Chapter 11
Developing Organic Minimum Tillage Farming Systems for Central and Northern European Conditions

Stephan M. Junge, Johannes Storch, Maria R. Finckh, and Jan H. Schmidt

Abstract Organic farming in temperate climatic conditions usually relies on intensive soil tillage to mineralize nutrients and suppress weeds in order to compensate for the lack of herbicides and synthetic fertilizers. In the long term, this may reduce soil organic carbon contents, and by this, soil fertility. Consequences are deterioration of soil structure and increased risks of water and wind erosion. For long-term sustainability, organic minimum tillage practices are needed that are based on strategies that circumvent problems with nutrient limitations and weed infestations. In three case studies, we demonstrate how the intensive use of cover crops, compost, and/or mulch help to improve soil structure and fertility and thus, enable the establishment of organic minimum tillage. This includes an example of practical research in a vegetable farm developing innovative, soil improving cultivation strategies. Traditional as well as participatory and on-farm research can be supported by a visual spade-based diagnostic method to determine the **Soil Structure Index** (SSI) that helps generate highly informative data. The success of organic minimum tillage hinges on (i) **Organic amendments** for balanced nutrient supply and increased crop performance while stimulating and enhancing the soil and rhizosphere microbiome; (ii) Effective **cover crop and crop residue management** for nutrition, weed suppression, prevention of pests and pathogens and climate resilience; (iii) **Technical solutions** and **professional support**, especially for direct planting and mulching. For organic farming, **soil fertility is not the result, but rather the prerequisite, for no- or minimum tillage.** Further research should focus on crop rotations, efficient cover crops, tillage strategies, and crop species adapted fertilization.

Keywords Soil fertility · Permanent soil cover · Cover crops · Transfer mulch · Soil structure index

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11.1 Introduction

Conventional no-till (NT) relies on the use of synthetic fertilizers and herbicides that are not permitted in organic farming. This leads to a number of very specific problems associated with no- or minimum tillage in organic farming. In Europe, organic NT and minimum tillage farming is predominantly practiced in the south, where soil degradation and water loss are more prevalent, and only rarely practiced in central and northern Europe (Peigné et al. 2015; Vincent-Caboud et al. 2017). Major obstacles are the reduced availability of nutrients in the top soil, unreliability in the termination of green manure crops, and (perennial) weed control (Stockdale et al. 2001; Berry et al. 2002).

Mulching of cover crops delays soil warming in spring and thereby often biological nitrogen (N) mineralization that is crucial for organic systems (Finckh and van Bruggen 2015). Especially in dense cover crop stands, their termination is often incomplete unless these are already in the generative phase. This restricts the choice (Peigné et al. 2007) and may delay the sowing of the subsequent cash crop (Mirsky et al. 2012; Carr et al. 2013). Consequently, reduced seedling germination and development (Peigné et al. 2007; Mirsky et al. 2012; Vincent-Caboud et al. 2017) and yield reductions of at least 10% under organic NT compared with inversion tillage have been reported (Cooper et al. 2016). Other factors impeding the adoption of NT in organic farming in Europe are high costs and low availability of NT equipment, additional costs for the more intensive use of high value cover or undersown crops such as vetches, specific clovers etc., the additional labor for weed management, and a lack of technical support (Casagrande et al. 2016).

It thus appears that in humid climates with slow soil warming in spring and optimum conditions for weed growth throughout the growing season, NT may not be the best solution for organic farmers (Vincent-Caboud et al. 2017). In contrast, in many cases shallow non-inversion tillage systems, not only have been shown to achieve similar yields than inversion tillage systems (Cooper et al. 2016) but also enable farmers to grow (vegetable) crops, such as potatoes, which depend on a minimum of soil tillage for optimum growth (Finckh et al. 2018).

Some of the problems with organic NT systems can be overcome by crop-livestock integration. Besides green manures, organic fertilizers can be obtained affordably through manure and composts produced on farm (Finckh and van Bruggen 2015). Livestock can serve for weed and seed destruction and enable farmers to grow perennial leys to improve the level of soil fertility without a financial burden. Consequently, the high proportion of specialized stockless crop farms that lack internally produced fertilizers depend on external resources to fill the nutrient gap and need solutions that allow for the minimization of tillage.

In recent years, a number of practitioners have developed innovative non-inversion tillage based organic growing systems especially for vegetable production. These integrate the shallow incorporation and mulching of cover crops and/or the use of cover crop and ley-based mulch materials that are transferred to neighboring fields. Our recent research concentrates on adapted non-inversion tillage methods combined with diligent residue and cover crop management in order to design locally adapted stockless minimum tillage systems.

In this chapter, we describe some of the alternative approaches that are being developed by us for organic non-inversion tillage in arable and vegetable cropping under central European conditions. These systems are also of great interest for conventional systems aiming to reduce inputs in view of the impending ban of glyphosate, and potentially many other herbicides, due to their effects on the environment (van Bruggen et al. 2018) and their role in the emergence of multiple antibiotic resistances worldwide due to their antibiotic properties (Kurenbach et al. 2015, 2018).

11.2 General Considerations

The most productive agro-ecosystem, independent of mineral nutrient input and soil tillage, is grassland. Compared to an arable field under NT or chisel ploughing, nitrogen mineralization in an undisturbed grassland is about 80–400% greater (Carpenter-Boggs et al. 2003). In such soils, the high plant diversity above-ground probably enhances microbial diversity and activity below-ground (Bartelt-Ryser et al. 2005) and the plant communities are the driving forces of mineralization in the absence of tillage (Yang et al. 2019). About 30–60% of the assimilated carbon is released in the form of organic acids to the soil by plant roots (Marschner 1995, p. 547). These help to make mineral nutrients available from the substrate directly and via the soil microbiome, enhancing soil life and plant nutrition.

Replacing the plough by surface composting and subsoiling results in less disturbance of the soil life (Roger-Estrade et al. 2010). The effect of plants and subsoiling on soil structure can be high (Fig. 11.1). A judicious combination of cover crops and reduced tillage enhances mycorrhizal networks (Bowles et al. 2017) that in turn will enhance nutrient uptake (Hallama et al. 2019) and protect plants from pathogens (Harrier and Watson 2004) and water stress (Evelin et al. 2009). A second very important group of organisms are free-living nematodes. Their trophic groups can serve as an indicator for the presence and abundance of fungal and bacterial decomposers and soil nutrient status, pH, and heavy metal contamination (Korthals et al. 1996; Bongers and Ferris 1999; Neher 2001). Their population size and composition are directly related to soil biodiversity and the stability of the soil food web (Yeates and Bongers 1999). In addition, they mineralize between 20 and 120 kg of N ha^{-1} $year^{-1}$ through consumption and digestion of bacteria and fungi (Hallmann and Kiewnick 2015).

In addition to direct effects on soil nutrient contents, organic matter management is the basis for soil health and the suppression of soil borne plant pathogens. Outside their plant host, pathogens usually suffer severely from competition for nutrients and direct antagonism by free-living soil organisms. The latter are innately fitter in the soil environment (Cook and Baker 1983; van Bruggen and Semenov 2015). Disease suppression can be greatly enhanced through long-term minimum tillage due to effects on soil microbial communities (Schlatter et al. 2017). High plant

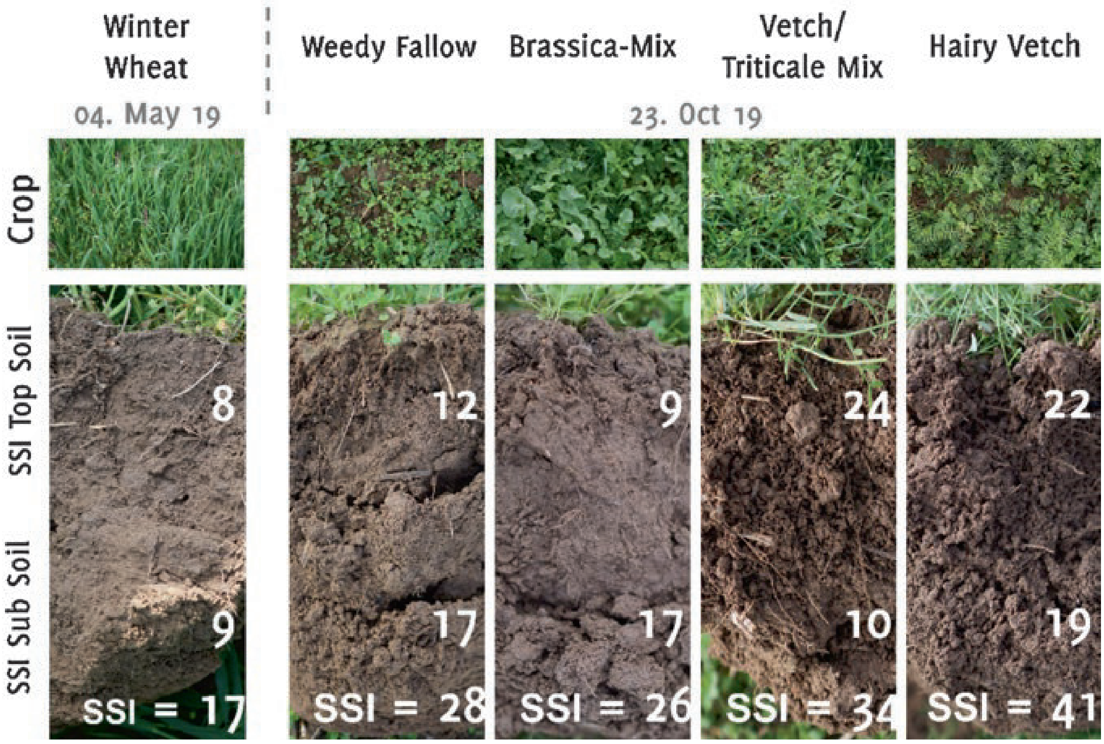

Fig. 11.1 Short term effects of cover crops on soil structure. The soil structure index (SSI) sums up the scores of the 0–0.15 m and 0.15–0.3 m soil layers. Scores range from 0 = poor to 100 = exceptional. Our experience indicates that SSI values for cultivated soils typically lie between 10 and 35 points; >40 points are the result of professional agricultural practices. The initial assessment was done on May 4 2019 (left) during a crop of winter wheat. After wheat harvest subsoiling was performed to about 0.3 m and soils rototilled to a depth of 0.05 m before sowing of cover crops on Sept. 17 2019. (Photos: Junge 2019)

diversity enhances soil microbial diversity (Bartelt-Ryser et al. 2005), this has led to greater suppression of *Rhizoctonia solani* AG-3 in grassland soils compared to long-term maize monoculture (Garbeva et al. 2006). Thus, diversification of arable farming systems through inclusion of more diverse crops in rotation, cover crops, and mixed cropping may contribute to disease suppression.

11.3 Case Study: Effects of Compost and Mulch Applications in Organic Minimum Tillage

Over the past 6 years, we have worked on the development of a ploughless cropping system with the aim of building soil fertility by systematically making use of cover crops on our experimental farm. The soil is a Haplic Luvisol (USDA: Typic Hapludalf) with 83% silt and 3% sand, and a measured pH often below 6. The field had been managed organically since 1989, but had not received substantial mineral fertilization or liming during that period. Despite organic management, C_{org} contents were rather low at about 0.9%. Deficiencies were apparent for S, P, K, and

B. Very high Mg contents led to low Ca availability requiring extensive Ca applications.

Thus, after 25 years of organic management, the rotation strategy without substantial (organic) fertilization had been unsustainable. An important reason was that cover crops were frequently sown too late due to management issues, resulting in poor crop stands before the onset of winter. Undersowing was not used and compost or manure rarely applied. The deficiencies of S and B also led to poor and patchy clover within the clover grass ley in the crop rotation.

We established two organic long-term trials in 2010–2011, comparing a ploughed system with non-inversion tillage. Superimposed was the use of nutrient rich mulch materials for potatoes and regular applications of a high value yard waste compost at a mean rate of 5 Mg DM ha^{-1} $year.^{-1}$. Mineral P and K at equivalent rates were supplied to plots that did not receive compost. After eight and 9 years in the top 0.15 m, C_{org} contents were 1.3% in the ploughed system without compost and mulch but 1.9% when mulch and compost had been applied under reduced tillage. Compost also increased N-, P-, K-availability by 10, 20 and 4%, respectively, while mulch combined with reduced tillage increased N-, P-, K-availability by 25, 48, and 147%, respectively compared to inversion tillage without mulch.

Free living nematodes were also significantly enhanced (Schmidt et al. 2017) and the effects persisted over time (Fig. 11.2a). After the use of two consecutive cover crops, nematode numbers were particularly high (Experiment 2, Fig. 11.2a). Also, potato yields correlated significantly with the number of free-living nematodes in that experiment (Fig. 11.2b).

Similar effects of cover crops and residue management on free-living nematodes have been reported under Mediterranean conditions. Leaving oat residues on the field followed by cover crops increased the number of bacterivorous nematodes. These nematodes correlated with mineral nitrogen in spring and, in turn, with increased tomato yields planted after the cover crops (Ferris et al. 2004). The driving forces for nitrogen mineralization, e.g. responsible species and decomposition pathways, in the two studies likely differed due to climatic conditions, nevertheless, the outcome was similar.

11.4 Case Study: Developing a Holistic Minimum Tillage Potato Cropping System

Ploughing, frequent hoeing, and hilling, are usually employed in organic potato production for mechanical weed control and enhanced mineralization of nutrients (Finckh et al. 2015; Döring and Lynch 2018). These methods reduce C_{org}, destroy the soil structure, and increase the risk of water and wind erosion. In the long-term trials on minimum tillage described above, potato yields were comparable under reduced and conventional tillage if a leguminous cover crop was combined with mulch application (Finckh et al. 2018). Since 2016, we have further experimented

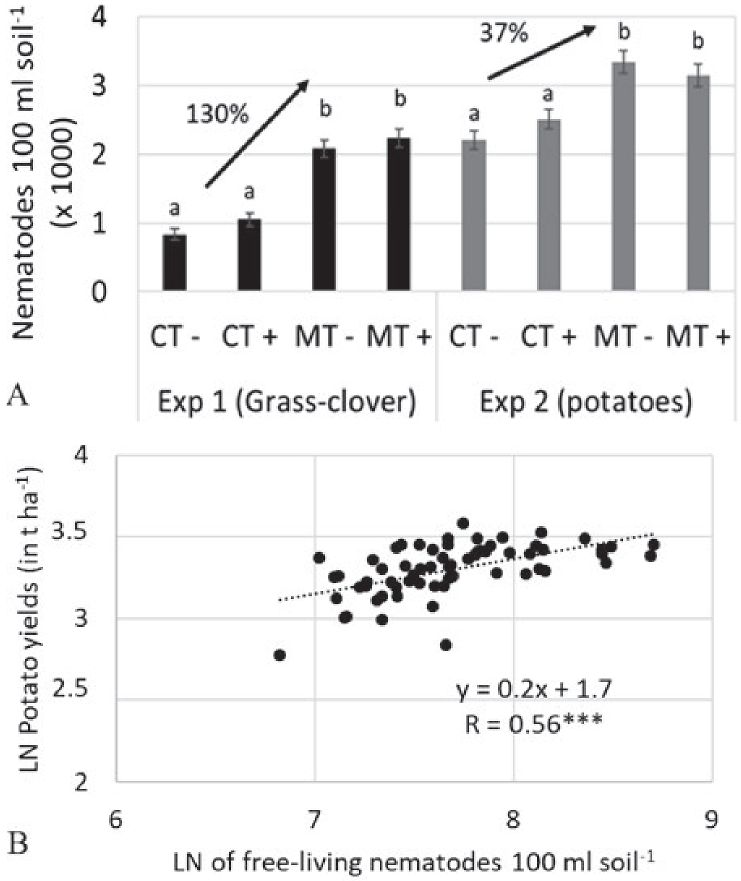

Fig. 11.2 (**a**) Total mean numbers (+ SE) of free-living nematodes 100 ml soil^{-1} in the first (black bars) and second (grey bars) field experiments with plough (CT) versus non-inversion (MT) tillage and mineral (–) versus organic compost (+) fertilizer treatments. Crop rotations were winter wheat-winter cover crop- potatoes- winter cover crop - grass clover (Exp 1) and winter wheat (terminated in summer) – summer cover crop – winter cover crop -potatoes (Exp 2). Arrows with percent values indicate the increase of free-living nematodes under MT compared to CT. Bars with no lower-case number in common are significantly different at $P < 0.05$; (**b**): Correlation between the natural logarithm (LN) of the number of free-living nematodes in 100 ml soil and potato yields under organic farming conditions in temperate European climates ($P < 0.001$). (Schmidt, Junge and Finckh, unpublished)

with surface composting of cover crops before potatoes through shallow rototilling at about 0.05–0.07 m depth followed by grubbing to 0.12–0.15 m depth with deep loosening chiselshares to reduce weed infestation and tillage. We adopted this approach in order to strive for a "regenerative" potato cropping system (Finckh et al. 2018), that aims at improving soil structure during intensive crop cultivation. To optimize the long-term trial, we set up a detailed experiment to evaluate the short-term effects of various cover crops and mulch types on the soil structure and performance of potatoes and a subsequent crop of triticale.

In 2017, a randomized split plot trial with four replicates was set up adjacent to the long-term trial in the same soil type as described above. Factor I was mulch type: (i) straw, (ii) hay, (iii) vetch/triticale-mix, (iv) clover grass, and (v) no mulch control applied in strips. Factor II were cover crops: (i) "Landsberger mix" (50%

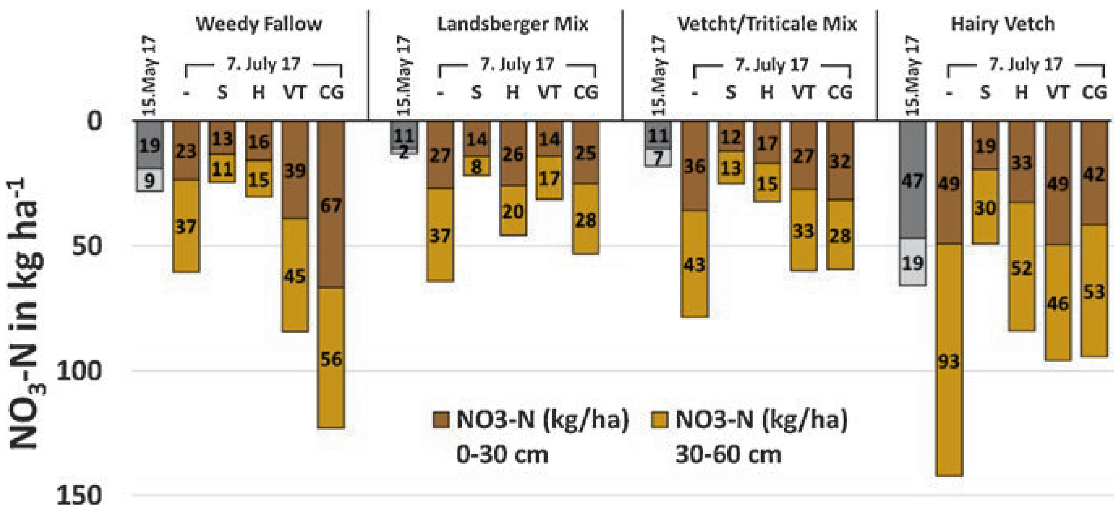

Fig. 11.3 Soil nitrate content about 3 weeks after the cover crops weedy fallow, Landsberger mix, hairy vetch/triticale mix, hairy vetch had been mulched and rototilled (15th May 2017, grey bars) and in response to different mulch materials at potato flowering on 7th July 2017. Mulch treatments were no-mulch control (–), straw (S), hay (H), hairy vetch/triticale-mix (VT), clover grass (CG)

Lolium multiflorum, 30% *Trifolium incarnatum,* 20% *Vicia villosa)*, (ii) hairy vetch, (iii) vetch/triticale-mix, and (iv) weedy fallow as control. The mulch quantity was approximately 50 Mg fresh matter ha^{-1}. Pre-germinated potatoes were planted on first May. Hilling was performed once and mulch applied before emergence on 16th May. Soils in mulched plots were tilled no more, un-mulched controls were once hilled and harrowed for weed control. No further fertilization was applied.

The preceding cover crops had different effects on the nitrogen supply in spring (Mid-May) (Fig. 11.3). The C:N ratios (above ground) were: "Landsberger mix" 22:1, hairy vetch/triticale mix 15:1 and hairy vetch 9:1 before being mulched and rototilled. They provided between 13 (weedy fallow) and 66 kg NO_3^- ha^{-1} (winter vetch) at a soil depth of 0–0.6 m (15th May, Fig. 11.3). In the absence of mulch, soil N at potato flowering on seventh July varied from 60 kg NO_3^- ha^{-1} (weedy fallow) to 142 kg NO_3^- ha^{-1} (vetch).

Mulch effects on N levels depended not only on the mulch materials but also on the pre-crop. Straw with a C:N ratio of 63 led to massive reductions in N-availability independent of pre-crop. With hay (C:N = 23), N-levels also stayed low except after vetch. After weedy fallow and "Landsberger" mix, clover/grass mulch (C:N = 14) was more effective than vetch/triticale (C:N = 20) in providing nutrients while the two types of mulch had similar effects after vetch and vetch/triticale cover crops. Late spring and early summer 2017 were very dry. As soils under mulch stay cooler, it is likely that mineralization of the hairy vetch and hairy vetch/triticale residues was reduced and nutrients released over a longer period. With the exception of straw mulch, canopy closure was only achieved when plots were mulched (Fig. 11.4). This was due to the additional nutrients due to mulching and water conservation under mulch.

Fig. 11.4 Comparison of un-mulched and mulched treatments. Mulch on the right reduced water stress allowing for canopy closure. Un-mulched plants stayed considerably smaller due to drought stress. Nutrient effects are also visible. The plot in the middle left marked by a frame is after the grass-dominated cover crop "Landsberger mix" that immobilized nitrogen early during the season. (Photo: Junge 2017)

Parallel to the nitrogen and water supply, cover crops in combination with the applied mulch materials influenced soil structure assessed before planting, during flowering, and before harvest with the spade diagnosis (Beste 2003). From this, the soil structure index (SSI) was calculated by relative means of the top- (0.15 m) and sub-soil (0.15–0.30 m) structure and aggregate stability assessments. Here, details are shown for weedy fallow, vetch/triticale and vetch cover crops combined with no mulch, straw, or vetch/triticale mulch (Fig. 11.5). Averaged across all factor combinations prior to potato planting (seventh April), SSI was lowest after the weedy fallow with 34 compared to 52 after vetch/triticale and after vetch cover crop. Therefore, the highest relative improvements of soil structure index were achieved under treatments with weedy fallow. In these treatments, straw mulch and vetch/triticale increased the soil structure index significantly by 74% and 82%, respectively. This can be explained by the poor structural condition on 7th of April in comparison to the treatments with cover crops. Straw mulch increased SSI after all three cover crops, however, except after vetch as cover crop, yields were as low as after weedy fallow without mulch. Vetch/triticale as mulch had the strongest impact on yield. However, if vetch/triticale was used as preceding crop and mulch, SSI greatly improved only until flowering. Before harvest, it had dropped to the lowest SSI among all treatments while it was associated with the highest yields (Fig. 11.5). The yield of the following triticale crop was 4.7 Mg ha^{-1} without mulch. Yields increased to 5.5–5.7 Mg ha^{-1} after all mulches except straw mulch, which resulted in no yield changes (4.5 Mg ha^{-1}). Thus, the effect of the high C:N ratio carried through. Practitioners have reported yield effects for up to 4 years.

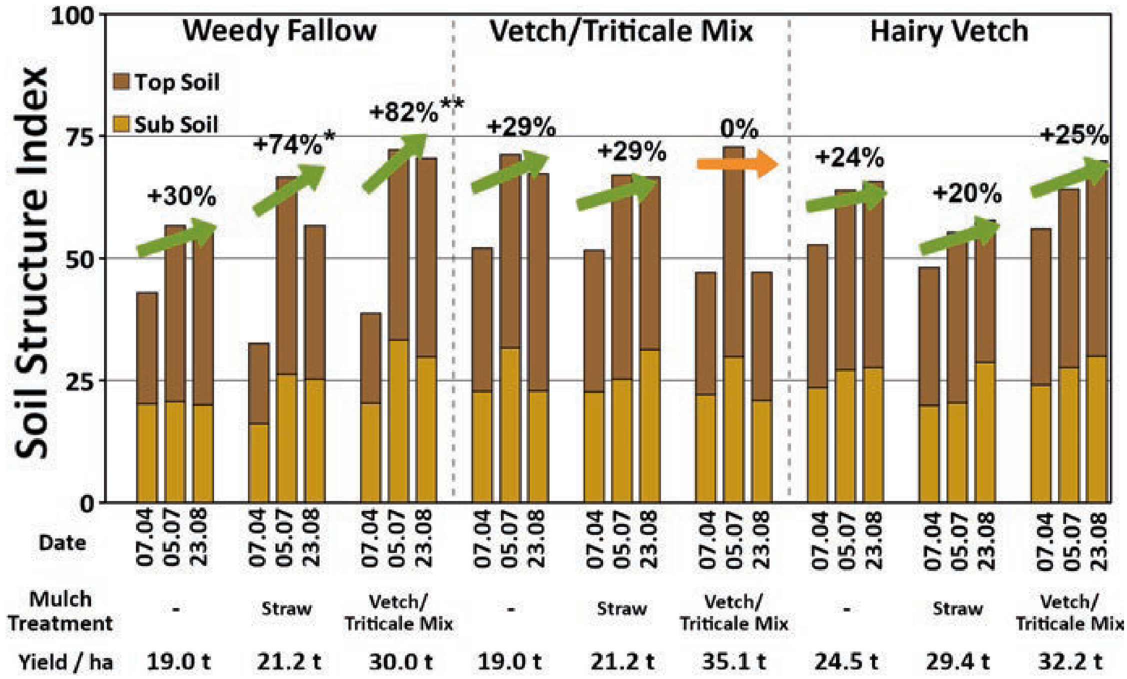

Fig. 11.5 Condition of the soil structure of selected treatment in top (dark brown bars) and sub soil (light brown bars) before killing of cover crops (Weedy Fallow, Hairy vetch/Triticale Mix, Hairy vetch) on 7th April and under different mulch types: without mulch (−), straw mulch (Straw), Vetch/Triticale Mix mulch at potato blossom on 5th July, and before harvest on 23th August. The change in the soil structure index in % and significant differences are marked by ∗ (linear contrasts)

Importantly, the results suggest that improvements of soil structure are possible with and without mulch, but that especially the use of a good cover crop can be a great advantage. Mulching is labor intensive and, particularly in larger operations, may not be practical. Nevertheless, it appears difficult to optimize soil structure and nutrient dynamics and thus yield at the same time. While the treatment of hairy vetch as cover crop without mulch appears encouraging and well feasible, it has to be ensured that the very high N-levels at flowering (Fig. 11.3) are successfully taken up by the crop and not lost. This will depend on the time and severity of damage by late blight (*Phytophthora infestans*) and/or Colorado potato beetles (*Leptinotarsa decemlineata*). If the crop is killed before the nutrients are taken up, nutrient leaching could occur.

In this context, it is important to mention that we observed repeatedly (Finckh et al. 2018) drastic reductions in infestation by Colorado potato beetles under mulch (Fig. 11.6). Similarly, potato late blight is consistently reduced in the mulched system. The mechanisms behind this likely include microclimatic effects as well as effects on beneficial insects (Zehnder and Hough-Goldstein 1990; Finckh et al. 2018). However, nutrition effects on plant attractiveness to the pests could also play a role (Schaerffenberg 1968; Zehnder and Hough-Goldstein 1990; Alyokhin et al. 2005). Thus, there may be a need for earlier planting without mulch than with mulch in order to escape late blight. Also, preventive and direct measures against potato beetles may be required (Finckh et al. 2015). No significant effects on tuber health and quality were observed. *Rhizoctonia* infestation, wireworm and mouse damage,

Fig. 11.6 Potato beetle damage on 9 July 2018. Larva and egg hatching were reduced in vetch/triticale mulched plots. In the picture canopy losses were 39% and 96% in the mulched and un-mulched plots, respectively. (Photo: Junge 2018)

and green tubers did not differ among treatments. The only exception was slug damage that was significantly higher in the clover grass mulch treatments ($P < 0.05$, Tukey HSD) than elsewhere. This is likely due to the slug's food preference for clover grass (Keiser et al. 2012).

Cover crops and mulch are used in this cultivation system to suppress weeds by competition (Kruidhof et al. 2008) and deprivation of light (Teasdale and Mohler 2000). Generally, closer C:N ratios enhanced crop growth, led to rapid canopy closure and thus to weed suppression through competition for light. Weed pressure after the different cover crops varied somewhat but not significantly: On July 19th, weed coverage was equally high (20%) after weedy fallow and "Landsberger" mix due to difficulties in termination of the grass in the "Landsberger" mix. The lowest weed cover occurred after hairy vetch cover crop with 12%. There were also no significant difference among mulch treatments for weed suppression. Under hairy vetch/triticale mulch, weed cover was lowest at 10%. The efficiency in weed suppression of hairy vetch is in part due to its high allelopathic effects (Fujii 2003). Seeds in the straw and hay mulch materials contributed to weed pressure, thus cover was 21 and 17%, respectively.

The cultivation system shows that high potato yields, soil fertility, and plant health are not contradictory under reduced tillage. While typically three to five hilling operations are performed for mechanical weed control and to enhance nutrient mineralization under German organic farming conditions, the mulch system requires no more hilling and cultivation during the season. It is important to harvest the potatoes as early as possible and to immediately establish a nitrogen demanding catch crop to maintain soil structure and prevent nutrient leakage. The basis for this is the skilled combination of cover cropping, tillage, and soil conservation methods to allow for the function of preventive agro-ecological mechanisms. The long-term effects can justify the high efforts and input required for mulch application. This type of cultivation is particularly interesting for intensive stockless cash crops on small fields, as the following practical example demonstrate.

11.5 Case Study: An Organic Minimum Till Mulch-Based Vegetable System

Vegetable farming is usually highly intense with much bare soil, leading to a decline in soil fertility (see Sect. 11.2). The cropping system of *live2give* developed for professional vegetable production aims at permanently active roots and soil cover. Since 2011, the farm "Bio-Gemüsehof Dickendorf" of *live2give* gGmbH is pioneering the use of mulch-direct-planting at field-scale organic vegetable production. Forty different crops are grown for direct marketing.

Precise driving and a level ground surface are important prerequisites. At the

> Bio-Gemüsehof Dickendorf (https://mulch-gemuesebau.de/)
> 4.6 ha vegetables incl. 2000 m² greenhouse
> 4 ha permanent grass land
> 350–450 m above sea level
> Mean annual temp. 7.6 °C
> Mean annual ppt: 700–1000 mm
> Loamy soils on brown soil and pseudogley on basalt rock
> C_{org} contents 1.6–2.6%

initiation of the system, mechanical soil-loosening in autumn to break up possible compaction and deal with perennial and root-spreading weeds is necessary. Right after that, a rapidly developing winter annual cover crop is sown to stabilize the mechanical tilth biologically (Fig. 11.7 left).

Typically, a high biomass cover crop of 60% triticale or rye, 30% hairy vetch, 10% winter peas that produces up to 10–12 Mg DM ha^{-1} by May/June is used. This is flail mown shortly before planting. Where the cover crop was not yet in full bloom, not producing enough biomass, or contained too many weeds, a subsequent covering of additional mulch material is necessary (total layer of 0.08 m is targeted).

Fig. 11.7 Soil structure 0–0.30 m of cover crop shortly before transplanting (left), transplanting leaks with the "MulchTec planter" (middle) and soil structure at harvest time (right)

Plantlets are transplanted into undisturbed, rooted, and covered soil and may use the mulch material itself for nutrition (Fig. 11.7 middle). This is the last step before harvest. The development of the “MulchTec planter” in 2012 was a breakthrough for economic realization of this system. Annual weeds, such as *Chenopodium album* and *Galinsoga*, are well controlled by the mulch layer and by avoiding soil disturbance. Perennial weed control, however, is limited and must be dealt with beforehand. By harvest time, soil cultivation was avoided for at least 1 year resulting in stable crumbs, no compaction zones, and a high density of roots and soil life (Fig. 11.7 right). This will allow for minimum tillage to the next winter annual cover crop thereby utilizing the residual mulch and crop residuals for soil cover and crop nutrition.

In order to provide enough material for a mulch layer of 12–15 Mg DM ha^{-1}, the crop rotation has been adapted for high biomass production (Table 11.1). This is provided by (i) 2 years of biomass producing mixtures of grains and legumes combined with undersown grass that are used as transferred mulch for the vegetable crops; and (ii) the yearly annual winter cover crops. The replacement of clover grass by high DM-yielding cover crops further improved DM-yields of the mulch material in the time of its highest demand (May/June). No problems with the repeated use of hairy vetch were observed over the last 10 years.

The estimated N-flows in the system result in an overall surplus of 21 kg N ha^{-1} $year^{-1}$ (Fig. 11.8). Overall, 88 kg N ha^{-1} $year^{-1}$ is exported from the system as vegetables, 77 kg N ha^{-1} $year^{-1}$ are supplied by biological N-fixation, 66 kg N ha^{-1} $year^{-1}$ is imported into the rotation by commercial organic fertilizers and 34 kg N ha^{-1} $year^{-1}$ is lost by emissions of mulch materials. In year 1, 3, and 4 a surplus of up to 141 kg N ha^{-1} accumulates (Fig. 11.8). This surplus is bound in an organic form and should thus not be subject to leaching. The N-mineralization from organic material is mainly a function of the C:N ratio of the material itself. Neglectable N-absorbance by vegetables was observed at a C:N ratio > 35 in the first year after mulch application at the farm of *live2give.* Data from 2017/18 indicated that 10% of the applied N in the form of grass silage mulch in Brussels sprouts was found as mineralized N in the following year at a depth of 0–0.3 m. This enhanced the total yield of beet roots by 10% (53.4 Mg ha^{-1}) and the first quality yield by 30% compared to the un-mulched control.

Table 11.1 Rotation scheme and dry matter balances for self-sufficient mulch supply

Rotation		DM production (Mg ha^{-1})		
year	Crop	*insitu*	demand	balance
1	Brassicas	6.7	15.0	–8.3
2	Biomass (spring sown)	10.4	0.0	10.4
3	High/medium N-demanding crops	6.8	11.1	–4.3
4	Lettuce, herbs	5.9	12.4	–6.5
5	Onions	3.9	6.7	–2.8
6	Carrots	7.0	0.0	7.0
7	Biomass (autumn sown)	17.0	0.0	17.0

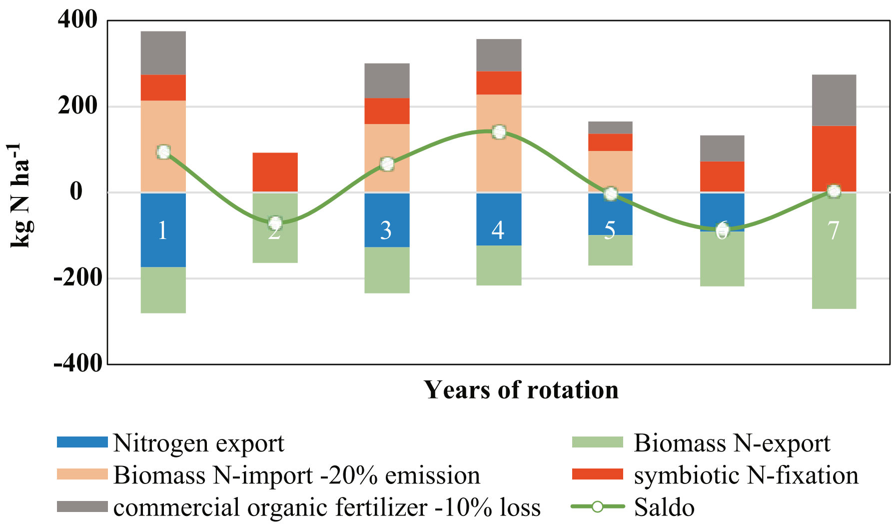

Fig. 11.8 N-flow in the seven-year crop rotation depicted in Table 11.1

As mulch is mineralizing more slowly than most commercial fertilizers, it is important to bridge the N-demand of the young plants with an underfoot dressing applied during the transplanting process. By an application of 95 kg N ha^{-1} in brussels sprouts the yield could be increased from 14–26 Mg ha^{-1}. Without "start-off fertilization" plants were weaker and could not utilize the estimated 151 kg N ha^{-1} provided by the mulch material.

The cropping system as described above has insignificantly lower production costs in comparison to common organic farming systems. The costs for human labor are lower, whereas costs for machinery are higher. However, yields and product qualities are generally higher in this system and can be raised to a conventional level. This may be attributed to higher resilience under extreme weather conditions, an overall better nutrition due to the innate soil fertility as well as low weed infestations (Fig. 11.9).

Permanently active roots and soil cover build up soil fertility in this usually highly intensive vegetable farming system. Foundations are laid for minimum tillage, because minimum tillage is not the condition, but the result of soil fertility.

11.6 Technological Adaptations in Organic Minimum Tillage Systems

The conversion to minimum tillage under organic conditions is particularly challenging with respect to weed and nutrient management. An important precondition for successful conversion is that the fields have been managed well before and overall weed pressure is not excessive (Reimer et al. 2019). Most important for successful organic minimum tillage systems is the diligent use and termination of subsidiary crops, such as cover crops or undersowings. The cover crop should be a mixture of winter-hardy legumes and grasses. We prefer a 4–6 ratio of hairy vetch and triticale

Fig. 11.9 From Top left: Cabbage, Brussels Sprouts, Zucchini, Kohlrabi, Endives, Fennel as well as Autumn and winter leaks at harvest time in mulch. Leeks yielded between 44.5–57 Mg ha^{-1}

as this results in high root and above ground biomass, fixes nitrogen, and suppresses weeds well. Winter peas may be used to substitute a proportion of vetches, unless peas are a main crop in the rotation. If crops are to be mulched, the mulch should have a C:N ratio < 20. This will accelerate plant growth through adequate nutrition and thus enhance weed suppression by the crop.

Roller crimpers seriously hurt the cover crops leading to strong leakage of fluids from the plants. In contrast to mowing, this often leads to plant death. In addition, by leaving most of the cover crop tissue intact, the decay of the residues on the surface is slowed down and weed suppression enhanced. The roller crimper works especially well if the cover crop is at the regenerative stage. Alternatively, mowing followed by incorporation with a high speed (1000 RPM) rotary cultivator with depth guidance at 0.05–0.07 m is very effective. The knives of the cultivator need to be skewed to avoid sealing moist soil. Surface composting will require about 2 weeks before a crop can be sown. An exception are potatoes, which can be planted almost immediately, but require the loosening of the soil by chisels down to about 0.12–0.15 m. The undisturbed capillary system below the tilling horizon on the one hand, and the water translocation by the roots of the dying cover crops on the other hand, enhance water availability.

Especially weakly textured sandy or silty loam soils are highly susceptible to subsoil compaction and may need deep ripping or subsoiling (Peigné et al. 2007), particularly during the transition to conservation tillage. Subsoiling at slow speed at a distance of 0.4–0.5 m the depth of compaction is recommended. The effects of this together with cover crops on soil structure can be seen in Fig. 11.1.

Perennial weeds need to be well managed. Using two short rotation cover crops can be very successful for weed control and building soil fertility as the highest amounts of root exudates are produced until the beginning of the generative stage (Sauerbeck and Johnen 1976). We have observed that thistles (*Cirsium arvense*) grow especially well if light reaches the soil. Others have experimented with variable success with rhizome fragmentation and mowing schemes against *Elymus repens* (Bergkvist et al. 2017; Kolberg et al. 2017).

Extension and support for farmers is crucial for successful transition to minimum tillage without the need for herbicides. A simple but highly effective and essential tool for farmers and extension workers is the spade diagnosis for assessing soil structure and quality for evaluation of tillage or crop rotation effects as shown in Fig. 11.2. Moebius-Clune et al. (2016) developed the first "Comprehensive Soil Assessment Framework" for farmers in the United States, with a focus on soil health. It describes improvement of soil health on field scale based on six steps: (1). Determination of farm management history and farming system; (2). Setting of goals and assessment of soil health status; (3). Identifying and prioritizing constraints; (4). Identifying management options; (5). Creating a short and long-term management plan; and (6). Implementation of soil health management, monitoring of results, and adaptation of soil health management (Moebius-Clune et al. 2016, p. 81). Although climatic conditions vary somewhat from those of North/central Europe, this framework may be a blueprint for a general framework, which can be adapted to climatic conditions.

11.7 Research Needs

In the previous sections, we highlighted the importance of a dense and continuous soil cover to protect soil and crops from biotic (e.g. weeds) and abiotic (e.g. water, nutrient limitations) stressors in temperate minimum tillage systems. To achieve this, precisely harmonized and likely farm specific combinations of (1) crop rotation; (2) cover crop species (and mixtures); (3) tillage; and (4) fertilization strategies are needed. Considering the interactions of these combinations, systemic research approaches based on mid- and long-term tillage trials are needed to find optimal management solutions for diverse soils and climates. The primary objective of such studies has to be the identification of the most suitable management combination at farm and/or field scale that fosters mineralization processes and the build-up of soil humus contents by enhancing soil microbial activity, finally leading to an optimum soil fertility and health status suitable for minimum or NT systems.

These research efforts should be assisted by (1) breeding for cover crop species and varieties that are suitable for mixed cropping and capable of producing large biomass stands under minimum tillage before the onset of winter, also when sown relatively late. Searching for new legume (cover crop) species with resistances to wide host range pathogens, such as *Fusarium*, *Didymella,* and *Peyronellaea spec.,* among others (Baçanoviç-Šišiç et al. 2018; Šišiç et al. 2018)*,* will also help reducing root necrosis of grain legumes in the rotation; (2) Breeding main crops for adaptation to mixed cropping, e.g. with cover crops undersown before harvest or with other cash crop species in order to increase above- and below ground diversity and by this, system health; (3) Developing new cover crop species mixtures consisting of several winter-hardy and frost-intolerant species to conserve water for spring-sown crops; (4) Technological developments to allow for the simultaneous removal of weed seeds during harvest and also direct sowing of cover crops before or at harvest to avoid bare soils; (5) Close collaboration with farmers that have been working on organic no- and minimum tillage systems in order to spread their knowledge (participative research); (6) Research for new (soil) indicators that can help to evaluate the success of management strategies/ combinations to achieve a self-regulatory system in terms of nutrition and nutrient cycling as well as weed, pest and pathogen tolerance (see Sect. 11.2).

11.8 Concluding Remarks

Organic rotations in temperate conditions are generally accompanied by heavy soil tillage and typically include clover grass leys for fertility building and as a means to control especially perennial weeds (Finckh and van Bruggen 2015). For stockless organic operations, the latter practice is very expensive as without cooperation with other farms the material produced cannot be made use of. Furthermore, clover grass leys alone do not necessarily result in sustainable plant nutrition (see Sect. 11.3), and soil inversion through ploughing excessively disturbs soil life and thus reduces soil fertility over time. Agricultural systems that do not rely on the import of synthetic fertilizers thus have to aim at supporting soil life by maximizing plant growth and their recycling at all times.

Constant nutrient supply through decaying roots, root exudates, organic fertilizer (manures, compost), surface composting, and organic mulches (cover crops, living and dead mulches), should keep the soil life strong and active across the whole vegetation period. In the long term, an improvement of soil quality due to increased soil organic matter and microbial biomass, as well as an increased baseline level of mineralization should be achieved (Carpenter-Boggs et al. 2003). Thus, agronomic practices in organic farming have to be thought within the system as nutrient limitations are the main drivers of the overall dynamics: Less plants mean less root exudates mean less soil fertility mean less plants. Consequences arise from this for weed, pest and disease dynamics. However, improving soil fertility is a long-lasting process that needs to be adapted to site-specific conditions, such as soil texture, rainfall, and livestock. The basis for improving soil fertility is a dense and continuous soil cover, preferably by living plants, all over the season expressed by high frequencies of diverse (leguminous) cover crops in the rotation. In such systems, weed pressure is generally low and nutrient mineralization processes are sped up enabling the farmer to reduce the tillage intensity. Indeed, **"Soil fertility is not the result, but rather the prerequisite for no- or minimum tillage"**. There is no sequence of principles by which conservation agriculture can be achieved but all stand side by side and are inseparable as defined by Hobbs (2007), namely (1) Permanent soil cover; (2) Crop rotations; and (3) Minimum of soil disturbance. Thus, permanent soil cover and crop rotation systems must be optimized in order for minimum tillage to be successful in organic farming.

However, we are still lacking deep knowledge of soil (microbial) processes and how to steer soil fertility in agricultural systems, for example through the use of plant communities to foster a general soil disease suppression (Mazzola 2004; Kinkel et al. 2012; Schlatter et al. 2017). Furthermore, there is a high demand for cheap and simple methods, preferably applicable by farmers, that allow assessment of the effects of farming system adaptations. The spade diagnosis as described in Fig. 11.1 is one such easily applicable method. The identification of free-living nematode densities and communities, while requiring a laboratory, could also be helpful to help the farmer judge whether a soil is ready for minimum tillage.

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