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Influence of Weed Control and Sulphur Fertilization on Growth and Yield of Quality Protein Maize

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Field experiments were conducted for two consecutive rainy seasons of 2009 and 2010 at Udaipur (Rajasthan) to study the effect of weed control and sulphur application on productivity of Quality Protein Maize, associated weeds and residual effect on succeeding crops. Fifteen treatment combinations comprising five weed control (weedy check, tank mixture of atrazine at 500 g with alachlor at 1500 g, pendimethalin at 750 g, ethoxysulfuron at 15 g ha^{-1} as pre-emergence spray and two hand weeding at 15 and 30 DAS and three sulphur levels (00, 20 and 40 kg ha^{-1}) were under randomized block design in three replications. Amongst the weed control treatments, pre-emergence application of atrazine at 500 g + ethoxysulfuron at 15 g ha^{-1} and two hand weeding at 15 and 30 DAS accounted for significant reduction in the density of all the weed flora. These two treatments accounted for 78.1 – 78.6 % reduction in total weed density and 79.2 – 79.3 % reduction in weed dry matter. Atrazine at 500 g + alachlor at 1500 g ha^{-1} was the next treatment in the order of superiority with 68.8 and 70.1 % reduction in weed density and dry matter. However, ethoxysulfuron caused significant injury to maize crop. Plant height at 60 and 90 DAS and at harvest increased significantly through all weed control treatments over weedy check. The crop dry matter accumulation at 30 DAS significantly increased by two hand weeding, while dry matter at 60 and 90 DAS and LAI at 55 DAS were significantly higher with two hand weeding but its result was at par with that of atrazine + alachlor. Highest grain, stover and biological yields were registered with two hand weeding; however, these were at par with those obtained by combination of atrazine + alachlor. Sulphur rates had no significant effect on weed density and dry matter. Significantly higher plant height and dry matter of crop at all growth stages and LAI at 55 DAS were found with 20 kg S ha^{-1}, but crop dry matter at 30 DAS was significantly enhanced up to 40 kg S ha^{-1}. Application of 40 and 20 kg S ha^{-1} increased grain and stover and yield by 24.7 & 14.6 and 14.4 & 8.9, respectively over control. The treatments had no adverse effect on germination per cent, shoot length and biomass of succeeding crops.

Key words: Maize Quality Protein, yield, growth, residual effect

Maize is one of the most important cereal crops. It is grown in diversified agro-ecological and edaphic conditions (Joshi *et al.,* 2005). Its production is of great consequence to meet the growing demands of human food, animal and poultry feed, as well as for industrial processing by the wet and dry millers to produce value -added products (Krishna *et al.*, 2012) . However, the contents of essential amino acids viz. lysine and tryptophan normally do not meet the minimum requirements established for human growth (Scott *et al.,* 2004). To overcome the problem of low lysine and tryptophan, quality protein maize (QPM) was developed at CIMMYT with higher yield potential and protein content along with balanced composition of amino acids (Vasal *et al.*, 1999). Since its discovery, the QPM has been extensively adopted worldwide as a means to achieve food and nutritional security. Maize is known to be very responsive to better management. However, weeds constitute a major problem in harnessing yield potential of maize. A variety of annual grasses, broad leaf weeds and sedges often account for 50 - 75 % yield loss (Joshi *et al.,* 2005). The problem of weeds is acute because of rains which keep the soil moist and encourage several flushes, hot and humid weather which is congenial for weed growth, wide crop spacing and slow initial growth. Maize is particularly sensitive to weed stress during early part of development phase (Gantoli *et al.,* 2013). This warrants a spotlight on early season weed control. Due to rapid industrialization, increased literacy and migration of rustic population to cities, labour availability for timely weeding is becoming scarce in villages. Therefore, various individual herbicides have been widely recommended for the control of weeds in maize. However, the tank mix or sequential application of herbicides holds a better perspective of broad-spectrum weed control in maize (Dogan *et al.*, 2005; Gopal *et al.,* 2010). The herbicides like alachlor, pendimethalin and ethoxysulfuron in conjugation with atrazine may hold a good promise for this purpose. Sulphur is the fourth major nutrient after nitrogen, phosphorus and potassium (Jamal *et al.,* 2010). Its deficiency in soils of various Indian

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states varies from 5 to 83 % with an overall mean of 41 % (Singh *et al.*, 2001). However, sulphur as an essential plant nutrient has received little scientific attention. Inadequate sulphur supply may limit maize production (Malik *et al.,* 2012). Therefore, attention is now being focused on importance of this element in plant nutrition. Considering these facts the present investigation was undertaken to study the effect of herbicide mixtures and sulphur on growth and yield of QPM and to conduct bioassay to evaluate their residual effect on selected succeeding crops.

Materials and Methods

The experiments were laid out at Agronomy Farm, Rajasthan College of Agriculture, Udaipur during rainy seasons of 2009 and 2010. The region falls under agro-climatic zone IVA (Sub-Humid Southern Plain and Aravalli Hills) of Rajasthan. The soil of the experimental site was clay loam and alkaline in reaction (pH 8.0 and 8.1). The soil was medium in available nitrogen (274.56 and 279.61 kg ha^{-1}) and phosphorus (19.27 and 18.69 kg ha^{-1}) and high in available potassium (318.83 and 324.17 kg ha^{-1}) during both the years (2009 and 2010, respectively). The fifteen treatment combinations comprising of five weed control (weedy check, tank mixture of atrazine at 500 g + alachlor at 1500 g ha^{-1}PE, atrazine at 500 g + pendimethalin at 750 g ha^{-1} PE, atrazine at 500 g + ethoxysulfuron at 15 g ha^{-1} PE and two hand weeding at 15 and 30 DAS) and three sulphur levels (00, 20 and 40 kg ha^{-1}) were tested under randomized block design in three replications. A uniform dose of 120 kg N and 40 kg P_2O_5 ha^{-1} was given to the crop. Half dose of N and full dose of P_2O_5 and S (as per treatment) were given as basal application by drilling the desired quantities of urea, DAP and finely ground mineral gypsum in crop rows at about 5 cm below the seedling depth. Remaining 50 % N was top dressed through urea at knee height stage. The QPM variety HQPM- 1 was sown in furrows opened at a row spacing of 60 cm as per treatment using 20 kg ha^{-1} seed rate. It was treated with bavistin at 2 g kg^{-1} and placed at a depth of about 4-5 cm. As per treatments, the herbicides were sprayed two days after sowing as pre-emergence. These herbicides were sprayed with the help of knapsac sprayer having flat fan nozzle using 500 litres of water ha^{-1}. Thinning was done at 15 DAS in order to maintain plant to plant distance of 25 cm. One prophylactic spray of endosulfan 35 EC (0.03 per cent) was carried out at 35 DAS during both the years. The crop was harvested at full physiological maturity which was determined by formation of black layer in placental region of maize grain. Each plot in the experiment was surveyed at two places using 0.25 m^2 quadrate for studying weed composition and expressed as number m^{-2}. Later these samples were dried at 70 ^{o} C till a constant weight was obtained. The dry matter was then computed in terms of g m^{-2}. The herbicide toxicity on crop stand and growth were recorded at 30, 60 and 90 DAS by rating it in the scale of 0 to 10 (Rao *et al.,* 2000). In order to assess the residual effect of herbicides applied in maize on succeeding crops in rotation, bioassay technique was used (Sankaran *et al.,* 1993). The test crops were wheat, mustard and gram.

Results and Discussion

The weed flora present in the experimental field included broadleaved weeds viz. *Amaranthus viridis L., Commelina benghalensis L., Convolvulus arvensis L., Digera arvensis* Forsk., *Parthenium hysterophorus L., Phyllanthus niruri* Hook F., *Portulaca oleracea L. and Trianthema portulacastrum* L.; grasses viz. *Echinochloa colonum* (L.) Link., *Echinochloa crusgalli* (L.) Beauv, *Cynodon dactylon* (L.) Pers. and *Setaria glauca* L. along with one sedge viz. *Cyperus rotundus* L.

Weed density

The results indicate that the effect of two hand weeding was at par with that of atrazine + ethoxysulfuron and resulted in 95.3 - 95.8 per cent reduction in density of *Echinochloa* sp. Application of atrazine + alachlor and atrazine + pendimethalin were found next in order of superiority that resulted in 94.2 and 91.7 per cent decrease in the count of this weed. There was a significant drop in the density of *C. dactylon* (55.5 and 48.8 %) by the tank mix application of atrazine + ethoxysulfuron and two hand weeding. These two treatments were at par to each other but superior over rest of the treatments. Atrazine + alachlor, atrazine + pendimethalin and weedy check were at par with each other and inferior to these two treatments. Atrazine + ethoxysulfuron proved superior over two hand weeding in reducing the density of *Digera arvensis.* While the effect of two hand weeding remained at par with that of atrazine + alachlor. The density of *D. arvensis* was reduced by 85.6, 75.2, 72.1 and 58.0 %, respectively by atrazine + ethoxysulfuron, two hand weeding, atrazine + alachlor and atrazine + pendimethalin compared to weedy check. Minimum *Commelina benghalensis* count was recorded by application of atrazine + ethoxysulfuron. This treatment was at par with two hand weeding with 84.2 and 83.8 % reduction, respectively. The density of *Parthenium hysterophorus* was reduced significantly with two hand weeding at 15 and 30 DAS compared to other treatments but its effect was at par with that of tank mix application of atrazine + ethoxysulfuron. These two treatments showed 28.0 and 23.9 per cent reduction in the population of this weed. The results point out perceptible variation in the density of other broad leaf weeds. Atrazine + ethoxysulfuron and two hand weeding provided 72.3 and 66.2 per cent control, respectively. The order of superiority was followed by atrazine + alachlor and atrazine + pendimethalin with 57.2 and 43.0 % reduction in density of these weeds. The density of C. rotundus tended to reduce significantly with two hand weeding. However, its effect was at par with that of atrazine + ethoxysulfuron. These two treatments were superior over rest of treatments with 44.7-

47.6 per cent decrease in weed count. While rest of the treatments viz. atrazine + alachlor, atrazine + pendimethalin were at par with weedy check.

The data conclusively reveal that total weeds were restricted when the field was hand weeded twice and by tank mix application of herbicides. Atrazine + ethoxysulfuron and two hand weeding were at par and accounted for 78.1 to 78.6 % reduction of weed density. The order of superiority was followed by atrazine + alachlor and atrazine + pendimethalin with 68.2 and 63.3 % reduction in total weeds count, respectively. Statistically non- significant difference in weed density was observed due to different levels of sulphur.

Total weed dry weight at harvest

Discernible variation in weed dry weight was recorded by applying different herbicide combinations and hand weeding twice at 15 and 30 DAS. Minimum dry weight was noticed in plots treated with two hand weeding and atrazine + ethoxysulfuron. Both of these treatments recorded 79.2 and 79.3 % decline in dry weight of total weeds, respectively compared to weedy check (60.13 gm^{-2}). This was followed by atrazine + alachlor and atrazine + pendimethalin with reduced total weed dry weight content of 70.1 and 65. 7 %, respectively at harvest. Doses of sulphur did not influence the dry weight of weeds (Table 1).

Plant height

Weed control through two hand weeding resulted in maximum plant height at 30 DAS but its effect was at par with all other treatments including weedy check except atrazine + ethoxysulfuron. The maximum plant height (62.49 cm) was recorded by controlling weeds through two hand weeding which was superior over that of atrazine + ethoxysulfuron (51.33 cm). However, its effect was at par with that of atrazine + alachlor (61.32 cm), atrazine + pendimethalin (60.42 cm) and weedy check (60.81 cm). Sulphur application exerted significant effect on plant height at 30 DAS. Though, maximum height of plant was observed when 40 kg S ha^{-1} was applied, however, its effect was at par with that of 20 kg S ha^{-1} on pooled basis. Compared to control, application of 20 kg S ha^{-1} tended to increase the plant height by 5.28 % (Table 2).

Table 1. Effect of herbicide combinations and sulphur on weed density and dry weight at harvest (Pooled data of two years)

Treatment	Weed density m^{-2}*								Total weed dry matter (g m^{-2})
	Echinochloa sp.	*Cynodon dactylon*	*Digera arvensis*	*Commelina benghalensis*	*Parthenium hysterophorus*	Other BL weeds	*Cyperus rotundus*	Total	
Weedy check	9.80 (95.45)	3.61 (12.53)	3.24 (9.97)	3.62 (12.63)	4.08 (16.14)	3.08 (9.00)	3.80 (13.98)	13.06 (170.04)	60.13
Atrazine+ Alachlor	2.46 (5.55)	3.48 (11.60)	1.81 (2.78)	1.76 (2.61)	3.85 (14.35)	2.09 (3.85)	3.66 (12.87)	7.38 (54.00)	17.98
Atrazine+ Pendimethalin	2.91 (7.94)	3.53 (11.94)	2.17 (4.19)	2.29 (4.76)	3.93 (14.94)	2.37 (5.13)	3.71 (13.24)	7.93 (62.40)	20.60
Atrazine+ Ethoxysulfuron	2.24 (4.51)	2.47 (5.58)	1.39 (1.44)	1.58 (1.99)	3.57 (12.28)	1.73 (2.49)	2.87 (7.73)	6.07 (36.32)	12.45
Two hand weeding (15 & 30 DAS)	2.13 (4.03)	2.63 (6.41)	1.72 (2.47)	1.60 (2.05)	3.47 (11.55)	1.88 (3.04)	2.80 (7.33)	6.14 (37.24)	12.48
S.Em.+	0.08	0.06	0.05	0.05	0.07	0.04	0.07	0.07	0.29
C.D. (P = 0.05)	0.23	0.18	0.13	0.14	0.21	0.13	0.19	0.21	0.83
Sulphur (kg ha^{-1})									
00	3.90 (14.72)	3.17 (9.53)	2.08 (3.82)	2.20 (4.32)	3.85 (14.34)	2.22 (4.45)	3.36 (10.77)	8.17 (66.18)	24.58
20	3.90 (14.68)	3.11 (9.18)	2.10 (3.90)	2.17 (4.23)	3.75 (13.53)	2.27 (4.66)	3.41 (11.13)	8.13 (65.56)	24.72
40	3.92 (14.85)	3.15 (9.40)	2.02 (3.59)	2.14 (4.09)	3.75 (13.54)	2.20 (4.32)	3.33 (10.60)	8.06 (64.41)	24.87
S.Em.+	0.06	0.05	0.04	0.04	0.06	0.03	0.05	0.06	0.23
C.d. (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Data subjected to $\sqrt{x} + 0.5$ transformation and figures in parenthesis are original weed count m^{-2}

The maximum plant height at 60 DAS was observed when the crop was hand weeded twice at 15 and 30 DAS, however, its effect was at par with that of atrazine + alachlor and atrazine + pendimethalin but superior over that of atrazine + ethoxysulfuron.

Two hand weeding accounted for an increase of 15.7 % height of crop plants compared to weedy check. The effect of atrazine + ethoxysulfuron was inferior to other treatments but superior over weedy check. The application of sulphur at different rates significantly enhanced the plant height at 60 DAS. Sulphur application at 20 and 40 kg S ha^{-1} significantly increased the plant height. On pooled basis, the per cent increase over weedy check was 6.9 and 4.7 by applying 40 and 20 kg S ha^{-1}, respectively.

Table 2. Effect of herbicide combinations and sulphur on crop dry matter accumulation (Pooled data of two years)

Treatment	Plant Height (cm)				Crop Dry Matter (g plant^{-1})			LAI
	30DAS	60DAS	90 DAS	At Harvest	30 DAS	60 DAS	90 DAS	55 DAS
Weedy check	60.81	122.72	180.22	185.33	17.57	55.59	86.03	2.91
Atrazine + Alachlor	61.32	141.30	221.09	225.12	26.58	83.51	123.22	3.20
Atrazine+ Pendimethalin	60.42	139.83	215.64	221.69	24.98	81.35	118.39	3.18
Atrazine+Ethoxysulfuron	51.33	130.53	198.15	203.48	18.21	70.40	101.46	3.03
Two hand weeding (15 & 30 DAS)	62.49	141.94	224.25	228.26	28.13	85.51	126.97	3.24
S.Em.±	0.89	2.26	4.97	3.48	0.38	1.34	2.10	0.04
C.D. (P = 0.05)	2.52	6.38	14.41	9.83	1.06	3.80	5.95	0.12
Sulphur (kg ha^{-1})								
Control	56.83	130.20	201.49	202.68	21.73	71.85	106.34	3.01
20	59.83	136.37	210.30	216.24	23.22	75.83	112.15	3.13
40	61.16	139.24	215.50	219.40	24.34	78.14	115.14	3.19
S.Em.±	0.690	1.750	2.722	2.694	0.29	1.04	1.63	0.03
C.D. (P = 0.05)	1.95	4.94	7.69	7.61	0.82	2.94	4.61	0.09

The height of QPM plants tended to increase significantly by controlling weeds through two hand weeding and various herbicide combinations over weedy check. Two hand weeding resulted in maximum plant height but its effect was at par with that of atrazine + alachlor and atrazine + pendimethalin. The pooled analysis of data reveal that the increase in plant height of maize by weed control was 24.7, 22.7, 16.8 and 10.0 % through two hand weeding, combination of atrazine with alachlor,

Table 3. Effect of herbicide combinations and sulphur on yield and harvest index

Treatment	Yield (t ha^{-1})								
	Grain			Stover			Harvest Index		
	2009	2010	Mean	2009	2010	Mean	2009	2010	mean
Weedy check	2.18	2.00	2.09	3.99	3.26	3.63	34.86	37.97	36.41
Atrazine + Alachlor	4.48	4.26	4.37	7.61	7.28	7.44	37.11	36.96	37.04
Atrazine+ Pendimethalin	4.16	4.04	4.10	7.20	7.00	7.10	36.64	36.53	36.58
Atrazine+Ethoxysulfuron	3.51	3.35	3.43	5.25	4.91	5.08	40.15	40.25	40.20
Two hand weeding (15 & 30 DAS)	4.70	4.40	4.55	7.91	7.54	7.72	37.26	36.88	37.07
S.Em.±	0.12	0.12	0.08	0.20	0.21	0.14	1.01	0.95	0.69
C.D. (P = 0.05)	0.35	0.34	0.24	0.57	0.60	0.40	2.94	NS	1.96
Sulphur (kg ha^{-1})									
Control	3.42	3.14	3.28	5.99	5.50	5.75	35.91	36.54	36.22
20	3.87	3.65	3.76	6.44	6.08	6.26	37.49	37.63	37.56
40	4.13	4.04	4.09	6.75	6.41	6.58	38.21	38.99	38.60
S.Em.±	0.09	0.09	0.06	0.15	0.16	0.11	0.79	0.73	0.54
C.D. (P = 0.05)	0.28	0.27	0.18	0.45	0.46	0.31	NS	NS	1.52

pendimethalin and ethoxysulfuron, respectively over plant height in weedy check plots. Application of 40 kg S ha^{-1} significantly enhanced the plant height over weedy check but at par with that of 20 kg S ha^{-1}. The pooled analysis of result indicates 4.4 % increase in plant height by applying 20 kg S ha^{-1} (Table 2).

Hand weeding twice and tank mix application of herbicides brought about significant increase in plant height at harvest. On pooled basis, maximum height (228.26 cm) was recorded by controlling the weeds through two hand weeding which represented 23.2 % increase over plant height in weedy check plots. However, its effect was at par with atrazine + alachlor (225.12 cm) and atrazine + pendimethalin (221.69 cm) with 21.5 and 19.6 % increase, respectively. The effect of atrazine + ethoxysulfuron was superior over weedy check with 9.8 % increase but inferior over other treatments. The application of sulphur (20 kg S ha^{-1}) tended to increase the height of maize plants. Further application of sulphur up to 40 kg S ha^{-1}, though brought about increase in plant height but the magnitude was not significant. On pooled basis, 20 kg S ha^{-1} of sulphur resulted in 6.70 % enhancement in height of maize plants.

Dry matter accumulation

Data in Table 2 reveal that the results of two hand weeding were superior over rest of the treatments to enhance the dry matter of crop plants at 30 DAS. The

effect of atrazine + alachlor was superior over atrazine + pendimethalin while atrazine + pendimethalin were superior over atrazine + ethoxysulfuron. The effect of atrazine + ethoxysulfuron was at par with that of weedy check. On pooled basis, the per cent increase in dry matter was 60.1, 51.3 and 42.2 under two hand weeding, atrazine + alachlor and atrazine + pendimethalin, respectively compared to weedy check. Application of 20 kg S ha^{-1} to maize crop brought about significant increase in crop dry matter. On an average 6.86 per cent increase was recorded by applying 20 kg S ha^{-1}. Further increase in the rate of sulphur application up to 40 kg S ha^{-1} was found to increase the dry matter of non significant magnitude.

At 60 DAS, plots with hand weeding twice and all herbicide combinations resulted in significantly higher crop dry matter accumulation over weedy check. Maximum dry matter was recorded in plots with two hand weeding. Its effect was at par with that of atrazine + alachlor and atrazine + pendimethalin, however, were superior over atrazine + ethoxysulfuron. The data reveal that maximum dry matter was recorded by two hand weeding. It was at par with that of atrazine + alachlor while the effect of this herbicide combination was at par with that of atrazine + pendimethalin. These three treatments showed increased dry matter by 53.8, 50.2 and 46.3 per cent, respectively. The effect of atrazine + ethoxysulfuron was less effective with only 26.6 per cent increase in crop dry matter compared to weedy check. Variable response of sulphur application was recorded during the two years of study. However, on pooled basis, the increase in over control was 8.7 and 5.5 per cent by applying 40 and 20 kg S ha^{-1}, respectively.

Compared to weedy check, two hand weeding and tank mix application of herbicides brought about significant enhancement in crop dry matter at 90 DAS. The effect of two hand weeding was at par with that of atrazine + alachlor, while the effect of atrazine + alachlor was at par with that of atrazine + pendimethalin. The effects of these three treatments were superior over atrazine + ethoxysulfuron. On pooled basis, atrazine + ethoxysulfuron, atrazine + pendimethalin, atrazine + alachlor and two hand weeding registered 17.9, 37.6, 43.2 and 47.6 % higher crop dry matter accumulation, respectively over weedy check. Application of 20 kg S ha^{-1} resulted in significant increase in crop dry matter. On pooled basis, this treatment recorded 5.5 per cent increase in dry matter. Though application of 40 kg S ha^{-1} increased the dry matter further but the extent of increase was at par with that of 20 kg S ha^{-1}.

Adequate availability of light, optimum temperature, space along with improvement in physiological and morphological characters of the plants can be reasoned for greater photosynthetic rate thereby more accumulation of dry matter (Korpff *et al.*, 1993). In general the overall improvement in growth of QPM with the addition of sulphur could be ascribed to its pivotal role in several physiological and biochemical processes which are of vital importance for development of the plants. It is well established that S in the form of sulphate (SO_{4-2}) is involved in the synthesis of S containing amino acids (methionine and cystine), various enzymatic processes and variety of oxidation reduction reactions in the plant (Lakkineni *et al.*, 1997). Similar findings were also reported by Jeet *et al.,* (2012).

Leaf area index at 55 DAS

Two hand weeding gave maximum enhancement in LAI of crop; its effect was superior over rest of treatments except with that of atrazine + alachlor and atrazine + pendimethalin. (Tables) These two herbicide combinations were at par with atrazine + ethoxysulfuron. However, the effect of atrazine + ethoxysulfuron was at par with that of weedy check. Weed control through two hand weeding and tank mix application of atrazine with alachlor, pendimethalin and ethoxysulfuron recorded 11.3, 10.0, 9.3 and 4.1 per cent increase in LAI compared to weedy check, respectively. The effect of sulphur application at 40 kg S ha^{-1} was at par with that of 20 kg S ha^{-1} but significantly increased LAI at 55 DAS over control. While the effect of 20 kg S ha^{-1} was at par with that of control. Application of sulphur at 40 kg S ha^{-1} gave 6.0 per cent higher LAI.

Grain yield

Two hand weeding and pre-emergence application of various herbicide mixtures resulted in significantly higher grain yield in comparison to crop under weedy check. Table3 Though higher grain yield was recorded during both the years (4.70 and 4.40 t ha^{-1}) when the crop was hand weeded twice at 15 and 30 DAS, however, the result of this treatment was at par with those of pre- emergence application of atrazine + alachlor (4.48 and 4.26 t ha^{-1}, respectively). A critical examination of data further reveals that the grain yield produced under the influence of atrazine + pendimethalin mixture was at par with those produced due to atrazine + alachlor mixture. Amongst the weed control treatments, application of atrazine + ethoxysulfuron was significantly the least effective treatment in this regard. The pattern of statistical significance was same in both the years except that the effect of atrazine + alachlor was superior over atrazine + pendimethalin. On pooled basis, weed control through two hand weeding and atrazine based herbicide mixtures with alachlor, pendimethalin and ethoxysulfuron accounted for 98.7, 90.8, 79.0 and 45.8 per cent increase in grain yield over control, respectively. The better expression of yield in these treatments might be due to poor resurgence frequency and growth of weeds as evident from weed dry matter studies in these plots (Table 1) hence weeds were unable to compete with the crop plants for different growth factors. Patel *et al.,* (2006) also reported improved yield with reduced weed density and dry

Soil fortification with sulphur tended to influence the grain yield of quality protein maize in both the years. However, the yearly variation did exist. The pooled results show that raising S dose from control to 20 and from 20 to 40 kg ha^{-1} resulted in significant yield increment (14.6 and 8.8 %, respectively). The activist effect of sulphur fertilization on yield appears to be due to vigrous growth of individual plant as reflected through increased plant height, dry matter and LAI. These improvements suggest greater availability of metabolites and nutrients synchronized to demand for growth and development of each reproductive structure. The results obtained here are in close conformity with the findings of Jeet *et al.,* (2012).

Stover yield

Weed control through two hand weeding and herbicide combinations resulted in significant enhancement in stover yield of quality protein maize over weedy check. The effect of two hand weeding was superior over rest of the treatments in both the years but found at par with that of atrazine + alachlor. The effect of atrazine + pendimethalin was at par with that of atrazine + alachlor but superior over atrazine + ethoxysulfuron. The trend of statistical significance was same for both the experimental years. On pooled basis, two hand weeding and atrazine + alachlor enhanced the stover yield by 112.4 and 112.7 per cent over weedy check. However, 95.6 and 39.9 per cent enhancement was recorded through atrazine + pendimethalin and atrazine + ethoxysulfuron, respectively.

Compared to no sulphur, application of 20 kg S ha^{-1} brought about significant increase in stover yield. The extent of increase being 7.51 and 10.54 % during the successive years. Sulphur application at 40 kg S ha^{-1} failed to exhibit significant result in this respect in comparison to preceding sulphur rate.

Bioassay studies

All herbicide combinations and sulphur levels had no significant effect on the germination percentage, shoot length and biomass at 30 DAS of the three succeeding test crops viz., wheat, mustard and gram.

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