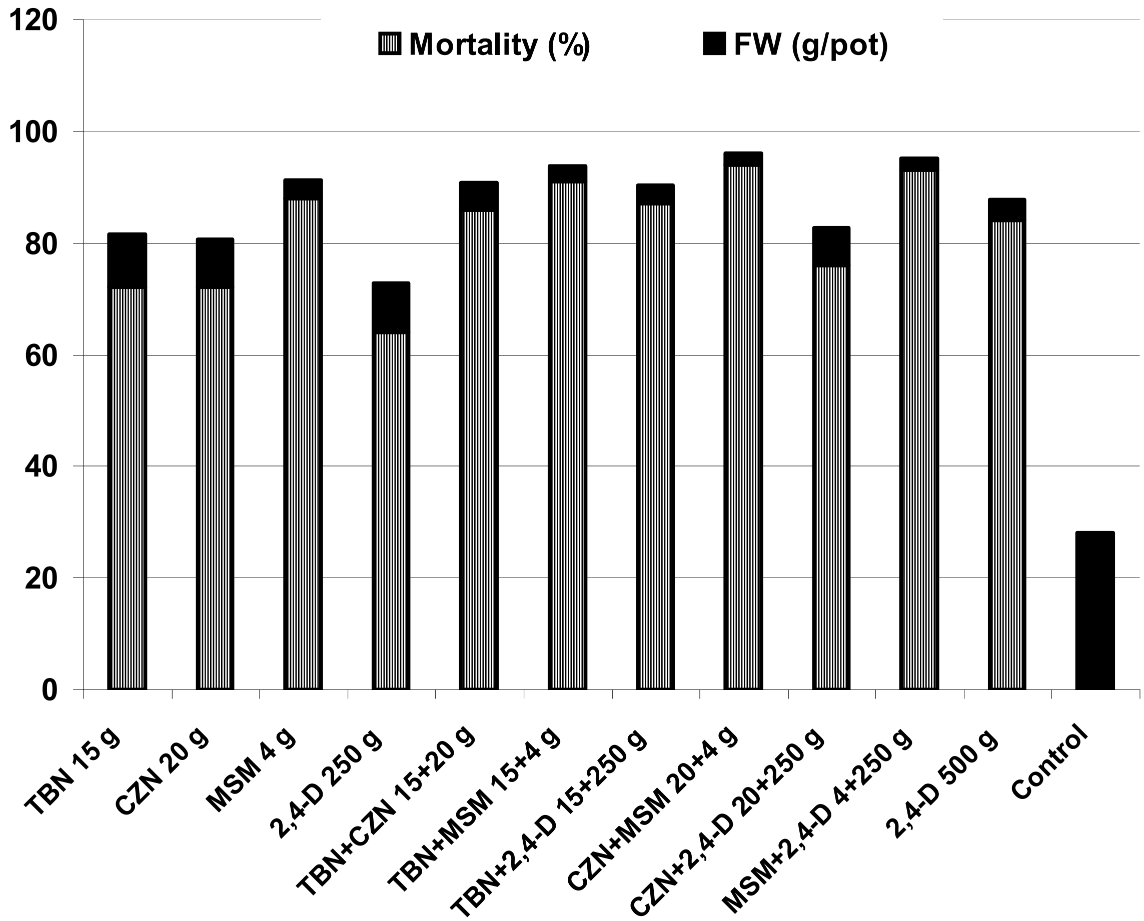

Fig. 5. Visual mortality and fresh weight of 13 weed species as affected by different herbicidal treatments [LSD (P=0.05), 7.0 for mortality and 2.3 for fresh weight], TBN–Tribenuron, CZN–Carfentrazone, MSM–metsulfuron.

sensitive crops. However, alone it was less effective against a range of broadleaf weeds compared to already recommended metsulfuron. There does not seem to be a significant improvement in the activity of new formulation of tribenuron over the old one (Singh and Malik, 1993, 1994; Balyan and Malik, 1994). Tribenuron 10 g/ha provided 68-78% control of broadleaf weeds in barley (Balyan and Malik, 1994). The efficacy of tribenuron increased with the addition of surfactant against *C. album*, *Rumex* spp. and other broadleaf weeds, but was not effective against *L. aphaca*. Singh and Malik (1993) recorded higher dry weight of weeds with 20 g/ha of tribenuron compared to 250 g/ha of 2,4-D ester. Fluroxypry+2,4-D was found more effective where metsulfuron, sulfosulfuron and thifensulfuron+ tribenuron only suppressed weed growth under drought conditions (Degenhardt *et al*., 2005). Under screen house condition, tribenuron provided similar weed mortality to that of carfentrazone, but had no specificity against any of the test species like carfentrazone which is best suited for *C. arvensis, Rumex* spp. and *M. parviflora*. The older formulation was also found effective against *V. sativa, A. tenuifolius* and *A. arvensis*, but was poor on *L. aphaca* and *M. indica* (Singh and Malik, 1994).

Thifensulfuron+tribenuron provided only 29% control of Hoary Cress (*Cardaria draba*) in winter wheat (Vasilakoglou *et al*., 2006). Similarly, thifensulfuron+ tribenuron (18+9 g/ha with 0.25% NIS) failed to control *Kochia scoparia* in wheat (Wolf *et al*., 2000); continuous use of tribenuron led to evolution of resistance in a major wheat weed, *Descurainia sophia* in China (Cui *et al*., 2008). Also some biotypes of wild mustard were found resistant to mixture of thinfesulfuron plus tribenuron in Canada (Warwick *et al*., 2005). Under the present field and screen house studies, tribenuron did not show any superiority against the target weed species compared to already recommended herbicides (metsulfuron and carfentrazone); the only plus point of its compatibility with grass herbicide may not prove effective if the field is infested with weed species that are not controlled by tribenuron alone (*M. parviflora* and *L. aphaca*).

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