Breaking the vicious cycle: a systems approach to weed management in organic production

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March 2023

INTRODUCTION

The context

Weeds are considered a nuisance group of plants and eradication has become the norm in most crop production systems since they cause economic losses for most farmers when not managed properly. Weeds have become the major challenge after soil fertility in most organic farms in Western Canada. Due to large-scale farms, deploying effective weed control programs is a daunting challenge. Organic farms heavily rely on tillage to control weeds and overreliance on tillage has negative impacts on soil fertility, crop productivity and subsequent weed management leading to a vicious cycle. Unlike weed management on conventional farms, weed management on organic farms requires a unique philosophical framework. It is first important to realize that weeds cannot be eradicated from organic farms due to the lack of a highly effective single weed control strategy that can substitute for herbicides in conventional agriculture. Second, it is important to realize that the main yield-limiting factor in Western Canadian organic farms is not weeds but soil fertility. Third, unlike in conventional systems, weeds have more ecosystem benefits to organic systems such as nutrient cycling, soil erosion control, and harbouring beneficial organisms (insects and micro-organisms) that have many agroecosystem benefits. Therefore, developing a long-term holistic cropping systems/agroecosystems approach to weed management, understanding priorities, and appreciating weeds as a component of the agroecosystem is critical for organic farms.

The overarching principles of nature

In natural systems, the biotic (crop, weeds, insects and microorganisms) and abiotic (soil, environmental factors and crop management) components are highly correlated and changes in one can have direct or indirect consequences on the other. In the agroecosystem approach, the interactions of the components of a farm and its interactions with the environment are considered for optimal management decision-making. Since organic cropping systems are closer to a natural system compared to the conventional system, the understanding of these interactions among components is critical in increasing overall systems productivity. In this approach, increasing the overall productivity of the system (crops, their temporal and spatial arrangement, and all the crop management practices) by means of a holistic approach to soil, weeds, pest, and disease management is crucial.

The most important overarching principle that applies to systems stability, resiliency, and sustainability is to mimic natural systems by increasing diversity and reducing the disturbances in the cropping system. Therefore, organic crop production systems need to be designed to minimize disturbances and increase diversity to manage weeds as well as to enhance overall productivity.

THE SYSTEMS APPROACH

Building soil productivity (the first principle)

Designing cropping systems to increase productivity and develop soil fertility is a prerequisite for good weed management. Producing a healthy and vigorous crop is the most fundamental requirement in the systems approach to weed management.

Accordingly, a crop that grows quickly and establishes good ground cover, and produces sufficient biomass can be very competitive with weeds thus reducing their emergence, growth, and seed production. Organic crops most often tend to establish slowly and develop less ground cover at early stages thus providing a good opportunity for the weeds to emerge, grow and outcompete. A healthy vigorous crop can always compete well with weeds. Since low soil fertility and high weed abundance simultaneously drag organic yields down, most farmers need to deal with both problems at the same time. However, some experiments carried out within a long-term organic and conventional comparison trial in Saskatoon, Saskatchewan by Benaragama et al. (2016, 2020) showed that weeds are not the main yield-limiting factor in organic systems but rather soil fertility. These studies also highlighted the fact that designing cropping systems to improve soil fertility should be the priority for most organic farms.

The focus on soil fertility and soil quality can help farmers to come out from the soil fertility, weed management and tillage vicious cycle (*Figure 1*).

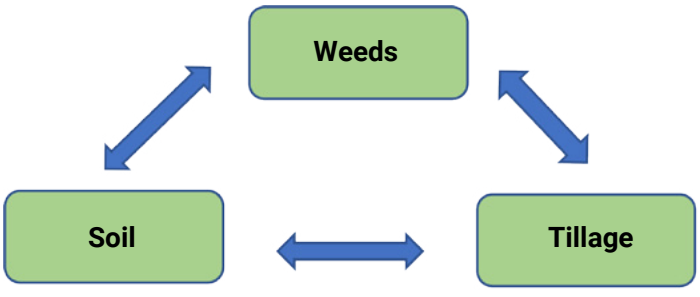

Figure 1. The vicious cycle identified in most organic farms. The main tool for weed management in organic farms is tillage. Excessive tillage hinders soil fertility and soil quality development. Poor soil fertility is the main limitation to achieving a healthy vigorous crop that can outcompete weeds while providing immunity to pests and diseases. Finally, farmers must rely more on tillage to manage weeds that emerge and grow from a non-competitive poor crop stand.

Most organic systems rely on green manure cover crops to develop soil fertility as well as to manage weeds, but producing a good cover crop biomass can be challenging due to the moisture and soil fertility issues on many organic farms. Particularly, most prairie organic crops were found to be deficient in phosphorous (P) content due to lack of available soil P, which could be the main reason for overall low productivity (Martin et al. 2007). Poor cover crop establishment leads to poor soil fertility for subsequent crops, which in turn helps weeds to outcompete crops, produce weed seeds and persist, ultimately forcing farmers to use tillage to control weeds. Excessive use of tillage causes the soil to degrade and reduces soil fertility further. This vicious cycle can only be broken by designing cropping systems to improve soil fertility.

In this approach, it is important to have a full-season soil fertility building green manure crop in the rotation and further supplement soil nutrient sources from diverse means (e.g., farmyard manure, compost, certified organic minerals etc.). Bringing in the fundamental principles of nature, increasing diversity and reducing soil disturbance also applies to building soil fertility and thereby weed management. Having multiple species in green manure provides greater benefits than having a single species (Halde et al. 2014). At the same time, it is important to maintain or enhance soil quality by reducing erosion, soil degradation, and nutrient losses by different means, including the reduction of excessive use of tillage. A good green manure crop serves dual purposes. It provides the nutrients needed to grow successful grain crops as well as biomass and ground cover for effective weed suppression. Thus, managing both the green manure and cash crop phases and building up the soil has multiple ecological roles for the agroecosystem. Further, a healthy vigorous crop is also crucial to tolerate diseases and other pests.

Reducing the disturbance/tillage (the second principle)

Tillage is considered a double-edged sword since it has both benefits and negative consequences in crop production. It is often claimed that the major obstacle to maintaining soil health is the overuse of tillage in organic systems to manage weeds. Adhering to nature's two principles, it is important to increase diversity in crop rotations while minimizing soil disturbance. Even though tillage is a major tool for weed control in organic systems, it is important to realize the long-term overall pros and cons of tillage. Reducing tillage restores soil health, increases organic matter content and carbon content, improves soil structure and minimizes soil erosion (Carter 2002; Hobbs 2007) and overall microbial activity and resource use efficiency. Since increasing the productivity of the overall system is the fundamental principle in weed management in organic systems, farmers always need to weigh the long-term balance of soil fertility and weed management.

Organic systems have highly relied upon ecological processes to build soil, and manage weeds, pests and diseases. The use of tillage opposes these ecological processes, degrading soil health and increasing carbon emissions. Even though it is challenging to minimize tillage, a systems approach with a proper design of all the components can help to reduce the reliance on tillage in organic systems and break the vicious cycle (*Figure 1*). In most organic farms, soil fertility and weed control have become the chicken and egg controversy as these two are highly interdependent. However, soil fertility should come first, and addressing soil fertility eventually leads to better weed management and to reduced tillage on organic farms. In parallel to the direct benefits of reducing tillage on soil fertility and soil quality, tillage has direct implications on weed management. Reducing tillage can reduce weed emergence and deplete soil seed banks due to increased weed seed predation.

The first step in achieving this goal is to reduce the frequency and intensity of tillage by adopting minimal inversion implements and incorporating cover crops in the rotation and rolling to terminate green manure crops. The cropping systems need to be designed in such a way that an increase in weeds, particularly perennial weeds, due to a reduction in tillage is managed using other tactics such as crop diversification and integrating non-invasive mechanical weed control strategies such as harrowing and hoeing. Having said that, tillage can be an essential component in crop production depending on the region. However, maintaining or increasing the overall soil quality is of the utmost importance. Even though excessive tillage can erode soil quality, proper planning and design of cropping systems with green manure crops and farmyard manure can compensate for that in the long run. What ultimately matters is to increase carbon sequestration, build soil organic carbon and improve soil structure whether tillage is used or not. This will facilitate the production of healthy, vigorous grain crops as well as green manure cover crops.

Increasing crop diversity (the third principle)

Designing cropping systems to include a diversity of crop management practices that target different time points of the weed life cycle can benefit both managing crop weed competition and weed persistence. In this approach, crop rotations and cover cropping systems can be highly useful.

Cover crops

Cover crops should be a key ingredient in designing an organic cropping system. Cover crops when managed well can provide multiple benefits such as building soil fertility, smothering weeds, reducing soil erosion, conserving moisture, and breaking pest and disease cycles. Weed management benefits of using cover crops are achieved due to cover crop growth, cover crop mulch, and sometimes due to allelopathic effects (such as fall rye). The key to achieving success in weed management from cover crops is to produce a high-biomass crop. Thus, soil fertility and soil moisture availability and picking the correct species or species mixture are crucial factors. According to Tisdale et al. (1991), a 97% ground cover is important to achieve 75% weed control. Or generally speaking, it is important to have a 6,000-8,000 kg dry matter/ha biomass crop to achieve weed management benefits. High biomasses can be achieved using a cereal cover crop, but it will be challenging to grow high a high biomass crop with the most common legume species. While the most common green manure legume crop, hairy vetch (Vicia villosa L.), can provide N benefits, it has less biomass productivity than cereal rye. Mixing these two species can be an alternative approach to achieve both objectives to some extent. Or growing a winter cereal cover crop in one year for silage production followed by late seeding pulse crops for grain and growing a pulse crop green manure (spring seeded) in another year can be a balanced approach for soil fertility building and weed management.

Whether the cover crop/green manure crop is incorporated or rolled for termination needs to be determined depending on the farm. Even though no-till cover crop systems have many benefits, it requires a lot of skills and machinery and commitment to terminate and seed into cover crop residue. Cover crops in the rotation should be planned in such a way that can break the vicious cycle (*Figure 1*). In order to do that there should be multiple cover crop phases with both soil fertility and weed management objectives at the beginning, since sometimes these objectives can be conflicting to achieve in one cover crop phase, particularly at the early stages of organic transition.

Functional diversity in crop rotations

In order to reduce weed emergence and competition while reducing their persistence, it is imperative to design crop rotations that have functional diversity. Functional diversity in crop rotation implies growing crops with different life forms (annuals, perennials), growing seasons (warm, cool season), seeding dates (early, later), competitive abilities (short, tall), harvesting time (early, late) and type of harvesting (silage, grain) on a rotational basis. Instead of just rotating crops, having this different functionality in crops makes the rotation less preferable for weeds. Thus, in a crop rotation, the crops should be arranged with dissimilar types such as cool season vs. warm season, spring vs. summer crops, and grain crops vs. forage crops. For example, typically, it was known that a three-year alfalfa crop could be a good strategy to manage perennial weeds such as Canada thistle and annuals such as wild oat. However, for the farmers who do not see other benefits of growing alfalfa for three years, it is possible to design a crop rotation with winter cereals cut for silage (similar functionality of alfalfa in managing weeds) followed by

seeding a competitive cover crop (double crop systems). This system can be useful to manage the perennial weeds Canada thistle and dandelion. The inclusion of winter cereals was found to be an effective alternative to three-year alfalfa in managing wild oat (Benaragama et al. 2022). Typically, organic crop rotations designed for weed management are long-term in nature and can span more than six years. In the United States, Anderson et al. (2015) proposed a nine-year crop rotation to manage weeds in organic systems. Other than these systems being long-term and can pose economic challenges for organic growers, these systems can compromise soil fertility management due to their focus only on weed management. Thus, it is critical to design cropping systems that are shorter cycles with both weed and soil management objectives.

Designing good crop rotations can reduce the importance of tillage in weed management. The rotation of cool and warm season crops with the inclusion of cover crops was found to eliminate the need for tillage in several cropping systems. More importantly, diversified crop rotation can have a greater benefit on weed management when coupled with no-till than with tillage (Anderson 2015).

PROPHYLACTIC/REACTIVE WEED MANAGEMENT

Prophylactic weed management or reactive weed management strategies are essential to supplement the long-term systems approach (preventive) for weed management. There is a diversity of approaches that can be implemented within the season to manage weeds. Most of these strategies typically aim to reduce weed density, weed biomass, and weed seed production within the season but have some long-term implications as well. Simple agronomic and mechanical methods can be implemented to manage crop-weed competition which can reduce yield loss as well as provide some long-lasting weed control by depleting weed seed banks. Some of the most widely studied cultural practices to manage weeds within the season are to increase crop competitive ability by selecting competitive crop cultivars, increasing crop seeding rates, narrow row planting, and early seeding. Further, many studies have found that integrating all these together provides more additive benefits for weed control in both organic and conventional systems. Further integration of mechanical methods such as post-emergence harrowing and hoeing, and inter-row cultivation can provide substantial weed control benefits. Therefore, these tools need to be incorporated on a regular basis to manage weeds within the season. In addition to these conventional strategies, weed seed bank management by chaff collection and weed seed destruction are gaining attention in both conventional and organic systems with a long-term weed management perspective.

SUMMARY

The challenges in organic systems are interrelated, thus addressing one and ignoring others will result in overall poor productivity and leads to the vicious cycle (*Figure 1*). The systems approach to crop management and designing cropping systems is necessary to address the most demanding challenges in organic crop production in the Prairies such as soil fertility and weed management. In the system's framework, designing cropping systems to prevent weed emergence and reduce competition and persistence is the key. Here, the most fundamental approach is to build soil fertility to produce a healthy vigorous crop using cover crops and other soil fertility management strategies. Second, it is important to bring crop functional diversity to the system by means of crop rotations. In parallel to crop diversification and soil building approaches, it is necessary to reduce the use of tillage to further build up soil fertility and reduce weed seed persistence in the soil seed bank. Finally, the reactive approaches to weed management such as the use of cultural and mechanical weed control methods can be integrated into the systems approach to supplement weed control. Overall this approach will be able to manage weeds as well as enhance the productivity of the cropping system.

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