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Review article

EFFECTS OF CONSERVATION TILLAGE INORGANIC BRKSHAVRZY

Auobamiri[1*], Ahmad Gholamalizadeh ahangar[2]

[1]Ph.D student of agroecology, department of Agero Ecology, Faculty of agriculture, Zabol University, Zabol, Iran.

[2]Department of Soil Sciences, Faculty of Soil and Water Engineering, University of Zabol, Zabol, IR Iran.

**Corresponding author's E-mail:* ayob.amiri62@gmail.com

ABSTRACT: Conservation tillage covers a range of tillage practices, mostly non-inversion, which aim to conserve soil moisture and reduce soil erosion by leaving more than one-third of the soil surface covered by crop residues. Organic farmers are encouraged to adopt conservation tillage to preserve soil quality and fertility and to prevent soil degradation – mainly erosion and compaction. Tillage affects the soil physical and chemical environment in which soil microorganisms live, thereby affecting their number, diversity and activity. Conservation tillage (CT) is practiced on 45 million ha world-wide, predominantly in North and South America but its uptake is also increasing in South Africa, Australia and other semi-arid areas of the world. The potential advantages of conservation tillage in organic farming are reduced erosion, greater macroporosity in the soil surface due to larger number of earthworms, more microbial activity and carbon storage, less run-off and leaching of nutrients, reduced fuel use and faster tillage. The disadvantages of conservation tillage in organic farming are greater pressure from grass weeds, less suitable than ploughing for poorly drained, unstable soils or high rainfall areas, restricted N availability and restricted crop choice. A high standard of management is required, tailored to local soil and site conditions. Innovative approaches for the application of conservation tillage, such as perennial mulches, mechanical control of cover crops, rotational tillage and controlled traffic, require further practical assessment.

Keywords: Conservation tillage, organic farming, weeds, crop residues

INTRODUCTION

For this review, tillage systems may be separated into two types [62], conservation tillage and conventional tillage. Conservation tillage covers a range of practices which conserve soil moisture and reduce soil erosion by maintaining a minimum of 30% of the soil surface covered by residue after drilling. Generally, conservation tillage includes a shallow working depth without soil inversion, i.e. no tillage or reduced or shallow tillage with tine or discs. Shallow ploughing, to no more than 10 cm, should be included in conservation tillage because burial of crop residues is usually incomplete. Conventional systems of tillage leave less than 30% of crop residues – and often none – on the soil surface after crop establishment. Conventional tillage is invariably deeper (20–35 cm) with inversion of the soil by mouldboard plough, disc plough or spading machine [54 and 92]. In most areas of the world currently still plough the soil, thereby inverting it, and then harrow it to create a fine seedbed [56 and 37] Such systems, named "conventional tillage" systems (CVT) [56], that highly effective in inhibiting annual weeds, counteracts nutrient leaching, and cleans the soil surface, facilitating precise seeding [34]. Conversely, plugging is often accompany by the degradation of soil structure, leading to subsoil compaction, soil surface seals, erosion, and a decrease in soil organic matter (SOM) [96 and 56]. Soil quality, biodiversity and productivity affected by seasonalplougging [54 and 92]. Conservation tillage leaves an organic mulch at the soil surface, which reduces run-off, increases the surface soil organic matter (SOM) promoting greater aggregate stability which restricts soil erosion [40]. Other beneficial aspects of conservation tillage are preservation of soil moisture and increase of soil biodiversity [56 and 103]. Reducing the intensity of soil tillage decreases energy consumption and the emission of carbon dioxide, while increasing carbon sequestration [56]. Reducing the intensity of tillage increases the sustainability of tillage systems by speeding up crop establishment and reducing labour demand [30]. Organic production of field crops generally consumes up to 20% less energy than non-organic agriculture [111].

However, environmental burdens, such as global warming potential or eutrophication, can be greater under organic farming [111]. Thus conservation tillage may improve the environmental and economic performance of organic farming. The International Federation of Organic Agriculture Movements standards [58] recommend that organic farmers 'should minimize loss of topsoil through minimal tillage, contour ploughing, crop selection, maintenance of soil plant cover and other management practices that conserve soil' and 'should take measures to prevent erosion, compaction, salinization, and other forms of soil degradation'. Conservation tillage offers benefits that could improve the soil fertility, soil quality and the environmental impact of organic crop production [44]. However, [61] reported that organic farmers generally use the mouldboardplough,working to a greater depth [76] or to a lesser depth [109] than in conventional agriculture. The relevance of conservation tillage should be assessed in organic crop production.Thus, the purpose of this paper is to highlight the advantages of, and limits to the adoption of conservation tillage in organic farming in terms of the main functions of tillage with emphasis on soil and agronomic aspects rather than economics. Mouldboardploughing is a traditional cultural operation, which incorporates surface organic residues, stimulates mineralization and thereby aids crop nutrition. Tillage management plays a key role in SOM turnover. Soils under organic farming receive frequent organic matter inputs as manures and organic fertilizers [94]. As organic fertilizers are expensive, generally fewer nutrients are supplied in organic farming [29]. Thus, the nutrient contributions from SOM are of greater importance in organic farming [99]. Nitrogen (N) is supplied by the combined use of N fixed in legumes in the rotation and organic manures. Tillage incorporates and distributes this organic matter through the topsoil providing conditions suitable for mineralizing nutrients, particularly N.Tillage also facilitates seedbed preparation, improving conditions for rooting and nutrient uptake [61]. Soil tillage, especially conventional ploughing, is crucial for the control of weeds in organic farming [104]. Weeds are one of the most important factors limiting organic crop production [22]. [90 and 57] found a greater density and diversity of weed species in organic fields than in conventional production.

According to these characteristics of organic farming, three main aspects will be emphasized in this review to determine the suitability of conservation tillage: (1) the preservation of the biological, chemical and physical components of soil fertility and quality; (2) the preservation of soil functions, such as mineralization, support of root growth, soil water drainage and storage; and (3) the role of soil management in weed, disease and pest control. We focus mainly on organic arable systems in western Europe.

Preservation of soil quality and fertility

The different types of tillage system involve different stratification of the soil layers. The soil is divided into three layers: the surface, the topsoil and the subsoil layers. The surface layer corresponds to the seedbed. The subsoil is the undisturbed part of the soil profile below the topsoil. The tilled layer varying from 5 to 40 cm contains the crop residues. Less crop residue is left on the soil surface with reduced or shallow tillage than with no tillage. The reduced tillage method leaving least residues at the surface is shallow ploughing. The main impacts of the different tillage systems on seedbed quality are due to changes in the thickness, extent of soil inversion and extent of mixing of crop residue caused by the implement [24 and 67].

Chemical and biological properties

The quantity of SOM in the whole topsoil varies due to the interacting influences of climate, topography, soil type and crop management history (fertilizer use, tillage, rotation and time) [60]. Thus, in conservation tillage, SOM and microbiological activity are stratified in the soil profile, according to the burial depth of crop residues and manures [77 and 40].However, several authors have shown that there is no significant increase in the overall mass of soil organic carbon (C) or of soil microbial biomass in the whole topsoil in different tillage systems. SOM, organic C and soil microbial biomass increase in the tilled layer and are unchanged or decreased in the untilled layer below conservation tillage compared with conventional tillage. Similarly, total N, organic N and mineralizable N, phosphorus(P) and potassium (K) follow the same pattern as C and SOM, with greater concentration in the soil surface layer (tilled layer) in conservation tillage, but without a significant increase in the whole topsoil. In a pan- European study, [11] concluded that additional carbon fixation by the storage of organic matter and oxidation of atmospheric methane was very limited under reduced tillage and likely to last for a short period only. The authors also considered that soil nitrate was vulnerable to loss by denitrification, particularly in wet, fine-textured soils. However, less N is likely to be lost as a result of run-off and leaching than under conventional tillage. According to [95], the combined action of conservation tillage and the input of fresh organic matter as leguminous residues increased the soil C and, in the long term, improved the mineral N supply to crops.In a long-term study, [38 and 82] showed that soil microbial biomass and its activity increased in organic farming compared with conventional management. Comparing properties of organically and conventionally managed soils of 28 sites on commercial farms, [76] concluded that soils in organic systems contained more organic matter and total N than conventionally farmed soils. Frequent input of fresh organic matter, with no pesticide use, is the most probable cause of the increasing percentage of organic matter and biological activity found in organic systems. However, according to [94](cited in [99], few differences in organic matter content exist between organically and conventionally managed pastures in the UK.

The main difference in SOM was found between conventional and organic arable land, where fresh organic matter was applied more frequently in organic systems. Moreover, no consistent difference was found in the quantity of nutrient reserves held in organic forms, between organically and conventionally managed soils [99].The quantity and quality of crop residues and animal manures will determine the amount of N which becomes available [20].Hence, although we expect that the combined effects of organic farming and conservation tillage could improve the SOM content and consequently the soil nutrient reserves in organic stockless system, further research on the combined effects is required.
The number of earthworms and their activity increase in conservation compared with conventional tillage [42, 46 and 93]. Thus, both organic farming and conservation tillage improve the activity of earthworms. This is especially important in arable systems where generally earthworm activity is much reduced compared with grassland [53 and 74].

Physical properties

One of the main objectives of conservation tillage is to reduce soil erosion [56].Soil organic matter, concentrated near the soil surface with conservation tillage and especially labile organic matter [14], encourages microbial activity leading to increased soil aggregate stability and improved soil structure. In the same way, fungal hyphae, more abundant in the surface layer in conservation tillage, play an important role in aggregating and stabilizing soil structure. Also, with no tillage, crop residues at the soil surface prevent surface crusting [7].This improved aggregate stability tends to enhance infiltration rate which in turn results in less run-off containing dissolved nutrients and adsorbed P.
Organic matter plays an important role in the maintenance of soil structure. [94] Assessed soil structure in over 90 arable fields managed under organic and conventional systems. They found that the potential for structural improvement in soils under organic production was greaterthan in conventional soils due to the greater biological and earthworm activity enhanced by regular application of organic matter, improving aggregate stability and biological porosity. [53] Found that increasing the duration of the ley phase in an organic ley-arable rotation increased aggregate stability. Compaction can result in deterioration of both topsoil and subsoil structures, mainly caused by vehicle traffic, soil tillage system (implement use and depth of work) and grazing intensity [48].Here we distinguish three kinds of compaction: (1) short-term compaction directly related to the bulk density of the plough layer, which can be reversed by deeper tillage; (2) long-term topsoil compaction resulting from sustained physical degradation and (3) long-term subsoil compaction [6].Tillage needs to be managed to prevent long-term topsoil and subsoil compaction problems. Conservation tillage improves surface soil structure and can reduce compactibility [11] due to the concentration of decomposing crop residues. However, [75]studying a weak sandy loam soil in a moist and cool climate, observed deterioration of the structure in the seedbed below the tilled layer, especially with single-disc direct drilling. This may have been due to the weak structure of soils of this texture. The modification of soil structure after the adoption of conservation tillage depends on structure-forming activity, itself related to clay content and clay mineralogy [2],weather conditions, organic matter content and biological activity. Actually, many studies in several soil and climate conditions have demonstrated additional compaction in the untilled layer of conservation tillage, with a decrease of the total porosity. Soil compaction is a crucial problem, although consolidation of an undisturbed soil may give the benefit of a firm, level surface for traffic with no adverse effects on cropping provided that coarse pore continuity is enhanced [30].According to [86]compaction of the untilled layer may be counterbalanced by an increase of biological macroporosity in conservation tillage. During the transition period to conservation tillage, [60]observed a decrease in the volume of the 30–100-lm pores in the 0–20-cm depth accounting for much of the decrease of total porosity, whereas biopores 100–500 lm may have increased at a depth of 10–30 cm. This effect can improve topsoil structure over a period of years [2, 107 and 83]. [2] have demonstrated that after equal compactive effort applied to a clay loam and a silt loam, the soils compacted more under shallow tillage than with ploughing. Nevertheless, in both treatments, after 4–5 years, no residual effects of the topsoil compaction on penetration resistance and bulk density were detected. According to the authors, the soils were originally well drained and earthworm burrows were present in all treatments. In organic farming, the topsoil is more dense under conservation tillage than conventional [74 and 64].Moreover, subsoil compaction remaining from earlier soil management operations [91] can persist after transition from conventional to conservation tillage [74].However, in the experiment detailed by [74], the duration of the measurement period during the transition to conservation tillage was too short to identify potential differences between organic and conventional farming. Thus, soils containing large percentages of silt and fine sand tend to have weak unstable structure, and a high content of non-expanding clay minerals tends to limit structural improvement by swelling and shrinking [25].This situation is worse when the soil is wet due to poor drainage and high rainfall. [33].

Although schemes of soil suitability for reduced or no tillage have been produced, [30]concluded that the flexibility of reduced tillage, particularly in depth of working, means that some degree of reduction of tillage input was possible in almost all farming situations, including root cropping. [25] Also suggested that tillage timing can be changed by use of crops which allow establishment at drier times of year, by use of crops with less need for tillage and by use of rotational cropping.

Alleviation of compaction

[48] Reviewed technical solutions to prevent, mitigate or loosen compacted soil, such as controlled traffic, the combination of soil management practices to reduce the number of passes and loosening compacted soil by subsoiling or deep ripping. Subsoiling and conservation tillage are compatible provided the deep loosening causes minimal inversion and consequently organic material stays near the soil surface. However, the subsoiling requirement for powerful tractors does not favour any reduction of cultivations costs. The adaptation of crop management, including the addition of organic matter which stabilizes soil aggregates and the insertion in the rotation of grain or fodder crops and plants with strong tap roots (e.g. winter oil seed rape), could break up compacted soils [48].The preservation of subsoil structure is particularly important in organically managed soils where mechanical weeding can compact a substantial area of subsoil [15].Perennial crops may be required in areas where subsoils are compact or waterlogged. Earthworm activity helps to alleviate subsoil compaction. However, under no tillage severe subsoil compaction may be difficult to alleviate through the cumulative effects of earthworm activity and effects of weather [27 and 106]. For example, [1]found that the effects of subsoil compaction under conservation tillage were still measurable 9 years after the compaction event in organic clay-loam soils. The capacity of earthworms to penetrate a plough pan is a key element (cited in [23], Lumbricusterrestris (anecic species) does not penetrate soil with a bulk density >1.6 Mg m). In the same way, [65] found that cast production was governed by the degree of compaction, with two threshold limits. These were a lower limit below which few casts are produced because there was no need to dig, and an upper limit beyond which the earthworms were constrained mechanically. Nevertheless, more research on the ability of earthworms to penetrate a compacted area under field conditions is required. Rotation is important in helping restore soil structure. It has long been recognized that a period under grass or under clover improves soil structure [78 and 52]. In mixed organic farming systems (cereals and fodder crops), the introduction of a perennial forage legume improved soil structure because of well-developed root systems and less grazing in the forage fields. [85] Compared several treatments of ploughing and reduced tillage in dry and wet conditions to restore a compacted Vertisol. The treatment with a lucerne ley plus Gatton panic (Panicum maximum, a subtropical grass) for 3 years (cut 10 times and returned to the soil), followed by reduced tillage in dry conditions was best for restoring and improving soil structure. In this experiment, crop and pasture roots improved soil structure by creating wet–dry cycles. However, the authors highlight two main limits of this system: the compaction due to animal grazing and/or the cutter used in wet soil conditions, and poor economic returns. Thus, although organic grain farmers can improve soil structure before the arable phase by growing a ley, for instance, 3 years dried lucerne [14],there needs to be a market for the produce and grazing and/or cutting should be confined to dry conditions. We recommend that, before starting to use conservation tillage, the soil profile is examined to detect any compact layers from the previous cropping system and that these are alleviated. We would also recommend that compaction-reducing measures, such as low ground pressure tyres and use of low tyre inflation pressures, be considered to improve the sustainability of conservation tillage. The viability of conservation tillage would be enhanced considerably by the use of wide-span gantries and permanent wheel ways [30].

Soil function

Nitrogen supply often limits yields in organic farming and increasing the efficiency of organic farming is possible mainly by adjusting the N status [111]. The release of available N for crop uptake depends on the mineralization–immobilization balance in organic matter turnover. The amount and timing of mineralization is favoured by several factors including soil moisture, aeration and temperature, and by the nature and accessibility of organic materials to the microbial biomass [20]. Fresh organic matter input with a high labile SOM fraction improves the mineralization rate by increasing microbial activity. Mineralization of the SOM is affected by the tillage system. Conventional tillage disrupts aggregates, exposes the SOM, and increases its decay rate. This phenomenon is due to an increase in the aeration and the temperature of the tilled layer, to the incorporation and mixing of C inputs improving microbial activity, and the release of previously physically protected SOM [8]. The timing and intensity of conventional tillage events affect net mineralization. For instance, more N is released when tillage coincides with periods of high soil temperature and/or moderate soil moisture [80]. Thus, conventional tillage increases net mineralization of SOM compared with conservation tillage. In conservation tillage, especially no tillage, there is a greater pool of soil labile N from microbial activity in the surface layer.

However, this pool has a slower turnover rate caused by the decrease of the decay rate of SOM [8 and 60]. [80] Indicated that net N immobilization can occur with slow SOM turnover during the transition period from conventional to conservation tillage. Moreover, soil compaction also affects the mineralization of soil C and N [48]. Thus, topsoil compaction in conservation tillage alters the habitat of soil micro-organisms and consequently their activity by modifying the content and diffusion of soil gases (CO2 and O2) and soil water [14]. For instance, more denitrification can occur [13], making less N available for crops. As many of the benefits of conservation or no tillage depend on enhanced microbial activity, [12] suggested that these techniques were best suited, for general use, in semi-humid or drier regions. In tillage experiments on organic farms, [61 and 105] found less mineralized nitrogen in shallow tillage than with ploughing. Although SOM content can increase in organic farming, the lack of mineral N input may slow down the supply of available N to crops. As conservation tillage and organic farming increase earthworm numbers, their activity in physically breaking down organic residues thereby encouraging microbial activity could lead to improved N release.

N supply and crop rotation

According to a detailed review by [109], crop N supply in organic farming can be managed with crop rotations. To make best use of the large quantity of N released after incorporation of leys, crops with a high N demand, such as winter wheat or potatoes, should be grown early in the arable phase. Crops with a lower N requirement, such as peas, should be grown later in the arable phase. The use of crops with a long period of N uptake, such as potatoes and spring barley, make good use of the slow but prolonged release of available N [20]. Other means to improve resource use are growing legumes and crops with different rooting depths, crop variety mixtures, intercropping (intercrop combination of cereals and legumes). These innovative uses of crops lead to rotations whose design needs to include other agronomic aspects, such as disease and weed control. Conservation tillage is normally used with non-root crops, although potatoes can be grown successfully using direct planting into stubble with tillage used only for the creation of ridges [35]. Another aspect to be aware of is inhibition of mid-season mineralization of N caused by mechanical weed control [79].

Soil water storage and infiltration

The increased C content in the soil surface layer under conservation tillage increases the water storage capacity [68] and consequently the water retention [41]. Soil water infiltration can vary greatly in conservation tillage, according to total porosity and pore size distribution [86]. In conservation tillage, residue cover at the soil surface increased the continuity of biological [39, 49 and 60] and microporosity [5 and 107].These conclusions are confirmed by several authors who found that the increased earthworm population under conservation tillage favoured water flow and infiltration [39 and 49].However, where wet conditions coupled with traffic have destroyed the macropore system, infiltration rates will be much slower than in ploughed soils.

Weed, disease and pest control

Tillage influences weed populations by the combined effects of mechanical destruction of weed seedlings and by changing the vertical distribution of weed seeds in the soil. Tillage also acts indirectly on weed populations, through the changes in soil conditions, influencing weed dormancy, germination and growth. Weed seeds are more uniformly distributed in the topsoil with conventional tillage, but are mainly located in the first few centimetres of soil under conservation tillage [43, 63, 36, 73 and 72]. Perennial and annual grasses are more highly represented in conservation tillage than in conventional [63, 102 and 73], and the control of grass weeds is critical to the success of reduced tillage [30]. Conservation tillage modifies the micro-topography, the light, water and temperature conditions in the soil surface layer [43], which in turn influences the emergence of weed seeds according to their type and the climatic conditions [32]. No tillage tends to modify the 0–5-cm soil layer, by decreasing aggregate size and increasing the total porosity. These modifications can also influence weed emergence. For instance, in conservation tillage, the seed–soil contact, modified by interference with crop residues, could be less advantageous for germination and emergence of small-seeded weeds [22]. Nevertheless, a greater proportion of the seed bank germinates in conservation tillage [47, 63 and 64] favouring the emergence of grass weeds and other species with a large rate of seed production [36]. For dicotyledonous weeds, the impact of tillage systems depends on the species [63 and 72]. For instance, conventional tillage tends to increase some annual dicotyledons, such as Chenopodium sp. and Papaverrhoeas, when their persistent seeds are brought back to the surface by ploughing [43 and 70]. With conservation tillage, there is no sudden and brief seed exposure to light and change of soil temperature as occurs when the topsoil is inverted. Thus, the germination of older and deeper located persistent weed seeds is slowed down [36 and 73]. Weeds with creeping roots or rhizomes are favoured by the absence of tillage [102]. However, conservation tillage with tines or discs can also assist their development by disrupting and dispersing their rhizomes, especially Agropyrumrepens. In the same way, Elymusrepens, favoured by conservation tillage, could present a major problem in organic farming [64]. The unfavourable changes in weed seed bank and weed emergence often deter organic farmers from adopting conservation tillage [89, 93 and 64].

In a review, [108] described the effects of the conversion from conventional to organic farming on weeds. The prohibition of inorganic N fertilizers decreases the nitrophilous weed species (e.g. Galiumaparine) and increases leguminous weed species. Perennial crops established traditionally in organic crop rotations favour fewer long-lived annual weeds but more perennial ones (e.g. Rumexcrispus and Rumexobtusifolius). Moreover, organic fields contain more perennial dicotyledons, such as Cirsiumarvense [61]. [64] Suggested that shallow ploughing (12–20 cm) was the best reduced tillage in shrink/swell soils for controlling weeds, especially perennials. In a long-term experiment in Rommersheim in Germany, [105] compared three tillage systems in organic farming: mouldboardploughing, 'two-layer ploughing' (i.e. deep loosening without soil inversion and shallow tillage) and shallow tillage with a cultivator. As expected, these authors found that dry matter production of weeds was smaller in ploughed fields compared with those treated with the tine cultivator. However, they found no significant difference in yield between the ploughed treatment and the 'two-layer ploughed' treatment [61]. This result suggests that soil inversion is not essential to prevent weed development. Also, important for weed growth is the depth and efficiency of the seedbed tillage following the ploughing.

Weed control

When conservation tillage is adopted in organic farming, weed management requires replacement of ploughing by other techniques. Several agricultural techniques can be used to control weeds in organic farming under conservation tillage. All these techniques contribute to improve crop competition against weed development [18 and 87].The efficiency of the cultural operations depends on several factors. These include the initial weed seed bank [87], soil and weather conditions which influence the efficacy of direct mechanical weed control, and stage of crop development.

Mechanical weed control

In shallow conservation tillage unlike no tillage, the partial burial of crop residues allows the use of direct mechanical weed control during the crop cycle, provided that crop residues on the soil surface do not obstruct the implements. After crop establishment, mechanical weed control is the most useful technique in organic farming irrespective of tillage system. The main methods used are hoeing, harrowing, finger weeding and brush weeding [22]. Other methods developed in organic farming are mowing, cutting, strimming and flaming. The effectiveness of all of these techniques depends on soil type and conditions, mainly soil water content, weed species and growth stage of crop and weeds. [3] compared chemical and mechanical weed control with powered rotary harrows or no tillage with disc implements. Slightly lower yields (5–10% reductions) were obtained with mechanical weed control. However, there was no information of their effectiveness over the transition period to conservation tillage. For perennial grass weeds in organic farming systems, cutting to prevent further seeding gives some control of C. arvense in conservation tillage. However, this method is not effective on all perennial weeds, e.g. Rumex spp. The intensive use of mechanical weed control increases crop damage. According to [87], in a wheat field with high weed pressure, cereals should be sown in wider than normal rows to enable post-emergence hoeing. This method is appropriate for winter cereals where post-emergence harrowing can damage the crop if soil is too wet. Post-emergence harrowing should be used at early weed growth stage. If the weeds are too large, increasing implement working depth to maintain effectiveness can increase the risk of damaging the root system of crops [51]. Finally, the repeated traffic associated with mechanical weeding can increase compaction [28]. To avoid soil compaction, mechanical weed control must be performed in good soil conditions, i.e.at appropriate moisture and, ideally, with light vehicles running on dedicated wheel tracks (bed system).

Effect of crop rotation

A diverse crop rotation introduces different crop growth periods, competitive characteristics and management practices. The regeneration niche of different weed species can be disrupted and increases in some weed species prevented [69]. Choice of crop sequence offers opportunities to disrupt the weed seed bank community [69 and 51].According to [101], the introduction of specific crops, i.e. Triticum spp. (wheat), Trifolium pretense (red clover) and Dactylisglomerata L. (ochardgrass) in an organic spring crop rotation (Zea mays spp. (maize) and/ or Glycine max (soyabean)) tends to decrease the weed seed bank and the abundance of annual broadleaf weed species. The introduction of forage legumes [19] reduces the weed seed bank partly through competition with weeds, but also by mowing and grazing [69]. In conservation tillage, seed predation is increased [36] and soil disturbance responsible for weed seed germination is decreased, both leading to less weed seed return to the soil and in the long term a depleted weed seed bank. For instance, [112] have demonstrated that increasing the proportion of grass/clover ley in an organic crop rotation can limit weed seed number.

Agronomic practices

In organic farming, intercropping and undersowing systems are recommended to avoid bare soils and to limit erosion [58]. Both systems represent another option to control weeds especially with no tillage where direct mechanical weed control is hampered by crop residues at the soil surface [17 and 22].Several reviews on cover crops [71, 16, 50 and 21] demonstrate that weed development is controlled by competition for light, nutrients and habitat (ecological niches), and also by allelopathic effects of cover crops.

However, undersown cover crops can compete with the main crop for resources. In conventional agriculture, herbicides are used to manage the development of cover crops [70]. In organic farming, cover crops can be killed by frost or by mechanical methods. Several mechanical control methods are used: (1) mowing; (2) undercutting [69 and 51]or (3) rolling techniques based on mechanical lodging and cutting coulters. Rolling suppresses growth of cover crops without cutting. Soon after rolling, the next crop is drilled directly into the rolled cover crop using special equipment. This allows the crop to establish before the cover crop regrows. The rolling techniques appear very promising for no tillage in organic farming although no western European references to their use are available. Another method involves the use of living mulches to suppress weeds with minimum competition to the main crop [55]. In Europe, the WECOF project (Strategies of Weed Control in Organic Farming) [30] was carried out to study weed control in organic farming by different cultural methods.

Disease and pest control

According to [59], conventional ploughing is effective for control of soil-borne pathogens. However, the review of [100] on plant disease indicates that conservation tillage in temperate humid agriculture induces pathogen interaction and microbial antagonism. Increased biological activity under conservation tillage can lead to competition effects and to the 'formation of disease-suppressive soils' [100]. For example, potatoes grown in a rotation with barley and red clover under conservation tillage were less diseased than those in a shorter rotation with conventional tillage [81]. This is an area for further research. In the temperate climate of western Europe, slugs representone of the most important crop pests [45]. In organic farming, chemical controls, such as metaldehyde and aluminium-based slug pellets, are forbidden. Thus, slug populations must be controlled by cultural and biological means. [45] in their review reported that tillage systems influence slug abundance and crop damage directly by the mechanical action of tillage implements, and indirectly by modifying soil surface conditions. They found that slug number and biomass generally increased with conservation tillage compared with ploughing. Crop residues left near the surface in conservation tillage create shelter and moisture conditions favourable for slug development. On the other hand, conservation tillage tends to increase natural enemies of slugs [45]. In a review on carabid beetles (natural predators of slugs), [66] reported that conservation tillage favourscarabid beetles more than ploughing. In organic farming, more carabid beetles were observed compared with conventional systems [66]. Slug damage to crops can be controlled by natural field predators or by biological control [45]. In organic farming, biological control with Phasmarhabditishermaphrodita (nematode parasite of slugs) is efficient for limiting populations of some slug species, but the cost of this method is very high [97 and 98].

CONCLUSIONS

Although the incorporation of crop protection in organic farming systems as there are limitations to this work. Although weed control without herbicide is possible, conservation tillage, and especially no tillage, tends to increase weed pressure to a critical level where crop production could be compromised. Moreover, mechanical weed control is not well adapted to conservation tillage because of crop residues on the surface. Another problem is topsoil compaction, particularly during the first year of transition from conventional to conservation tillage. The risk of compaction will be worst on weakly structured soils particularly when conditions are wet. The transition period from conventional tillage to conservation tillage tends to be particularly prone to compaction leading to impeded drainage, restricted crop emergence and poorer root development. Another risk of conservation tillage for organic farmers is the limited availability of nitrogen. Thus, we suggest a staged approach to the adoption of conservation tillage in organic farming. The first stage is to identify whether the soil and climate are suitable. Organic farmers, just as conventional farmers, will encounter more problems on weakly structured soils containing high proportions of sand and silt, particularly in a wet climate. Conservation tillage is particularly suited to areas prone to wind erosion and to drier areas with soils of stable structure which are resistant to compaction. Any problems of compaction or other structural degradation need to be assessed and rectified before adopting conservation tillage. The tillage requirement will vary within a crop rotation [25].In an organic rotation, deeper tillage is likely to be required for incorporating the ley phase to provide weed incorporation and N mineralization. However, within the arable phase, shallower conservation tillage allows rapid breakdown of residues near the surface. Application of the concept of no tillage within a living mulch looks promising [55 and 84].On soils less suited to conservation tillage where compaction below the tilled layer is a potential problem, a system of conservation tillage combined with 'low-lift' tine loosening of the lower topsoil ('two-layer' tillage) may be possible, preferably with controlled traffic systems. However, the successful adoption of conservation tillage in organic farming is not proven and further research is required.

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