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Influence of Post Emergence Application of Glyphosate on Weed Control Efficiency and Yield of Transgenic Maize

Duraisamy Ravisankar*, **Chinnagoundar Chinnusamy, Purushothaman Muthukrishnan**

Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, India.
Email: *ravi.agri@gmail.com

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ABSTRACT

Field experiment was conducted during *kharif* 2009 and *rabi* 2009-2010 at Tamil Nadu Agricultural University, Coimbatore to evaluate the weed control efficiency and yield potential of glyphosate resistant transgenic maize. Treatments consisted of two transgenic maize hybrids named Hishell and 900 M gold with application of glyphosate as post emergence at 900, 1800 and 3600 g a.e/hathese were compared with non-transgenic counterpart maize hybrids with application of atrazine as pre-emergence at 0.5 kg/ha followed by one hand weeding at 40 Days After Sowing along with need based insect control practices. Post emergence application of glyphosate at 900, 1800 and 3600 g a.e/ha in transgenic maize hybrids was recorded with lower weed density and higher weed control efficiency compared to other treatments. Higher grain yield was recorded with post emergence application of glyphosate at 1800 g a.e/ha in transgenic hybrid 900 M Gold and 3600 g a.e/ha in transgenic hybrid Hishell during *kharif* 2009 and *rabi* 2009-2010 seasons, respectively.

Keywords: Glyphosate Tolerant Maize; Weed Control Efficiency; Yield

1. Introduction

Weed infestation in maize is one of the key factors responsible for the lower productivity and poor quality of produce. Reduction in grain yield is ranged from 33 to 50 per cent or even more depending upon the intensity and nature of the weed flora [1]. The traditional method of manual and mechanical weeding is quite effective, but arduous, time consuming and highly costly. Under such situation, chemical weed control is a better option to conventional methods and use of herbicides forms an integral part of the modern crop production. In the last few decades different herbicides were used alone or in combination to eliminate the weeds but their efficiencies differ because of their narrow spectrum of weed control.

In the recent years, the introduction of herbicide tolerant crops has transformed the way of chemical weed management method. Herbicide tolerant crops and their weed management systems allowed the use of broad-spectrum post emergence herbicides, which have reduced environmental impact. These systems may reduce the use of soil applied residual herbicides and consequently reduce the potential for these herbicides to leach into groundwater [2]. Transgenic stacked hybrid maize (MON 89034 × NK 603) 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 for the effective weed management system. The plants become tolerant to the herbicide while weed flora are suppressed after application of herbicide. These efficacious systems allow post emergence use of glyphosate for total weed management in glyphosate tolerant transgenic maize. In view of the importance of chemical weed control in herbicide tolerant transgenic maize, field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore to evaluate the weed control efficiency and yield of transgenic stacked maize hybrids.

*Corresponding author.

2. Material and Methods

2.1. Experimental Site and Initial Soil Characteristics

The research was conducted with glyphosate resistant maize hybrids during *kharif* 2009 and *rabi* 2009-2010 seasons at experimental site of Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. The experimental site is situated in Western Agro climatic zone of Tamil Nadu with 11˚N longitude, 77˚E latitude and at an altitude of 426.7 m above mean sea level and the farm receives the normal annual total rainfall of 674.2 mm in 45.8 rainy days. The soil of the experimental field was sandy clay loam in texture with low available nitrogen (165 kg/ha), medium available phosphorus (11.2 kg/ha) and high available potassium (585 kg/ha).

2.2. Experimental Design, Selection of Cultivar and Sowing

The experiment was laid out in randomized complete block design (RBD) with fourteen treatments and replicated thrice. The gross plot size adopted was 18.0 Sq. meter (3.6 m × 5.0 m). Two herbicide tolerant transgenic maize test hybrids named transgenic Hishell and Transgenic 900 M Gold were used for the experiment. The seeds were dibbled at a depth of 4 cm and adopting a spacing of 60 cm between rows and 25 cm between the plants.

2.3. Treatment Details

Treatments consisted of post emergence application of glyphosate at 900, 1800 and 3600 g a.e/haat 2 - 4 leaf stage of weeds (approximately 25 Days After Sowing of transgenic maize hybrids) in transgenic maize hybrids. In non-transgenic maize hybrids *viz*., Hishell, 900 M Gold, COHM 5 (local test hybrid) and Proagro (national test hybrid) with pre-emergence application of atrazine 0.5 kg/ha at 3 Days After Sowing (DAS) followed byone hand weeding (HW) at 40 DAS along with insect control was done by whorl application of carbofuran at 1.0 kg a.i/ha at 20 DAS.

2.4. Observations

2.4.1. Weed Density

The weed count was recorded species wise using 0.5 m × 0.5 m quadrat from four randomly fixed places in each plot and the weeds falling within the frames of the quadrat were counted and the mean values were expressed in number m^{-2}. The densities of grasses, sedges and broad leaved weeds and the total weeds were recorded at 10 and 25 days after first and second spraying of glyphosate and expressed in number m^{-2}.

2.4.2. Weed Dry Weight

The weeds falling within the frames of the quadrat were collected, categorised into grasses, sedges and broad-leaved weeds, shade dried and later dried in hot-air oven at 80˚C for 72 hrs. The dry weight of grasses, sedges and broadleaved weeds were recorded separately at 10 and 25 days after first and second spraying of glyphosate and expressed in kg/ha.

2.4.3. Weed Control Efficiency

Weed control efficiency (WCE) was calculated as per the procedure [3].

$$\text{WCE\%} = \frac{\text{WD}_c - \text{WD}_t}{\text{WD}_c} \times 100$$

where, WCE—weed control efficiency (percent); WD_c—weed biomass ($g \cdot m^{-2}$) in control plot; WD_t—weed biomass ($g \cdot m^{-2}$) in treated plot.

2.5. Statistical Analysis

The data were statistically analysed following the procedure [4] for randomised block design. The data pertaining to weeds were transformed to square root scale of $\sqrt{(X+2)}$. Whenever significant difference existed, critical difference was constructed at five per cent probability level. Such of those treatments where the difference are not significant are denoted as NS.

3. Results and Discussion

3.1. Weed Flora

The results of the experiment revealed that the broad leaved weeds dominated over grasses and sedge. Among the individual weed species, *Trianthema portulacastrum*, *Cleome gynandra*, *Digera arvensis*, *Datura stramonium*, *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Commelina bengalinsis* and *Cyperus rotundus* were predominant in maize field during both the seasons. Among broad leaved weeds, *Trianthema portulacastrum*was the dominant one during both the seasons. This might be due to the smothering effect of broad leaved weeds on monocots. The leaf area of the weed was more favourable for interception of brighter solar radiation. Similar studies reported that maize crop infested with major broad leaved weeds were *Trianthema pórtulacastrum*, *Digera arvensis*, *Phyllanthus niniri*, *Amaranthus viridis*. Among the grassy weeds *Cynodon dactylon* and *Dactyloctenium aegyptium* had dominated. *Cyperus rotundus* was the major sedge weed [5].

3.2. Total Weed Density and Dry Weight

Significant variation in total weed density was observed

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among the weed control treatments. During *kharif* 2009, significantly lesser and comparable density of total weeds was achieved with pre-emergence application of atrazine at 0.5 kg/ha followed by HW under non-transgenic Hishell (T_7) and Proagro (T_{13}). These were comparable with non-transgenic 900 M Gold and CoHM 5 maize hybrids with same treatment at 20 DAS. Relatively, higher densities were observed under unweeded checks and transgenic maize without application of glyphosate. Whereas, at 40 DAS, significantly lesser and comparable density of weeds were observed under transgenic 900 M Gold maize hybrid with post emergence application of glyphosate at 3600 g a.e/ha (T_6). During *rabi* 2009-2010, lesser weed density was recorded under non-transgenic Hishell maize hybrid applied with pre-emergence atrazine at 0.5 $kg \cdot ha^{-1}$ followed by HW (T_7) at 20 DAS. This was comparable withsame treatment applied under non-transgenic 900 M Gold, Proagro and CoHM 5. Whereas at 40 DAS, with post emergence application of glyphosate at 1800 and 3600 g a.e/ha under transgenic Hishell and 900 M Gold registered significantly lesser density of weeds. This was closely followed by POE glyphosate at 900 g a.e/ha under the same hybrids (**Table 1**).

Among the various rates of glyphosate, glyphosate at 1800 g a.e/ha in transgenic 900 M Gold (1.0 No's/m^2) and 3600 g a.e/ha 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/hagave 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.* Glyphosate provides marginal or no control of weeds such as *Cynodon dactylon*, *Solanum carolinense* and tropical *Commelina benghalensis* [6]. In non-transgenic maize hybrids, application of atrazine at 0.5 kg/ha 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. Application of atrazine at 0.5 kg/ha as pre-emergence followed by inter cultivation at 35 DAS in maize significantly reduced the total weed density and weed dry weight [7].

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

Table 1. Effect of weed management methods on total weed density in transgenic and non-transgenic maize.

Treatments	Total weed density (No. m^{-2})			
	Kharif 2009		*Rabi* 2009-2010	
	40 DAS	65 DAS	40 DAS	65 DAS
T_1—Transgenic Hishell POE glyphosate @ 900 g/ha	3.61 (11.0)	3.83 (12.7)	4.24 (16.0)	3.96 (13.7)
T_2—Transgenic Hishell POE glyphosate @ 1800 g/ha	2.65 (5.0)	3.32 (9.0)	3.16 (8.0)	2.52 (4.3)
T_3—Transgenic Hishell POE glyphosate @ 3600 g/ha	2.00 (2.0)	2.45 (4.0)	2.08 (2.3)	2.00 (2.0)
T_4—Transgenic 900 M Gold POE glyphosate @ 900 g/ha	3.79 (12.3)	4.47 (18.0)	4.40 (17.3)	3.87 (13.0)
T_5—Transgenic 900 M Gold POE glyphosate @ 1800 g/ha	1.73 (1.0)	3.31 (9.0)	3.00 (7.0)	2.71 (5.3)
T_6—Transgenic 900 M Gold POE glyphosate @ 3600 g/ha	1.73 (1.0)	2.38 (3.7)	2.16 (2.7)	1.73 (1.0)
T_7—Hishell PE atrazine @ 0.5 kg/ha + HW + IC	8.02 (62.3)	5.03 (23.4)	7.30 (51.3)	5.10 (24.0)
T_8—Hishell No WC and no IC	13.04 (168.0)	12.42 (152.3)	11.39 (127.7)	10.94 (117.7)
T_9—900 M Gold PE atrazine @ 0.5 kg/ha + HW + IC	7.66 (56.7)	5.10 (24.0)	7.28 (51.0)	5.26 (25.7)
T_{10}—900 M Gold No WC and no IC	13.29 (174.7)	12.40 (151.7)	11.82 (137.7)	10.68 (112.0)
T_{11}—Proagro PE atrazine 0.5 @ kg/ha + HW + IC	8.02 (62.3)	4.87 (21.7)	7.12 (48.7)	5.10 (24.0)
T_{12}—Proagro 4640 No WC and no IC	13.06 (168.7)	12.14 (145.3)	11.56 (131.7)	10.46 (107.3)
T_{13}—CoHM 5 PE atrazine @ 0.5 kg/ha + HW + IC	7.72 (57.7)	4.90 (22.0)	7.24 (50.4)	5.20 (25.0)
T_{14}—CoHM 5 No WC and no IC	12.82 (162.3)	12.41 (152.0)	11.72 (135.3)	10.98 (118.7)
SEd	**1.01**	**0.79**	**0.77**	**0.69**
CD (P = 0.05)	**2.12**	**2.14**	**1.58**	**1.41**

Figures in parenthesis are original values; POE—Post emergence application; PE—Pre-emergence; WC—Weed control; IC—Insect control; HW—Hand weeding.

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 in transgenic 900 M Gold and 3600 g a.e/ha in transgenic Hishell (0.29 and 1.20) at 40 DAS during *kharif* 2009 and *rabi* 2009-2010, respectively (**Table 2**). This might be due to total weed control as achieved by glyphosate. The findings are in accordance with that post emergence application of glyphosate, following pre emergence herbicides, or three applications of post emergence glyphosate only without pre emergence herbicides reduced total weed dry weight by at least 97 percent when compared to without glyphosate applied plots [8]. Total weed dry weight was effectively reduced in non-transgenic hybrids with pre emergence application of atrazine at 0.5 kg/ha followed by 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.

3.3. Weed Control Efficiency

During *kharif* 2009, higher weed control efficiency of 86.42 percent was recorded with the application of atrazine at 0.5 kg/ha followed by HW under CoHM 5 maize hybrid, followed by other non-transgenic hybrids *viz.*, Hishell (83.63), Proagro (83.49) and 900 M Gold (83.18) with same treatment at 20 DAS. Whereas at 40 DAS, transgenic 900 M Gold maize hybrid applied with post emergence glyphosate at 3600 g a.e/ha recorded maximum weed control efficiency (99.68 percent), followed by same dose of glyphosate under transgenic Hishell (99.40 percent). Whereas during *Rabi*, 2009-2010, Pre-emergence application of atrazine at 0.5 kg/ha followed by HW recorded higher weed control efficiency of 81.21 percent in non-transgenic 900 M Gold maize hybrid. This was followed by other non-transgenic hybrids *viz.*, Hishell, CoHM 5 and Proagro with same treatment at 20 DAS. At 40 DAS, transgenic 900 M Gold applied with glyphosate as post emergence at 3600 g a.e/ha recorded maximum weed control efficiency (98.51 percent), followed by same dose of glyphosate under transgenic Hishell (98.21 percent). Among non-transgenic hybrids with weed control practices, Proagro recorded maximum WCE of 70.62 percent (**Table 3**). The findings are in line with that two sequential post applications of glyphosate in maize provided up to 92 percent control of ivyleaf-morningglory (*Ipomoea* spp.) as compared to the variable

Table 2. Effect of weed management methods on total weed dry weight in transgenic and non-transgenic maize.

Treatments	Total weed dry weight (g·m^{-2})			
	Kharif 2009		*Rabi* 2009-2010	
	40 DAS	65 DAS	40 DAS	65 DAS
T_1—Transgenic Hishell POE glyphosate @ 900 g/ha	2.10 (2.40)	2.67 (5.11)	3.01 (7.09)	3.13 (7.77)
T_2—Transgenic Hishell POE glyphosate @ 1800 g/ha	1.76 (1.10)	2.32 (3.37)	2.35 (3.51)	2.13 (2.52)
T_3—Transgenic Hishell POE glyphosate @ 3600 g/ha	1.62 (0.62)	1.90 (1.62)	1.79 (1.20)	1.79 (1.21)
T_4—Transgenic 900 M Gold POE glyphosate @ 900 g/ha	2.23 (2.98)	2.95 (6.68)	3.26 (8.66)	3.06 (7.34)
T_5—Transgenic 900 M Gold POE glyphosate @ 1800 g/ha	1.51 (0.29)	2.48 (4.17)	2.29 (3.25)	2.21 (2.89)
T_6—Transgenic 900 M Gold POE glyphosate @ 3600 g/ha	1.53 (0.33)	1.85 (1.41)	1.82 (1.32)	1.62 (0.64)
T_7—Hishell PE atrazine @ 0.5 kg/ha + HW + IC	5.06 (23.61)	3.49 (10.21)	5.39 (27.06)	3.71 (11.74)
T_8—Hishell No WC and no IC	10.07 (99.43)	9.87 (95.49)	8.80 (75.43)	9.40 (86.32)
T_9—900 M Gold PE atrazine @ 0.5 kg/ha + HW + IC	5.33 (26.45)	3.60 (10.93)	5.29 (26.01)	3.98 (13.81)
T_{10}—900 M Gold No WC and no IC	9.69 (91.92)	9.94 (96.78)	9.43 (86.89)	9.36 (85.64)
T_{11}—Proagro PE atrazine 0.5 @ kg/ha + HW + IC	5.24 (25.45)	3.72 (11.87)	5.29 (26.00)	4.21 (15.70)
T_{12}—Proagro 4640 No WC and no IC	9.51 (88.42)	9.78 (93.72)	9.09 (80.58)	9.33 (85.12)
T_{13}—CoHM 5 PE atrazine @ 0.5 kg/ha + HW + IC	5.35 (26.67)	3.63 (11.18)	5.34 (26.50)	4.01 (14.10)
T_{14}—CoHM 5 No WC and no IC	10.29 (103.95)	10.31 (104.23)	9.51 (88.50)	9.71 (92.32)
SEd	**0.69**	**0.68**	**0.60**	**0.56**
CD (P = 0.05)	**1.42**	**1.44**	**1.49**	**1.00**

Figures in parenthesis are original values; POE—Post emergence application; PE—Pre-emergence; WC—Weed control; IC—Insect control; HW—Hand weeding.

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Table 3. Effect of weed management methods on weed control efficiency and yield in transgenic and non-transgenic maize.

Treatments	Weed control efficiency (%)				Yield (t/ha)	
	Kharif 2009		*Rabi* 2009-2010		*Kharif* 2009	*Rabi* 2009-2010
	40 DAS	65 DAS	40 DAS	65 DAS		
T_1—Transgenic Hishell POE glyphosate @ 900 g/ha	97.69	95.10	91.99	91.58	11.19	8.96
T_2—Transgenic Hishell POE glyphosate @ 1800 g/ha	98.94	96.77	96.03	97.27	11.64	9.86
T_3—Transgenic Hishell POE glyphosate @ 3600 g/ha	99.40	98.45	98.20	98.69	11.78	10.12
T_4—Transgenic 900 M Gold POE glyphosate @ 900 g/ha	97.13	93.59	90.21	92.05	11.30	9.33
T_5—Transgenic 900 M Gold POE glyphosate @ 1800 g/ha	98.72	96.00	96.33	96.87	12.01	10.00
T_6—Transgenic 900 M Gold POE glyphosate @ 3600 g/ha	99.68	98.65	98.51	99.31	11.68	9.92
T_7—Hishell PE atrazine @ 0.5 kg/ha + HW + IC	77.29	90.20	69.42	87.28	10.52	8.89
T_8—Hishell No WC and no IC	-	-	-	-	7.57	6.36
T_9—900 M Gold PE atrazine @ 0.5 kg/ha + HW + IC	74.56	89.51	70.61	85.04	10.27	9.27
T_{10}—900 M Gold No WC and no IC	-	-	-	-	7.61	7.19
T_{11}—Proagro PE atrazine 0.5 @ kg/ha + HW + IC	75.52	88.61	70.62	82.99	8.00	6.95
T_{12}—Proagro 4640 No WC and no IC	-	-	-	-	5.98	5.62
T_{13}—CoHM 5 PE atrazine @ 0.5 kg/ha + HW + IC	74.34	89.27	70.06	84.73	8.04	7.15
T_{14}—CoHM 5 No WC and no IC	-	-	-	-	6.08	5.73
SEd					**0.72**	**0.84**
CD (P = 0.05)					**1.46**	**1.69**

Figures in parenthesis are original values; POE—Post emergence application; PE—Pre-emergence; WC—Weed control; IC—Insect control; HW—Hand weeding.

control (27 to 81 percent) provided by soil applied *s*-triazines [9].

3.4. Yield

Weed management practices showed significant variation in grain yields in both transgenic and non-transgenic hybrids during *kharif* 2009. Among the treatments evaluated, post emergence application of glyphosate at 1800 g a.e/ha in transgenic 900 M Gold maize hybrid resulted in higher grain yield of 12.01 t/ha. This was 36.64 percent higher than the unweeded check plots of non-transgenic 900 M Gold maize hybrid (T_{11}). The yield obtained under glyphosate as post emergence application at 1800 g a.e/ha was similar with that obtained under the treatments of post emergence application of glyphosate at different rates in Hishell (11.19 - 11.78 t/ha) and in 900 M Gold at 900 and 3600 g a.e/ha (11.30 and 11.68 t/ha). This was followed by non-transgenic Hishell and 900 M Gold with pre emergence application of atrazine at 0.5 kg/hafollowed by HW (10.52 and 10.27 t/ha). Unweeded check plots recorded lesser grain yield. Significant variation in grain yield of transgenic and non-transgenic maize hybrids was observed due to various weed control practices during *rabi*, 2009-2010. Post emergence application of glyphosate at 3600 ga.e/ha in transgenic Hishell maize hybrid resulted in higher grain yield of 10.12 t/ha. This was 37.15 percent higher than the unweeded check plots of non-transgenic Hishell maize hybrid. Grain yield under post emergence application of glyphosate at 3600 g a.e/ha 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) and in Hishell at 1800 g a.e/ha (9.86 t/ha) as well in non-transgenic Hishell and 900 M Gold maize hybrids with atrazine at 0.5 kg/hafollowed by HW (8.89 and 9.27 t/ha) (**Table 3**). Unweeded maize hybrids resulted in lesser grain yield. Chemical weeding at 2 - 3 leaf stage of weeds followed by hand weeding at 50 DAS gave promising results of 34 percent and, 33 percent of increases in grain and stalk yields [10].

4. Conclusion

On the basis of the above results, both the transgenic maize hybrids with single application of glyphosate at 2 -

4 leaf stage of weeds (approximately 25 DAS of transgenic maize hybrids) could provide the season long weed control. Higher grain yield was recorded with POE application of glyphosate at 1800 g a.e/ha in transgenic 900 M Gold and 3600 g a.e/ha in transgenic Hishell during *kharif*, 2009 and *rabi*, 2009-2010 seasons, respectively.

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