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Weed Management Strategies in Direct Seeded Rice: A Review

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ABSTRACT

Rice (*Oryza sativa*) is a staple food of more than half of the population of the world and provides food security and livelihoods for millions of population. Direct seeding of rice (DSR) refers to the process of direct sowing the seeds in the field rather than by transplanting seedlings from the nursery. Direct seeded rice is an age old practice and before the introduction of green revolution in India. Rainfed rice was often broadcasted into moist soil and crops were highly prone to weed competition resulted into low yield. Rice ecosystems and establishment methods determined the weed spectrum and degree of infestation in rice field (DSR). Weeds are considered as a major biological constraint in direct seeded rice. In direct seeded rice, weed management depend on weed flora, critical period of weed control, availability of water and method to be adopted. Integrated weed management (IWM) is essential to achieve the long term, sustainable and economic management of weeds in direct seeded rice. The literature regarding the direct seeded rice, critical period of crop weed competition, different types of weed flora and different methods for the effective and sustainable management of weeds in direct seeded rice are reviewed in this paper.

Key words: Direct-seeded rice, IWM, Weeds, Weed flora, Weed management, Weed shifting.

Rice (*Oryza sativa* L.) is a major cereal crop is regarded as staple food by majority of world's population and about 90% of the world's rice is produced and consumed in Asia only (FAO, 2014). In India, it is grown on an area of about 43.66 m ha with a total production of 118.87 m t during 2019-20 (Anonymous, 2020-21). More than half of the world's population depends on rice for their daily sustenance (Chauhan and Johnson 2011a) and it is the primary source of income and employment for more than 100 million households in Asia (Singh *et al.,* 2016). To meet the world's increasing demand of rice in a sustainable way with shrinking natural resources is a great challenge. To ensure good crop establishment rice is predominantly grown by transplanting after puddling and kept flooded for most part of the growing season (Singh *et al.,* 2016) and it has been a major traditional method of rice establishment. Puddling adversely affects soil physical properties and requires a large amount of water, labour and more energy to achieve proper soil tilth for succeeding crops. Excessive pumping of water for puddling in most part of the rice growing areas, water table has been declining. Water scarcity in most of the rice growing areas of India and labour costs have increased dramatically due to migration of labours from rural areas to cities as well as non agricultural sectors of rural economy (Chauhan, 2012a and Singh *et al*., 2016). Production of rice with conventional transplanting method has been limited by a number of factors such as water scarcity, high input and labour costs, shortage of skilled labour resulting into low rice yield. In DSR system, dry rice seeds are sown with or without tillage and irrigation is applied periodically to maintain soil at field capacity.

Faster and easier planting, improve soil health, higher tolerance to water deficit, less methane emission and often higher profit in areas with an assured water supply (Kumar and Ladha 2011). Weed competition reduced multiple rice yield components and weed biomass in wet-seeded rice was six-fold greater that in rice transplanted into puddled soil and twice as much again in dry-seeded rice sown either after dry tillage or without tillage (Singh *et al*. 2011). Weed problem is sought to be addressed from two basic points of view: weed control and weed management. Weed control approach only emphasizes on reduction of weed pressure and in contrary the management approach focuses on keeping weed infestation at economic threshold level which are compatible with environmentally and economically sustainable production. Different weed control options are available for rice such as physical, chemical and biological control. Physical control is eco-friendly but labour intensive and delayed in weeding due to unavailability of sufficient labour in time. Biological control by using different bio-agents and mycoherbicides are practiced in irrigated lowland rice, but these may not be effective under aerobic soil conditions. Chemical control, on the contrary, is the most effective, economic and practical way of weed management (Hussain *et al.* 2008, Anwar *et al*. 2012a).

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Though, to overcome these challenges, direct seeding of rice (DSR) seems promising under several ecologies and production systems and is considered as viable and potential alternative to PTR (Puddled Transplanted Rice).

Yield losses due to weeds in DSR

Direct seeded rice (DSR) is a cost effective rice establishment method where dry seed are directly drilled into the unpuddled soil. It provides opportunities of saving irrigation water by 12-35%, labour up to 60% and provides higher net returns with at par yield than transplanted rice (Kumar and Ladha, 2011). In addition to higher economic returns, DSR is shorter duration, less labour intensive, consume less water (Bhushan *et al*. 2007) and have less methane emissions (Wassmann *et al*. 2004). Despite multiple benefits of dry direct seeded rice, weed control remains one of the major challenges for its success in South Asia (Kumar and Ladha, 2011; Rao *et al*., 2007; Singh *et al*., 2008). Weed control is more difficult in dry- DSR than conventional tillage (CT)- Transplanted rice (TPR) because weeds emerge with rice seedlings in dry–DSR which are less competitive than 30-35 days old rice seedlings use in CT- TPR and initial flooding used in CT-TPR helps in weed control but it is lacking in dry- DSR (Kumar and Ladha, 2011).

Weeds adversely affected yield, quality and cost of production as a result of competition for various growth factors in DSR system. Extent of loss due to weeds may vary depending upon cultural methods, rice ecosystems, management practices, cultivars, weed species and their association, growth rate, their density and duration of crop-weed competition. The weeds do compete with crop for various growth factors, *viz*. nutrients, moisture, light and space resulting into greatest loss (Walia 2006). Globally, actual yield losses due to pests have been estimated ~40%, of which weeds caused the highest loss (32%) (Rao *et al*. 2007). Yield reduction due to weeds is more critical in direct-seeded rice than in transplanted rice (Karim *et al*. 2004). Red rice (*Oryza sativa* f.sp. *spontanea*) is highly competitive and causes severe rice yield losses ranging from 15% to 100% (Farooq *et al*. 2009). On average, estimated losses from weeds in rice are around 10% of total grain yield; however, can be in the range of 30 to 90%, reduces grain quality and enhances the cost of production (Rao *et al*. 2007). Season-long weed competition in direct- seeded aerobic rice may cause yield reduction up to 80% (Sunil *et al*. 2010). On an average, yield loss, due to weed competition ranges from 15 to 20 per cent, but in severe cases it may exceed 50 per cent (Hasanuzzaman *et al*., 2009). In case of heavy infestation and extreme cases, weed infestation may cause complete failure of aerobic rice (Jayadeva *et al*. 2011). Thus direct-seeded aerobic rice is highly vulnerable to weeds compared with other rice ecosystems (Anwar *et al*. 2011).

Critical period of crop-weed competition

The critical period for crop-weed competition refers to the period from sowing of crop upto which it has to be maintained in a weed free environment for remunerative crop production. Weed control during the critical period is essential to reduce the weed competition and for effective utilization of available resources for enhanced productivity and profitability. Due to alternate events of wetting and drying and emergence of weeds and rice simultaneously, crop-weed competition is more severe in DSR than in transplanted rice. The severity of competition depends not only on competing species but also on its density, duration and the fertility status of the soil. In DSR, it is important to minimize the crop-weed competition during the early stages of the crop before it forms a closed leaf canopy (Singh 2008). In DSR, the critical period of weed competition has been reported to be 14- 41 days after sowing (Chauhan and Johnson, 2011b). Azmi *et al*. (2007) reported that critical period for weed control under mixed weed infestation in DSR was from 12 to 60 DAS. In aerobic rice cultivation, weed free condition during the initial crop growth period (upto 35 DAS) is critical which has the potential to reduce grain yield drastically.

Major weed flora in DSR

The DSR crop faces severe challenges from weeds and effective weed management is essential for successful rice production from DSR. About 350 species have been reported as weeds of rice, of which grasses are ranked as first posing serious problem followed by sedges and broad-leaf weeds causing major losses to rice production worldwide (Singh *et al*., 2016). In DSR, fields are dominated by different grasses, sedges and broad leaf weeds (BLW) and weed flora will vary depending on the season, climatic and edaphic conditions. Among major grassy weeds *Echinochloa colona* (L.), *Echinochloa crusgalli* (L.), *Leptochloa chinensis* (L.), *Oryza sativa* L. f. *spontanea* Roshev and *Ischaemum rugosum* Salisb causes major yield loss. *Echinochloa colona* and *E. crusgalli* are the most serious weeds affecting DSR. The density of these weeds in DSR depends upon moisture condition in the field. *E. colona* requires less water, so it is more abundant in DSR (Singh *et al*., 2016). Sedges causing major yield losses are *Cyperus iria, Cyperus difformis* L., *Schoenoplectus juncoides*. Broad-leaves weeds (BLW) causing major yield losses are *Eclipta prostrata* (L.), *Spheoclea zeylanica* Gaertner and *Ludwigia hyssopifolia* (G. Don.) Excell. Raj *et al*., (2013b) reported that in Kuttanad, during *kharif* season BLW predominate (39.3 per cent) followed by sedges (38.9 per cent) and grassy weeds (21.8 per cent) while in *rabi* season sedges predominate (96.8 per cent) followed by BLW (2.7 per cent) and grasses (0.5 per cent). During the first 30 days after sowing, broad-leaf weeds dominated the grassy weeds and sedges, contributing more than 62% of the total weed population. At later stages, grasses dominated over non-grasses and sedges, contributing more than 90% of the total weed population at 75 DAS, at which *E. colona* alone contributed more than 80% of the total weed population at 60 DAS and beyond (Singh 2008). Changes in crop establishment, from transplanting to direct seeding also resulted in marked changes in the composition of weed flora (Singh *et al*., 2008). Direct seeding increased the population of annual grasses such as *Echinochloa crusgalli*, *Echinochloa colona* and *Leptochloa chinensis*, perennial sedge *Cyperus rotundus* and BLW such as *Commelina diffusa* and *Caesulia axillaris* (Singh *et al*., 2008). Adoption of direct seeding technology may result in weed flora shifts towards more difficult to control and competitive grasses and sedges (Kumar and Ladha, 2011).

Weed management strategies in DSR

Weed prevention methods

This method restricts introduction and spread of weeds and is the most basic of all weed control methods (Buhler, 2002). It includes using weed-free seeds, maintaining clean fields, borders and irrigation canals and cleaning farm equipments (Datta and Baltazar, 1996). Rice seeds contaminated with weed seeds may introduce problematic weed species to a new field and enrich the soil weed seed bank. In addition to clean crop seed, the machinery used for tillage, sowing, harvesting, or threshing operations should also be cleaned before moving it from one field to another. Bunds and irrigation canals free from weeds may also help to reduce the spread of weed seeds through irrigation water (Hossain *et al*., 2016).

Cultural methods

Cultural practices play significant role to determine the crop-weeds competition for above ground and below ground resources and hence influence weed management (Grichar *et al*., 2004 and Dass *et al*., 2016). Some cultural practices like selection of cultivars, stale seedbed technique, tillage, seeding density, crop residue, crop rotation, intercropping, cover crops, fertilizer management and water management etc to be used in DSR could be a good alternative to control weeds.

(A) Land leveling

Land levelling is essential to achieve uniform crop stand before sowing. Levelling is usually done by using a wooden or metal board. However, laser land levelling ensures better crop establishment (Jat *et al*., 2009), precise water control and increased herbicide use efficiency (Chauhan, 2012a). Laser land levelling reduces the weed population by up to 40 per cent and the labor requirement for weeding by 75 per cent (Rickman, 2002) and 86.7 per cent compared to traditional method of land levelling (Banerjee, 2015).

(B) Selection of cultivars

Cultivars to be used in DSR could be a good alternative to control weeds. Rice cultivar having strong weed competitiveness is deemed to be a low cost safe tool for weed management in DSR (Gibson and Fischer, 2004). In general, tall and traditional cultivars with high tillering ability, high early growth rate, high leaf area index and specific leaf area, long leaves and droopy plant type are more weed suppression ability than short-statured early maturing, modern cultivars with erect leaves Early maturing rice cultivars and rice hybrids also have a smothering effect on weeds due to improved vigour and having the tendency of early canopy cover (Mahajan *et al*. 2011). Rice hybrids are more competitive and usually have better vigor than inbreds and effectively suppressed the infestation of *Echinochloa spp*. and helped reduce herbicide dependency (Gibson *et al*., 2001). Rice cultivars having good mechanical strength in the coleoptiles to facilitate early emergence of the seedlings under crust conditions (generally formed after light rains), early seedling vigour for weed competitiveness (Zhao *et al*., 2006), higher tiller number (Fischer *et al*., 1997), rapid canopy ground cover (Lotz *et al*., 1995) and yield stability over planting times are desirable traits for DSR. Rice cultivars having allelopathic effect can contribute to weed suppression. Kumar *et al*. (2013) reported that variety Gautam was highly competitive in suppressing the *Echinochloa spp* compared to the Prabhat and Krishna Hamsa.

(C) Stale seedbed technique

Stale seedbed technique is an important cultural practice and a method of weed control where weeds are allowed to germinate and the emerged weed seedlings are killed by shallow tillage or using a non selective herbicide that can be used to reduce the weed seed bank. Those weed species that have low initial dormancy and are present in the top soil layers are more conducive to be controlled by this practice, such as *Eclipta prostrate, Leptochloa chinensis, Ludwigia hyssopifolia* and *Digitaria ciliaris*. The use of the stale seedbed practice could also help to reduce the problems of some hard weeds, such as *Cyperus rotundus*, weedy rice and volunteer rice seedlings (Chauhan, 2012). Singh *et al*. 2009 reported 53% lower density in Dry- DSR after a stale seed bed than without this practice. Stale seedbed combined with herbicide (paraquat) and zero-till results in better weed control of *Cyperus iria, Cyperus difformis, Fimbristylis miliacea* (L.) Vahl, *Leptochloa chinensis* and *Eclipta prostrata* because of low seed dormancy of weeds and their inability to emerge from a depth greater than 1 cm (Chauhan and Johnson, 2008; Chauhan and Johnson 2010).

(D) Tillage

Tillage can affect weed species through the changes and disturbances in weed seed distribution in the soil. Primary tillage can reduce annual weed species, especially when planting is delayed to allow weed seeds to emerge before final tillage (Buhler and Gunsolus, 1996). On the other hand, zero tillage favors weed infestation. Conservation tillage has been criticized particularly in relation to lower yields and perennial weed problems which results in an increase in herbicide application (Singh *et al*. 2011). Zero tillage DSR had more equivalent yield than DSR CT. Another study recorded that the direct-seeded ZT gave at par yield as compared with transplanted (TP) rice (Singh *et al*. 2008).

Shallow tillage before crop emergence and post plant tillage after crop establishment help to remove annual weeds and inhibit the growth of perennial weeds (Buhler, 2002).

(E) Seed rate and spacing

Seed rate and spacing influence the weed population. Higher seeding rate of rice has been advocated not only for weed control but also for avoiding higher risk of poor seedling establishment (Anwar *et al*., 2011). Higher seeding rates would be beneficial if no weed control is planned or if only partial weed control is expected. A quadratic model predicted that seeding rates of 48- 80 kg/ha for the inbred varieties and 47-67 kg/ha for the hybrid varieties were needed to achieve maximum grain yield when grown in the absence of weeds, while rates of 95-125 kg seed/ha for the inbred varieties and 83-92 kg seed/ha for the hybrid varieties were needed to achieve maximum yields in competition with weeds. Such high seeding rates may be prohibitive when using expensive seed and maximum yields are not the only consideration for developing recommendations for optimizing economic returns for farmers (Chauhan *et al*. 2011). Weeds grown in wider rows may have greater biomass than weeds grown in narrow rows. Therefore, a direct-seeded crop should be grown using narrow row spacing to obtain faster canopy closure and less penetration of light and ultimately less weed growth (Chauhan, 2012b).

(F) Crop residue and *Sesbania* co-culture (Brown Manuring)

Crop residues have a chemical and physical effect on the growth of crops and weeds by reducing sunlight and modifying soil temperature. Seedlings of many weed species can be suppressed by using crop residue as mulches (Chauhan, 2012b). Growing *sesbania* as a green manure with rice is called brown manuring (*sesbania* co-culture). After 25-30 days of growth *sesbania* is killed with 2, 4-D ester at 0.5 kg ha^{-1}. This co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield (Singh *et al*., 2007 and Dhyani *et al*. 2007). These residues may not only help in suppressing weed emergence but also add fertility to the soil. *Sesbania* co-culture was more effective against BLW and sedges and less effective on grasses. So, it is recommended to use pendimethalin as pre-emergence to overcome the problem of grass weeds in this technique (Kumar and Ladha, 2011).

(G) Seed priming and seed quality

Quality seeds which are free from any contaminants might be an important approach to manage weeds in DSR systems. A robust seedling stand obtained from primed seeds enhanced rice competitiveness against weeds (Anwar *et al*., 2012). Juraimi *et al*. (2012) reported that priming treatments also produced the most vigorous seedlings with 50 per cent more vigour index compared to unprimed seeds. Higher and synchronized emergence of primed seeds can ensure vigorous crop stand with rapid canopy development giving rice plants a preliminary advantage over weeds (Anwar *et al*., 2012). Relative yield loss was reduced by around 10 per cent due to priming (Juraimi *et al*., 2012). This was mainly due to the fact that priming reduces the risk of poor stand establishment and crop losses due to weeds.

(H) Crop rotation

Crop rotation considered as a vital tool of weed management and helps in breaking the weed seed cycle as well as facilitating the identification of weedy rice and it leads to better control. Effective control of weedy rice can be obtained by rotating the rice crop with other crops, such as soybean, mungbean, cotton, maize, *etc.,* which allow using other herbicides and cultural practices that cannot be used in rice (Singh *et al*., 2013). Planting mung bean in dry season in Northern India also reduced weed growth and weeding time and increased herbicide performance (Mahajan *et al*. 2012).

(I) Intercropping and cover crops

Intercropping can reduce both weed density and biomass to a great extent due to decreased light transmission through the canopy Intercropping for 30 days were found effective in controlling weeds in DSR (Singh *et al*., 2007). Incorporation of cover crop into the soil may add allelo-chemicals to the soil to prevent germination and establishment of weeds and decreased light transmission to the ground (Buhler, 2002). Intercropping with *Sesbania* for 30 days were found effective in controlling weeds in DSR (Singh *et al*., 2007a).

(J) Fertilizer management

Fertilizer management can definitely alter the competitive balance between crops and weeds and should be aimed at maximizing nutrient uptake by crop and minimizing nutrient availability to weeds. Manipulation of crop fertilization is a promising approach to reduce weed infestation and may contribute to long-term weed management (Blackshaw *et al*. 2004). Weeds become less competitive when N was applied at early growth stages of crop compared with later application and weeds are found to be more responsive to added N than that of crop (Blackshaw *et al*., 2000 and Buhler, 2002). When weeds were controlled, rice crop responded to higher amount of N application but under weedy and partially-weedy conditions, grain yield reduced drastically with higher amount of N fertilization (Mahajan and Timsina, 2011).

(K) Water management: Every weed species has an optimum soil moisture level, below or above which its growth is hampered and therefore time, depth and duration of flooding could play an important role in suppressing weeds in DSR system. Good water management together with chemical weed control offers an unusual opportunity for conserving moisture and lowering the cost of rice production (Rao *et al*. 2007).

Physical methods

Manually or mechanically control of weeds are called physical control of weeds. Hand weeding is very easy and environment-friendly but tedious and highly labor intensive and thus is not an economical for the farmers (Juraimi *et al*., 2013). Mechanical weeding using hand pushed weeders is feasible only where rice is planted in rows; however, weeds emerging within rows are difficult to remove with these weeders (Chauhan, 2012b).

Chemical methods

Due to scarcity of labour during the critical period of weed competition, high labour cost and unfavourable weather at weeding time manual and mechanical methods could not find much place among farmers and not economical. Under such situation, most effective, economical and practical way of weed management is the use of weedicides (Hussain, 2008). Herbicides may be considered to be a viable alternative to hand weeding due to scarcity and high wages of labour (Chauhan and Johnson, 2011a; Anwar *et al*., 2012a). Singh *et al*. (2004) reported that a ready mix formulation of metsulfuron methyl + chlorimuron ethyl was very effective against diverse weed flora. Singh *et al*. (2010) found effective control over the density of *C. rotundus* with the application of azimsulfuron + Metsulfuron-methyl. Application of penoxsulam at 20, 22.5 and 25 g/ha have better control over the density of grasses and broad-leaf weeds in DSR (Singh *et al*. 2012). Lowest population of *E. colona* was recorded with application of pendimethalin at 2.0 kg while of *C. axillaris* was with combined application of bentazone with pendamethalin (Singh *et al*. 2005). Singh *et al*. (2016) also reported that treatments with pendimethalin PRE fb bispyribac-sodium + azimsulfuron POST had lower weed biomass at 45 days after sowing (DAS). Highest grain yield of scented basmati rice (3.43 t ha^{-1}) was recorded with the sequential application of pendimethalin PRE fb bispyribac-sodium + azimsulfuron POST. Applying oxadiargyl by mixing with sand onto flooded field was less effective than spray applications in non-flooded field. Other herbicides that are found effective in DSR are pyrazosulfuron and oxadiragyl as pre-emergence and azimsulfuron, penoxsulam, cyhalopfop-butyl and ethoxysulfuron as post-emergence (Rao *et al*. 2007).

Due to narrow spectrum activity of single herbicides these are seldom furnishes satisfactory and season long weed control. Herbicides with different mode of action when mixed together, bind to different target sites in weeds and prevent the probability of target site resistance in susceptible species (Paswan *et al*. 2012). Chauhan and Yadav (2013) opined that in future, the combination of two or more herbicides may become a part of an effective and integrated approach to achieve more satisfactory control of complex weed flora in DSR. Lap *et al*. (2013) revealed that combination products containing penoxsulam and cyhalofop butyl increased the rice productivity in direct seeded systems. Raj *et al*. (2013a) reported that the application of bispyribac sodium + metamifop 14 per cent SE @ 70 g ha^{-1} + PIW -111 wetter, 10 -15 DAS resulted in enhanced rice yield in wet DSR.

Biological methods

It involves utilization of natural living organisms such as insects, pathogens and competitive plants to limit the weed infestation. Different herbivorous bio-agents such as fish, tadpoles, shrimps ducks and pigs are used to control weeds in irrigated lowland rice but these cannot be used in the area where there is no standing water. The main objective of the biological control is reduction and regulation of the weed population below the level of economic injury. Weed control by micro herbicides are now being studied to reduce herbicide dependency. COLLEGO, a powder formulation of *Colletotrichum gloeosporioides* (Penz.) Sacc. *f. sp. Aeschynomene* for the control of *Aeschynomene virginica* (L.) in rice. The endemic fungus *Colletotrichum gloeosporioides f. sp. jussiaeae* (C.g.j.) controlled >80 per cent of water primrose in rice after four weeks (Boyette *et al*., 1979). Thi *et al*., 1999 reported that myco-herbicides using most promising fungi *e.g. Exserohilum monocerus* and *Cocholiobolus lunatas* found to control barnyard grass. *Setosphaeria sp*. and *C. rostrata* were also found to control *Leptochloa chinensis* effectively without causing any damage to rice plant.

Integrated weed management

Various agronomic tools have been evaluated for managing weeds. But, all the agronomic tools may not work perfectly with every crop or weed species. Integration of higher seed rate and spring-applied fertilizer in conjunction with limited herbicide use managed weeds efficiently and maintained high yields (Blackshaw *et al*., 2005). Adoption of IWM approach for sustainable rice production has been advocated by many researchers (Sunil *et al*. 2010, Jayadeva *et al*. 2011). Sequential application of pre-emergence herbicides such as pendimethalin, in dry seeded rice or early post-emergence application of anilofos/thiobencarb for the control of annual grasses in wet-seeded rice and post-emergence application of 2, 4-D against sedges and non-grassy weeds in wet and dry-seeded rice may be a better option than the use of one herbicide.

CONCLUSION

Direct seeded rice appears to be a viable alternative to overcome the problem of labour and water shortage and it has a potential to produce slightly lower or comparable yields as that of transplanted rice. Weeds however are the major biological constraint in direct seeded rice production. To achieve effective, long term and sustainable weed control in direct-seeded system, all suitable management techniques are to be wisely utilized in such a compatible way as to reduce the weed population below the economic threshold levels and to deplete the weed seed bank from the soil and enable rice crop to be more competitive by either delaying the emergence or suppressing the weed emergence and growth. The use of any single strategy cannot provide effective, season-long and sustainable weed control. To achieve this goal there is a need to integrate the use of different weed management strategies, such as cultural (selection of cultivars, stale seedbed technique, tillage, seed rate and spacing, crop residue, quality seed with priming, crop rotation, intercropping, cover crops, fertilizer and water management), physical (manual and mechanical), chemical (appropriate herbicide mixtures, timing and rotation) and biological (use of different bioagents, insects *etc.*) weed management practices.

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