



Weed management in conservation agriculture, its issues and adoption : a review

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ABSTRACT

Conventional agriculture is tillage driven system that increases the cost of crop production, accelerates soil erosion and contributes towards climate change. These difficulties in conventional agriculture demands shift in agriculture system, and conservation agriculture (CA) become the best feasible option. CA is becoming popular as it brings sustainability of the production system without compromising crop and soil productivity. CA is based on three pillars viz., minimal mechanical tillage, permanent residue cover on the soil and crop diversification. However, adoption of CA, influences the weed population differently over conventional agriculture as tillage manipulates the weed habitat. Thus, weed management in CA possesses a great challenge for farmers. This mainly due to minimum soil disturbance resulting in most of the weed seeds remain over the top layer of soil and crop diversification brings change in weed composition. Thus shift in weed flora becomes more problematic for farmers to control it effectively under CA. In zero tillage, perennial weeds become more problematic. However, when crop residue is uniformly spread with appropriate quantity, it may suppress weed seed germination and provide a competitive advantage for crop over the weed and also help in moisture retention, lowering the soil temperature and increase in soil organic matter (SOM). Generally, the use of herbicides brings effective weed control. However, crop residue incorporation followed by the application of post-emergence herbicide is found more effective than pre-emergence herbicide. Thus under CA, herbicide efficacy depends on the time of application, formulation and quantity of application. Moreover, integrated weed management (IWM) is the best way to manage weeds effectively in an eco-friendly and cost-effective manner under CA. IWM approaches comprise crop establishment, crop rotations, use of cover crops and crop residues as mulch with a combination of pre- and post-emergence herbicides could be integrated to develop sustainable and operative weed management strategies under CA systems. However, there are some problems in the adoption of CA that are the mindset of farmers towards tillage, timely availability of improved implements, the initial purchasing power of farmers and technical knowledge.

Keywords: Conservation agriculture, herbicide, integrated weed management, tillage, weed shift

Agriculture (crop and livestock production) is a worldwide stirring activity that relates unswervingly and vigorously to the present and future condition of environments, economies, and societies. It provides the basic, social and economic needs of individuals (Smit and Smithers, 1993). Exponentially increase in global population and continuously increase in global food, feed, fibre, bio-energy demand, creates hunger and poverty problem. To tackle this issue, the demand for intensive agriculture, increase in agricultural productivity, and associated total and individual factor productivities are focused (Kassam *et al.*, 2015). This brings faulty production system, which may threaten the sustainability of the agro-ecosystem by groundwater over exploitation, development of herbicide resistance of weeds, chemical contamination in food, soil, water and air, development of sub-soil hardpan, deterioration of soil health, multi-nutrient deficiency and high cost of cultivation (Day *et al.*, 2016). Hence, there is a need to enhance the sustainability in production systems. Further, it is necessary to circumvent the degradation of

agricultural land and ecosystem, and the rehabilitation of degraded and waste agricultural land. In this view, conservation agriculture (CA) is one of the best options. FAO defines CA as an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security with preserving and enhancing the resource base and the environment simultaneously. This includes three principles viz., continuous minimum mechanical soil disturbance (*i.e.* zero and/or no-tillage, broadcasting of crop seeds, line sowing, band placement of seed, set bed planting), permanent soil organic cover (with crop residue and/or cover crops such as mulch crop with at least 30 per cent soil surface) and crop diversification (with crop rotation, mixed cropping and intercropping of crop) (FAO, 2014).

History and status of conservation agriculture

Tillage is the physical manipulation of soil. It is intended to loosen the soil, preparation of seedbed to bring good and uniform seed germination, manage

weeds, help in good crop growth through mineralization, incorporation of crop residues and soil amendments (Hobbs *et al.*, 2008). In a fragile ecosystem, tillage was first questioned in the 1930s, when a huge area of the mid-west United States was devastated by the dustbowls. That brought the new concepts of soil-crop cover and termed as conservation tillage. Principles of CA were illustrated first time in their book by Edward Faulkner in “Ploughman’s Folly” (Faulkner, 1945) and Masanobu Fukuoka in “One Straw Revolution” (Fukuoka, 1975). Thereafter, in early 1970s increase in fuel price led to shifting of farmers towards CA. In this way, farmers are now adopting CA for mitigating drought-induced soil erosion and energy-saving (Farooq and Siddique, 2015). The estimated area under conservation agriculture by FAO was about 157 million ha in 2013 worldwide, with 35.6 million ha in the USA ranks first and India having 1.5 million ha. In some areas of Indo-Gangetic plains zero or/and no-till farming, laser-assisted precision land levelling, direct drilling into the residues, direct-seeded rice (*Oryza sativa* L.), raised-bed planting are being practised in nearly 5 million ha that includes India, Pakistan, Nepal and Bangladesh (Kassam *et al.*, 2015; Jat *et al.*, 2016). It is estimated that the area under CA is increasing slowly but continuously year after year. But the major problem under CA is weeds, the shift in weed flora and its management.

Conservation agriculture and weeds

Weed management is an essential part of the agriculture production system and CA requires special attention for its management. Based on habitat, weeds act differently. Tillage provides different habitat for weeds by manipulating and changing the microclimate of soil and play an important role in weed management (Bajwa, 2014; Choudhary, 2015). Weed management in CA depends upon good agronomical practices, use of herbicide and tillage level (Lafond *et al.*, 2009). In the CA system, during initial years higher the weed influx (Shahzad *et al.*, 2016), small-seeded weeds get favoured for germination and growth as most of the seeds remain on the surface whereas, dormant seeds buried in soil remains dormant due to minimum soil disturbance against in the conventional system (Chauhan *et al.*, 2006). It leads to shifting of weeds under the CA system. Many small-seeded annual and biennials weeds germinate under no and/or zero-till system with no or minimal soil cover whereas, perennial weeds get dominated and proliferated in the first year where few plants get a chance to germinate (Curran *et al.*, 1996).

Furthermore, in CA perennial weeds tend to dominate over annual broadleaf and grasses. This indicates that in CA there is the shift in weed flora from docile weeds to obnoxious perennial weeds such as bermudagrass

(*Cynodondactylon* L.) and mexican clover (*Richardia scabra* L.) (Mashingaidze *et al.*, 2012; Shahzad *et al.*, 2016).

Conservation agriculture and shift in weed flora

The shift in weed flora takes place from the transformation of conventional to conservation tillage system (Singh *et al.*, 2017). It depends on the frequency and intensity of tillage that disturbs the soil surface (Baker *et al.*, 2018). Under zero tillage (ZT) system, gramineous weeds are favoured more over the other weed species and spread more easily that mimic pasture or roadside surroundings (Nichols *et al.*, 2015). Annual grasses increase gradually whereas annual dicotyledonous weeds population decreases (Tuesca *et al.*, 2001). In contrary to this, Mekonnen and Markos (2016) found that the family of broadleaf weeds were to be the most abundant under CA system. Long-term field experiment and farmer surveys viewed change in the weed continuum in ZT wheat with lesser soil disturbance and found that broad-leaved weeds density get increased (Ramesh, 2015). Also, weed dynamics is associated with cropping system and other management practices along with CA (Ball and Miller, 1993; Swanton *et al.*, 1993). Crop residues under CA influences weed composition. Small-seeded weed species are inhibited more than large-seeded one. A relatively large-seeded, light-insensitive weed, velvetleaf (*Abutilon theophrasti*) was less affected than the small-seeded redroot pigweed (*Amaranthus retroflexus* L.), and common lambsquarters (*Chenopodium album* L.). In general, small-seeded annual weed species that require light for germination affected more by crop residue (Teasdale, 1996). In CA, weeds species tolerant to shade, wet condition and low temperature can flourish more than the other weed species and have the capacity to be troublesome in reduced tillage (Martin *et al.*, 2002). Owen (2008) reported that CA with the application of herbicide having a single mode of action hastens in weed population shifts.

Weed control measures under conservation agriculture

In CA, weed interference is more subjective compared to the conventional system (Singh *et al.*, 2015). Under crop residue, weed density was reduced by nearly 50 to 75% (Mohler and Teasdale, 1993). Conservation practices *viz.*, crop residues, crop rotation, herbicide use, integrated weed management (IWM) well fitted for weed management are elaborated below:

Crop residues

Under CA, crop residues comprise organic material like live/green mulch or crop/plant residue and sometimes non-living materials such as plastic sheets

used in various cropping systems (Slims *et al.*, 2018). Crop residues, its quantity and allelopathic property effect the weed seed germination and emergence (Chauhan *et al.*, 2006; Singh *et al.*, 2017; Vivek *et al.*, 2019). After the harvest of crop, crop residues are distributed mechanically or manually. In CA, mulch of cover crop on the soil surface suppresses weed seed germination by decreasing the light transmission and their allelopathic effect (Chauhan *et al.*, 2012; Choudhary and Kumar, 2014; Slims *et al.*, 2018). Delayed weed emergence provides crop to take competitive advantage over weeds which have less impact on crop yield loss (Chauhan and Johnson, 2010). Ranaivoson *et al.* (2017) reported that incorporation of crop residue of 1 t ha⁻¹ or more helps in reduction of weed emergence and its biomass by 50% compared to conventional system, however, maximum effect was observed under 4 t ha⁻¹ or above. Application of rice straw at 4 t ha⁻¹ could effectively manage weeds under direct wet seeded rice method (Devasinghe *et al.*, 2011). Apart from the amount of crop residue, types of residue also influence the weed dynamics. Radicetti *et al.* (2013) observed that weed suppression ability of oat residues was higher than rapeseed and hairy vetch residues. The emergence of weed reduces by increasing the crop residue when spreads uniformly over the soil surface (Ranaivoson *et al.*, 2018; Choudhary and Kumar, 2019). Crop residue helps in moisture retention, lowering the soil temperature and increases the soil organic matter content that helps in germination of some weeds too *e.g.*, *Avena fatua* (Young and Cousens, 1999; Choudhary *et al.*, 2015). In general, crop residue reduced the germination of most of the weed species. In wheat crop, ZT with crop residue along with early sowing results in suppression of *Phalaris minor* and other weeds (Bhullar *et al.*, 2016; Singh *et al.*, 2017). Singh *et al.* (2013) reported that in Punjab, happy seeder sown crop leads to an average reduction of weed population over the rotavator and farmer's practice was 26.5 and 47.7%, respectively. To achieve long-term weed control there is a need for integrating the use of herbicide. Also, to decide the quantity of crop residue that will not hamper the germination of the crop.

Crop rotation

Continuous monocropping under similar management practices favours the dominance of specific weed species (Jena and Meena, 2017). Under crop rotation, diversity of weeds increases as compared to monocropping. Higher weed diversity prevents the dominance of any particular weed flora (Demjanova, 2004). Rotation of crops alters selection pressures that prevent one weed species to remain dominant in a

particular regime (Choudhary, 2016). It alters selection pressures *via* three mechanisms *viz.* altering management *e.g.*, agronomical means (Choudhary *et al.*, 2016), different patterns of resource competition, and allelopathy (Nichols *et al.*, 2015). Crop rotation brings diversification of crop and breaks the cycle of dominating weed flora under monoculture (Martin *et al.*, 2002; Rahman, 2017). Every crop has unique architecture and requires variable management techniques that generate different microclimate. The type of crop canopy filters the incoming solar radiation that can inhibit the germination of most weed species (Silvertown, 1980). Mimic weeds can successfully be eradicated by rotation (Derksen *et al.*, 2002). Crop rotations with a different duration such as winter wheat-maize and winter wheat-sugar beet brought a reduction in the weed seed bank (Koocheki *et al.*, 2009). Crop used in rotation must have quick growing ability that helps in suppressing weed growth *e.g.*, cowpea, soybean *etc.*, (Vishwakarma *et al.*, 2017). Phophi *et al.* (2017) reported that the use of cowpea and lablab in CA for effective weed suppression due to its high smothering effect. Sowing of soybean and sunflower under no-tillage with desiccated rye mulch resulted in 90% reduction in weed biomass of *Chenopodium album*, *Amaranthus retroflexus* and *Ambrosia artemisiifolia* as compared to tillage and no rye mulch (Gnanavel, 2015). It was reported that rice-wheat-green gram sequence showed lower weed population compared to rice-wheat, rice-chickpea and rice-pea sequence (Singh *et al.*, 2012). Therefore, regardless of tillage, crop rotation is an effective practice to use for weed management.

Herbicide use

Chemical used for controlling weeds called herbicide. It is the one of effective and economical way under CA system for managing weeds (Muoni *et al.*, 2013). Minimum or ZT system under CA has obligated farmers to be more dependent on herbicides for effective weed control (Eslami, 2014). Its efficacy under CA system depends on the suitability of herbicide, application time (either pre- or post-emergence) and the amount of crop residue on the soil surface (Vargas and Wright, 2005). Under CA, post-emergence herbicides are more effective as crop residue on soil surface dilutes the effect of pre-emergence herbicide. Post-emergence herbicide applied after the weed emergence and its efficacy is not influenced by tillage practices under both conventional and CA (Bajwa, 2014). The study shows that under CA, crop residue can intercept nearly 15-80% of applied herbicide that results in its reduced efficiency (Buhler, 1995; Rao and Chauhan, 2015). Application of atrazine in wheat stubble shows that only 40% of applied

herbicide reaches the ground (Ghadiri *et al.*, 1984). Herbicidal efficacy also depended on its formulation under CA. For example, pre-emergence herbicides with granular formulation are more effective than the liquid one (Bhullar *et al.*, 2016). It is assumed that granular molecules reach the soil surface more effectively than liquid formulated herbicide (Johnson *et al.*, 1989). Therefore, herbicide performance in CA systems should be undertaken carefully; such as suitable herbicide type, application time, and formulation. Since the timing of weed emergence is inconsistent in CA than in the conventional system and suggested that farmers should wait for application of post-emergence herbicide until the weed get emerged (Chauhan *et al.*, 2012).

Non-selective herbicide and conservation agriculture

In CA, during the planning of crops, non-selective herbicides are required to control the existing weeds. Some of the non-selective herbicides are glyphosate, paraquat and glufosinate (Chauhan *et al.*, 2012). That should apply either before or after planting but before the crop emergence (Hartzler and Owen, 1997). But the unremitting application of the same herbicide such as glyphosate year after year may result in weed flora shifts or may hasten the development of glyphosate resistance in weeds. Therefore herbicides rotation with different modes of action may reduce the selection pressure that can avoid or delay the development of resistance (Bhullar *et al.*, 2016).

Selective herbicide and conservation agriculture

CA poses more challenge for the efficacy of pre-emergence herbicide than the post-emergence. Hence, a higher rate of pre-emergence herbicide is required for effective weed control (Locke *et al.*, 2002). However, satisfactory weed control was observed when supplementing with post-emergence herbicides such as glyphosate along with the pre-emergence herbicide (Vanlieshout and Loux, 2000). For effective weed control in Direct Seeded Rice (DSR), pre-emergence (pendimethalin or pretilachlor or oxadiargyl with safner) followed by post-emergence (bispiribac or bispiribac based tank mixture including bispiribac + pyrazosulfuron/2,4-D / azimsulfuron / fenoxaprop or halosulfuron with saftner or fenoxaprop based tank mixture including fenoxaprop + ethoxysulfuron) herbicide application have provided efficient weed control in DSR (Malik *et al.*, 2018). Singh *et al.* (2017) reported that application of metsulfuron + clodinafop ($4 + 60 \text{ g ha}^{-1}$) in wheat under ZT with crop residues (R) of preceding soybean under ZT+R-ZT+R-ZT+R and ZT-ZT+R-ZT+R system has resulted in lower weed density and biomass resulted with higher weed control efficiency.

Under ZT, atrazine 750 g ha^{-1} (as pre-emergence) followed by (fb) one hand weeding was effective in controlling weeds in maize crop (Khedwal *et al.*, 2017).

To combat the ill effect of herbicide with effective and profitable weed management, integrated weed management strategy is required.

Integrated weed management (IWM)

IWM is a multidimensional approach that helps in bringing the weed population below the threshold level. It offers a combination of different weed management practices *viz.*, good agronomical practices, in-time field operation and withholding of crop residue that improve weed control efficiency. Weeds can be effectively controlled by planting of the weed-competitive cultivar in narrow rows with high seeding rates and use of residue as mulch and an effective post-emergence herbicide may manage weeds effectively in CA systems (Jena and Meena, 2017). The combined use of higher seed rate (150 kg ha^{-1}) narrow row spacing (15 cm), and 25% lower dose of clodinafop reduced *P. minor* density than the normal spacing (22.5cm), normal seed rate (125 kg ha^{-1}) and field dose of clodinafop (Bhullar and Walia, 2004). IWM helps in boosting agricultural productivity and keeping apprehension on environmental safety.

Conservation agriculture and soil physical and chemical properties

CA has a significant effect on these soil physical and chemical properties. Under CA, it improved due to a decrease in the impact of soil degradation *viz.*, crusting of soil, organic matter depletion, soil compactness and deterioration of soil structure (Dalal and Bridge, 1996). Crop residues present on the soil surface improve soil tilth and conserve moisture (Locke and Bryson, 1997; Choudhary *et al.*, 2013). Size of soil aggregate increases under both wet and dry condition due to increase in soil organic matter content that helps in the binding of soil particle (Lichter *et al.*, 2008; Govaerts *et al.*, 2009). Soil bulk density decreases due to an increase in the number of soil aggregates (Shaver, 2010). The direct impact of raindrops on the soil surface may create the soil crust by sealing the soil pores through splashed soil particles. This might be due to negligible crop residue in the conventional system of cultivation. Whereas, under CA crop residue over the soil surface avoid the soil crust formation and increasing the infiltration rate (Benyamini and Unger, 1984). The conventional system of cultivation reduces the number of macro and micropores and increases the bulk density whereas, vice-versa true in CA (Indoria *et al.*, 2017). Relative lower temperature with little fluctuation in soil temperature in CA as compared to a conventional system, this might be due to

least tillage operation and retention of crop residue on it (Kosterna, 2014). Dahiya *et al.* (2007) reported that due to mulching, average soil temperature reduced by 0.74°C, 0.66°C, 0.58°C at 0.05, 0.15, and 0.30 m soil depth, respectively. Residue cover over the bare soil reduced run off and erosion of soil particle (Mailapalli *et al.*, 2013). The 30% of soil surface cover with residue is expected to reduce the erosion by 80% (Jat *et al.*, 2014).

Soil organic matter content is the prime indicator of soil property. Verhulst *et al.* (2012) reported that under ZT soil organic matter content increases on the surface of the soil as compared to conventional tillage. Low available nitrogen was reported under ZT with cereal residues which might be because of immobilization due to greater availability of residue on the soil surface. However, legume residues with a low C/N may result in N mineralization (Turmel *et al.*, 2015). Higher extractable phosphorus and potassium compared to the tilled soil was observed under ZT due to less mixing with soil (Zibilske *et al.*, 2002). Availability of micronutrients (Zn, Fe, Mn and Cu) remain higher under ZT with retention of crop residue compared to conventional tillage. The retention of crop residue significantly increases the cation exchange capacity in 0-5cm of soil and soil turn to more acidic at the surface (Govaerts *et al.*, 2007).

Conservation agriculture for crop yield and economics

CA may advance the crop yield through recuperating soil productivity by conserving resources *viz.*, soil, water and sequestering soil organic carbon in farmland (Zheng *et al.*, 2014). The real effect of CA on crop yield may depend on specific CA practices, micro and macro-climate and cropping systems (Hobbs *et al.*, 2008). But in the short term, ZT generally resulted in lower yields than with conventional tillage (CT) (Brouder and Macpherson, 2014). Sommer *et al.* (2012) observed that the improvement in wheat yield under ZT with residue retention in comparison with C.T. Kutu (2012) reported that under ZT highest maize grain yield under supplementary irrigation and dryland conditions was 2805 and 2776 kg ha⁻¹, respectively. ICARDA (2018) demonstrated that under CA, reduction in the cost of crop production and improvement in yield occur simultaneously. Nearly US\$ 120 ha⁻¹ net return can be generated by farmers under CA with good crop management and 12% higher yield and low cost of production (about US\$ 40 ha⁻¹ saving). Jat *et al.* (2015) reported that wheat data collected from 100 randomly selected farmers shows that wheat yield in CA was 6 and 13% higher in 2013-14 and 2014-15, respectively, in comparison to conventional cultivation. Also, less yield

loss was observed. Bayala *et al.* (2012) revealed that increases in the yield in low to medium productive soil for sorghum, maize and millet under CA practices. Sharma and Jat (2014) observed higher system productivity (15.8 t ha⁻¹) in CT with transplanted rice (TPR) *fb* ZT in wheat *fb* ZT in greengram with previous crop residues retention than complete ZT + previous crop residues in rice *fb* wheat *fb* greengram (14.8 t ha⁻¹) and CT in TPR *fb* CT in wheat cropping system (13.0 t ha⁻¹). However, energy use was more (73832 MJ ha⁻¹) in CT in both TPR and wheat than CT in TPR *fb* ZT in wheat *fb* ZT in greengram (56543 MJ ha⁻¹) and ZT + previous crop residues in rice *fb* wheat *fb* greengram cropping system (51582 MJ ha⁻¹).

Edralin *et al.* (2017) conducted a study in 10 farmer's fields to estimate the effect of CA and CT on the yield of vegetables and found significantly higher yield than the CT. Marahatta (2014) observed that through the adoption of ZT-wheat, reduced tilled-wheat and dry DSR farmers can save the production cost by 32, 34 and 34% as well as an increased benefit-cost ratio by 52, 29 and 54%, respectively. Several studies show that saving of nearly 2000-3000 Rs ha⁻¹ takes place in wheat crop under CA (Choudhary *et al.*, 2016). In degraded agricultural land, an increase of 1 ton of soil carbon pool may enhance crop yield by 0.5 to 1 kg ha⁻¹ for cowpeas, 10 to 20 kg ha⁻¹ for maize, and 20 to 40 kg ha⁻¹ for wheat (Lal, 2004). Thus, the above research finding clearly indicates that CA may enhance yield and net return and reduced the cost of cultivation.

Conservation agriculture and climate change

Agriculture is vulnerable to climate change that is associated with a rise in temperature, an increase in atmospheric CO₂ concentration and rainfall variability that leads to a decline in crop yield (Mall *et al.*, 2017; Kumar *et al.*, 2017). The rise in temperature leads to an increase in oxidation of the soil organic carbon and brings down the soil organic content. Runoff and wind erosion may accelerate due to an extreme weather event. These changes bring poor soil fertility, loss of soil microbial population and water stress (FAO, 2011). Faulty agricultural practices are associated with GHGs emission in the atmosphere result in climate change that consequence in low agricultural production (Six *et al.*, 2004). Thus, promoting agricultural practices that alleviate climate change by reducing GHGs emissions is essential (Bisht *et al.*, 2016).

CA agricultural practices make the agricultural system more resilient to climate change (FAO, 2012). This may be due to the application of soil management practices that help increase in soil organic carbon, reduced soil disturbance and reduces the use of fuel

consumption that helps to reduce GHG emission (Choudhary *et al.*, 2012; Choudhary *et al.*, 2016). Organic agriculture (OA) is one of the best management practices in CA. Worldwide adoption of OA has the potential to sequester up to the equivalent of 32% of all current anthropological GHG emissions (FAO, 2009). Lal (2004) reported that if 1,500 million ha land under CT is converted into CA practices, it will be able to fix 0.6-1.2 gigatons of carbon/year.

Conservation agriculture and problems in adoption

CA benefited the farmers to gain more returns with a reduced amount of labour, irrigation and other external inputs, maintain soil health and its productivity and sustain the agro-ecosystem. About 8-10% of farmers across the world go after CA (Dhar *et al.*, 2017). Regardless of the sepercptiblere compenses, expansion of CA is relatively slow. The transformation from conventional agriculture practice to CA practice seems to require considerable farm management skills and availability of equipment and implements suitable for CA; that may require minimum levels of capital to encourage its spread out. Limited availability of crop residues for CA practices and farm animals feeding, crop residue burning and overcoming the mindset of farmers regarding tillage are barriers for adopting CA (Bhan and Behra, 2014). Heavy incidence of weed without tillage practices and limited accessibility to buy expensive herbicides has been observed for small and marginal farmers (Meena *et al.*, 2016).

This review indicates that conventional agriculture leads to indiscriminative use of limited natural resources, declining crop productivity, deprived soil health and the high production cost that pose a threat for food security and sustainability. CA is the best alternative over conventional agriculture. That brings all possible solution towards achieving higher crop productivity with sustainability, conserving natural resources, eco-friendly and more climate-resilient agriculture system. Minimum tillage in the combination of residue retention enhances soil organic carbon in the top layer of soil surface. Residue retention or inclusion of cover crops on the soil surface improves soil moisture retention, temperature moderation and weed control. ZT reduced the CO₂ emission and enhances the SOC in soil. Crop diversification may break the cycle of dominating weed flora under monoculture. Weed infestations were found to be the major threat under CA and shift in weed flora were observed. Depending upon the type of crops, ZT could increase or decrease certain weed species. Use of herbicide, mulching and cover crops helps in managing weeds in CA system. However, IWM is the best way to bring down the weed population below the threshold

level. Besides the huge advantages of CA, there are also many constraints for its adoption *viz.*, the attitude of people towards tillage, availability of suitable implements and lack of knowledge. Therefore, the paradigm shift from tillage intensive conventional agriculture to CA systems require technical know-how, technological support and policy framework that will help to enhance system productivity, improve environmental quality, bring sustainability and spread rapidly across the globe.

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