Weed Management in Conservation Agriculture Systems

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Abstract

Adequate food production for ever-increasing global population can only be achieved through the implementation of sustainable growing practices that minimize environmental degradation and preserve resources while maintaining high-yielding profitable systems. Conservation agriculture practices are designed to achieve agricultural sustainability by implementation of sustainable management practices that minimize environmental degradation and conserve resources. Weeds are the major constraints in CA-based systems. Tillage affects weeds by uprooting, dismembering, and burying them deep enough to prevent emergence, by moving their seeds both vertically and horizontally, and by changing the soil environment and so promoting or inhibiting weed seed germination and emergence. Still There is a need to gain understanding on weed management as it is the major hindrance in CA-based crop production systems. Weed control in CA is a greater challenge than in conventional agriculture because there is no weed seed burial by tillage operations. Preventive measures are first and the most important steps to be taken to manage weeds in general and especially under CA as the presence of even a small quantity of weed seeds may cause a serious infestation in the forthcoming seasons. Considering the diversity of weed problems, no single method of weed control, viz. cultural, mechanical or chemical, could provide the desired level of weed control efficiency under CA. Therefore, a combination of different weed management strategies should be evaluated for widening the weed control spectrum and efficacy for sustainable crop production.

Keywords: Agriculture system, conservation, tillage, weed management

1. Introduction

Transformation of 'traditional animal-based subsistence farming' to 'intensive chemical and tractor - based conventional agriculture' has led to multiplicity of issues associated with sustainability of these production practices. Conventional crop production technologies have inculcated: (i) intensive tillage to prepare fine seed- and root-bed for sowing to ensure proper germination and initial vigour, improve moisture conservation, control weeds and other pests, mixing of fertilizers and organic manures, (ii) monocropping systems, (iii) clean cultivation involving removal or burning of all residues after harvesting leading to continuous mining of nutrient and moisture from the soil profile; and bare soil with no cover, (iv) indiscriminate use of pesticides, and excessive and imbalanced use of chemical fertilizers leading declining input-use efficiency, factor productivity and environmental, ground water, streams, rivers and oceans pollution, and (v) energy intensive farming systems.

2. Emerging Concerns

Green Revolution contributed to food security through increased food production and reduced volatility of foodgrain prices, and also demonstrated that agricultural development provides an effective means for accelerating economic growth and reducing poverty. But, post-Green Revolution input intensive conventional agriculture production systems have led to several global concerns, such as: (i) declining factor productivity, (ii) declining ground water table, (iii) development of salinity hazards, (iv) deterioration in soil fertility, (v) deterioration in soil physical environment, (vi) biotic interferences and declining biodiversity, (vii) reduced availability of protective foods, (viii) air and ground water pollution, and (ix) stagnating farm incomes.

2.1. Change in conventional agricultural systems

Widespread resource degradation problems under conventional system, and the need of reducing production costs, increasing profitability and making agriculture more competitive, have made the conservation issues more imperative. Globally innovations of conservation agriculture-based crop management technologies are said to be more efficient, use less inputs, improve production and income, and address the emerging problems. Additionally, secondary drivers, such as: (i) availability of new farm machinery, (ii) availability of new biocide molecules for efficient weed, insectpest and disease control, (iii) ever-decreasing labour force and ever-increasing labour cost, (iv) increasing production costs, energy shortages, erosion losses, pollution hazards and escalating fuel cost, and (v) residue burning, have accelerated change in thinking of researchers, policy makers and farmers to adopt modified methods for cultivation of crops aimed at improving productivity and resource-use efficiency.

2.2. Conservation agriculture- a new paradigm in crop production

Adequate food production for ever-increasing global population can only be achieved through the implementation of sustainable growing practices that minimize environmental degradation and preserve resources while maintaining high-yieldingprofitable systems. Conservation agriculture practices are designed to achieve agricultural sustainability by implementation of sustainable management practices that minimize environmental degradation and conserve resources while maintaining high-yieldingprofitable systems, and also improve the biological functions of the agro-ecosystem with limited mechanical practices and judicious use of external inputs. It is characterized by three linked principles, viz. (i) continuous minimum mechanical soil disturbance, (ii) permanent organic soil cover, and (iii) diversification of crop species grown in sequences and/or associations. A host of benefits can be achieved through employing components of conservation agriculture or conservation tillage, including reduced soil erosion and water runoff, increased productivity through improved soil quality, increased water availability, increased biotic diversity, and reduced labour demands.

2.3. Adoption of conservation agriculture systems

Conservation agriculture systems are being advocated since 1970s but it is only in the last 2 decades that the area has been increasing rapidly. This has been accelerated due to development of efficient farm machinery and availability of effective herbicides coupled trained manpower, which have resulted in reduced production costs and higher profitability, besides several indirect benefits. Presently, about 125 M ha area is practiced following the concepts and technologies for conservation agriculture; the major countries being USA, Brazil, Argentina, Canada and Australia.

Farmers of the developing countries have also initiated to practice some of the conservation agriculture technologies. According to available estimates, the resource conservation technologies are practiced in >3 M ha under the rice-wheat based system in the Indo-Gangetic plain. The major CA-based technology being adopted in this region is zero-till (ZT) wheat in the rice-wheat system; and it is now foreshadowing the age-old concept, popularly known as "more you till and more you harvest". Adoption and spread of ZT wheat has been a success story in north-western parts of India due to: (i) reduction in cost of production by ` 2000-3000 per ha, (ii) enhance soil quality i.e. soil physical, chemical and biological conditionsin the long-term, (iii) enhance C sequestration and build-up in soil organic matter, (iv)reduce incidence of weeds, such as *Phalaris minor* in wheat, (v) enhance water- and nutrient-use efficiency, (vi) enhance production and productivity, (vii) advance sowing date, (viii)reduce greenhouse gas emission and improve environmental sustainability, (ix) avoid crop residue burning, loss of nutrient, environmental pollution, reduces serious health hazard, (x) provide opportunities for crop diversification and intensification, (xi) enhance resource use efficiency through residue decomposition, soil structural improvement, increased recycling and availability of plant nutrients, and (xii) surface residues as mulch control weeds, moderate soil temperature, reduce evaporation, and improve biological activity.

2.4. Weed problems in CA

Weeds are the major constraints in CA-based systems. Tillage affects weeds by uprooting, dismembering, and burying them deep enough to prevent emergence, by moving their seeds both vertically and horizontally, and by changing the soil environment and so promoting or inhibiting weed seed germination and emergence. Any reduction in tillage intensity or frequency may, therefore, influence the weed infestation. The composition of weed species and their relative time of emergence differ between CA systems and soil-inverting conventional tillage systems. Some weed seeds require scarification and disturbance for germination and emergence. Their germination and emergence may be accelerated by the type of equipment used in soil-inverting tillage systems than by CT machinery.

Shifts in weed populations from annuals to perennials have been observed in CA systems. Perennial weeds are known to thrive in reducedor no-tillage systems. Most perennial weeds have the ability to reproduce from several structural organs other than seeds. For example, Bermuda grass (*Cynodondactylon*), nutsedge (*Cyperusrotundus*) and Johnson grass (*Sorghum halepense*) generally reproduce from underground plant storage structures: stolons, tubers or nuts and rhizomes, respectively. Conservation tillage may encourage these perennial reproductive structures by not burying them to depths that are unfavorable to emergence or by failing to uproot and kill them.Weed species shifts and losses in crop yield as a result of increased weed density have been cited as major hurdles to the widespread adoption of CA. Crop yield losses in CA due to weeds may vary depending on weed dynamics and weed intensity. However, the recent development of post-emergence broad-spectrum herbicides provides an opportunity to control weeds in CA. Crop yields can be similar for conventional and conservation tillage systems if weeds are controlled and crop stands are uniform. Results of on-farm trials at several locations in Haryana, India revealed that population density of *Phalaris minor* was considerably lower and grain yield of wheat was comparatively higher under zero tillage than conventional tillage.

In CA systems the presence of residue on the soil surface may influence soil temperature and moisture regimes that affect weed seed germinationand emergence patterns over the growing season.This shows that under CA system, farmers have to change the timing of weed control measures in order to ensure their effectiveness. Soil surface residues can interfere with the application of herbicides, so there is a greater likelihood of weed escapes if residue is not managed properly or herbicide application timings or rates are not adjusted.

2.5. Weed seed bank dynamics

The success of CA system depends largely on a good understanding of the dynamics of the weed seed bank in soil. A soil weed seed bank is the reserve of viable weed seeds present in the soil. The seed bank consists of new seeds recently shed by weed plants as well as older seeds that have persisted in the soil for several years. The seed bank in the soil builds-up through seed production and dispersal, while it depletes through germination, predation and decay. Different tillage systems disturb the vertical distribution of weed seeds in the soil, in different ways. Moldboard ploughing buries most weed seeds in the tillage layer, whereas chisel ploughing leaves most of the weed seeds closer to the soil surface. Similarly, depending on the soil type,60-90% of the weed seeds are located in the top 5 cm of the soil in reduced or no-till systems. As these seeds are at a relatively shallow emergence depth, they are likely to germinate and emerge more readily due to suitable moisture and temperature than those seeds which are buried deeper in conventional systems.

2.6. Weed management practices

There is a need to gain understanding on weed management as it is the major hindrance in CA-based crop production systems. Weed control in CA is a greater challenge than in conventional agriculture because there is no weed seed burial by tillage operations. The behaviour of weeds and their interaction with crops under CA tend to be complex and not fully understood. CA often causes weed shift resulting in increase in the density of certain weeds. The weed species in which germination is stimulated by light are likely to be more problematic in CA. In addition, in the absence of tillage, perennial weeds may also become more challenging in this system. Hence, effective weed control techniques are required to manage weeds successfully. In the past, attempts to implement CA have often caused a yield penalty because reduced tillage failed to control weed interference. However, the recent development of post-emergence broad-spectrum herbicides provides an opportunity to control weeds in CA.Various approaches being employed to successfully manageweeds in CA systems include: preventive measures, cultural practice (tillage, crop residue as mulches, intercropping, cover cropping, competitive crop cultivars, planting geometry, sowing time, nutrient management etc.), use of herbicide-tolerant cultivars, and herbicides.

2.7. Preventive measures

Weed seeds resembling the shape and size of crop seeds are often the major source of contamination in crop seeds. Contamination usually happens during the time of crop harvesting ifthe life cycles of crops and weeds are of similar duration. Preventive measures are first and the most important steps to be taken to manage weeds in general and especially under CA as the presence of even a small quantity of weed seeds may cause a serious infestation in the forthcoming seasons. The various preventive measures include: (i) using weed-free crop seed, (ii) preventing the dissemination of weed seeds or propagules from one area to another, (iii) using well-decomposed manure or compost so that it does not contain any viable weed seeds, (iv) inspecting nursery stock or transplants to prevent transplanting of weed seedlings from nursery to main field, (v) removing weeds near irrigation ditches and fence rowsprior to flowering, (vi) mechanically cutting the reproductive part of weeds prior to seed setting, and (vii) implementing stringent Weed Quarantine Laws to prevent the entry of alien invasive and obnoxious weed seeds or propagules in the region.

2.8. Cultural practices

A long-term goal of sustainable and successful weed management is not to merely control weeds in a crop field, rather to create a system that reduces weed establishment and minimizes weed competition with crops.Further, since environmental protection is a global concern, the age-old weed management practices, viz. tillage, intercultivation, intercropping, mulching, cover crops, crop rotation or diversification and other agro-techniques, which were once labeled as uneconomical or impractical should be relooked and be given due emphasis in managing weeds under CA. One of the pillars of CA is ground cover with dead or live mulch, which leaves less time for weeds to establish during fallow or a turnaround period. Some other common problems under CA include emergence from recently produced weed seeds that remain near the soil surface, lack of disruption of perennial weed roots, interception of herbicides by thick surface residues, and change in timing of weed emergence.

Laser land leveling is an integral component of CA as it provides uniform moisture distribution to the entire field and allows uniform crop stand and growth, leading to lesser weed infestation. On the other hand, unleveled fields frequently exhibit patchy growth of crops. The areas with sparse plant populations are zones of higher weed infestation. Weed management in laser leveled field is relatively easier and requires less labour and time for manual weeding operation due to lesser weed infestation than unleveled one. A reduction of 75% in labour requirement for weeding operation was reported due to precision land leveling.

2.9. Chemical weed control

Herbicides are an integral part of weed management in CA. Use of herbicides for managing weeds is becoming popular as it is cheaper than traditional weeding methods, requires less labour even to tackle difficult-to-control weeds, and allows flexibility in weed management. However, for the sustenance of CA systems, herbicide rotation and/or integration of weed management practices is preferable as continuous use of a single herbicide over a long period of time may result in the development of resistant biotypes, shifts in weed flora, and negative effects on the succeeding crop and environment. In CA, the diverse weed flora that came up in the field after harvesting of preceding crop must be killed by using non-selective herbicides like glyphosate, paraquat, or ammonium-glufosinate.Non-selective burn-down herbicides can be applied before or after crop planting but prior to crop emergence in order to minimize further weed emergence.

Unlike in conventional system, crop residues present at the time of herbicide application in CA systems may decrease the herbicide's effectiveness as the residues intercept the herbicide and reduce the amount of herbicide that can reach the soil surface and kill germinating seeds. Proper selection of herbicide formulations for application under CA may be necessary to increase its efficacy. For example, pre-emergence herbicides applied as granules may provide better weed control than liquid-formations in no-till systems. Some herbicides intercepted by crop residues in CA systems are prone to volatilization, photo-degradation, and other losses. The extent of loss, however, may vary depending upon their chemical properties and formulations. Herbicides with high vapour pressure, e.g. dinitroanilineherbicides are susceptible to volatilization loss from the soil surface. Climatic conditions and herbicide application methods may also have significant effect on herbicide persistence under CA systems. Crop residues canintercept the applied herbicides and this mayresult in reduced efficacy of herbicides in CA systems. Choosing an appropriate herbicide and appropriate timing is very critical in CA systems as the weed control under no-till systems varies with weed species and herbicides used. Several low-dose, high-potency, selective,post-emergence herbicides and mixtures are presently available in India for effectively managing weeds in crops like rice and wheat grown in sequence under CA.

2.10. Integrated weed management

Considering the diversity of weed problems, no single method of weed control, viz. cultural, mechanical or chemical, could provide the desired level of weed control efficiency under CA. Therefore, a combination of different weed management strategies should be evaluated for widening the weed control spectrum and efficacy for sustainable crop production. Integrated weed management system is basically an integration of effective, dependable and workable weed management practices that can be used economically by the producers as a part of sound farm management system. This approach takes into account the need to increase agricultural production, reduce economic losses, risk to human health and potential damage to flora and fauna, besides improving the safety and quality of the environment. Integrated weed management system is not meant for replacing 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. The use of clean crop seeds and seeders and field sanitation (weed-free irrigation canals and bunds) should be integrated for effective weed management. Combining good agronomic practices, timeliness of operations, fertilizer and water management, and retaining crop residues on the soil surface improve the weed control efficiency of applied herbicides and competitiveness against weeds. Approaches such as stale seedbed practice, uniform and dense crop establishment, use of cover crops and crop residues as mulch, crop rotations, and practices tor enhanced crop competitiveness with a combination of pre-and post-emergence herbicides could be integrated to develop sustainable and effective weed management strategies under CA systems.

3. Payoff-trade of Equilibrium in Adopting CA Systems

Conservation agriculture is not a panacea to solve all the agricultural production constraints, but offers potential solutions to scientists and farmers to break productivity barriers and sustain natural resources and environmental health. But, for wider adoption of CA, there is an urgent need for researchers and farmers to change the past mindset and explore these opportunities in a site- and situation-specific manner for local adaptation. The current major barriers in spread of CA systems can be summarized as: (i) lack of trained human resources at ground, (ii) non-availability of suitable machinery other than north-western India and no quality control mechanism in place for CA machinery, (iii) competing use of crop residues in rainfed areas, (iv) weed management strategies, particularly of perennial species, (v) localized insect and disease infestation, and (v) likelihood of lower crop productivity if the site-specific component technologies are not adopted. Several factors including bio-physical, socio-economic and cultural limits the adoption of this promising innovation by the resource-poor small land farmers of south and south-east Asia. Despite several payoffs, there are also many trade-offs to adoption of CA systems.

4. Conclusion

Conservation agriculture practices are designed to achieve agricultural sustainability by implementation of sustainable management practices that minimize environmental degradation and conserve resources. There is a need to gain understanding on weed management as it is the major hindrance in CA-based crop production systems. Considering the diversity of weed problems, no single method of weed control, could provide the desired level of weed control efficiency under CA. Therefore, a combination of different weed management strategies should be evaluated for widening the weed control spectrum and efficacy for sustainable crop production.

