

Weed dynamics and management

in conservation agriculture: challenges and way forward

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Conservation Agriculture is a concept of resource-saving agricultural crop production system that strives to achieve maximum acceptable profits together with high and sustained production levels, while concurrently conserving the environment. It is based on the practical application of three inter-linked principles: continuous zero or minimum mechanical soil disturbance by direct planting, permanent vegetative soil cover or mulch to protect the soil surface, and diversification of cropping systems including legumes. Conservation Agriculture systems require a total paradigm shift from conventional agriculture with regard to management of crops, soil, water, nutrients, weeds, and farm machinery. Weed management is a major challenge in Conservation Agriculture. Crop husbandry practices, such as sowing practices, tillage, weed control options, fertilizations, residue management, cropping systems, and inputs usages influences weed infestation and their preponderance/virulence. Continuous adoption of one or few practices may increase or decrease the infestation of certain or some weed species, and weed diversity may show a gradual change in course of time.

Key words: Agriculture, Conservation Agriculture, Management, Weed Dynamics

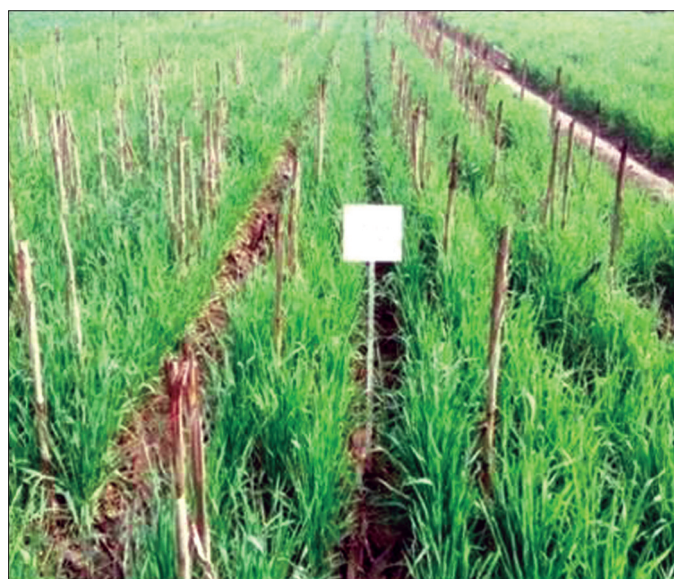


Fig 1. Wheat under zero tillage permanent narrow bed with maize residue



Fig 2. Brown manuring in rice

Conventional agricultural practices have led to degradation of soil resource base with a concomitant reduction in crop production capacity. The resource

degradation problems *vis-à-vis* the need for reducing production costs, increasing profitability and making agriculture more competitive, have made the conservation issues more

imperative. Conservation agriculture can help in reducing many negative effects of conventional agriculture such as soil erosion, soil organic matter decline, water loss, soil

physical degradation, and fuel use. It helps to improve biodiversity in natural as well as agro-ecosystems. Combined with other good agricultural practices like quality seeds, integrated pest, nutrient and water management, Conservation agriculture can provide higher productivity than traditional intensive tillage systems with substantially lower production.

Weeds in conservation agriculture

Zero tillage causes a paradigm shift in weed germination and growth, and requires a clear understanding for formulating a strategy for their management. Certain weed species germinate and grow more profusely than others under continuous Zero tillage system. As a consequence, a weed shift occurs due to the change from conventional tillage to Zero tillage system. Weed shifts towards perennials were observed in *Conservation Agriculture* systems. Perennial weeds thrive in reduced or no-till systems because the root system is not disturbed and herbicides used to control annual weeds are not so effective against perennial weeds. Perennial monocots like *Cyperus rotundus* (Purple nutsedge), *Saccharum spontaneum* (Tiger grass), *Cynodon dactylon* (Bermuda grass) and *Sorghum halepense* (Johnson grass) reproduce from underground vegetative structures, tubers, rhizomes, stolon, corms etc. Perennial dicots weeds such as *Polygonum plebejum/aviculare* (Indian knotweed), *Alternanthera philoxeroides* (Alligator weed) were observed in continuously Conservation Agriculture plots under rice-wheat system and *Sonchus arvensis* (Sow thistle) infestation under Conservation agriculture -based rice-mustard system. Annual weed shifts towards small-seeded ones is generally observed under Conservation agriculture systems. But, *Phalaris minor* although has small seeds, is reduced gradually under Zero tillage compared to Conventional tillage system in the Indo-Gangetic Plains. This may be attributed to: (i) higher soil strength in Zero tillage because of crust development in the absence of tillage, which can impede seedling

emergence, (ii) less soil temperature fluctuation under Zero tillage, or (iii) relatively lower levels of light stimuli, N mineralization and gas exchange under Zero tillage.

WEED MANAGEMENT

There are several ways for weed management. Some of them are discussed here.

Prevention of weed seed rains

Preventive methods of weed control are equally or even more important than curative measures under conservation agriculture. Several ways to reduce seed rains, which add to the seed bank are:

(i) use of certified seeds or clean seeds free of weeds; (ii) minimize the weed entry and establishment in a new area; (iii) prevent invasive and alien weeds; (iv) cleaning of farm implements and machineries before and after use; (v) application of well rotten compost, and (vi) cleaning of farm bunds. Even after practising weed control, some weeds escape and can produce a large number of seeds with variable dormancies, which can further reduce yields or increase weed management costs in subsequent years. Attention should also be given to preventing seed production from weeds growing during the fallow period (between harvesting and seeding of next crop) and on bunds and channels.

Stale seed bed technique

In the Stale seed bed technique, weed seeds are encouraged to germinate and then killed by non-selective herbicide (paraquat, glyphosate, and glufosinate). This technique is effective not only in reducing weed emergence during the crop season but also in reducing the weed seed bank. This technique is most effective against: (i) weed seeds present in top soil, (ii) weeds having low initial dormancy, and (iii) weed seeds requiring light to germinate. Susceptible weed species include *Cyperus iria*, *Digitaria ciliaris*, *Eclipta prostrata*, *Leptochloa chinensis* and *Ludwigia hyssopifolia*.

Adjusting sowing time

Due to dormancy, many weeds

germinate during specific seasons. If the approximate date of emergence is known for problem weeds, sowing time can be adjusted so that either

(i) the crop emerges before the weeds for a competitive advantage, or (ii) weeds are allowed to germinate and are controlled before or during crop planting. Planting earlier by even a few days can give the crop a significant competitive advantage over weeds. The potential weed suppression offered by early sowing of wheat is demonstrated by the case of *Phalaris minor* in rice-wheat systems (Fig. 1). Adoption of zero tillage permitted wheat sowing 1–2 weeks earlier, allowing the crop to establish before emergence of the still dormant *Phalaris minor*.

Bed planting

Bed planting is growing of crops on the raised-beds alternated by furrows for conserving inputs like seed, fertilizer, water etc. Beds are usually made at 0.6–1.2 m apart, and 2–3 rows of crops are sown on the beds and irrigation water is applied in the furrows (Fig. 2). Close growing of crops, particularly wheat on the beds reduces weed emergence and competition. The height of beds is maintained at about 15 to 20 cm and having a width of about 40 to 70 cm depending on the crops. In case of wheat around 40 cm bed width is maintained and generally 2–3 rows are sown. The furrow width is generally 30 cm. The bed planting conserves resources and reduces cost of cultivation, saves water by 20 to 30%, increases fertilizer-use efficiency, leads to better management of weeds like *Phalaris minor*, and increases yield by 10 to 20%.

Cultivar selection

The varieties for conservation agriculture should be quick-growing in nature so that they have early seedlings establishment to smother weeds. They should be more competitive with weeds by virtue of their plant architectures. Designing breeding programme to select for competitive ability under conservation agriculture is challenging due to the complexity of

characteristics and large variation between location and year. Two wheat varieties (HDCSW 18 and HDCSW 16) were developed at IARI for conservation agricultural-based cropping systems.

Brown manuring

Another approach that showed promise for suppressing weeds in Zero tillage is brown manuring (Fig. 3). In this system, both the main crop of rice or maize and *Sesbania* are sown together and allowed to grow for 25 to 30 days. Then, subsequently co-culture *Sesbania* crop is knocked down with 2,4 D at 500 g/ha in both maize (*Zea mays*) and rice and bispyribac-Na at 20 g/ha in rice. It resulted in almost 50% reduction in weeds population. Brown manuring reduces infestations of problematic *Cyperus rotundus* considerably.

Crop rotations

Rotating crops having dissimilar life-cycles or cultural conditions so as to break the cycle of the weeds is among the most effective of all weed control methods. Rice-fallow-sugarcane-ratoon sugarcane-sunflower- rice-wheat-sugarcane is a 4-year rotation, common in the north-east districts of Haryana. This rotation offers little opportunity for *Phalaris minor* to proliferate. Other rotations include rice-potato-sunflower, rice-mustard-sugarcane and rice-potato-onion. (*Allium cepa*). Inclusion of berseem (*Trifolium alexandrinum*) in the rice-wheat cropping system helps to reduce seed bank of *Phalaris minor* within a lesser period of time because the emerged plants of *Phalaris minor* were cut with each cutting of berseem and these were not given any opportunity to set and shed seeds in field.

Chemical weed management

Conservation agriculture system is fully dependent on herbicides and agronomic practices for controlling weeds. Usually, less persistent, non-selective herbicides like glyphosate, paraquat or glufosinate-AM are recommended before crop sowing for ensuring weed-free conditions for crop germination. Besides, a pre-emergence herbicidal treatment is required to control flushes of annual weeds coming up with the germination of crops. Selective post-emergence herbicides, if available may be applied at recommended doses at an appropriate crop growth stage depending on the weed intensity. To reduce the herbicide build-up in conservation agriculture systems, non-chemical options must also be integrated with herbicides with an emphasis on increasing the competitiveness of crop against

Table 1. Promising herbicides for weed control in different field crops under conservation agriculture

Herbicides	Doses (g/ha)	Time of applications	Remarks
Rice			
Pendimethalin	1,000 to 1,500	2-3 days after sowing/ days after treatment (DAT)	Broad-spectrum control of annual grasses and some broad-leaved weeds. Ensure sufficient moisture at the time of application. Does not control sedges, <i>Digera arvensis</i> , and <i>Parthenium hysterophorus</i> effectively.
Oxadiargyl	80-90	Pre-em (3-5 days after sowing/DAT) or early post-em (15-20 DAT)	Broad-spectrum control of weeds; Do not spray, if rains expected within 6 hr. Could be used under surface sown direct-seeded rice using drum seeder.
Pretilachlor (S)	750	Pre-em (3-days after sowing)	Broad-spectrum control of weeds
Pyrazosulfuronethyl	25–30	20–25 days after sowing/DAT	Annual grasses and some broad-leaved weeds
Azimsulfuron	35	20 days after sowing/DAT	Annual grasses, sedges and some broad-leaved weeds
Bispyribac-Na	25	15–25 days after sowing/DAT	Annual grasses and some broad-leaved weeds
Cyhalofop-butyl	100	Post-em (20-30 days after sowing)	Good control of grassy weeds; Apply if field dominated by grassy weeds.
Chlorimuron-ethyl + metsulfuron-methyl	4	15 to 20 days after sowing/DAT	Annual broad-leaved weeds and sedges
2,4-D	750	20 to 25 days after sowing/DAT	Annual broad-leaved weeds and sedges
Ethoxysulfuron	20 to 22	Pre-em (3 to 5 DAT) or early post-em (15-20 DAT)	Broad-spectrum control but mostly broad-leaved weeds
Wheat			
Clodinafop propargyl	60	30 to 35 days after sowing	Annual grasses, specially wild oat and <i>Phalaris minor</i>
Sulfosulfuron	25	Post-em (30 to 35 days after sowing)	Broad-spectrum weed control; can control resistant <i>Phalaris minor</i> .
Clodinafop propargyl + metsulfuron methyl	60 + 5	Post-em (30 to 35 days after sowing)	Ensures broad-spectrum weed control; clodinafop controls resistant <i>Phalaris minor</i> .
Clodinafop-propargyl+ carfentrazone-ethyl	60+20	Post-em (30 to 35 days after sowing)	Ensures broad-spectrum weed control; clodinafop controls resistant <i>Phalaris minor</i> .
Sufosulfuron + metsulfuron	25 + 2	25 to 30 days after sowing	Annual grasses and broad-leaved weeds
Mesosulfuron+idosulfuron	12 + 24	20–25 days after sowing	Annual grasses and broad-leaved weeds
Isoproturon + metsulfuron	1,000 + 4	20–25 days after sowing	Annual grasses and broad-leaved weeds
2,4-D	500–750	20–25 days after sowing	Annual broad-leaved weeds and sedges

Contd.

Table 1. (Continued from page 16)

Herbicides	Doses (g/ha)	Time of applications	Remarks
Maize			
Atrazine	1,000-1,500	Pre-em (1-2 days after sowing) or early post-em (15-20 days after sowing)	Broad-spectrum control of weeds; Does not have effective control against <i>Acrachne racemosa</i> , <i>Commelina beghalensis</i> and sedges
Pendimethalin	1,000-1,500	Pre-em (1-2 days after sowing)	Broad-spectrum control of annual grasses and some broad-leaved weeds. Ensure sufficient moisture at the time of application. Does not control sedges, <i>Digera arvensis</i> and <i>Parthenium hysterophorus</i> effectively
Metolachlor	1,000-1,500	Pre-em (1-2 days after sowing)	Controls a broad-spectrum of weeds, mainly grasses
Atrazine + Pendimethalin (Tank-mix)	750+750	Pre-em (1-2 days after sowing)	Controls a broad-spectrum of weeds and can render maize field almost free of weeds, except sedges.
Atrazine + metolachlor (Tank-mix)	1,000+1,000	Pre-em (1-2 days after sowing)	Controls a broad-spectrum of weeds and can render maize field almost free of weeds except sedges.
Atrazine fb tembotrione (resp.)	1,000 and 100	Pre-em (1-2 days after sowing)+ Post-em (25-30 days after sowing)	Controls a broad-spectrum of weeds and can render maize field almost free of weeds including edges
2,4-D	750	Post-em (30-35 days after sowing)	Controls broad-leaved weeds and few sedges.
Soybean			
Pendimethalin	1,000	Pre-em (1-2 days after sowing)	Broad-spectrum control of annual grasses and some broad-leaved weeds. Ensure sufficient moisture at the time of application. Does not control sedges, <i>Digera arvensis</i> and <i>Parthenium hysterophorus</i> effectively
Metribuzin	300-400	Pre-em (1-2 days after sowing)	Annual grasses and broad-leaved weeds
Imazethapyr	100	20–25 days after sowing	Annual grasses, broad-leaveds and sedge weeds
Pendimethalin + imazethapyr (Tank-mix)	750+100	Pre-em (1-2 days after sowing)	Broad-spectrum control of weeds including sedges, e.g., <i>Cyperus rotundus/esculentus</i>
Pendimethalin followed by (fb) imazethapyr	750 and 100 (resp.)	Pendi as pre-em (1-2 days after sowing) fb imazetha post-em (20-25 days after sowing)	Broad-spectrum control of weeds including sedges, e.g. <i>Cyperus rotundus/esculentus</i>
Pendimethalin followed by (fb) quizalofop-ethyl	750 and 50 (resp.)	Pendi as pre-em days after sowing) (1-2 fb quizalo post-em (20 to 25 days after sowing)	Broad-spectrum control of weeds, but quizalofop should be applied as post-em where grassy weeds are a problem, otherwise not.
Chlorimuron ethyl	9 to 12	15 to 20 days after sowing	Annual grasses, broad-leaved weeds and sedges
Fenoxaprop	80 to 100	20 to 25 days after sowing	Annual grasses
Fenoxaprop + Chlorimuron	80 + 9	20 to 25 days after sowing	Annual grasses and broad-leaved weeds
Pigeonpea and mungbean			
Pendimethalin	1,000 to 1,500	Pre-em (1-2 days after sowing)	Broad-spectrum control of annual grasses and some broad-leaved weeds. Ensure sufficient moisture at the time of application. Does not control sedges, <i>Digera arvensis</i> and <i>Parthenium hysterophorus</i> effectively
Pendimethalin followed by (fb) imazethapyr	750 and 100 (resp.)	Pendi as pre-em (1-2 days after sowing) fb Imazetha post-em (25-30 days after sowing)	Broad-spectrum control of weeds including sedges, e.g. <i>Cyperus rotundus/esculentus</i>
Pendimethalin followed by (fb) quizalofop-ethyl	750 and 50 (resp.)	Pendi as pre-em after sowing) fb (1-2 days quizalo post-em (25-30 days after sowing)	Broad-spectrum control of weeds, but quizalofop should be applied as post-em where grassy weeds are a problem, otherwise not.
Groundnut/ sunflower			
Pendimethalin	1,000	Pre-em (1-2 days after sowing)	Broad-spectrum control of annual grasses and some broad-leaved weeds. Ensure sufficient moisture at the time of application. Does not control sedges, <i>Digera arvensis</i> and <i>Parthenium hysterophorus</i> effectively
Imazethapyr (groundnut)	100	Post-em (20-25 days after sowing)	Broad-spectrum control of weeds including sedges, e.g., <i>Cyperus rotundus</i>
Oxadiazon (for sunflower)	500-1,000	Post-em (20-25 days after sowing)	Soil moisture is a pre-requisite for its activity

DAT, Days after treatment. Non-selective herbicides like paraquat and glyphosate should be applied prior to sowing to kill existing weeds

weeds. The use of herbicides for managing weeds is becoming popular because they are cheaper than conventional weeding methods, require less labour, tackle difficult-to-control weeds, and allow flexibility in weed management. Pre-emergence herbicides may not be as efficient in controlling weeds in conservation agriculture systems due to the presence of crop residues, which can bind to soil-applied herbicides and favour the weed seedlings to escape the applied herbicides. To overcome such problems, the following tactics may be adopted:

- Use of high volume rate at pre-emergence sprays.
- Use of higher dose of herbicide than normal to increase efficacy.
- Use of granular herbicide formulation for soil application.
- Use of broad-spectrum and non-selective herbicide during off-season to control perennial weeds.
- Post-emergence herbicides are more preferred than pre-emergence.

Several selective pre-emergence and post-emergence herbicides, some of which are low-dose and high-potency molecules are now available to effectively manage weeds in major field crops like rice, wheat, soybean, cotton, sugarcane, pulses and oilseeds under conservation agriculture (Table 1).

Herbicide-tolerant crops

Herbicide-tolerant crops facilitate adoption of no-till practices in selected crops, but may restrict crop rotations. Herbicide-tolerant crops must be grown in conjunction with other weed control methods, particularly rotational use of herbicidal mode-of-actions to avoid resistance. Herbicides such as glyphosate and glufosinate-AM being non-selective in nature provide complete control of weeds and the crops/ varieties being resistant remain completely safe from herbicidal ill-effects even though herbicide is applied across their growth stages. Therefore, traditional pre-emergence herbicides selective to that crop can

also be applied in herbicide-tolerant crops, if situation demands.

From 1996 to 2016, herbicide-tolerant crops have consistently occupied the largest planting area of biotech crops. In 2016, herbicide-tolerant crops occupied 86.5 million ha (~47%) of the 185.1 million ha of biotech crops planted globally. The most common are the glyphosate and glufosinate tolerant varieties. Adoption of biotech crops including herbicide-tolerant crops (185.1 million ha) and conservation agriculture-based technologies (157 million ha) grew hand-in-hand over the past 25 years. In fact, no other technology spread so fast as the biotech crops in a relatively short period of time. Despite some apprehensions, this technology had positive impacts on crop productivity and profitability. However, there is a problem of herbicide resistant weeds, which needs to be tackled through integrated weed management and new innovations in biotechnology. It is hoped that herbicide-tolerant crops will also become a reality in Indian agriculture after the anticipated concerns are suitably addressed.

Integrated weed management

A single isolated approach cannot be a fool-proof strategy for achieving desired level of weed control, if we consider weed problems under conservation agriculture systems. IWM is not meant to replace selective, safe and efficient herbicides but is a sound strategy to encourage judicious use of herbicides along with other safe, effective, economical and eco-friendly control measures. In fact, the three conservation agriculture principles are interlinked and interactive enough to counter/reduce weed problems in course of time. It would be wise, if approaches such as stale seed bed, uniform and dense crop establishment, cover crops, crop residues as mulch, crop rotations, and practices for enhanced crop competitiveness with a combination of pre- and post-emergence

herbicides are integrated to develop sustainable and effective weed management strategies under conservation agriculture systems. Therefore, a combination of different weed management strategies is needed to widen the weed control spectrum and efficacy for sustainable crop production.

SUMMARY

The levels of disturbance in habitat (tillage, mulching, fire, flooding, drought etc.) and changes made in the agronomic practices towards raising a crop may lead to changes in weed species over time. Weeds are ubiquitous, having a widerange of ecological amplitude that determines their adaptability. Conservation agriculture is a paradigm shift from conventional mode of agriculture. Continuous residue cover and no/minimal disturbance of soil under conservation agriculture provides specific micro-climate for weeds in crop fields and herbicide continues to be the sole option for weed control. Weed management remains crucial under zero-till residue-laden conditions. Application of higher dose of herbicides, granular formulations, non-selective herbicide during off-season, high volume rate for pre-emergence herbicide application and preferential application of post-emergence herbicides are required to increase the herbicide efficacy under conservation agriculture. However, an integrated weed management practice involving tillage, residue, cover crops, intercrops, herbicides would go a long way towards efficient weed management under Conservation agriculture.

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