Weed management in Conservation Agriculture systems: farmers' testimonies

Gottlieb Basch, Mediterranean Institute for Agriculture, Environment and Development (MED) – Universidade de Évora, Portugal; Søren Ilsøe, Knudstrupgaard Farm, Denmark; Miguel Barnuevo-Rocko, Finca Munibañez s/n Chinchilla, Spain; Anderson Schmitz, Schmitz Family Farm, Brazil; Marcelo Zanella, Agricultural Research and Rural Extension Company of Santa Catarina (EPAGRI), Brazil; Benjamin Dias Osorio Filho, Chalé do Seival/State University of Rio Grande do Sul, Brazil; Luiz Antônio Pradella, Pradella Group, Brazil; Valmor dos Santos, Inovação Agrícola, Brazil; Corey Loessin, Aidra Farms Ltd, Canada; and Marie Luise Carolina Bartz, Federal University of Santa Catarina, Brazil/University of Coimbra, Portugal

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1 Introduction

Since the dawn of agriculture several millennia ago, farmers have tried to manage unwanted, spontaneous vegetation to give their crops an advantage over such vegetation and produce more of the desired yield in the crops they grow. After the shift by humans from a hunter-gatherer existence to producing their own food through agriculture, a variety of methods to manage weeds have been developed based on the knowledge and technologies available at a given time. Apart from hand weeding to reduce the pressure of weeds on crops, the use of soil tillage has been the preferred method over centuries to suppress weeds, whether selectively or non-selectively, through uprooting, burial or creating unfavourable conditions for unwanted vegetation.

Although the first organic chemical herbicide was developed at the end of the nineteenth century, the broad development and use of both organic and synthetic compounds as weed killers started in the middle of the last century. There is no doubt that chemical weed control was revolutionary, making weed management more effective, faster and cheaper. It also allowed for reducing soil tillage intensity, as weed control was no longer solely dependent on tillage. At the same time, interest in reduced tillage started to grow in countries such as the United States in response to the Dust Bowl conditions in the 1930s. In the decades that followed, more and better herbicides became available. This helped to stimulate more interest in no-till planting which, in turn, helped no-till seeding equipment to develop and improve.

The history of no-till development is well documented (Phillips and Young, 1973; Phillips and Phillips, 1984; Derpsch, 1998; Baker at al., 2007). However, the definition of a new concept known as Conservation Agriculture (CA), which integrated minimum soil disturbance (ideally no-till) into a more complex system of sustainable soil management, was launched at the turn of the last century. The additional components which define CA, permanent organic soil cover and crop diversity, provide opportunities for integrated weed management in CA systems.

As detailed in the previous chapters, there are many approaches, whether stand-alone or combined with one another, that can contribute to weed management in CA systems. The adequate combination of approaches will depend on several factors such as agroecological conditions, crops and cropping systems, history of land use, and soil management.

Conventional, tillage-based crop establishment in combination with herbicides, whether applied in pre-seeding, pre-emergence, or post-emergence, has developed over decades and adapted to emerging challenges such as the appearance of new weeds or the development of herbicide resistance. However, the relatively recent and sudden shift from tillage to CA-based crop production has confronted farmers with a new reality from the day of transition. The chapters in this book have discussed the many aspects of this transition and changes in weed management, whether in different cropping systems or through the use of different cultural, physical, chemical, or biological approaches. In this concluding chapter, several testimonies by farmers about their experiences of weed management after the shift to CA are presented to emphasize the importance of practitioners' views when profound changes in farming methods are needed.

The testimonies in this chapter comprise different agroecologies and farming systems:

- two in Europe, one in the Atlantic Central region (Denmark) and the other in the Mediterranean South (Spain), both working in annual cropping systems;
- three in Brazil, one in the South, in the Santa Catarina state, with a temperate but hot summer climate, specialized in horticultural crops; another in the Cerrado biome of Bahia state in the Northeast, dedicated to annual broadacre crops; and a third one practicing organic no-till farming in Rio Grande do Sul; and
- finally, a farmer from the cold semi-arid Canadian prairies, cropping cereals, oilseed rape, and pulses.

Each is listed by country and farmer.

2 Farmer experiences of weed management under Conservation Agriculture systems: Denmark (Søren Ilsøe)

2.1 Farm and farming system description

Location: Knudstrupgaard, Denmark (55.41775 11.62764).

Cropping area: 295 ha.

Minimum-tillage since the year 2000 and a transition to direct seeding following the principles of CA since 2011.

Several different seeders have been tested on the farm over the years, but we have ended up with a disc drill as the best solution. We use a Weaving GD 6-meter machine with very little soil disturbance.

Over the years, the crop rotation has become simpler with fewer crops due to problems with roe deer, which cause major damage to broad beans. In addition, summer drought has become more widespread, resulting in significant yield losses in broad beans. Also, the price is simply too low for this crop to be profitable.

Winter rapeseed is the only broadleaf crop, and its position in the rotation is important because grass weeds can be effectively controlled in this crop.

Winter wheat is grown on the largest proportion of the farm area. Currently, there is a transition to bread wheat varieties to meet the desire to grow higher-quality bread-making wheat instead of feed wheat, in part, because the demand for wheat for human nutrition is expected to increase in the coming years.

Spring barley is grown focussing on malting varieties. It is a challenging crop to grow throughout Denmark due to the short growing season. Farmers practicing direct seeding, in particular, face problems in achieving satisfactory yields as a result of the slower germination of spring barley in the no-till system.

However, on our farm, over the last 12 years under CA, average yields compared to the last 10 years with traditional ploughing (1990–1999) have increased by 6.9% in winter wheat, while spring barley yields have grown by 26.6%.

Fuel and time consumption have decreased, and the average fuel consumption for all field work is now 42 L/ha.

2.2 Challenges and solutions in weed management: grass weed species occurrence and dynamics

At the end of the 'ploughing period' in the late 90s, there were major problems with Couch Grass (*Elymus repens* L.). However, within a few years after switching to no-till cultivation, this grass weed started to disappear and now, under pure no-till, this problem weed is completely forgotten; it simply does not occur anymore.

In the years 2000–2010, a new grassy weed appeared all over the country. This was Barren Brome (*Bromus sterilis* L.), likely due to the phasing out of Isoproturon, a very effective grass weed herbicide. Although a very common weed on conventionally cultivated fields, it has never been a major problem on our farm and nowadays is almost non-existent. It is easy to control. The use of glyphosate applied before sowing seems to contribute decisively to keeping this species under control.

Soft Brome (*Bromus hordeaceaus* L.) is almost absent today on our no-till cultivated fields. However, it can be found in roadside embankments and fences in some places.

In contrast, Italian Ryegrass (*Lolium multiflorum* Lam.) is becoming an increasing problem in some parts of Denmark, and resistance has developed in certain areas. Luckily, it has never been detected on our farm.

Black-grass (*Alopecurus myosuroides* Huds.) has become a huge problem on farms with intensive winter crop rotations. It is a major issue but, again, this species has never been detected on our farm.

Annual Meadow-grass (*Poa annua* L.) can be found in the fields and is almost exclusively seen in trampled areas. So far, it is not a problem as its occurrence is still very rare. In some years with more favourable conditions for the species, it may be seen to a slightly larger extent.

Rats's Tail Fescue (*Vulvipa myuros* L.), on the other hand, is a problem (Fig. 1). This genus was first detected in 2006 in a field with Red Fescue (*Festuca rubra* L.). It is not known whether it originated from seed contamination or was introduced with a foreign straw baler. This new species has escaped regular weed control and spread to the other fields with the combined harvester. Additionally, the problem was underestimated at first since the species was relatively unknown.

Since then, it has been the biggest challenge in annual cropping systems (Fig. 1, left), and it is responsible for higher glyphosate consumption than if this species were not present. Controlling large plants requires 1000–1100 grams of glyphosate per hectare. To ensure an effective treatment, we acidify the spray solution and add ammonium sulphate. Without this grass weed, glyphosate usage could be halved!

In spring barley, the species cannot be controlled, so field desiccation is crucial before sowing (Fig. 1, right).

In winter wheat, there is a moderate effect of the herbicide mix of Mateno Duo + Boxer (a.i.: Aclonifen, Diflufenican + Prosulfocarb) at growth stage 10–11. Atlantis (a.i.: Mesosulfuron-methyl, Propoxycarbazone, Mefenpyr-diethyl (Safener)) also has an effect. In early spring, Broadway, a mix of Florasulam, Pyroxsulam, and Cloquintocet (a.i.) has an effect that is highly dependent on weather conditions and growth.

In winter rapeseed, Kerb 400 SC (Propyzamid) is an important solution that is nearly 100% effective against *V. myuros* L. if applied correctly. This means that having winter rapeseed crop in the rotation is very important. It is probably impossible to completely eradicate this weed but, as long as it is kept under control and only occurs at acceptable densities, yield impacts are tolerable.

Figure 1 Rats's Tail Fescue (*Vulvipa myuros* L.); Infested field (left) (Photo: Muhammad Javaid Akhter), sprayed-off before seeding (right).

2.3 Broadleaved weed occurrence and dynamics

The species composition of dicotyledonous weeds has changed significantly since we stopped ploughing. Previously, common chickweed (*Stellaria media* L.) was widespread but is now very rare. Mayweed (*Tripleurospermum inodorum* L.) has also been greatly reduced. This species is typically a problem in winter oilseed rape but is now only seen at the edges of fields. However, it must be controlled as weed plants can grow very large and cause problems at harvest, as well as produce a lot of new seeds, thereby increasing the seed bank.

Shepherd's purse (*Capsella bursa-pastoris* L.) is commonly found but easily controlled. Sow-thistle (*Sonchus* spp.) is also common and easily controlled. In years with lower plant densities and rainy weather, it can sprout very late in the season and grow rapidly.

Field poppy (*Papaver rhoeas* L.) occurs in all fields but is easily controlled. Common field-speedwell (*Veronica persica* Poir.) is widespread in all fields and easily controlled with standard techniques. Cranesbill (*Geranium* spp.) is increasing in prevalence. It did not exist 10 years ago, but now it is found in almost all fields. It can be quite difficult to control with low doses of glyphosate, but it is easily controlled with other common herbicides.

Cleavers (*Galium aparine* L.) has become more widespread and is the dominant weed in most fields. It has a tremendous ability to reproduce, especially in winter oilseed rape, where it can sprout late in the season and produce seeds. It is easily controlled in cereal crops using 2-*methyl*-4-*chlorophenoxyaceticacid (*MCPA*)* but persists longer in winter oilseed rape before harvest.

Creeping thistle (*Cirsium arvense* L.) is the new major weed problem! Commonly used herbicides have very little effect on this species, and it requires a targeted application of MCPA herbicide, which increases overall herbicide use. The species invades from areas where fallow is legally required (farmers are required by the Danish government to leave some land fallow on environmental grounds). Seeds are blown from these areas far into cultivated areas. Mechanical mowing is not allowed in these areas from May to September and, during this period, the species disperses many seeds over the fields via the wind.

2.4 Changes in pesticide use after going ploughless (1999) and converting to Conservation Agriculture *in 2011*

When looking at the overall use of pesticides on the farm, it naturally varies greatly from year to year due to the weather conditions and, especially, the amount of rainfall.

Insecticides have been completely phased out and have not been used for the past 10 years.

Fungicides appear to have reduced in dosage generally, but more years of experience are needed to confirm this trend. In recent years on our farm, the application of around 50% of the dosage used under conventional conditions has proven to be sufficient.

There can be some slug attacks in the field, but the promotion of aboveground biodiversity under CA conditions, especially birds, helps to control this problem. Figure 2 shows seagulls hunting. They visit fields in the mornings to find slugs but, unfortunately, earthworms as well.

When we have dense and well-developed crops, the strong competition they provide against weeds requires reduced amounts of herbicide. We can now skip glyphosate application before the establishment of winter wheat after spring barley (Fig. 3) since a good barley stand helps to suppress weeds, as

Figure 2 Seagulls invading a no-till cereal field feeding on slugs, earthworms, and other small animals.

Figure 3 Field (left) and detailed (right) view of dense residue cover allowing for avoiding pre-seeding herbicide treatment.

well as due to the absence of grass weeds that are successfully controlled in previous crops.

Using the web-based application, Plant Protection Online allows for a more targeted, need-based dosage and helps in the selection of products, providing great help in finding good solutions and individual application strategies at the field level. When cover crops are successfully established and dense, they can effectively compete with weeds (Fig. 4). Unfortunately, it is not always possible to establish them at the desirably early stage after the main crop.

A test with planting pure summer vetch at a high plant density has proven to be very effective in suppressing weeds, possibly due to allelopathy. More focus should be placed on this approach in the coming years. For the past 2 years, winter rapeseed has been grown without the use of glyphosate before sowing (Fig. 5). This method works very well when the previous crop has been weed-free, and it will likely become common practice in the future.

The use of new technologies for digital weed recognition will definitely become widely adopted, and new machines for non-chemical control are also gaining popularity. Direct seeding with disc openers (Fig. 6) is also very effective in avoiding the germination of new weeds from the existing seed pool in the soil as almost no soil disturbance takes place. After several years of using disc openers, the number of weeds has significantly reduced. Weed seeds on the soil surface are consumed by beetles and many are largely destroyed by fungi and birds, so it is very important to disturb the soil as little as possible to optimize these biological methods of control.

Figure 4 Crop establishment into a dense cover crop.

Figure 5 Rapeseed established into cereal residues without pre-seeding weed control.

Figure 6 No-till with strongly inclined disc openers for minimum soil disturbance.

3 Farmer experiences of weed management under Conservation Agriculture systems: Spain (Miguel Barnuevo-Rocko)

3.1 Farm and farming system description

Munibañez Farm where I started using no-tillage is located in the south-central part of Spain, in Chinchilla in the province of Albacete. We have two types of soils: some are deep, basic, with low organic matter content and loamy and clay loam textures (Calciorthid). Other soils are shallow with a calcareous crust at shallow depths, with little organic matter and light-to-loamy and sandy loam textures.

The average annual rainfall is 375 mm, and the climatic classification is Continental Mediterranean. Rainfall is irregularly distributed in autumn, winter and spring, with long dry periods, especially in summer. The frost-free period occurs from May to September. Due to climate change, in recent years, there has been a tendency for the spring to start much earlier and for autumns to lengthen: the frost-free period is widening from April to October, but there are still heavy frosts in winter. The average temperature has increased by more than 1.5°C, and, more seriously, high temperatures begin to occur in the spring (March and April), significantly affecting the phenology of both herbaceous and woody crops. In 2023, the duration of high temperatures was so severe that, together with a prolonged drought since December 2022, it led to a complete failure of rainfed crops in a large part of the province. Irrigated cereal crops suffered yield losses of more than 35%.

At the farm level, there are two types of managements:

- Rainfed farming on an area of 300 ha, with barley, oats, triticale, wheat, and legumes, mainly peas and vetches, all sown in autumn. Spring-sown summer crops are very risky due to erratic rainfall in spring. Sunflower has been tried sporadically on the deeper soils, but frequently results in very low yields.
- On the irrigated part of the farm, crops can be grown throughout the year, choosing species that are adapted to the climate. Rotations used consist mainly of alfalfa, maize, barley, wheat, oats, and ryegrass for fodder, oilseed rape, and sunflower, all sown using the no-till system on an area of around 100 ha.

In addition to cultivating our own farm, we provide services for no-till crop establishment on other farms representing around 1000 ha/year (500 ha of winter cereals and leguminous crops and 500 ha of mainly maize and sunflower).

3.2 Challenges and solutions in weed management

In rainfed farming, when we started in 1993 with no-till, the usual cropping practice was to have one crop every second year. This meant that 1 year a crop was planted (e.g. barley, wheat, oats, triticale) and the following year the land was kept fallow. Weed problems were relatively low, with wild oats (*Avena sterilis* L.) and poppies (*P. rhoeas* L.) being the main problems. During the fallow period, wild oats were controlled using glyphosate and poppies with a selective 2,4-D or similar treatments within the cereal crop. Erosion rates were quite high.

During the initial years of no-till, a tine-coulter seeder was used without incorporating fertilizer. Fertilizer was broadcast at the surface and applied at the same rates as in the conventionally tilled plots. During the first years, we used the same doses in both systems (tillage and no-tillage).

After 3 years of cereal monoculture, it became clear that we had to rotate with leguminous crops every third year to ensure sufficient nutrients in the soil. We also concluded that 'continuous' cultivation (every year) was much better than fallow in between two main crops. This was because the fields that were not cultivated for 1 year resulted in the development of spontaneous vegetation (Fig. 7), consisting mainly of volunteers from the previous crop and weeds. To deal with this vegetation, glyphosate was applied at the beginning of spring (April and May) before weed seed setting. Occasionally, there was a

Figure 7 Spontaneous vegetation developing in years under fallow.

need to have another spray-off treatment at the end of winter to keep some grass weeds such as brome grass (*B. sterilis* L.), wild oats (*A. sterilis* L.), annual ryegrass (*Lolium rigidum* Gaudin), and fescues (*Vulpia* sp.) under control.

In the early 2000s, we started to notice the proliferation of some weeds such as Veronica (*Veronica* sp.), 'verruguera' or European heliotrope (*Heliotropium europaeum* L.), and shepherd's purse (*C. bursa-pastoris* L.). However, we did not find it necessary to eliminate these as they did not compete with our crops. We started to apply the principle of tolerating some plants which contributed to forming a protective cover for the soil.

It was also during these years that we began to have problems with prickly saltwort (*Salsola kali* L.) (Fig. 8, left). In some summers, when it rained in July–August after harvest, there were significant infestations of this weed. These had to be eliminated, as otherwise, they greatly hindered subsequent sowing in autumn with tine-coulter seeders. The control of this weed was expensive and complicated, as eradication was difficult. The solution came within a few years, with the use of disc seeders of several brands (Semeato, Tatu Marchesan, Kuhn, etc.) which all had almost no problem in 'cutting' prickly saltwort and sowing on top of them (Fig. 8, right).

Conyza sp., mainly hairy fleabane/horseweed (*Conyza bonariensis* L.), also began to appear, but their presence did not compete with crops as they developed in August and September, which is an off-season cropping period under rainfed farming conditions in Spain.

During this period, we also tested different glyphosate doses in the autumn treatments to see whether it was possible to reduce the application rates. The conclusion was that glyphosate doses could be reduced to 0.75 L/ha (360 g/L). However, over the years, the experience taught us that it was not worth 'fine-tuning' too much, as low doses could not be 100% effective, thus risking generating resistance, especially in brome grass and annual ryegrass.

Another lesson we learnt, especially in irrigated plots, was that the earlier treatment (15–20 days before sowing) was always better for sowing quality than treating volunteers of the previous crop and weeds just before sowing.

Figure 8 Prickly saltwort (*Salsola kali* L.) infestation after unusual summer rainfall.

In 2000, we started to experiment with sowing on irrigated fields with large amounts of residues from the previous crop. Such conditions are prone to become a big problem if the seed drills are not able to cut the large amount of plant remains and place the seed at the correct depth. To overcome this potential problem, we started to use sweepers to clean the sowing line (Fig. 9). At the same time, we started to carry out post-emergence herbicide treatments as pre-emergence treatments were less effective due to the large quantity of residues and organic matter on the surface of the soil.

At this time we also started to apply fertilizers with the seed drill. The improvement in yields, especially in maize, was noticeable.

In recent years, we have had some problems due to autumn droughts. The lack of rain in September–October, and in some years even November, causes a delay in the germination of the first weed 'wave'. This means that the spray-off before autumn sowing is not very effective in protecting a crop sown in almost dry soil against the weeds mainly germinating after sowing together with the crop. This has made subsequent treatments with other active ingredients than glyphosate necessary, and thus more expensive. It obliges us to have spraying equipment of sufficient width as possible and in good condition to make the most of the short time available to carry out treatments in the autumn–winter period. The price of spraying equipment, as well as seed drills, has risen enormously in recent years.

One interesting aspect is that, in certain years, either because of a strong infestation of a certain weed species or because of a low expectation of grain yield mowing the cereal crop for fodder was preferable, thus avoiding the seed-setting of weeds. The problem of controlling weeds by mowing is that, in the end, other creeping weeds that are difficult to control by mowing can become established. Weed control on irrigated land has turned out to be much easier, especially with alfalfa in the crop rotation.

Figure 9 Row-cleaners used for crop establishment into residue-rich no-till seedbed.

As for insecticides after the shift to no-till, we still used them preventively until 2005–2006, applying them together with the seeding operation. Subsequently, we observed that there were no problems, so we have not used them since then as a preventive measure.

4 Farmer's experiences of weed management under Conservation Agriculture systems: Brazil (Anderson Schmitz and Marcello Zanella)

4.1 Farm and farming system description

My name is Anderson Schmitz, and my wife is Milena Jasper Schmitz. We are farmers in the municipality of Aguas Mornas, Santa Catarina, Brazil. My family has been growing vegetables for at least 30 years. My parents, Afonso Schmitz and Aurea Sebold Schmitz, and I farm a total area of 20 ha. The area used for cultivation is 3 ha, where we grow tomatoes, eggplant, cauliflower, bell peppers, zucchini, string beans, and Japanese cucumbers. The property is located in a mountainous region with a predominance of Quartz Neosol soils and a humid subtropical climate, with hot summers and rainfall of approximately 1500 mm/year.

Our family has always grown vegetables using the conventional system, which involves a lot of soil preparation and intensive use of herbicides, fungicides, bactericides, and insecticides. We have frequently discussed as a family how we could improve our management to reduce production costs, soil losses from constant tillage in hilly terrain, and the direct and indirect damage caused by herbicides used to control weeds between rows of crops.

In 2016, I participated in a course for rural youth organized by the Agricultural Research and Rural Extension Company of Santa Catarina (EPAGRI). I learned about a new system for working with vegetables. Through the classes and technical visits to properties in the vegetable-producing region of Florianópolis, I discovered new ways of cultivating and managing the cultivation systems based on the No-Till System for Vegetables (SPDH). The principles of this system are based on promoting plant health, a better understanding of how plants grow, their relationships with each other and with microorganisms, their capacity to rebuild and improve the cultivation environment, and their ability to co-exist with spontaneous plant growth throughout their life cycle. This approach improved soil quality and, in many cases, eliminated problems with soil fungi and bacteria that were harming the plants.

The first step in changing our property's management was acquiring equipment such as a roller crimper (Fig. 10, left) and a brush cutter to manage cover crops and spontaneous plants and a two-wheel walking tractor equipped with a roller, cutting disk, and straight rotary device to open rows for crop establishment with minimal soil disturbance (Fig. 10, right).

Figure 10 Roller crimper to terminate the cover crop consisting of pearl millet (left); two-wheel walking tractor, equipped with a roller, cutting disk and straight rotary device as row opener (right).

4.2 Challenges and solutions in weed management

One of the main challenges of this new approach was overcoming the fear of allowing coexistence between commercial/cash crops and spontaneous plant/weed growth. Rethinking crop management, including changing fertilization, was also a significant challenge, mainly because we were accustomed to conventional management, where the presence of spontaneous plants during the growing season of the main crop was considered unthinkable.

After 6 years of managing cropping areas without turning over the soil, we have gathered new knowledge that has allowed a considerable reduction in the use of chemical inputs. We have already reduced the use of pesticide products to control fungal and bacterial diseases by 60%, insecticides by 50%, and herbicides by 90%. Additionally, we have reduced the use of fertilizers by 40%. Previously, we used more inputs than needed, which ended up harming the plants. This reduction in inputs has also led to a reduction in labour and production costs, along with an increase in productivity and better-quality food.

In the conventional system, we used to harvest approximately 75 000 kg of tomatoes per hectare. Today, we harvest up to 140 000 kg/ha. In the case of cauliflower, where we used to achieve a harvest index of 60%, we now can harvest more than 90% of the plants. We have also eliminated erosion that occurred in areas under soil tillage, reduced the use of water for irrigation, and increased soil organic matter content. The use of cover crops, ensuring permanent soil cover throughout the year, has facilitated management of spontaneously growing plants/weeds.

In long-cycle crops such as tomatoes, the residues left by the cover crop suppress spontaneous plants during the initial phase of the main crop. At a later stage, spontaneous vegetation coexists with the commercial crop and is managed mechanically, thus maintaining enhanced biodiversity in the system (Fig. 11, left). This approach is also effective for bell pepper and eggplant crops.

Figure 11 Tomato crop cultivated under the 'No-Till System for Vegetables (SPDH)' established into oats residues with emerging spontaneous vegetation controlled by cutting (left); weed control in a cauliflower crop solely based on the residues of a pearl millet cover crop (right).

In string bean, cauliflower, and Italian zucchini crops, residues of cover crops are sufficient to suppress spontaneous vegetation throughout the whole cycle without any need for additional management (Fig. 11, right).

In general, the population of spontaneous plants remains constant. However, with the adoption of management practices under the SPDH, we noticed that in the hottest period (summer), grass species such as *Brachiarias*, *Digitarias*, and *Commelina* spp. predominate. In winter, *Sonchus* spp. and *Galinsoga* sp. are more common. As the system evolves and soil quality improves, some spontaneous plants no longer establish themselves. Since we mechanically manage spontaneous plants coexisting with vegetables, we only perform chemical control when climbing species such as Ipomea appear in order to prevent them from climbing on the plants. After harvesting vegetable crops, we immediately sow cover crops so that they establish themselves as quickly as possible, avoiding the appearance of new spontaneous plants.

We work with winter and summer cover crops. In the summer, we mainly use Millet, and in the winter Black Oats intercropped with Vetch. The largest volumes and consequently the best coverage always occur with summer plants because Millet produces a large amount of biomass, covering the soil for a long period (Fig. 11, right). The winter cover crops produce less biomass but, when rolled without using herbicides, they sufficiently cover the soil to suppress weeds effectively during a cropping cycle of up to 80 days, which is enough for commercial crops such as cauliflower. We realized that, when we used herbicides to terminate cover crops, the process of residue degradation is accelerated, thus promoting faster soil exposure. When the cover crops do not produce enough biomass to fully cover the soil, the weeds that germinate between the rows are managed mechanically with a brush cutter to prevent them from shading the main crop. The objective is to manage but not destroy them altogether so as to maintain biodiversity in the system.

The establishment of cover crops is done by broadcasting seeds superficially. We still do not have the equipment to perform direct no-till seeding, as many producers already do in the region, which would be the preferable and optimal option. Our system of cover crop establishment requires some adaptations to guarantee sufficient germination. We broadcast the cover crop seeds into standing spontaneous vegetation and later brush cut this vegetation so that the seeds are protected under the spontaneous vegetation residues. If soil moisture is insufficient, we irrigate twice in a period of 1 week to ensure uniform germination, obtaining a crop stand necessary for good biomass production and comprehensive soil cover.

In the SPDH that we practice, crop rotation is fundamental. We always use intercropping with a cash crop and later with cover crops. This way, the soil will always have plants and will always be covered with some kind of vegetation. This management has facilitated coexistence with spontaneous plants without harming the commercial crop. Through crop rotation, we have areas in production and under cultivation throughout the year, providing continuous income for the family. Our experience is that with adequate management of the system, the use of appropriate machinery, and planning of commercial crops and cover crops, we can reduce and even eliminate the use of herbicides in our system of horticultural crop production.

5 Farmer's experiences of weed management under Conservation Agriculture systems: Brazil (Luiz Antônio Pradella and Valmor dos Santos)

5.1 Farm and farming system description

In our testimony we would like to respectfully address all the food producers in this immense and diverse Brazil, diverse both in terms of soil and climate and in cultural traditions inherited from our ancestors, including descendants of Europeans and others. Our main objective is to provide some brief historical background, offer a diagnosis of current challenges, and offer some solutions. Our main aim is to stimulate interest and independent thinking which does not necessarily have to align with ours. The important thing is to think and reflect as a basis for productive change.

It is important to emphasize the agroclimatic conditions of our 'Cerrado' region which, unlike the northern hemisphere, experiences high temperatures practically year-round, severely penalizing any agricultural mismanagement. It is also important to note that in our region, land tenure is characterized by large farms that are highly mechanized and grow mainly cotton, soybean, and corn in intensive forms of production. These types of production have had a number of negative consequences, including on soil health. We have learned that a concerted action of all involved parties is needed to understand problems that have emerged, take the right corrective actions, and change established behaviours to overcome problems.

One example of emerging problems was the push in the early 2000s to authorize the use of modern biotechnologies such as genetic modification (GM). The development of new GM pesticide-resistant crop varieties made it easier to use pesticides to manage pests, diseases, and invasive weed species. However, it also had some negative impacts, particularly on fibre quality, increased susceptibility of new varieties to some diseases, and greater demands on soil fertility. With conventional soybean production, producers struggled to control invasive plants, but there were practically no reports of plants resistant to glyphosate and/or graminicides. Issues with white mold (stem rot) (*Sclerotinia sclerotiorum* (Lib.) de Bary) or soybean cyst nematode (*Heterodera glycines* Ichinohe) were also minimal.

However, the use of new GM varieties has been associated with the development of corn stunt disease (*Spiroplasma kunkelii* Whitcomb) transmitted by the corn leafhopper (*Dalbulus maidis* DeLong) and, more recently, by the fall armyworm (*Spodoptera frugiperda* Smith) in maize cultivation. Both seem to have been 'selected for' by more susceptible GM varieties and have become serious pests, far more virulent than the corn earworm (*Helicoverpa armigera* Hübner). This has raised legitimate questions about placing too much reliance on biotechnology. It is fair to say that, on most farms, the weed problem is growing. Perhaps it is time to consider alternative approaches to control invasive plants more intelligently. By shifting the focus from anthropic to syntropic solutions, we can use nature to act in our favour.

5.2 Challenges and solutions in weed management

This section describes in more detail some of the invasive plant problems that exist in our region (Cerrado of Western Bahia) which, we believe, are not very different from other regions. Given that invasive plants can be defined as those that are in an undesirable place at a given time, we first need to think of cultivated plants, so-called volunteers, that can become invasive in following crops. This is the case for all our main crops: cotton, soybean, and corn, which are all based on genetically modified Roundup-Ready varieties which can therefore become invasive and resistant to control. Secondly, there are several indigenous plants such as crowfoot grass (*Eleusine indica* L.), shrubby false buttonweed (*Spermacoce verticillata* L.), hairy spurge (*Euphorbia hirta* L.), all highly tolerant to glyphosate, and sour grass (*Digitaria insularis* L.) and hairy fleabane/horseweed (*C. bonariensis* L.), which are resistant to glyphosate. The development of resistance has been slowed, but not halted, by the development of new herbicides such as Enlist and Xtend.

In the next section, we will look at solutions for managing both volunteers and indigenous 'weed' species with a particular focus on combining chemical control and intercropping. An important point to note that modern concepts of integrated weed management no longer aim to completely eliminate a weed but rather to adopt a more balanced approach by limiting weed populations to levels that do not significantly affect cash crop yields

Cotton seeds that survive harvesting are dormant. When chemical control is used, these potential volunteer plants (known as 'tiguera' cotton) remain on the soil surface and gradually become inviable. Mechanical destruction, e.g. via tillage can both damage soil structure and mean that cotton seeds are incorporated into the soil where they invariably germinate and emerge in different waves, making them extremely difficult to control. Avoiding soil disturbance also favours rainwater infiltration into the soil profile, promoting aquifer recharge. To illustrate this point, Fig. 12 shows the result of chemical management of cotton stalks, while Fig. 13 shows the result of mechanical management of stalks with significant resprouting.

The chemical approach to destroying cotton bolls has continuously evolved. Since the late 1990s, chemical control has been combined intercropping the subsequent maize crop with a grass species, *Brachiaria* sp., based on the No-Till System (NTS) (Fig. 14) which involves no-till crop establishment into plant/crop residues. This raises the question of how to avoid competition between *Brachiaria* sp. and maize as the main crop. Experience shows that, if well managed, the two can coexist, contributing to the integrated control of invasive plants.

In this case, the main problem is the cotton itself, either through volunteer seeds or shoot regrowth (stalks), since the following maize crop on its own

Figure 12 Chemical control of cotton stalks (no resprouting).

Figure 13 Mechanical management of stalks (a lot of resprouting, not allowed by law).

Figure 14 Maize under the No-Till System intercropped with *Brachiaria* sp.

provides excellent conditions for hosting volunteers. However, an intercropped species can smother cotton volunteers and resprouts. Figure 14 shows the excellent control of cotton resprouting and volunteers in this system. By incorporating *Brachiaria* sp. into the maize planting, the system benefits from the aggressive growth habit of *Brachiaria* sp., which helps suppress the growth of cotton volunteers. The key is to manage *Brachiaria* sp. in a way that does not compete excessively with the maize crop. This can be done through timely mowing or herbicide application that targets *Brachiaria* sp. without harming maize, allowing both crops to coexist while suppressing unwanted cotton volunteers. Residues from the maize and *Brachiaria* sp. also contribute to soil organic matter, improve water infiltration, and reduce erosion, creating a more sustainable cropping system. In western Bahia and other regions, soybeans can also be used as a living cover which avoids the development of invasive plants as well as delivering other benefits such as improving water infiltration and storage in the soil (Fig. 15).

Figures 16–19 showcase one of the most advanced cotton NTS in the world, developed in western Bahia through a Technical Cooperation (TC) between Regional Consultants (CRs) and Rural Producers (PRs). Only in a well planned and executed NTS, is it possible to effectively control weeds in a crop, avoiding such problems as over-reliance on herbicides (which promotes resistance), heavy cultivation (which both damages soil structure and can even promote some invasive plants), insufficient cover (which then fails to prevent volunteer or invasive plant emergence) or competition between cover and cash crop

Figure 15 No-Till System of soybean in rotation with cotton – excellent control of stalk resprout and volunteers.

Figure 16 Cotton under the No-Till System in rotation with maize + *Brachiaria* sp.

Figure 17 Cotton under a high-quality No-Till System in rotation with maize + *Brachiaria* sp.

Figure 18 Maize under a high-quality No-Till System into residues of *Panicum Maximum* cv. Mombaça, intercropped with *Brachiaria brizantha* cv. Piatã.

which may then affect cash crop yields). Complementing the use of *Brachiaria* sp. is intercropping of maize with another grass species, *Crotalaria spectabilis* Roth, a practice developed approximately 10 years ago. Implementing this technology in the field requires a lot of experience as operations are more complex. Figure 20 illustrates the performance of this intercropping species in maize.

Figure 21 (left) shows soybean and *Brachiaria* planted simultaneously at a small plot scale. With the remaining soil moisture retained in the system, there is exponential growth of the grass shortly after the soybean harvest. This requires careful management, e.g. with selected applications of herbicide to

Figure 19 Maize under a high-quality No-Till System, intercropped with *Brachiaria ruziziensis*.

Figure 20 Maize under a high-quality No-Till System, intercropped with *Crotalaria spectabilis*.

ensure the resulting cover is properly controlled. Figure 21 (right) shows this approach at field scale.

Figures 22 and 23 show the key role that cover or 'second' crops can play in suppressing weeds. Figure 22 shows a field with (T1) and without (T2) Brachiaria as a second crop after soybean, where T2 shows a mix of invasive species. In Fig. 23, without Brachiaria (T2), hairy spurge (*Euphorbia hirta* L.), which is tolerant to glyphosate, finds an excellent opportunity to develop.

Figures 24 and 25 show pearl millet (*Cenchrus americanus* L.) and sorghum (*Sorghum bicolor* L.) after soybean, intercropped with *Brachiaria brizantha*

Figure 21 Soybean intercropped with *Brachiaria*, at plot scale (left), at field scale (right).

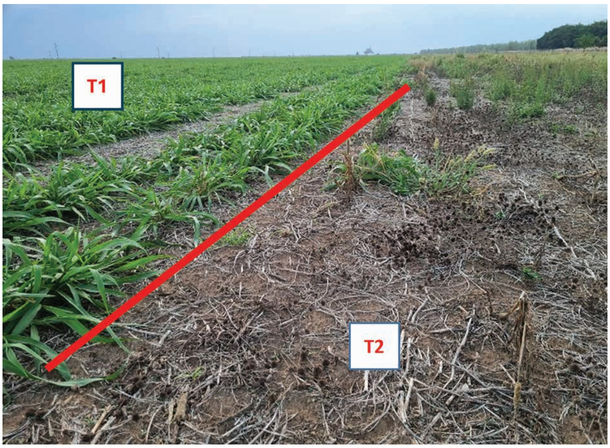

Figure 22 Field after soybean with (T1) and without (T2) *Brachiaria brizantha* cv. Marandu.

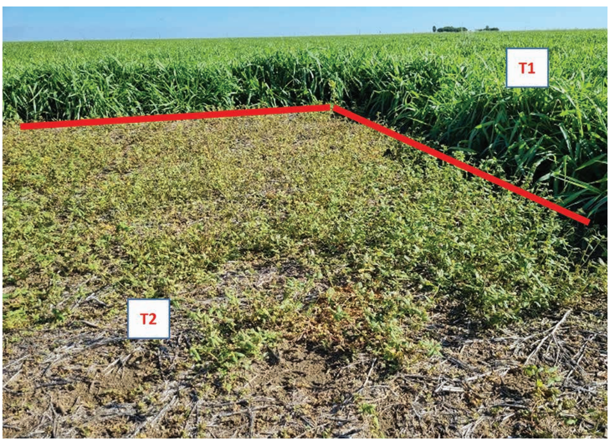

Figure 23 Field after soybean with (T1) and without (T2) *Brachiaria brizantha* cv. Marandu. T2 infested with hairy spurge.

Figure 24 Pearl millet (*Cenchrus americanus* L.) intercropped with *Brachiaria brizantha* cv. Piatã.

Figure 25 Rainfed sorghum (*Sorghum bicolor* L.) intercropped with *Brachiaria ruziziensis*.

cv. Piatã and *B. ruziziensis*, respectively. No soybean volunteers are visible, indicating full control of this potential invasive plant. After the harvest of the cereal crop (corn, millet, or sorghum), *Brachiaria* sp. develop rapidly (Fig. 26) providing enough biomass for excellent soil cover for the following soybean crop (Figs. 27 and 28).

Some farmers argue that it is only feasible to use *B. ruziziensis* Germ. & C.M. Evrard on their farms, claiming that other grass species such as *Brachiaria brizantha* cv. Piatã, cv. Marandu, and *Megathyrsus maximus* B.K. Simon & S.W.L. Jacobs, cv. Mombaça require higher doses of glyphosate to control. While *B.*

Figure 26 Pearl millet (*Cenchrus americanus* L.) intercropped with *Brachiaria brizantha* cv. Piatã, right after harvest (left), 10 days after harvest (right). Source: authors.

Figure 27 No-till (NT) of soybean in soil covered with guinea grass (*Megathyrsus maximus* B.K.Simon & S.W.L.Jacobs, cv. Mombaça). Source: authors.

ruziziensis is an excellent choice, the other species mentioned can accelerate the improvement of a NTS without relying on higher doses of glyphosate.

As suggested by the discussion above, achieving a high-level NTS requires co-operation between different parties, exchange of ideas and a period of experimentation and leaning from practical experience. We are fully aware that achieving a high-level NTS is hard work and requires teamwork, planning, and patience from everyone involved. A fundamental objective of ours to call upon those all those involved to develop agriculture further together. We are facing increasing climatic adversities and greater risks for agricultural activities. Only through the development of appropriate soil and crop management technologies we can mitigate these impacts and increase the resilience of production systems.

Figure 28 No-till (NT) of soybean in rotation with corn into soil covered with *Brachiaria ruziziensis*. Source: authors.

6 Farmer experiences of weed management under CA systems: Brazil (Benjamin Dias Osorio Filho)

6.1 Farm and farming system description

Organic farming has always attracted my attention. While studying agronomy, I became interested in agroecology and soil management. I chose the path of teaching, and since then, I've been a university lecturer involved in research and extension work in regenerative and organic agriculture. Meanwhile, my family's property was leased for conventional soybean and rice production, which created a paradox that bothered me. In 2020, we started an organic grain production project on the property, focusing on soybean, maize, and beans. We began with just over 20 ha and have since expanded to around 70 ha. Along with producing organically, I have always been concerned with soil conservation and carbon sequestration. This laid the foundation for a fundamental shift to organic no-till farming.

In the first year of my Agronomy degree, back in 1999, I had the privilege of attending a lecture by Dr. Ana Maria Primavesi, a prominent figure in Agroecology in Brazil. According to her, organic no-till farming is viable as long as a large amount of mulch is provided, and cover crops are properly managed near maturity. These observations stuck with me and ultimately guided the implementation of our project more than 20 years later. We chose to use winter cover crops based on black oats (*Avena strigosa* Schreb) and Persian (*Trifolium resupinatum* L.) and white (*T. repens* L.) clovers. In May 2020, we sowed this mixture but due to the presence of a considerable seed bank of ryegrass (*L. multiflorum* L.), ryegrass emerged alongside the other crops. Through allelopathy, it dominated the area, hindering the growth of oats and clovers. Consequently, we were forced to rely on ryegrass cover for direct sowing of our summer crops. The pleasant surprise was that, thanks to the allelopathic effect of the ryegrass, the incidence of spontaneous plant growth was strongly inhibited, and ryegrass became an excellent cover crop for our production system, especially for soybean and beans. The ryegrass biomass is flattened with a knife roller when the summer crops are sown (Fig. 29).

For maize, however, while ryegrass cover suppresses spontaneous plants due to its higher C/N ratio, it also causes nitrogen immobilization, requiring higher doses of nitrogen fertilizer. In our organic maize crop, chicken litter is

Figure 29 Sowing soybeans on ryegrass straw managed with a knife roller.

Figure 30 Growing organic soybeans on ryegrass straw.

our main nitrogen source, but it is costly because it must be sourced from some distance away. One alternative we have not yet successfully implemented, due to the allelopathic properties of ryegrass, is to grow winter legumes before maize. In the case of soybeans and beans, ryegrass cover has proven to be an effective ally in suppressing spontaneous plant growth (Fig. 30).

6.2 Challenges and solutions in weed management

In the first harvest (2020/2021), weeds were less of a problem due to the previous years of conventional herbicide use, which reduced the seed bank and perhaps left some residual effects. However, in subsequent cropping seasons, spontaneous plants such as fanpetals (*Sida* spp.), rice grass (*Echinochloa* spp.) (Fig. 31), millet (*Digitaria* spp.), and corriola (*Ipomoea* spp.) were quite prevalent. In case of deficient crop establishment, weeds easily occupy the space where the cover crop was cut to allow the main crop to emerge (Fig. 32). It is important to note that these weeds emerge late, thanks to the ryegrass cover. During the critical period for preventing soybean interference, the area remains relatively weed free. However, at the end of the crop cycle, when the soybean leaves begin to fall, weeds become dominant, affecting grain filling and making mechanical harvesting difficult.

Spontaneous plant management in our system is based on the allelopathic effect of ryegrass cover crops and the use of mechanical control between the

Figure 31 Rice grass (Echinochloa spp.) infesting the space between rows of organic soybeans.

rows. Ryegrass has proven to be an excellent ally in weed suppression and is a low-cost cover crop. Thanks to the seed bank established over the past 20 years, we do not need to sow ryegrass annually. When the summer crops finish in the autumn, ryegrass begins to emerge spontaneously. To increase its biomass and, consequently, its weed-suppressing effect, we apply fertilizers, especially poultry waste, earlier during summer crop growth. This nitrogen also enhances ryegrass growth. Another strategy we have employed is rolling the ryegrass during the milky grain stage while it is still green and combining it with earlier sowing of soybeans or beans. At this stage, there is still some regrowth, but the suppressive effect lasts longer.

In our pursuit of organic no-till grain production, we have found allies along the way. One such partner is the company Gebana Brasil®, which buys our organic grains and is researching technologies to support such initiatives. The company has provided a prototype of an inter-row brush cutter (Fig. 33). The machine, attached to a tractor, cuts the aerial parts of weeds without disturbing the cultivated rows. It has proven effective in controlling dicotyledonous weeds, which do not regrow after being cut. However, grass weeds tend to regrow a few days after mowing, requiring improvements to the prototype. One proposed solution is using winged rods that cut the roots with minimal soil disturbance, preserving the straw cover.

Figure 32 Failures of soybeans' emergence allowing spontaneous oat to emerge where the disc cut through the straw cover.

In addition to summer crops, we plan to grow winter grains such as white oats, wheat, or peas. However, ryegrass, which is crucial as a cover crop in our system and supports summer no-till farming, becomes an obstacle for winter planting. To address this, we aim to introduce turnip rape (*Raphanus sativus* L.) immediately after the summer crops to inhibit ryegrass growth, making no-till planting of winter crops feasible. Each situation, depending on its environmental conditions – such as soil type, climate, seed bank size, and commercial crop preferences – requires specific spontaneous plant management strategies. As Ana Primavesi suggested, organic no-till farming is viable, provided there is abundant biomass and proper timing for managing cover crops. Observation and continuous adjustment are key.

Figure 33 Spontaneous plant control using an inter-row brush cutter developed by Gebana Brasil®.

In summary, there is no question that direct seeding/zero till production has stabilized and improved production, nearly eliminated any soil erosion and has resulted in soil organic matter increase. The use of diesel fuel is also much lower per unit output than would be required if tillage were still a significant weed control means. There are a few weed species that are increasing, and multi-group herbicide resistant populations are a cause for concern. This will require new modes of action, and/or a more diverse set of weed control tools. Modern production is currently fairly heavily reliant on herbicide weed control, and this needs to change and become more diverse if the same level of effective control is to be maintained. Farms here are very large with a low labour component, so to be successful, additional methods will need to be able to be incorporated into production systems without dramatic increases if any in labour requirements. Robotic and autonomous machinery employed for weed control may well be part of the future system.

There is not a single farmer I know or have ever met that would reverse the adoption of zero till production. Everyone recognizes the benefits to the soil and to the farm business. Challenges must be overcome using methods and technology that allows zero till to continue, as it is too important from a soil conservation and soil health perspective to deviate from it.

7 Farmer experiences of weed management under CA systems: Canada (Corey Loessin)

7.1 Farm and farming system description

Owner: Corey Loessin, Aidra Farms Ltd.

Radisson, Saskatchewan, Canada (52.5°N, 107.5°W).

Our farm is in north-central province of Saskatchewan in the heart of the Canadian Prairies. We have thin black soils (Chernozem), primarily loam texture with clay subsoil. This region would be classed 'semi-arid' and receives about 300 mm of moisture annually including snowfall, although precipitation is highly variable with both extended dry and wet spells being common. The frost-free season is about 100–120 days from May to September so there is only time for one crop per year. Our cold winters help to lessen soil carbon losses, reduce disease pressures, improve soil structure among other benefits.

We currently farm 3500 acres (1400 ha) in a continuous cropping system (no fallow) with a crop rotation that alternates a broadleaf crop with a monocot crop. A typical 4-year rotation is spring wheat – canola – wheat – pulse crop, then back to wheat (Fig. 34). Spring barley or oats can replace wheat in the rotation, and the pulse can be either lentils or peas. Canola is typically the most profitable so it is always part of the crop cycle.

We have been direct seeding since 1996 so approaching 30 years with the only soil disturbance occurring during seeding. We have always used a Bourgault air drill with 3/4 inch (1.9 cm) knife style openers and the fertilizer blend is applied with mid-row banding discs (Fig. 35).

Before and into the 1980s, farms in this area would crop 2/3 of their land base each year and fallow 1/3. Fallow was performed by several tillage passes with a disc or cultivator through the growing season to control weeds and try to save moisture for the next crop (dust mulch). However, soil erosion from

Figure 34 Wheat (left), lentils (centre), and canola (right) as key crops in the rotation under Conservation Agriculture.

Figure 35 Planting equipment used on the farm with knife opener for seed placement and discs for fertilizer banding.

wind, primarily, was catastrophic. When the top soil got dry, and had little or no cover, frequent prairie winds would move tonnes of topsoil to the field edge and beyond. Lighter texture soils lost so much soil that some fields became uneconomic to farm.

During the 1980s, several farms switched to continuous cropping. Some equipment improvements made this easier. I began farming in 1991 and we continuously cropped our land at that time. Seeding was done with an air seeder using large sweep openers with maximum disturbance. Depth control was poor, and packing following seeding was a separate operation. Fertilizer application was also done in a separate pass, either early in spring or late in previous fall. Soil erosion was reduced but not eliminated.

7.2 Challenges and opportunities in weed management

Weed control was also very challenging during this period of transition to continuous cropping. Glyphosate was not widely used as it was too expensive. Quack Grass (*E. repens* L.) was seriously out of control and the seeding operation dragged the rhizomes all over the field where they promptly grew new plants in the soft, moist soil. Canada Thistle (*Cirsium arvense* L.) was also very prevalent in fields as the elimination of the fallow part of the cycle was the only real control mechanism. Both of these perennial weeds were major problems and caused a lot of crop loss. Several annual or winter annual weeds were also common problems, such as Narrow-Leaved Hawksbeard (*Crepis tectorum* L.), Shepherd's Purse (*C. bursa-pastoris* L.), Stinkweed (*Thlaspi arvense* L.), and Wild Buckwheat (*Polygonum convolvulus* L.).

Two changes occurred that completely changed the direction of this production system – glyphosate became more economical to use, and the practice of a pre-seed burn-off application became common. Typically applied at 0.5 L/acre (1.25 L/ha), virtually all weeds present before seeding were controlled. Fall (post-harvest) spraying also provided excellent control of the two biggest weed issues – Quack Grass and Canada Thistle. The other major change was the development of narrow opener direct seeding machine capable of seeding and fertilizing in a single field pass and disturbing the soil very little.

Another development of great significance was the introduction of herbicide-tolerant canola. Systems with either glyphosate-tolerant or glufosinate-tolerant canola became available, and enabled the control of a wide spectrum of weeds previously difficult or impossible to control. Cleavers (*G. aparine* L.) was a common weed issue in canola crops as the seed is inseparable from canola seed. These new systems controlled it. Stinkweed was also very common in canola crops and could now be controlled.

Introduction of pulse crops (first field peas and then lentils) was another helpful development that enabled the use of some different herbicides during that year. Both crops are rather weak competitors and require robust weed control programs. Perennial weeds must be well controlled before the pulse crop in the crop rotation.

Generally, planting of annual crops occurs earlier in the season in a zero till system than what used to be done using a conventional tillage-based system. Obviously, the less preparation work that needs to be done ahead of zero till planting partly enables this. Additionally though, the changes in the soil that improve water infiltration from multi-year zero till allow field operations to begin earlier. The earlier start helps crops to begin growth ahead of weeds and increases the likelihood of full maturity being reached before a damaging fall frost.

About 10 years following the introduction of direct seeding, Quack Grass had virtually disappeared from the fields. Canada Thistle was also much better controlled as well. A pre-seed application of glyphosate, followed by an in-crop herbicide application, then a pre-harvest or post-harvest application of glyphosate dramatically changed the weed spectrum and weed population density on fields. Overall, fields now have the fewest weeds that they have ever had during my farming career. Some annual weeds such as Wild Oats (*Avena fatua* L.), Shepherd's Purse, Cleavers, and Wild Buckwheat are still present in small, well-controlled populations. Many winter-annual weeds that used to be very prevalent such as Narrow Leaved Hawksbeard and Stinkweed are now very rare. We have not seen a Quack Grass plant on any of our fields in 20 years. Canada Thistle (wind blown seeds) will still be present particularly if a fall control application is not done for 2 years in a row. Fields with very low weed populations can now occasionally forego the spring burn-off application with no economic penalty.

A few weeds are increasing in zero till and are cause for some concern. One small area weed is Field Horsetail or Scouring Rush (*Equisetum arvense* L.). It typically grows in small patches that do not spread readily, but there is no herbicide that can control it. This weed was very minor back when tillage was a frequent part of the cropping system, so it clearly thrives under no-tillage.

Another problematic weed is Kochia (*Bassia scoparia* L.). It has been increasing rather dramatically and has also developed resistant populations to several groups of herbicides. Weakly competitive pulse crops enable Kochia to become established and then its control becomes challenging. The extensive use of Roundup Ready canola is also becoming a problem, as glyphosate-tolerant kochia populations are also rising rapidly. To a lesser extent, Foxtail Barley (*Hordeum jubatum* L.) has increased. Later fall glyphosate applications still seem to control it fairly well. Some annual weeds, such as Stinkweed and Shepherds Purse, may begin to increase, as they are largely resistant to herbicides used in pulse crops. However, several other herbicide groups still provide good control, thus underlining the positive impact of diverse crop rotations.

Herbicide application technology has undergone considerable advances. GPS-controlled machines have been common for some time. Nearly all sprayers now have many sections along the boom with automatic control. Our latest unit has individual nozzle control and turn compensation, so application rate is very precise and overlap is virtually eliminated. The first 'see-and-spray' technology is being trialled by some. It seems green on brown spraying (where computer vision technology is used to identify weeds in fallow fields) works fairly well, although the economics of the equipment is not yet favorable, given its current cost. Green on green spraying (which seeks to identify weeds in a growing crop) is being developed but is not yet working to the point of commercial availability.

Almost all farms have their own sprayer. Spray timing is critical, and farms can best time the operation with their own unit. Custom applicators are quite rare, with the exception of some aerial applications (plane and helicopter) more common for crop desiccation or insect control.

Other aspects of weed control are starting to be implemented. Weed seed destructors on combine harvesters are starting to be used. This technology may become widespread over the next few years. Other non-herbicide control strategies – timely mowing of problem patches, for example, or strategic patch tillage operations, are being incorporated by some.

Most farmers are paying attention and rotating herbicide groups through fields as best they can (various published and online tools are available). That said, one of the most worrisome issues on the horizon are increased populations of herbicide-resistant weeds.

Costs of weed control have been relatively stable for some time. Some product costs have decreased typically as patent protection runs out. However, the cost of application equipment has increased dramatically. Our system remains reliant on herbicides as the most cost-effective weed control method.

Virtually all modern combine harvesters have highly effective crop residue chopping and spreading capability. While crop residue chopping was once a limitation, it no longer is. Furthermore, widespread adoption of semi-dwarf cereal crop varieties means there is less residue produced which further enables successful direct seeding. Some operations include a harrow post harvest to help spread residue and provide some further straw breakdown.

The principal reason farmers adopted no-till (approximately 75% of the cropped acres in western Canada) was to reduce wind erosion of top soil. The system also reduced diesel fuel consumption (ours is now about 18 L/acre/year; 44 L/ha/year). It saves topsoil moisture which enables better crop establishment. Continuous cropping with a diverse crop rotation also improves the soil. On our home quarter, e.g. soil organic matter has increased from 3% to 4.5% during the 33 years we have farmed it. Soil tilth has visibly improved, as has moisture-holding capacity and infiltration rate. Earthworms are very prevalent throughout the fields now while they were almost non-existent when we started.

Insecticides are used in zero tillage systems relatively rarely. Insecticide seed treatment on canola seed is 100% employed for the control of flea beetles, and its effectiveness reduces the need for foliar applications dramatically. Occasionally, other insect issues do arise – currently grasshopper is a significant pest in the dry cycle and in the driest areas. However, overall, insecticide use is quite low.

Fungicide use is also occasional. Wet cycles necessitate some disease control measures but many years there is simply not enough moisture to create an environment that is conducive to serious disease.

Nearly 100% of farms practice responsible and 'closed-loop' systems with respect to pesticide containers. Common and higher rate products are now almost exclusively handled in returnable and reuseable totes (typically 1000 L). Smaller use rate products in plastic jugs are emptied, rinsed, and then returned to collection depots at all retailers in large bags for collection and recycling. This program is run by CleanFarms – an initiative funded by manufacturers, and participated in by virtually all users of their products – works exceptionally well (https://cleanfarms.ca/).

Although our farm and many others have been in zero till systems for a long time, and it is difficult to make comparisons, it does seem like the amount of pesticide use has actually fallen as a ratio of productivity. Some studies conducted by the University of Saskatchewan quantify this. Many weeds, as well as some insects and diseases that used to be very problematic, are either not present or not present in economically damaging levels. The zero till system itself is partly responsible for this. Improvement in genetics of every crop type has made a major contribution (disease resistant varieties, for example). And again, a more diverse crop rotation has improved soil health, reduces disease pressures in crops and enables farms to optimize use of resources.

Cover crops are not used at all in this region. Generally, there is hardly enough moisture for one crop, let alone more. Fall planted crops are also used little, although they can work satisfactorily some years. They would be a good addition from a weed control/weed life cycle perspective.

8 Conclusions and the future of weed management in Conservation Agriculture systems

The testimonies of farmers who have transitioned from conventional-to-CA-based farming systems many years ago provide valuable insights into what must be taken into account regarding weed management after making this change:

- There is no 'one-size-fits-all' solution. The adaptation of weed management strategies, alongside the significant change in soil management, needs to be tailored to existing conditions in terms of crops, weeds, soils, climate, and agricultural management practices and their interactions.
- Changes in the composition and incidence of weed communities will occur, requiring farmers to have a better knowledge of prevalent weed species and their ecology, their sensitivity to herbicides, available herbicides (particularly their mode of action and efficacy at different crop residue levels and weed development stages), and the period of weed interference on crop yield. A key issue is keeping the seedbank at a low level (even with diverse composition), preventing the prevalence of a single or small group of weeds well adapted to the crops and management practices. This requires crop diversification and diverse management practices.
- Under CA, successful weed control strategies are accomplished by the combined use of several direct and indirect methods and management practices, both preventive (e.g. cover crops, mulch layers) and cultural methods (e.g. intercropping, crop varieties, sowing time). In other words, the full implementation of all CA principles is key for keeping the weed population manageable, thus avoiding negative impacts on yields, especially in the long term, and even allowing for a reduction in herbicide use over time.
- Biotechnological advancements, such as the development and use of single or multi-herbicide tolerant crop varieties, could facilitate weed

management (not only under CA) in the short term. However, they might not be sustainable in the medium/long term due to the adaptation of weed communities, the reliance on chemical weed control, and the likely disincentive for alternative weed management strategies offered by the CA approach.

- A continuous attitude of observation and improvement, willingness to take risks, and eagerness to innovate are key ingredients for making weed management under CA successful and less reliant on herbicides over time.

The testimonies of the pioneer farmers presented in this chapter, though from different corners of the globe, are certainly not exhaustive regarding the vast variety of conditions and farming systems. However, these examples demonstrate that it is possible to adapt to and cope with site- and cropping system-specific challenges after a shift towards CA. They can serve as case studies providing potential approaches for different agroecological and farming conditions.

The main objectives of soil tillage have always been to ease the placement of seeds, plants, or tubers into the soil and to reduce competition from unwanted vegetation with the established or soon-to-be-established crop. While the challenge of the first objective has gradually been overcome through the development of increasingly sophisticated machinery, often equipped with precision technologies able to adapt to local conditions, the challenge of the second objective remains for both tillage-based and no-till cropping systems. Due to their effectiveness, low cost, ease of use, and high return, chemical weed control is widely used among farmers in both conventional and CA systems.

In some regions more than others, existing concerns among consumers and society as a whole, along with more restrictive regulations on the use and environmental exposure to pesticides, are increasingly limiting the use of agrochemicals, especially pesticides. Based on these concerns, the benefits and necessity of using pest and disease control products for crop production and global food security are often overlooked. When it comes to herbicides, the benefits of replacing mechanical, tillage-based weed control with chemical weed control are almost completely ignored. These benefits largely derive from the avoidance of tillage-induced soil disturbance, thus reducing soil erosion to a minimum, as well as the mineralization and loss of soil organic matter, not to mention the positive impact on soil life.

Moreover, the widespread assumption that no-till farming is more reliant on herbicides is not true. While tillage may terminate existing weeds, it also creates loose, bare ground, perfect conditions for weed seeds to germinate. In essence, tillage can increase weed germination and growth. Conversely, no-till farming, in combination with other elements of CA, hosts a wide range of mechanisms and processes that, over time, lead to reduced weed pressure and a decrease in overall herbicide use. Most of these mechanisms and processes are well known and described (Eslami, 2014; Singh et al., 2015; Mhlanga et al., 2016; Basch et al., 2020), while others require further investigation and field studies (Rueda-Ayala et al., 2015).

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10 References

Baker, C.J., et al. (2007), *No-tillage seeding in conservation agriculture* (2nd ed.) CABI and FAO. Cromwe Press, Trowbridge, p. 352.

Basch, G., et al. (2020), 'Weed management practices and benefits in CA systems'. In A. Kassam (Ed.), *Advances in conservation agriculture, volume 2: practice and benefits*, Cambridge, UK, Burleigh Dodds Science Publishing, pp. 105–141. https://doi.org/10.19103/AS.2019.0049.04. (ISBN: 978-1-78676-2689).

Derpsch, R. (1998), 'Historical review of no-tillage cultivation of crops', *Proc. 1st JIRCAS Seminar on Soybean Research. No-tillage Cultivation and Future Research Needs*. 1–18.

Eslami, S.V. (2014), Weed management in conservation agriculture systems. In B.S. Chauhan and G. Mahajan (Eds.), *Recent advances in weed management*, Springer, New York, NY, USA, pp. 87–124.

Mhlanga, B., et al. (2016), 'Weed management in maize using crop competition: a review'. *Crop Prot.*, 88, 28–36.

Phillips, E.R. and Phillips, S.H. (1984), *No-tillage agriculture, principles and practices*, Van Nostrand Reinhold Co., New York, p. 319.

Phillips, S.H. and Young, H.M. (1973), *No-tillage farming*, Reiman Associates, Milwaukee, Wisconsin, p. 224.

Rueda-Ayala, V., et al. (2015), 'Investigation of biochemical and competitive effects of cover crops on crops and weeds', *Crop Prot.*, 72, 79–87.

Singh, V.P., et al. (2015), Weed management in conservation agriculture systems'. In M. Farooq and K.H.M. Siddique (Eds.), *Conservation agriculture*, Springer International Publishing, Cham, pp. 39–78. ISBN 978-3-319-11620-4.