Agricultural Reviews, 38(4) 2017 : 245-259
Print ISSN:0253-1496 / Online ISSN:0976-0539

AGRICULTURAL RESEARCH COMMUNICATION CENTRE
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# Weed management options in transgenic stacked and non transgenic maize (*Zea mays*) hybrids-A review

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Received: 09-12-2016 Accepted: 20-10-2017 DOI: 10.18805/ag.R-1671

**ABSTRACT**

Weeds are generally hardy species having fast growth, deep root system and capable of competing very efficiently with cultivated crops for the available resources and adversely affect the crop growth and yield. Weed management systems that rely on post emergence control assume that crops can tolerate competition for certain periods of time without suffering yield losses. Initial slow growth particularly at early crop growth stages and wider plant spacing of maize crop encourages fast and vigorous growth of weeds. It is of paramount importance that, competition from weeds must be minimized to achieve optimum yield. Among the different weed control methods, chemical method bears many advantages in suppressing weed growth and to get healthy and vigorous crop stand. Non-selective herbicide molecules with a variety of mode of action were discovered, developed and marketed for successful weed control programme.

**Key words**: Crop weed competition, Glyphosate, Transgenic, Weed spectrum.

**Weed spectrum in maize:** Effective weed control strategies could be formulated only when the weed flora composition of the field is known very well. Slow growth of maize particularly in the early stages encourages fast and vigorous growth of weeds. The weed flora differs widely with environment and soil conditions. Generally weeds are found in larger numbers and with more vigour, because of extremities of climatic, edaphic and biotic stresses.

**Predominant weed flora in maize across different locations:** Weed flora varies with locality**.** The major weed flora observed in the experimental plots of Bangalore were *Cynodon dactylon, Digitaria marginata, Dactyloctenium aegyptium, Eragrostis pilosa, Eragrostis riparia* and *Panicum* spp. among grasses, under sedge *Cyperus rotundus* and *Aegratum conyzoides, Amaranthus viridis, Acanthospermum hispidum, Mimosa pudica, Phyllanthus niruri, Portulaca oleracea* and *Cleome monophylla* among broad leaved weeds at maize field (Ramachandra Prasad *et al*., 1990). In Yugoslavia, *Amaranthus albus, Amaranthus retroflexus, Solanum nigrum, and Triticum* spp. were dominated in dry land, while *Sorghum halepense*, *Digitaria sanguinalis*, *Triticum* spp. in irrigated plots in maize (Momirovie *et al*., 1998). At Islamabad, *Cyperus rotundus*, *Cynodon dactylon*, *Dactyloctenium aegyptium, Echinochloa colonum and Portulaca oleracea* were prodominant in maize fields (Shad *et al*., 1993). Experimental fields in Turkey, average weed ground cover at the 3 leaf stage of maize was 10 per cent of *Cyperus rotundus*, 5 per cent of *Amaranthus retroflexus*, 3 per cent of *Chenopodium album* and 2 per cent of *Portulaca oleraceae* (total weed ground cover was 20 per cent) (Nedim *et al.,* 2004).

Ramesh and Nadanasababady (2005) reported that major dominant weed species in maize field were *Amaranthus viridis*, *Trianthema portulacastrum, Phyllanthus niruri* and *Digeria arvensis* among broadleaved weeds*, Cyanodon dactylon* and *Dactyloctenium aegyptium* were dominated under grass weeds and *Cyperus rotundus* was only the sedge weed. Hassan and Ahmed (2005) reported that *Portulaca oleracea*, *Amaranthus spp*, *Xanthium spinosum*, *Echinochloa colonum*, *Cyperus rotundus*, *Convolvulus arvensis* were dominant weed species in maize field at Egypt. Chikoye *et al*. (2005) reported that the most outstanding weed flora composition in the experimental field at Nigeria included *Panicum maximum*, *Passiflora foetida*, *Commelina benghalensis*, *Tridax procumbens*, *Cyperus* spp and *Talinum triangulare.* According to Sarma and Gautam (2006), *Commelina benghalensis, Convolvulus arvensis, Digitaria* spp. and *Ipomoea alba* were notified as highly problematic weeds. Grass weeds have maximum competition to crop, reducing grain yield by 77.4 per cent followed by broad leaved (44.2 per cent) and sedges (38. per cent). Similarly, Chalka and Nepalia (2006) observed that *Echinochloa colonum*, *Echinochloa crusgalli*, *Commelina benghalensis*, *Digera arvensis*, *Trianthema portulacastrum*, *Phyllanthus niruri* were the dominant weeds in maize field at Udaipur of Rajasthan. Experimental fields of Faisalabad consisted with three major weeds, *viz., Trianthema portulacastrum, Cyperus rotundus* and *Coronopus didynamus* (Nadeem *et al*., 2008).

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The most common weeds in the experimental field at southern east of Iran were *Chenopodium album*, *Salsola kali*, *Heliotropium europaeum* and *Alhagi pseudalhagi*. These four species represented nearly 80 per cent of the total weed population. *Chenopodium album* and *Salsola kali* were the most predominant species and accounted for more than 50 per cent of the weed populations (Mahmoodi and Rahimi, 2009). Abouziena *et al*. (2008) indicated that *Portulaca oleracea, Sida alba* as broad leaved weeds and *Echinochloa colonum*, *Dactyloctenium aegyptium* as grasses were the dominant weeds in Egypt. The most outstanding weed flora composition in the experimental field at Coimbatore included *Echinochloa colonum* (44.92 %), *Digitaria longiflora* (5.31 %), *Dactyloctenium aegyptium* (3.11 %), *Cyperus rotundus* (4.55 %) and the annual broad leaved weeds constituted 39.64 % of the total weed population comprising of *Parthenium hysterophorus* (27.77 %), *Digera arvensis* (4.40 %) and *Trianthema portulacastrum* (3.60%) as reported by Mynavathi *et al*. (2008). Weed flora in the experimental field under Kanpur location consisted of number of weed species *viz., Chenopodium album, Phalaris minor, Convolvulus arvensis, Melilotus alba* and *Anagallis arvensis* among which abundant population of *Chenopodium album* appeared to be very aggressive at initial growth and developmental stages of maize (Verma *et al*., 2009). The maize field of Coimbatore, Tamil Nadu was predominantly infested with *Digera arvensis, Trianthema portulacastrum* and *Parthenium hysterophorus* among broad leaved weeds, *Cynodon dactylon, Dactyloctenium aegyptium and Panicum flavidum* among the grasses and only sedge weed *Cyperus rotundus* (Arulmani, 2010).

**Predominant weed flora in maize across different soils:** According to Sher Singh and Rajput (1995), the most outstanding weed flora composition in the maize fields at Faizabad included *Cyperus rotundus, Launea asplenifolia, Chenopodium album, Anagallis arvensis, Phyllanthus niruri, Melilotus indica, Ganaphalium pulvinatum, Polygonum plebejum, Trianthema monogyna* and *Euphorbia dracunculoides* in sandy loam soils. The clay loam soils of Tamil Nadu consisted of major weed species like *Panicum repens* (17.1 per cent) *Dactyloctenium aegyptium* (9.1 per cent) and *Cynodon dactylon* (8.4 per cent), the grasses (34.6 per cent), *Cyperus rotundus* the sedge (8.4 per cent) and the annual broad leaved weeds constituted 57 per cent of the total weed population comprising *Trianthema portulacastrum* (19.2 per cent) *Parthenium hysterophorus* (18.3 per cent), *Flavaria australasica* (12.1 per cent) and (7.4 per cent) of *Amaranthus viridis* (Kandasamy and Chandrasekhar, 1998). Sharma *et al.* (1998) reported that *Digitaria sanguinalis, Eleusine indica, Setaria glauca, Panicum dichotomiflorum, Cynodon dactylon, Sorghum halepense* among grasses, *Cyperus* spp. Among sedges and *Commelina benghalensis, Galinsoga parviflora, Ipomoea pestigridis* and *Euphorbia hirta* in broad leaved weeds were dominant in maize under sandy loam soils of North western Himalayan regions. In loamy clay soils, *Echinochloa colonum*, *Brachiaria ramose*, *Digitaria sangunalis*, *Dactyloctenium aegyptium*, *Eleusine indica*, *Setaria gluaca*, *Sorghum halepense* among grasses, *Ageratum conyzoides*, *Galinsoga parviflore*, *Linderina cilata*, *Oxalis latifolia* among non grass weeds and *Cyperus rotundus* among sedges were observed in maize fields at Uttaranchal (Pandey *et al*., 2001). Pandey *et al.* (2002) concluded that in the silty loam soils at Faizabad, *Cyperus rotundus, Cynodon dactylon*, *Eclipta alba*, *Solonum nigrum*, *Digeria arvensis*, *Phyllanthus niruri*, *Echinochloa colonum* and *Commelina benghalensis* were the dominant weeds. Sarma and Gautam (2006) observed that clay loam soils of Pantnagar region, dominant weed species namely *Cynodon dactylon*, *Cyperus rotundus*, *Echinochloa crusgalli*, *Echinochloa colonum*, *Agropyron repens*, *Parthenium hysterophorus*, *Digitaria sangunalis*, *Eclipta alba*, *Euphorbia hirta* and *Commelina benghalensis* were observed. Malviya and Singh (2007) observed that experimental field at Faizabad with silty loam soils infested with weed species such as *Cyperus rotundus, Cynodon dactylon*, *Eclipta alba*, *Solonum nigrum*, *Digera arvensis*, *Phyllanthus niruri*, *Echinochloa colonum* and *Commelina benghalensis*. Chopra and Angiras (2008) reported that, in silty clay loam soils of Himachal Pradesh, major weeds of the experimental field were *Digitaria spp* (38.08 per cent), *Panicum dichotomiflorum* (13.84%), *Commelina benghalensis* (11.54 %), *Cyperus iria* (4.96 %), *Bracharia ramose* (3.56 %) and others including *Oxalis latifolia*, *Ageratum conyzoides*, *Cynodon dactylon*, *Ipomoea purpurea* and *Polygonum alatum* (5.70 %). Singh *et al.* (2009) observed the predominance of *Cyperus rotundus, Cynodon dactylon, Eclipta alba, Solanum nigrum, Digera arvensis, Phyllanthus niruri, Echinochloa colonum and Commelina benghalensis* in medium to deep black soils of Bijaipur district in Karnataka.

**Predominant weed flora in maize across different seasons:** During *kharif* season, *Echinochloa colonum, Trianthema portulacastrum, Cyperus rotundus* and *Eleusine indica* were the dominant weeds in maize fields at Pantnagar of Uttar Pradesh (Govindra Singh and Ram Prasad, 1994). On the other hand during winter season, *Chenopodium album*, *Melilotus indica*, *Euphorbia hirta, Convolvulensis arvensis* among broad leaved weeds, *Cyperus rotundus* among sedge and *Cynodon dactylon* among grass were the dominant weeds flora in maize (Porwal, 2000). During *kharif* season, major weed flora present in the experimental field at Uttaranchal were *Echinochloa colonum, Digitaria sanguinalis, Dactyloctenium aegyptium* and *Panicum spp*. among grasses, *Ageratum conyzoides, Commelina bengalensis, Euphorbia geniculata* and *Oxalis latifolia* among broad leaved weeds and *Cyperus rotundus* among sedge (Pandey *et al*., 2001). In Peshawar during *kharif* season, after first irrigation, *Cyperus rotundus* and *Digitaria*

*sanguinalis* were the major weed species. However, after second and third irrigations, the population of *Echinochloa crusgalli* and *Leptochloa chinensis* dominated all the species throughout the remaining season (Khan *et al.,* 2003). Mynavathi *et al.* (2008) reported that major weed species present in the experimental field at Coimbatore during *kharif* season were *Echinochloa colonum* (44.92 per cent), *Digitaria longiflora* (5.31 per cent), *Dactyloctenium aegyptium* (3.11 per cent), *Cyperus rotundus* (4.55 per cent) and the annual broad leaved weeds constituted 39.64 per cent of the total weed population comprising of *Parthenium hysterophorus* (27.77 per cent), *Digera arvensis* (4.40 per cent) and *Trianthema portulacastrum* (3.60 per cent).

**Critical period of crop - weed competition in maize:** Establishing the critical period of competition is the most essential to develop effective and economical weed control measures. Shad *et al*. (1993) reported that the critical crop-weed competition in maize was found to be in between three and five weeks after sowing. However, In corn, several studies have shown that weeds, especially annual grasses, competing beyond the 4 inch height can reduce corn yields (Carey and Kells 1995). Maize grows very slowly during early stages and due to that subjected to vigorous competition from a wide variety of weeds. Due to weed competition, yield losses occur from 15 to 75 per cent in maize crop (Sen *et al*., 2000). During the first six weeks after germination of maize, weeds are very competitive. It was found that three weeks after germination there were on an average of 55 weed plants for every maize plant (Irvine and Radboud, 2000). Critical periods for weed control (CPWC) are defined as the period in the crop growth cycle during which weeds must be controlled to prevent unacceptable yield losses (Knezevic *et al*., 2002). Nedim *et al*. (2004) reported that a weed-free period between the 3 and 7 -10 leaf stages of the crop was enough to prevent these losses under the growing conditions of maize in Turkey. Corresponding weed cover at the beginning of the critical period was 20-25 %. Kamble *et al.* (2005) reported that the critical stage of crop weed competition in maize crop is 30 to 45 days from sowing.

**Weed competition for resources in maize:** Hosmani (1976) studied that influence of weeds on evapotranspiration loss in maize and found that moisture loss due to weed infestation was more than 66 percent from 0-45 cm soil layer compared to weed free treatment. Weeds and crops compete for same resources such as nutrients, water, space and light. Twomlow *et al.* (1997) reported that in maize the driest soil profiles and lowest yields were observed under the unweeded control. Johnson *et al*. (2000) described that increasing corn population to the recommended level would be the first approach to increase corns competitive ability against weeds using narrow rows which appears to have less potential for improving weed control. Sinha *et al*. (2000) reported that nutrient depletion by weeds was minimum under hand weeding while it was maximum 23.18 kg N, 4.92 kg P and 27.83 kg $Kha^{-1}$ under weedy check in maize in calcareous soils of North Bihar. Iremiraon *et al*. (2001) found that nutrient content of weeds was greater in the unweeded plots than the weeded maize plots. Unweeded check registered higher nutrient removal of weeds when compared to herbicide applied plots as reported by Kumar (2007). Saeed *et al.* (2010) observed that narrow spacing enhanced competitive ability of maize crop and suppressed weed growth, eventually resulted in higher yield, depicting that *Trianthema portulacastrum* is a strong competitor of maize and may cause substantial yield losses depending on plant spacing and weed density.

**Critical period for weed control in maize:** The critical period for weed control is a key component of an effective weed control program. It is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses. Timing of weed control measures is important to maintain optimum crop yield. Determining the critical period for weed control could help to reduce yield losses due to weed interference. Maqsood *et al.* (1999) reported that weed removal throughout the maize growth period produced the highest grain yield (44.38 q $ha^{-1}$) and lowest grain yield was recorded in the weed infestation throughout the maize growth period was only 28.73 q $ha^{-1}$. According to Porwal (2000) observed that in the rainy season, emergence of maize and weeds were simultaneous, crop suffer from more weed competition in this situation and it is presumed that first 20-30 days are most critical competitive period for maize. Maximum number of grains per cob (437) was obtained in a crop which was kept weed free until harvest. Lower plant height, number of cobs per plant, cob length, cob girth, grains per cob and 100 grain weight were recorded by weedy check due to uncontrolled growth of weed flora present in field (Pandey *et al*., 2001). Knezevic *et al.* (2002) reported that the critical period for weed control in corn greatly vary with weed removal time, duration of weed interference, effective yield and yield components. Evans *et al.* (2003) stated that ear number per plant and 100 grain weight of maize decreased linearly with increasing duration of weed interference. In addition, they found that grain number per ear was the most sensitive yield component to weed interference and nitrogen rate and its response was similar to relative yield. Zimdahl and Irvine (2004) suggested that Critical Period of Weed Control in corn is from 3 to 6 weeks after seeding and it has been determined under different conditions and results varied from country to country. Nedim *et al.* (2004) observed that highest grain yield was obtained from plots kept weed free between 3 and 7 leaf stages. Ghodralollah (2005) also reported that uncontrolled weeds in weedy check significantly reduced the plant height, total dry matter, leaf area index, number of rows, grains per row and 100 grain weight in maize. Another study conducted in Turkey, showed that the critical period for weed control was 5 week, which corresponded to the one to five leaf stage of

maize (Isik *et al*., 2006). Sohrab and Ali (2009) reported that critical period for weed control is the period in the crop growth cycle during which weeds must be controlled to prevent unacceptable yield losses.

**Nutrient removal by weeds in maize:** Hoveland *et al*. (1976) found that weeds were more sensitive to low P and K levels than the crop species. Tollenaar *et al.* (1997) reported that under limiting nitrogen conditions, maize yield was reduced due to weeds by 47 per cent but under higher levels of N, the reduction was only 14 per cent. Balasubramanian and Veerabadran (1998) reported that reduction in nutrient removal by weeds through suitable weed management practices enhanced the nutrient uptake, dry matter production and grain yield of crop. Cavero *et al*. (1999) reported that *Datura stramonium* had higher nitrogen content and N uptake by weeds than the maize crop through the season when grown maize as an monoculture. Sinha *et al.* (2000) reported that nutrient depletion by weeds was minimum under hand weeding while it was maximum (23.18 kg N, 4.92 kg P and 27.83 kg K $ha^{-1}$) under un weeded control in maize in the calcareous soils of North Bihar. According to Rajcan and Swanton (2001) little information were known about the P and K interaction effects on the influence of weed competition with maize but the occurrence of processes similar to those occurring with nitrogen is likely. The extent of nutrient loss varied from 30 to 40 per cent of the applied nutrients in maize with presence of weeds (Mundra *et al*., 2002). Similarly, Nitrogen deficiency symptoms develop earlier in maize infested with weeds than in maize kept weed free. This would imply in soil N depletion in maize grown with weeds, since maize yield reductions due to weeds are lower under high nitrogen rates than under lower rates (Silva *et al*., 2004). Sinha *et al.* (2005) observed that total nutrient uptake by winter maize was maximum (169.41 kg N, 55.67 kg $P_2O_5$ and 60.77 kg $K_2O$ /ha) under the treatment alachlor + french bean (*Phaseolus vulgaris*) as smother crop. The nutrient uptake by crop in weedy condition was the least. Chemical weeding checked nutrient drain by weeds significantly compared with weedy check. Kumar *et al*. (2007) reported that obviously unweeded check registered higher nutrient removal of weeds when compared to herbicide applied plots.

**Effect of weeds on growth attributes of maize:** According to Chakor and Awasthi (1983) observed that there was a significant reduction in height of plants and about more than 50 per cent reduction in grain yield and stover yield of maize under rainfed conditions of Himachal Pradesh. Kapusta *et al.* (1995) observed that broad leaved and grass weeds reduced maize growth and development significantly if left uncontrolled. Varga *et al.* (2000) found that absolute control plots recorded the greatest decrease (about 40 per cent) of leaf area in maize. Similarly, maize in the untreated plot produced less dry matter and less leaf area than plants in the treated plots (James *et al*., 2000). Shinde *et al.* (2001) recorded lower plant height, number of leaves per plant, dry matter per plant at harvest under uncontrolled weedy crop than in the weed free control. According to Ishaya *et al.* (2007) weed infestation decreased the height of plants in classical hybrids by 0.26 m. The duration of weed competition and time of weed removal also affect tasseling, silking, plant height, stem diameter, first ear's height and number of kernels in an ear, all of which correlate significantly with corn yield. Maqsood *et al.* (1999) opined that weed-crop competition from 6 to 8 weeks after emergence was very critical as for as plant height is concerned. Unchecked weed growth significantly reduced the plant height, total dry matter, leaf area index, number of rows, grains per row and 1000 grain weight in maize (Ghodralollah, 2005). Similarly, Cox *et al.* (2006) reported that unweeded control affects the silking date, dry matter accumulation, leaf area index, kernel per plant and grain yield of maize while compared to chemical weed control and weed-free situation of maize growth. In maize field under clay loam soil at Pantnagar, two hand weedings at 25 DAS and 45 DAS resulted in significantly higher plant height, dry matter accumulation and yield attributes as compared to unweeded control (Sarma, 2007). Reports by Riaz *et al.* (2007) revealed that chemical weeding at 2-3 leaf stage of weeds + hand weeding at 50 DAS gave promising results of maximum plant height and 34 per cent grain and 33 per cent of increased grain and stalk yield, and 1000 grain weight of maize**.** Samad *et al.* (2008) suggested that the parts (the whole plant, stem, leaf, root and five weed mixtures) of selected weed species exhibited inhibition of seed germination, seedling height, radicle growth and dry matter production of maize crop. But among the five weed species *Imperata cylindrica* and *Amaranthus spinosus* had more inhibitory effect on maize seed germination, growth and development in comparison to *Chenopodium album, Cyperus rotundus* and *Polygonum hydropiper.* Among the weed parts, stem was more harmful than other parts in reducing the maize yields. The maximum reduction in crop growth rate by 38 per cent, leaf area index by 44 per cent and grain yield by 51 per cent were recorded in full season weed-crop competition as compared with weed free crop. The total dry matter accumulation per plant was significantly higher in sole maize as compared to maize intercropped with either soybean, black gram or green gram or maize grown under predominant weeds due to competition for above and below ground resources (Sawargaonkar *et al.,* 2008). Maximum crop growth rate (0.067 g dm $day^{-1}$) and dry weight of plant (3.0 g) at 45 DAS were recorded with atrazine 0.5 kg a.i $ha^{-1}$ while compared to lesser crop growth rate (0.043 g dm $day^{-1}$) and dry weight of plant (1.94 g) was recorded under weedy check (Verma *et al*., 2009). Lima *et al*. (2010) reported that weed presence in the maize field reduced the leaf area index, green ear and grain yields, as well as other maize characteristics, in an unweeded situation.

**Effect of weeds on Yield parameters and yield of maize:** *Echinochloa crusgalli* at a density of 100 plants per $m^2$ reduced the yield of maize by 18 per cent (Kropff *et al*., 1984). Amador Ramirez (1995) highlighted that maize grown in the presence of weeds *viz*., *Amaranthus patmeri, Eragrostis diffusa, Bidens compestris* for the entire life cycle of the crop showed 86 and 90 per cent reduction in grain yield at Mexico. Sher Singh and Rajput (1995) reported that pre emergence application atrazine (1.0 kg/ha) produced maize grain yield equal to that weed free condition. Similar results were observed by Maqsood *et al.* (1999) who have reported that the maximum number of grains per cob (437) was obtained where the crop was kept weed free till harvest, while the minimum number of grains (358) was found in case of weed infestation till harvest. Grain yield decreased significantly with an increase in the duration of weed infestation in maize, while it increased significantly with the increasing duration of weed free period. Anderson (2000) reported that dry mass and yield were significantly affected by the intensity of weed infestation. The yield decreases due to weed infestation throughout the whole vegetative period by 65 per cent. The highest dry matter yield was obtained in the variant of inter row tillage during the whole vegetative season. Similarly, Irvine and Radboud (2000) concluded that the first six weeks after germination of maize, weeds are highly competitive. Maize favours high weed density in early growth period and resulted in poor vegetative growth and grain yield. Weed infestation caused the grain yield reduction by 86-90 per cent throughout the whole vegetation period. Similarly, Knezevic *et al.* (2002) reported that percentage maize yield losses ranged from 5 to 34 per cent for redroot pigweed (*Amaranthus retroflexus*) densities of 0.5-8 plants $m^{-1}$ of row.Knezevic, S.Z., Weise, S.F. and Swanton, C.J., 1994. Interference of redroot pigweed (*Amaranthus retroflexus*) in corn (*Zea mays*). *Weed Sci.* **42**, pp. 568–573. View Record in Scopus | Cited By in Scopus (107) Meyyappan and Kathiresan (2005) reported that hand weeding twice significantly increased the maize grain yield up to 2.42 times higher than weedy check. Mannan *et al.* (2006) opined that weeds are one of the most important yield reduction factors in maize production in Iran. They cause important yield losses worldwide with an average of 12.8 per cent despite weed control applications and 29.2 per cent in the case of no weed control. Similarly, Sarma and Gautam (2006) reported that maximum numbers of cobs were recorded with two hand weeding compared to unweeded plots. Hand weeding at 25 and 45 DAS recorded significantly higher grain yield and lower weed dry weight at silking and maturity stages. Riaz *et al.* (2007) observed that the maize with unchecked weed growth recorded significantly lower grain and stalk yields compared to chemical weeding at 2 to 3 leaf stage of weeds along with hand weeding at 50 DAS. Rao and Nagamani (2007) have proved that integration of herbicides with hand weeding is the most effective and economical method of weed management. Saeed *et al*. (2010) recorded higher 1000 kernel weight of 201.1 and 194.6 g in weed control plots as compared to lower 1000 kernel weight of 183.4 and 173.8 g in plots having higher weed density of 18 plants $m^{-2}$ during 2006 and 2007, respectively. Further they concluded that harvest index of maize was reduced due to presence of *Trianthema portulacastrum* in the maize field.

**Effect of weeds on quality parameters of maize:** Weed species, densities and their associated interactions influence maize yield loss. When Johnsongrass (*Sorghum halepense*) density increased from 4 to 12 plants 9.8 $m^{-1}$ of row, maize grain yield was reduced from 8.5 to 46.6 per cent (Ghosheh *et al.,* 1996). More over germination and vigour of maize seeds decreased with an increase in weed density (Saayman *et al*., 1997). Weed eradication throughout the maize growth period, produced the highest grain yield (44.38 q $ha^{-1}$), while the lowest grain yield (28.73 q $ha^{-1}$) was recorded in case of weed infestation throughout the maize growth period. Grain yield decreased significantly with an increase in the duration of weed infestation in maize, while it increased significantly with the increasing duration of weed free period as reported by Maqsood *et al.* (1999). Sen *et al.* (2000) found that, due to weed competition yield losses occur upto 15 to 75 per cent in maize crop. The loss in grain yield due to unchecked weed growth was to the extent of 33 to 50 per cent (Sharma *et al.,* 2000). Similarly, Knezevic *et al.* (2002) reported that percentage maize yield losses ranged from 5 to 34 per cent for redroot pigweed (*Amaranthus retroflexus*) densities of 0.5-8 plants $m^{-1}$ of row. Pandey *et al.* (2002) proved that grass weeds offered maximum competition to crop reducing grain yield by 77.4 per cent followed by non-grass weeds of about 44.2 per cent and sedges 38.4 per cent, respectively. Maximum numbers of cobs were recorded with two hand weeding compared to unweeded plots (Sarma and Gautam, 2006). Hand weeding at 25 and 45 DAS recorded significantly higher grain yield and lower yield and lower weed dry weight at silking and maturity stages. Maize, being a rainy season and widely spaced crop, gets infested with variety of weeds and subjected to heavy weed competition, which often inflicts huge losses ranging from 28 to 100 per cent (Patel *et al.,* 2006). Riaz *et al.* (2007) observed that the maize crop with unchecked weed growth recorded significantly lower grain and stalk yield compared to chemical weeding at 2 to 3 leaf stage of weeds along with hand weeding at 50 DAS. Maximum plant height and higher biological yield of (9118 kg $ha^{-1}$) was recorded with hand weeding as compared to weedy check (5537 kg $ha^{-1}$) and black plastic mulch (8982 kg $ha^{-1}$) (Bakhtiar et *al.,* 2009). Maximum crop growth rate (0.067 g dm $day^{-1}$) and dry weight of plant (3.0 g) at 45 DAS were recorded with atrazine 0.5 kg $ha^{-1}$ while compared to lesser crop growth rate (0.043 g dm $day^{-1}$) and dry weight of

plant (1.94 g) was recorded under weedy check (Verma *et al.,* 2009). Saeed *et al.* (2010) recorded higher 1000 kernel weight of 201.1 and 194.6 g in weed control plots as compared to lower 1000 kernel weight of 183.4 and 173.8 g in plots having higher weed density of 18 plants $m^{-2}$ during 2007 and 2008, respectively, further they concluded that harvest index of maize was reduced due to presence of *Trianthema portulacastrum* in the experimental field.

**Effect of weeds on nutrient uptake:** Competition for nutrients between maize and weeds is influenced by type and amount of nutrient available, amount of precipitation and nature of weed species. The yield of maize was reduced by weeds more under limited than under luxury N supply. Hoveland *et al*. (1976) found that weeds were more sensitive to low P and K levels than the crop species. According to Tollenaar *et al.* (1997) under N limiting conditions maize yields were 47 per cent lesser under weedy situation than weed-free conditions. Under high N levels, however yields were only 14 per cent lesser under uncontrolled condition than under weed-free conditions. Mundra *et al*. (2002) indicated that adoption of various weed management treatments significantly enhanced N and P uptake by maize and reduced removal of nutrients by weeds as compared to weedy check and maximum saving of 30.1% nitrogen and 26.4% phosphorus was achieved with atrazine at 0.5 kg/ha as pre-emergence + inter-cultivation at 35 days after sowing (DAS). Sinha *et al.* (2005) observed that total nutrient uptake by winter maize was maximum (169.41 kg N, 55.67 kg $P_2O_5$ and 60.77 kg $K_2O/ha^{-1}$) under the treatment alachlor + French bean (*Phaseolus vulgaris* L.) as smother crop. The nutrient uptake by crop in weedy condition was the least. Chemical weeding checked nutrient drain by weeds significantly compared with weedy check. Sharma *et al.* (2008) stated that application of polythene mulch, straw as well as soil mulch resulted in a significant increase in N and P status of the soil as compared with the control plots in maize-wheat sequence.

**Manual and cultural methods of weed management in maize:** Weed control is one of the most important objectives of cultural operations in crop production. These methods include controlling weeds either by hand weeding, mechanical weeding, hoeing or discing. Sharma *et al.* (2000) reported that earthing up at 30 DAS resulted in the virtual elimination of weeds throughout the crop growth period. Singh *et al.* (2001) recorded higher WCE of 82.2 per cent with two hand weedings done at 15 and 30 DAS. Wiltshire *et al.* (2003) reported that plant population density was not affected by mechanical weeders associated with chemical weeding, at the same time, higher weed control efficiency was achieved compared to hand weeding. Manual weeding twice registered reduction of *Cyperus rotundus* (22.2 per cent), *Digeria arvensis* (17.6 per cent), *Phyllanthus niruri* (22.0 per cent) and *Commelina benghalensis* (20.3 per cent) population resulting in heavy decline in weed dry weight and higher weed control efficiency (87.8 per cent) in rainy season maize in Central Uttar Pradesh (Tripathi *et al.,* 2005). Nagalakshmi *et al.* (2006) noticed that hand weeding twice at 3 and 6 weeks after sowing showed significant effect in reducing weeds and also increased the yield. Singh *et al*. (2007) observed that two hand weedings each at 20 and 40 DAS proved most effective followed by alachlor at 2.0 kg $ha^{-1}$ + hand weeding at 30 DAS and they reduced weed density and weed biomass significantly in maize grown under rainfed condition at Faizabad. Verma *et al.* (2009) reported that two weedings recorded 87.55 per cent WCE and one weeding followed by earthing up treatment recorded maximum of 93.88 per cent WCE at 45 DAS indicating suppression of first flush of weeds successfully in maize.

**Chemical method of weed management in maize:** Timely weed management is obvious to check the weeds and create proper environment for crop establishment particularly during initial stage of the crop. Number of researchers reported positive response in maize growth and yield due to chemical weed control methods. Ullah *et al.* (2008) reported that, herbicide application proved effective in controlling weeds and increasing the grain yield of maize.

**Pre-emergence herbicides:** Pre-emergence herbicides provide early season weed control by suppressing or killing the weed seeds at germination itself. Atrazine is a triazine group, selective systemic pre - emergence herbicide having both knockdown effects and residual activity. It is one of the most popular herbicides in World, despite criticisms against its continued use in crop fields. Atrazine was more effective against *Ageratum conyzoides* and less effective against *Echinochloa colonum* and *Brachiaria romosa* than pendimethalin or alachlor (Pandey *et al.,* 2001). Capel and Larsen (2001) concluded that atrazine behaviour in the soil is influenced by soil type, pH, temperature, organic matter content and moisture availability. Atrazine is a widely used triazine herbicide for the pre-emergence control of broadleaved and grass weeds in a variety of commercial crop as well as roadside and fallow fields (Munier-Lamy *et al.,* 2002). Jacob (2003) reported reduced weed biomass due to use of selective pre-emergence herbicides like S-metolachlor emerged as the best among pre-emergence herbicides for controlling different weeds of maize. Pre-emergence application of atrazine at 0.5 kg $ha^{-1}$ followed by inter cultivation at 35 DAS increased the maize grain yield by 93 per cent over weedy check. The yield under this treatment was comparable with inter cultivation at 20 and 35 DAS in clay loam soils of Udaipur (Mundra *et al.*, 2003). According to Chopra and Angiras (2008) revealed that atrazine at 1.5 kg/ha being statistically on par with acetachlor 1.25 kg $ha^{-1}$ produced significantly lower weed density and dry matter of weeds and resulted in significant increase in the entire yield attributes of maize crop and thereby its grain yield by 75.18 and 71.66 % respectively over unweeded check.

**Status of GM crops in the world and India:** Popularly known genetically modified organisms (GMO's) are organisms in which the genetic material (DNA) has been altered from natural processes. The technology is often called "gene technology" or "genetic engineering". While some of the developed countries, especially the United States, Australia, Canada and the European Union have long been using genetic engineering in the agricultural production. According to James (2008) number of countries planting biotech crops reached the historical milestone of 25 countries during 2008, totally 800 million hectares of GM crop was planted. Among different countries, U.S.A ranks first, planted with 62.5 million hectares of land and the major reported biotech crops are soybean, maize, cotton, canola, squash, papaya, alfalfa and sugar beet followed by Argentina and Brazil. In 2009, *Bt* maize was planted in the EU on 94850 hectares across six countries like Czech Republic (6480 ha), Poland (3000 ha), Portugal (5094 ha), Romania (3344 ha), Slovakia (875 ha) and Spain (76057 ha). In 2009-10, 86% of the genetically modified maize varieties were used by United States (NASS, 2010). The global coverage of biotech crops continued to grow strongly reaching 125 million hectares during 2008, from 114.3 million hectares in 2007. The number of countries electing to grow biotech crops has increased steadily from six in 1996, the first year of commercialization to 18 in 2003 and 25 in 2008. Biotech soybean continued to be the principal biotech crop in 2008, occupying 65.8 million hectares or 53 per cent of global biotech crop area, followed by biotech maize (37.3 million hectares at 30 per cent), biotech cotton (15.5 million hectares at 12 per cent) and biotech canola (5.9 million hectares at 5 per cent of the global biotech crop area). In the same year number of farmers benefiting from biotech crores of maize stacked straits globally in 25 countries reached 13.3 million, an increase of 1.3 million over 2007. In 2009, 134 million hectares of GM crops were grown worldwide from which 41.7 million hectares were maize (9.2 million hectares of BT maize, 6.4 million hectares of herbicide tolerant maize and 26.1 million hectares of maize stacked traits. Of the global total of 13.3 million beneficiary biotech farmers in 2008 (up from 12 million in 2007), remarkably over 90 per cent or 12.3 million (up from 11 million in 2007) were small and resource-poor farmers from developing countries (James, 2009). In India, 5 million small farmers benefited from planting 7.6 million hectares of *Bt* cotton during 2008. An average, conservative estimates for small farmers indicate that yield increased by 31 per cent, insecticide application decreased by 39 per cent and profitability increased by 88 per cent equivalent to Rs.12,500 per hectare. The major yield reducing factors for corn cultivation in India are weeds and insects. Transgenic corn hybrids with stacked event, TC1507 X NK603 were developed for preventing yield losses of corn crop and improve productivity. The stacked product having both insect protection and herbicide tolerant traits will provide protection to the crop against target pests and also provide effective weed management system to farmers. A transgenic stacked maize (TC1507xNK603) obtained by crossing two transgenic maize lines by using traditional plant breeding techniques. TC1507 maize expresses a *Bt* insecticidal protein (Cry1F) for control of certain lepidopteron (stem borers) pests, and NK603 corn expresses a modified maize 5-enolpyruvylshikimate-3-phosphate—synthase enzyme (CP4 EPSPS) that confers tolerance to herbicide products containing glyphosate.

**Herbicide tolerant crops:** In the early 1980s, the tools for producing transgenic crops were becoming available. Introduction of transgenic crops made resistant to broad-spectrum, non-selective herbicides was rightfully perceived as a better strategy in terms of weed management and market share. Several companies saw the advantage of using this technology to produce crops resistant to very broad spectrum herbicides. The two herbicides that ûtted this approach best were glyphosate and glufosinate. Both compounds are amino acid analogues that have molecular targets in amino acid biosynthesis pathways. Herbicide-resistant crops were the ûrst major wave of transgenic crops (Duke, 2005). In 2008, herbicide tolerance deployed in soybean, maize, canola, cotton and alfalfa occupied 63 per cent or 79 million hectares of the global biotech area of 125 million hectares. For the second year running in 2008, the stacked double and triple traits occupied a larger area (26.9 million hectares) 22 per cent of global biotech crop area than insect resistant varieties (19.1 million hectares) at 15 per cent (James, 2009). Wide-spread adoption of GR crops and glyphosate had significant economic effects in agriculture, from replacement of previous herbicide markets (Gianessi, 2008) to cost savings for farmers in weed management (Brookes and Barfoot, 2008). Moreover, GR crop technology has generally reduced the adverse environmental and health impacts of weed management (Gardner and Nelson, 2008).

**Role of glyphosate in weed management:** 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 (WSSA, 2007). Inhibition of aromatic amino acid biosynthesis speciûcally inhibition of 3-phospho-5-enolpyruvylshikimte 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, when applied, glyphosate is taken up by the green leaves and is translocated to the growth points (meristems), presently in the main shoots and root tips, where it blocks the meristem development (WSSA, 2007). The primary benefits of this technology were to provide a more flexible option for broad-spectrum weed control with minimal crop injury. In addition to applying less total herbicide, the

reduction in cost was also found to be very advantageous (Burnside and Wicks, 1980).

According to Watrud *et al*. (2004) reported that, 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. 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 GR plants. Likewise, 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 (Bradshaw *et al.,* 1997). GR crops were the most quickly adopted technology in the history of agriculture (James, 2007). 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*). 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 tolerant maize:** Advancement of modern technologies emphasize 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 (Duke and Cerdeira, 2009). The ûrst 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 modiûed (maize EPSPS) coding sequence (chloroplast transit peptide sequences from *Helianthus annuus* and the RuBisCo gene from *Zea may*). Effectively, this maize contains a modiûed 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 NK 603 was produced by two copies of the CP4 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 ûeld 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 ûrst 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 (James, 2007).

**Efficacy of glyphosate tolerant maize:** According to Hetherington *et al.* (1999) revealed 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 and 4 kg a.e. $ha^{-1}$, 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. According to Erickson *et al*. (2003) indicated that no significant differences observed between herbicide tolerant corn event NK 603 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. No visual injury was observed in glyphosate tolerant maize crop by POE of glyphosate (Nurse *et al.,* 2006).

**Weed control efficiency of glyphosate tolerant maize:** The efficacy of glyphosate can result in reduced usage of pre-emergence herbicides. Glyphosate-resistant maize is advantageous compared to conventional hybrids. According to Johnson *et al.* (2000), two post emergence glyphosate applications on corn can provide better weed control than a single glyphosate application, especially if interfering weeds are controlled at heights less than 15 cm. Application of glyphosate at 0.84 kg $ha^{-1}$ followed by 0.63 kg $ha^{-1}$ as early post emergence provided effective control of shattercane (100 per cent) and giant foxtail (99 per cent) while single application of glyphosate provided only 58 per cent and 69 per cent of shattercane and giant foxtail, respectively at Columbia (Hans and Johnson, 2002). Ferrell and Witt (2002) found that sequential applications of glyphosate at 5 to 10 cm height of weeds in glyphosate tolerant maize provided 87 to 92 per cent control of *Ipomoea spp*. and more than 95 per cent control of *Setaria faberi* and large crabgrass. Timely

sequential applications of glyphosate have been shown to be effective in season-long control of *Amaranthus rudis*, *Setaria faberi*, *Abutilion theophrasti*, *Xanthum strumanium* and *Chenopodium album* at levels of more than 90 per cent through the season (Hellwig *et al.,* 2002). Control of *Xanthium strumarium* was found to be greater than 90 per cent with glyphosate (Ferrell and Witt, 2002). Gower *et al.* (2002) documented that, sequential post emergence applications of glyphosate were most effective for control of giant foxtail (95 per cent), *Abutilon theophrasti* and *Chenopodium album* (90 per cent) in late planted maize while in early planting of maize provided lower weed control. The same study observed, single application of glyphosate at 5 cm weed height rarely resulted in greater than 90 per cent control. Broadleaf control from a single application of glyphosate at the time of 5, 10, 15, 23 and 30 cm height of weeds were 84, 91, 94, 95 and 93 per cent, respectively. Control at the 5 cm height was signiûcantly lower than at later timings. A single application of glyphosate occasionally provided 70 per cent control of annual broadleaf weeds at the 5 to 10 cm application timings because of secondary seedling ûushes. Broadleaf weed control was more than 93 per cent with a single glyphosate application when broadleaf weeds were 15 cm or more in height. Although grass weeds present at the time of application of early emergence were controlled, regardless of size, tall broadleaf weeds could be more difficult to control (Gower *et al.,* 2003). Puricelli and Tuesca (2005) found that sequential application of glyphosate provided excellent control of early emergence annual broad leaved weeds such as *Portulaca oleracea* and grass annuals such as *Digeria sanguinalis*. However, continual glyphosate application for longer periods of time may lead to the development or higher increase in abundance of weeds tolerant to the herbicide. Purba and Desmarwansyah (2008) reported that the least weed coverage of weeds (26.7 per cent) was found in plots were received glyphosate was applied twice at third and the twelfth leaf stage of maize growth while unweeded control obtained 100 per cent control.

**Time of POE glyphosate application in transgenic maize:** The crop development stage at which weed interference occurred is an important factor in determining potential yield loss. Corn tolerates the early season weed competition without yield loss only until the third leaf stage in the cool spring conditions of Ontario, Canada. The results from the study in Canada suggested that glyphosate can be applied as early as the three leaf stage to prevent yield losses from early season weed competition in regions with cool spring conditions. Glyphosate application should be done before weeds attain 15 cm in height to avoid the yield losses. Re-infestation of weed after early post-emergence (EPOST) application had less potential to reduce yield than delaying application and allowing weeds to compete with corn for long period before removal (Gower *et al.,* 2002). In north-central USA the optimum timing for weed control to avoid maize grain yield loss for an initial application of glyphosate at four leaf stage when the weeds were less than 10 cm in height and not more than 23 days after corn planting (Cox *et al.*, 2006). In another study, Dalley *et al.* (2004) reported that optimum timing of weed control and corn yield depended on specific annual growing conditions. In highly competitive conditions, optimum glyphosate application for weed control and corn yield occurred by the four leaf stage. Under the less competitive conditions, optimum glyphosate application for weed control and corn yield occurred by the nine leaf stage. Cox *et al.* (2005) reported that season-long weed interference versus weed-free corn reduced dry matter yield by 70 to 75 per cent, but if the glyphosate sprayed at the three to six leaf stage, the yield reduction decreased to 20 to 25 per cent only. Weed removal time at the five and six leaf stage of maize growth resulted in 10 and 20 per cent of grain yield reduction, respectively .Similarly, Purba and Desmarwansyah (2008) indicated that application of glyphosate delayed until the fifth leaf stage of maize resulted 17 per cent grain yield reduction.

**POE glyphosate on growth, yield and quality of maize:** According to Purba and Desmarwansyah (2008), reported that the tallest maize plants (237.5 to 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. Grain yield (9135 kg $ha^{-1}$) was recorded under this treatment was comparable with weed free treatment, while unweeded control plots recorded 38.3 per cent lesser. Dalley *et al.* (2004) observed that, sequential applications of glyphosate in maize crop did not increase the grain yield. Cox *et al.* (2006) 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. The fat and crude protein levels reached 40 g $kg^{-1}$ and 97 g $kg^{-1}$ of dry matter, respectively. Results of Ridley *et al.* (2002) 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. The values for components in corn event NK603 all fell within the range of natural variability found in non-transgenic corn hybrids. Transgenic maize was shown to be as safe and nutritious as the parental lines and conventional maize by analysis of key nutrients including protein, fat, carbohydrates, amino acids, fatty acids and minerals, as well as by a feed performance study using grain fed to broiler chickens (Taylor *et al*., 2007). Sidhu *et al*. (2000) observed similar contents of moisture, protein, fat, ash, carbohydrates, ADF, NDF, Ca, P in grain and whole plant green chop from a glyphosate tolerant maize hybrid. Erickson *et al*. (2003) observed similar contents of moisture,

protein, fat, ash, carbohydrates, ADF, NDF, Ca, P in grain and whole plant green chop from a glyphosate tolerant hybrid results in a higher composition of DMI, milk yield and milk composition of lactating dairy cows fed with round up ready corn plant silage and grain to lactating cows. According to Sandra *et al*. (2011) indicated that Bt corn has greater yield and higher lignin, carbon and nitrogen concentrations in the corn. Moreover Bt corn residue may be more susceptible to decomposition rate than non bt corn residue.

**Residual effect of POE glyphosate on soil and soil micro flora:** Glyphosate is relatively immobile in most soil environments as a result of its strong adsorption to soil particles (Ghassemi *et al*., 1982). Muller *et al*. (1981) found that glyphosate degrades at very low temperatures and does not adversely affect nitrogen fixation, nitrification or denitrification activity. In general, glyphosate is moderately persistent in soil. Soil studies have determined glyphosate half-lives ranging from 3 to 130 days. One of the most signiûcant advancements in intensive agriculture was the introduction of glyphosate resistant crops in the 1990s. Indeed, based on average application rate and frequency and area treated, the amount of glyphosate applied to glyphosate resistant soybean in the U.S. increased by 52 million kg from 1997 to 2004 (Benbrook, 2004). Stratton and Stewart (1992) observed on the effects of glyphosate on microbial biomass revealed that glyphosate generally had no significant effect on the numbers of bacteria, fungi or actinomycetes in forest soil and overlying forest litter. There was no effect of glyphosate on *in situ* respiration in most of the treated systems while the remainder showed an increase in respiration. Means *et al.* (2007) detected a signiûcant increase in soil Fusarium within two weeks after glyphosate was applied at recommended rates in the ûeld. Meriles *et al.* (2006) verified that the population growth and sporulation of soil *Fusarium spp*. increased after glyphosate application to soils containing maize or peanut crop residues compared with lower *Fusarium* populations in similar fallowed soils lacking crop residues. Castro *et al.* (2007) observed in an culture based studies, indicated that indicates that isolated *Fusarium spp*. from soil were able to metabolize glyphosate and use it as a phosphorus source. A follow-up study veriûed that long-term exposure of soil microorganisms to glyphosate led to a fungal community dominated by *Fusarium spp* (Krzysko-Lupicka and Sudol, 2008). In contrast, Simonsen *et al*. (2008) recently demonstrated that agricultural soils amended with phosphorus fertilizers are high in unbound glyphosate because soil sorption sites are occupied by competing phosphate ions, thus, glyphosate remaining in the soil solution is vulnerable to potential uptake by plant roots, microbial metabolism or leaching into groundwater. Kremer and Means (2009) observed that *Fusarium* colonization was higher on GR soybean treated with glyphosate throughout the growing season, generally two to ûve times higher compared with soybean receiving no herbicide or a conventional (non-glyphosate) herbicide. The frequency of root colonizing *Fusarium* increased signiûcantly within one week after glyphosate application throughout the growing season. Similarly *Fusarium* colonization of roots of GR maize receiving glyphosate was three to ten times higher colonization levels than for colonization levels for the atrazine treatment.

**Effect of POE glyphosate on soil weed seed bank:** Application of glyphosate was done during reproductive stage of soybean can be beneficial to producers by reducing weed seed impact (Clay and Griffin, 2000). Seed bank with little modification to their production practices, reducing future weed interference and providing greater flexibility in weed management decisions. According to Hilgenfeld *et al.* (2004) conducted a two year, multi-site study on weed species shifts in glyphosate tolerant soybean systems. This particular study found that continuous use of glyphosate for weed management could alter the presence of weed species found within a given ûeld. This was due to the inconsistent control of all the species and allowing some species such as *Ipomoea hederacea* and *Sorghum bicolor* disproportionately replenish the seed bank. Results observed by Owen and Zelaya, 2005 M.D.K. Owen and I.A. Zelaya, Herbicide-resistant crops and weed resistance to herbicides, *Pest Manage. Sci.* **61** (2005), pp. 301–311. **Full Text** via CrossRef | View Record in Scopus | Cited By in Scopus (63)Owen and Zelaya (2005), glyphosate application may cause shifts in weed population and seed bank dynamics. Jeschke and Stoltenberg (2006) found that eight years of continuous usage of glyphosate alone in a corn-soybean rotation resulted in greater weed species richness compared to more diverse management systems which included tillage and or non-glyphosate herbicides. Walker and Oliver (2008) reported that, weed seed reduction efforts must be sustained to realize long-term benefits, such as reduced early-season weed densities. Moreover, properly-timed glyphosate applications must reduce seed production of the entire weed complex and a minimum number of glyphosate applications must effectively reduce weed seed production.

**Economics analysis of weeding options in maize:** Pre-emergence application of atrazine at 0.25 kg $ha^{-1}$ with a follow-up hand weeding at 35 DAS not only maintained the yield but also enhanced economic advantage through better weed control efficiency (Kandasamy and Chandrasekhar, 1998). Results by Porwal (2000), reported that maximum Benefit : Cost ratio (3.32) over farmers practice of mechanical weeding (twice) was recorded under atrazine @1.0 kg $ha^{-1}$ applied as post emergence on 30-35 DAS, followed by its pre-emergence application. According to Sathyamoorthi *et al*. (2001) reported that higher maize grain yield and better economic returns through land preparation with tractor drawn disc plough followed by cultivator tillage combined with integrated weed management of pre-emergence

application of atrazine at 0.25 kg ha$^{1}$ followed by one hand weeding. Similarly, Subramanyam *et al.* (2001) concluded that the pre-emergence application of atrazine at 1.0 kg ha$^{-1}$ + metolachlor at 1.0 kg ha$^{-1}$ with one hand weeding at 40 DAS was effective and economic weed management practices for irrigated maize. According to Kamble *et al.* (2005) results observed that pre-emergence application of atrazine at 0.5 kg ha$^{-1}$ plus one hand weeding and one hoeing at 20 DAS was the most economical and effective method of weed control in maize. Chemical weeding at two-three leaf stage of weeds + hand weeding at 50 DAS resulted in higher net benefit (Riaz *et al*., 2007). Mishra and Singh (2009) reported that among weed control treatments higher net returns were obtained from herbicide plus hand weeding. Rao *et al.* (2009) revealed that higher grain yield, higher gross and net returns and benefit : cost ratio could be achieved in zero till sown maize by two hand weeding or by adopting pre emergence application of atrazine at 1.5 kg ha$^{-1}$ either alone or followed by hand weeding at 30 DAS. Ravisankar *et al.* (2011) reported that application of glyphosate at 1800 g a.e/ha in transgenic maize hybrid gave maximum net return and benefit: cost ratio as compared to conventional maize hybrids. Johnson *et al.* (2000) reported that net income was positively correlated with transgenic maize yield. All glyphosate based treatments produced higher net income while least profit was recorded with without glyphosate and unweeded control. Reddy and Whiting (2000) reported that, net return of Rs. 20,350 ha$^{-1}$ was observed with a sequential glyphosate program in GR soybean compared to Rs. 13,550 ha$^{-1}$ in conventional soybean with a standard pre-emergence herbicide application followed by a post emergence herbicide program. However, the economic returns of glyphosate-resistant corn systems are greater than or equal to any other type of weed management system, while efficacy of weed control is equivalent or better than conventional systems (Zuver *et al.,* 2006).

## RESULTS

During *kharif,* 2010, higher gross and net returns of Rs. 85470 and 60499 ha$^{-1}$ were obtained with POE application of glyphosate at 1800 g a.e ha$^{-1}$ in transgenic 30V92 maize hybrid. The next higher net return was obtained with glyphosate at 1800 g a.e ha$^{-1}$ in transgenic maize hybrid of 30B11 followed by transgenic 30V92 with application of glyphosate at 900 g a.e ha$^{-1}$. However, glyphosate at 900 g a.e ha$^{-1}$ 30 B11 registered higher gross and net returns next to glyphosate at 900 g a.e ha$^{-1}$ 30V92 during the *kharif*, season of 2011. Higher B:C ratio of Rs. 3.42 was obtained as return for every rupee invested on cost of cultivation with POE application of glyphosate at 1800 g a.e ha$^{-1}$ in transgenic 30V92 maize hybrid and the same dose of glyphosate under transgenic 30B11 was recorded as next best B:C ratio of Rs. 3.36 .Obviously, lower gross and net return and benefit cost ratio were registered in unweeded check. Likewise during *kharif,* 2011, higher gross and net returns of Rs.78610 and 52177 ha$^{-1}$ were obtained with glyphosate at 1800 g a.e ha$^{-1}$ in non transgenic 30V92 and glyphosate at 1800 g a.e ha$^{-1}$ in transgenic 30B11 maize hybrids respectively. The next higher net return was obtained with glyphosate at 1350 g a.e ha$^{-1}$ transgenic 30V92 followed by same hybrid with glyphosate at 1800 g a.e ha$^{-1}$. Higher B:C ratio of Rs.2.97 and 2.75 were obtained with glyphosate at 1800 g a.e ha$^{-1}$ in transgenic30V92 and 30B11 maize hybrids, respectively.

## CONCLUSION

It can be concluded that post emergence application of glyphosate @ 1800 g a.e ha$^{-1}$ at 20 DAS could keep the weed density and weed dry weight reasonably at a lower level and enhanced the productivity of herbicide tolerant transgenic maize resulting in higher productivity and profitability compared to non-transgenic hybrids.

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