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Editorial

Conservation Agriculture and Agroecological Weed Management

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Conservation agriculture (CA) relies on three fundamental pillars [1,2]: crop species diversification (in time and space such as crop rotation and crop association, respectively; at least three different crops according to FAO [3]); permanent soil organic cover (more than 30% of the ground area must be covered immediately after the direct seeding operation [3], Figure 1C–G); and no-till (referring to low disturbance, no-tillage and direct seeding, the disturbed area must be less than 15 cm wide or less than 25% of the cropped area; no periodic tillage that disturbs a greater area than the aforementioned limits; strip tillage being allowed if the disturbed area is less than the set limits [3]). To understand how this farming system was implemented and developed by farmers, it is necessary to look back at farmers' motivations and the consequences of past agricultural practices on the environment. The intensive use of tillage, including mouldboard ploughing, was questioned when soil erosion was observed in the United States [4]. To address this issue while maintaining high agricultural production, the Soil Conservation Service (now called the Natural Resource Conservation Service) started research and communication campaigns with farmers to promote practices known as "soil conservation techniques". Any tillage technique that maintains a minimum of 30% of the soil surface covered by vegetation (living or dead) after sowing the crop was qualified as a soil conservation technique [5]. Progressively implemented in the United States during the 1950s [6], in Europe in the 1960s [7], then in Latin America in the 1970s [6], these soil conservation techniques encountered major difficulties in their implementation, particularly related to crop establishment and weed management [8]. When further technical progress was made, these soil conservation techniques became more accessible. The appearance of non-selective, effective, and inexpensive foliar herbicides for summer fallow periods such as aminotriazole (1958), paraquat (1963), glyphosate (1975) and glufosinate (1986) helped to control the development of perennial weeds, which are a major threat in reduced-tillage systems [9,10]. The development of heavier and better adapted seeders has also facilitated the diffusion of soil conservation techniques [11–13].

In CA, there are fewer weed control possibilities because pre-sowing tillage is prohibited, and in-crop mechanical weeding is not possible due to the presence of living or dead mulch [14]. This may impact the weed community's taxonomic or functional composition [15] and thus weeding tactics over time [16]. Despite the ecosystem services provided by CA systems, weed (including crop volunteer) management, as well as cover crop termination, mainly relies on herbicides such as glyphosate [17]. In no-till systems, the cover crop may be terminated with non-chemical methods [18], but some weed species (particularly grasses) and crop volunteers remain difficult to kill (Figure 1B,D). Injudicious and continuous use of a single herbicide over a long period of time may result in the development of resistant weed biotypes, shifts in weed flora and negative effects on the succeeding crop and environment. CA proposes to diversify crop rotations and use cover crops to increase ecosystem services. However, the effects of diverse crop rotations and cover crops on weeds remain to be studied in the no-till context [14,19]. The role of CA pillars to control weeds and how to implement these pillars in a way that maximizes weed regulation over time is crucial knowledge but remains to be well understood.

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Figure 1. An overview of weeds, agroecological weed management and farming practices in conservation agriculture in France. (**A**) Diversity of seed size, form, weight of weed species found in CA systems. Copyright © 2022, Annick Matejiceck, INRAE. (**B**) Factorial experiment assessing herbicide-free cover crop termination methods along a gradient of soil disturbance (CA-SYS platform, INRAE Dijon, France). Copyright © 2021, Guillaume Poussou and Rodolphe Hugard, INRAE. (**C**) Clover living mulch growing after the harvest of oilseed rape (pesticide-free Rés0pest cropping system experiment, INRAE Dijon, France). Copyright © 2018, Stéphane Cordeau, INRAE. (**D**) Cambridge roller terminating cover crop (forage pea, vetch, nyger, lacy phacelia) in a CA system before the sowing of triticale/fababean intercropping (INRAE Dijon experimental farm, France). Copyright © 2010, Pascal Farcy, INRAE. (**E**) Direct drilling of winter wheat in maize residues (GIEE Magellan farmers' group developing CA in France). Copyright © 2019, Bertrand Nicolas, INRAE. (**F**) Direct drilling of winter wheat in summer fallow cover crop (INRAE Dijon experimental farm, France). Copyright © 2015, Pascal Farcy, INRAE. (**G**) Mulching sorghum residues after grain harvest to sow fababean in herbicide free-system (INRAE Dijon experimental farm, France). Copyright © 2012, Pascal Farcy, INRAE. (**H**) Oilseed rape intercropped with frost sensitive spring fababean as companion crop (GIEE Magellan farmers' group developing CA in France). Copyright © 2018, Stéphane Cordeau, INRAE.

The potential glyphosate ban in Europe has raised concerns from farmers and stakeholders as to how CA may break free from the use of this active compound. However, the scientific community has addressed few of these concerns [20]. A recent survey conducted in Europe by the ENDURE network (http://www.endure-network.eu/endure, accessed on 14 December 2021) revealed either occasional or recurrent uses of glyphosate in both CA and tillage-based systems [17]. Such results encourage the investigation of alternative solutions along the substitution-to-redesign gradient [21]. The report also indicated that there are various non-chemical alternatives to glyphosate, but that their effectiveness, cost, and adoption implications were highly variable and/or difficult to quantify [17]. Furthermore, very few non-chemical alternatives to glyphosate, other than occasional tillage, are efficient and available. As a consequence, the quest to accomplish the principles of CA, while managing weeds, has hindered CA farmers from moving towards organic agriculture (i.e., CA bans the use of tillage) and organic farmers from moving towards CA (i.e., organic agriculture bans the use of herbicide). Thus, the benefits and drawbacks of straying from one of the three pillars remains unclear [20], particularly regarding weed management.

The Special Issue, "Conservation Agriculture and Agroecological Weed Management" welcomed new research, reviews, and opinion articles covering topics related to weed management in CA systems. Specifically, it presented papers investigating the relative role of the three CA pillars on weed management, biodiversity-based weed management, new practices to reduce weed establishment or spread, weed dynamics over time, functional approaches to weed management, weed–crop competition, seedbanks, biotic interactions between weeds and other organisms in CA, successful experiences in designing and testing pesticide-free CA systems and the role of livestock in CA systems to manage weeds. Not all topics were covered, but the Special Issue reviewed the major challenges CA is currently facing and provided avenues for a better understanding of weed dynamics and management in CA.

1. Transitioning towards Conservation Agriculture

Transitioning towards conservation agriculture requires farmers and farmworkers to learn how their fields and the surrounding landscape work as an ecosystem, combining observations, predictions, and experiments with ecological principles honed by the farmers, sometimes alongside scientists. To succeed, CA farmers must do the long-term work of building place-based acumen: observing living soils, adapting to shifting climates, and establishing socially and ecologically resilient farm systems. Modifying weed management tactics is among the biggest challenge CA farmers are facing, and it implies redesigning aspects of their cropping system (i.e., fertilization, choice of crops, cover crop, etc.).

1.1. Mastering Weed Management in Conservation Agriculture Takes Time

Conservation agriculture still faces some challenges, particularly from weed management. Derrouch et al., [16] described weed management challenges that can arise when farmers transition to CA through a survey of 425 French farmers. Weed management practices used by farmers were assessed during three periods: before CA adoption, during the first years of CA (one to two years after adoption), and when the agricultural system is considered "mastered" by the farmer. The use of each farming practice was studied independently for each period. Then, a multiple correspondence analysis followed by a hierarchical ascendant classification elucidated groups of farmers with different combinations of practices for each period. Finally, the groups of farmers were followed through the periods. The results showed multiple changes in weed management from when a farmer adopted until they mastered CA. Furthermore, weed management practices varied across farmers and were affected by weed management systems before CA adoption. Upon mastering the agricultural system, farmers' choices become more apparent.

1.2. Improved Weed Regulation through Selection of the Best Crop/Cover Crop Cultivars

Moving integrated weed management towards biodiversity-based agroecological approaches [22] to further reduce herbicide use will require the use of beneficial biotic interactions that naturally regulate weeds [23]. Annual cover crops can suppress weeds [24,25], but their suppressive effect is limited by the length of the growing period. However, living mulches have the potential to be an important component in agroecosystems (Figure 1C) and can be a useful tool for weed suppression in sustainable agricultural systems [26,27]. Living mulches are crops grown simultaneously with the main crop that can significantly suppress weed growth without reducing the main crop yield through an ability to grow fast or because they are planted at a high density [28]. Living mulches can suppress weed growth by competing for light, water and nutrients, and through the production of allelopathic compounds [29]. Many studies have confirmed the weed suppression ability of living mulches in different cropping systems.

Leoni et al. [30] studied the effect of permanent legume living mulches (pLM) on weed control in organic CT vegetable systems. The successful use of pLM is largely determined by the choice of appropriate legumes that provide adequate weed control with a marginal competitive effect on the cash crop(s). However, the availability of legumes for such systems is limited, and their characterization is based on growth traits that can support the selection of suitable legumes for CA organic vegetable systems. The authors investigated the weed control capacity and variability in the morphological and phenological traits relevant for interspecific competition among 11 commercial legume cultivars and 7 ecotypes of *Medicago polymorpha* (bur medic). For commercial cultivars, *Lotus corniculatus* (bird's-foot trefoil) and *Trifolium repens* (white clover) showed the best weed control capacity, while *Trifolium subterraneum* (subterranean clover) and *Medicago polymopha* had more suitable characteristics for a rapid and complete establishment of the pLM. Overall, legume mulches appeared more effective in controlling dicotyledonous than monocotyledonous weed. Organic vegetable farmers need innovative tools that allow them to take advantage of the benefits of no-till or reduced tillage systems. These innovative tools need to combine the characteristics of organic farming practices (i.e., non-chemical weed-control, organic fertilization and crop protection), with the principles of conservation agriculture (i.e., no-till or strip tillage, permanent soil cover with living mulch). In light of this perspective, the use of pLM is a promising solution.

2. Effect of the Pillars of Conservation Agriculture

Conservation agriculture is based on simultaneous implementation of three pillars: diversified crop rotation, permanent soil cover, and no soil disturbance [1–3]. The systemic approach of simultaneously implementing all three pillars in CA generates ecological habitats that are different from those generated by conventional systems. Very few studies have investigated the effect of the joint implementation of all three pillars [15,31,32]. In contrast, many studies have investigated tillage intensity, cover cropping, and crop rotation diversification individually. When research is conducted in fields implementing CA principles for years, it can provide insights on how to optimize the three pillars of CA, especially for weed management [20,33].

2.1. Increased Crop Diversity as a Lever of Weed Management

Crop rotation diversification is a key lever of sustainable weed management [34–36]. The timing of weed control is also important: eradication, both chemical and mechanical, should be initiated, while weeds are seedlings and sometimes should be repeated to improve efficacy. Butkevicien et al. [37] studied a long-term field experiment established in 1966 at Vytautas Magnus University Experimental Station, Lithuania. The study compared five types of crop sequences, i.e., intensive rotation, 3-year rotation, rotation with row crops, rotation for green manure and rye monoculture, on weed density and seed bank and grain yield. The results confirmed that long-term crop rotations are likely to increase crop productivity, reduce weeds and weed soil seedbanks.

Research is needed to investigate if incomplete weeding can be compensated for with the use of diversified crop rotations and suite of weed management tactics [38,39], particularly in CA systems, where the set of management tools is reduced. Cropping systems which rely on a combination of a well-balanced crop rotation and a diverse set of weed management tactics, rather than intensive herbicide use, appear to increase weed diversity while maintaining crop productivity [34,40]. Increasing crop functional diversity could allow a greater tolerance to weeds through the prevention of exponential weed density evolution at the cropping system scale [34].

2.2. Crop Diversity Modifies the Resource Pool Diversity and Weed–Crop Competition

Weeds compete with crops for resources (light, water, and nutrients). When resources are limited and when crop and weeds share the same spatial niche (i.e., root depth) and share the same type of resource (i.e., nitrate) at the same time of the year, weeds generate increased yield loss [41]. However, when resources are diversified, in space and time, yield loss could be alleviated [42]. Smith et al. [42] proposed the Resource Pool Diversity Hypothesis (RPDH), which explains how soil resource pool diversity may mediate competition for soil resources between weeds and crops. The primary tenets of the RPDH are that (i) in plant communities, the intensity of interspecific competition can depend upon the degree to which niche differentiation and resource partitioning occur among species; (ii) agricultural systems are unique in that management practices, such as crop rotation, source of fertility and weed management, result in inputs to the soil; and (iii) these inputs directly or indirectly become soil resource pools from which crops and weeds may partition resources.

Menalled et al. [43] explored the role of crop diversity legacies in mediating the intensity of weed–crop competition by altering soil nutrient availability and plant–soil microbe interactions in a greenhouse experiment. Soil greenhouse treatments included field soils (i.e., soil nutrient and microbial legacies), a sterile greenhouse potting mix inoculated with microorganisms of the field soils (i.e., microbial legacies), and a sterile greenhouse potting mix. They showed that weed–crop competition increased with crop diversity legacy in both the field soil and inoculated soil treatments in the annual system. In the perennial system, differences in weed–crop competition intensity were driven by crop yield potential. In the perennial field soil treatment, crop yield potential was the greatest in the soils with the highest crop diversity legacy, whereas in the perennial inoculated soil treatment, crop yield potential was greatest in the soils with the lowest crop diversity legacy. Broadly, results show potential for negative effects of crop diversity on weed–crop competition when a crop is taxonomically related to its predecessors in a rotation. Furthermore, Menalled et al. [43] showed that the microbial and nutrient legacies of crop rotations can have diverging effects on yield. Future research should aim to evaluate the consistency of crop rotation legacy effects and identify principles that can guide soil and crop management, especially in CA systems, where soil tillage and its microbial legacy reducing effects are minimized.

2.3. Effect of Mulching

Residues on the soil surface can influence the emergence of most plant species. Cover crop mulches suppress weeds by acting as a physical barrier [44] and altering light [45], temperature [46], water and nutrient availability [47]. However, to act as a physical barrier and effectively suppress weeds, the mulch needs to be thick. Dry summers and increasing climate variability make it challenging to grow enough cover crop biomass and create a sufficient mulch for weed suppression. In addition, while no-till planting into a terminated cover crop mulch provides many agroecosystem benefits in the face of climate change, non-chemical weed and cover crop management in these systems is challenging [38]. This is especially true in regions where cover crop biomass production is limited by short growing seasons, and the resulting mulch is insufficient as the sole means of weed suppression. Supplementation with inorganic mulch can help suppress weeds in some type of farming systems, straying from one of the pillars (permanent soil organic cover [3]).

Khan et al. [48] assessed the effect of six different organic and inorganic mulch materials for weed suppression in wheat under rain-fed conditions in Pakistan through a two-year study. Six mulch material treatments were used along with Buctril super (used as an herbicide check) at the rate of 1.235 L ha^{-1} to control the most problematic weed species of wheat in Pakistan. They showed a significant decrease in weed density, relative weed density, fresh and dry plant biomass at 25, 50 and 75 days after sowing (DAS), where Buctril super at 1.235 L ha^{-1} and a mulch of black plastic were used followed by sugarcane (*Saccharum officinarum*) bagasse and dry leaves of mulberry (*Morus* spp.), as compared with the untreated control. The net economic benefits were higher where grass clippings were applied followed by sugarcane bagasse and mulberry leaves, while the lowest net economic benefits were obtained when lentil (*Lens culinaris*, grown as live mulch crop) with wheat was intercropped. Khan et al. [48] concluded that sugarcane bagasse and grass clippings could help control weeds in wheat while minimizing economic costs.

2.4. Interactive Effect of Tillage and Crop Residues on Weed Community Composition

To optimize the transition towards CA, it would be useful to understand the individual or combined effect of the three pillars of CA on weed community composition. The response of weed communities to changes in cropping practices have often been studied from the taxonomic perspective [49,50]. Recently, the use of functional traits has been proposed as an effective method for identifying the rules governing community assembly [51]. Most studies using a functional approach have focused on the response of weed communities to the reduction in tillage intensity [36,52].

Steponavičienė et al. [53] studied the combined effect of reduced-tillage vs. no-till and the presence/absence of crop residues (Figure 1E,G) on the composition of weed communities through a 2-year survey in a long-term field experiment located in Lithuania. They observed an increase in the abundance of weed species, indicating moderate acidity and low acidity, moderately wet and wet and nitrogen-rich and very nitrogen-rich soils in the reduced tillage and no-tillage systems. The application of plant residues decreased the weed species' abundance. In the reduced tillage and no-tillage systems, the quantitative distribution of weed was often unbalanced. These results suggest that achieving a large amount of residues in tillage-based systems remains a challenge.

2.5. Optimization of Herbicide Weed Management

CA systems combine a diverse set of farming practices, which may evolve when farmers optimize the farming practices [16]. However, CA systems still face problems in managing weeds [54], which are no longer controlled by tillage. The set of non-chemical weed management tools is more limited in CA than in tillage-based systems, and this is usually reflected by an increase in herbicide use after the adoption of CA [16,34,36]. However, chemical weed management needs to be optimized when transitioning to CA [55]; otherwise, the over-reliance on herbicide use with limited modes of action could increase the risk of herbicide resistance [56].

Zahan et al. [57] assessed the types and distribution of weeds in non-puddled rice and strip-planted wheat fields and tried to identify the most economic and effective ways to manage weeds in both cereals. The field study was conducted with a CA-based rice–wheat–mung bean (*Vigna radiata*) cropping pattern during two consecutive years (2017–2018 and 2018–2019). The performance of two herbicides—pendimethalin (as pre-emergence) and carfentrazone–ethyl + isoproturon (as post-emergence)—for strip-planted wheat and three herbicides—two pre-emergence herbicides pretilachlor and pyrazosulfuron–ethyl, as well as the post-emergence herbicide bispyribac–sodium—for non-puddled rainy season rice were evaluated in comparison to a 'weedy check' (not treated) and 'weed free' treatments. The most frequent species were *Cynodon dactylon, Digitaria sanguinalis, Echinochloa colona, Physalis heterophylla, Leptochloa chinensis, Leersia hexandra, Fimbristylis miliacea, Ludwigia decurrens, Jussiaea repens, Enhydra fluctuans and Alternanthera sessilis.* Zahan et al. [57] showed that sequential application of pendimethalin as a pre-emergence treatment followed by carfentrazone–ethyl + isoproturon as post-emergence treatment was the most effective and economically viable for weed control in strip-till wheat. For weed management in non-puddled rainy season rice, the application of pyrazosulfuron–ethyl (pre-emergence) and bispyribac–sodium (post-emergence) was the most effective combination.

Research on herbicide efficacy in CA systems encourages judicious herbicide use in CA. While herbicide-focused research does not improve our understanding on agroecological levers to reduce herbicide use, it can help ensure the profitability of the CA systems for farmers in some production situations [58,59].

3. Management Options Straying from the Pillars of Conservation Agriculture

3.1. Superficial Tillage Is Worst Than Ploughing after a Long-Term CA Phase

No soil disturbance ensures that weed seeds remain on the soil surface, a condition deemed to be unfavorable to weed germination [60,61], particularly for big seeds (Figure 1A). However, many studies have reported higher weed pressure under no-till than under ploughing [62,63]. Such observations could suggest that physical (e.g., seeder, especially if drilled with tines), biological (e.g., carabids, earthworms), or natural disturbances (e.g., rain, humectation/desiccation) could improve seed–soil contact and/or seed burial, thereby allowing weed germination and establishment in no-till [64]. Alternatively, permanent no-till systems could provide a stable habitat for a new suite of adapted species, as observed for annual grasses, perennials and anemochorous/low seed mass species [52,65,66].

Rather than perpetuating the sterile debate between those considering CA through its means (i.e., the three pillars described above) and therefore banning the use of tillage, and those considering CA though its objectives (e.g., increasing soil health), and therefore, willing to consider a wider set of weed management tools (including occasional and superficial tillage), we highlight that little is known on the influence of tillage in fields previously conducted under CA principles. Strategic tillage could help to diversify selection pressures and cope with certain challenges encountered in no-till [67], such as the management of herbicide resistant-weeds [68] or other pests (e.g., slugs, voles) [69], soil compaction [70] or reduced crop productivity [70–73].

Cordeau et al. [33] asked if tillage is a suitable option for short-term weed management in conservation agriculture. Based on preliminary results, they provide insights on how to assess the effect of introducing different levels of tillage intensity, after a long-term CA sequence, on weed communities and crop yield. The experiment compared three types of fallow management including ploughing (CT), reduced tillage (RT), no-till with glyphosate (NT) after 17 years of no-plough, which ended with 7 years of CA. They found that the introduction of tillage is a major driver of weed communities (density, richness and composition) before weeding in winter wheat. Weed density and species richness before weeding was greatest in RT, intermediate in CT and lowest in NT. However, tillage effects on weed community were not visible after weeding, highlighting the tremendous potential of herbicides to homogenize initially contrasted weed flora and the difficulty to link agronomic practices and weed observations, when the latter is made after weeding [74]. The authors provide avenues for future research through detailed methods and key references. From a multicriteria perspective, the long-term benefits associated with CA could largely exceed short-term yield increases associated with occasional tillage.

3.2. Compensating Minimum Tillage Implemented in CA Systems by Increased Mulching

Cropping systems in Bangladesh typically include monsoon (aman) rice (*Oryza sativa*) during the rainy kharif season, followed by a second rice (boro) crop in areas where irrigation water is in ample supply. Cropping following CA principles has become increasingly attractive among farmers in recent years. Conservation tillage practices such as zero, strip and reduced tillage or permanent raised beds may improve crop establishment and sowing timing, increase yield, reduce irrigation requirements, lower production costs and boost income, though they have yet to be systematically studied on-farm in Bangladesh [75].

Furthermore, in Bangladesh's intensively cropped rice-based rotations, the nature of weed seed bank shifts over time after adopting CA are poorly known.

Hossain et al. [76] showed that strip tillage and crop residue retention decreased the size but increased the diversity of the weed seed bank under intensive rice-based crop rotations in Bangladesh, through two 2-year on-farm studies under wheat–mungbean–winter rice and monsoon rice–mustard–winter rice rotations. They investigated whether reduced soil disturbances (i.e., by practicing strip-tillage (ST)) could be combined with increased deposition of standing residue from previous crops (0 vs. 50%). ST with 50% mulch had a lower weed abundance and biomass and fewer weed species than conventional tillage (CT) without residue. They confirmed that reducing tillage tended to increase perennials, finding more perennials (density and biomass) in strip tillage (*Ageratum conyzoides*, *Alternanthera philoxeroides*, *Cynodon dactylon*, *Cyperus rotundus*, *Jussia decurrence*, *Leersia hexandra*, *Scirpus mucronatus* and *Solanum torvum*) and more annuals (*Cyperus difformis*, *Cyanotis axillaris*, *Echinochloa crus-galli*, *Eleusine indica*, *Fimbristylis miliacea* and *Rotala ramosior*) than conventional tillage [15]. In addition, they also confirmed that tillage reduction in rice-based rotations concentrated weed seeds on the top horizon and increased weed diversity, as shown in other contexts [15,77,78].

Results from rice-based cropping systems in Bangladesh [76] sustain conclusions made in European and North American grain-based cropping systems that reducing tillage needs to be implemented along with cover cropping (Figure 1F,H) and living (Figure 1C) or dead mulches; otherwise, weeds can rapidly become the major issue in CA. Despite this, Hossain et al. [76] reminds us that perennial weeds are a major issue in CA and that farmers reducing herbicide use while reducing tillage intensity need to think about CA systems/rotation/practices differently from what we still do currently.

4. Effect of Weed Management on Ecosystem Services Provided by Conservation Agriculture

Non-chemical weed control can be effective but sometimes at the expense of other objectives. Blanco-Sepúlveda et al. [79] studied the impact of weed control by hand tools on soil erosion under no-till. The maintenance of permanent cover is challenging during hand weeding but is crucial to limit water erosion. In addition, limiting erosion is vital in tropical environments, where rain can damage soil structure and fertility.

The traditional cultivation system that continues in many upland areas of Central America is based on no-till and high rates of soil coverage by crops [80]. The authors showed that the use of machetes for weed control led to soil disturbance, explaining the high rates of erosion, and disturbed the litter layer, making it less effective in preventing erosion in the humid tropical mountains of northern Nicaragua. This study highlights that in all regions of the world, farmers are facing important and sometimes very different local problems, but that in all these situations, it is necessary to consider the advantages and drawbacks of implementing a particular practice. The study also highlights that limiting erosion was one of the primary motivations for farmers who implemented CA decades ago but that sustainable weed management could challenge this primary objective.

5. Conclusions

The Special Issue "Conservation Agriculture and Agroecological Weed Management" gathered studies from across the world that were focused on improving weed management for CA systems. This collection of scientific articles illustrates the weed management challenges that arise from the absence of tillage in CA systems and, consequently, the need to optimize crop rotations and cover cropping for effective weed management. This collection is also a reminder that weed management in CA is challenging because the primary objective of CA is to limit soil erosion. Finally, some studies in the Special Issue opened avenues for future research on agroecological weed management, based on a better use of cover cropping, mulches and the role of soil diversity in mitigating weed–crop interference. Implementing CA is a major disturbance for weed communities that evolved with more than 10,000 years of tillage-based agriculture. However, the sustainability of weed management in conservation agriculture relies on a major principle that could represent the fourth CA pillar as it represents the most important principle of agroecological or integrated weed management: Despite the limiting number of weed management tools in CA, farmers should "keep their weeds guessing" by utilizing a diverse set of spatio-temporal weed management tools.

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