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Weed Control Efficacy and Economics of Pre-emergence Herbicides in Maize (*Zea mays* L.)

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ABSTRACT

A field study was conducted to evaluate the efficacy and economics of different pre-emergence herbicides in maize var. Azam. A randomized complete block design, having four replications was used in the experiment. The treatments were: 1) Stomp 330 E (pendimethalin) at 3.75 L ha^{-1}, 2) Dual Gold 960 EC (s-metolachlor) at 2 L ha^{-1}, 3) Primextra Gold 720 SC (s-metolachlor + atrazine) at 0.98 L ha^{-1}, 4) Atrazine 38 SC (atrazine) at 1 L ha^{-1}, 5) hand weeding and 6) weedy check for comparison. The major weeds infesting the experimental field were *Cyperus rotundus*, *Sorghum halepense*, *Echinochloa crus-galli*, *Digitaria sanguinalis*, *Portulaca oleracea* and *Digeria muricata.* Weed density, weed biomass, plant height, cob length, kernels cob^{-1}, 500-kernel weight, and grain yield were significantly affected by all the herbicidal treatments. Primextra gold greatly suppressed weed density and dry biomass 25 and 75 days after sowing (DAS) and proved to be the most efficient in controlling weeds. Maximum grain yield (2.84 t ha^{-1}) was recorded in Primextra gold 720 SC while minimum grain yield (1.94 t ha^{-1}) was recorded in weedy check. Weed control treatments increased grain yield and yield-related traits of maize as compared to weedy check. Overall, Primextra gold proved more economical by giving maximum net profit.

Keywords: herbicides, profit, weed competition, yield

INTRODUCTION

Maize, being the highest yielding cereal crop in the world (712 million tons during 2004-05: http://www.karvycommodities.com/downloads/karvySpecialReports/karvysSpecialReports_20060727_01.pdf) is of significant importance for developing countries like Pakistan, where a rapidly increasing population has already out-stripped the available food supplies (http://www.pakissan.com). In Pakistan maize is third most important cereal after wheat and rice. Maize accounts for 4.8% of the total cropped area and 3.5% of the value of agricultural output. It is planted on an estimated area of 0.9 million ha with an annual production of 1.3 million tonnes (http://www.pakissan.com). The bulk (97%) of total production comes from two major provinces, NWFP, accounting for 57% of the total area and 68% of total production. Punjab contributes 38% acreage with 30% of total maize grain production. Very little maize (2-3%) is produced in Sindh and Balochistan provinces. Though not included in Pakistan official statistics maize is an important crop of Azad Jammu and Kashmir with about 0.122 million ha being planted during summer. It is one of the most important food crops in Pakistan and is increasingly gaining an important position in crop husbandry because of its higher yield potential and short growth duration. It contributes a lot to the economy of the country, as it is a rich source of food, fodder, feed and also provides raw materials for industries. In recent years corn oil is becoming popular among people due to its non-cholesterol character. In addition, its products like corn starch, corn flakes, gluten germ cake, lactic acid, alcohol and acetone are either directly consumed as a food or used by various industries like paper textile, foundry and fermentation by about two-thirds of the total world production (Khalil and Jan 2004). It is estimated that almost 40-50% of the Pakistan maize is consumed on farm, 15-20% is marketed locally and 40% sold in the organized wholesale market (http://www.pakissan.com/english/allabout/crop/maize.shtml).

Weeds compete with maize for nutrients, soil moisture, space and light and considerably reduce the yield and the quality of the crop (Hussain 1983). Introduction of chemical weed control is necessary to replace traditional weed control measures as traditional measures are sometimes uneconomical, laborious and impossible. Chemical weed control certainly has its merits over traditional weed control methods. Weed control in maize cultivation through the use of herbicides has received little attention in Pakistan and particularly in NWFP (Shah 1998). Today, high-yielding agriculture heavily depends on herbicides, as they constitute a vital and integral component of weed management practices (Rao 2000; Baghestani *et al.* 2005). Atrazine is one of the most widely used herbicides in world agriculture (Alvi *et al.* 2003) and despite being banned in most European countries, it is still widely used in the United States and is registered in more than 70 countries worldwide (Kauffmann *et al.* 2000). Chemical weed control increases maize yield due to effective weed control. Baghestani *et al.* (2007) reported that application of nicosulfuron at 80 g ai/ha resulted in the highest maize yield after a weed-free check. However, chemical weed control should be better studied to assess the economics of weed control and, more importantly, the net return to farmers: farmers are more interested in net return rather than increased yield. Our study: (1) evaluates the effect of pre-emergence herbicides on yield and yield-related traits of maize, (2) compares the effectiveness of different herbicides in the control of weeds and (3) estimates the economics of different herbicides in maize.

MATERIALS AND METHODS

This study was conducted at the Pakistan Academy for Rural Development, Peshawar, Pakistan during the summer of 2007.

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Original Research Paper

Peshawar lies between 71°-27′ and 72°-47′ E longitude and 33°-40′ and 34°-31′ N latitude and 359 m asl. Wheat was previously cropped in the experimental field and the soil pH was 7.3. The field was ploughed thrice at proper moisture after irrigation to make a fine seed bed followed by planking. The soil was leveled and maize seeds were planted at proper moisture conditions by the drill method. Maize var. 'Azam' was used in the experiment as this is the widely used variety in the locality. The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications. The size of each treatment was 3 × 5 m with 6 treatments and a row-to-row distance of 75 cm. There were four rows per treatment. Recommended doses of nitrogen and phosphorus (N:P) were 120 and 90 kg ha^{-1}, respectively. Full P and half N were applied at sowing and the remaining N during third irrigation where the crop was irrigated 5 times during the crop season.

The experiment comprised of the following treatments:

T1 = Stomp 330 E (pendimethalin) at 3.75 L ha^{-1};

T2 = Dual Gold 960 EC (s-metolachlor) at 2 L ha^{-1};

T3 = Primextra gold 720 SC (s-metolachlor + atrazine) at 0.98 L ha^{-1};

T4 = Atrazine 38 SC (atrazine) at 1 L ha^{-1};

T5 = hand weeding once 10 days after sowing;

T6 = weedy check.

As pre-emergence herbicides were used in the experiment, therefore herbicides were applied soon after planting maize and all precautionary measures were taken into account to avoid herbicide exposure by using a knap sack sprayer. Data on the following parameters was recorded during the course of the experiment.

a) Weed data: Weed density (m^{-2}) 25 and 75 days after sowing (DAS); dry biomass of weeds (m^{-2}) 25 and 75 days after sowing (DAS).

Crop data: Plant height (cm), cob length (cm), number of kernels cob^{-1}, 500 kernels weight (g), grain yield (t ha^{-1}) and economic evaluation of herbicides.

The data was statistically analyzed using MSTATC Software program. The purpose of ANOVA was to determine the significant effect of treatments on weeds and maize. The LSD test at a 5% probability level was applied when ANOVA showed a significant difference between treatments (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Weed density

Statistical analysis of the data presented in **Table 1** shows that the treatment means were significantly ($P<0.05$) affected by different herbicidal treatments. Data indicated that maximum weed density was observed in weedy check followed by plots treated with Stomp 330 E. Weed density recorded in Dual gold, Atrazine and hand weeding were statistically equal to each other. Minimum weed density was recorded in the Primextra gold treatment. Among the time means, maximum weed density was observed in 75 DAS. The major weeds infesting the experimental field were *Cyperus rotundus*, *Sorghum halepense*, *Echinochloa crus-galli*, *Digitaria sanguinalis*, *Portulaca oleracea* and *Digeria muricata.* These findings suggest that Primextra gold controlled weeds equally on 25 and 75 DAS at early stages, in which atrazine could also successfully be used to control weeds. We previously reported similar results (Khan *et al.* 2003) where we indicated that weed control methods like application of herbicides and hand weeding significantly decreased weed density. The present findings also indicate that atrazine or s-metochlor alone is not effective to kill weeds and any herbicide having a combination of these two (like Primextra gold) is more effective against different weeds. It was noted that weed density increased with the passage of time. This indicates that weed control before a critical period is good to avoid yield losses. However, weeds can become a problem for crop husbandry even at the time of harvesting and can also shed seeds. Thus the weed seed bank will be enriched due to deposition of weed seeds in the soil and will become a problem in the next season. Hence our findings suggest that weeds always need a long term management strategy to tackle the problem. Mahadi *et al.* (2007) reported that a weedy check produced the highest weed cover score and weed dry weight at harvest in both years, while herbicides significantly lowered weed density.

Table 1 Weed density m^{-2} 25 and 75 days after sowing (DAS).

Treatment	Weed density 25 DAS	Weed density 75 DAS	Treatment means
Stomp 330 E	82.25	96.00	89.12 a
Dual Gold	69.50	81.00	75.25 b
Primextra Gold 720 SC	31.75	46.25	39.00 c
Atrazine 38 SC	56.00	72.00	64.00 b
Hand weeding	66.70	78.50	72.62 b
Weedy check	92.25	109.00	100.62 a
Time means	66.417 a	80.45 b	

LSD value for treatment means = 13.15

Values followed by different letters are significantly different from each other at $P<0.05$ according to LSD test.

Table 2 Weed biomass (g m^{-2}) 25 and 75 days after sowing (DAS)

Treatment	Weed biomass 25 DAS	Weed biomass 75 DAS	Treatment means
Stomp 330 E	241.25	217.00	229.12 ab
Dual Gold	211.25	206.75	209.00 b
Primextra Gold 720 SC	153.00	174.50	163.75 c
Atrazine 38 SC	190.50	203.00	196.75 bc
Hand weeding	203.25	208.25	205.45 b
Weedy check	246.75	262.50	254.62 a
Time means	207.66	12.30	

LSD value for treatment means = 37.22

Values followed by different letters are significantly different from each other at $P<0.05$ according to LSD test.

Weed biomass

Treatment mean data presented in **Table 2** shows that weed biomass (g m^{-2}) at 25 and 75 DAS was significantly ($p<0.05$) affected by different treatments while its effect over time was non significant ($P>0.05$). Maximum weed biomass was recorded in the weedy check followed by Stomp 330E-treated plots. However weed biomass noted in Atrazine and Dual gold was statistically equal while the minimum weed biomass was recorded in Primextra gold treatment. Among the herbicides used, Primextra gold controlled weeds more effectively than other treatments, which ultimately resulted in higher grain yield of maize. Hafeezullah (2000) and Khan *et al.* (2003) also reported similar results. They concluded that the dry weight of weeds was significantly affected by different herbicidal treatments. Analogous results were reported by Mahadi *et al.* (2007) who noted that a weedy check produced the highest weed cover score and weed dry weight at harvest while herbicides significantly lowered weed density. As the dry weight of weeds indicates the photosynthetic matter produced, a reduction in dry weight of weeds will automatically increase the grain yield if there is competition for resources. However, it can be inferred from the results that although there was a significant increase in weed density 25 and 75 DAS, the effect on dry weight was non-significant. This might be due to the fact that there was intraspecific competition among the weed species at 75 DAS and thus weeds attained maximum vegetative growth earlier. As increasing dry weight of the weed decrease the yield of crop (Marwat and Khan 2007), the present findings suggest that weeds should be controlled well before the vegetative growth to prevent crop yield losses.

Plant height

Plant height is the factor that can contribute significantly to grain yield by capturing more sunlight and thus ultimately obtaining more resources. Our data shows that the plant height of maize was significantly ($P<0.05$) affected by dif-

Table 3 Plant height (cm) and cob length (cm) of maize as affected by different treatments.

Treatment	Plant height (cm)	Cob length (cm)
Stomp 330 E	190.00 b	16.70 b
Dual Gold	203.50 b	16.55 bc
Primextra Gold 720 SC	221.75 a	18.92 a
Atrazine 38 SC	191.50 b	17.12 b
Hand weeding	192.50 b	15.15 cd
Weedy check	172.50 c	14.77 d

LSD value for plant height means = 16.267
LSD value for cob length = 1.429
Values followed by different letters are significantly different from each other at P<0.05 according to LSD test.

ferent treatments (**Table 3**). Maximum plant height was recorded in Primextra gold followed by Dual gold-treated plots, which was statistically equal to Stomp 330 E, Atrazine and hand weeding treatments; while minimum plant height was recorded in the weedy check. Plant height is a function of genetic as well as environmental conditions. The difference in plant height in the present studies can be attributed to various intensities of weed competition with maize plants. Ishaya *et al.* (2008) reported that herbicide applied under minimum tillage increased crop vigour. Overall data depicted that taller plants were recorded in treatments where Primexta gold was applied. This might be due to the fact that there was a severe intraspecific competition among the crop plants. In the weed control treatments, however, there were sufficient resources for the maize crop plants. Analogous results were reported by Mahadi *et al.* (2007) who showed that some herbicides applied to maize increased the plant height of maize more than the weedy check. Inherently, maize is taller than its associated weed species recorded in this study. Therefore, at later stages of the crop, maize plants can suppress weeds due to prevention of sunlight to underground weeds. However, prevention of maize from weed competition during an early stage is necessary to avoid yield losses.

Cob length

Cob length is an important yield-related component and greatly affects the overall yield of maize. Data presented in **Table 3** depicts that the cob length was significantly (P<0.05) affected by different herbicidal treatments. Maximum cob length was recoded in Primextra gold followed by plots treated with Atrazine which was statistically equal to Stomp, while minimum cob length was observed in the weedy check. Primextra gold was more efficient in controlling weeds at an early stage which resulted in better growth of maize plants as nutrients were available in a sufficient amount. As cob length is an important parameter that contributes to higher yield, maize yield can thus be increased by increasing the cob length through weed control. In similar results Aladesanwa and Akinbobola (2007) reported that herbicide application to maize significantly increased cob length compared to the weedy check. Due to severe interspecific competition, cob length was greatly affected which ultimately decreased the grain yield of maize.

Number of kernels cob^{-1}

Number of kernels cob^{-1} was significantly affected by different treatments (**Table 4**). Greater number of kernels cob^{-1} were recorded in treatments where Primextra gold was used to control weeds, which was however statistically at par with Atrazine treated plots followed by Dual gold treated plots. As expected, minimum number of kernels cob^{-1} was observed in weedy check followed by hand weeding. The results indicate that with the increasing weed control efficiency number of grains and ultimately the yield of maize increased. This shows that weed compete with the maize crop plants for nutrients and other resources and thereby decreases yield by decreasing the yield related traits. Number of kernels is an important yield related trait of maize and contribute to final yield and economics of farming enterprise. Usually, farmers that manually remove weeds in maize during or just after tasseling cause shedding of pollen which might cause sterility of the ear. This might cause decrease in the number of kernels cob^{-1}. Khan *et al.* (2002) reported that herbicide application in maize increased the number of kernels cob^{-1} which ultimately increased the grain yield.

500-kernel weight

Statistical analysis of the data indicated that 500-kernel weight was significantly (P<0.05) affected by different herbicidal treatments (**Table 4**). Heavier 500-kernel weight was recoded in Primexta gold; while the 500-kernel weight in all other treatments were statistically at par with each other. However in those treatments where the weeds were controlled, 500-kernel weights were heavier as compared to uncontrolled treatments as weeds shared the resources with the crop plants. These results are in agreement with those of Khan *et al.* (2003). They reported that weed infestation decreased the 500-kernel weight in maize as compared to weed control treatments. Due to interspecific competition among the maize and weeds, the available resources were used and with deficiency of resources competition starts; that consequently affects the kernels weight. Our findings indicate that weed infestation not only decreased the quantity but also the quality of the produce as lighter and small grains are of low quality due to poor germination ability and low seedling vigour if planted.

Grain yield

Table 4 indicates that grain yield was significantly (P<0.05) affected by different herbicidal treatments. Maximum grain yield was recorded in case of Primextra gold. However all other treatments, including weedy check and hand weeding were statistically at par with each other. Although numerically lower value was obtained in weedy check plot however, it was statistically similar to all other treatments. As the number of kernels cob^{-1}, 500-kernel weight and cob length increased significantly by different herbicidal treatments therefore ultimately the yield of the maize was increased. Gonzalez and Salas (1995) reported that high grain yield was obtained from those plots in which weeds were controlled. Controlling weeds by herbicide application in maize significantly increased the grain yield of maize (Khan *et al.* 2002; Mahadi *et al.* 2007; Aladesanwa and Akinbobola 2007). The present results indicate that herbicide application in maize prove to be effective in controlling the weeds and thereby increasing the grain yield. Herbicide application not only increases yield but also decrease the weed population and hence less deposition of seed in the weed seed bank. However keeping in view the deleterious effect of herbicides on the environment, other methods of weed

Table 4 Number of kernels cob $^{-1}$, 500-kernel weight (g) and grain yield (t ha^{-1}) of maize as affected by different treatments.

Treatment	№ of kernels cob^{-1}	500-kernel weight (g)	Grain yield (t ha^{-1})
Stomp 330 E	382.50 b	163.52 b	2.07 b
Dual Gold	391.75 ab	165.40 b	2.06 b
Primextra Gold 720 SC	446.75 a	206.80 a	2.84 a
Atrazine 38 SC	446.50 a	146.77 b	2.17 b
Hand weeding	365.75 bc	143.02 b	2.05 b
Weedy check	315.25 c	136.37 b	1.94 b

LSD value for number of kernels cob^{-1} = 60.297
LSD value for 500-kernel weight = 35.350
LSD value for grain yield = 0.411
Values followed by different letters are significantly different from each other at P<0.05 according to LSD test.

Table 5 Net benefit of weed control in maize at Peshawar, Pakistan.

	Treatments					
	T6	**T4**	**T3**	**T2**	**T1**	**T5**
Average yield (t/ha):	1.94	2.17	2.84	2.06	2.07	2.05
Price of produce (Rs/kg): (a):	640	640	640	640	640	640
Gross benefit (1):	30,555	34,177	44,750	32,445	32,602	32,287
Herbicide costs: (b):	00.0	130.0	415.0	475.0	550.0	00.0
Hand weeding cost: (c):	00.0	00.0	0.00	00.0	00.0	3000.0
Net benefit (3) = (1) - (2):	30,555	33,347	44,335	31,970	32,052	29,287

Note: The treatments are placed in order of increasing costs. (a) Average sale price of maize yield produce at Rs.640/100 kg bag (2007 market rate). (b) Cost of herbicide Atrazine 38 SC ha^{-1} at Rs.325 L^{-1}. Cost of herbicide Primextra Gold 720 SC ha^{-1} each at Rs.1050 L^{-1}. Cost of herbicide Dual Gold 960 EC ha^{-1} at Rs. 950 L^{-1}. Cost of herbicide Stomp 330 E ha^{-1} at Rs. 550 L^{-1}. (c) Labor charges for hand weeding ha^{-1} at Rs.150 $kanal^{-1}$ (6 persons/season) in hand weeding.
T1 = Stomp, T2 = Dual gold, T3 = Primextra gold, T4 = Atrazine, T5 = hand weeding, T6 = weedy check.

control need to be incorporated in an integrated weed management approach to protect the environment and the future generations. All methods of weed control have a certain demerit. However, the integration of these methods in mutual supportive manner can reduce the herbicide hazard and ultimately will prove to be acceptable to the farmers.

Net benefit

Net benefit of weed control in maize presented in **Table 5** indicated that maximum net benefit of Rs. 44335 ha^{-1} (US$ 668; 1 US$ = 66.6 Rs.) was obtained in treatments where Primextra Gold was applied followed by Rs. 33,347 (US$ 502) ha^{-1} net benefit in atrazine. The minimum net benefit Rs. 29,287 (US$ 441) ha^{-1} was recorded in treatments where hand weeding was done. However net benefit of 30,555 (US $ 460) ha^{-1} was recorded in weedy check plots. Our findings suggest that Primextra gold is the most economical herbicide that costs less and provides maximum weed control, which ultimately results in higher yields. Hand weeding was observed to be a more expensive weed control strategy due to increasing labor cost.

CONCLUSIONS

Findings of the instant field experiment showed that herbicides significantly controlled weeds which ultimately increased the yield and yield-related traits of maize. However, keeping in view the importance of weed seed production, herbicides controlled weeds which will help to prevent weed seed production against future infestations. Results also showed that Primextra gold is the most economical and effective herbicide while hand weeding is not more economical, except for farmers having a small land holding. Although labour is comparatively cheaper in Pakistan, yet it does not prove economical. As temperatures are very high (up to 45°C) during the summer maize growing season in Pakistan therefore farmers are reluctant to remove weeds manually in maize fields.

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