Journal of Agricultural Science and Technology B 10 (2020) 317-326
doi: 10.17265/2161-6264/2020.06.001

Agronomic Efficiency of Herbicide Tolerant Crops in Peninsular India—A Review

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Abstract: Crops made resistant to herbicides by biotechnology are being widely adopted in various parts of the world and several herbicide resistant crops have become available in many countries for commercial cultivation. But in India, the technology of herbicide tolerant crops is in initial stage of field evaluation. Hence, field trials have been carried out to evaluate and consolidate the agronomic advantages of herbicide tolerant transgenic cotton and maize. Herbicide tolerant stacked traits of maize and cotton have been evaluated under Bio-safety Research Level (BRL I) as confined field trials for its agronomic efficiency on weed control and enhanced crop productivity at Tamil Nadu Agricultural University (TNAU), Coimbatore and Punjab Agricultural University (PAU), Ldhiana for many years. In both crops, potassium salt formulation of glyphosate was sprayed at different doses (900, 1,350, 1,800, 2,700, 3,600 and 5,400 g a.e./ha twice at 25 days after sowing (DAS) and 60 DAS in cotton and 900, 1,800 and 3,600 g a.e./ha at 25 DAS in maize). Evaluation was made on weed control efficiency, phyto-toxicity on crops, yield and economics and carry over effects on the succeeding crops. Application of glyphosate at 2,700 g a.e./ha recorded lower weed density, dry weight and higher weed control efficiency (WCE) in cotton. Post-emergence (POE) glyphosate at 900, 1,800 and 3,600 g a.e./ha registered lower weed density, dry weight and higher WCE in transgenic Hishell and 900 M Gold and in 30V92 and 30B11 corn hybrids. Post-emergence application of glyphosate in transgenic maize hybrids did not affect the germination percent, vigour and yield of succeeding green gram in the transgenic maize trials and sunflower, soybean and pearl millet in cotton trials. Phytotoxicity symptoms were not observed in cotton with glyphosate at lower doses viz., 900, 1,350, 1,800 and 2,700 g a.e./ha. Higher doses viz. 3,600 g a.e./ha and 5,400 g a.e./ha were noticed with phytotoxicity symptoms at early stages of herbicide application. Glyphosate applied at 900, 1,350, 1,800 and 2,700 g a.e./ha recorded more number of bacteria, fungi and actinomycetes compared to atrazine treatments. Higher grain yield was recorded with POE application of glyphosate at 900, 1,800 and 3,600 g a.e./ha in Hishell and 900 M Gold transgenic hybrids and higher net return and benefit cost ratio were recorded in glyphosate at 1,800 g a.e./ha in transgenic 900 M Gold in all the four seasons. Post-emergence application of glyphosate at 900 g a.e./ha and 1,800 g a.e./ha registered higher grain yield in transgenic 30V92 and 30B11 corn hybrids. In maize and cotton transgenic crops, post-emergence weed management with glyphosate proved to be the better management option for the control of weeds.

Key words: Herbicide tolerant crops, weed control efficiency, phytotoxicity, carry over effect, corn and cotton, productivity and profitability.

1. Introduction

Crops made resistant to herbicides by biotechnology are being widely adopted in various parts of the world. From the genesis of commercialization in 1996 to 2018, herbicide tolerance has consistently been the dominant trait. Those containing transgenes that impart resistance to post-emergence, non-selective herbicides such as glyphosate and glufosinate will have the major impact. These products allow the farmer to more effectively use reduced or no-tillage cultural practices, eliminate use of some of the more environmentally suspect herbicides and use fewer herbicides to manage nearly the entire spectrum of weed species [1]. In some cases, non-selective herbicides used with herbicide resistant crops reduce plant pathogen problems because of the

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chemicals' toxicity to certain microbes [2]. According to Knezevic and Cassman [3], herbicide tolerant crops can be produced by either insertion of a "foreign" gene (transgene) from another organism into a crop, or by regenerating herbicide tolerant mutants from existing crop germplasm. In 2018, the 22nd year of commercialization of biotech crops, 191.7 million hectares of biotech crops were planted by up to 17 million farmers in 26 countries. From the initial planting of 1.7 million hectares in 1996 when the first biotech crop was commercialized, the 191.7 million hectares planted in 2018 indicate 113-fold increase in biotech crop commercialization [4]. Thus, biotech crops are considered as the fastest adopted crop technology in the history of modern agriculture. The inclusion of several transgenes in a single hybrid or variety commonly referred as stacked genes or stacked traits. For example, some corn and cotton hybrids have been genetically engineered to contain two transgenes, one for insect tolerance and another for herbicide tolerance (e.g., Bt/glyphosate, or Bt/glufosinate). Furthermore, some corn hybrids have three traits, two for herbicide tolerance and one for insect tolerance (e.g., Liberty, Clearfield and Bt). Stacked traits occupied ~25% of the global 190 million hectares [5].

From the genesis of commercialization in 1996 to 2018, herbicide tolerance has consistently been the dominant trait. In 2018, herbicide tolerance deployed in soybean, maize, canola, cotton, sugar beet and alfalfa, occupied 50% or 95.9 million hectares of the global biotech area of 160 million hectares. In 2018, the stacked double and triple traits occupied a larger area (42.2 million hectares, or 26% of global biotech crop area) than insect resistant varieties (23.9 million hectares) at 15%. The stacked genes were the fastest growing trait group between 2017 and 2018 at 31% growth, compared with 5% for herbicide tolerance and 10% for insect resistance [5]. Over the past few years, several herbicide resistant crops, both transgenic and non-transgenic, have become available in many countries for commercial cultivation. But in India, the technology of herbicide tolerant crops is in initial stage of field evaluation. Efforts have been made to evaluate and consolidate the agronomic management and advantages of herbicide tolerant transgenic crops.

2. Development of Herbicide Tolerant Crops

Glyphosate is a foliar applied, broad spectrum, post emergence herbicide capable of controlling annual and perennial grasses and dicotyledonous weeds [6]. Glyphosate was classified as a herbicide after it was discovered by J.E. Franz in 1971 at Monsanto and was commercialized under the trade name Roundup. Today, glyphosate is sold as an isopropylamine salt, trimethylsufonium (trimesium) salt, sesquisodium salt, potassium salt and ammonium salt under several hundred trade names by Monsanto and other chemical companies. The mode of action of glyphosate is inhibition of aromatic amino acid biosynthesis specifically inhibition of the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) which reduces the plant's ability to form aromatic amino acids such as tryptophan, tyrosine, phenylalanine and other important secondary compounds. Glyphosate is a foliar applied herbicide which once absorbed is readily translocated in the xylem and phloem throughout the plants with primary sinks being actively growing vegetative tissue and reproductive tissue; however, it has no soil residual activity [7].

In 1983, scientists at Monsanto and Washington University isolated the common soil bacteria, *Agrobacterium tumefaciens* strain CP4, which is highly tolerant to glyphosate because its EPSPS is less sensitive to inhibition by glyphosate than EPSPS found in plants [8]. When plants expressing the CP4 EPSPS proteins are treated with glyphosate, the plants continue to grow. The continued action of the tolerant CP4 EPSPS enzyme provides the plant's need for aromatic acids. Aromatic amino acid biosynthesis is not present in animals. This explains the selective activity in plants and contributes to the low mammalian toxicity of glyphosate. By 1986, they had successfully inserted the CP4 EPSPS gene into the plant genome and obtained glyphosate resistant (GR) plants. Within 10 years, GR soybean was commercialized. This gene transformation resulted in soybean plants resistant to high levels of glyphosate. This event was patented as the Roundup Ready gene technology, expressed in soybeans and released into the commercial marketplace in 1996 [9]. The initial GR crops were the most quickly adopted technology in the history of agriculture. This rate of adoption continues at more than 10% per year in both developing and developed countries. The introduction of GR crops transformed the way many growers manage weeds. Growers chose GR crops because glyphosate made weed control easier and more effective, increased profit, required less tillage, and did not restrict crop rotations. Glyphosate-resistant crops approved for sale in the USA include canola, corn (*Zea mays*), cotton (*Gossypium hirsutum* and *G. barbadense*), soybean (*Glycine max*) and sugarbeet (*Beta vulgaris*).

3. Herbicide Tolerant Maize

Modern technologies introduce the new approaches to weed management systems in maize that include the use of post emergence application of non-selective herbicides in hybrids for which resistance genes have been inserted. Two different glyphosate-resistant events, GA21 and NK603, are commercially available in maize. Both the events were released for commercial production in the United States in 1998 and 2001, respectively [10]. The first commercial glyphosate-tolerance event to be transformed into maize plants was GA21, which was commercialized during 1998 in USA and Canada in 1999. GA21 maize contains the modified (maize EPSPS) coding sequence (chloroplast transit peptide sequences from *Helianthus annuus* and the RuBisCo gene from *Zea mays*). Effectively, this maize contains a modified version of its own EPSPS gene that could tolerate glyphosate and produce aromatic amino acids for protein production. The second generation of glyphosate-tolerant maize event NK603 was produced by two copies of the (aroA: CP4—gene responsible for the inactivation of enzyme EPSPS) CP4 enzyme EPSPS gene was introduced into the maize genome to produce Roundup Ready corn event NK603. The CP4 EPSPS gene derived from the common soil bacterium *Agrobacterium* sp. strain CP4 encodes for the naturally glyphosate tolerant EPSPS protein. NK603 has high tolerance to recommended field application rates of glyphosate, and the transgenic insertion neither created nor was linked to negative parameters that could affect human and animal health, the environment or yield performance. NK603 was first marketed in 2001 in both the USA and Canada and it has been commercialized in an increasing number of countries in the tropic regions including South Africa, Argentina, Philippines and Honduras [11].

4. Efficacy of Herbicide Tolerant Maize

Regarding glyphosate efficacy of transgenic maize [12] verified that transgenic maize showed substantially greater resistance to glyphosate applied as Roundup than the corresponding untransformed parental control. Treatment with 20 µg glyphosate applied as droplets to the second leaf was sufficient to produce complete kill in the parental controls, while 786 µg glyphosate had no effect upon survival of the transgenic plants. Equivalent field application rates for these dosages would be around 0.1 kg a.e./ha and 4 kg a.e./ha, respectively. Reduction in foliage fresh weight was a more sensitive indicator of a given glyphosate treatment than mortality in both types of maize. Both methods for assessing herbicide efficacy indicated the transgenic plants to have more than 100 fold glyphosate resistance than the parental controls. The results of Erickson *et al*. [13] indicated that no significant differences observed between herbicide tolerant corn event NK603 and conventional maize hybrids. This was confirmed by evaluation of the feed performance in broiler chickens and a rat feeding study, included clinical and histological evaluations.

The same study indicated that the environmental impact of Roundup Ready corn is comparable to conventional corn. Finally, the results of all these studies demonstrate that corn event NK603 is comparable to traditional corn with respect to food, feed and environmental safety. In experimental fields at Ontario, no visual injury was observed in glyphosate tolerant maize crop by post-emergence (POE) of glyphosate [14]. Similarly, another study revealed that there were no adverse effects on plant establishment, plant height, maturity, vigour, yield or quality in glyphosate resistant cotton plants [15]. The tallest maize plants (237.5-240.2 cm) were found in the plots that received glyphosate treatment singly at the three leaf stage of maize growth or repeated either at the seventh or twelfth leaf stage [16]. Grain yield (9,135 kg/ha) was recorded under this treatment was comparable with weed free treatment, while unweeded control plots recorded 38.3% lesser. In the early maize planting at South Charleston, weed control with single application at the 5 cm weed height not exceed 62%, but yield was not reduced compared with the weed free condition. The same study suggested that the application of glyphosate at 23 cm weed height resulted in 22% and 15% yield reduction in the early and late plantings, respectively, compared with weed free control [17]. Dalley *et al.* [18] concluded that, sequential applications of glyphosate in maize crop did not increase the grain yield. Cox *et al.* [19] reported that early post treatment (EPOST) at three to four leaf stage of maize growth and weed-free treatment had similar results in silking date, dry matter accumulation, leaf area index in silking date, kernel per plant and grain yield. Tapia *et al.* [20] witnessed that application of glyphosate as late post emergence and atrazine plus S-metalolachlor followed by glyphosate as post emergence or late post emergence produced higher grain yield (4,790 kg/ha) compared to the lowest grain yield with unweeded control and glyphosate alone as early post emergence. Chrenkova *et al.* [21] found that both the conventional and glyphosate tolerant maize hybrids have high starch contents (729 g/kg and 736 g/kg of dry matter) and thus also a high nitrogen free extract content. The fat and crude protein levels reached 40 g/kg and 97 g/kg of dry matter, respectively. Padgette *et al.* [22] who compared the amino acid levels in genetically modified glyphosate-tolerant soybean also indicated the differences to be non-significant. These results of Ridley *et al.* [23] indicated that the levels of proximate components (protein, ash and carbohydrate), fiber and minerals (calcium, copper, iron, magnesium, manganese, phosphorus and zinc) in the grain and forage of herbicide resistant corn event NK603 were comparable to those in the grain and forage of the non-transgenic control. In addition, these values were either within the published literature ranges. The content of the 18 amino acids measured in the grain of corn event NK603 was comparable to that in the grain of the non-transgenic control. The values for components in corn event NK603 all fell within the range of natural variability found in non-transgenic corn hybrids.

5. Agronomic Efficiency of Herbicide Tolerant Crops

5.1 Spectrum of Weeds Control

Non-selective herbicides such as glyphosate and glufosinate aid in broadening the spectrum of weeds controlled, which is particularly important in no-till systems, and those “weedy” fields. The genetically modified herbicide tolerant maize and spring oil seed rape cultivars used were tolerant to glufosinate ammonium (Liberty, 200 g a.i./ha) which gives post-emergence broad spectrum control of annual grasses and broad leaved weeds [24]. In general, glyphosate is the most widely used herbicide in the world and literature about its use and characteristics is extensive [25].

Results of field trials conducted at Tamil Nadu Agricultural University (TNAU), Coimbatore, have clearly revealed that application of glyphosate at 2,700 g/ha recorded lower weed density, dry weight and higher weed control efficiency when compared to other doses of glyphosate and hand weeding in cotton. Similarly from the field experiments on bio-efficacy of glyphosate in Roundup Ready Bt cotton hybrid conducted during summer season at Punjab Agricultural University (PAU), Ludhiana, it is inferred that potassium salt of glyphosate at 900 g/ha and 1,800 g/ha applied twice as post-emergence gave effective control of weeds and produced significantly higher seed cotton yield than hand weeding (Table 1). Systemic activity of glyphosate also helped with the control of perennial weeds and their perennial vegetative structures such as stolons and rhizomes. Weed control is often excellent (95%) with the application of glyphosate as post-emergence in cotton.

Similarly, the field trials carried out at PAU, Ludhiana also clearly revealed that glyphosate at 900 g/ha and 1,800 g/ha applied at 25 days after sowing (DAS) recorded effective control of sedges, grasses and broadleaf weeds and significantly reduced weed population and dry matter as compared to TNAU recommended practice and was safe to both the transgenic hybrids (Table 2). Single application of glyphosate as early or late post-emergence effectively controlled the broad spectrum of weeds in maize. According to Franz *et al.* [26], the systemic activity of glyphosate also helped with the control of perennial weeds and their perennial vegetative structures such as stolons and rhizomes. Crops can be planted or seeded directly into treated areas of glyphosate because it has no pre-emergent activity even when applied at high rates. Keeling *et al.* [27] also observed that weed control is often excellent (95%) with the application of glyphosate as post-emergence in cotton. Post-emergence application of glyphosate at 900, 1,800 and 3,600 g a.e./ha registered lower weed density, dry weight and higher weed control efficiency in transgenic Hishell and 900 M Gold corn hybrids in the maize trial I and post-emergence application of glyphosate at 900 g a.e./ha and 1,800 g a.e./ha registered lower weed density, dry weight and higher weed control efficiency in transgenic 30V92 and 30B11 corn hybrids in the maize trial II compared to their state and national checks at TNAU, Coimbatore (Table 3). Grichar *et al.* [28] had found that single application of glyphosate as early or late post-emergence effectively controlled the broad spectrum of weeds.

5.2 Carry over Effect of Herbicides

Glyphosate and glufosinate have almost no soil residual activity because they are tightly bound to the organic particles in the soil. Hence, there are few restrictions for planting or replanting intervals or injuries to the subsequent crops. This trait facilitates crop rotation by providing flexibility in selection of potential rotation crops. Herbicide tolerant crops will not cause any residual effect on succeeding crops. Succeeding crops like sunflower, soybean and pearl millet have been sown after cotton crop in the treatment blocks to assess the carry over effect of potassium salt of glyphosate (MON 76366). Observations were recorded on germination percentage, vigour, plant height and yield for all the treatments. Treatment differences were found to be insignificant for all the parameters hence there was normal growth and development of succeeding crops. The results are in line with the findings of Nadanassababady *et al.* [29] who had reported that bioassay of herbicide residues indicated that none of the herbicides evaluated for the chemical control of weeds in cotton persisted in the soil to the level of affecting the germination and growth of succeeding crops like finger millet and cucumber. Post-emergence application of glyphosate in transgenic maize hybrids did not affect the germination percent, vigour and yield of succeeding green gram in both the transgenic maize trials.

5.3 Reduced Crop Injury

Various post-emergence type herbicides used for weed control in soybean, canola, or corn can cause crop injury and ultimately yield loss. Crop injury is more severe when the crop is under stress or unfavourable environmental conditions occur. In contrast, crop injury is reduced with the use of herbicide tolerant crops. The phytotoxicity symptoms were not observed in cotton with glyphosate at lower doses viz., 900, 1,350, 1,800 and 2,700 g a.e./ha. Higher doses viz. 3,600 g a.e./ha and 5,400 g a.e./ha were noticed with phytotoxicity symptoms at early stages of herbicide application. Glyphosate causes almost no crop injury, compared to some traditional herbicides (e.g., lactofen, chlorimuron), especially when applied to cotton. The greatest benefit to growers is the broad spectrum weed control with post-emergence application of glyphosate to cotton without crop injury as earlier reported by Wilcut *et al.* [30]. Regarding transgenic maize hybrids, there was no phytotoxic symptom observed in transgenic maize hybrids due to application of various doses of glyphosate at 900, 1,800 and 3,600 g a.e./ha throughout the crop growth in both the trials. Peterson *et al.* [31] revealed that no injury was recorded in maize crop due to application of POE glyphosate product at various levels of concentrations.

5.4 Use of Environmentally Safe Herbicides

In general, glyphosate and glufosinate have lower toxicity to humans and animals compared to some other herbicides. Since they are absorbed by the organic particles in the soil and decompose rapidly, they pose little danger for leaching and contamination of ground water or toxicity to wildlife [3]. Glyphosate applied at lower doses like 900, 1,350, 1,800 and 2,700 g a.e./ha recorded with more number of bacteria, fungi and actinomycetes. In transgenic maize hybrids, POE application of glyphosate at lower doses like 900 g a.e./ha and 1,800 g a.e./ha recorded with more number of bacteria, fungi and actinomycetes population compared to atrazine applied treatments (Table 4). This might be due to glyphosate applied directly on the weeds that added organic materials to the soil, during decomposition of organic material, microbial population might have been increased. Reports showed that glyphosate was available to soil and rhizosphere microbial communities as a substrate for direct metabolism leading to increased microbial biomass and activity [32]. Results of earlier trials revealed that glyphosate had only small and transient effects on the soil microbial community, even when applied at greater than field rates [33]. Higher doses of glyphosate with 3,600 g a.e./ha and 5,400 g a.e./ha led to slight reduction in microbial population as observed at initial stages and recovered within 45 d.

5.5 Mode of Action for Resistance Management

Since the discovery and report of triazine resistance almost 40 years ago, weed resistance to herbicides has been well documented. For example, there are 40 dicot and 15 monocot species known to have biotypes resistant to triazine herbicides. Also, at least 44 weed species have been reported to have biotypes resistant to one or more of 15 other herbicides or herbicide families [34]. The list of herbicide-resistant weeds will continue to grow, especially with repeated use of herbicides with the same mode of action. Many of the selective herbicides in corn and soybean have similar or identical mechanisms of action such as the inhibition of enzyme acetolactate synthase (ALS) or the inhibition of acetyl-co-enzyme-A-carboxylase (ACCase). Therefore, herbicide tolerant crops particularly cotton (e.g., glyphosate and glufosinate) can provide a new mode of action when used in an integrated weed management program as an aid in resistance management.

5.6 Crop Management Flexibility

The herbicide tolerant technology is simple to use. It requires neither special skills nor training. The technology does not have major restrictions and is flexible, which is probably one of the reasons for such wide adoption by producers. In particular, crops that are tolerant to broad-spectrum herbicides such as glyphosate extend the period of herbicide application for effective weed control, which is helpful in dealing with rainy and windy days during the optimal periods for weed control measures. In contrast, poor weather during the critical period for weed control can greatly limit the effectiveness of more selective herbicides [31]. According to Chinnusamy *et al*. [35], total weed density was significantly lowered with post-emergence application of glyphosate in transgenic cotton and corn hybrids when compared to hand weeding plots in transgenic cotton and national and state checks in transgenic maize. Keeling *et al*. [27] also observed that weed control is often excellent (95%) with the application of glyphosate as post-emergence in cotton.

5.7 Increased Yield and Income

Cotton crop being slow in its initial growth and is grown with wider spacing, is always encountered with severe weed competition during early stages, which results in lower yield. A broad spectrum of weeds with wider adaptability to extremities of climatic, edaphic and biotic stresses is infesting the cotton fields. High persistence nature of weeds is attributed to their ability of high seed production and seed viability. Hand weeding or hoeing twice is the most commonly adopted method of weed control in cotton. However, complete weed control could not be achieved by using any single method alone. Herbicidal weed control seems to be a competitive and promising way to control weeds at initial stages of crop growth. Higher yield of herbicide tolerant transgenic cotton recorded with glyphosate at 2,700 g/ha over hand weeding twice during winter season (Table 1) due to efficient control of weeds during the cropping period as observed at TNAU, Coimbatore and PAU, Ludhiana field trials. Roundup Ready Flex cotton could provide producers with acceptable weed control without compromising cotton yield. Glyphosate at 2,700 g/ha recorded with higher gross and net returns and benefit cost ratio in herbicide tolerant transgenic cotton [36]. The findings are in accordance with observation of Tharp *et al*. [37] who had earlier reported that Roundup Ready Flex cotton could provide producers with acceptable weed control without compromising cotton yield. Glyphosate at 2,700 g a.e./ha recorded with higher gross and net returns and benefit cost ratio in herbicide tolerant transgenic cotton.

Higher grain yield was recorded with POE application of glyphosate at 900, 1,800 and 3,600 g/ha in Hishell and 900 M Gold transgenic hybrids (Table 2), even though higher and comparable weed control and yield were obtained with glyphosate at 900 g/ha and 3,600 g/ha, higher net return and benefit cost ratio were recorded in glyphosate at 1,800 g/ha in transgenic 900 M Gold in all the four seasons in trial I. Post-emergence application of glyphosate at 900 g/ha and 1,800 g/ha registered higher grain yield in transgenic 30V92 and 30B11 corn hybrids in the maize trial II compared to their state and national checks (Table 3). Average yield obtained in transgenic hybrids was 10 t/ha and conventional transgenic maize hybrids was 8 t/ha at TNAU, Coimbatore. Research reports of PAU, Ludhiana revealed that morphological and phenotypic characters of both the transgenic hybrids were similar to their non-transgenic counterparts. Transgenic hybrids with glyphosate applications recorded higher maize grain yield, net return and benefit cost ratio as compared to university recommendation practices in transgenic or non-transgenic maize hybrids. Earlier research findings brought out that yields of herbicide resistant maize hybrids were maximum with glyphosate at 0.84 kg/ha when applied at the fifth leaf stage. The findings are in accordance with observation of Main *et al*. [36] who had earlier reported that maize yields of herbicide resistant hybrids were maximum with glyphosate at 0.84 kg a.e./ha of glyphosate when applied at the fifth leaf stage of maize.

6. Conclusions

Herbicide tolerant crops are strongly impacting weed management choices. In many crops their use will decrease the cost of effective weed management in the short to medium term. However, they offer the farmer a powerful new tool that, if used wisely, can be incorporated into an integrated pest management strategy that can be used for many years to more economically and effectively manage weeds. In maize and cotton transgenic crops, post-emergence weed management with glyphosate proved to be the better management option for the control of weeds.

Table 1 Glyphosate on weed control and yield in transgenic cotton.

Weed management techniques	TNAU, Coimbatore		PAU, Ludhiana	
	Weed control (%)	Seed cotton yield (kg/ha)	Weed control (%)	Seed cotton yield (kg/ha)
Glyphosate 900 g/ha	92.3	2,539	95.9	1,126
Glyphosate 1,350 g/ha	93.7	2,708	96.5	1,435
Glyphosate 1,800 g/ha	96.6	2,915	97.2	1,346
Glyphosate 2,700 g/ha	97.3	3,144	-	-
Hand weeding 15 & 30 days after sowing (DAS)	85.2	2,504	84.3	1,032

TNAU: Tamil Nadu Agricultural University; PAU: Punjab Agricultural University.
Source: [38].

Table 2 Weed control and grain yield in transgenic maize hybrids.

Weed management techniques	TNAU, Coimbatore		PAU, Ludhiana	
	Weed control (%)	Grain yield (t/ha)	Weed control (%)	Grain yield (t/ha)
Hishell POE glyphosate at 1,800 g/ha	96.69	10.34	95.2	8.50
900 M Gold POE glyphosate at 1,800 g/ha	95.41	10.46	90.8	8.14
Hishell PE atrazine at 0.5 kg/ha + Hand weeding (HW) + Inter-cultural operations (IC)	91.54	9.23	68.6	7.71
900 M Gold PE atrazine at 0.5 kg/ha + HW + IC	88.38	8.77	74.4	7.16
Proagro PE atrazine at 0.5 kg/ha + HW + IC	84.84	7.43	69.9	5.98
CoHM 5 PE atrazine at 0.5 kg/ha + HW + IC	82.92	7.08	71.7	7.73

TNAU: Tamil Nadu Agricultural University; PAU: Punjab Agricultural University; POE: post-emergence.
Source: [38].

Table 3 Weed control efficiency and grain yield in transgenic corn hybrids (Coimbatore).

Weed management techniques	Weed control efficiency (%)	Grain yield (t/ha)
30V92HR glyphosate at 1,800 g/ha	99.53	12.21
30B11HR glyphosate at 1,800 g/ha	98.97	11.98
30V92 pre-emergence atrazine at 0.5 kg/ha + HW + IC	72.57	10.23
30B11 PE atrazine at 0.5 kg/ha + HW + IC	70.33	9.76
BIO9681 PE atrazine at 0.5 kg/ha + HW + IC	68.73	8.00
CoHM5 PE atrazine at 0.5 kg/ha + HW + IC	68.56	7.33

Source: [38]

Table 4 Glyphosate on soil microbes ($\times 10^4$ CFU/g) in transgenic maize (Coimbatore).

Weed management techniques	Bacteria	Fungi	Actinomycetes
30V92HR glyphosate at 1,800 g/ha	39.77	28.54	13.26
30B11HR glyphosate at 1,800 g/ha	39.11	28.61	12.90
30V92 PE atrazine at 0.5 kg/ ha + HW + IC	30.47	26.34	11.23
30B11 PE atrazine at 0.5 kg/ha + HW + IC	31.07	26.81	11.67
BIO9681 PE atrazine at 0.5 kg/ha + HW + IC	28.28	26.00	11.56
CoHM5 PE atrazine at 0.5 kg/ha + HW + IC	27.08	25.61	11.82

Source: [38]

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