Int.J.Curr.Microbiol.App.Sci (2020) *9*(8): 411-424

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 8 (2020)**
Journal homepage: http://www.ijcmas.com

Review Article https://doi.org/10.20546/ijcmas.2020.908.048

Integrated Weed Management in Conservation Agriculture-A Review

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Keywords

Conservation Agriculture, Weeds dynamics in CA, IWM, Weed control strategies

Article Info

Accepted:
10 July 2020
Available Online:
10 August 2020

A B S T R A C T

Presence of diverse weed flora during critical period of crop-weed competition, is one of the major obstacles in conservation agriculture that reduces which can reduce the crop yield appreciably significantly. During critical period of crop-weed competition, chemical method of weed control is by far the most preferred way to minimize the weed infestation of weeds, farmers are mostly relying on chemical methods of weed management. However, its continuous and over use of herbicide has led leads to resistance, and it's as well as the persistence in soil bore a negative effect on crops singly and in rotation. of herbicides, this may affect the crops in rotation. Conservation agriculture emphasizes on preserving the resources and discourages the use of chemicals. Weeds are controlled in conservation agriculture system through Crop rotation, selection of suitable varieties with optimum seed rate, tillage with proper land levelling, cover crop and proper water management are the options under conservation agriculture. But for a However, an efficient, ecofriendly and economically viable strategy warrants an integrated approach to manage the weed menace. The article attempts to take a stock of available research work on various aspects. proper weed control under conservation agriculture should be integration of these different practices. So, implement the Integrated Weed Management (IWM) in conservation agriculture is highly recommended. IWM plays as a key component in CA systems. For this, compatible, viable, economic and eco-friendly weed management practices should be integrated in a harmonious manner to control the weeds in conservation agriculture. The multiple weed management practices include preventive method, physical method, cultural method, biological method and chemical method.

Introduction

Conservation agriculture is a system designed to achieve sustainably sustainability in agriculture production by enlightening the biological functions of the agro-ecosystem with judicious use of chemical inputs and mechanical practices. Direct sowing/planting with minimum soil disturbance using zero, strip or reduced tillage, permanent vegetative residue for soil cover, and rotation of primary crops in combination with other crop management practices are the major principles of conservation agriculture (CA).

Globally it has been adopted on over 257 million hectares (M ha) in large farming systems, and the trend is increasing by due to its adoption adopting by the small farmers holding in the Asian countries. The system moves under the constraints of severe suffers severely from weed competition during the critical period and by and large, is causing the major obstacle to achieve higher yield. The diverse weed flora under CA can cause a significant yield reduction during critical period of weed competition. Therefore, weed management is a key element in conservation agriculture systems.

With CA, crop production is now not handiest concerned with the production of food and industrial crops. Attention is geared in the direction of crop production in an environmentally sustainable manner. Conservation agriculture which brings the environment of producing the crop in ecofriendly manner by harmonizing the crop production and management practices in tune with that practice with minimal adverse on soil-water- crop environment. The major threat to its success is endangered by the problems of weed. challenged with weed problems that reduce agricultural productivity when not checked. Adoption of a compactable, comprehensive physical, biological and chemical weed management approach with that of existing cultural weed management of CA, fulfills the multiple strategies of integrated weed management (IWM). Integrated weed control attempts to provide a scope to use different weed control methods in combination and possible compatible manner to manage the weed growth and its population at a level that causes minimal reduction in yield and also provide a safe passage to the environment

IWM is useful to conservation agriculture; as it assists inside the management of weed problems and non-availability of some weed control options. In order to get rid of the weeds in conservation agriculture, farmers are using herbicides. Though, in recent past, numerous pre and post-emergence herbicides have been endorsed for controlling weeds in different crops transplanted rice. And some new era herbicides like azimsulfuron and ethoxysulfuron have been found to control the broad spectrum weeds released recently that are in a powerful manner powerful against broad spectrum of weeds with very low dose (Mahajan and Chauhan, 2013), but single utility of one herbicide has seldom been observed effective against complex weed flora throughout the critical period of competition. The combined application of herbicides is rising as another effective tool to tackle the trouble of complicated weeds, particularly in transplanted rice. For an efficient IWM approach, the knowledge of weed ecology, their dynamics, their period of dominance, the crop growing environment and locally adoptable weed control methods is necessary. One can get the maximum benefit of applied monetary inputs by adopting integrated weed management (IWM) as the better substitutions of herbicides. For this, compatible and viable weed management practices should be integrated in a harmonious manner to control the weeds in conservation agriculture. But there is little information on IWM for the control of weeds in conservation agriculture. So, there is a need to implement and evaluate the IWM in conservation agriculture systems.

This review article discusses integrated weed management on the subject of conservation agriculture and the issues of environmental sustainability.

Weeds dynamics in conservation agriculture

The community composition of weeds varies in accordance to different factors particularly tillage practices, climatic conditions, and the inherent weed flora within the area (Duary *et al.,* 2015). There can be a drastic exchange in weed flora composition whilst moving from convention altars planting to ZT- DSR (Bhuller *et al.,* 2016). Under, ZT-DSR, weed flora frequently changes, becomes more difficult to control and competitive grasses and sedges (Kumar and Ladha 2011, Singh *et al.,* 2015a). Based on experiences with ZT-DSR in India and other Asian countries, the shift from CT-TPR to ZT-DSR is expected to favour grass weed species including *Dactyloctenum aegyptium*, *Leptochloa chinensis*, *Eragrostis* sp., weedy rice (*Oryza sativa*), along with *Echinochloa crusgalli* and *E. colona*; sedges such as *Fimbristylis miliacea*, *Cyperus rotundus* and *Cyperus iria;* broadleaf weeds Which include *Eclipta prostrate* and *Digera arvensis* also increase in DSR systems(Kumar and Ladha 2011, Singh *et al.,* 2015a, Singh *etal.,* 2015b).

Seed bank

It is the reservoir of viable weed seeds present in soil causing weed trouble in an area. It is dynamic (addition and losses take vicinity constantly) and continues on changing over times (Baghel *et al.,* 2018). Soil bank consists of new seeds, recently shed by weeds (i.e. seed rain) as well as older seeds that are persisting in soil for several years. Generally, 1-9% of the feasible seed produced in a year develop seedling, the rest remain viable and germinate in subsequent years, relying on depth of their burial. Tillage affects the vertical weed seed distribution in a soil profile and this distribution further affects weed seed germination by influencing the soil environment surrounding the seeds (Chauhan and Johnson, 2009b). Weed seeds present at different depths experience differential moisture, diurnal temperature fluctuation, mild availability, and predator activity (Chauhan *et al.,* 2006b). Systems with less soil disturbance, such as zero tillage, concentrate most of the weed seeds on or close to soil surface; whereas, conventional tillage systems mix weed seeds more or less uniformly within the tilled soil depth (Chauhan and Johnson, 2009b). Tillage systems can also influence the periodicity of weed emergence, as seeds present close to the soil surface might also emerge earlier than seeds buried in deeper soil layers due to the extra favourable situations for germination. Weed seed bank was more at 0-5 cm soil depth as compared to 5-10 and 10-15 cm depth. Significantly the bottom weed seeds were observed beneath ZT+R-ZT+R-ZT+R (4.41 and 3.39) in *kharif* and *rabi* season (7.43and 5.77) at 0-5 and 5-10 cm soil depth, respectively (Sapre *et al.,* 2015). After four years, the seed bank of the *Rabi* season (winter/dry) weeds *Phalaris minor*, *Rumex dentatus*, *Melilotus indica*, and *Coronopus didymus* decreased by way of 90-100, 75-100, 70 and 78%, respectively in CA-primary based systems (ZT+R-ZT+R), compared to the conventional till system. For *kharif* (rainywet) season, the seed bank of aerobic species (*e.g*. *Bracharia* spp., *D. aegyptium*) in addition to *E. colona* increased in ZT+R-ZT+R) rice or maize based systems compared to conventional till system. Seed predation of *P. minor*, a main weed of wheat was more dominant in CA based compared to conventional systems. Singh *et al.,* (2006) observed that the density of *Echinocloa colona*, *D. aegyptium*, *L. chinensis* and *Eleusine indica* was higher in wet-DSR followed by dry-DSR and ZT-DSR, respectively. However, the maximum density of *Corchorus acutangulus* and *C. rotundus* had been more in ZT-DSR than dry-DSR. Maximum weed population and dry weight recorded under CT-DSR followed by ZT-DSR and least underneath transplanting. This resulted in lowest yields and net returns observed by CT-DSR followed by ZT-DSR (Yadav and Singh, 2006). Sinha *et al.,* (2008) found that despite the fact that weed growth increased appreciably in dry-DSR there were no differences among direct-seeding methods (CT dry-DSR, CT wet-DSR, ZT-DSR). ZT markedly decreased the total population and dry matter of weeds compared with conventional tillage in DSR. However, the yield difference was no longer significant (Mishra and Singh, 2008).Singh (2012) suggested that zero-till DSR with anchored residue was found most effective in minimizing the density of weeds (m^{-2}), weed dry weight ($g\ m^{-2}$) and N, P and K depletion ($kg\ ha^{-1}$) by weeds at 20, 40 and 60DAS(at maximum growth stage). Reduced till DSR recorded significantly higher weed density, weed dry weight and N, P and K depletion by weeds than zero-till DSR and zero-till DSR with anchored residue. Dev *et al.,* (2013) reported that minimum weed density and dry matter accumulation was found under zerotillage.

Weed emergence under reduced tillage systems can be higher over tilled field, because of the absence of soil inversion. Weed seeds remained or buried inside the soil surface layer wherein they enforce dormancy until suitable conditions inspired their germination (Mashingaidze *et al.,* 2012).The shift from CT to ZT inwheat has resulted in a shift in weed flora. Emergence of *Phalaris minor* is lower under ZT than CT in wheat (Malik *et al.,* 2002, Chhokar *et al.,* 2007, Franke *et al.,* 2007, Gupta and Seth 2007) but higher for some of the broad-leaf weeds, including *Rumex dentatus* (Chhokar *et al.,* 2007).

Integrated weed management strategies for conservation agriculture

The decline in crop productivity due to the presence of weed has justified the need to manage weed infestation. Over the years, many weed control strategies have been employed. Adoption of a right strategy will not only increase the productivity but it also creates a pollution free environment. Despite the benefits of CA, it has only been practiced globally on about 9% of the total cropped area (Friedrich *et al.,* 2012). Weed management is one of the impediments affecting its adoption globally. The benefits that IWM portends necessitate that its adoption in CA be reviewed. Irrespective of farming system, IWM is constant in approach with multiple tactics, economic and environmental considerations constituting its fundamentals. However, IWM differs in CA from when practiced in conventional agriculture base on the limited available weed control options. Keeping tabs on environmental safety is the main objective of IWM and CA. Weed control strategies in CA are restricted to those that align with the components of CA. For instance, tillage is not an option for weed control in CA (Nichols *et al.,* 2015), likewise bush burning that does not allow for retention of crop residue.

The reduced weed control options in CA tend to increase reliance on herbicides with attendant weed resistance (Singh *et al.,* 2015a). The persistence of some herbicides affects the crop rotation component of CA especially when the herbicide is not selective to the next crop in rotation (Colquhoun, 2006). This gives rise to the challenge of compatibility amongst the weed control tactics, since the crop rotation components of CA is also a weed control strategy (Nichols *et al.,* 2015). Crop rotation breaks the life cycle of weeds and crop–weed specificity (Rao, 2000), thereby reducing weed persistence and its attendant challenges. The crop residue retention of CA creates environmental sieve that inhibit weed seed germination either by preventing sunlight to the seeds and providing a physical barrier to impede their emergence (Bahadur *et al.,* 2015). However, the effectiveness of pre-emergence herbicides on the soil surface is reduced due to interference of crop residues present (Hartzler and Owen, 1997). Also, crop residue could be source of weed seeds. However, the preventive weed management component of IWM could effectively put this to check.

Integrated weed management is a sustainable practice that boosts agricultural productivity with an environmental conscious approach. Its aims at maintaining weeds with considerations such as thresholds and critical periods (Harker and O'Donovan, 2013). According to Akobundu (1992), 'weed-free crop fields may be aesthetically desirable, but they predispose the soil to erosion, especially before the crop develops full canopy cover'. Therefore, weed control, that attempts to create weed-free situation is not environmental friendly. Integrated Weed Management (IWM) is part of integrated pest management (IPM) that is based on multiple control tactics and integration of pest biology knowledge for the management of the pest (Buhler, 2006). IWM is 'the utilization of available weeds science knowledge to manage weeds so that they do not cause economic loss nor adversely affect the environment' (Akobundu, 1992). Thill *et al.,* (1991) defined IWM explicitly as 'the integration of effective, environmentally safe, and socially acceptable control tactics that reduce weed interference below the economic injury level'. It can be deduced from these definitions that IWM places emphasis on multiple tactics, economic consideration, and environmental safety. Eradication of weeds is not the focus of IWM but the reduction of weeds' competitive advantage below economic threshold (Buhler, 2006). IWM therefore balances between weed control and safety of the environment.

Based on various weed control strategies and reduced reliance on herbicides, there are intimations that IWM excludes the application of herbicides. IWM does not side-step any strategy to another. It instead influences the judicious utilization of all weed control systems (Harker and O'Donovan, 2013). Integrated weed management complements the declining weed control efficacy that the use of single control method portends. The continuous use of any successful pest management practice without appropriate incorporation or rotation of other tactics, results in reduced control efficiency over time (Monaco *et al.,* 2002). For instance, crop mimics are mistakenly omitted by hand-weeding in rice (*Oryza sativa* L.). The chronic use of hand weeding in rice allowed rice-mimic biotypes to break out weed management (Harker and O'Donovan, 2013). Also, sole dependence on herbicide for weed control results in herbicide resistance, weed flora shift, soil and environmental pollution (Chhokar *et al.,* 2014). Integrated weed management is appropriate for some weed infestation situations that a single weed management method cannot control efficiently. Parasitic weeds can be successfully managed through the combination of cultural weed control (by rotating the host crop) and biological weed control (with trap crops) (Singh *et al.,* 2015). Aladesanwa and Ayodele (2011), reported that paraquat and glyphoshate applied alone and in mixture in jute plots require supplementary hand weeding to enhance weed control and promote jute production. This buttresses the need for IWM and supports that integrated herbicide management that involves the use of multiple herbicides either sequentially or in mixtures does not sum up to IWM, since it has only the chemical control component. The multiple tactics of IWM need to be further clarified. It has been addressed as multiple direct control strategies by some weed scientists with less emphasis on preventive weed management (Chhokar *et al.,* 2014; Robinson, 2014); whereas some perceived preventive weed management as an integral part IWM (Harker and O'Donovan, 2013). The underemphasized distinction between preventive weed control and preventive weed management could be responsible for this variance. Preventive weed control deters the establishment of weeds in the next cropping season. Bàrber, 2003). It is applicable when weeds or its propagative parts is already present and being debarred from growing or getting to the next cropping season whereas, preventive weed management methods prevent weeds from moving into a new environment (Zimdahl, 2007). The following strategies may help the cropping system under CA.

Preventive weed management method

Prevention method encompasses all measures that curb the introduction and spread of weeds (Rao, 2000). It is always be a better option to go for prevention of weed infestation from the start of crop cultivation. These preventive measures include use of clean crop seeds, cleaning the bunds and roads, using clean agricultural implements. It would be a better option to control the weeds in a small area and or restricts them in a smaller portion of the field. For this hand-rouging of weeds seed-shed found to be an important practice (Bhuller *et al.,* 2016). These measures are indirect methods of weed control whose objective is mainly to reduce the numbers of other plants emerging with a crop (Bàrber, 2003). Prevention focuses on potential problem that is not in existence. Hence, the results of preventive efforts are difficult to assess (Zimdahl, 2007).

Physical weed control method

Physical weed control involves the use of force, heat or some other physical forms of energy to break, cut off, destroy, burn or severely injure weeds (Swarbrick and Mercado, 1987). Manual weeding, mechanical weeding, and thermal weeding are examples of physical weed control. Manual weeding involves hand weeding and the use of simple hand tools. Mechanical weed control involves the cutting, uprooting, and burying of weeds (Riemens, 2016) through the use of machinery (Ehi-Eromosele *et al.,* 2013).

Cultural weed control method

Cultural weed control involves the manipulation of farm practices to the advantage of crop growth at the expense of weeds. Basically, cultural weed control involves the use of farm practices to suppress weed growth through the modification of the environment. Manipulation of sowing time, crop fertilization, and spatial arrangement are examples of cultural practices commonly used to enhance the competitive advantage of crops over weeds (Das, 2008).

Uniform land levelling/ Laser land leveling

A proper land levelling would always not only help for a uniform germination of crop seeds due to a proper soil moisture retention but it also helps to reduce the weed growth due to the uniform crop growth. Reduction in weed population in wheat was recorded under precisely levelled fields in comparison to traditional leveled fields (Jat *et al.,* 2009).

Stale seed bed

Weeds seeds generally present on the upper side of the soil layer. A pre sowing irrigation or any rainfall received will create a favorable condition for the weed seeds to germinate. These flash of weed, can be completely destroy by the application of any non-selective herbicide. Stale seedbed significantly reduced weed pressure in ZT-wheat (Mahajan *et al.,* 1999). A fallow period of 45-60 days between wheat harvest and the sowing of rice provides an excellent opportunity to implement stale seedbed for weed management before planting DSR. The crop develops under stale seed bed remains weed-free and it will have a viable advantage over late-emerging weed seedlings. With the limited options available to manage weedy rice in ZT-DSR, the stale seedbed technique is recommended as part of an IWM strategy in many weedy rice-infested areas (Rao *et al.*, 2007).

Crop establishment measure

Crop establishment method is another important aspect in controlling the weeds. Generally, the weed intensification is too many in CA method due to no tillage practices. Kumar *et al.*, (2013) reported that in the absence of weed control measures, yield losses due to weeds were 90% under ZT-DSR, compared with 35 to 42% under ZT-TPR. Where DSR is preferred for saving labor and water resources. Rice can be sown in Zero-till system either direct seeding (ZT-DSR) or by transplanting (ZT-TPR) rice seedlings manually or mechanically. In both the situation weed plays an important role in yield reduction if proper management was not taken at proper time. From the results obtained from experiments from Ludhiana under herbicides and integrated weed management (IWM) treatments, ZT-DSR recorded at par grain yield to CT-DSR and CT-PTR at (AICRP-WM 2014). It was also observed from the same experimental location among DSR methods, under IWM treatment, ZT-DSR with residue retention on the surface recorded 19% higher yield than CT-DSR. Dhillon *et al.,* 2005 stated that succeeding wheat crop, sown with CT or ZT with and without residues retention on the surface recorded similar grain yield. However, when wheat planted on the raised bed reduced weed density and biomass as compared to conventional method or flat method with a higher grain yield too.

Tillage and residue management and date of sowing

Sowing time of different crops changes under CA. When wheat is sown 2 weeks earlier than conventional system in the north-western Indo genetic plains (IGP) the crop faces a tough initial time against the *Phalaris minor* (Singh *et al.*, 1999). Franke *et al.*, (2007) observed that the density of all three flushes of *P. minor* in wheat sown on the same date were lower in ZT compared with CT. it has been observed that zero tillage along with surface residue retention under early sown condition results in the suppression of *P. minor* and other weeds of wheat (Bhullar). Use of improved technologies made it possible to grow wheat using heavy mulch. Sowing of wheat with 'Turbo happy seeder' has made it possible to sow wheat in heavy residue mulch of up to 8 to 10 t ha^{-1} without any adverse effects on crop establishment (Sharma *et al.*, 2008, Kumar and Ladha 2011). Such heavy mulch has the potential to reduce the establishment of weeds in crops. A yield reduction upto 48% has been recorded when wheat in sown with 'Turbo happy seeder' as compared to conventional till sown wheat in Punjab (Singh *et al.*, 2013).

Use of optimum seed rate and plant geometry

It is a well-known fact that of optimum seed rate always reduced the weed infestations. Chauhan (2012) stated that the crop weed competition in ZT-DSR is reduced by using optimum seed rate and crop geometry. Kumar and Ladha, 2011, Gill *et al.,* 2013 documented that the recommended seed rate for DSR is 20 to 25 kg ha^{-1} in the IGP. Although, Chauhan *et al.*, (2011) suggest that a seeding rate of 95 to 125 kg ha^{-1} for inbred varieties and 83 to 92 kg ha^{-1} for hybrid varieties is needed to achieve maximum yields in competition with weeds. The crop's complet ability becomes higher against weeds with a higher seed rate (Bhuller *et al.,* 2016). Reducing the spacing between rows always sub presses the weeds. When wheat sown under ZT condition, with narrow row spacing (15 cm), it reduced the biomass of *P. minor* by 16% compared with normal spacing of 22.5 cm (Mahajan and Brar, 2002). Bhullar and Walia, 2004 reported, narrow row spacing (15 cm) and higher seed rate (150 kg ha^{-1}) and 25% lower dose of recommended herbicide reduced *P. minor* density compared with normal spacing (22.5cm), normal seed rate (125 kg ha^{-1}) and full dose of recommended herbicide.

Growing cover crops

Fast growing crops spread its canopy over the soil surface and cut the sunlight penetration, at the same time it creates a unfavorable conditions for the weed seeds to germinate or its initial growth. These crops lives for a short time period but its effectiveness in controlling weeds are much more. Brown manuring often practiced in rice field. It not only increases the nutrient status of the soil but also suppresses the weeds to a considerable amount. Generally, in ZT rice production in IGP, sowing *Sesbania* sp. with a seed rate of 25 kg ha^{-1} along with rice are sown. It has shown promise for suppressing weeds. *Sesbania* sp. is allowed to grow with rice to suppress weeds and is then killed with 2, 4-D ester at 25 to 30 days after sowing (Bhuller *et al.,* 2016). Singh *et al.,* 2007 documented reduced broad leaf weed density of 76 to 83% lower and 20-33% grassy weed density under such rice, *Sesbania* sp. crop cultivation as compared to only rice crop.

Competitive crop cultivar

Different crop cultivars vary in their individual traits. A fast-growing cultivar substantially affects the crop weed competition balance. These types of cultivars having a high spreading nature, thus covers the ground very fast during vegetative stage, resulting in suppression of weeds. In general, it has been observed that early maturing inbred and hybrids because of their faster early growth and ground cover are more effective in smothering weeds than medium- to long-duration cultivars (Gill *et al.,* 2013, Singh *et al.,* 2014).

Soil moisture condition and water management

High soil moisture always favors weeds establishment. Singh *et al.,* 1995 stated that high soil moisture in Rice wheat systems favors moisture-loving weeds like *P. minor*, *R. dentatus* and *P. monspeliensis.* Wheat seeds can even germinate less soil moisture condition (Chhokar *et al.,* 1999). So, sowing under dry condition facilitates reduction in weed population and crop weed competition. Water management is always an important component towards controlling the weeds. In conventional rice, where submergence is maintained from the planting weeds gets suppressed. In ZT-DSR flooding only can be applied after the crop established, so weeds get sufficient time to germinate and it make the weed management very difficult (Chauhan, 2012). The development of rice cultivars capable of germinating under anaerobic conditions would highly recommend which will simplifies weed management via flooding in DSR (Chauhan, 2012).

Crop rotation

Mono cropping or following a same crop sequence allows a certain weeds species to become dominant in such system and in time it becomes difficult to control. So, introducing a new crop in the system would certainly break the chain of common weeds and would ease up the process of controlling such problematic weeds. Diversification and intensification of the RW system by introducing a short duration vegetable crop like pea or potato followed by late sown wheat can also improve weed control without increasing herbicide use (Chhokar *et al.*, 2008). Diversified crop rotation can be exploited to improve the management of problematic weeds, because the selection pressure is diversified by changing patterns of weed control tactics (Bhuller *et al.*, 2016)

Chemical weed control method

Chemical weed control involves the use of synthetic herbicides to kill or adversely affect the growth of weeds. Herbicide could be foliar applied or soil applied. Base on the time of application, herbicides are classified into pre-emergence and post-emergence herbicides; and base on herbicide movement in plants, there are systemic and non-systemic (contact) herbicides. Selectivity of herbicides determines their compatibility with crop and the type of weed they control. The use of herbicides is an effective means of controlling weeds. However, this is associated with concerns such as weed flora shift, weed resistance, and environmental pollution. Now a day's various herbicides are registered for use in world (Table-1). However, the adoption of chemical weed control is challenged by availability of herbicide, cost of herbicides (Kughur, 2012), adulteration of herbicides and farmers' inability to read label instructions.

Biological weed control method

Biological weed control involves the use of other living things in controlling weeds. It encompasses the use of organisms and biologically based products (Ehi-Eromosele *et al.*, 2013). Bio-herbicides are phytopathogenic microorganisms or microbial phytotoxins use for biological weed control, applied in similar ways to conventional herbicides (Boyetchko and Peng, 2004). Other commonly used biological weed control strategies are allelopathy, animal grazing, use of resistant or tolerant crop varieties and use of phytophagous insect.

Table.1 List of Herbicides Registered by NAFDAC for use

Organophosphorus	Amideherbicides	Triazines and triazoles	Chlorophenoxy herbicides	Urea and guanidine	Other herbicides
Anilofos	Aceochlor	Atrazine	Prometryn	Diuron	Dimethachlor
Glyphosate	Alachlor	Ametryn	Simazine	Linuron	Metazachlor
Glyphosate Trimesium	Propanil	Terbuthalazine	2,4-D	Fluometurone	Monosodium methyl arsonate(MSMA)
	Butachlor	Terbutrex, Terbutryne		Chloroxuron	Imazaquine
	Metalochlor			Neburon	Oxadiazone
					Trifluralin
					Pendimethalin

Source: Federal Ministry of Agriculture and Rural Development (2013)

Table.2 A comparison between traditional tillage, conservation tillage and conservation agriculture

Issues	Traditional tillage (TT)	Conservation tillage (CT)	Conservation agriculture (CA)
Practice	disturbs the soil and leaves a bare surface	reduces the soil disturbance in TT and keeps the soil covered	minimal soil disturbance and soil surface permanently covered
Erosion	wind and soil erosion: maximum	wind and soil erosion: reduced significantly	wind and soil erosion: the least of the three
soil physical health	the lowest of the three	significantly improved	the best practice of the three
water infiltration	lowest after soil pores clogged	good water infiltration	best water infiltration
Weeds	controls weeds and also causes more weed seeds to germinate	reduced tillage controls weeds and also exposes other weed seeds for germination	weeds are a problem especially in the early stages of adoption, but problems are reduced with time and residues can help suppress weed growth
soil organic matter	oxidizes soil organic matter and causes its loss	soil organic build-up possible in the surface layers	soil organic build-up in the surface layers even better than CT
soil temperature	Surface soil temperature: more variable	surface soil temperature: intermediate in variability	surface soil temperature: moderated the most
Yield	can be lower where planting delayed	yields same as TT	yields same as TT but can be higher if planting done more timely

Source: Hobbs *et al.*, 2008

In conclusion, emergence of unique weed challenges in CA requires that its inbuilt weed management component (cover crop, crop residue mulching and crop rotation) be complemented with other weed management strategies without compromising its principles. Adoption of any compatible preventive, physical, biological or chemical weed management strategy to the existing cultural weed management of CA fulfills the multiple tactics of IWM. The reduced weed management options in CA tend to increase reliance on herbicide which could cause water contamination, weed resistance, weed flora shift, and herbicide carryover. IWM checks overreliance on herbicide. Hence, embracing IWM in CA assists its sustainability and enhances the environment protection focus.

Authors contribution

Mr. Subhaprada Dash and Dr. Md. Riton Chowdhury has planned the topics and written the article. Mr Koushik Sar has helped in reviewing the article, arranged it according the theme and Mr Jagadish Jena has helped in collecting references and contributed in writing. Prof JML Gulati has given valuable information in writing the article.

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How to cite this article:

Subhaprada Dash, Md. Riton Chowdhury, Koushik Sar, Jagdish Jena and Gulati, J.M.L. 2020. Integrated Weed Management in Conservation Agriculture-A Review. *Int.J.Curr.Microbiol.App.Sci.* 9(08): 411-424. doi: https://doi.org/10.20546/ijcmas.2020.908.048