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Glyphosate use in transgenic maize: Effect on weeds and crop productivity in North-Western Indo-Gangetic Plains of Haryana

Dharam Bir Yadav*, Samar Singh, Ran Singh and Ashok Yadav

CCS Haryana Agricultural University, Hisar, Haryana 125004, India

**Email: dbyadav@gmail.com*

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ABSTRACT

A field experiment was conducted during *Kharif* 2012 at Khrindwa research farm of CCS Haryana Agricultural University, Regional Research Station, Karnal, under the Bio-safety Research Trial Level-1 for transgenic maize hybrids to evaluate the bio-efficacy of glyphosate as post-emergence herbicide against weeds. There were 14 treatment combinations, including two transgenic hybrids of Monsanto, *Hishell-NK603* and *900M Gold-NK603*. Weed flora of the field included *Echinochloa crus-galli, Dactyloctenium aegyptium, Brachiaria reptans* and *Eragrostis tenella* among grassy weeds, *Physalis minima* and *Phyllanthus niruri* among broadleaf weeds and *Cyperus rotundus* among sedges along with few other minor weeds. Use of glyphosate 900-1800 g/ha in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*, provided 98.2-99.5% weed control efficiency, which was higher than the atrazine 750 g/ha treatments (62.1-68.6%); and resulted in improved grain yield of maize (7.7-8.7 t/ha) than unweeded checks (4.7-5.9 t/ha) and atrazine treatments (5.8-7.5 t/ha). At 60 DAT, minimum weed population (8.0-9.3/m^2) was recorded in the glyphosate treatment at both the doses in transgenic maize hybrids, which was significantly lower than the atrazine treatments (19.3-21.3/m^2) in transgenic/ conventional hybrids, as well as the non-weeded (37.3-41.3/m^2) checks in conventional hybrids. Glyphosate 900-1800 g/ha in *900M Gold-NK603* produced maximum grain yield (8.6-8.7 t/ha) which was followed by glyphosate 900-1800 g/ha in *Hishell-NK603* (7.7-7.8 t/ha). The growth, yield and yield attributes indicated superiority of *900M Gold-NK603* over *Hishell-NK603*, however, the differences in yield were not significant. Present study indicated the suitability of glyphosate use as post-emergence in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*. There was no phyto-toxicity of glyphosate 900-1800 g/ha on the transgenic crop.

Maize (*Zea mays* L.) is one of the most important cereals in the world agricultural economy, and grown over an area of 197 mha with production of 1135 m tonnes and productivity of 5.75 t/ha in 2017 (FAO 2019). It ranks as the third most important food grain crop next to rice and wheat in the country. In India, maize is grown in a wide range of situations, extending from extreme semi-arid to sub-humid and humid regions. The average productivity of maize (2.68 t/ha) in India is far below world average of 5.75 t/ha. Weeds are the major constraints in maize to lower down the production; and being a *Kharif* season crop, diverse type of weeds infest the crop which are difficult to control with a single herbicide. Initial slow growth, wider spacing and high moisture during rainy season are the factors favouring the growth of weeds in maize. Herbicides are one of the most important weed management tools in maize. Sustainability of maize under zero-tillage systems has been well documented (Jat *et al*. 2013, Khedwal *et al*. 2017).

Herbicide tolerant and insect resistant GM crops have become leading features in agro- ecosystem of many of the world's agricultural regions (ISAAA 2016). During the recent past, many transgenic and non-transgenic herbicide tolerant crops (HTCs) have been made available to cultivators in many countries. But in India, HTCs are in the initial stage of field evaluation (Chinnusamy *et al*. 2014). Glyphosate ready maize was first marketed in the late 1990s. This technology confers tolerance to glyphosate by production of glyphosate-tolerant CP4 EPSPS (5-enolpyruvylshikimate-3-phosphate synthase) proteins. A glyphosate-based system has many advantages, including low cost, excellent crop safety, broad spectrum of weed control, and application flexibility (Norsworthy *et al*. 2001, Dewar 2009, Creech *et al*. 2012). The efficacy of glyphosate tolerant transgenic stack maize hybrids against insect-pests like *Chillo partellus, Helicoverpa armigera etc*. has also been documented, indicating dual-benefit of such transgenic maize hybrids

(Sushilkumar *et al*. 2017). This paper presents the results of efficacy of glyphosate tolerant transgenic maize for control of weed complex in Haryana conditions in North-Western Indo-Gangetic Plains.

A field experiment was conducted during *Kharif* (rainy) season of 2012 at Khrindwa Research Farm of CCS Haryana Agricultural University, Regional Research Station, Karnal, under the Bio-safety Research Trial Level-1 for transgenic maize hybrids to evaluate the bio-efficacy of glyphosate as post-emergence against weeds. The geographical location of the experiment was situated at 30°11'N latitude and 76°93'E longitude with an altitude of 252 m above mean sea level in Kurukshetra district of Haryana. The climate of the area was typically sub-tropical with an average annual rainfall of about 700 mm. During the crop season, the daily minimum and maximum temperatures were 13.8-29.5 ^{0}C and 27.0-37.2^{0}C, respectively, with total rainfall of 285 mm. The soil of the research farm was low in nitrogen, medium in phosphorus and potash. Two transgenic stacked corn hybrids of Monsanto, *viz*. *Hishell* and *900M Gold* containing CP4 EPSPS genes (Event NK603) were evaluated in the trial. There were 14 treatment combinations, including two GM-hybrids *Hishell (NK603)* and *900M Gold (NK603)* each with application of glyphosate (MON 76366) 900, 1800 g/ ha (at 2-4 leaf stage) and atrazine 750 g/ha (0-3 DAS), and conventional (non-GM) hybrids *Hishell*, *900M Gold*, national check (*Pro 4640*) and local check (*HM 10*) each with atrazine 750 g/ha (at 0-3 DAS) and non-weeded check. The experiment was laid out in randomized block design with three replications. The sowing of maize was done at a spacing of 60 x 25 cm using seed rate of 22.5 kg/ha on 10 July, 2012. The plot size was 5.0 × 3.6 m. The herbicide atrazine was applied as pre-emergence (PE) on 12th July, 2012, and glyphosate as post-emergence (PoE) on 2nd August, 2012 with knapsack sprayer fitted with flat fan nozzle using a spray volume of 250 L/ha. At the time of glyphosate spray, mean leaf stage values of different weeds were 3.6-3.7 (**Table 1**) with plant height of 9.1-9.3 cm (**Table 1**) and total ground coverage of 50-52% (**Table 2**). Recommended doses of fertilizer nutrients (150:60:60 kg of NPK/ha) were given in the form of urea, diammonium phosphate and muriate of potash. Crop was raised by adopting the recommendations of the state University for hybrid maize. As per protocol, buffer crop of fodder maize variety *'African Tall'* was grown all around the experimental area to act as barrier to aerial dispersal of pollens; in addition, an aerial isolation distance of 300 m was maintained in periphery of experimental area. Total area of the experimental field including *'African Tall'* was 2632 m^2 (70 x 37.6 m), out of which 324 m^2 was under transgenic maize cultivars.

The data on weed density was recorded at the time of application of glyphosate, 30 and 60 days after treatment (DAT), weed dry weight at 21 DAT and at maturity/ harvest, and yield at harvest. Crop was harvested on 18-19 October, 2012. The weed control efficiency (WCE) was computed based on dry weight of weeds by using the following formula,

Table 2. Percent ground cover by weeds at the time of glyphosate herbicide application

Maize hybrids	Ground cover by weed (%)			
	Hishell-NK603		*900M Gold-NK603*	
	GS (900 g/ha)	GS (1800 g/ha)	GS (900 g/ha)	GS (1800 g/ha)
Echinochloa crus-galli	8.7	7.7	8.0	8.3
Dactyloctenium aegyptium	17.0	17.0	18.0	16.3
Brachiaria reptans	4.3	4.7	5.3	5.3
Eragrostis tenella	1.7	2.0	2.0	2.3
Physalis minima	8.0	7.3	7.7	6.7
Phylanthus niruri	6.3	6.0	6.7	5.7
Other broad-leaf weeds	3.0	3.7	2.7	3.3
Cyperus rotundus	2.3	2.7	2.0	2.7
Total	51.3	51.0	52.3	50.7

GS: Glyphosate

Table 1. Leaf stage and plant height of weeds at the time of glyphosate herbicide application

Maize hybrids	Leaf stage of weed				Plant height of weed (cm)			
	Hishell-NK603		*900M Gold-NK603*		*Hishell-NK603*		*900M Gold-NK603*	
	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)
Echinochloa crus-galli	4.3	4.1	4.6	4.3	16.2	15.0	14.5	16.8
Dactyloctenium aegyptium	3.3	3.6	3.6	3.3	8.0	7.2	7.7	7.2
Brachiaria reptans	3.3	3.0	3.2	3.0	5.7	5.5	6.0	5.2
Eragrostis tenella	4.0	3.8	3.9	3.8	7.7	8.3	8.5	7.5
Physalis minima	3.7	3.9	4.0	3.8	12.8	12.8	13.5	12.1
Phylanthus niruri	3.3	3.4	3.4	3.3	6.8	6.8	7.3	6.5
Other broad-leaf weeds	4.0	3.9	3.7	3.8	9.3	8.9	8.6	9.2
Cyperus rotundus	3.3	3.0	3.2	3.2	8.2	8.1	8.5	8.1
Mean	3.7	3.6	3.7	3.6	9.3	9.1	9.3	9.1

$$WCE\ (\%) = \frac{(\text{Weed dry weight in unweeded plot} - \text{Weed dry weight in treated plot})}{\text{Weed dry weight in unweeded plot}} \times 100$$

From four unweeded checks, the treatment having maximum weed dry weight was used for calculation of WCE. The data were subjected to the Fisher's method of analysis of variance (ANOVA) (Fisher 1958) and significant treatment effect was judged with the help of 'F' test at the 5% level of significance by adopting the procedure described by Panse and Sukhatme (1985). Before statistical analysis, the data on density of weeds were subjected to square root transformation $(\sqrt{x+1})$ to improve the homogeneity of the variance.

Effect on weeds

Density of weeds: Weed flora of the field included *Echinochloa crus-galli, Dactyloctenium aegyptium, Brachiaria reptans* and *Eragrostis tenella* among grassy weeds, *Physalis minima* and *Phyllanthus niruri* among broad-leaf weeds and *Cyperus rotundus* among sedges along with few minor weeds (**Table 3** and **4**). At the time of glyphosate application, maximum weed density was recorded under the non-weeded plots of different conventional hybrids (*900M Gold*-Conv., *Pro 4640, HM10*) (166.0-194.0/m^2), and under glyphosate treatments of both GM hybrids (*Hishell-NK603, 900M Gold-KN603*) (168.7-188.7/ m^2), which were statistically similar to each other and lower than the atrazine treatments of different GM and non-GM hybrids (31.3-38.0/m^2). Similar trends were observed for different weed species and weed groups (**Table 3** and **4**). Higher density of weeds under glyphosate treatments was expected, as these plots were maintained as unweeded till the date of this observation *i.e.* before glyphosate spray.

At 30 DAT, minimum density of weeds was under glyphosate (MON 76366) 1800 g/ha (in both GM hybrids) closely followed by glyphosate 900 g/ha (in both GM hybrids) with total of 4.7, 6.0, 7.3 and 8.7 weeds per sq m, respectively, in transgenic corn hybrids *Hishell-NK603* and *900M Gold-NK 603* (**Table 5, 6** and **7**). However, these treatments were statistically similar to each other. In the treatments where atrazine was applied, population at this stage ranged from 34 to 42 weeds/m^2. This was significantly higher than that observed in glyphosate treatments. Among different weed groups, grassy weeds were maximum, followed by broad-leaf weeds and sedges with a similar pattern of density except no control of sedges under atrazine. Among grasses, *Echinochloa crus-galli* and *Dactyloctenium aegyptium* were maximum in density.

At 60 DAT, overall weed density reduced in all the treatments including weedy checks. Non-weeded check treatments recorded maximum weed population (37.3-41.3/m^2), and weed density under the atrazine treatments (19.3-21.3/m^2) were lower than the weedy check (**Table 5**, **6** and **7**). Minimum weed population (8.0-9.3/m^2) was found in the glyphosate treatment at both the doses, which was significantly lower than the atrazine treatments as well as the non-weeded checks. Similar to 30 DAT, grassy weeds were maximum in weed count. Among grassy weeds, *Echinochloa crus-galli* and *Brachiaria reptans,* and *Physalis minima* among BLW were on the higher side.

Dry weight of weeds

At 21 DAT, maximum dry weight of weeds (160.35-169.14 g/m^2) was recorded in non-weeded checks (**Table 8**). It was negligible under glyphosate

Table 3. Weed density (group wise) under different herbicidal treatments in GM-Corn at the time of glyphosate herbicide application

Maize hybrid	Herbicide	Weed density (no./m^2)			
		Grassy weeds	Broad-leaf weeds	Sedges	Total weeds
Hishell-NK603	Glyphosate 900 g/ha	10.3(105.3)	7.5(56.0)	2.8(7.3)	13.0(168.7)
Hishell-NK603	Glyphosate 1800 g/ha	10.4(107.3)	8.2(66.7)	2.7(6.7)	13.5(180.7)
Hishell-NK603	Atrazine 750 g/ha	4.4(19.3)	2.5(5.3)	3.1(8.7)	5.8(33.3)
900M Gold-NK603	Glyphosate 900 g/ha	10.5(109.3)	8.2(67.3)	2.8(6.7)	13.5(183.3)
900M Gold-NK603	Glyphosate 1800 g/ha	10.7(114.7)	8.1(64.7)	3.1(9.3)	13.8(188.7)
900M Gold-NK603	Atrazine 750 g/ha	4.4(18.7)	1.7(2.0)	3.3(10.0)	5.6(30.7)
Hishell Conv.	Atrazine 750 g/ha	4.4(19.3)	2.0(4.0)	2.7(8.0)	5.6(31.3)
Hishell Conv.	No weeding	10.1(102.0)	7.6(57.3)	2.5(6.7)	12.9(166.0)
900M Gold Conv.	Atrazine 750 g/ha	4.7(22.0)	1.5(1.3)	3.2(9.3)	5.8(32.7)
900M Gold Conv.	No weeding	10.2(104.7)	8.0(62.7)	2.8(6.7)	13.2(174.0)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	5.0(24.0)	2.3(4.7)	3.2(9.3)	6.2(38.0)
National check hybrid (*Pro 4640*)	No weeding	10.9(117.3)	8.5(71.3)	2.5(5.3)	14.0(194.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	4.6(20.7)	1.9(2.7)	3.2(9.3)	5.8(32.7)
Local check hybrid (*HM 10*)	No weeding	10.4(108.0)	8.4(70.7)	3.1(8.7)	13.7(187.3)
LSD (p=0.05)		1.26	1.12	NS	1.09

*Original figures in parentheses were subjected to square root transformation before statistical analysis

Table 4. Density of different weed species under different herbicidal treatments in GM-Corn at the time of glyphosate herbicide application

Maize hybrid	Herbicide	Density of weeds (no./m^2)*							
		Ec	Da	Br	Et	Pm	Pn	OBLW	Cr
Hishell-NK603	Glyphosate 900 g/ha	4.9(24.0)†	7.5(56.0)	4.4(18.7)	2.7(6.7)	4.8(22.0)	5.3(27.3)	2.8(6.7)	2.8(7.3)
,,	Glyphosate 1800 g/ha	4.9(23.3)	7.6(57.3)	4.6(20.7)	2.6(6.0)	5.4(28.7)	5.4(28.7)	3.2(9.3)	2.7(6.7)
,,	Atrazine 750 g/ha	3.1(8.7)	2.3(5.3)	2.0(3.3)	1.7(2.0)	1.5(2.0)	1.2(0.7)	1.8(2.7)	3.1(8.7)
900M Gold-NK603	Glyphosate 900 g/ha	4.8(22.7)	7.8(60.7)	4.6(20.0)	2.6(6.0)	5.2(26.0)	5.9(34.7)	2.8(6.7)	2.8(6.7)
,,	Glyphosate 1800 g/ha	4.8(22.0)	8.0(63.3)	4.9(23.3)	2.6(6.0)	5.0(24.7)	5.8(32.7)	2.8(7.3)	3.1(9.3)
,,	Atrazine 750 g/ha	2.9(7.3)	3.0(8.7)	1.7(2.0)	1.2(0.7)	1.0(0.0)	1.4(1.3)	1.2(0.7)	3.3(10.0)
Hishell Conv.	Atrazine 750 g/ha	3.0(8.0)	2.8(7.3)	1.8(2.7)	1.4(1.3)	1.7(2.7)	1.0(0.0)	1.5(1.3)	2.7(8.0)
,,	No weeding	5.0(24.7)	7.3(52.7)	4.3(18.0)	2.8(6.7)	4.6(20.7)	5.4(28.7)	3.0(8.0)	2.5(6.7)
900M Gold Conv.	Atrazine 750 g/ha	2.5(5.3)	3.2(10.0)	2.3(4.7)	1.7(2.0)	1.0(0.0)	1.0(0.0)	1.5(1.3)	3.2(9.3)
,,	No weeding	5.2(26.7)	7.2(51.3)	4.5(19.3)	2.9(7.3)	4.9(22.7)	5.7(32.0)	3.0(8.0)	2.8(6.7)
National check hybrid (Pro 4640)	Atrazine 750 g/ha	2.7(6.7)	3.4(10.7)	2.3(4.7)	1.7(2.0)	1.0(0.0)	1.7(2.7)	1.7(2.0)	3.2(9.3)
,,	No weeding	5.2(26.7)	7.8(59.3)	5.0(24.7)	2.8(6.7)	5.1(25.3)	5.9(34.7)	3.5(11.3)	2.5(5.3)
Local check hybrid (HM 10)	Atrazine 750 g/ha	2.9(8.0)	2.7(7.3)	2.1(4.0)	1.4(1.3)	1.0(0.0)	1.0(0.0)	1.9(2.70)	3.2(9.3)
,,	No weeding	5.1(25.3)	7.4(54.0)	4.7(21.3)	2.8(7.3)	5.2(26.0)	6.1(36.7)	3.0(8.0)	3.1(8.7)
LSD (p=0.05)		0.82	1.30	1.11	0.87	0.94	1.03	0.73	NS

*Original figures in parentheses were subjected to square root transformation before statistical analysis
Abbreviation: Ec, *Echinochloa crus-galli*; Da, *Dactyloctenium aegyptium*; Br, *Bracharia reptans*; Et, *Eragrostis tenella*; Pm, *Physalis minima*; Pn, *Phylanthus niruri*; OBLW, Other broad-leaf weeds; Cr, *Cyperus rotundus*

Table 5. Weed density (group wise) at 30 and 60 days after application of glyphosate in GM-Corn

Maize hybrid	Herbicide	Weed density (no./m^2)							
		30 DAT				60 DAT			
		Grassy weeds	Broad-leaf weeds	Sedges	Total weeds	Grassy weeds	Broad-leaf weeds	Sedges	Total weeds
Hishell-NK603	Glyphosate 900 g/ha	1.2(0.7)	2.8(7.3)	1.2(0.7)	3.1(8.7)	1.2(0.7)	2.9(7.3)	1.0(0.0)	3.0(8.0)
Hishell-NK603	Glyphosate 1800 g/ha	1.0(0.0)	2.3(4.7)	1.0(0.0)	2.3(4.7)	1.0(0.0)	2.9(7.3)	1.2(0.7)	3.0(8.0)
Hishell-NK603	Atrazine 750 g/ha	5.1(25.3)	2.5(5.3)	3.0(8.0)	6.3(38.7)	3.3(10.0)	2.5(5.3)	2.2(4.0)	4.5(19.3)
900M Gold-NK603	Glyphosate 900 g/ha	1.2(0.7)	2.6(6.0)	1.2(0.7)	2.9(7.3)	1.2(0.7)	3.0(8.7)	1.0(0.0)	3.1(9.3)
900M Gold-NK603	Glyphosate 1800 g/ha	1.2(0.7)	2.3(4.7)	1.2(0.7)	2.6(6.0)	1.0(0.0)	2.8(7.3)	1.2(0.7)	2.9(8.0)
900M Gold-NK603	Atrazine 750 g/ha	5.2(26.0)	1.8(2.7)	3.1(8.7)	6.2(37.3)	3.3(10.0)	2.5(5.3)	2.2(4.0)	4.5(19.3)
Hishell Conv.	Atrazine 750 g/ha	5.3(28.0)	2.8(6.7)	2.9(7.3)	6.5(42.0)	3.3(10.0)	2.5(5.3)	2.4(4.7)	4.6(20.0)
Hishell Conv.	No weeding	8.6(72.7)	5.3(27.3)	1.0(0.0)	10.0(100.0)	4.9(22.7)	3.9(14.7)	1.0(0.0)	6.2(37.3)
900M Gold Conv.	Atrazine 750 g/ha	4.8(22.7)	2.1(4.0)	2.8(7.3)	5.9(34.0)	3.5(11.3)	2.5(5.3)	2.1(3.3)	4.6(20.0)
900M Gold Conv.	No weeding	8.7(74.7)	5.3(28.0)	1.0(0.0)	10.2(102.7)	4.9(23.3)	4.2(16.7)	1.4(1.3)	6.5(41.3)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	5.1(24.7)	2.3(4.7)	3.1(8.7)	6.2(38.0)	3.3(10.0)	2.7(6.7)	2.3(4.7)	4.7(21.3)
National check hybrid (*Pro 4640*)	No weeding	8.7(74.0)	5.5(30.0)	1.0(0.0)	10.2(104.0)	4.7(21.3)	4.4(18.7)	1.0(0.0)	6.4(40.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	4.8(22.7)	2.6(7.3)	3.3(10.0)	6.4(40.0)	3.3(10.0)	3.0(8.0)	2.1(3.3)	4.7(21.3)
Local check hybrid (*HM 10*)	No weeding	8.4(70.7)	5.3(27.3)	1.0(0.0)	9.9(98.0)	4.9(22.7)	4.0(15.3)	1.0(0.0)	6.2(38.0)
LSD (p=0.05)		0.98	1.17	0.64	0.91	0.57	0.69	0.60	0.85

*Original figures in parentheses were subjected to square root transformation before statistical analysis

Table 6. Density of different weed species at 30 days after application of glyphosate in GM-Corn

Maize hybrid	Herbicide	Weed density (no./m^2)							
		Ec	Da	Br	Et	Pm	Pn	OBLW	Cr
Hishell-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.8(7.3)	1.2(0.7)
Hishell-NK603	Glyphosate 1800 g/ha	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.2(4.0)	1.0(0.0)
Hishell-NK603	Atrazine 750 g/ha	3.1(8.7)	3.2(9.3)	2.8(7.3)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.5(5.3)	3.0(8.0)
900M Gold-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.5(5.3)	1.2(0.7)
900M Gold-NK603	Glyphosate 1800 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.2(4.0)	1.2(0.7)
900M Gold-NK603	Atrazine 750 g/ha	2.6(6.0)	3.6(12.0)	3.0(8.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	1.7(2.0)	3.1(8.7)
Hishell Conv.	Atrazine 750 g/ha	3.2(9.3)	3.5(12.0)	2.7(6.7)	1.0(0.0)	1.7(2.0)	1.0(0.0)	2.3(4.7)	2.9(7.3)
Hishell Conv.	No weeding	5.5(30.0)	5.3(27.3)	4.0(15.3)	1.0(0.0)	4.2(17.3)	2.6(6.0)	2.2(4.0)	1.0(0.0)
900M Gold Conv.	Atrazine 750 g/ha	2.7(6.7)	3.2(9.3)	2.7(6.7)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.0(3.3)	2.8(7.3)
900M Gold Conv.	No weeding	5.6(30.7)	5.4(28.7)	4.0(15.3)	1.0(0.0)	4.3(18.0)	2.5(5.3)	2.3(4.7)	1.0(0.0)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	3.2(9.3)	3.0(8.0)	2.8(7.3)	1.0(0.0)	1.0(0.0)	1.7(2.0)	1.8(2.7)	3.1(8.7)
National check hybrid (*Pro 4640*)	No weeding	5.4(28.0)	5.6(30.7)	4.0(15.3)	1.0(0.0)	4.4(18.7)	2.8(7.3)	2.1(4.0)	1.0(0.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	2.7(6.7)	3.3(10.0)	2.6(6.0)	1.0(0.0)	1.0(0.0)	1.7(2.0)	2.3(5.3)	3.3(10.0)
Local check hybrid (*HM 10*)	No weeding	5.3(27.3)	5.3(27.3)	4.0(16.0)	1.0(0.0)	4.1(16.0)	2.6(6.0)	2.5(5.3)	1.0(0.0)
LSD (p=0.05)		0.87	0.75	0.83	NS	0.73	0.73	NS	0.64

*Original figures in parentheses were subjected to square root transformation before statistical analysis

900 g/ha (1.58-1.87 g/m^2) and 1800 g/ha (0.00-0.26 g/m^2) in both the transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*. In the treatments where atrazine was applied (GM and Non-GM hybrids), dry weight of weeds was 30.53-35.68 g/m^2, which was higher than the glyphosate treatments. However, it was significantly lower than the un-weeded checks. In all the treatments, grassy weeds *Echinochloa crus-galli* and *Dactyloctenium aegyptium* accumulated higher dry weight under the treatments with atrazine and weedy checks. Maximum dry weight of sedges (*Cyperus rotundus*) was recorded under atrazine treatments.

At crop maturity, overall weed dry weight was reduced than what it was at 21 DAT, obviously due to drying of weeds till this stage. In non-weeded checks, dry weight of weeds was recorded to be maximum (77.83-83.75 g/m^2) among all the treatments (**Table 8**). In atrazine PE treatments, weed dry weight was 26.95-31.30 g/m^2, which was significantly lower than weedy checks, but higher than the glyphosate 900-1800 g/ha treatments in GM-Corn hybrids (0.41-1.49 g/m^2). The glyphosate treatments were the best among all the treatments in reducing the dry weight of weeds, and both the doses of glyphosate were similar to each other.

Weed control efficiency

Based on dry weight reduction at 21 DAT, the treatments with atrazine in transgenic/ conventional

Table 7. Density of different weed species at 60 days after application of glyphosate in GM-Corn

Maize hybrid	Herbicide	Weed density (no./m^2)							
		Ec	Da	Br	Et	Pm	Pn	OBLW	Cr
Hishell-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.9(2.7)	1.5(1.3)	2.0(3.3)	1.0(0.0)
Hishell-NK603	Glyphosate 1800 g/ha	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.1(3.3)	1.5(1.3)	1.9(2.7)	1.2(0.7)
Hishell-NK603	Atrazine 750 g/ha	2.2(4.0)	1.5(1.3)	2.4(4.7)	1.0(0.0)	2.1(3.3)	1.2(0.7)	1.4(1.3)	2.2(4.0)
900M Gold-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.9(2.7)	1.5(1.3)	2.3(4.7)	1.0(0.0)
900M Gold-NK603	Glyphosate 1800 g/ha	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.7(2.0)	1.2(0.7)	2.4(4.7)	1.2(0.7)
900M Gold-NK603	Atrazine 750 g/ha	2.1(3.3)	1.7(2.0)	2.4(4.7)	1.0(0.0)	1.7(2.0)	1.2(0.7)	1.9(2.7)	2.2(4.0)
Hishell Conv.	Atrazine 750 g/ha	2.2(4.0)	1.9(2.7)	2.1(3.3)	1.0(0.0)	1.7(2.0)	1.2(0.7)	1.8(2.7)	2.4(4.7)
Hishell Conv.	No weeding	3.1(8.7)	2.5(5.3)	3.1(8.7)	1.0(0.0)	3.6(12.0)	1.0(0.0)	1.9(2.7)	1.0(0.0)
900M Gold Conv.	Atrazine 750 g/ha	2.2(4.0)	1.7(2.0)	2.5(5.3)	1.0(0.0)	1.7(2.0)	1.5(1.3)	1.7(2.0)	2.1(3.3)
900M Gold Conv.	No weeding	3.4(10.7)	2.4(4.7)	3.0(8.0)	1.0(0.0)	3.8(13.3)	1.0(0.0)	2.1(3.3)	1.4(1.3)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	2.1(3.3)	1.7(2.0)	2.4(4.7)	1.0(0.0)	1.4(1.3)	1.7(2.0)	2.1(3.3)	2.3(4.7)
National check hybrid (*Pro 4640*)	No weeding	3.0(8.0)	2.5(5.3)	3.0(8.0)	1.0(0.0)	3.7(12.7)	1.0(0.0)	2.6(6.0)	1.0(0.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	2.1(3.3)	1.9(2.7)	2.2(4.0)	1.0(0.0)	1.9(2.7)	1.7(2.0)	2.1(3.3)	2.1(3.3)
Local check hybrid (*HM 10*)	No weeding	3.1(8.7)	2.4(4.7)	3.2(9.3)	1.0(0.0)	3.4(10.7)	1.0(0.0)	2.4(4.7)	1.0(0.0)
LSD (p=0.05)		0.48	0.44	0.44	NS	0.77	NS	NS	0.60

*Original figures in parentheses were subjected to square root transformation before statistical analysis

Abbreviations: Ec, *Echinochloa crus-galli*; Da, *Dactyloctenium aegyptium*; Br, *Bracharia reptans*; Et, *Eragrostis tenella*; Pm, *Physalis minima*; Pn, *Phylanthus niruri*; OBLW, Other broad-leaf weeds; Cr, *Cyperus rotundus*

Table 8. Dry weight of weeds at 21 days after application of glyphosate and at harvest under different herbicidal treatments in GM-Corn

Maize hybrid	Herbicide	Dry weight of weed (g/m^2)								Weed control efficiency (%)	
		21 DAT				At harvest					
		Grassy weeds	BLW	Sedges	Total weeds	Grassy weeds	BLW	Sedges	Total weeds	21 DAT	At harvest
Hishell-NK603	Glyphosate 900 g/ha	1.09	0.21	0.57	1.87	0.55	0.95	0.00	1.49	98.9	98.2
Hishell-NK603	Glyphosate 1800 g/ha	0.00	0.00	0.00	0.00	0.00	0.35	0.21	0.55	100.0	99.3
Hishell-NK603	Atrazine 750 g/ha	24.77	2.21	4.31	31.29	21.18	8.52	1.33	31.03	81.5	62.9
900M Gold-NK603	Glyphosate 900 g/ha	0.73	0.14	0.71	1.58	0.26	1.03	0.00	1.29	99.1	98.5
900M Gold-NK603	Glyphosate 1800 g/ha	0.26	0.00	0.00	0.26	0.00	0.23	0.17	0.41	99.8	99.5
900M Gold-NK603	Atrazine 750 g/ha	23.30	2.15	5.09	30.53	23.29	6.71	1.29	31.30	81.9	62.6
Hishell Conv.	Atrazine 750 g/ha	26.96	1.99	4.40	33.35	20.53	5.49	1.39	27.40	80.3	67.3
Hishell Conv.	No weeding	136.18	22.07	2.09	160.35	58.99	23.27	0.00	81.59	-	-
900M Gold Conv.	Atrazine 750 g/ha	25.47	2.05	4.39	31.91	18.71	6.21	1.04	25.95	81.1	69.0
900M Gold Conv.	No weeding	142.88	23.53	2.73	169.14	57.87	25.83	0.05	83.75	-	-
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	28.53	2.19	4.96	35.68	18.91	6.57	1.46	26.95	78.9	67.8
National check hybrid (*Pro 4640*)	No weeding	136.08	23.91	2.36	162.35	53.75	24.08	0.00	77.83	-	-
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	26.71	2.56	5.15	34.42	22.77	6.97	1.07	30.81	79.6	63.2
Local check hybrid (*HM 10*)	No weeding	138.23	24.02	2.21	164.46	56.17	26.46	0.00	82.63	-	-
LSD (p=0.05)		8.80	2.92	0.96	10.50	6.93	3.36	0.44	6.48	-	-

Abbreviations: DAT- Days after treatment, BLW- broad-leaf weeds

hybrids of maize gave 78.9-81.9% weed control efficiency (**Table 8**). Maximum weed control efficiency (98.9-100.0%) was recorded under the glyphosate 900-1800 g/ha treatments in GM-Corn hybrids. At maturity/ harvest, the atrazine treatments gave 62.1-68.6% weed control efficiency, which was lower than the WCE (98.2-99.5%) recorded under the glyphosate 900-1800 g/ha treatments. This indicated suitability of glyphosate use as PoE in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*. Both the doses of glyphosate provided almost similar weed control efficiency indicating 900 g/ha to be the optimum dose for use in transgenic maize.

The safe use of glyphosate for effective weed control in transgenic maize hybrids has been reported in other parts of the country earlier also. Chinnusamy *et al.* (2014) reported that post-emergence application of glyphosate at 900 g/ha registered lower weed density, dry weight and higher weed control efficiency in transgenic maize hybrids in Tamil Nadu conditions of peninsular India. In studies at Jabalpur, complete control of weeds with glyphosate in all transgenic maize hybrids was reported by Dixit *et al.* (2016).

Effect on crop

Growth and yield attributes: Hybrid *900M Gold* (GM/ Conv.) had the maximum plant height (213.9-216.8 cm) closely followed by *HM 10* (212.4 cm) under herbicide treated plots. *Hishell* (GM/ Conv.) (203.6-207.5 cm) and *Pro 4640* (206.3 cm) had lower plant height than *900M Gold* (**Table 9**). Plant height of different hybrids except *HM 10* was lower under weedy situations. There was no suppression of plant height of *Hishell-NK603* and *900M Gold-NK603* under glyphosate treatments at both the doses, indicating its safety to the transgenic hybrids.

Maximum cob length (20.2-20.4 cm) was found in local check hybrid '*HM 10*', under herbicide treated as well as non-weeded plots, and was significantly higher than the rest of the treatments (**Table 9**). It indicated the varietal character of better cob length and weed competitive ability in this respect. The herbicide treated plots under hybrids *Hishell, 900M Gold* (GM/ Conv.) and *Pro 4640* produced statistically similar cob length and were superior to unweeded plots; however, the differences were not always significant. Cob length under un-weeded plots was lower than herbicidal treatment of the same hybrid, except *Pro 4640* where these were similar. Maximum cob girth (4.96 cm) was recorded under *900M Gold-NK603* (glyphosate 1800 g/ha), which was similar to *900M Gold-NK603* (glyphosate 900 g/ha), *900M Gold* (atrazine 750 g/ha), and *Pro 4640* (atrazine 750 g/ha). Minimum cob girth (4.46 cm) was recorded in *Hishell-NK603* (atrazine 750 g/ ha), which was similar to *Hishell-NK603* (glyphosate 900 g/ha), *Hishell* (atrazine 750 g/ha) and *HM 10* (atrazine 750 g/ha). The cob girth was lower under unweeded plots, but the differences with herbicide treated counterparts were not significant. Maximum shelling percentage (81.9%) was recorded in *Hishell-NK603* (atrazine 750 g/ha), which was statistically similar to *Hishell-NK603* (glyphosate 900 or 1800 g/ha), *900M Gold-NK603* (glyphosate 900 or 1800 g/ha, atrazine 750 g/ha), *Hishell* Conv. (atrazine 750 g/ha), and *900M Gold* Conv. (atrazine 750 g/ha). Lower shelling percentage (72.2-74.5%) was recorded under *HM 10* (atrazine 750 g/ha) and *Pro 4640* (atrazine 750 g/ha).

Yield

Glyphosate 900-1800 g/ha in *900M Gold-NK603* produced maximum grain yield (8.6-8.7 t/ha) which was followed by glyphosate 900-1800 g/ha in

Table 9. Growth, yield attributes and yield of conventional and GM-Corn hybrids under different herbicidal treatments

Maize hybrid	Herbicide	Plant height (cm)	Cob length (cm)	Cob girth (cm)	Shelling (%)	Grain yield (t/ha)	Stover yield (t/ha)
Hishell-NK603	Glyphosate 900 g/ha	203.6	17.8	4.52	81.9	7.7	9.7
Hishell-NK603	Glyphosate 1800 g/ha	204.1	17.0	4.67	81.2	7.8	9.4
Hishell-NK603	Atrazine 750 g/ha	206.3	17.8	4.46	81.9	7.2	9.4
900M Gold-NK603	Glyphosate 900 g/ha	213.9	16.7	4.79	78.4	8.7	11.0
900M Gold-NK603	Glyphosate 1800 g/ha	214.1	17.4	4.96	79.8	8.6	11.0
900M Gold-NK603	Atrazine 750 g/ha	216.5	16.5	4.75	78.9	7.5	10.5
Hishell Conv.	Atrazine 750 g/ha	207.5	17.7	4.62	81.6	7.0	9.5
Hishell Conv.	No weeding	191.6	15.6	4.52	79.7	6.4	8.0
900M Gold Conv.	Atrazine 750 g/ha	216.8	16.5	4.80	79.0	7.4	10.8
900M Gold Conv.	No weeding	206.1	16.3	4.79	78.7	5.9	8.3
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	206.3	17.7	4.92	74.5	6.9	9.7
National check hybrid (*Pro 4640*)	No weeding	192.3	16.2	4.74	73.9	4.7	5.3
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	212.4	20.4	4.55	72.2	5.8	8.9
Local check hybrid (*HM 10*)	No weeding	211.3	20.2	4.50	72.5	5.0	7.1
LSD (p=0.05)		9.4	1.5	0.19	4.7	1.5	1.8

Hishell-NK603 (7.7-7.8 t/ha) (**Table 9**). Glyphosate 900-1800 g/ha in transgenic maize hybrids gave grain yield higher than atrazine treatment; however, the differences were not significant. Minimum grain yield was recorded under weedy check plots in *Pro 4640* (4.7 t/ha) which was followed by unweeded checks in *HM 10* (5.0 t/ha), *900M Gold* (5.9 t/ha) and *Hishell* (6.4 t/ha).

Maximum stover yield was obtained from treatments of glyphosate 900-1800 g/ha in *900M Gold-NK603* (11.0 t/ha), which was similar to glyphosate 900-1800 g/ha in *Hishell-NK603* (9.4-9.7 t/ha), atrazine treated plots in *900M Gold* (10.8 t/ha), *900M Gold-NK603* (10.5 t/ha), *Hishell* (9.5 t/ha), *Hishell-NK603* (9.4 t/ha), *Pro 4640* (9.7 t/ha) and *HM 10* (8.9 t/ha) (**Table 9**). Minimum stover yield was recorded in conventional weedy check plots of *Pro 4640* (5.3 t/ha) followed by *HM 10* (7.1 t/ha), *Hishell* (8.0 t/ha) and *900M Gold* (8.3 t/ha).

Chinnusamy *et al.* (2014) also reported higher weed control efficiency under glyphosate in transgenic maize hybrids with improved grain yields in Tamil Nadu. Dixit *et al.* (2016) reported complete control of weeds with glyphosate in all transgenic maize hybrids and three times higher yield than the normal hybrid with conventional herbicidal treatment in Jabalpur. Sushilkumar *et al*. (2017) also reported higher yields of stacked transgenic hybrids *Hishell-NK603* and *900M Gold-NK603*.

Based on this study, it may be concluded that glyphosate 900 g/ha in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603* provided effective control of weeds with improved grain yields and with no phyto-toxicity even up to 1800 g/ha dose. Hence, herbicide tolerant cultivars of maize may be the viable options from weed management point of view provided due permission and regulatory approvals are granted by the appropriate authority based on research inputs and other safety considerations.

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