

New opportunities for weed control in maize

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Maize has shown impressive growth over the last decade due to extension of its cultivation to non-traditional areas and introduction of superior single cross hybrids. Being a widely-sown and predominantly warm-season crop, weeds are a serious constraint for realizing potential productivity. Till recently, atrazine was the only maize herbicide available for pre-emergence application. New low-dose high-potency herbicides like topramezone and tembotrione are now available for post-emergence broad-spectrum weed control including the grassy species. Halosulfuron can also be used for the control of most troublesome Cyperus spp. in specific situations. Further, zero-till maize cultivation along with appropriate herbicides were found beneficial for improving productivity. It is also possible to grow legumes like dhaincha, sunnhemp and compea either before sowing or along with maize for reducing weed infestation besides conserving soil moisture and providing N-nutrition.

Key words: Control, Maize, Weed

MAIZE (*Zea mays*) is an important grain crop cultivated in almost all parts of India. Presently, the crop is grown on 9.5 million ha producing 24.5 million tonne. The average productivity of maize (2.6 tonnes/ha) is only about half of the world's average (5.2 tonne/ha). However, the crop showed impressive growth during the past 2 decades as its cultivation was extended to new areas/seasons for diversified uses and single cross hybrids were introduced for cultivation. In some areas, maize is grown and harvested in every month of the year due to its wide adaptability. Broadly, the crop is grown in *kharif* (June/July to September/October), *rabi* (October/November to April/May), spring (January/February to May/June), and summer (March/April to June/July).

Production of maize is influenced by various biotic (weeds, insects and diseases) and abiotic factors (temperature, light, humidity, salinity/alkalinity) that cause

reductions in yield. Among these the losses caused by weeds are severe and can be up to 100 % or even complete failure of the crop under unchecked weed growth. Weed infestations are more severe in the *kharif* and spring / summer (85% area) due to ideal conditions of temperature and humidity when weeds appear in multiple flushes throughout the crop season. Management of these weeds is essential not only during the critical period of crop-weed competition but virtually throughout the season so that the late-emerged weeds do not produce seeds and acquire the same or even higher population during the next season than in the current season. This is essential to ensure long-term weed control and minimize weed seed bank in the soil.

Weed species

Maize is infested with various kinds of weeds belonging to groups such as grassy (narrow-leaved), broad-leaved and sedges (Table 1).

The occurrence of complex weed flora requires a critical examination of the species present, their growth behaviour and severity of damage. Different kinds of species occur at different times and cause damage to the crop. *Echinochloa colona* is the most important grassy weed in all parts of India. *Trianthema partulacastrum*/T. *monogyna* cause serious damage in the north-western plains as well as eastern India. *Cyperus rotundus*/C. *esulentus* are the most troublesome species in most situations. *Ageratum conyzoides*/A. *haustonianum* is emerged as a very serious problem in maize and non-crop lands in the hilly tracts of northern India. This weed starts appearing by the end of August, takes away the residual soil moisture with receding rains and renders ploughing of the field after harvest extremely cumbersome. Moreover, the weed is poisonous, and its manual removal, cutting or burning causes giddiness, vomiting, itching and irritation in the eyes.

Table 1. Weed species infesting maize crop in different seasons

Species	English name	Botanical name
<i>Rainy/Spring/Summer</i>		
Grassy	Barnyard grass / jungle rice	<i>Echinochloa colona</i>
	Goose grass	<i>Eleusine indica</i>
	Yellow foxtail	<i>Setaria glauca</i>
	Love grass	<i>Eragrostis tenella</i>
	Crab grass	<i>Digitaria sanguinalis</i>
	Itch grass	<i>Rottboelia cochinchinensis</i>
	Johnson grass	<i>Sorghum halepense</i>
	Bermuda grass	<i>Cynodon dactylon</i>
Broadleaved	Horse purselane	<i>Trianthema partulacastrum</i> / <i>T. monogyna</i>
	False amaranth	<i>Digera arvensis</i>
	Pig weed	<i>Amaranthus viridis</i>
	Spurge	<i>Euphorbia hirta</i>
	Stone breaker	<i>Phyllanthus niruri</i>
	White cock's comb	<i>Celosia argentea</i>
	Bill goat weed	<i>Ageratum conyzoides</i>
	Day flower	<i>Commelina benghalensis</i>
Sedges	Purple nutsedge	<i>Cyperus rotundus</i>
	Yellow nutsedge	<i>Cyperus esculentus</i>
<i>Rabi</i>		
Grasses	Little seed canary grass	<i>Phalaris minor</i>
	Wild oat	<i>Avena ludoviciana</i>
	Annual blue grass	<i>Poa annua</i>
Broad-leaved	Field bind weed	<i>Convolvulus arvensis</i>
	Common lambsquarter	<i>Chenopodium album</i>
	Wild senji	<i>Melilotus indica</i> / <i>M. indica</i>
	Swine cress weed	<i>Coronopus didymus</i>
	Pimpernel	<i>Anagallis arvensis</i>
	Aligator weed	<i>Alternanthera philoxeroides</i>

Weed management approaches

Weeds do not cause harm to maize equally all through the growing period. There are certain stages in crop growth cycle when weeds are more damaging to crop growth and yield. Usually early season weed competition is most detrimental, although weeds present at the later stages also cause yield loss and harvesting inconveniences, and add seed rains. The critical period of weed competition in maize is 30 to 60 days. Normally, to eliminate early weed competition, the planning should be done in such a way that boosts up the crop plants and provides better competition against weeds. Time of sowing influences weed competition. If initial flush of weeds germinating at one time is bypassed through manipulation of sowing, the crop germinates and acquires good growth under almost weed-free or less weedy environment. Maize sown 15 days before the onset of usual monsoon rains with pre-sowing irrigation has a better competitive edge against the weeds. Closer spacing suppresses the growth

of weeds, leading to reduced infestations. Similarly, varieties / hybrids with better initial vigour also tend to suppress the growth of weeds.

Conventional practices

Traditionally maize fields are subjected to hoeing, interculturing (haloding) and earthing-up during the initial stages (up to about one month) when the weeds are also removed. With increasing labour scarcity and arduous nature of these operations, weeding is often ignored or delayed resulting in considerable loss of productivity. In view of this, use of chemicals is becoming popular due to their quick response, control

of problem weed flora, and less cost compared with manual operations.

Atrazine is one of the early herbicide discovered in the 1950s and still widely used as pre-emergence application. This provides control of most broad-leaved species and some grassy weeds appearing in the early stages of growth. Atrazine can also be applied as sand-mix if there is sufficient moisture at sowing (Table 2). To ensure broad-spectrum weed control, tank-mix application of atrazine and pendimethalin or alachlor is also suggested because pendimethalin or alachlor takes care of the grassy weeds which are otherwise not controlled by Atrazine. that cannot be used when maize is intercropped with any other broad-leaved crop like legumes or vegetables. For such situations, use of pendimethalin or alachlor alone is recommended.

Pre-emergence herbicides provide control of weeds for 20-25 days of growth, while the weeds keep emerging even after that due to congenial conditions of soil moisture, cloudy and humid weather in the rainy season. Therefore, a manual weeding is often needed after about a month to control the second flush of weeds, which may also not be feasible due to incessant rains. Although a herbicide like 2,4-D can be applied as post-emergence but it controls only the broad-leaved weeds and makes little impact on grassy species, which grow luxuriantly and inflict considerable losses. Moreover, 2,4-D cannot be used in maize-based intercropping systems. Another option is applying mulch biomass of pruned trees or crop residues, which may control the later flushes of weeds and thus avoid the need of post-emergence herbicide application in maize.

Table 2. Weed control in maize with pre- and post-emergence application of atrazine in Kandi area of Punjab

Treatments	Weed count at 30 days after sawing (no./m ²)	Weed dry weight at 30 days after sawing (g/m ²)	Grain yield (tonne/ha)
Unweeded	101	78.7	2.14
Atrazine (pre-emergence spray)	33	8.3	2.54
Atrazine (pre-emergence sand-mix)	36	4.8	2.53
Atrazine (Post-emergence, spray)	16	8.8	2.50
Atrazine (post-emergence, sand-mix)	21	12.2	2.52

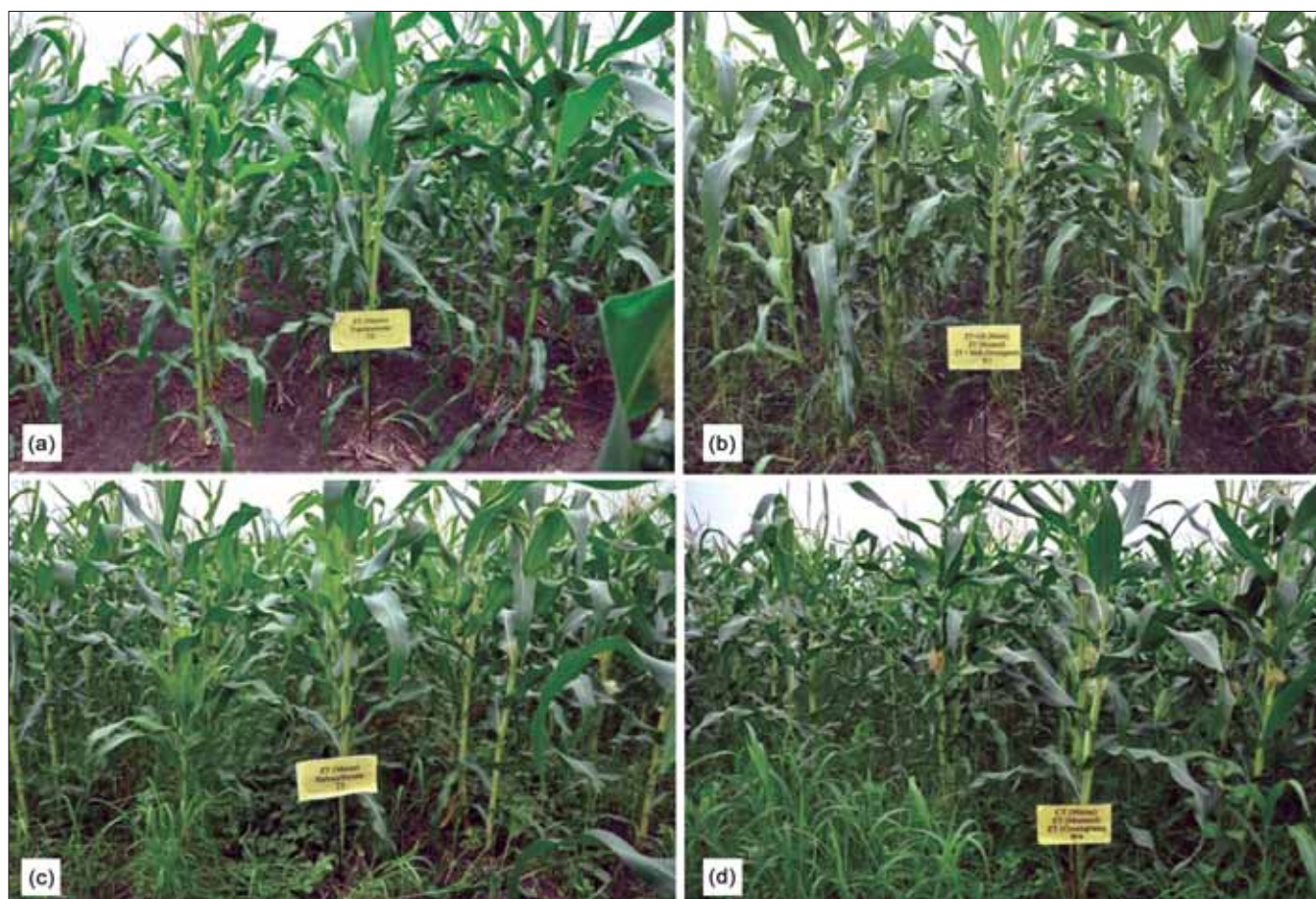


Fig. 1. Relative efficacy of new low-doses high-potency post-emergence herbicides in zero-till maize at Directorate of Weed Research, Jabalpur (a) Topramezone@ 25.2 g/ha ensured weed-free conditions, (b) Tembotrione @ 60-100 g/ha was also equally effective, but some grassy weeds re-emerged later, (c) Halosulfuron @ 60 g/ha gave complete control of *Cyperus* spp. but was less effective against grass and broad-leaved weeds, (d) Unweeded control

New low-dose high-potency herbicides

Management of grassy weeds appearing late in the season is a serious issue concerning most maize growers. Till now, no post-emergence herbicide was available to control grassy weeds in maize. It was however, suggested to control these weeds in the inter-row spaces with directed spray of paraquat when the maize plants have grown to sufficient height (about 1 m, at 40 days after sowing) and adequate care is taken during spraying using a hood and ensuring that no droplets of the herbicide solution fall on the maize leaves (Table 3). This requires expertise, and can cause injury, if due precautions are not taken during spraying.

After extensive research over the last 5-7 years, herbicides for post-emergence weed control, particularly of the grassy and sedges type identified, registered and recommended for general use in maize crop (Table 4). Tembotrione

and topramezone are particularly weed species and can be applied at effective against broad-spectrum 20-25 days of growth. Even a delayed

Table 3. Weed control in maize through directed spraying of paraquat at IARI, New Delhi

Treatments	Weed count at 60 days after sowing (no./m ²)	Weed dry weight at 60 days after sowing (g/m ²)	Grain yield (tonne/ha)
Unweeded	203	418.3	1.79
Atrazine (pre-emergence)	71	202.4	2.73
Atrazine (pre-emergence) + Hand weeding	132	118.6	3.24
Atrazine (pre-emergence) fb paraquat as directed spray at 40 days after sowing	15	106.6	3.19

Table 4. Effect of new low-dose high-potency post-emergence herbicides on weed growth and yield of maize at Directorate of Weed Research, Jabalpur

Treatments	Weed count at 60 days after sowing (no./m ²)	Weed dry weight at 60 days after sowing (g/m ²)	Grain yield (tonne/ha)
Unweeded	303.9	378.1	3.20
Atrazine + Pendimethalin (pre-emergence) fb Hand weeding	128.7	82.7	5.24
Atrazine + pendimethalin (pre-emergence) fb 2,4 D (post-emergence)	99.3	102.5	4.92
Tembotrione (post-emergence)	105.9	111.8	5.05
Topramezone (post-emergence)	55.3	51.2	5.30
Halosulfuron (post-emergence)	120.3	133.6	5.00



Fig. 2. Manual weeding in maize is highly laborious and costly, (b) Stale seed-bed by dhaincha manuring before seeding zero-till maize, (c) Weed-free crop with tembotrione (in front) and weedy plot (in the back), (d) Topramezone application resulting in whitening of grassy weeds

application of topramezone (35-40 days) was found to check the growth of established weeds without any harm to the maize crop. Both of these herbicides cause typical toxicity symptoms on the leaves of grassy weeds, render the green tissue dechlorophyllous and whitening of the leaf blade. It is also suggested to apply these chemicals in combination with atrazine to ensure broad-spectrum weed control in maize. In that case, pre-emergence application of atrazine can be dispensed with, if no serious early weed infestation is anticipated. Halosulfuron-methyl is another herbicide which can also be used in maize as post-emergence application. This herbicide is particularly more effective against *Cyperus* and can suppress its growth even leading to complete kill, if applied early in the season.

Zero-till maize

Cultivation of zero-till maize is being advocated in view of the emerging concerns of resource

degradation, higher cost of cultivation and also growing weed infestations. Efficient weed management under zero-till conditions is known to reduce weed infestations over time and lessen the use of chemicals. There has been a virtual revolution in zero-till maize in rice-growing areas of coastal Andhra Pradesh where the growers were previously cultivating black gram or green gram with yields <1 tonne/ha and now harvesting up to 10 tonne/ha of maize. Weeds do cause damage under zero-till conditions and the problem can be even more serious, if allowed unchecked than conventional tillage conditions.

If there are previously growing weeds of any species in the field at the sowing, these must be killed before sowing of maize by using a non-selective herbicide like paraquat or glyphosate. In some situations, there may also be the problem of rice sprouts from the root stubbles which start emerging after rice harvest and interfere with maize growth. In such

situations also, pre-sowing application of these herbicides is essential. However, these herbicides make no effect on the weeds that emerge after sowing, for which, the recommended weed control measures as suggested earlier should be adopted. Retention of at least a part of the crop residues on soil surface has added advantage of soil moisture conservation and temperature moderation besides suppression of weed growth.

Contrary to the conventional thinking to provide 7 to 10 days between the application of non-selective herbicides and before sowing, it was found that maize seed can be sown almost immediately after the application of herbicide with no injury to the germinating seed. This is because paraquat and glyphosate act on the green foliage of plants and become inactive after contact with the soil.

Green manuring in zero-till maize

Green manure crops of *dhaincha*,

Table 5. Weed control through herbicides and brown manuring in maize at IARI, New Delhi

Treatments	Total weed population (no./m ²)*	Weed control efficiency (%)	Grain yield (tonne/ha)
Weedy check	15.2 (231.3)	0.0	2.53
Weed-free	0.7 (0.0)	100.0	4.12
Atrazine + pendimethalin (tank-mix Post-emergence)	8.4 (70.3)	69.6	3.65
Atrazine fb hand weeding	7.1 (50.0)	78.4	3.53
Atrazine + crop residue mulch	8.8 (77.7)	66.4	3.76
Brown manuring (<i>Sesbania</i> co-culture fb 2,4-D)	8.8 (82.0)	64.6	3.29

Source: Susha *et al.* (2014), Data in parentheses are SQRT transformed values

sunnhemp or cowpea can be grown before sowing or along with the maize crop for controlling weeds as well as providing N supply to the crop. Growing these legumes before sowing also results in weeds seed germination, which are cut along with legume plants at about 30 days of growth. This acts as a stale seedbed and zero-till maize can be grown successfully after the

application of a non-selective herbicide. Brown manuring involves sowing of maize along with a fast-growing legume like *dhaincha*, sunnhemp or cowpea, and knocking down the legume after about 30 days either by using a selective herbicide like 2,4-D (Table 5). This ensures early coverage of the ground through quick development of canopy of the legume and suppression of weed

growth. Further, this practice also checks soil erosion, conserves moisture and provides nutrients after decomposition of the biomass. The seeds of green manure crops can be sown @ 15 to 20 kg/ha in the inter-row spaces of maize either through broadcasting or in rows spaced at 15-20 cm. A spray of pendimethalin after sowing checks the growth of grassy weeds. Green manure crops grow faster than maize and soon cover the ground. A uniform and blanket spray of 2,4-D at about 30 days of growth knocks down the legume without harming the maize plants. The legume may provide about 1.0 tonne/ha biomass (dry weight) containing 30-40 kg N/ha, which benefits the subsequent crop as well.

Precautions

A number of herbicides are now

Table 6. Herbicide recommendations in maize for effective weed control

Herbicides	Brand name/ formulation	Dose (kg ai/ha)	Dose (kg product/ ha)	Time of application	Cost of herbicide (₹/unit)	Remarks
<i>Pre-sowing</i>						
Paraquat	24% SL: Gramoxone	0.5	2.08	Before sowing in ZT maize, or as protected spray at knee-high stage	400/litre	Kills all monocot and dicot weeds
Glyphosate	41% SL: Round-up, glycil, no-weed	0.75	1.82	Before sowing in ZT maize, or as protected spray at knee-high stage	400/litre	Kills all monocot and dicot weeds
<i>Pre-emergence</i>						
Atrazine	50% WP: atrataf, solaro, dhanuzine,	1.0	2.0	Within 2-3 days or even after sowing up to 15 DAS	400/kg	Basically a broad-leaved killer; no control of <i>Acrachne</i> , <i>Commelina</i> and sedges.
Pendimethalin	38.7% CS: stomp extra, pendigold, stop, penda, dhanustomp, speed	0.75	1.94	Within 2-3 days after sowing	500/litre	Most grasses and some broadleaved weeds. Does not control sedges, <i>Digera</i> , <i>Parthenium</i> effectively
Alachlor	50% EC: Lasso	1.5	3.0	Within 2-3 DAS	500/litre	Most grasses and some broad-leaved weed species
<i>Post-emergence</i>						
2,4-D	Na salt: 80% WP (Weedmar, fernoxone, safaya); Amine salt: 58% SL (champion, heera, twister) and Ethyl-ester: 38% EC (slash, weedmar, heera, hit)	0.75-1.00	As per the formulation	20-25 days after sowing	350/kg	Broadleaved weeds and some sedges
Tembotrione	42% SC: Laudis	0.10	0.24	20-25 days after sowing	1,600/24 g	Broad-spectrum weeds control including <i>Cyperus</i> and <i>Cynodon</i>
Topramezone	33.6% SC: Tynzer	0.025	0.075	20-25 days after sowing	1,600/75 g	Broad-spectrum weed control
Halosulfuron-methyl	75% WG: Sempra	0.060	0.080	20-25 days after sowing	2,000/pkt	Kills mostly sedges and some grassy / broad-leaved species

ZT, Zero tillage

available for weed control in maize, which can be applied before sowing, as pre-and post-emergence applications depending on the infestation of specific weed flora (Table 6). Considering the various emerging practical problems in weed management, the use of herbicides is gaining popularity although other methods of weed control should also not be lost sight of. It is equally or even more important to give emphasis on preventive weed management so that the costs for actual control of weeds in the field can be minimized.

SUMMARY

The use of herbicides in the present context appears to be indispensable but these chemicals need to be applied judiciously for effective weed control that through

herbicides requires technical expertise and experience. The following precautions must be observed:

- It is essential to ensure adequate soil moisture at the application of pre-emergence herbicide like atrazine and pendimethalin.
- Directed spray of paraquat should be undertaken by using a hood with utmost care when the maize plants have reached about 1 m height and the inter-row weeds are trampled to the ground level.
- Ensure at least 3-4 hours of bright sunshine after the application of post-emergence herbicide so that it is absorbed and translocated into the weed plant system.
- Atrazine can also be applied as tank-mix along with tembotrione or topramezone as early post-emergence (15-20 days after sowing) in case there is no serious

problem of early infestation of weeds.

- Pre-sowing application of non-selective herbicides like paraquat and glyphosate is essential in case there are previously growing weeds in the field at sowing of zero-till maize.
- Never apply 2,4-D when maize was intercropped with any other broad-leaved crop like legume, oilseed or vegetable. Such crops grown in the vicinity of maize may also be affected by the spray drift of 2,4-D.
- Do not apply 2,4-D as post-emergence when the maize is largely infested with grassy weeds.

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AGRICULTURE SINCE INDEPENDENCE

Nearly 50 years ago, a panel of experts in the agriculture field met in Italy (called the club of Rome) and predicted massive food shortages and death due to hunger. In India their predictions were supported by the then data which indicated that after 1947 (since Independence) the agriculture output fell a way short of the demand for food. Indian resilience proved them wrong.

Today, India is the largest producer of milk (128 million tonne) second largest producer of rice (over 100 million metric tonne), wheat over 90 million tonnes, sugar 25 million tonnes, cotton 34 million bales and fruits and vegetables, over 200 million metric tonnes. Besides, it is a significant producer of a variety of spices, plantation crops, poultry and fishery products. How did all this come about? The government support was there but not enough. Green Revolution, a process which improved the food production significantly and developed with the support of the Indian Scientists likes of the caliber of Dr M. S. Swaminathan and Dr Kurien played a very big role in achieving this near self sufficiency. Currently agriculture accounts for 15% of India's GDP, employs about 55 % of the work force and contributes to around 10% of exports. Unfortunately once we reached a certain level of output our government had become complacent. Funding all activities of agriculture like the subsidies have become a political issue. It is myopic and hurting. Our last year agriculture growth is less than 2 percent. The question to debate is not what has gone wrong, what needs to be done to make our country free of poverty and hunger. Several challenges exist like land constraints, water shortage, climate change, low productivity. To handle this we need to encourage the research and development in agriculture in a big way. If Israel can use their scanty rain filled desert land to produce oranges and tomatoes, why can't we do it? Yes we can if we put our minds to it.

Financial Year 2014 is a blessed year as far as agriculture is concerned. With copious flow of rains bumper harvest is possible with all time high food production exceeding 260 tonnes are all reasons to celebrate. But we can't forever count on our luck. We need to take advantage of all our blessings.

There are several advantages in favor of India like abundant sunshine for 270 days, nearly 90 cm of monsoon rain during June-Sept every year, 8000 km of coast line, hundreds of crisis crossing rivers, extraordinary bio diversity, availability of adequate labor force and a resilient spirit.