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Effect of Post Emergence Application of Glyphosate on Weed Control and Yield of Herbicide Tolerant Transgenic Stacked Maize Hybrids

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Field experiments were conducted during *kharif* 2009 and *rabi* 2009-10 at Tamil Nadu Agricultural University, Coimbatore to evaluate the weed control efficiency of various weed management practices and yield of transgenic stacked maize hybrids. Treatments consisted of two transgenic hybrids named Hishell and 900 M Gold applied with glyphosate as early post emergence application (POE) at 900, 1800 and 3600 g a.e ha^{-1} compared with non-transgenic counterpart maize hybrids applied with pre-emergence (PE) atrazine at 0.5 kg ha^{-1} followed by one hand weeding (HW) on 40 DAS and with and without insect management. Among the treatments higher weed control efficiency was achieved by POE application of glyphosate at 900, 1800 and 3600 g a.e ha^{-1} and higher grain yield was recorded with POE application of glyphosate at 1800 g a.e ha^{-1} in transgenic 900 M Gold and 3600 g a.e ha^{-1} in transgenic Hishell during *kharif* 2009 and *rabi* 2009-10 seasons, respectively.

Key words: Herbicide tolerant, Transgenic maize, Glyphosate, Weed control efficiency, Yield

Maize is the third most important cereal food crop of India after rice and wheat and is cultivated in an area of 8.11 million ha with a production of 19.77 million tonnes. Nearly 28 per cent of maize produced is used for food purpose, 11 per cent as livestock feed, 48 per cent as poultry feed, 12 per cent in wet milling industry for starch and oil production and 1per cent as seed (DMR, 2008). The major yield reducing factors in maize cultivation in India are weeds and insects. Weeds cause considerable yield loss due to competition for resources with maize crop. Season long competition reduced the grain yield of maize in as much as 70 per cent (Malviya and Singh, 2007). Therefore, weed management is an important agronomic practice to ensure optimum grain yield.

Weed management in maize is carried out by manual, mechanical and chemical methods, among which chemical method is the most economical and effective tool to suppress weeds in order to get healthy crop stand and good yield. Manual and mechanical methods of weed control are less effective, costly and time demanding as well as need to be repeated at frequent intervals. In chemical method of weed control, many pre- emergence herbicides are presently used in maize which takes care of weeds only for a limited period of early stages of crop growth. The extensive and continued use of pre-emergence herbicides like atrazine and metolachlor affect the surface and groundwater resources due to their long persistence character (Donald *et al.,* 1998). Because of the potential negative impacts of certain pre-emergence herbicides, alternative methods of weed control are needed which will result in similar or higher crop productivity and provide the same or greater level of weed control. Genetic engineering is one form of biotechnological tool that is used to enhance the agronomic characteristics of plants by inserting a gene or sequence of genes that express desirable traits. The most successful example has been glyphosate-resistant technology. The ability to manipulate the plant genome directly gave scientists new ways to create maize crop tolerant to glyphosate. The introduction of glyphosate-resistant crops has created new opportunities for the use of effective, non-selective herbicide like glyphosate as selective weed control in crop production. Prior to the introduction of glyphosate- resistant crops, glyphosate is being applied to control existing vegetation prior to sowing of crops. Now, it can be used as a post emergence herbicide in crops like soybean, cotton, canola and maize (Norsworthy *et al.,* 2001). Transgenic stack hybrid maize (MON 89034 X NK603) was developed for preventing yield losses of maize crop due to pests and weeds and to improve productivity. The stacked maize crop having both insect protection and herbicide tolerant traits will provide protection to the crop from target pests and also provide tolerance to glyphosate herbicide. MON 89034 is second generation Bt corn technology effective against lepidopteron insect pests with a unique and innovative dual mode of action. NK 603 is the glyphosate tolerant technology

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for the effective weed management system. The plants become tolerant to the herbicide while weed flora are suppressed after application of herbicide.

Materials and Methods

The field experiments were conducted during *kharif* 2009 and *rabi* 2009-10 at Tamil Nadu Agricultural University, Coimbatore. The soil of the experimental field was sandy clayey loam in texture with low available nitrogen, medium available phosphorus and high available potassium. The treatments comprised of three levels of glyphosate as POE in two transgenic maize hybrids and these were compared with their counterparts. Treatment details are given in Tables.

The experiments were laid in Randomized Block Design (RBD) with three replications. The maize hybrids were sown with the spacing of 60 X 25 cm. POE application of glyphosate was done at 25 DAS of transgenic maize. Observations were made on predominant weed flora, weed control efficiency and maize yield.

Results and Discussion

Predominant weed flora of the experimental field

Weed flora of the experimental fields consisted predominantly of ten species of broad leaved weeds, five species of grassy weeds and a sedge weed. The predominant broad leaved weeds were *Trianthema portulacastrum*, *Cleome gynandra*, *Boerhavia diffusa, Digera arvensis* and *Cyanotis axillaris*. Among the grassey weeds, *Cynodon dactylon* and *Dactyloctenium aegyptium* were dominant. *Cyperus rotundus* was the only sedge weed found in the experimental fields.

The different treatments had significant influence on weed flora. During *kharif* 2009 broad leaved weeds dominated the weed flora (89.60 %) and it was followed by sedges (5.83 %) and grasses (4.57 %) at 20 DAS. At 40 DAS and 65 DAS broad leaved weeds were more (83.98 and 83.77 %) followed by grasses (8.42 and 8.78 %) and sedges (7.60 and 7.45 %). During *rabi,* 2009-10 at 20 DAS, broad leaved weeds were more (74.75 %) compared to grasses (15.55 %) and sedges (9.70 %). At 40 DAS and 65 DAS broad leaved weeds (70.20 and 70 .51 %) dominated the grasses (16.99 and 15.72 %) and sedge (12.80 and 13.76 %).

Weed density and dry weight

The weed control methods effectively reduced the density of all the weeds under both transgenic and non-transgenic maize hybrids at different stages of crop growth as compared to unweeded control (Table 1). Among the various rates of glyphosate, glyphosate at 1800 g a.e ha^{-1} in transgenic 900 M Gold (1.0 No's m^{-2}) and 3600 g a.e ha^{-1} in transgenic Hishell (2.3 No's m^{-2}) recorded lesser total weed density during *kharif* and *rabi* seasons, respectively at 40 DAS. Glyphosate at 900 g a.e ha^{-1} gave lesser control when compared to higher doses, also it failed to control weeds after 60 DAS. Lower dose of glyphosate was not effective in controlling *Cyperus rotundus* and some broad leaved weeds like *Commelina benghalensis* and *Cyanotis axillaris.* Koger and Reddy (2005) also found that, glyphosate provides marginal or no control of weeds such as *Cynodon dactylon, Solanum carolinense* and tropical *Commelina benghalensis*. In non-transgenic maize hybrids, application of atrazine at 0.5 kg ha^{-1} was proved as effective pre-emergence weed control option in maize. Atrazine effectively controlled majority of broad leaved and grassy weeds at earlier stages of maize growth. Mundra *et al.* (2003) reported that application of atrazine at 0.5 kg ha^{-1} as pre-emergence *fb* inter cultivation at 35 DAS in maize significantly reduced the total weed density.

Weed dry weight is the most important parameter to assess the weed competitiveness for the crop growth and productivity. Sparse weeds with high biomass might be more competitive for crops than dense weeds with lesser dry matter. Considerable reduction in weed dry weight was recorded with the application of glyphosate at 1800 g a.e ha^{-1} in transgenic 900 M Gold and 3600 g a.e ha^{-1} in transgenic Hishell (0.29 and 1.20 g m^{-2}) at 40 DAS during *kharif* 2009 and *rabi* 2009- 10, respectively (Table 1). This might be due to total weed control as achieved by glyphosate. The findings are in accordance with Reddy and Boykin (2010) who reported that POE application of glyphosate, following PE herbicides, or three applications of POE glyphosate only without PE herbicides reduced total weed dry weight by at least 97 per cent when compared to without glyphosate applied plots. Total weed dry weight was effectively reduced in non-transgenic hybrids with PE application of atrazine at 0.5 kg ha^{-1} *fb* HW. The dry weight of weeds exhibited an increasing trend from crop germination to harvest in unweeded checks. It might be due to early germination, establishment and quick growth of weeds than crop. Kumar and Thakur (2005) also found that application of atrazine recorded the least weed dry weight, nutrient removal by weeds and higher weed control efficiency.

Weed control efficiency

Weed control efficiency was highly influenced by different weed control treatments. Application of glyphosate at 1800 g a.e ha^{-1} in transgenic 900 M Gold and 3600 g a.e ha^{-1} in transgenic Hishell recorded higher weed control efficiency of 99.72 and 98.64 per cent during *kharif*, 2009 and *rabi,* 2009-10, respectively. Different rates of glyphosate under transgenic maize hybrids recorded more than 90 per cent control efficiency at 40 DAS. Whereas, at the same time PE application of atrazine in non-transgenic hybrids recorded only 70 to 80 per cent. This might be due to application of glyphosate which did not allow weeds to accumulate sufficient biomass and ultimately resulted in higher weed

Table 1. Effect of weed management methods on total weed density and dry weight in maize

Treatment	Total weed density (No. m^{-2})				Total weed dry weight(g. m^{-2})			
	Kharif 2009		*Rabi* 2009-10		*Kharif* 2009		*Rabi* 2009-10	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1 - T. Hishell POE glyphosate @ 900 g a.e/ha	15.81 (248.0)	3.61 (11.0)	12.10 (144.3)	4.24 (16.0)	6.91 (45.76)	2.10 (2.40)	6.47 (39.81)	3.01 (7.09)
T_2 - T. Hishell POE glyphosate @ 1800 g a.e/ha	15.45 (236.7)	2.65 (5.0)	12.65 (158.0)	3.16 (8.0)	7.19 (49.64)	1.76 (1.10)	6.76 (43.71)	2.35 (3.51)
T_3 - T. Hishell POE glyphosate @ 3600 g a.e/ha	15.39 (235.0)	2.00 (2.0)	12.03 (142.7)	2.08 (2.3)	6.67 (42.48)	1.62 (0.62)	6.91 (45.72)	1.79 (1.20)
T_4 - T. 900 M Gold POE glyphosate @ 900 g a.e/ha	15.70 (244.4)	3.79 (12.3)	11.82 (137.7)	4.40 (17.3)	7.07 (47.98)	2.23 (2.98)	6.06 (34.67)	3.26 (8.66)
T_5 - T. 900 M Gold POE glyphosate @ 1800 g a.e/ha	14.38 (204.7)	1.73 (1.0)	12.83 (162.7)	3.00 (7.0)	6.66 (42.35)	1.51 (0.29)	7.08 (48.10)	2.29 (3.25)
T_6 - T. 900 M Gold POE glyphosate @ 3600 g a.e/ha	14.10 (196.7)	1.73 (1.0)	12.46 (153.3)	2.16 (2.7)	6.51 (40.36)	1.53 (0.33)	6.40 (38.97)	1.82 (1.32)
T_7 - N.T+ Hishell PE atrazine @ 0.5 kg ha^{-1} + HW+ IC	7.26 (50.7)	8.02 (62.3)	5.17 (24.7)	7.30 (51.3)	3.48 (10.11)	5.06 (23.61)	3.22 (8.38)	5.39 (27.06)
T_8 - N.T+ Hishell No WC and no IC	16.14 (258.4)	13.04 (168.0)	12.96 (166.0)	11.39 (127.7)	6.82 (44.54)	10.07 (99.43)	7.21 (50.04)	8.80 (75.43)
T_9 - N.T+ Hishell No WC and only IC	15.88 (250.3)	13.24 (173.3)	12.29 (149.0)	10.65 (111.3)	7.34 (51.85)	10.39 (106.00)	6.79 (44.06)	8.25 (65.99)
T_{10} - N.T+ 900 M Gold PE atrazine @ 0.5 kg a.i/ha+ HW+ IC	7.02 (47.3)	7.66 (56.7)	5.39 (27.0)	7.28 (51.0)	3.52 (10.39)	5.33 (26.45)	3.17 (8.07)	5.29 (26.01)
T_{11} - N.T+ 900 M Gold No WC and no IC	14.86 (219.0)	13.29 (174.7)	12.64 (157.7)	11.82 (137.7)	6.82 (44.45)	9.69 (91.92)	7.06 (47.79)	9.43 (86.89)
T_{12} - N.T+ 900 M Gold No WC and only IC	15.39 (234.7)	12.73 (160.0)	11.83 (138.0)	11.15 (122.3)	7.44 (53.34)	10.03 (98.63)	6.23 (36.82)	8.68 (73.30)
T_{13} - Proagro PE atrazine @ 0.5 kg a.i/ ha + HW+ IC	6.93 (46.0)	8.02 (62.3)	5.94 (33.3)	7.12 (48.7)	3.49 (10.20)	5.24 (25.45)	3.49 (10.21)	5.29 (26.00)
T_{14} - Proagro 4640 No WC and no IC	14.99 (222.6)	13.06 (168.7)	12.38 (151.3)	11.56 (131.7)	7.47 (53.76)	9.51 (88.42)	6.93 (45.99)	9.09 (80.58)
T_{15} - CoHM 5 PE atrazine @ 0.5 kg a.i/ ha + HW+ IC	7.21 (50.0)	7.72 (57.7)	5.48 (28.0)	7.24 (50.4)	3.22 (8.39)	5.35 (26.67)	3.27 (8.70)	5.34 (26.50)
T_{16} - CoHM 5 No WC and no IC	16.27 (262.6)	12.82 (162.3)	12.92 (165.0)	11.72 (135.3)	7.99 (61.77)	10.29 (103.95)	6.70 (42.95)	9.51 (88.50)
SEd	1.38	1.01	1.07	0.77	0.69	0.69	0.59	0.60
CD (P=0.05)	2.82	2.12	2.18	1.58	1.41	1.42	1.20	1.49

T.Hishell - Transgenic stacked Hishell ; N.T. Hishell - Non-transgenic Hishell ; T. 900 M Gold - Transgenic stacked 900 M Gold ; N.T. 900 M Gold - Non-transgenic 900 M Gold ; HW - Hand Weeding ; IC - Insect Control; WC - Weed Control

control efficiency (Table 2). Hellwig *et al.* (2002) also reported that, properly timed sequential application of glyphosate was effective in season-long control of common waterhemp (*Amaranthus rudis*), giant foxtail (*Setaria faberi*), velvetleaf (*Abutilion theophrasti*), common cocklebur (*Xanthum strumarium*) and common lambsquarters (*Chenopodium album*) at levels more than 90 per cent through the season.

Maize yield

Weed management practices showed significant variation in grain yields in both transgenic and non-transgenic hybrids (Table 3). During *kharif* 2009, POE application of glyphosate at 1800 g a.e ha^{-1} in transgenic 900 M Gold maize hybrid resulted in higher grain yield of 12.01 t ha^{-1}. This was 36.64 per cent higher than the unweeded check plots of non-transgenic 900 M Gold maize hybrid (T_{11}). The yield obtained under POE glyphosate at 1800 g a.e ha^{-1} was similar with that obtained under the treatments of POE glyphosate at different rates in Hishell (11.19 - 11.78 t ha^{-1}) and in 900 M Gold at 900 and 3600 g a.e ha^{-1} (11.30 and 11.68 t ha^{-1}). This was followed by non-transgenic Hishell and 900 M Gold with PE application of atrazine at 0.5 kg ha^{-1} *fb* HW (10.52 and 10.27 t ha^{-1}). Unweeded check plots recorded lesser grain yield. Whereas during *rabi* 2009-10, POE application of glyphosate at 3600 g a.e ha^{-1} in transgenic Hishell maize hybrid resulted in higher grain yield of 10.12 t ha^{-1} (Table 3). This was 37.15 per cent higher than the unweeded check plots of non-transgenic Hishell maize hybrid (T_8). Grain yield under POE application of glyphosate at 3600 g a.e ha^{-1} in transgenic Hishell maize hybrid was comparable with POE application of glyphosate at different rates in transgenic 900 M Gold (9.3-10.0 t ha^{-1}) and in Hishell at 1800 g a.e ha^{-1} (9.86 t ha^{-1}) as well in non-transgenic Hishell and 900 M Gold maize hybrids with atrazine at 0.5 kg ha^{-1} *fb* HW (8.89 and 9.27 t ha^{-1}). Unweeded maize hybrids resulted in lesser grain yield. These results are in corroboration with the findings of Gower *et al.* (2002) who suggested that grain yields were highest with two

Table 2. Effect of weed management methods on weed control efficiency (WCE) in maize

Treatment	Weed control efficiency (%)			
	Kharif 2009		*Rabi* 2009-10	
	20 DAS	40 DAS	20 DAS	40 DAS
T - T. Hishell POE glyphosate @ 900 g ha^{-1}	0.0	97.69	0.0	91.99
T^{1} - T. Hishell POE glyphosate @ 1800 g ha^{-1}	0.0	98.94	0.0	96.03
T^{2} - T. Hishell POE glyphosate @ 3600 g ha^{-1}	0.0	99.40	0.0	98.20
T^{3} - T. 900 M Gold POE glyphosate @ 900 g ha^{-1}	0.0	97.13	0.0	90.21
T^{4} - T. 900 M Gold POE glyphosate @ 1800 g ha^{-1}	0.0	98.72	0.0	96.33
T_6^{5} - T. 900 M Gold POE glyphosate @ 3600 g ha^{-1}	0.0	99.68	0.0	98.51
T_7 - N.T. + Hishell PE atrazine @ 0.5 kg ha^{-1} + HW+ IC	83.63	77.29	80.49	69.42
T_8 - N.T. + Hishell No WC and no IC	0.0	0.0	0.0	0.0
T_9 - N.T. + Hishell No WC and only IC	0.0	0.0	0.0	0.0
T_{10} - N.T. + 900 M Gold PE atrazine @ 0.5 kg ha^{-1}+ HW+ IC	83.18	74.56	81.21	70.61
T_{11} - N.T. + 900 M Gold No WC and no IC	0.0	0.0	0.0	0.0
T_{12} - N.T. + 900 M Gold No WC and only IC	0.0	0.0	0.0	0.0
T_{13} - Proagro PE atrazine 0.5 @ kg ha^{-1} + HW+ IC	83.49	75.52	76.23	70.62
T_{14} - Proagro 4640 No WC and no IC	0.0	0.0	0.0	0.0
T_{15} - CoHM 5 PE atrazine @ 0.5 kg ha^{-1} + HW+ IC	86.42	74.34	79.74	70.06
T_{16} - CoHM 5 No WC and no IC	0.0	0.0	0.0	0.0

Data not statistically analysed; T_1-T_6 : Transgenic maize hybrids applied with different doses of glyphosate as POE at 25 DAS
T.Hishell - Transgenic stacked Hishell ; N.T. Hishell - Non-transgenic Hishell ; T. 900 M Gold - Transgenic stacked 900 M Gold ; N.T. 900 M Gold - Non-transgenic 900 M Gold ; HW - Hand Weeding ; IC - Insect Control; WC - Weed Control

herbicide applications, the ûrst being applied when weeds were only five cm tall.

Table 3. Effect of different weed management methods on yield of maize

Treatment	Grain yield (t ha^{-1})	
	Kharif 2009	*Rabi* 2009-10
T_1 - T. Hishell POE glyphosate @ 900 g a.e/ha	11.19	8.96
T_2 - T. Hishell POE glyphosate @ 1800 g a.e/ha	11.64	9.86
T_3 - T. Hishell POE glyphosate @ 3600 g a.e/ha	11.78	10.12
T_4 - T. 900 M Gold POE glyphosate @ 900 g a.e/ha	11.30	9.33
T_5 - T. 900 M Gold POE glyphosate @ 1800 g a.e/ha	12.01	10.00
T_6 - T. 900 M Gold POE glyphosate @ 3600 g a.e/ha	11.68	9.92
T_7 - N.T. + Hishell PE atrazine @ 0.5 kg a.i/ha + HW+ IC	10.52	8.89
T_8 - N.T. + Hishell No WC and no IC	7.57	6.36
T_9 - N.T. + Hishell No WC and only IC	8.05	7.21
T_{10} - N.T. + 900 M Gold PE atrazine @ 0.5 kg a.i/ha + HW+ IC	10.27	9.27
T_{11} - N.T. + 900 M Gold No WC and no IC	7.61	7.19
T_{12} - N.T. + 900 M Gold No WC and only IC	8.14	8.37
T_{13} - Proagro PE atrazine 0.5 @ kg a.i/ha + HW+ IC	8.00	6.95
T_{14} - Proagro 4640 No WC and no IC	5.98	5.62
T_{15} - CoHM 5 PE atrazine @ 0.5 kg a.i/ha + HW+ IC	8.04	7.15
T_{16} - CoHM 5 No WC and no IC	6.08	5.73
SEd	0.72	0.84
CD (P=0.05)	1.46	1.69

T.Hishell - Transgenic stacked Hishell ; N.T. Hishell - Non-transgenic Hishell ; T. 900 M Gold - Transgenic stacked 900 M Gold ; N.T. 900 M Gold - Non-transgenic 900 M Gold ; HW - Hand Weeding ; IC - Insect Control; WC - Weed Control

Conclusion

The results of this experiment revealed that, the density and dry weight of weeds were significantly reduced with POE application of glyphosate at 1800 g a.e ha^{-1} in transgenic 900 M Gold and 3600 g a.e ha^{-1} in transgenic Hishell during *kharif* 2009 and *rabi* 2009-10 seasons, respectively. Higher grain yield was recorded with POE application of glyphosate at 1800 g a.e ha^{-1} in transgenic 900 M Gold and 3600 g a.e ha^{-1} in transgenic Hishell during *kharif* 2009 and *rabi* 2009-10 seasons, respectively. It was comparable with lower dose of glyphosate (900 g a.e ha^{-1}) and PE application atrazine *fb* HW in non-transgenic Hishell and 900 M Gold during *rabi,* 2009-10.

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