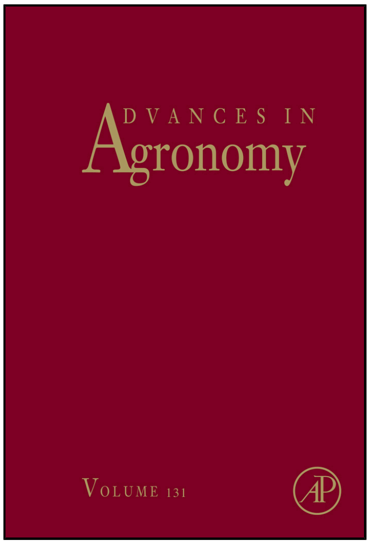

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CHAPTER FOUR

Weed Problems, Ecology, and Management Options in Conservation Agriculture: Issues and Perspectives

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Abstract

The unsustainable exploitation of the inelastic resources for farming has led to a widespread degradation of soil resources, which has forced us to rethink our food production strategies into conservation agriculture (CA). It would be difficult to slow down the intensive-production process keeping in view, the demographic pressure. The present-day systems are posing challenges to land, water, and atmosphere, besides the biodiversity. CA involves minimal disturbance of the land, coupled with good agronomic principles such as crop residue management and crop rotation, with the application of chemicals for weed management. With a view to sustainable development in agriculture, CA is a concept trying to reconcile ecology, economy, and performance.

Tillage is practiced since ages, for the preparation of field and making weed-free conditions and is an integral component of traditional agricultural systems. However, soil erosion was inevitable. The focal theme of CA revolves around reducing tillage operations. From a weed management point of view, soil tillage brought buried seeds to the upper layer and stimulated their germination and the maintenance of crop residues hampered the herbicide efficacy. However, there are reports of shift in weed population due to the adoption of CA as compared to the conventional agricultural practices posing a formidable challenge to the CA concept. The interaction of weed–crop system becomes too complex. Reduced tillage and zero tillage allowed seed to stay on the surface so that they become prey to the predators. The crop/cover crop residue may also release some chemicals, which may also reduce weed seed germination process. Understanding the weed seed ecology and weed ecology could aid in devising appropriate management options for successful implementation of CA. An integrated management encompassing selection of appropriate crop cultivar and cropping system coupled with CA principles would aid in the management of weeds. Understanding weed seed predation would add value to the management issues. Herbicide resistance need to be given due attention for chemical weed management.

1. INTRODUCTION

Understanding and adoption of conservation agriculture (CA) is one of the most important farming method taking place in agriculture today which prompted organization of five world CA congresses in different parts of the world. Region-wise CA prospects have been studied and reviewed by various authors viz., central Saskatchewan (Gray et al., 1996), Argentina (Dıaz-Zorita et al., 2002), Brazil (Bolliger et al., 2006), Queensland (Thomas et al., 2007), Australia (D'Emden et al., 2008; Llewellyn et al., 2012), Africa (Giller et al., 2009, 2011), east and southern Africa (Rockström et al., 2009), central Mexico (Govaerts et al., 2009a), United Kingdom (Morris et al., 2010), Zimbabwe (Thierfelder and Wall, 2010; Baudron et al., 2012), Mozambique (Nkala et al., 2011), Uzbekistan (Nurbekov et al., 2011), Turkey (Avci, 2011), US Great Plains (Hansen et al., 2012), central Asia (Kienzler et al., 2012), Morocco (Mrabet et al., 2012), Mediterranean climate (Flower et al., 2012; Kassam et al., 2012), Malawia (Ngwira et al., 2012), South Africa (Thierfelder et al., 2013), and China (Zhang et al., 2014) etc. Although, there are reports of production disadvantages and lower yields in conservation tillage (CT) over conventional tillage (CoT), CT is attractive to farmers primarily because of the potential for reduced production costs; conservation benefits are only secondary (Allmaras and Dowdy, 1985).

CA is defined as an agricultural management system that aims to minimize soil disturbance, permanent residue for soil cover, and rotation of crops (FAO, 2012a). Recently, fertilizer application has been proposed as a separate principle in addition to good agronomic practices as fertilizer is essential for CA to exhibit its fullest potential, while the suboptimal implementation of other crop management practices might not lead to the success of CA as such (Vanlauwe et al., 2014) particularly in the African countries.

Unger and McCalla (1980) have discussed the CT systems in detail. Reduced (RT) and no tillage (NT)/Zero tillage (ZT), with appropriate cultivar and herbicide selection, provided advantages over CoT (Tubbs and Gallaher, 2005), which covers a range of tillage but it never/partially involves inverting the soil, besides cover crop/previous crop residue management and crop rotation as the focal pillars of CA. Thus, soil disturbance is minimized and crop residues remain on the top soil (Putte et al., 2010). Hence, it is not just an elimination of ploughing; it involves the development of a combination of agroecologically sound management practices (Han et al., 2013), changes in soil processes, lower soil temperature, and high soil moisture (Addae et al., 1991; Blevins and Frye, 1993; Leon and Owen, 2006), which could influence the ecosystem services, and the biodiversity too (Palm et al., 2014). Although, the environmental consequences of adopting CT (Holland, 2004) have been widely discussed, the slow pace of growth due to weed menace is a cause of concern.

Weeds are certainly as old as agriculture and farmers were aware that their presence interfered with crop production (Ghersa and Martinez-Ghersa, 2000). The daunting weed menace in CA and species shifts either through succession or temporary fluctuation were imminent. Literature worldwide has proved the dominance of grassy perennial weeds under RT (Froud-Williams et al., 1983a,b, 1984) as well as NT, as species shifts and adaptation might occur when an environment changes over time (Martinez-Ghersa et al., 2000) and the management of shift to perennials is a major concern. The perennial species varies from one cropping system to another, of which field bindweed in corn/soybean rotation (Buhler et al., 1994) is a classic example in the United States. Swanton et al. (1993) opined that this shift may either represent long-term ecological succession or temporary fluctuations in species composition. The goals of succession management would involve reducing populations of the species most likely to proliferate under CT since changes in weed communities are inevitable and an intrinsic consequence of growing crops over time (Owen, 2008) as the physical movement of soil is restricted to minimum for crop production (Price et al., 2011).

Noninversion tillage challenges the scientific basis of ploughing as an universal method of field preparation vis-a-vis weed management. Soil tillage, aimed at eliminating weeds (e.g., Oeconomicus by Xenophon c. 375 BC, De Re Rustica by Lucius Junius Moderatus Columella c. AD 42), allowed weed seeds to germinate so that they could be removed (Colbach et al., 2014). However, under CA a plethora of herbicide availability has made RT as a significant (Cannell, 1985) means of making farming profitable and lucrative. Many poor smallholders cultivate poorer soil than their neighbors, which may have heavier infestations of weed or respond more slowly to CA (Govaerts et al., 2009b).

In this paper, a modest attempt has been made to review the current status of CA for weed concerns, weed seed ecology, and weed community ecology under the CT systems besides management options for its success.

2. GROWTH AND CONCERNS IN CA WORLDWIDE

Global demand for agricultural products is expected to double in the next decades, imposing tremendous pressure on land to produce more and more to cope-up with the demographic pressure unambiguously. The bulk of this increase has to come from developing countries, which host most biodiversity-rich areas of the planet (Baudron and Giller, 2014). CA stems from the fundamental rethink on the concept of tillage, involves major changes in cropping operations deflecting from the widely used tillage-based farming systems (Lumpkin and Sayre, 2009) and the stakeholders have realized the need of soil organic matter maintenance for attaining the sustainable crop productivity.

CT is practiced worldwide, predominantly in North and South America, but its adoption is also increasing in South Africa, Australia, and other semiarid areas of the world (Holland, 2004). Attempts made over the past four decades to develop ZT/RT seeding practices with possible crop residue retention led to an estimated area of 95 m ha under CA worldwide (Derpsch, 2005), with the United States sharing 21 million ha, followed by Brazil (Bernoux et al., 2006), albeit only 7% of the land was under CA (Friedrich and Kassam, 2009). In 2009, the coverage was 111 million ha (Derpsch et al., 2010), and 124.8 million ha (FAO, 2012b) in 2012.

Short- and long-term costs of production determined for four tillage systems on a corn farm showed that in the short term, total production costs were about 18% greater for the NT over the conventional system while long-term costs were equal (Mueller et al., 1985).

A significant change in winter wheat (*Triticum aestivum* L.)—fallow system to warm-season crops along with winter wheat and fallow in the semiarid Central Great Plains due to NT (Anderson, 2005) and a growing trend toward RT in cropping systems to allow stubble retention have been witnessed over the past decade. However, it would certainly alter weed management practices. Singh et al. (2010) have reviewed the current status of ZT in Rice–wheat cropping system of Indogangetic plains, and it is foreshadowing the age-old concept "more you till and more you harvest" (Sharma et al., 2013).

Modification of the microenvironment of seeds by RT, could influence the pattern of recruitment from the weed seedbank (Chauhan et al., 2006). Proponents of CA argue that weeds are only problems for the first 2 years and decline thereafter (Mashingaidze, 2013), if proper weed management is resorted with good crop stands CA crop yields can match conventional farming (Norwood, 1994; Mahajan et al., 2002). Six to seven weedings in the first year got reduced to three in the second season, and only two in the subsequent season (Wagstaff and Harty, 2010) for optimum crop yields in the semiarid districts of Zimbabwe.

Efficient weed management has been identified as a limiting factor in the adoption of CT systems (Buhler et al., 1994; Stevenson et al., 1998; Mas and

Verdu, 2003), as under noninversion tillage systems weed seeds are not buried when soil is inverted by the plough (Morris et al., 2010). Other than weed menace, the problems associated with the maintenance of crop residues in the field; in countries where there are alternate uses for the crop residues is also a serious concern. Although a consortia of chemicals are available in the market, the efficiency might be poorer than expected due to the presence of crop and/or cover crop residues. A thorough understanding of the weed and weed species ecology for weed management in CA are discussed in the ensuing paragraphs.

3. WEED SEED ECOLOGY

Understanding the ecological and evolutionary processes that dictate the establishment and proliferation of weed species is essential to formulate suitable management measures in CA. Weed seed ecology comprises of seed dormancy, germination, and weed seed recruitment. Seed dormancy may either be due to innate dormancy or induced due to depth of burial, and is related to seedling emergence. Seed size also determines the extent of density-dependent predation and the exploitation of buried seed. Dormancy (Forcella et al., 1992) is a common attribute of many weed seed populations and tillage can modify it by exposing seeds to short pulses of light needed as germination triggers (Milberg et al., 1996) as the interaction between soil thermal and hydric conditions decide its modification (Benech-Arnold et al., 2000), which might be a factor in CT. It hampers the task of predicting timing and extent of emergence of weeds under NT (Batlla and Benech-Arnold, 2007).

Depth-mediated variation in weed emergence obeyed sigmoidal–polynomial regression as excessive burial depth generally induced dormancy (in roughly 85% of cases) rather than suicide germination (Benvenuti et al., 2001). At 10 cm, only Johnson grass and velvetleaf emerged, albeit only in limited numbers. Species most severely inhibited by burial depth were buckhorn plantain, large crabgrass, common purslane, chickweed, and corn spurry, but not beyond 6 cm. Rate of seedling emergence decreased when depth of burial increased.

Explicit research work on seed longevity enhancement caused by seed burial after ploughing for many weed species can be found elsewhere (Roberts and Feast, 1973; van Esso et al., 1986; Ballare et al., 2008). However, it is worth noting that James and Rahman (2000) found that the relatively long persistence of viable ragwort seed in the surface layer of the soil posed management problems. Even if additions of fresh seed were eliminated, the remaining viable seed could still infest over a decade. A study in the Canadian prairies showed that more than 50% of green foxtail seeds were alive after 2 years when buried 10 cm in soil, in contrast less than 10% of seeds survived when they remained on the soil surface. Even when seeds were buried only 1 cm in soil, survival was still twofold greater after 2 years compared with seeds on the soil surface (Anderson, 2007).

Although, growth and fecundity of late-emerging weeds were reduced due to increased soil cover under CA besides, light interception by a crop canopy would shorten the critical period for weed control, the seeds produced from them might add to the soil seedbank. *Senecio vulgaris* was one such example to adjust its morphology to low light conditions through phenotypic plasticity (Baumann et al., 2001). Further, postdispersal seed predators may play a key role in the evolution of seed characteristics (Hulme, 1998) in CA.

3.1 Vertical Weed Seed Distribution

Spatial weed dynamics (Lutmen and Rew, 1997) determined the current and future weed density in CA, as the physical movement of seeds and propagules both within and between fields had profound implications (Marshall and Brain, 1999). While studying the vertical distribution of seeds in the soil, using data from nine studies in five European countries, Bekker et al. (1998) found significant correlations between seed shape and distribution in the soil. They could find a wide range of variations in depth distribution of individual weed species (*Ranunculus repens*, *Holcus lanatus*, *Juncus acutiflorus*, *Veronica spicata*, *Helictotrichon pratense* etc.) in species-rich grassland communities, understorey vegetation of a wood-land and young deciduous forest in the Netherlands. With the assembly of contributions by several authors that ZT determined vertical seed distribution in the soil (Froud-Williams et al., 1983a; Hoffman et al., 1998; Dorado et al., 1999; Torresen and Skuterud, 2002; Torresen et al., 2003), and has broken the links between the size and shape with the distribution (Ghersa and Martinez-Ghersa, 2000); In addition, seed heterogeneity in the vertical distribution in the soil profile (Traba et al., 2004) and their viability (Torresen et al., 2003; Carter and Ivany, 2006) due to NT has also been observed. However, their impact on weed seedling recruitment was poorly understood. Indeed seed burial was proportional to seedling recruitment (Chauhan et al., 2006).

Studies conducted elsewhere revealed that ZT facilitated weed self-death through environmental extremes and predation. Half of the weed seedbank was occupied by common Lambsquarters in an NT corn–soybean rotation at Fingal, Ontario (Clements et al.,. 1996). As much as 33% of seeds in the top 4 cm after tillage arrived from deeper layers (Mohler et al., 2006) as the vertical position of seeds in the soil was one of the critical factors governing the density of emerged seedlings. It is universally reported that weed seeds were present in the top few inches of soil under NT (Clements et al., 1996; Lyon et al., 1996; Swanton et al., 1999, 2000; Locke et al., 2002; Streit et al., 2002; Konstantinovic et al., 2010) and had 60% of the weed seedbank in the top 1 cm (Yenish et al., 1992), or 5 cm (Clements et al., 1996), while 90% in the 0- to 5-cm soil layer in a corn–soybean–winter wheat rotation at Delhi, Ontario (Swanton et al., 2000). Studies on wheat, sugarbeet, and Clover at Vojvodina too found weed seeds in the top layer of 0–10 cm, due to lack of deep cultivation (Torresen et al., 2003; Konstantinovic et al., 2010). As soil depth increased, concentration of weed seed declined logarithmically under NT (Yenish et al., 1992) at Ariington, the United States. A 6-year study in soybean/corn rotation and continuous corn rotation has found Foxtails (*Setaria* spp.) near the soil surface (Hoffman et al., 1998).

3.2 Weed Seedbank Dynamics and Seedling Emergence

In contrast to the modern tillage systems, the deep and frequent tilling of the soil stimulated the old and dormant seeds and exposed them to favorable conditions for seed germination. The weed seedbank refers to the resting place of weed seeds and forms an important component of the life cycle. Reviews on weed seedbank dynamics analyzed the significance of various crop management practices (Buhler et al., 1997; Christoffoleti and Caetano, 1998). Soil weed seedbank was found to obey negative binomial distribution (Chauvel et al., 1989), which refers to the reserves of viable seeds and vegetative propagules present (Ghosheh and Al-Hajaj, 2005) in the soil. It comprised of an inactive (McGraw and Vavrek, 1989) part and another active part that is ready for germination (Auškalnienė and Auškalnis, 2009). It develops either through (1) increase in amount from those weed seeds, which mature weed plants spread by wind and running water into soil, and (2) decrease by the amount which germinates or is lost due to activity of soil fauna. Evidence from NT systems further supported the hypothesis that changes in soil surface conditions may regulate the abundance of "safe sites" for weed establishment, thereby modulating the size of the effective seedbank (Gallandt, 2006). In annual and some perennial weed species that reproduce by seed only, seedbanks were the sole source of future weed populations (Torresen et al., 2003), which provided opportunities of prediction of weed species (Konstantinovic et al., 2010). When weed seeds entered the seedbank, several factors influenced the duration; (Gulden and Shirtliffe, 2009), e.g., they can sense the surrounding environment and use these stimuli to become dormant or initiate germination (Gulden and Shirtliffe, 2009) and they can germinate deep in the soil (Caroca et al., 2011). Depending on the viability of the buried seeds few may die within a short period, and rest can remain viable over decades.

In short, soil seedbank, an assortment of weed species, a major determinant for the succession of plant communities, and the species stratification depends on the composition and production of current and previous plant communities, as well as the longevity of seeds under local conditions, besides those brought in from surrounding areas (Parlak et al., 2011).

3.2.1 Crops and Cropping Systems

Weed seeds in NT corn field were found to be contagiously distributed and concentrated on the soil surface (Kellman, 1978). Weed seedbank of wheat-dominated rotation was higher than barley (Salonen, 1992) as plant density was positively correlated with previous or current year seedbank in a spring barley monoculture versus spring barley–red clover 2-year rotation (Legere et al., 2005a). Over 6 years, seedbank declined in NT from 41,000 to 8000 seeds m^{-3} (Murphy et al., 2006). Study over 9 years in France in a crop rotation has indicated that shallow ploughing enhanced seedbank density by fivefold, while deep ploughing by twofold only (Dessaint et al., 1997). Studies at Poland under four winter wheat tillage systems viz., monoculture with direct drilling into white clover mulch; monoculture with direct drilling into wheat stubble; monoculture with CoT and crop rotation with CoT revealed that presowing wheat tillage had prominent effect on weed seedbank than crop rotation (Wojciechowski and Sowiński, 2005). Diversified farming systems with several crop species might facilitate weed seed destruction by predators (Heggenstaller et al., 2006).

3.2.2 No Tillage

Despite the strong relationship between disturbance and average seed persistence, the latter in CoT was inversely related to the frequency of tillage (Ballare et al., 2008). The seedbank study revealed a significant increase in the number of weed seeds and species, mainly of annual grasses such as *Digitaria sanguinalis* and *Panicum dichotomiflorum*, in CoT and NT (Menalled et al., 2001). Positive relationship was noted among weed seed rain (16–77%), seedbank (12–78%), and seedling recruitment (32% of the emerged seedlings) in NT for the annual grasses viz., yellow foxtail, giant foxtail, and fall panicum (Webster et al., 2003). Obviously weed species assembly in NT and CoT had assorted weed species, confirming the ability of seedbanks to buffer disturbances across a variety of cropping systems (Legere et al., 2005a).

Although, NT favored seedbank to concentrate on the surface (Hoffman et al., 1998), the effective distribution in the soil depended on soil texture and seed characteristics. In general, NT likely favored the development of younger seedbanks, irrespective of soil texture (Benvenuti, 2007). If weed seed production is suppressed in the first few years of NT, the active weed seedbank would decline. Without tillage, weed seeds positioned deeper in the soil could not move to the soil surface and germinate to replenish the seedbank if the plants could produce seed (Shaw et al., 2012).

3.2.3 *Reduced Tillage*

Although, after 3 and 6 years with RT, more viable seeds were found in the upper soil layer (Torresen et al., 2003), they could not detect any consistency as tillage produced smaller differences in the weed seedbank in scattered years. Weed species that need light for germination were likely to become more dominant under RT. Similarly, species that require burial for germination may become less prevalent (Chauhan et al., 2006). Since a reduction in tillage enhanced seedbank density (Legere et al., 2011), floristic composition, and diversity of weed infestation depend (at least in part) on the soil seedbank in agroecosystems (Gulshan et al., 2013). Weed seed population persistence was an increasing function of disturbance frequency in soils and shallow disturbances, e.g., RT was more advantageous for weed seeds because they allow them to stay close to the surface and not miss any germination opportunity (Eager et al., 2013), however the chances of predation was also enhanced.

3.2.4 *Crops and Crop Rotations with Tillage*

A study by Medd (1990) over a period of 3 years revealed that the seedbank of wild oats in wheat in Australia oscillated irrespective of soil tillage. The effect of new seed was a major factor than the seedbank carry over. Tillage had a larger seedbank and more weed seedlings, especially in the upper 5 cm of the soil profile in previously tilled continuous maize cropping for 10 years at Hamilton (Rahman et al., 2000).

MT/NT over a decade in two crop rotations viz., continuous winter wheat and a pigeon pea/winter wheat 2-year rotation have shown that tillage influenced weed seedbank more than crop rotation, as expected. With NT, more than half of the total seedlings emerged from the surface layer, compared with an average 43% in other tillage systems. The weed seedbank was dominated by *Amaranthus retroflexus* (L.), under NT due to higher seedling recruitment from the topsoil (Barberi and Cascio, 2001).

NT seedbanks in a corn–soybean–wheat crop sequence were dominated by grasses and weed biomass showed a strong association of grasses with the corn phase of NT (Davis et al., 2005). The weed seedbank of a long-term tillage study in subarctic Alaska at the end of 10 years of continuous spring barley (*Hordeum vulgare* L.) resulted that NT had a significant effect on seed density of *Capsella bursa-pastoris* (L.), *Potentilla norvegica* L., *Hordeum jubatum* L., and on total seed density and the seed density was higher near the soil surface (Conn, 2006).

3.3 Weed Seed Predation

One potentially important ecosystem service in CA fields was the regulation of weeds by seed predation (Westerman et al., 2003a,b; Ichihara et al., 2011). Maintenance of 30% crop residues on the soil surface and the coexistence of different plant species provided a congenial environment for the proliferation of diverse weed seed predator populations viz., rodents, birds, ants, ground beetles, and crickets. A predation of 25–50% of weed seeds might be enough to curtail weed population growth substantially (Firbank and Watkinson, 1985) and the normal field weed seed predation rates can exceed this level (Bohan et al., 2011). The predation might occur either pre-dispersal while the seeds were still attached with the weed plants or post dispersal ("choke point" period in the weed life cycle), a form of biological means of keeping weeds under check could contribute significantly to weed population regulation (Ward et al., 2011) under NT.

Nonlinear relationship between the level of disturbance and predation was observed and the predation of common lambsquarters and barnyardgrass was highest in NT (32%) at southern Ontario. Predation inclination of crop residues in NT viz., corn residue, soybean, and wheat were akin to the other (Cromar et al., 1999). Baraibar et al. (2009) also found that NT increased seed predation in cereal production.

Rodents also have greater potential as seed predators in temperate ecosystems (Hulme, 1998). Minimal soil disturbance and surface deposition of weed seeds in NT and RT enhanced possibilities for seed predation and further secondary dispersal by animals (Baskin and Baskin, 1998). Species such as arthropods, birds, and mammals could also aid in restructuring weed communities in NT (Ghersa and Martinez-Ghersa, 2000). Although, in arid and semiarid ecosystems, ants (Hulme, 1998) were identified to be significant postdispersal seed predators, they merely act as seed dispersers in temperate ecosystems. However, Pullaro et al. (2006) noticed abundant fire ants under mulched cover and served as predators of weed seeds in killed cover crops *Mucuna pruriens* (L.) DC. var. utilis, *Vicia sativa* cv. Cahaba and *Secale cereale* L. in *Capsicum annuum* L. and *Brassica olaracea* L., acephala group fields in the south-eastern United States.

Heggenstaller et al. (2006) have shown that weed seed predation exhibited a temporal variation. Removal of *Abutilon theophrasti* and *Setaria faberi* seeds by predators measured in a 2-year (maize/soyabean), 3-year (maize/soyabean/triticale + red clover) and 4-year (maize/soyabean/triticale + lucerne/lucerne) crop rotations in Iowa, the United States has revealed that in maize and soyabean, seed predation was low, high and low in spring, summer and autumn respectively, whereas in triticale–legume it was high, low, and moderate. Possibilities of host preference and associated factors cannot be ignored.

3.3.1 Invertebrates and Vertebrates

More than three-fourth of weed seeds annually produced in cereals may not emerge as seedlings (Cardina and Norquay, 1997), probably due to weed seed predation (Westerman et al., 2003a.) by vertebrates and invertebrates in the CA fields. While studying the influence of weed seed predation by invertebrates and vertebrates in maize fields of southwestern Michigan, it was found that there was preferential predation by vertebrates upon seeds of *A. retroflexus* and *Chenopodium album*. However, in winter, significant seed predation by vertebrates on *A. theophrasti*, *C. album*, *Panicum dichotomflorum*, and *Setaria lutescens* except *A. retroflexus* was detected (Marino et al., 1997).

A comparison between weed seed (*D. sanguinalis*, *S. faberi*, *A. retroflexus*, and *A. theophrasti*) predation by invertebrates and vertebrates in southern Michigan showed a high degree of variability in seed predation (Menalled et al., 2000) as there existed variation in the abundance and availability of weed food resources between fields (Moorcroft et al., 2002). Many insects were found to dominate under conservation farming, which feed on weed seeds. For example, large ground beetles (F. Carabidae: O. Coleoptera) (Brust and House, 1988; Titi, 2003), *Harpalus rufipes* DeGeer

(Westerman et al., 2003b), fire ants on seeds of *A. retroflexus*, *Poa annua*, *C. album*, and *Solidago altissima* (Seaman and Marino, 2003) etc.

The invertebrate seed predator activity density would be higher in NT cropping systems. Postdispersal seed predation by vertebrate and invertebrate granivores might cause high rates of seed mortality in a wide range of cropping systems, but seed dispersal asynchronous with predator activity, and seed burial, may limit the overall effect on the seedbank (Gallandt et al., 2005) and *C. album*, *Sinapis arvensis*, *Stellaria media*, and *Polygonum aviculare* in spring barley were predated by invertebrates (Mauchline et al., 2005). *Gryllus pennsylvanicus* (Orthoptera: Gryllidae), the most abundant invertebrate seed predator, was trapped more often in maize than soybean and least often in triticale–alfalfa and alfalfa. Predation of *S. faberi* seeds by invertebrates was higher in maize and soybean compared to triticale–alfalfa and alfalfa and there were higher predation rates in RT soybean (O'Rourke et al., 2006). In contrast to all the above findings, Cardina et al. (1996a) could not detect any measurable variation in predator populations between NT and moldboard plough in corn suggesting that soil disturbance might not affect the weed seed predator community rather crop diversification in terms of monocrop heterogeneity and intercropping enhanced carabids (Kromp, 1999).

3.3.2 Arthropods

Abundance of arthropods and other invertebrates was noticed in CA fields (Stinner, 1990) and they interact with weeds in agricultural systems directly serving as food sources etc. (Norris and Kogan, 2005). Carabid beetles were important predators of arthropods and weed seeds in annual crops but may be limited due to soil disturbances. The spring breeders *Poecilus chalcites*, *Harpalus herbivagus*, and *Agonum cupripenne*, and the phytophagous fall breeder *Harpalus pensylvanicus* occurred in greater proportions in the crop areas in a soybean–oats–corn rotation (Carmona and Landis, 1999).

Significantly, more ground predators were found in the weedy and clover plots (Altieri et al., 1985) of corn, tomato, and cauliflower in California as vegetation had a significant influence on the predation rates, with maximum rates at a medium-dense plant cover (Navntoft et al., 2009). A negative exponential relationship existed between activity density of carabids and aphid density (Hajek et al., 2007) in three NT fields with canopy closure in Soybean. Surface residues could affect the abundance of several arthropods viz., carabids, wolf spiders, and crickets. *Amara*, *Anisodactylus*, *Harpalus*, *Calathus*, and Crickets (Orthoptera: Gryllidae) were more common under NT conditions. Wolf spiders (Araneae: Lycosidae) were also common where there was a previous cover crop (Davis et al., 2009a).

3.3.3 Carabids

Carabid beetles comprise a diverse and ubiquitous family of insects and are important in conservation biology and often have close associations with particular habitat types, making them useful biomonitoring organisms. Many carabids are also important biological control agents due to their predatory habits, but feeding habits within the family are quite diverse, and seed-eating or granivorous carabids can play an important role in shaping plant diversity and distributions (McCravy and Lundgren, 2011). They have bioindicative value as they were enhanced by RT systems and their assemblages were not bound to any specific crop. However, carabid beetles may be very localized even in agricultural habitats (Kinnunen et al., 2001). Intercrops of canola and wheat have the potential to enhance populations of some carabid species (Hummel et al., 2012).

In laboratory studies, the carabid beetle *Amara cupreolata*, the slugs *Arion subfuscus* and *Deroceras reticulatum*, and cutworms (*Agrotis ipsilon*) consumed imbibed velvetleaf seeds (Cardina et al., 1996a).

Ground-dwelling invertebrates (Shearin et al., 2007) were the dominant seed predators and were responsible for 80–90% of common lambsquarters and barnyardgrass seeds consumed at southern Ontario (Cromar et al., 1999) and these beetle banks contribute to conservation of biodiversity in agroecosystems (MacLeod et al., 2004).

Bohan et al. (2011) have found that carabids can elicit regulatory effects on moncotyledon and total weed seedbanks from fields undergoing management by farmers. Contrasting cover-cropping systems were compared to determine whether fundamental differences in cover-cropping strategies affect weed seed predators and resulting seed predation. The predominant invertebrate seed predator, the ground-dwelling carabid beetle, *H. rufipes*, was more abundant in red clover (Gallandt et al., 2005). Tillage has generally been shown to have a negative effect on ground beetles, but it is not known whether this is because of direct mortality or the result of indirect losses resulting from dispersal caused by habitat deterioration (Shearin et al., 2007).

Rotary tillage and moldboard plowing reduced the activity density of weed seed predators viz., *H. rufipes* DeGeer, *Agonum muelleri* Herbst, *Anisodactylus merula* Germar and *A. cupreolata* Putzeys and *Pterostichus melanarius* Illiger in the northeastern United States, respectively and confirmed the need to consider both direct and indirect effects of management of invertebrate seed predators (Shearin et al., 2007).

Activity density, species richness and diversity of carabids in RT corn showed that severe drought nullified the weed-type preference of carabids. However, normal rainfall favored predation of broad-leaved weeds (Pavuk et al., 1997). Further, in a rain-fed cropping system from a crop rotation of barley (*H. vulgare* L.), wheat (*T. aestivum* L.), spring dry pea (*Pisum sativum* L.) found more beetles in CT than in NT because of the dominance of *Poecilus scitulus* in CT, whereas species richness and biological diversity were generally higher in NT. The dominant weed species were *P. scitulus* L., *Poecilus lucublandus* Say, *Microlestes linearis* L., *P. melanarius* and *Calosoma cancellatum* (Eschscholtz). All species responded idiosyncratically to tillage (Hatten et al., 2007). Cover crop systems were investigated for activity-density (a function of movement and density) of carabids *H. rufipes* DeGeer in pea/oat–rye/vetch cover crop. Pea/oat–rye/vetch cover crop systems were apparently beneficial for *H. rufipes* during the cover crop year as well as planted into cover crop's residues. It was inferred that some level of disturbance might be beneficial for *H. rufipes*, but the mechanism was not clear (Shearin et al., 2008). Peak activity-density of *Amara aenea* was found in the mustard/buckwheat/canola and *H. pensylvanicus* in oat–pea/rye–hairy vetch than in soybean with seed predation rates between 38% and 63% suggesting that cover crops had a positive effect on the activity-density of *carabids* and that disturbance negatively influenced their activity-density in the absence of cover crops (Ward et al., 2011).

4. WEED COMMUNITY ECOLOGY IN CA

The study of weed community ecology is an important aspect to be studied for devising appropriate management strategies in CA, involves aspects of species life forms, diversity, and spatial and temporal variability (Derksen, 1996) in man-engineered ecosystems. Increasingly, research suggests that the level of internal regulation of function in agroecosystems is largely dependent on the level of plant and animal biodiversity present (Altieri, 1999), which is mediated through CA. As weed populations can readily adapt to new environments because of their diversity (Harker, 2004), there always seems to be a weed species or biotype that can adapt to and thrive in the agricultural environments man has created. Conservation of weed diversity on agricultural systems is of great importance as plant diversity is generally low and mostly enhanced by weed occurrence (Plaza et al., 2011), the complex interactions of biotic and abiotic ecological processes result in heterogeneos and dynamic landscapes, which are further influenced by the pattern of exogenous environmental drivers (Crossman et al., 2011) in CA fields.

Sicklepod growing alone in fallow plots produced more seeds per plant, resulting in significantly more seedlings than sicklepod growing in a peanut–cotton–corn cropping system. Sicklepod growing in corn produced the fewest seeds per plant (Johnson et al., 1994) suggesting that the weed ecology in fallow fields cannot be compared with crops in CA.

4.1 Weed Diversity

Derksen et al. (1995) has shown that after 5 years of ZT, MT, and CoT, community diversity remained unaffected. Effect of differences in relative community composition were apparent only upto the application of herbicides. NT had a more heterogeneous distribution of species suggesting that tillage reduced the diversity of weeds (Zelaya et al., 1997).

Corn–soybean–wheat with NT at Michigan, the United States has shown that species density and diversity were intermediate in the NT over CoT (Menalled et al., 2001). Short-term changes were related to the adoption of a particular tillage system, like shifts on the disturbance regime, may be cumulative and could not generate a response in weed diversity (Smith et al., 2009) only and so long-term studies are needed.

Tillage had little effect on weed diversity indices but had a more major role in determining weed community composition (Legere et al., 2005a). This instability might be either from overcompensating yield–density responses or from threshold management (Freckleton and Watkinson, 2002). Tillage had the largest effect on weed diversity and density in continuous corn, corn–soybean, corn–soybean–winter wheat rotations at Ontario. NT promoted the highest weed species diversity and followed the ecological succession theory (Murphy et al., 2006). Observations of Blackshaw et al. (2001) and Gruber et al. (2000) have indicated the weed diversity in NT, while Derksen et al. (1995) could find inconsistency in the pattern. Changes in the physicochemical soil characteristics of fields converted to direct drilling for several years may affect the composition of weed communities through a filtering of species according to their ecological requirements (Dickey et al., 1994; Stavi et al., 2011).

Seedbanks in NT and CoT had more distinctive species composition in spring barley–red clover cropping systems with higher diversity indices in

NT. Weed species assembly has shown little discrimination, confirming the ability of seedbanks to buffer disturbances across a variety of cropping systems (Legere et al., 2005a).

Both RT (Zelaya et al., 1997) and NT increased species diversity (Murphy et al., 2006; Gruber et al., 2000; Blackshaw et al., 2001) however, the number of weed species in the NT decreased with NT from second year onward (Ngouajio et al., 2003). However, Derksen et al. (1995) could find inconsistency in this pattern. CT practices over 23 years did not represent any concern for weed diversity conservation in cereal–leguminous rotations in the conditions of central Spain (Plaza et al., 2011). Community composition of the soil seedbank characterized for 35 years in continuous corn, corn–soybean, corn–oat–hay with CT, MT, and NT have shown that species diversity (richness, evenness and the Shannon–Weiner index) was found to be influenced by crop rotation rather than tillage. Species richness was indirectly proportional to soil disturbance (Sosnoskie et al., 2006).

4.2 Weed Spatial Distribution

The importance of spatial distribution in weed populations (Dessaint et al., 1991), for long-term weed management has drawn attention over the years. This is an important variable in the interactions among plants, influencing competition, survival, fecundity, and propagule dispersal (Cardina et al., 1996b). The current weed management methods have largely considered the distribution of weeds in cultivated fields as uniform distribution and accordingly weed management strategies (Gonzalez-Andujar and Fernandez-Quintanilla, 1993) have been devised, however, the patterns are not random (Gonzalez-Andujar and Saavedra, 2003). Changes in the spatial pattern of weed seedling emergence could happen quickly following NT (Lemerle et al., 1996). Results from long-term study in Italy has shown that the species linked to soil disturbance were annual weed species and in particular *Amaranthus* spp., *C. album*, and *Echinochloa crusgalli* (Zanin et al., 1997). Studies on a permanent field experiment in rice–wheat, revealed that density of weeds was maximum in CT–CT and it was distributed in all soil depths being more in 5–10 and 10–15 cm soil depths. In ZT–ZT and CT–ZT, density of weeds was minimum and concentrated in 0–5 cm soil depth (Punia et al., 2005). Phytotoxicity from red clover residues, the differential suitability of crop residues in different rotations as habitat for seed predators contributed to changes in giant foxtail demography (Davis and Liebman, 2003).

4.3 Weed Community Heterogeneity

A shift in the spectrum of weeds toward grassy weed species was imminent due to noninversion tillage from predominantly broad-leaved weeds since shallow tillage systems encourage their survival and germination (Froud-Williams et al., 1983a,b; 1984). When NT/RT is used, the density of certain annual and perennial weeds could increase (Moyer et al., 1994). The perennial species, field horsetail, quack grass, white clover, and perennial sowthistle were more frequent aboveground than in the seedbank, so also for annuals such as common hemp nettle, sun spurge, catchweed bedstraw, and grasses. Plant density was positively correlated with previous or current year seedbank in a spring barley monoculture versus spring barley–red clover 2-year rotation (Legere et al., 2005b).

However, Farooq et al. (2011) while reviewing ZT/RT over CoT found inconsistency on weed pressure in diversified cropping systems. Densities of some biennial and perennial weeds have increased with ZT in Canada. Additionally, winter annual weeds that emerge in fall and survive cold Canadian winters often became more prevalent with CT, perhaps due to the combined effect of less fall tillage and the insulating effect of increased snow cover facilitated by standing crop stubble. Summer annual weeds with wind-disseminated seed capable of germinating on or near the soil surface sometimes increased with ZT. However, densities of many other annual weeds declined markedly with CT (Blackshaw and Moyer, 2006).

Tillage practices altered the weed community heterogeneity (Zanin et al., 1997) and so tillage was recognized as one of the primary factors that changes weed communities (Owen, 2008). Several studies have documented that NT increased the density of perennial weeds (Buhler et al., 1994; Bryson and Hanks, 2001; Torresen and Skuterud, 2002). In contrast, Derksen et al. (1993) concluded from several experiments that an increased association of perennial and annual grasses did not generally occur. A switch from CoT to CT altered the weed species composition and temporal pattern of emergence of weeds (Samarajeewa et al., 2005). The increase in weed species diversity resulted from 20 species being associated with NT over 6 years, 15 of which were winter annuals, biennials, or perennials (Murphy et al., 2006).

Froud-Williams et al. (1983b) found numerous annual grass weeds viz., *Alopecurus myosuroides* and *Poa* spp.under NT and MT together with perennial and wind-borne species in the former. In contrast, annual dicotyledonous species, in particular *Polygonum* spp., *Anagallis arvensis* and *Viola* *arvensis* occurred more often on CoT. Inferences drawn by Torresen et al. (2003) indicated that perennial weeds and overwintering weed species increased with RT as compared to CoT and obviously NT dominated with grassland perennials.

Wind-disseminated horseweed, a common plant along roadsides and field edges could easily establish in NT (Regehr and Bazzaz, 1979; Bhowmik and Bekech, 1993; Buhler and Owen, 1997; Weaver, 2001) and may behave either as winter or summer annual (Regehr and Bazzaz, 1979; Buhler and Owen, 1997; Davis and Johnson, 2008).

4.4 Tillage Systems in Cropping Systems

4.4.1 Zero Disturbance Systems

Since inversion is zero in NT, deposition of a greater proportion of weed seeds near the soil surface had various implications for weed abundance. Results of 8-year-long study have shown that the tillage systems profoundly altered the weed community: in undisturbed soils *D. sanguinalis*, *Conyza canadensis*, and *Kickxia elatine* were increased (Zanin et al., 1997). Irrespective of the wheat-based crop rotation, ZT registered maximum weed density at Alberta. Dandelion and perennial sowthistle were increased in MT and ZT. However, flixweed, field penny crees, wild buckwheat, and common lambsquarters were reduced under ZT, besides an increase in downy brome, red pigweed, and Russian thistle was noted (Blackshaw et al., 1994).

Evaluation of the effects of CT (RT and ZT with glyphosate) on the weed density in barley (*H. vulgare* L.), canola (*Brassica campestris* L.), and wheat (*T. aestivum* L.) after 5 decades resulted in a trend: ZT > RT > CT (broad leaf population) implying that relative contribution of the broadleaf weeds was proportional to tillage intensity. Species diversity of the broadleaf and total populations exhibited a relatively greater proportion of common and rare species under the CT and ZT, respectively (Gill and Arshad, 1995).

Annual weed species such as *Apera spicaventi*, *C. album*, *Erysimum cheiranthoides*, *Galium aparine*, *Matricaria perforata*, and *Silene noctiora*, besides, perennials like *R. repens*, and *Sonchus arvensis* were found to be dominated by NT under Spring-sown barley (*Hordeum distichon* L.) and oats (*Avena sativa* L.) crop rotations (Bostrom and Fogelfors, 1999). Domination of annual grasses such as *D. sanguinalis* and *P. dichotomiflorum* (Menalled et al., 2001) was noted in NT corn–soybean–wheat at Michigan.

Tillage frequency studied in a 3-year rotation (wheat–vetch (green manure)–cotton–barley) resulted in decrease in frequency and species density under NT. Perennial weed density dominated under NT. The number of species was not altered in CT and MT, but was decreased in NT. In winter crops, annual species under CT and MT, and perennial species under NT were observed. In cotton, perennial species under CT and MT, and annual species under NT were observed (Bilalis et al., 2001). Greater weed densities in ZT than MT/CoT in a long-term study on a winter wheat-based (*T. aestivum* L.) cropping systems was noticed. Russian thistle, downy brome, kochia, and *A. retroflexus* L. were associated with ZT while *Polygonum convolvulus* L., *C. album* L., flixweed, and *S. arvensis* L. were associated with CoT. Perennials such as dandelion and perennial sowthistle were associated with ZT but Canada thistle was associated with CoT (Blackshaw et al., 2001).

More number of weeds were noticed on the soil surface (Cardina et al., 2002) in an 8-year-long-term study and it lowered down with increasing depth of soil profile in a Pearlmillet-wheat cropping sequence in India (Yadav et al., 2005). ZT recorded significantly lower population of *Phalaris minor* than CoT in wheat under farmers' fields in Haryana, India, however, the density of broad leaf weeds was significantly higher under ZT (Sharma et al., 2004; Kakkar et al., 2005). Dominating weed species in CT-based wheat cultivation systems at Poland were *C. album* L., *A. retroflexus* L., *A. spicaventi* L., *Lamium purpureum* L., and *V. arvensis* Murr. (Wojciechowski and Sowiński, 2005).

The main species of weeds were crabgrass and panic grass, while three-colored amaranth and Common purslands were secondary at China in a loamy soil in a corn field for both CT and CoT (Kecheng et al., 2006). Prevalence of *A. spicaventi*, *L. purpureum*, and *V. arvensis* were typical for direct drilling of wheat in Poland (Wojciechowski and Sowiński, 2005), while *Phalaris minor*, *Rumex dentatus*, *Medicago denticulata*, *Melilotus alba*, and *Coronopus didymus* were dominant at Haryana, India (Chhokar et al., 2007), besides carpetweed (*Trianthema portulacastrum*) in Mungbean in Haryana, India (Kumar et al., 2005).

Though ZT does not build up a soil seedbank from the first harvest of rape crop, it enabled the growth of volunteers. If an outcrossing into neighboring rape crop need to be prevented ZT should be avoided (Gruber et al., 2004).

Weed management system studied for a decade in NT corn in wheat-corn double cropping in north China revealed that weeds emerged earlier than corn and most of them were above three to four leaf stages before corn emerged in ZT corn, furthermore perennial weeds increased after several years of ZT, made weed management difficult (Xiangju et al., 2006). In the weed seedbank of a wheat–maize rotation, the highest number of weed seed was found under CoT. *Chenopodium album* was a dominant species irrespective of tillage. *Poa annua* was the most important species associated with NT weed seedbank followed by *Cichorium intybus* L. and *Sonchus* spp., whereas the CT weed seedbank was dominated by *Euphorbia helioscopia* and *E. crusgalli* (L.) P. Beauv (Caroca et al., 2011).

Wrucke and Arnold (1985) have found that population of grassy weed *Setaria viridis* was higher under NT in corn–soybean rotation over 5 years. Fresh weed biomass was higher in the ZT in Maize at Pakistan (Gui et al., 2011) and *Polygonum pensylvanicum*, *Polygonum persicaria*, *Polygonum orientale*, *Oldenlandia diffusa*, *Cynodon dactylon*, and *D. sanguinalis* were dominant (Mukherjee and Debnath, 2013) in tarai region of West Bengal, India. Yadav et al. (2005) could not notice any major change in the composition of weed flora due to ZT in a Pearl millet–Wheat cropping system. Grassy weeds were less and broadleaf weeds were more under ZT as compared to CoT. Under CT, there were volunteer wheat plants in the summer corn field.

4.4.2 Reduced/Minimum Disturbance Systems

RT may influence weed frequency through modification of microenvironment of seeds in the soil. Buhler et al. (1994) have noticed greater and more diverse populations of perennial weeds under RT systems in corn–soybean rotations.

Buhler (1995) found that the densities of large-seeded dicot species often decreased under RT in corn–soybean rotation as minimizing soil disturbance affected the composition of weed communities (Zanin et al., 1997), e.g., small-seeded weeds, such as pigweeds, emerged only from shallow burial depths (0.5–2.5 cm) (Buhler et al., 1996; Ghorbani et al., 1999; Oryokot et al., 1997). Torresen et al. (1999) found that due to survival of more weeds to the next growing season more seeds were produced as compared to autumn ploughing at Norway. An increase in the prevalence of weeds was observed in RT wheat (Samarajeewa et al., 2005) as replacing inversion tillage by RT increased weed pressure (Baudron et al., 2007).

Field study over 7 years in south-western Slovakia in maize with RT indicated that CoT significantly reduced perennial weed population. Only 2.6 perennial weed plants per quadrant in CoT as compared to 7.5–9.0 in RT (Demjanova et al., 2009) was found. A 4-year study near Barcelona in a rotation of winter crops (pea: *P. sativum* L., wheat: *T. aestivum* L., wheat–barley: *H. vulgare* L.) on a deep silty loam soil with RT/NT recorded higher biomass of *Avena sterilis* L. under RT, while *Diplotaxis erucoides* (L.) DC and *Sonchus tenerrimus* L. under NT (Mas and Verdu, 2003). RT systems were found to affect the development of weed populations of maize crops under the humid, temperate climate of Europe at Swiss midlands in a winter wheat (*T. aestivum* L.)—oil seed rape (*Brassica napus* L.)—winter wheat–maize (*Zea mays* L.) crop rotation. Perennial weeds such as *Epilobium* spp. L. and *S. arvensis* L. were related to NT, and annual broad-leaved species were associated with MT and CT (Streit et al., 2002).

Since many fields of wheat (*T. aestivum* L.) and sunflower (*Helianthus annuus* L.) in Spain have been converted to NT or RT, perennial weeds such as *C. arvensis* became more troublesome since they cannot be controlled by NT (Jurado-Exposito et al., 2005).

4.5 Weed Population Shift

Many researchers (Froud-Williams et al., 1981, 1983a; Hinkle, 1983; Koskinen and McWhorter, 1986) could identify the potential "weed shifts" under CT. Glenn-Lewin and van der Maarel (1992) was of the opinion that in vegetational fluctuations, changes in floral composition were not irreversible, whereas they are unidirectional and continuous in a succession where changes are permanent. Field experiments on NT soybean has witnessed a shift from horseweed to goldenrod within first 2 years itself (Kapusta and Krausz, 1993). Weed shift has been clearly differentiated by Swanton et al. (1993) as weed succession, fluctuation and weed shift deduced from 123 references. The impact of changing management regimes on weed abundance cannot be predicted and the weed population dynamics may show chaotic dynamics (Freckleton and Watkinson, 2002). Undoubtedly, a change in soil tillage led to shift in weed flora composition (Conn, 2006; Montanya et al., 2006).

Weed seedbanks reflect past weed populations and management practices and are the source of future weed infestations. Adopting NT increased weed seed exposure to predators (ants, beetles, etc.) and retention of crop residues could suppress weed seedling emergence. Rotation of tillage or crop could also be adopted to deflect the "trajectories" of weed population shifts (Chauhan and Johnson, 2010). Sharma et al. (2013) has found that in the Vertisols of Jabalpur, India, NT significantly increased the population of *V. sativa*, but reduced the population of *C. album*.

The minimized soil disturbance would cause major changes in weed population dynamics (Buhler, 1995). Over 60% of the cropped lands on the Canadian Prairies follow RT practices and concerns regarding potential shifts in weed communities was felt (Gill and Arshad, 1995). Crop management practices have major impacts on seedbank processes in annual weed species and regulate the development of weed communities. Altering tillage practices changed patterns of soil disturbance and weed seed depth in the soil, which played a role in weed species shifts (Buhler et al., 1997). Later Zanin et al. (1997) too opined that "ecological successions" are among the most promising in terms of evaluating, if floral changes under RT are simple vegetational fluctuations or an ecological succession. With CoT, seedbank of the weeds buried over seasons in subsurface soil layers comes to the surface. Both long-term trials and farmer surveys suggested a change in the weed spectrum in ZT wheat and lesser soil disturbance (Malik et al., 1998). They found an increase in the density of broad leaved weeds. Presumably, the main variables explaining weed distribution in a survey was the tillage system in Soybean (de la Fuente et al., 1999). Torresen and Skuterud (2002) observed a shift in weed composition i.e., more winter annual, biennial, and perennial, weed species with RT systems in five long-term field trials. ZT typically reduced the incidence of weeds in the wheat crop (Malik et al., 2004)—primarily due to the early emergence of wheat. RT practices on the Canadian Prairies witnessed potential shifts in weed communities as a result of changing tillage practices. Perennial species such as Canada thistle and perennial sowthistle were associated with RT/ZT, but annual species were associated with a range of tillage systems. Russian thistle was abundant in the ZT group and wild buckwheat and common lambsquarters were equally abundant in all tillage systems (Thomas et al., 2004). Weed species shifts were noted in Great Britain where tillage was reduced for small grain production and also in Alaska (Conn, 2006). While monitoring weed populations in France, Fried and Reboud (2007) revealed that a large range of species with a continuous shift in weed communities in oilseed rape and about 30% of the increasing species have been selected by cultivation methods. But the possible homogenization of the weed flora could be due to the extension of some rotations including summer crops (maize, sunflower), which could favor the species able to rebuild their soil seedbank every year (Owen, 2008). However, the long-term site where ZT has been practiced for many years has seen no major shift in weed flora (Singh et al., 2010). The adoption of CT and single herbicide mode of action has hastened several important weed population shifts (Owen, 2008). Rotation of tillage or crop could also be adopted to deflect the "trajectories" of weed population shifts (Chauhan and Johnson, 2010).

5. WEED MANAGEMENT IN CA

Effective weed management has been identified as a limiting factor in the adoption of CT systems (Mas and Verdu, 2003) and understanding the effects of cropping system characteristics on entire weed life cycles would facilitate the design of integrated suites of complementary weed management tactics (Davis and Liebman, 2003) in CA. Manipulation of cropping systems to improve weed management requires a better understanding of how crop- and soil-related factors affect weed life cycles (Davis and Liebman, 2003). Understanding how the different tillage systems affect weed evolution could be decisive for organizing more effective weed management programs (Swanton et al., 1993).

Knowledge of seedling emergence is critical for improving weed management strategies (Buhler et al., 1996; Forcella et al., 1992, 2000; Myers et al., 2004). This includes determining the effect of tillage and crop canopy formation on seedling emergence (Jha and Norsworthy, 2009). A successful management system should increase the seed mortality; manipulate the germination and emergence of weeds and remove sufficient amount of the above ground biomass (Riemens et al., 2007). Postdispersal seed predation is an important source of mortality for arable weed populations that can potentially contribute to ecologically based management strategies in CA (Heggenstaller et al., 2006). Considering the awareness of the dangers associated with sole reliance on herbicides for weed management in agriculture, and interest has shifted toward various approaches and one such possible alternative approach is the management of the weed seedbank (Bellinder et al., 2004). A thorough understanding of the weed population dynamics under modern tillage systems is essential (Samarajeewa et al., 2005) in order to achieve successful weed control without using herbicides under a sustainable soil management system.

5.1 CA Components in Weed Management

5.1.1 Cover Crops

The practice of raising allelopathic cover crops in RT/ZT cropping systems might prove better through the release of allelopathic chemicals, an ecological way of weed management. This hypothesis was strengthened by Putnam et al. (1983) that the residues of certain fall-planted cereal and grass cover crops significantly reduced dry masses of weeds in the following summer. Studies conducted elsewhere have indicated that cover crops may suppress weeds either by resource competition or alleopathic interaction, albeit their effect is often inconsistent (Moore et al., 1994). NT along with rye, crimson clover, and subterranean clover curtailed weed biomass between 19% and 95% than CoT without cover crops. Weed biomass was eliminated or nearly eliminated in all cover systems with pre- plus postherbicide in an NT corn at North Carolina (Yenish et al., 1996). The prolonged effect cannot be expected and herbicide usage might be necessary. The herbicide desiccated cover crop effect of weeds might also vary. The effects of mulches of cover crops have dissimilar effects on weeds and subsequent crops: in general, broad leaved weeds were more susceptible to mulch effect than grassy weeds (Einhellig and Leather, 1988), whereas growth of large-seeded crops (maize, cucumber, pea, and snapbean has been less affected than that of small-seeded crops like carrot, tomato, and lettuce (Putnam et al., 1983). Winter cover crops with extended weed suppression potential may also serve as potential options in NT. Subterranean clover cover crop is an example, which decreased weed seedbank density as compared to cover crops (Moonen and Barberi, 2004). However, Bellinder et al. (2004) has proved that a rye cover crop did not deter seed return or recruitment to the seedbank as much as the legumes did.

The activity–density of invertebrate seed predators in CA systems indicate that cover-cropping strategies should focus on late-season weed management to provide desirable habitat for invertebrate predators (Gallandt et al., 2005). The inclusion of high-residue cover crops (in a mixture of crimson clover (*Trifolium incarnatum* L.), fodder radish (*Raphanus sativus* L.), and white lupin (*Lupinus albus* L.) prior to corn and rye (*Secale cereale* L.) and black oat (*Avena strigosa* Schreb.) mixture before cotton) into a CT system at Alabama, the United States showed that weed seeds can be reduced within the upper 7.6 cm of the soil seedbank (Kelton et al., 2011) only.

5.1.2 Crop Residues

Similar to cover crops where allelopathic potential has been explored, crop residues followed the suit. Residues of fall-planted/spring-killed rye reduced total weed biomass over bare-ground controls through allelopathy, and also mulching effect, contributed to weed control (Barnes and Putnam, 1983). Weed suppression effects of cover crops was due to competition for natural resources such as light, soil moisture, and nutrients (Teasdale and Mohler, 2000). Previous crop residues in NT probably made it more difficult for weeds to germinate as compared to MT and CT systems (Johnson et al., 1993), besides allelopathy (Chauhan et al., 2006). This might be an in-built mechanism of weed management in CA. Response of *C. album* emergence due to corn residues and tillage has shown temporal variation (Buhler et al., 1996). It acts as a physical barrier and can exert weed suppression by intercepting solar radiation (Altieri et al., 2011).

Globally, there is mounting evidence that retention of crop residues from one season to the next suppressed the germination and development of weeds in RT, thus enhancing system productivity, however, Mashingaidze et al. (2009) could find significant effect for retention of neither maize nor sorghum residue on weed biomass on both the clay loam and sandy soils at Zimbabwe. In contrast to the above, the presence of previous crop harvest residues suppressed weeds in Maize under rainfed conditions at Zimbabwae (Muoni et al., 2013).

5.1.3 Crop Rotation and Diversification

Crop rotation has traditionally been regarded as an important strategy for weed control (Froud-Williams, 1988), which had an important role in deciding the weed flora composition especially in CT in a study on continuous corn (Ball and Miller, 1993) and reduced weed density and maintained species diversity, thus preventing the domination of a problem weeds (Doucet et al., 1999). Cropping system diversity is regarded as the proactive weed resistance management (Beckie, 2009), because cropping sequence dictated other agricultural management practices, variations in weed populations between cropping systems may be either the direct result of crop rotation itself, or weed management practices associated with crop rotation, or both.

In one of the most popular double cropping of winter wheat–summer corn in north China, corn was either sole planted in standing wheat or immediately after wheat under NT. Weeds emerged before wheat harvest continued their life cycle were more competitive and corn yield reduced (Xiangju and Binghua, 1998). Results of a 10-year crop rotation study to understand the dynamics of the standing weed vegetation in *Z. mays* L., *Glycine max* L., and *T. aestivum* L is worth mentioning. In the 10th year, when all plots were sown with *Z. mays*, few cumulative effects of crop rotation were apparent, with few exceptions (Doucet et al., 1999).

Surveys have shown that there has been a dramatic decrease in the weed density (Teasdale et al., 2004) and flora of fields under rotational cultivation (Hald, 1999). Effectiveness of a short-term management decision depends on the choice of the rotation and its elasticity patterns. Effectiveness of decreasing seedling survival in one crop may be more in a particular rotation and may not suit for the other. Phase-wise (Year of rotation) variation might also be visible. However, highest elasticity would be the best or vice versa (Mertens et al., 2002). Diverse rotations that exploit multiple stress and mortality factors, including weed seed predation, could contribute to the effective weed suppression with less reliance on herbicides (Westerman et al., 2005).

RT with a good crop rotation might reduce weed density (Murphy et al., 2006), however, crop rotation had insignificant influence on variability of species richness in maize (Demjanová et al., 2009). A 9-year study initiated in 1988 at Delhi, Canada, on a loamy sand soil to evaluate the effect of tillage systems viz., CoT and NT and cover crops (only in NT) on winter wheat (*T. aestivum* L.)/bean (soyabean (*G. max* L. Merr.), white bean (*Phaseolus vulgaris* L.), and kidney bean (*P. vulgaris* L.)/winter wheat rotation (NT had rye (*S. cereale* L.) or maize (*Z. mays* L.) as cover crop) showed that weed densities were unaffected either by tillage or cover crops in wheat but, in the beans, densities were greater in the CT than in the NT (Shrestha et al., 2002).

A 4-year study on plant and seedbank density examined to study the effects of crop rotation (spring barley monoculture vs spring barley–red clover 2-year rotation), tillage (moldboard plow, chisel plow, NT), and weed management (intensive, moderate, minimum) for 19 weed species, showed that although, species density regulated by weed management, the relative frequency (difference between aboveground and seedbank frequency) was influenced by rotation (Legere et al., 2005a). Koocheki et al. (2009) has reviewed the effect of cropping systems and crop rotations on weeds. Results of a literature survey indicated that weed population density and biomass production may be markedly reduced using crop rotation (temporal diversification) and intercropping (spatial diversification) strategies (Liebman and Dyck, 1993).

Although, Davis et al. (2007) could not notice any advantage in rotating corn with soybean versus continuous soybean to reduce horseweed in NT in the initial years, after third and fourth year a soybean–corn rotation consistently lowered horseweed densities compared to the continuous soybean rotation (Davis et al., 2009b). Crop rotations have a say on weed population dynamics and it is an important tool for managing weed populations. The possibility might be the diversity of environments caused by crops that a weed population encounters. Other than the number of crops, the sequence of crops could play a lead role (Mertens et al., 2002). Crop rotations, by altering the weed seedbank community, can lead to improved weed management strategies. Rotational crops significantly increased both the weed seedbank density and diversity (Bellinder et al., 2004). The inclusion of pea in a crop rotation provided refugees for weed species that were otherwise suppressed by the dominating cereal crops in a Pea–wheat rotation. The degree to which a crop reduced both species diversity, abundance, and the amount of propagules produced by the survivor weeds during its growing period would be reflected in the weed community structure of the following crop (Poggio et al., 2004). Weed growth suppression through intercropping, as it covered the soil surface could be employed to minimize herbicide use (Poggio, 2005) in CA.

A review by Petit et al. (2011) on weeds in agricultural landscapes has highlighted that alternative cropping systems can deliver both good levels of crop productivity with weed management. It is also necessary to understand that cropping systems do not only influence weeds directly, for instance by destroying seedlings by herbicides or mechanical weeding (Gardarin et al., 2012) indirectly too.

In contrast to the above, weed management accounted for 37.9% of the variation in total weed density, whereas crop rotation accounted for only 5.5% in maize-based cropping systems. The effectiveness of rotations in reducing weed density was dependent upon the crop (Doucet et al., 1999).

5.2 Crop Parameters

Selection of appropriate crop cultivar with weed competitive ability would ensure optimum yield under CA. Spring barley was reported to aid in weed suppression (Christensen, 1995) suitable for CA and many studies have proven that enhancing crop competitive ability can curtail weed seed production (Lemerle et al., 2001). Evidently, allelopathy has potential in weed management to reduce the reliance on herbicides (Wu et al., 1999) under CA. For example, spring-planted living rye reduced weed biomass by 93% over without rye (Barnes and Putnam, 1983) and Barley (*H. vulgare*) contains water-soluble allelochemicals (Jones et al., 1999) that inhibit the germination and growth of quack grass (*Agropyrum repens*) (Ashrafi et al., 2009). Thus barley may be included in a cropping system as a depressive prior crop for wheat-based cropping sequence.

The recent concepts of corn (*Z. mays* L.) hybrids with large leaf area above the ear, early maturity, and higher population densities may suit better for CA to compete with weeds. Field experiments at Ontario have shown that maize hybrids LRS and P3979 were least affected by weed pressure (Begna et al., 2001). Soybean canopy closure caused reductions in soil thermal amplitudes and an increase in light interception following soybean canopy formation resulted in reduced Palmer amaranth (*Amaranthus palmeri*) emergence, especially under NT (Jha and Norsworthy, 2009). Reduced PAR, and increased FR transmitted light due to canopy coverage (Norsworthy, 2004) inhibited germination of *Amaranthus* species, (Leon and Owen, 2003).

A rather recent development is the trait-based approaches, in crop-based weed management, to understand response of weed communities assemble or change in response to filters imposed by management was outlined by Trichard et al. (2013).

5.3 Other Agronomic Practices

Adjusting the time of crop sowing can also minimize weed pressure in some crops. Earlier planting of wheat in north India, for example, gave the crop a competitive advantage over *P. minor*, a noxious grassy weed species. The adoption of NT and early planting of wheat in north India proved profitable to farmers as these helped reduce the problems of *P. minor* (Chauhan and Mahajan, 2012) since, micro climatic conditions were unfavorable for its germination. The mechanical control of weeds is one of the main traditional methods used in plant production (Chicouene, 2007), which partly or fully avoided in CA. Judicious use of shallow preseason tillage in an otherwise NT cropping system can be able to manage persistent grassy weed populations without affecting soil quality and crop yields (Campbell et al., 1998).

Selection of narrow-row crops, which would promote early canopy closure, would aid in late-season Palmer amaranth management, partially because of reduced emergence as a result of the crop canopy coverage (Jha and Norsworthy, 2009). Reduced recruitment of weed seedlings from the soil seedbank, an alteration of crop–weed competitive relations to the benefit of the crop and a gradual reduction of the size of the weed seedbank (Bastiaans et al., 2008) were necessary for a successful weed management program.

The ecological approach for NT weed management outlined by Anderson (2005) for semiarid Central Great Plains emphasized the weed population dynamics: natural loss of weed seeds, reducing seedling establishment, and minimizing seed production by established plants. Although the NT had the most diverse weed community, Mas and Verdu (2003) could not detect any tillage effect on weed biomass and concluded that weed flora would not constitute an obstacle to an increasing use of NT for cereal production in Barcelona in a rotation of winter crops on a deep silty loamy soil.

5.4 Chemical Weed Management

Allelopathic cover crops and crop rotation could provide some degree of weed control, but the total management might require herbicide usage. An understanding of the weed species shifts whether it was due to succession or temporary fluctuation could be of help (Ball and Miller, 1993). Unfortunately, our first and often only response to weed infestations was to kill them with chemicals (Harker and Clayton, 2006). In NT, appropriate herbicide was indispensable and dosage and timing are the other deciding factors. The weed species shift could result in the emergence of tolerant weeds also.

Studies by Bachthaler (1974) on the effects of direct drilling in 6- and 4-year field trials in wheat, barley, and oats revealed that ZT combined with herbicides have decreased the population of dicotyledonous weed species. On the other hand, the population of grassy weeds has increased, particularly *Agropyron repens* within the cereal rotation in Germany. Thus, minimal cultivation is preferred to ZT because it provided for the effective use of soil herbicides, which required incorporation. The general trends in weed population dynamics have arisen as tillage is reduced are viz., increased populations of perennial, summer annual grass, biennial, and winter annual species (Buhler, 1995).

5.4.1 Burndown Herbicides

Partial or total skipping of soil disturbance in CA, necessitated the mandatory use of pre- and/or postemergence herbicides for keeping the weed population below the threshold level, which otherwise might cause damage to the crops. Wherever cover crops were used, desiccation of cover crops too required herbicide usage. Since NT and CT harbor an array of weed populations at the time of sowing of crops, nonselective burndown herbicides such as glyphosate, paraquat etc., need to be applied prior to crop emergence to minimize the early season crop–weed competition.

A burn down, herbicide before sowing need to be used to reduce early season Palmer amaranth interference (Jha and Norsworthy, 2009). Adoption of CT increased phenomenally with the advent of transgenic, glyphosate-resistant crops that permitted in-season, over-the-top use of glyphosate a broad-spectrum herbicide (Price et al., 2011). The ability to control emerged weeds prior to soybean planting was an important factor that influenced the optima cereal rye cover crop management timing for weed suppression (Nord et al., 2012). Dry-seeded rice sown under ZT was applied with glyphosate at 0.75 kg a.e. ha^{-1} plus 2, 4-D at 0.4 kg a.e. ha^{-1} 3–4 days before crop sowing registered slightly higher weed biomass than CoT (Chauhan, 2013). Most herbicides used pre-emergent in crops could control germinating weed seeds and may not destroy established perennial plants. Weed management in experiments on cotton planted in Sorghum stubble under CT effectively controlled by Dipropetryn (Keeling and Abernathy, 1989). Studies by Puricelli and Tuesca (2005) on the effect of regular application of glyphosate in wheat–soybean, soybean monoculture, and soybean–maize sequences including soybean and maize GR cultivars under NT revealed that regardless of sequence and tillage system, regular glyphosate application reduced richness and density of the most weeds. Careful combination of herbicides were recommended for upland rice either in CoT or NT (Olofintoye, 1987). Under Mediterranean conditions, it was possible to reduce or even avoid the application of postemergence herbicides in NT wheat, as weeds can be efficiently controlled before sowing through presowing herbicide (nonselective, systemic, and nonpersistent) (Calado et al., 2010). In NT, density of wind-dispersed weeds such as *Carduus acanthoides* was higher in the inception year, later disappeared in the last 3 years in wheat–soybean rotation (Tuesca and Puricelli, 2007).

5.4.2 Postemergence Herbicides

Postemergence weed control was more efficient than preemergence weed control regardless of the tillage system in a winter wheat–oil (*T. aestivum* L.) seed rape (*B. napus* L.)—winter wheat–maize (*Z. mays* L.) crop rotation for maize under the humid, temperate climate of Europe at two sites of the Swiss midlands (Streit et al., 2002). A combination of glyphosate and postemergence herbicide was necessary to control different biological groups of weeds in an RT system (Torresen et al., 2003). The *P. minor* density was significantly lower at lower rates of herbicides with added surfactant than the weedy plots. Postemergence herbicide (isoproturon 750 g ha^{-1} + 2, 4-D 500 g ha^{-1} or isoproturon 1000 g ha^{-1} + metsulfuron 4 g ha^{-1}) as tank mixture was sprayed at 30–35 DAS in wheat to manage complex weed flora in ZT Sorghum–wheat cropping system in India (Kadian et al., 2005). Seed production of velvetleaf was greater with higher predation in 4-year rotation (corn–soybean–triticale + alfalfa–alfalfa) that received 82% less herbicide than 2-year rotation system (corn–soybean) managed with conventional rates of herbicides (Westerman et al., 2005). Two postemergence herbicides (paraquat plus acifluorfen plus bentazon and imazapic were studied under NT at Florida in Peanut. Grassy weeds viz., *P. dichotomiflorum* Michx., *Panicum texanum* L.), and *D. sanguinalis* (L.), were controlled more effectively with imazapic (Tubbs and Gallaher, 2005).Although in a previous study *P. minor* was effectively controlled with the application of clodinafop 60 g and sulfosulfuron 25 g ha^{-1} alone or in combination with metsulfuron 1.6 g ha^{-1}, during first year its poor response was observed against broad-leaved weeds due to heavy infestation of *R. dentatus*. Sulfosulfuron was ineffective in controlling *R. dentatus*. Metsulfuron methyl provided effective control of broad-leaved weeds only and had no effect on *P. minor* at karnal, India in a Rice–wheat cropping system under ZT (Chhokar et al., 2007). A combination of glyphosate and postemergence herbicide was necessary to control different biological groups of weeds in an RT system (Torresen et al., 2003). CT + atrazine as pre- or postemergence registered highest weed control efficiency (95.75–98.04%) in maize (Mukherjee and Debnath, 2013) in Tarai region of India.

5.4.3 Herbicide Efficacy

As there was no weed seed burial, weed management in CA is a greater challenge than in conventional agriculture and since soil-applied herbicides were not incorporated, herbicide efficacy might be reduced as crop residues can intercept 15–80% of the applied herbicides (Chauhan et al., 2012) and higher dose might be warranted. Further, the organic matter in the soil might also reduce the herbicide efficacy and dissipation might also occur.

Imazquin, imazethapyr, and clomazone in NT double-crop soybean controlled more than 93% of jimsonweed, velvetleaf, and giant foxtail. Imazaquin and imazethapyr were more persistent in the soil than clomazone. Clomazone was not detected 10–20 cm in the soil profile. More imazethapyr was detected 10–20 cm in the soil profile than imazaquin in 1985 (Mills and Witt, 1989). RT in corn (*Z. mays* L.) and soybean (*G. max* (L.) Merr.) has shown that reduced herbicide efficacy has slowed adoption of CT as CT systems rely heavily on herbicides (Buhler, 1995). Crop residues present on the soil surface can intercept a considerable amount of the applied herbicide and, depending on the herbicide; this intercepted component is susceptible to losses. Therefore, CT systems are expected to have lower efficacy of soil active herbicides (Chauhan et al., 2006).The presence of a minimum of 30% of the previous crop residue CT systems would interfere with the performance of the preemergence herbicide as they are surface applied. The partially decomposed crop residues may interact with the herbicides too.

6. HERBICIDE RESISTANCE

6.1 Herbicide-Resistant Weeds in CA

Differential levels of tolerance to glyphosate between species have led to changes in weed succession (Baylis, 2000) and the intense herbicide selection over genetically diverse weed populations resulted in herbicide resistance. The intense selection pressure from herbicide use will result in the evolution of herbicide-resistant weed biotypes or shifts in the relative prominence of one weed species in the weed community (Owen, 2008). A study by Mulugeta and Stoltenberg (1997) concluded that reduced herbicide inputs plus interrow cultivation were as effective as full-rate herbicides to manage several annual weeds in CT in continuous corn and soybean–corn rotation. However, the serious concern was that a herbicide dose lower than the recommended dose resulted in rapid herbicide resistance evolution in rigid rye grass populations (Manalil et al., 2011) and the populations are evolving as a natural response to selection pressure imposed by the practices (Norsworthy et al., 2012).

Glyphosate has become the dominant herbicide worldwide under CA (Duke and Powles, 2008). Most of the transgenic crops grown worldwide are Glyphosate resistant (GR) offered significant environmental benefits with a caution of GR weeds (Duke and Powles, 2008). GR populations of the economically damaging weed species *Ambrosia artemissifolia* L., *Ambrosia trifida* L., *A. palmeri* S Watson, *A. rudis* JD Sauer, *A. tuberculatus* (Moq.) JD Sauer and various *Conyza* and *Lolium* spp. Likewise, in areas of transgenic GR crops in Argentina and Brazil, there are now evolved GR populations of *Sorghum halepense* (L.) Pers and *Euphorbia heterophylla* L., respectively. However, GR weeds are not yet a problem in many parts of the world. Maintenance of diversity in weed management systems may be crucial for glyphosate (Powles, 2008). The practice of CT is threatened by the GR Palmer amaranth (*A. palmeri* [S.] Wats.), besides, common waterhemp (*A. rudis* Sauer) (Price et al., 2011).

The main HR weeds are wild oat, green foxtail, kochia, and chickweed etc. The risk of weed resistance is greatest in MT and NT in fields with cereal-based rotations and least in fields with forage crops. Hence, it is understood that cropping system diversity is the foundation of proactive weed resistance management (Beckie, 2009). Resistance to herbicides in arable weeds is threatening global food security (Delye et al., 2013). HR annual rye grass has widespread occurrence across areas of intensive crop production in the southern Australian cereal and pulse crop production (Lovett and Knights, 1996).

65% of survey respondents in a survey among corn and soybean growers across Indiana have expressed moderate or low levels of concern about weeds developing resistance to glyphosate, whereas 36% expressed a high level of concern (Johnson and Gibson, 2006). Although, horseweed is reported to be easy to control with tillage (Kapusta, 1979; Brown and Whitwell, 1988), difficulty with postemergence soybean herbicides have been reported worldwide (Bruce and Kells, 1990; Moseley and Hagood, 1990; Vangessel et al., 2001) and the increased reliance on glyphosate under NT farming has increased the potential for the evolution of GR weeds (Davis et al., 2009b), like Giant ragweed (*A. trifida*) in cotton (Barnett and Steckel, 2013). Occurrence of resistant weeds in the Ebro valley maize fields has been significant (Peña-Asin et al., 2013).

A review by Johnson et al. (2009) on the influence of GR cropping systems on weed species shifts has highlighted that the increased reliance on glyphosate, many times as the only active ingredient used, has resulted in weed species shifts and the evolution of GR weed populations. The continuous use of isoproturon against *P. minor* for 10–15 years in wheat under rice–wheat cropping system resulted in the buildup of its resistant populations against isoproturon in some pockets of Haryana and Punjab (Malik and Singh, 1993). Six weed species viz., *C. Canadensis*, *A. trifida*, *A. artimisiifolia*, *Sorghum halapense*, *Lolium multiforum*, and *A. palmeri* have been identified as GR in NT cropping in the southern United States (Steckel et al., 2010). Heavy reliance on herbicides resulted in HR blackgrass (*A. myosuroides* Huds.) biotypes in France. Cropping systems evaluated against HR blackgrass, one with winter crops and the other with spring crops over 3 years resulted in reduction in Black grass densities (Chauvel et al., 2001). Rotation with an alternation of spring and winter crops was the most efficient solution against *A. myosuroides*. Percentage of resistant proportion did not vary over 6 years, in different crop rotations suggesting that the resistance gene persisted, despite the removal of selection pressure by the aryloxy-phenoxypropionate herbicides (Chauvel et al., 2009).

By 1993, the *P. minor*, a problem weed in the rice–wheat cropping system of north-western India had developed resistance to isoproturon, a herbicide which had delivered effective weed control for 15 years (Corbishley and Pearce, 2006). Weed control tactics imposed by growers create the ecological selection pressure that ultimately changes the weed communities. Tillage (disturbance) is one of the primary factors that affect changes in weed communities. The glyphosate-based weed management tactics used in GRCs imposes the selection pressure that supports weed population shifts. Examples of weed population shifts in GRCs include common waterhemp (*A. tuberculatus* (Moq. ex DC.) JD Sauer), horseweed (*C. canadensis* L), giant ragweed (*A. trifida* L.), and other relatively new weed problems (Owen, 2008). Strong dependence on glyphosate in South America resulted in GR populations of *Lolium multiflorum* Lam., *Conyza bonariensis* L., and *C. canadensis* L., while in fruit orchards from Colombia, it was *Parthenium hysterophorus* L., *S. halepense* L., and *E. heterophylla* L. in soybean fields of Argentina and Brazil. The evolution of GR has taken place where glyphosate exerted a strong and continuous selection pressure. The massive adoption of NT together with GR soybean has encouraged increased glyphosate use, as evident from Argentina and Brazil (Vila-Aiub et al., 2008).

Field studies on reduced rates of glyphosate to NT, GR soybean showed that sequential applications, regardless of rate, provided greater weed control over the reduced-rate single applications (Wait et al., 1999). Herbicide doses are based on weed growth stages at a particular point of time, but in practice, uniform plant sizes or phenological stages within weed populations are hardly possible. This variability results in differential exposure of the leaf area and a "diluting effect" promoting sublethal conditions and leading to poor weed controls (Vila-Aiub et al., 2003) and development of HR. Vila-Aiub and Ghersa (2005) found that application of a series of sublethal rates of diclofop-methyl herbicide to *L. multiflorum* L. increased their level of resistance.

6.2 Herbicide Resistant/Tolerant Crops

Duke and Powles (2008) stated that almost 90% of all transgenic crops grown worldwide are GR. Although GR/HR crop weed management offered significant environmental and other benefits GR challenged them (Duke and Powles, 2008). Herbicide-tolerant crops need to be introduced in CA systems and oil seed rape is an excellent example for HT crop in CA (Senior and Dale, 2002; Graer et al., 2007). Glufosinate- and glyphosate-resistant (GR) crops promoted the adoption on NT agriculture (Duke and Cerdeira, 2005). GR crops were first introduced in the United States in soybeans in 1996. Adoption has been very rapid in soybeans and cotton since introduction and has grown significantly in maize in recent years. GRCs have grown to over 74 million hectares in 5 crop species in 13 countries (Dill et al., 2008). A survey made by Givens et al. (2009) has proved that tillage intensity declined more in continuous GR cotton and GR soybean (45% and 23%, respectively) than in rotations that included GR corn or non-GR crops.

Aulakh et al. (2010) found that glyphosate-tolerant cotton produced 13–29% greater yields over the glufosinate-tolerant cotton and conventional cotton. GR crops are currently grown on approximately 70 million ha worldwide (Price et al., 2011). With the development of HR crops, particularly GR crops, herbicides such as glyphosate minimized the need for tillage as a weed control tactic; the resulting crop production systems have been primary enablers for the success of USDA Natural resource soil conservation programs (Shaw et al., 2012) and the introduction of HR crops like cotton, soybean, and corn have provided post emergence options for difficult to control weeds such as giant ragweed (Barnett and Steckel, 2013). Herbicide-tolerant weed beet population could be difficult to manage irrespective of the crop rotation (Sester et al., 2007).

7. CONCLUSIONS

There is a general perception that CA is "chemically dependent" (Kassam et al., 2012) particularly for weed management, but in reality the basic pillars of CA promote integrated weed management.

1. Tillage is the primary factor deciding the weed problems and crop rotation only follows it.
2. It must be realized that selection pressures would dictate weed communities.
3. Characterizing the long-term effect of agricultural management systems on weed communities will aid in developing sustainable weed management practices.
4. Economical and environmentally sound weed management in CT will require integration of new information with established principles of weed management.
5. Poor understanding of weed population dynamics and lack of suitable control alternatives resulted in increased herbicide use in CT systems.
6. Changes in sowing techniques and weed control tactics will most probably be required to manage new problems.
7. Invertebrates with opportunistic feeding that feed on weed seeds may be significant in CA affecting weed population dynamics.
8. Weed seed predation can significantly contribute to biological/cultural weed management in CA.
9. Broadleaved weeds are relatively more susceptible to mulching than grassy weeds.

10. The exclusive reliance on glyphosate as the main herbicide resulted in agroecosystems biologically more prone to GR evolution.

Issues ahead

11. There is a continued need for long-term approaches to weed management in cropping systems, to minimize weed seedbank replenishment.
12. Many weeds display some degree of clumped distribution (Auld and Tisdell, 1988); estimates of yield loss based on mean density over a large area may be incorrect. Hence, the extent of this effect in CA, in determining threshold for herbicide use, needs investigation.
13. Further studies are needed to identify mechanisms driving weed shifts to determine whether they are fluctuational or successional and to develop suitable management strategies.
14. Developing ways of reducing weed seed carry over.
15. Research on crop competitive ability to reduce weed seed production.
16. Research to determine whether the weed seeds that fail to germinate would become part of a total seedbank.
17. Research on the rate of loss of soil active herbicides under RT systems.
18. Research on the impact of NT systems on weed ecology, herbicide performance and persistence.
19. Research to minimize the competitive effects of legume cover crops on crops, for efficient use of entomological advantages.

REFERENCES

Addae, P.C., Collis-George, N., Peterson, C.J., 1991. Over-riding effects of temperature and soil strength of wheat seedlings under minimum and conventional tillage. Field Crops Res. 28, 103–116.

Allmaras, R.R., Dowdy, R.H., 1985. Conservation tillage systems and their adoption in the United States. Soil Till. Res. 5, 197–222.

Altieri, M., 1999. The ecological role of biodiversity in agroecosystem. Agric. Ecosyst. Environ. 74, 19–31.

Altieri, M.A., Lana, M.A., Bittencourt, H.A., Kieling, A.S., Comin, J.J., Lovato, P.E., 2011. Enhancing crop productivity via weed suppression in organic no-till cropping systems in Santa Catarina, Brazil. J. Sustain. Agric. 35, 855–869.

Altieri, M.A., Wilson, R.C., Schmidt, L.L., 1985. The effects of living mulches and weed cover on the dynamics on foliage- and soil-arthropod communities in three crop systems. Crop Prot. 4, 201–213.

Anderson, R.L., 2005. A multi-tactic approach to manage weed population dynamics in crop rotations. Agron. J. 97, 1579–1583.

Anderson, R.L., 2007. Managing weeds with a dualistic approach of prevention and control. A review. Agron. Sustain. Dev. 27, 13–18.

Ashrafi, Z.Y., Sadeghi, S., Mashhadi, H.R., 2009. Inhibitive effects of barley (*Hordeum vulgare*) on germination and growth of seedling quack grass (*Agropyrum repens*). Icel. Agric. Sci. 22, 37–43.

Aulakh, J., Price, A.J., Balkcom, K.S., Arriaga, F.J., Delaney, D.P., 2010. Weed control efficacy and lint yield of herbicide resistant cotton technologies under different tillage systems and row spacing. In: Conservation Agriculture Impacts – Local and Global-Proceedings of the 32nd Southern Conservation Agricultural Systems Conference 20–22 July 2010. Tennessee, Jackson.

Auld, B.A., Tisdell, C.A., 1988. Influence of spatial distribution of weeds on crop yield loss. Plant Prot. Q. 3, 81.

Auškalnienė, O., Auškalnis, A., 2009. The influence of tillage system on diversities of soil weed seed bank. Agron. Res. 7, 156–161.

Avci, M., 2011. Conservation agriculture in Turkish research. Agron. Sustain. Dev. 31, 299–307.

Bachthaler, G., 1974. The development of the weed flora after several years' direct drilling in cereal rotations on different soils. In: Proceedings the 12th British Weed Control Conference, 18–21 November 1974. Brighton, England, pp. 1063–1071.

Ball, D.A., Miller, S.D., 1993. Cropping history, tillage and herbicide effects on weed flora composition in irrigated corn. Agron. J. 85, 817–821.

Ballare, C.L., Scopel, L., Ghersa, C.M., Sanchez, R.A., 2008. The fate of *Datura ferox* L. seeds in the soil as affected by cultivation depth of burial and degree of maturity. Annu. Appl. Biol. 112, 337–345.

Baraibar, B., Westerman, P.R., Recasens, J., 2009. Effects of tillage and irrigation in cereal fields on weed seed removal by seed predators. J. Appl. Ecol. 46, 380–387.

Barberi, P., Cascio, B.L., 2001. Long-term tillage and crop rotation effect on weed seed bank size and composition. Weed Res. 41, 325–340.

Barnes, J.P., Putnam, A.R., 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chem. Ecol. 9, 1045–1057.

Barnett, K.A., Steckel, L.E., 2013. Giant ragweed (*Ambrosia trifida*) competition in cotton. Weed Sci. 61, 543–548.

Baskin, C.C., Baskin, J.M., 1998. Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination. Academic Press, San Diego, 666 pp.

Bastiaans, L., Paolini, R., Baumann, D.T., 2008. Focus on ecological weed management: what is hindering adoption? Weed Res. 48, 481–491.

Batlla, D., Benech-Arnold, R.L., 2007. Predicting changes in dormancy level in weed seed soil banks: implications for weed management. Crop Prot. 26, 189–197.

Baudron, F., Giller, K.E., 2014. Agriculture and nature: trouble and strife? Biol. Conserv. 170, 232–245.

Baudron, F., Mwanza, H.M., Triomphe, B., Bwalya, M., 2007. Conservation Agriculture in Zambia: A Case Study of Southern Province. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développment, Food and Agricultural Organization of the United Nations, Nairobi.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., Giller, K.E., 2012. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Res. 132, 117–128.

Baumann, D.T., Bastiaans, L., Kropff, M.J., 2001. Effects of intercropping on growth and reproductive capacity of late-emerging *Senecio vulgaris* L., with special reference to competition for light. Annu. Bot. 87, 209–217.

Baylis, A.D., 2000. Why glyphosate is a global herbicide: strengths, weaknesses and prospects. Pest Manage. Sci. 56, 299–308.

Beckie, H.J., 2009. Herbicide resistance in weeds: influence of farm practices. Prairie Soils Crops J. 2, 17–23.

Begna, S.H., Hamilton, R.I., Dwyer, L.,M., Stewart, D.W., Cloutier, D., Assemat, L., Foroutanpour, K., Smith, D.L., 2001. Morphology and yield response to weed pressure by corn hybrids differing in canopy architecture. Eur. J. Agron. 14, 293–302.

Bekker, R.M., Bakker, J.P., Grandin, U., Kalamees, R., Milberg, P., Poschlod, P., Thompson, K., Willems, J.H., 1998. Seed size, shape and vertical distribution in the soil: indicators of seed longevity. Funct. Ecol. 12, 834–842.

Bellinder, R.R., Dillard, H.R., Shah, D.A., 2004. Weed seed bank community responses to crop rotation schemes. Crop Prot. 2, 395.

Benech-Arnold, R.L., Sanchez, R.A.S., Forcella, F., Kruk, B.C., Ghersa, C.M., 2000. Environmental control of dormancy in weed seed banks in soil. Field Crops Res. 67, 105–122.

Benvenuti, S., 2007. Natural weed seed burial: effect of soil texture, rain and seed characteristics. Seed Sci. Res. 17, 211–219.

Benvenuti, S., Macchia, M., Miele, S., 2001. Quantitative analysis of emergence of seedlings from buried weed seeds with increasing soil depth. Weed Sci. 49, 528–535.

Bernoux, M., Cerri, C.C., Cerri, C.E.P., Neto, M.S., Metay, A., Perrin, A.S., Scopel, E., Razafimbelo, T., Blavet, D., Piccolo, M.C., Pavei, M., Milne, E., 2006. Cropping systems, carbon sequestration and erosion in Brazil, a review. Agron. Sustain. Dev. 26, 1–8.

Bhowmik, P.C., Bekech, M.M., 1993. Horseweed (*Conyza canadensis*) seed production, emergence and distribution in no-tillage and conventional-tillage corn (*Zea mays*). Agron. Trends Agric. Sci. 1, 67–71.

Bilalis, D., Efthimiadis, P., Sidras, N., 2001. Effect of three tillage systems on weed flora in a 3-year rotation with four crops. J. Agron. Crop Sci. 186, 135–141.

Blackshaw, R.E., Larney, F.J., Lindwall, C.W., Watson, P.R., Derksen, D., 2001. Tillage intensity and crop rotation affect weed community dynamics in a winter wheat cropping system. Can. J. Plant Sci. 81, 805–813.

Blackshaw, R.E., Larney, F.O., Lindwall, C.W., Kozub, G.C., 1994. Crop rotation and tillage effects on weed populations on the semiarid Canadian prairies. Weed Technol. 8, 231–237.

Blackshaw, R.E., Moyer, J.R., 2006. Weed management in conservation tillage systems conservation agriculture technology and application. In: Proceedings of China–Canada Conservation Agriculture Forum. September 2006, Beijing, China, pp. 59–64.

Blevins, R.L., Frye, W.W., 1993. Conservation tillage: an ecological approach to soil management. Adv. Agron. 51, 33–78.

Bohan, D.A., Boursault, A., Brooks, D.R., Petit, S., 2011. National-scale regulation of the weed seed bank by carabid predators. J. Appl. Ecol. 48, 888–898.

Bolliger, A., Magid, J., Amado, T.J.C., Scora Neto, F., Dos Santos Ribeiro, M.D.F., Calegari, A., Ralisch, R., De Neergaard, A., 2006. Taking stock of the Brazilian "zero-till revolution": a review of landmark research an farmers' practice. Adv. Agron. 91, 47–110.

Bostrom, U., Fogelfors, H., 1999. Type and time of autumn tillage with and without herbicides at reduced rates in southern Sweden 2. Weed flora and diversity. Soil Till. Res. 50, 283–293.

Brown, S.M., Whitwell, T., 1988. Influence of tillage on horseweed (*Conyza canadensis*). Weed Technol. 2, 269–270.

Bruce, J.A., Kells, J.J., 1990. Horseweed (*Conyza canadensis*) control in no-till soybean (*Glycine max*) with preplant and preemergence herbicides. Weed Technol. 4, 642–647.

Brust, G.E., House, G.J., 1988. Weed seed destruction by arthropods and rodents in low-input soybean agroecosystems. Am. J. Altern. Agric. 3, 19–25.

Bryson, C.T., Hanks, J.E., 2001. Weed shifts in deep hollow watershed, leflore county, MS. In: Rebich, R.A., Knight, S.S. (Eds.), The Mississippi Delta Management Systems Evaluation Areas Project, 1995–1999, Mississippi Agricultural and Forestry Experimental Station Information Bulletin, vol. 377, pp. 86–90.

Buhler, D.D., Hartzler, R.G., Forcella, F., 1997. Weed seed bank dynamics- implications to Weed management. J. Crop Prod. 1, 145–168.

Buhler, D.D., Mester, T.C., Kohler, K.A., 1996. The effect of maize residues and tillage on emergence of *Setaria faberi*, *Abutilon theophrasti*, *Amaranthus retroflexus*, and *Chenopodium album*. Weed Res. 36, 153–165.

Buhler, D.D., 1995. Influence of tillage systems on weed population dynamics and management in corn and soybean in the central USA. Crop Sci. 35, 1247–1258.

Buhler, D.D., Owen, M.D.K., 1997. Emergence and survival of horseweed (*Conyza canadensis*). Weed Sci. 45, 98–101.

Buhler, D.D., Stoltenberg, D.E., Becker, R.L., Gunsolus, J.L., 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. Weed Sci. 42, 205–209.

Calado, J.M.G., Basch, G., Carvalho, M.D., 2010. Weed management in no-till winter wheat (*Triticum aestivum* L.). Crop Prot. 29, 1–6.

Campbell, C.A., Thomas, A.G., Biederbeck, V.O., McConkey, B.G., Selles, F., Spurr, D., Zentner, R.P., 1998. Converting from no tillage to pre-seeding tillage: influence on weeds, spring wheat grain yields and N, and soil quality. Soil Till. Res. 46, 175–185.

Cannell, R.Q., 1985. Reduced tillage in north-west Europe—a review. Soil Till. Res. 5 (2), 129–177.

Cardina, J., Norquay, H.M., 1997. Seed production and seedbank dynamics in subthreshold velvetleaf (*Abutilon theophrasti*) populations. Weed Sci. 45, 85–90.

Cardina, J., Herms, C.P., Doohan, D.J., 2002. Crop rotation and tillage system effects on weed seed banks. Weed Sci. 50, 448–460.

Cardina, J., Norquay, H.M., Stinner, B.R., McCartney, D.A., 1996a. Post dispersal predation of velvetleaf (*Abutilon theophrasti*) seeds. Weed Sci. 44, 534–539.

Cardina, J., Sparrow, D.H., McCOY, E.L., 1996b. Spatial relationships between seed bank and seedling populations of common lambs quarters (*Chenopodium album*) and annual grasses. Weed Sci. 44, 298–308.

Carmona, D.M., Landis, D.A., 1999. Influence of refuge habitats and cover crops on seasonal activity-density of ground beetles (Coleoptera: Carabidae) in field crops. Environ. Entomol. 28, 1145–1153.

Caroca, R.P., Candia, P.S., Hinojosa, E.A., 2011. Characterization of the weed seed bank in zero and conventional tillage in central Chile. Chil. J. Agric. Res. 71, 140–147.

Carter, M.R., Ivany, J.A., 2006. Weed seed bank composition under three long-term tillage regimes on a fine sandy loam in Atlantic Canada. Soil Till. Res. 90, 29–38.

Chauhan, B.S., Gill, G.S., Preston, C., 2006. Tillage system effects on weed ecology, herbicide activity and persistence: a review. Aust. J. Exp. Agric. 46 (12), 1557–1570.

Chauhan, B.S., 2013. Effect of tillage systems, seeding rates, and herbicides on weed growthand grain yield in dry-seeded rice systems in the Philippines. Crop Prot. 54, 244–250.

Chauhan, B.S., Mahajan, G., 2012. Role of integrated weed management strategies in sustaining conservation agriculture systems. Curr. Sci. 103, 135–136.

Chauhan, B.S., Singh, R.G., Mahajan, G., 2012. Ecology and management of weeds under conservation agriculture: a review. Crop Prot. 38, 57–65.

Chauhan, B.S., Johnson, D.E., 2010. Chapter 6 – the role of seed ecology in improving weed management strategies in the tropics. Adv. Agron. 105, 221–262.

Chauvel, B., Guillemin, J.P., Colbach, N., 2009. Evolution of a herbicide-resistant population of *Alopecurus myosuroides* Huds. in a long-term cropping system experiment. Crop Prot. 28, 343–349.

Chauvel, B., Guillemin, J.P., Colbach, N., Gasquez, J., 2001. Evaluation of cropping systems for management of herbicide-resistant populations of blackgrass (*Alopecurus myosuroides* Huds.). Crop Prot. 20, 127–137.

Chauvel, B., Gasquez, J., Darmency, H., 1989. Changes of weed seed bank parameters according to species, time and environment. Weed Res. 29, 213–219.

Chhokar, R.S., Sharma, R.K., Jat, G.R., Pundir, A.K., Gathala, M.K., 2007. Effect of tillage and herbicides on weeds and productivity of wheat under rice–wheat growing system. Crop Prot. 26, 1689–1696.

Chicouene, D., 2007. Mechanical destruction of weeds. A review. Agron. Sustain. Dev. 27, 19–27.

Christensen, S., 1995. Weed suppression ability of spring barley varieties. Weed Res. 35, 241–247.

Christoffoleti, P.J., Caetano, R.S.X., 1998. Soil seed banks. Sci. Agric. Piracicaba 55, 74–78 (Número Especial).

Clements, D.R., Benoit, D.L., Murphy, S.D., Swanton, C.J., 1996. Tillage effects on weed seed return and seedbank composition. Weed Sci. 44, 314–322.

Colbach, N., Busset, H., Roger-Estrade, J., Caneill, J., 2014. Predictive modelling of weed seed movement in response to superficial tillage tools. Soil Till. Res. 138, 1–8.

Conn, J.S., 2006. Weed seed bank affected by tillage intensity for barley in Alaska. Soil Till. Res. 90, 156–161.

Corbishley, J., Pearce, D., 2006. Zero tillage for weed control in India: the contribution to poverty alleviation. Impact Assess. Ser. Rep. No 40, 8.

Cromar, H.E., Murphy, S.D., Swanton, C.J., 1999. Influence of tillage and crop residue on post-dispersal predation of weed seeds. Weed Sci. 47, 184–194.

Crossman, N.D., Bryan, B.A., Cooke, D.A., 2011. An invasive plant and climate change threat index for weed risk management: Integrating habitat distribution pattern and dispersal process. Ecol. Indic. 11, 183–198.

D'Emden, F., Llewellyn, R., Burton, M., 2008. Factors influencing adoption of conservation tillage in Australian cropping regions. Aust. J. Agric. Resour. Econ. 52, 169–182.

Davis, A.S., Liebman, M., 2003. Cropping system effects on giant foxtail (*Setaria faberi*) demography: I. Green manure and tillage timing. Weed Sci. 51, 919–929.

Davis, A.S., Renner, K.A., Gross, K.L., 2005. Weed seed bank and community shifts in a long-term cropping systems experiment. Weed Sci. 53, 296–306.

Davis, H.N., Currie, R.S., French, B.W., Buschman, L.L., 2009a. Impact of land management practices on Carabids (Coleoptera: Carabidae) and other arthropods on the western high plains of North America. Southwest. Entomol. 34, 43–59.

Davis, V.M., Johnson, W.G., 2008. Glyphosate-resistant horseweed (*Conyza canadensis*) emergence, survival, and fecundity in no-till soybean. Weed Sci. 56, 231–236.

Davis, V.M., Gibson, K.D., Bauman, T.T., Weller, S.C., Johnson, W.G., 2007. Influence of weed management practices and crop rotation on glyphosate-resistant horseweed population dynamics and crop yield. Weed Sci. 55, 508–516.

Davis, V.M., Gibson, K.D., Bauman, T.T., Weller, S.C., Johnson, W.G., 2009b. Influence of weed management practices and crop rotation on glyphosate- resistant horseweed (*Conyza canadensis*) population dynamics and crop yield- years III and IV. Weed Sci. 57 (4), 417–426.

Delye, C., Jasieniuk, M., Corre, V.L., 2013. Deciphering the evolution of herbicide resistance in weeds. Trends Genet. 29, 649–658.

Demjanová, E., Macák, M., Ĉaloviü, I., Majerník, F., Týr, S., Smatana, J., 2009. Effects of tillage systems and crop rotation on weed density, weed species composition and weed biomass in maize. Agron. Res. 7, 785–792.

Derksen, D.A., 1996. Weed community ecology: tedious sampling or relevant science? A Canadian perspective. Phytoprot 77, 29–39.

Derksen, D.A., Lafond, G.P., Thomas, A.G., Leoppky, H.A., Swanton, C.J., 1993. Impact of agronomic practices on weed communities: tillage systems. Weed Sci. 41, 409–417.

Derksen, D.A., Thomas, A.G., Lafond, G.P., Loeppky, H.A., Swanton, C.J., 1995. Impact of post-emergence herbicides on weed community diversity within conservation-tillage systems. Weed Res. 35, 311–320.

Derpsch, R., 2005. The extent of conservation agriculture adoption worldwide: Implications and impact. In: III World Congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation. 3–7 October 2005 Nairobi, Kenya, p. 15.

Derpsch, R., Friedrich, T., Kassam, A., Li, H., 2010. Current status of adoption of no-till farming in the world and some of its benefits. Int. J. Agric. Biol. Eng. 3, 1–25.

Dessaint, F., Chadoeuf, R., Barralis, G., 1991. Spatial pattern analysis of weed seeds in the cultivated soil seed bank. J. Appl. Ecol. 28, 721–730.

Dessaint, F., Chadoeuf, R., Barralis, G., 1997. Nine years' soil seed bank and weed vegetation relationships in an arable field without weed control. J. Appl. Ecol. 34, 123–130.

Dıaz-Zorita, M., Duarte, G.A., Grove, J.H., 2002. A review of no-till systems and soil management for sustainable crop production in the subhumid and semiarid pampas of Argentina. Soil Till. Res. 65, 1–18.

Dickey, E.C., Jasa, P.J., Grisso, R.D., 1994. Long-term tillage effects on grain-yield and soil properties in a soybean grain-sorghum rotation. J. Prod. Agric. 7, 465–470.

Dill, G.R., CaJacob, C.A., Padgette, S.R., 2008. Glyphosate-resistant crops: adoption, use and future considerations. Pest Manage. Sci. 64, 326–331.

Dorado, J., Del Monte, J.P., Lopez-Fando, C., 1999. Weed seed bank response to crop rotation and tillage in semiarid agro-ecosystems. Weed Sci. 47, 67–73.

Doucet, C., Weaver, S.E., Hamill, A.S., Zhang, J., 1999. Separating the effects of crop rotation from weed management on weed density and diversity. Weed Sci. 47, 729–735.

Duke, S.O., Cerdeira, A.L., 2005. Potential environmental impacts of herbicide resistant crops. Collect. Biosaf. Rev. 2, 66–143.

Duke, S.O., Powles, S.B., 2008. Glyphosate: a once-in-a-century herbicide. Pest Manage. Sci. 64, 319–325.

Eager, E.A., Haridas, C.V., Pilson, D., Rebarber, R., Tenhumberg, B., 2013. Disturbance frequency and vertical distribution of seeds affect long-term population dynamics: a mechanistic seed bank model. Am. Nat. 182, 180–190.

Einhellig, F.A., Leather, G.R., 1988. Potentials for exploiting allelopathy to enhance crop production. J. Chem. Ecol. 14, 1829–1844.

van Esso, M.L., Ghersa, C.M., Soriano, A., 1986. Cultivation effects on the dynamics of a Johnson grass seed population in the soil profile. Soil Till. Res. 6, 325–335.

FAO (Food and Agriculture Organization), 2012a. Available online at: http://www.fao.org/ag/ca/doc/FLYER_Conservation_Agriculture.pdf.

FAO (Food and Agriculture Organization), 2012b. Food and Agriculture Organization of the United Nations, 2012. Available online at: http://www.fao.org/ag/ca/6c.html.

Farooq, M., Flower, K.C., Jabran, K., Wahid, A., Siddique, K.H.M., 2011. Crop yield and weed management in rainfed conservation agriculture. Soil Till. Res. 117, 172–183.

Firbank, L.G., Watkinson, A.R., 1985. On the analysis of competition within two-species mixtures of plants. J. Appl. Ecol. 22, 503–517.

Flower, K.C., Cordingley, N., Ward, P.R., Weeks, C., 2012. Nitrogen, weed management and economics with cover crops in conservation agriculture in a Mediterranean climate. Field Crops Res. 132, 63–75.

Forcella, F., Benech-Arnold, R.L., Sanchez, R., Ghersa, C.M., 2000. Modelling seedling emergence. Field Crops Res. 67, 123–139.

Forcella, F., Wilson, R.G., Renner, K.A., Dekker, J., Harvey, R.G., Alm, D.A., Buhler, D.D., Cardina, J.A., 1992. Weed seed banks of the U.S. Corn Belt: magnitude, variation, emergence, and application. Weed Sci. 40, 636–644.

Freckleton, R.P., Watkinson, A.R., 2002. Are weed population dynamics chaotic? J. Appl. Ecol. 39, 699–707.

Fried, G., Reboud, X., 2007. Shift in oilseed rape weed community composition as influenced by agronomic practices. Ol. Corps Gras Lipides 14, 130–138.

Friedrich, T., Kassam, A., 2009. Adoption of conservation agriculture technologies: constraint and opportunities. In: 4th World Congress on Conservation Agriculture, 4–7 February 2009, New Delhi, p. 258.

Froud-Williams, R.J., Chancellor, R.J., Drennan, D.S.H., 1981. Potential changes in weed floras associated with reduced-cultivation systems for cereal production in temperate regions. Weed Res. 21, 99–109.

Froud-Williams, R.J., Drennan, D.S.H., Chancellor, R.J., 1983b. Influence of cultivation regime on weed floras of arable cropping systems. J. Appl. Ecol. 20, 187–197.

Froud-Williams, R.J., 1988. Changes in weed flora with different tillage and agronomic management systems. In: Altieri, M., Liebman, M.A. (Eds.), Weed Management in Agro-ecosystems: Ecological Approaches. CRC Boca Raton, Florida, USA, pp. 213–236.

Froud-Williams, R.J., Chancellor, R.J., Drennan, D.S.H., 1984. The effects of seed burial and soil disturbance on emergence and survival of arable weeds in relation to minimal disturbance. J. Appl. Ecol. 21, 629–641.

Froud-Williams, R.J., Chancellor, R.J., Drennan, D.S.H., 1983a. Influence of cultivation regime upon buried weed seeds in arable cropping systems. J. Appl. Ecol. 20, 199–208.

de la Fuente, E., Suarez, S.A., Ghersa, C.M., LeoÂn, R.J.C., 1999. Soybean weed community: relationships with cultural history and crop yield. Agron. J. 91, 234–241.

Gallandt, E.R., 2006. How can we target the weed seed bank? Weed Sci. 54, 588–596.

Gallandt, E.R., Molloy, T., Lynch, R.P., Drummond, F.A., 2005. Effect of cover-cropping systems on invertebrate seed predation. Weed Sci. 53, 69–76.

Gardarin, A., Dürrb, C., Colbach, N., 2012. Modeling the dynamics and emergence of a multispecies weed seed bank with species traits. Ecol. Model. 240, 123–138.

Ghersa, C.M., Martinez-Ghersa, M.A., 2000. Ecological correlates of weed seed size and persistence in the soil under different tilling systems: implications for weed management. Field Crops Res. 67, 141–148.

Ghorbani, R., Seel, W., Leifert, C., 1999. Effects of environmental factors on germination and emergence of *Amaranthus retroflexus*. Weed Sci. 47, 505–510.

Ghosheh, H., Al-Hajaj, N., 2005. Weed seedbank response to tillage and crop rotation in a semi-arid environment. Soil Till. Res. 84, 184–191.

Gill, K.S., Arshad, M.A., 1995. Weed flora in the early growth period of spring crops under conventional, reduced, and zero tillage systems on a clay soil in northern Alberta, Canada. Soil Till. Res. 33, 65–79.

Giller, K.E., Corbeels, M., Nyamangara, J., Triomphe, B., Affholder, F., Scopel, E., Tittonell, P., 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crop Res. 124, 468–472.

Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: the heretics' view. Field Crops Res. 114, 23–34.

Givens, W.A., Shaw, D.R., Kruger, G.R., Johnson, W.G., Weller, S.C., Young, B.G., Wilson, R.G., Owen, M.D.K., Jordan, D., 2009. Survey of tillage trends following the adoption of glyphosate-resistant crops. Weed Technol. 2, 3150–3155.

Glenn-Lewin, D.C., van der Maarel, E., 1992. Patterns and processes of vegetation dynamics. In: Glenn-Lewin, D.C., Peet, R.K., Veblen, T.T. (Eds.), Plant Succession: Theory and Prediction. Chapman & Hall, New York, USA, pp. 11–59.

Gonzalez-Andujar, J.L., Fernandez-Quintanilla, C., 1993. Strategies for the control of *Avena sterilis* in winter wheat production systems in central Spain. Crop Prot. 12, 617–623.

Gonzalez-Andujar, J.L., Saavedra, M., 2003. Spatial distribution of annual grass weed populations in winter cereals. Crop Prot. 22, 629–633.

Govaerts, B., Sayre, K.D., Goudeseune, B., Corte, P.D., Lichter, K., Dendooven, L., Deckers, J., 2009a. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Till. Res. 103, 222–230.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K.D., Dixon, J., Dendooven, L., 2009b. Conservation agriculture and soil carbon sequestration: between myth and farmer reality. Crit. Rev. Plant Sci. 28, 97–122.

Graer, F., Stachow, U., Werner, A., Schutte, G., 2007. Agricultural practice changes with cultivating genetically modified herbicide-tolerant oilseed rape. Agri. Syst. 94, 111–118.

Gray, R., Taylor, W., Brown, J., 1996. Economic factors contributing to the adoption of reduced tillage technologies in central Saskatchewan. Can. J. Plant Sci. 76, 661–668.

Gruber, H., Haendel, K., Broschewitz, B., 2000. Influence of farming system on weeds in thresh crops of a six-year crop rotation. Z. Pflanzenk. Pflanz. Spl. Issue 17, 33–40.

Gruber, S., Pekrun, C., Claupein, W., 2004. Population dynamics of volunteer oilseed rape (*Brassica napus* L.) affected by tillage. Eur. J. Agron. 20, 351–361.

Gui, B., Marwat, K.B., Saeed, M., Hussain, Z., Ali, H., 2011. Impact of tillage, plant population and mulches on weed management, and grain yield of maize. Pak. J. Bot. 43, 1603–1606.

Gulden, R.H., Shirtliffe, S.J., 2009. Weed seed banks: biology and management. Prairie Soils Crops J. 2, 46–52.

Gulshan, A.B., Dasti, A.A., Mahmood, S., Hussain, S., Atta, I., 2013. Role of soil seed bank in pattern of species distribution along the aridity gradient by using the technique of multivariate analysis. ARPN J. Agri. Biol. Sci. 8, 13–23.

Hajek, A.E., Hannam, J.J., Nielsen, C., Bell, A.J., Liebherr, J.K., 2007. Distribution and abundance of carabidae (Coleoptera) associated with soybean aphid (Hemiptera: Aphididae) populations in central New York. Annu. Entomol. Soc. Am. 100, 876–886.

Hald, A.B., 1999. The impact of changing the season in which cereals are sown on the diversity of the weed flora in rotational fields in Denmark. J. Appl. Ecol. 36, 24–32.

Han, H., Ning, T., Li, Z., 2013. Effects of tillage and weed management on the vertical distribution of microclimate and grain yield in a winter wheat field. Plant Soil Environ. 59, 201–207.

Hansen, N.C., Allen, B.L., Baumhardt, R.L., Lyon, D.J., 2012. Research achievements and adoption of no-till, dryland cropping in the semi-arid US Great Plains. Field Crops Res. 132, 196–203.

Harker, K.N., 2004. My view. Weed Sci. 52 (2), 183–184.

Harker, K.N., Clayton, G., 2006. Weed dynamics in direct-seeding systems. Conservation agriculture technology and application. In: Proceedings of China–Canada Conservation Agriculture Forum. September 2006, Beijing, China, pp. 8–12.

Hatten, T.D., Bosque-Pérez, N.A., Labonte, J.R., Guy, S.O., Eigenbrode, S.D., 2007. Effects of tillage on the activity density and biological diversity of carabid beetles in spring and winter crops. Environ. Entomol. 36, 356–368.

Heggenstaller, A.H., Menalled, F.D., Liebman, M., Westerman, P.R., 2006. Seasonal patterns in post-dispersal seed predation of *Abutilon theophrasti* and *Setaria faberi* in three cropping systems. J. Appl. Ecol. 43, 999–1010.

Hinkle, M.K., 1983. Problems with conservation tillage. J. Soil Water Conserv. 38, 201–206.

Hoffman, M.L., Owen, M.D.K., Buhler, D.D., 1998. Effects of crop and weed management on density and vertical distribution of weed seeds in soil. Agron. J. 90, 793–799.

Holland, J.M., 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric. Ecosyst. Environ. 103, 1–25.

Hulme, P.E., 1998. Post-dispersal seed predation: consequences for plant demography and evolution. Perspect. Plant Ecol. Evol. Syst. 1, 32–46.

Hummel, J.D., Dosdall, L.M., Clayton, G.W., Harker, K.N., O'Donovan, J.T., 2012. Ground beetle (Coleoptera: carabidae): diversity, activity density, and community structure in a diversified agro-ecosystem. Environ. Entomol. 41, 72–80.

Ichihara, M., Maruyama, K., Yamashita, M., Sawada, H., Inagaki, H., Ishida, Y., Asai, M., 2011. Quantifying the ecosystem service of non-native weed seed predation provided by invertebrates and vertebrates in upland wheat fields converted from paddy fields. Agric. Ecosyst. Environ. 140, 191–198.

James, T.K., Rahman, A., 2000. Longevity of buried ragwort seed in four soils. N. Z. Plant Prot. 53, 253–257.

Jha, P., Norsworthy, J.K., 2009. Soybean canopy and tillage effects on emergence of palmer amaranth (*Amaranthus palmeri*) from a natural seed bank. Weed Sci. 57, 644–651.

Johnson, G.A., Defelice, M.S., Helsel, Z.R., 1993. Cover crop management and weed control in corn (*Zea mays*). Weed Tech. 7, 425–430.

Johnson, W.,G., Davis, V.M., Kruger, G.R., Weller, S.C., 2009. Influence of glyphosate-resistant cropping systems on weed species shifts and glyphosate-resistant weed populations. Eur. J. Agron. 31, 162–172.

Johnson, W.C., Cardina, J., Mullinix Jr., B.G., 1994. Dynamics of sub economic threshold populations of sicklepod (*Cassia obtusifolia*) in a peanut-cotton-corn rotation. Weed Sci. 42, 364–368.

Johnson, W.G., Gibson, K.D., 2006. Glyphosate-resistant weeds and resistance management strategies: an Indiana grower perspective. Weed Technol. 20, 768–772.

Jones, E., Jessop, R.S., Sindel, B.M., Hoult, A., 1999. Utilising crop residues to control weeds. In: Bishop, A., Boersma, M., Barnes, C.D. (Eds.), Proceedings of The12th Australian Weeds Conference. Tasmanian Weeds Society, Devonport, pp. 373–376.

Jurado-Exposito, M., Lopez-Granados, F., Gonzalez-Andujar, J., Garcıa-Torres, L., 2005. Characterizing population growth rate of Convolvulus arvensisin wheat–sunflower no-tillage systems. Crop Sci. 45, 2106–2112.

Kadian, V.S., Yadav, A., Malik, R.S., Malik, R.K., 2005. Long-term double zero-tillage in sorghum (fodder)–wheat in south-western Haryana. In: Proceedings of the Project Workshop on Accelerating the Adoption of Resource Conservation Technologies in Rice-wheat Systems of the Indo-gangetic Plains, June 1–2, 2005 Hisar (Haryana), India, pp. 32–36.

Kakkar, V., Sharma, S.D., Punia, S.S., Malik, R.K., 2005. Efficacy of herbicides for the control of *Phalaris minor* in wheat under different tillage practices at farmer's field. In: Proceedings of the Project Workshop on Accelerating the Adoption of Resource Conservation Technologies in Rice-wheat Systems of the Indo-gangetic Plains, June 1–2, 2005 Hisar (Haryana), India, pp. 39–53.

Kapusta, G., 1979. Seedbed tillage and herbicide influence on soybean (*Glycine max*) weed control and yield. Weed Sci. 27, 520–526.

Kapusta, G., Krausz, R.F., 1993. Weed control and yield are equal in conventional, reduced, and no-till soybean (*Glycine max*) after 11 years. Weed Technol. 7, 443–451.

Kassam, A., Friedrich, T., Derpsch, R., Lahmar, R., Mrabet, R., Basch, G., González-Sánchez, E.J., Serraj, R., 2012. Conservation agriculture in the dry Mediterranean climate. Field Crops Res. 132, 7–17.

Kecheng, Z., Huizhu, Y., Xiangju, L., Kebin, L., 2006. Preliminary studies on weed and pest management under conservation tillage. In: Proceedings of China–Canada Conservation Agriculture Forum. September 2006, Beijing, China, pp. 109–112.

Keeling, J.W., Abernathy, J.R., 1989. Pre-emergence weed control in conservation tillage cotton (*Gossypium hirsutum*) cropping system on sandy soils. Weed Technol. 3, 182–185.

Kellman, M., 1978. Microdistribution of viable weed seed in two tropical soils. J. Biogeogr. 5, 291–300.

Kelton, J.A., Price, A.J., van Santen, E., Balkcom, K.S., Arriaga, F.J., Shaw, J.N., 2011. Weed seed bank density and composition in a tillage and landscape variability study. Commun. Biometry Crop Sci. 6, 21–30.

Kienzler, K.M., Lamers, J.P.A., McDonald, A., Mirzabaev, A., Ibragimov, N., Egamberdiev, O., Ruzibaev, E., Akramkhanov, A., 2012. Conservation agriculture in Central Asia – what do we know and where do we go? Field Crops Res. 132, 95–105.

Kinnunen, H., Tiainen, J., Tukia, H., 2001. Farmland carabid beetle communities at multiple levels of spatial scale. Ecography 24, 189–197.

Konstantinovic, B., Meseldzija, M., Korac, M., Mandic, N., 2010. Weed seed bank under some field cultures. Res. J. Agric. Sci. 42, 61–66.

Koocheki, A., Nassiri, M., Alimoradi, L., Ghorbani, R., 2009. Effect of cropping systems and crop rotations on weeds. Agron. Sustain. Dev. 29, 401–408.

Koskinen, W.C., McWhorter, C.G., 1986. Weed control in conservation tillage. J. Soil Water Conserv. 41, 365–370.

Kromp, B., 1999. Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. Agric. Ecosyst. Environ. 74, 187–228.

Kumar, A., Malik, Y.P., Yadav, A., Malik, R.K., 2005. Resource conservation techniques and weed management in kharif Mung bean. In: Proceedings of the Project Workshop on Accelerating the Adoption of Resource Conservation Technologies in Rice-Wheat Systems of the Indo-gangetic Plains, June 1–2, 2005 Hisar (Haryana), India, pp. 97–100.

Kumar, V., Bellinder, R.R., Gupta, R.K., Malik, R.K., 2008. Role of herbicide resistant rice in rice-wheat cropping system of India. Crop Prot 27, 290–301.

Legere, A., Stevenson, F.C., Benoit, D.L., 2005b. Diversity and assembly of weed communities: contrasting responses across cropping systems. Weed Res. 45, 303–315.

Legere, A., Stevenson, F.C., Benoit, D.L., 2011. The selective memory of weed seed banks after 18 years of conservation tillage. Weed Sci. 59, 98–106.

Legere, A., Stevenson, F.C., Benoit, D.L., Samson, N., 2005a. Seedbank-plant relationships for 19 weed taxa in spring barley-red clover cropping systems. Weed Sci. 53, 640–650.

Lemerle, D., Gill, G.S., Murphy, C.E., Walker, S.R., Cousens, R.D., Mokhtari, S., Peltzer, S.J., Coleman, R., Luckett, D.J., 2001. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. 52, 527–548.

Lemerle, D., Sutherland, S., Koetz, E., Smith, A., 1996. Suppressing weeds in conservation farming. In: Proceedings of Eleventh Australian Weeds Conference. Weed Science Society of Victoria, Melbourne, pp. 705–708, 30 September–03 October.

Leon, R.G., Owen, M.D.K., 2006. Tillage systems and seed dormancy effects on common waterhemp (*Amaranthus tuberculatus*) seedling emergence. Weed Sci. 54, 1037–1044.

Leon, R.G., Owen, M.D.K., 2003. Regulation of weed seed dormancy through light and temperature interactions. Weed Sci. 51, 752–758.

Liebman, M., Dyck, E., 1993. Crop rotation and intercropping strategies for weed management. Ecol. Appl. 3, 92–122.

Llewellyn, R.S., D'Emden, F.H., Kuehne, G., 2012. Extensive use of no-tillage in grain growing regions of Australia. Field Crops Res. 132, 204–212.

Locke, M.A., Krishna, N.R., Zablotowicz, R.M., 2002. Weed management in conservation crop production systems. Weed Biol. Manag. 2, 123–132.

Lovett, J.V., Knights, S.E., 1996. Where in the world is weed science going?. In: Proceedings of Eleventh Australian Weeds Conference. Weed Science Society of Victoria, Melbourne, pp. 3–13, 30 September–03 October.

Lumpkin, T.A., Sayre, K., 2009. Enhancing resource productivity and efficiency through conservation agriculture. In: 4th World Congress on Conservation Agriculture, 4–7 February 2009, New Delhi, p. 3.

Lutmen, P.J.W., Rew, L.J., 1997. Spatial Selective Weed Control in Arable Crops-Where Are We Now? 1997 Brighton Crop Protection Conference-weeds. BCPC, Farnham, UK, pp. 637–640.

Lyon, D.J., Miller, S.D., Wicks, G.A., 1996. The future of herbicides in weed control systems of the great plains. J. Prod. Agric. 9, 209–215.

MacLeod, A., Wratten, S.D., Sotherton, N.W., Thomas, M.B., 2004. 'Beetle banks' as refuges for beneficial arthropods in farmland: long-term changes in predator communities and habitat. Agric. For. Entomol. 6, 147–154.

Mahajan, G., Brar, L.S., Walia, U.S., 2002. Phalaris minor response in wheat in relation to planting dates, tillage and herbicides. Indian J. Weed Sci. 34, 213–215.

Malik, R.K., Gill, G., Hobbs, P.R., 1998. Herbicide resistance-A major issue for sustaining wheat productivity in rice wheat cropping systems in the Indo-Gangetic Plains. In: Rice-Wheat Consortium Paper Series. New Delhi, India.

Malik, R.K., Singh, S., 1993. Evolving strategies for herbicide use in wheat : resistance and integrated weed management. In: Proceedings of ISWS Intl. Symp. On Integrated Weed Management for Sustainable Agriculture. CCSHAU, Hisar. November 18–20.

Malik, R.K., Gupta, R.K., Singh, C.M., Brar, S.S., Singh, S.S., Sinha, R.K., Singh, A.K., Singh, R., Naresh, R.K., Singh, K.P., Thakur, T.C., 2004. Accelerating the Adoption Resource Conservation Technologies for Farm Level Impact on Sustainability of Rice–Wheat System of the Indo-gangetic Plains. NATP Progress Report. Chaudhary Charan Singh Haryana Agricultural University, Hisar, India.

Manalil, S., Busi, R., Renton, M., Powles, B., 2011. Rapid evolution of herbicide resistance bt low herbicide dosages. Weed Sci. 59, 210–217.

Marino, P.C., Gross, K.L., Landis, D.A., 1997. Weed seed loss due to predation in Michigan maize fields. Agric. Ecosyst. Environ. 66, 189–196.

Marshall, L.J.P., Brain, P., 1999. The horizontal movement of seed in arable soil by different soil cultivation methods. J. Appl. Ecol. 36, 443–454.

Martinez-Ghersa, M.A., Ghersa, C.M., Satorre, E.H., 2000. Coevolution of agricultural systems and their weed companions: implications for research. Field Crops Res. 67, 181–190.

Mas, M.T., Verdu, A.M.C., 2003. Tillage system effects on weed communities in a 4-year crop rotation under Mediterranean dryland conditions. Soil Till. Res. 74, 15–24.

Mashingaidze, N., 2013. Weed dynamics in Low-Input Dryland Small Holder Conservation Agriculture Systems in Semi-Arid Zimbabwe. Ph.D thesis submitted to University of Pretario.

Mashingaidze, N., Twomlow, S.J., Hove, L., 2009. Crop and weed responses to residue retention and method of weeding in first two years of a hoe-based minimum tillage system in semi-arid Zimbabwe. SAT eJ. 7, 1–11.

Mauchline, A.L., Watson, S.J., Brown, V.K., Froud-Williams, R.J., 2005. Post-dispersal seed predation of non-target weeds in arable crops. Weed Res. 45, 157–164.

McCravy, K.W., Lundgren, J.G., 2011. Carabid beetles (Coleoptera: Carabidae) of the midwestern United States: a review and synthesis of recent research. Terr. Arthropod Rev. 4, 63–94.

McGraw, J.B., Vavreck, M.C., 1989. Buried viable seeds in artic and alpine communities. In: Leck, M.A., Parker, V.T., Simpson, R.L. (Eds.), Ecology of Soil Seed Banks. Academic Press, San Diego, pp. 91–105.

Medd, R.W., 1990. Seed bank dynamics of wild oats (Avena fatua L.) populations in wheat. In: Proceedings of the Ninth Australian Weeds Conference, August 6–10, Adelaide, pp. 16–19.

Menalled, F.D., Marino, P.C., Renner, K.A., Landis, D.A., 2000. Post-dispersal weed seed predation in Michigan crop fields as a function of agricultural landscape structure. Agric. Ecosyst. Environ. 77, 193–202.

Menalled, F.D., Gross, K.L., Hammond, M., 2001. Weed aboveground and seed bank community responses to agricultural management systems. Ecol. Appl. 11, 1586–1601.

Mertens, S.K., van den Bosch, F., Heesterbeek, J.A.P., 2002. Weed populations and crop rotations: exploring dynamics of a structured periodic system. Ecol. Appl. 12, 1125–1141.

Milberg, P., Andersson, L., Noronha, A., 1996. Seed germination after short-duration light exposure: implications for the photo-control of weeds. J. Appl. Ecol. 33, 1469–1478.

Mills, J.A., Witt, W.W., 1989. Efficacy, phytotoxicity, and persistence of imazaquin, imazethapyr, and clomazone in no-till double-crop soybeans (*Glycine max*). Weed Sci. 37, 353–359.

Mohler, C.L., Frisch, J.C., McCulloch, C.E., 2006. Vertical movement of weed seed surrogates by tillage implements and natural processes. Soil Till. Res. 86, 110–122.

Montanya, I.S., Catalan, G., Tenorio, J.L., Garcia-Baudin, J.M., 2006. Effect of the tillage systems on weed flora composition. Options Mediterr. Ser. A Numero CIHEAM 69, 143–147.

Moonen, A.C., Bàrberi, P., 2004. Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. Weed Res. 44, 163–177.

Moorcroft, D., Whittingham, M.J., Bradbury, R.B., Wilson, J.D., 2002. The selection of stubble fields by wintering granivorous birds reflects vegetation cover and food abundance. J. Appl. Ecol. 39, 535–547.

Moore, M.J., Gillespie, T.J., Swanton, C.J., 1994. Effect of cover crop mulches on weed emergence, weed biomass and soybean (*Glycine max*) development. Weed Technol. 8, 512–518.

Morris, N.L., Miller, P.C.H., Orson, J.H., Froud-Williams, R.J., 2010. The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment—A review. Soil Till. Res. 108, 1–15.

Moseley, C.M., Hagood Jr., E.S., 1990. Horseweed (*Conyza canadensis*) control in full-season no-till soybeans (*Glycine max*). Weed Technol. 4, 814–818.

Moyer, J., Roman, E., Lindwall, C., Blackshaw, R., 1994. Weed management in conservation tillage systems for wheat production in North and South America. Crop Prot. 13, 243–259.

Mrabet, R., Moussadek, R., Fadlaoui, A., Van Ranst, E., 2012. Conservation agriculture in dry areas of Morocco. Field Crops Res. 132, 84–94.

Mueller, D.H., Klemme, R.M., Daniel, T.C., 1985. Short- and long-term cost comparisons of conventional and conservation tillage systems in corn production. J. Soil Water Conserv. 40, 466–470.

Mukherjee, P.K., Debnath, P., 2013. Weed control practices in maize (zea mays l.) under conventional and conservation tillage practices. In: Proceedings of 24th Asian-Pacific Weed Science Society Conference, October 22–25, 2013, Bandung, Indonesia, p. 302.

Mulugeta, D., Stoltenberg, D.E., 1997. Weed and seedbank management with integrated methods as influenced by tillage. Weed Sci. 45, 706–715.

Muoni, T., Rusinamhodzi, L., Thierfelder, C., 2013. Weed control in conservation agriculture systems of Zimbabwe: identifying economical best strategies. Crop Prot. 53, 23–28.

Murphy, S.D., Clements, D.R., Belaoussoff, S., Kevan, P.G., Swanton, C.J., 2006. Promotion of weed species diversity and reduction of weed seed banks with conservation tillage and crop rotation. Weed Sci. 54, 69–77.

Myers, M.M., Curran, W.S., Vangessel, M.J., Calvin, D.D., Mortensen, D.A., Majek, B.A., Karsten, H.D., Roth, G.W., 2004. Predicting weed emergence for eight annual species in the northeastern United States. Weed Sci. 52, 913–919.

Navntoft, S., Wratten, S.D., Kristensen, K., Esbjerg, P., 2009. Weed seed predation in organic and conventional fields. Biol. Control 49, 11–16.

Ngouajioa, M., McGiffen Jr., M.E., Hutchinson, C.M., 2003. Effect of cover crop and management system on weed populations in lettuce. Crop Prot. 22, 57–64.

Ngwira, A.R., Thierfelder, C., Lambert, D.M., 2012. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renew. Agric. Food Syst. 1–14. First View.

Nkala, P., Mango, N., Zikhali, P., 2011. Conservation agriculture and livelihoods of smallholder farmers in Central Mozambique. J. Sustain. Agric. 35, 757–779.

Nord, E.A., Ryan, M.R., Curran, W.S., Mortense, D.A., Mirsky, S.B., 2012. Effects of management type and timing on weed suppression in soybean no-till planted into rolled crimped cereal rye. Weed Sci. 60, 624–633.

Norris, R.F., Kogan, M., 2005. Ecology of interactions between weeds and arthropods. Annu. Rev. Entomol. 50, 479–503.

Norsworthy, J.K., 2004. Soybean canopy formation effects on pitted morning glory (*Ipomoea lacunosa*), common cocklebur (*Xanthium strumarium*), and sicklepod (*Senna obtusifolia*) emergence. Weed Sci. 52, 954–960.

Norsworthy, J.K., Ward, S.M., Shaw, D.R., Llewellyn, R.S., Nichols, R.L., Webster, T.M., Bradley, K.W., Frisvold, G., Powles, S.B., Burgos, N.R., Witt, W.W., Barrett, M., 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci. 60, 31–62.

Norwood, C., 1994. Profile water distribution and grain yield as affected by cropping system and tillage. Agron. J. 86, 558–563.

Nurbekov, A., Suleimenov, M., Freidrich, T., Taher, F., Ikramov, R., Nurjanov, N., 2011. No-till practices in the drought and salt-affected region of Uzbekistan. In: Proceedings of the 5th World Congress on Conservation Agriculture, 26–29 September, Brisbane, Australia, pp. 410–412.

O'Rourke, M.E., Heggenstaller, A.H., Liebman, M., Rice, M.E., 2006. Post-dispersal weed seed predation by invertebrates in conventional and low-external-input crop rotation systems. Agric. Ecosyst. Environ. 116, 280–288.

Olofintoye, J.A., 1987. Effects of tillage and weed growth and performance of savanna of Nigeria. Niger. J. Agron. 2, 82–87.

Oryokot, J.O.E., Murphy, S.D., Swanton, C.J., 1997. Effect of tillage and corn on pigweed (*Amaranthus* spp.) seedling emergence and density. Weed Sci. 45, 120–126.

Owen, M.D.K., 2008. Weed species shifts in glyphosate-resistant crops. Pest Manage. Sci. 64 (4), 377–387.

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., Grace, P., 2014. Conservation agriculture and ecosystem services: an overview. Agric. Ecosyst. Environ. 187, 87–105.

Parlak, A.O., Gökkuş, A., Demiray, H.C., 2011. Soil seed bank and aboveground vegetation in grazing lands of southern marmara, Turkey. Not. Bot. Hort. Agrobot. Clu. 39, 96–106.

Pavuk, D.M., Purrington, F.F., Williams, C.E., Stinner, B.R., 1997. Ground beetle (Coleoptera: Carabidae) activity density and community composition in vegetationally diverse corn agroecosystems. Am. Midl. Nat. 138 (1), 14–28.

Peña-Asin, J., Costar, A., Alvarez, A., 2013. Effect of weeding management on the performance of local maize populations. Span. J. Agric. Res. 11, 1078–1084.

Petit, S., Boursault, A., Le Guilloux, M., Munier-Jolain, N., Reboud, X., 2011. Weeds in agricultural landscapes. A review. Agron. Sustain. Dev. 31, 309–317.

Plaza, H.E., Kozak, M., Navarrete, L., Gonzalez-Andujar, J.L., 2011. Tillage system did not affect weed diversity in a 23-year experiment in Mediterranean dryland. Agric. Ecosyst. Environ. 140, 102–105.

Poggio, S.L., 2005. Structure of weed communities occurring in monoculture and intercropping of field pea and barley. Agric. Ecosyst. Environ. 109, 48–58.

Poggio, S.L., Satorre, E.H., de la Fuente, E.B., 2004. Structure of weed communities occurring in pea and wheat crops in the Rolling Pampa (Argentina). Agric. Ecosyst. Environ. 10, 225–235.

Powles, S.B., 2008. Evolved glyphosate-resistant weeds around the world: lessons to be learnt. Pest Manage. Sci. 64, 360–365.

Price, A.J., Balkcom, K.S., Culpepper, S.A., Kelton, J.A., Nichols, R.L., Schomberg, H., 2011. Glyphosate-resistant Palmer amaranth: a threat to conservation tillage. J. Soil Water Conserv. 66, 265–275.

Pullaro, T.C., Marino, P.C., Jackson, D.M., Harrison, H.F., Keinath, A.P., 2006. Effects of killed cover crop mulch on weeds, weed seeds, and herbivores. Agric. Ecosyst. Environ. 115, 97–104.

Punia, S.S., Yadav, A., Malik, R.K., Singh, S., Singh, S., 2005. Effect of tillage practices on weed dynamics, bulk density and grain yield of rice and wheat in rice-wheat cropping system. In: Proceedings of the Project Workshop on Accelerating the Adoption of Resource Conservation Technologies in Rice-wheat Systems of the Indo-gangetic Plains, June 1–2, 2005 Hisar (Haryana), India, pp. 111–117.

Puricelli, E., Tuesca, D., 2005. Weed density and diversity under glyphosate-resistant crop sequences. Crop Prot. 24, 533–542.

Putnam, A.R., Defrank, J., Barnes, J.P., 1983. Ex-ploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 9, 1001–1010.

Putte, A.V., Govers, G., Diels, J., Gillijns, K., Demuzere, M., 2010. Assessing the effect of soil tillage on crop growth: a meta-regression analysis on European crop yields under conservation agriculture. Eur. J. Agron. 33, 231–241.

Rahman, A., James, T.K., Mellsop, J., Grbavac, N., 2000. Effect of cultivation methods on weed seed distribution and seedling emergence. N. Z. Plant Prot. 53, 28–33.

Regehr, D.L., Bazzaz, F.A., 1979. The population dynamics of *Erigeron canadensis*, a successional winter annual. J. Ecol. 67, 923–933.

Riemens, M.M., Groeneveld, R.M.W., Lotz, L.A.P., Kropff, M.J., 2007. Effects of three management strategies on the seedbank, emergence and the need for hand weeding in an organic arable cropping system. Weed Res. 47, 442–451.

Roberts, H.A., Feast, P.M., 1973. Changes in the numbers of viable weed seeds in the soil under different regimes. Weed Res. 13, 298–303.

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W.M., Temesgen, M.L., Mawenya, L., Barron, J., Mutua, J., Damgaard-Larsen, S., 2009. Conservation farming strategies in east and southern Africa: yields and rainwater productivity from on-farm action research. Soil Till. Res. 103, 23–32.

Salonen, J., 1992. Efficacy of reduced herbicide doses in spring cereals of different competitive ability. Weed Res. 32, 483–491.

Samarajeewa, K.B.D.P., Horiuchi, T., Oba, S., 2005. Weed population dynamics in wheat as affected by *Astragalus sinicus* L. (Chinese milk vetch) under reduced tillage. Crop Prot. 24, 864–869.

Seaman, R., Marino, P., 2003. Influence of mound building and selective seed predation by the red imported fire ant (*Solenopsis invicta*) on an old-field plant assemblage. J. Torrey Bot. Soc. 130, 193–201.

Senior, I.J., Dale, P.J., 2002. Herbicide-tolerant crops in agriculture: oilseed rape as a case study. Plant Breed. 121, 97–107.

Sester, M., Durr, C., Darmency, H., Colbach, N., 2007. Modelling the effects of cropping systems on the seed bank dynamics and the emergence of weed beet. Ecol. Model. 204, 47–58.

Sharma, A.R., Singh, V.P., Singh, R., 2013. Weed management in conservation agriculture systems – problems and prospects. In: Proceedings of 24th Asian-Pacific Weed Science Society Conference, October 22–25, 2013, Bandung, Indonesia, pp. 31–35.

Sharma, R.K., Babu, K.S., Chhokar, R.S., Sharma, A.K., 2004. Effect of tillage on termites, weed incidence and productivity of spring wheat in rice–wheat system of North Western Indian plains. Crop Prot. 23, 1049–1054.

Shaw, D.R., Culpepper, S., Owen, M., Price, A., Wilson, R., 2012. Herbicide-resistant weeds threaten soil conservation gains: finding a balance for soil and farm sustainability. Cast. Issue Pap. 49, 1–16.

Shearin, A.F., Reberg-Horton, S.C., Gallandt, E.R., 2007. Direct effects of tillage on the activity density of ground beetle (Coleoptera: Carabidae) weed seed predators. Environ. Entomol. 36, 1140–1146.

Shearin, A.F., Reberg-Horton, S.C., Gallandt, E.R., 2008. Cover crop effects on the activity-density of the weed seed predator *Harpalus rufipes* (Coleoptera: carabidae). Weed Sci. 56, 442–450.

Shrestha, A., Knezevic, S.Z., Roy, R.C., Ball-Coelho, B.R., Swanton, C.J., 2002. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. Weed Res. 42, 76–87.

Singh, V.P., Kumar, A., Banga, A., 2010. Current status of zero tillage in weed management. Indian J. Weed Sci. 42, 1–9.

Smith, M.D., Knapp, A.K., Collins, S.L., 2009. A framework for assessing ecosystem dynamics in response to chronic resource alterations induced by global change. Ecology 90, 3279–3289.

Sosnoskie, L.M., Herms, C.P., Cardina, J., 2006. Weed seed bank community composition in a 35-year-old tillage and rotation experiment. Weed Sci. 54, 263–273.

Stavi, I., Lal, R., Owens, L.B., 2011. On-farm effects of no-till versus occasional tillage on soil quality and crop yields in eastern Ohio. Agron. Sustain. Dev. 31, 475–548.

Steckel, L., Culpepper, S., Smith, K., Bond, J., Marshal, M., York, A., Stephenson, D., Mueller, T., Patterson, M., Price, A., 2010. Impact of glyphosate–resistant weeds on no-till row crop production: situation in southern us row crops. In: Conservation Agriculture Impacts – Local and Global-Proceedings of the 32nd Southern Conservation Agricultural Systems Conference 20–22 July 2010. Tennessee, Jackson, pp. 44–45.

Stevenson, F.C., Légère, A., Simard, R.R., Angers, D.A., Pangeau, D., Lafond, J., 1998. Manure, tillage, and crop rotation: effects on residual weed interference in spring barley cropping systems. Agron. J. 90, 496–504.

Stinner, B.R., 1990. Arthropods and other invertebrates in conservation-tillage agriculture. Annu. Rev. Entomol. 35, 299–318.

Streit, B., Rieger, S.B., Stamp, P., Richner, W., 2002. The effect of tillage intensity and time of herbicide application on weed communities and populations in maize in central Europe. Agric. Ecosyst. Environ. 92, 211–224.

Swanton, C.J., Clements, D.R., Derksen, D.A., 1993. Weed succession under conservation tillage: a hierarchical framework for research and management. Weed Technol. 7, 286–297.

Swanton, C.J., Shrestha, A., Knezevic, S.Z., Ro, R.C., Ball-Coelho, B.R., 2000. Influence of tillage type on vertical weed seedbank distribution in a sandy soil. Can. J. Plant Sci. 80, 455–457.

Swanton, C.J., Shrestha, A., Roy, R.C., Ball-Coelho, B.R., Knezevic, S.Z., 1999. Effect of tillage systems, N, and cover crop on the composition of weed flora. Weed Sci. 47, 454–461.

Teasdale, J.R., Mohler, C.L., 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci. 48, 385–392.

Teasdale, J.R., Mangum, R.W., Radhakrishnan, J., Cavigelli, M.A., 2004. Weed seedbank dynamics in three organic farming rotations. Agron. J. 96, 1429–1435.

Thierfelder, C., Wall, P.C., 2010. Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. J. Crop Improv. 24, 113–121.

Thierfelder, C., Cheesman, S., Rusinamhodzi, L., 2013. Benefits and challenges of crop rotations in maize-based conservation agriculture cropping systems of southern Africa. Int. J. Agri. Sustain. 11, 108–124.

Thomas, A.G., Derksen, D.A., Blackshaw, R.E., Van Acker, R.C., Légère, A., Watson, P.R., Turnbull, G.C., 2004. A multistudy approach to understanding weed population shifts in medium- to long-term tillage systems. Weed Sci. 52, 874–880.

Thomas, G., Titmarsh, G., Freebairn, D., Radford, B., 2007. No-tillage and conservation farming practices in grain growing areas of Queensland—a review of 40 years of development. Aust. J. Exp. Agric. 47, 887–898.

Implications of soil tillage for weed communities. In: Titi, A.A.E. (Ed.), 2003. Soil Tillage in Agro-ecosystems. CRC Press, Boca Raton, pp. 147–186.

Torresen, K.S., Skuterud, R., Tandsaether, H.J., Hagemo, M.B., 2003. Long-term experiments with reduced tillage in spring cereals. I. Effects on weed flora, weed seed bank and grain yield. Crop Prot. 22, 185–200.

Torresen, K.S., Skuterud, R., Weiseth, L., Tandsvther, H.J., Jonsen, S.H., 1999. Plant protection in spring cereal production with reduced tillage. I. Grain yield and weed development. Crop Prot. 18, 595–603.

Torresen, S., Skuterud, R., 2002. Plant protection in spring cereal production with reduced tillage. IV. Changes in the weed flora and weed seed bank. Crop Prot. 21, 179–193.

Traba, J., Azcárate, F.M., Peco, B., 2004. From what depth do seeds emerge? A soil seed bank experiment with Mediterranean grassland species. Seed Sci. Res. 14, 297–303.

Trichard, A., Alignier, A., Chauvel, B., Petit, S., 2013. Identification of weed community traits response to conservation agriculture. Agric. Ecosyst. Environ. 179, 179–186.

Tubbs, R.S., Gallaher, R.N., 2005. Conservation tillage and herbicide management for two peanut cultivars. Agron. J. 97, 500–504.

Tuesca, D., Puricelli, E., 2007. Effect of tillage systems and herbicide treatments on weed abundance and diversity in a glyphosate resistant crop rotation. Crop Prot. 26, 765–1770.

Unger, P.W., McCalla, T.M., 1980. Conservation tillage systems. Adv. Agron. 33, 1–58.

Vangessel, M.J., Ayeni, A.O., Majek, B.A., 2001. Glyphosate in full season no-till glyphosate-resistant soybean: role of pre plant applications and residual herbicides. Weed Tech. 15, 714–724.

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerardf, B., Nolteg, C., 2014. A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. Field Crops Res. 155, 10–14.

Vila-Aiub, M.,M., Ghersa, C.M., 2005. Building up resistance by recurrently exposing target plants to sub lethal doses of herbicide. Eur. J. Agron. 22, 195–207.

Vila-Aiub, M.,M., Ghersa, M.M., Ghersa, C.M., 2003. Evolution of herbicide resistance in weeds. vertically transmitted fungal endophytes as genetic entities. Evol. Ecol. 17, 441–456.

Vila-Aiub, M.M., Vidal, R.A., Balbi, M.C., Gundel, P.E., Trucco, F., Ghersa, C.M., 2008. Glyphosate-resistant weeds of south american cropping systems: an overview. Pest Manage. Sci. 64, 366–371.

Wagstaff, P., Harty, M., 2010. The impact of conservation agriculture on food security in three low veldt districts of Zimbabwe. Trócaire Dev. Rev. 67–84.

Wait, J.D., Johnson, W.G., Massey, R.E., 1999. Weed management with reduced rates of glyphosate in no-till, narrow-row, glyphosate-resistant soybean (Glycine max). Weed Tech. 13, 478–483.

Ward, M.J., Ryan, M.R., Curran, W.S., Barbercheck, M.E., Mortensen, D.A., 2011. Cover crops and disturbance influence activity-density of weed seed predators *Amara aenea* and *Harpalus pensylvanicus* (Coleoptera: Carabidae). Weed Sci. 59, 76–81.

Weaver, S.E., 2001. The biology of Canadian weeds. 115. *Conyza canadensis*. Can. J. Plant Sci. 81, 867–875.

Webster, T.M., Cardina, J., White, A.D., 2003. Weed seed rain, soil seedbanks, and seedling recruitment in no-tillage crop rotations. Weed Sci. 51, 569–575.

Westerman, P.R., Liebman, M., Menalled, F.D., Hegenstaller, A.H., Hartzler, R.G., Dixon, P., 2005. Are many little hammers effective? Velvetleaf (*Abutilon theophrasti*) population dynamics in two- and four-year crop rotation systems. Weed Sci. 53, 382–392.

Westerman, P.R., Hofman, A., Vet, L.E.M., van der Werf, W., 2003a. Relative importance of vertebrates and invertebrates in epigaeic weed seed predation in organic cereal fields. Agric. Ecosyst. Environ. 95, 417–425.

Westerman, P.R., Wes, J.S., Kropff, M.J., van der Werf, W., 2003b. Annual losses of weed seeds due to predation in organic cereal fields. J. Appl. Ecol. 40, 824–836.

Wojciechowski, W., Sowiński, J., 2005. Changes in the number of weed seeds in soil under different tillage systems of winter wheat. J. Plant Prot. Res. 45 (2), 83–92.

Wrucke, M.A., Arnold, W.E., 1985. Weed species distribution as influenced by tillage and herbicides. Weed Sci. 33, 853–856.

Wu, H., Pratley, J., Lemerle, D., Haig, T., 1999. Crop cultivars with allelopathic capability. Weed Res. 39 (3), 171–180.

Xiangju, L., Binghua, L., 1998. Allelopathy and its role in weed control. J. Hebei Agric. Sci. 1, 5–8.

Xiangju, L., Jun, L.Y., Guiqi, W., Cuiqin, F., Blackshaw, R.E., 2006. Weed management in no-till corn in wheat-corn double cropping system in north china. In: Proc. Conservation Agriculture Technology and Application. "Proceedings of China-Canada Conservation Agriculture Forum". September 2006, Beijing, China, pp. 131–138.

Yadav, A., Malik, R.K., Punia, S.S., Malik, R.S., Singh, S., 2005. Studies on the impact of long-term zero-tillage in pearlmillet-wheat cropping sequence. In: Proceedings of the Project Workshop on Accelerating the Adoption of Resource Conservation Technologies in Rice-wheat Systems of the Indo-gangetic Plains, June 1–2, 2005 Hisar (Haryana), India, pp. 35–38.

Yenish, J.P., Doll, J.C., Buhler, D.D., 1992. Effects of tillage on vertical distribution and viability of weed seed in soil. Weed Sci. 40, 429–433.

Yenish, J.P., Worsham, A.C., York, A.C., 1996. Cover crops for herbicide replacement in no-tillage corn (*Zea mays*). Weed Technol. 6, 815–821.

Zanin, G., Otto, S., Riello, L., Borin, M., 1997. Ecological interpretation of weed flora dynamics under different tillage systems. Agric. Ecosyst. Environ. 66, 177–188.

Zelaya, I.A., Owen, M.D.K., Pitty, A., 1997. Effect of tillage and environment on weed population dynamics in the dry tropics. Ceiba 38, 123–135.

Zhang, H.-L., Lal, R., Zhao, X., Zue, J.-F., Chen, F., 2014. Opportunities and challenges of soil carbon sequestration by conservation agriculture in China. Adv. Agron. 124, 1–36.