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The concurrent assessment of agronomic, ecological, and environmental variables enables better choice of agroecological service crop termination management

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Abstract

1. Although organic farming was originally promoted as an alternative farming system to address agronomic, environmental, and ecological issues, its conventionalisation has led to an intensification and specialisation of production. In light of this, several studies have questioned the environmental benefits of organic farming as well as its agronomic viability. Thus, there is a need to improve organic vegetable systems to reduce their environmental impact without affecting their productivity. To tackle this challenge, European farmers and researchers have recently started to focus on agroecological service crops (ASCs). However, few studies have simultaneously evaluated the agronomic, environmental, and ecological aspects of ASC management under different European pedo-climatic conditions.
2. We evaluated effects of the ASC management strategies: no-till roller crimping (NT-RC) and green manuring (T-GM) on cropping system performance using agronomic, environmental, and ecological indicators, to exemplify the need for multidimensional analysis to understand management implications for addressing environmental and agronomic challenges. We combined the results from eleven organic vegetable field trials conducted in seven European countries over a period of two years to test for general trends.
3. Our results provide solid evidence that NT-RC management across different pedo-climatic conditions in Europe enhances the activity density of ground and rove beetles, and improves both the potential energy recycling within the system and weed control. However, in NT-RC plots lower cash crop yield and quality, energetic efficiency of production, and activity density of spiders was observed compared to T-GM.
4. *Synthesis and applications:* Multidimensional analyses using agronomic, environmental, and ecological indicators are required to understand the implications of agricultural management in agroecosystem functioning. Introducing agroecological service crops combined with the use of no-till roller crimping is a promising strategy for improving agronomic performance (e.g., fewer weeds) and reducing environmental (e.g., increasing the potentially recyclable energy), and ecological (e.g., enhancing the activity density of beneficial taxa such as ground and rove beetles) impacts. However, our study also indicates a need for agronomic and environmental improvements while promoting a wider acceptance of this strategy.

Key words

Energetic efficiency; ground beetles; potentially recyclable energy; rove beetles; spiders; weed control; yield

1. Introduction

Agriculture provides multiple ecosystem services that are indispensable for human welfare and these depend on a network of supporting (e.g., soil fertility and nutrient cycling) and regulating (e.g., pest and weed control) services. However, the management of cropping systems can also generate disservices that reduce productivity (e.g., pest damage), generate environmental issues (e.g., nutrient leaching), and affect both the maintenance and functioning of ecosystems and human well-being (Power, 2010; Zhang, Ricketts, Kremen, Carney, & Swinton, 2007).

In Europe, 1.9 % of arable land (2.2 million ha) is devoted to vegetable crops and produces approximately 65 million tonnes of fresh vegetables (De Cicco, 2016; EUROSTAT, 2019). Vegetables are the crops that need the highest energy input (Elsoragaby, Yahya, Mahadi, Nawi, & Mairghany, 2019) and, to ensure yields, vegetable production currently requires the greatest agrochemical input (i.e., fertilisers and pesticides) and the highest irrigation rates of all arable systems. Intensive management of these crops has caused environmental problems, including the notable consumption of non-renewable resources and nutrient leaching (Min, Zhang, & Shi, 2012; Torrellas et al., 2012) as well as health concerns derived from the presence of pesticide residues (González-Rodríguez, Rial-Otero, Cancho-Grande, & Simal-Gándara, 2008).

Organic farming was originally promoted as a holistic farming system aimed at improving soil health, and environmental and social aspects of agricultural production (Seufert, Ramankutty, & Mayerhofer, 2017). In recent decades, its conventionalisation has led to the intensification and specialisation of organic production (Buck, Getz, & Guthman, 1997; Darnhofer, Lindenthal, Bartel-Kratochvil, & Zollitsch, 2010), and several studies have questioned the environmental benefits and agronomic viability of organic farming (Seufert et al., 2017; Trewavas, 2001, 2004; Tuomisto, Hodge, Riordan, & Macdonald, 2012).

There are also agronomic limitations to the widespread implementation of organic farming, of which weed management is identified by organic farmers as one of the main constraints on organic arable vegetable production (Turner, Davies, Moore, Grundy, & Mead, 2007). For example, the dependence on frequent soil tillage for controlling weeds negatively affects the sustainability of soil management in organic systems (Trewavas, 2001, 2004). This is because tillage is very energy-consuming and increases fossil fuel consumption (Alluvione, Moretti, Sacco, & Grignani, 2011). In addition, tillage has a direct impact on soil organisms (i.e., by directly killing or injuring them) and their habitat, and modifies inter-specific relationships (Roger-Estrade, Anger, Bertrand, & Richard, 2010). In particular, ground and rove beetles are known to be sensitive to soil disturbance (Pretorius et al., 2018; Rivers, Mullen, Wallace, & Barbercheck, 2017; Tamburini, De Simone, Sigura, Boscutti, & Marini, 2016). Moreover, the negative impact of tillage on certain groups of soil-dwelling predatory invertebrates also affects the biological pest-control potential of this cropping system (Tamburini et al., 2016). Finally, intensive tillage causes changes in the biological quality of the soil and, for example, affects the activity of enzymes (e.g., beta-glucosidase) that play important roles in organic matter degradation (Ekenler & Tabatabai, 2003).

Another important constraint is related to the gap in crop yield between organic and conventional farming systems (Ponisio et al., 2015). Some studies argue that organic farming is less efficient as it requires more land to produce the same amount of food as conventional farming, and that more fossil fuel is required for weed control (Trewavas, 2001, 2004). Additionally, under organic farming, the adoption of less intensive tillage management has been shown to potentially reduce the cash crop yield and fruit quality (i.e., the marketable parameters) (Ciaccia, Montemurro, et al., 2015; Diacono, Persiani, Fiore, Montemurro, & Canali, 2017). Fertilisation strategies based on the application of animal or green manure, as well as the recycling of energy and nutrients within the cropping system, are also argued to have potentially negative impacts on the environment (Trewavas, 2001, 2004). On the one hand, the process of manure decomposition and nutrient release from animal or green manure is not always well synchronised with the cash crop uptake. After the cash crop cycle, the manure remaining in the soil continues to decompose and release nutrients that can lead to nitrate leaching and the eutrophication of natural water bodies (Trewavas, 2001). On the other hand, Trewavas (2004) highlighted the fact that recycling energy and nutrients within the cropping system cannot compensate for the absorption of nutrients by the cash crop. Therefore, this type of management can lead to a progressive depletion of these nutrients in the soil.

To overcome some of these constraints, organic vegetable cropping systems need to be re-evaluated and their impacts addressed from an agronomic, environmental, and ecological perspective. The introduction of agroecological service crops (ASCs) (e.g., catch crops, cover crops, and complementary crops) (Canali, Diacono, Campanelli, & Montemurro, 2015) in crop rotations is a widely recognised strategy for improving the environmental performance of cropping systems (Silva, Moore, Silva, & Moore, 2017; Wezel et al., 2014). Nevertheless, several authors have concluded that the environmental and agronomic performance of ASCs depends on the management strategy used to terminate them (Canali et al., 2013; Ciaccia et al., 2016; Navarro-Miró, Blanco-Moreno, et al., 2019; Navarro-Miró, Iocola, et al., 2019).

Traditionally, European organic farmers have managed ASCs as green manure (T-GM) by chopping up and incorporating plant material into the soil by tillage (Peigné et al., 2016). However, as stated above, tillage can negatively affect the soil system. In recent years, therefore, the use of no-till roller crimping (NT-RC) for ASC management has attracted the interest of European farmers and researchers (Casagrande et al., 2016; Vincent-Caboud, Peigné, Casagrande, & Silva, 2017) because it can improve weed management and reduce dependence on tillage in organic farming. The roller-crimper flattens the ASC, creating a dense layer of plant residue on the soil surface (i.e., mulch) without soil disturbance. The use of NT-RC for ASC management originated in Brazil (Kornecki, Price, Raper, & Arriaga, 2009), and this approach has been studied and developed mainly in Latin America, Canada, and the USA (Altieri et al., 2011; Carr, Gramig, & Liebig, 2013; Delate, Cwach, & Chase, 2012; Shirtliffe & Johnson, 2012). The few studies performed in European organic vegetable systems have concluded that NT-RC reduces weed abundance dramatically and requires less fossil fuel than the T-GM approach (Canali et al., 2013; Ciaccia, Testani, et al., 2015; Diacono et al., 2017). Nevertheless, both positive and negative effects have been observed on cash crop yields when NT-RC is implemented under Mediterranean conditions (Canali et al., 2013; Ciaccia et al., 2016; Diacono et al., 2017). In addition, few studies have examined the impact of cover crop termination on beneficial soil fauna (Depalo et al., 2020; Magagnoli et al., 2018), root growth, and soil nitrogen (Hefner, Canali, et al., 2020; Hefner, Gebremikael, et al., 2020).

Most studies that have analysed NT-RC have focused on agronomic aspects and, to a much lesser extent, on environmental performance. To our knowledge, no studies have used a multidimensional approach to evaluate different agronomic, environmental, and ecological aspects simultaneously. Furthermore, most studies have been conducted under the particular conditions of specific experimental sites (including crops, weather, and soil), which may have influenced the findings. Given that agroecological patterns can be affected by the nature of the receiving environment, validation of practices must take into account this potential variability. The only studies to have analysed the effect of NT-RC on energy flows and weed control across Europe are, respectively, Navarro-Miró, Iocola, et al. (2019) and Navarro-Miró, Blanco-Moreno, et al. (2019).

In this study, we analysed effects of the ASC management strategies (NT-RC vs. T-GM) on organic vegetable cropping system performance by means of agronomic, environmental, and ecological indicators, in different vegetable crops, soils and climatic conditions across Europe. We compared NT-RC and T-GM using a system comparison approach to exemplify the need for multidimensional analysis to address some of the most frequent criticisms and constraints as mentioned above. We also aimed to show the importance of an appraisal of the environmental and ecological implications—as well as the agronomic benefits to the agroecosystem—under different crop, soil, and climatic conditions to evaluate the pros and cons of the different management systems before promoting them to organic vegetable farmers, advisors, and policymakers. To this end, we combined results obtained over a two year period from eleven organic vegetable field trials located in seven European countries as part of the SoilVeg project (ERA-Net CORE Organic Plus).

2. Material and methods

2.1. Locations and field trials

We combined results from 11 organic arable vegetable field trials located in Belgium (BE), Denmark (DK), Estonia (EE), France (FR), Italy (IT), Slovenia (SI), and Spain (ES). In BE, three different trials were set up across the country (BE-ILVO, BE-INAGRO, and BE-CRA-W). These vegetable production trials were located in different climatic zones (Metzger, Bunce, Jongman, Mücher, & Watkins, 2005) and had different soil textures (Table 1).

Two parallel field experiment types were carried out during two crop cycles as part of the SoilVeg project. Field experiment type A (FtA) was established at all trial locations (BE-ILVO, BE-INAGRO, BE-CRA-W, DK, EE, ES, FR, IT, SI) and involved the introduction of cold-rainy season ASCs into the crop rotation, followed by a spring-summer cash crop. The first FtA cycle took place during 2015 and 2016 and the second, during 2016 and 2017. Field experiment type B (FtB) was performed only at the IT and ES locations where the Mediterranean climatic conditions enabled introduction of the ASCs in the warm-dry season (i.e., summer) with irrigation, followed by the transplantation of an autumn-winter cash crop. The first FtB cycle took place during 2014 and 2015 and the second, during 2015 and 2016. The comparison between ASC management strategies (NT-RC vs. T-GM) was carried out within each trial for both experiment types. In total, results from twenty-two original datasets were analysed (i.e., from 11 field experiments carried out over two years) (Table 1).

2.2. Trial management

All field trials were newly established. Both experiment types were repeated in the same plots during both years in ES and BE-ILVO, whereas in the other trial locations, new plots were established in adjacent areas of the same experimental field following a planned rotational design for the second year of experimentation. Notwithstanding different weather conditions, soil textures, ASC compositions, and experimental designs (Table 1), a comparison between the two ASC management strategies (NT-RC vs. T-GM) could be made for all trials. The NT-RC strategy involved: (1) ASC flattening by several roller crimper passages (2–4) to obtain a mulch of plant residue, and (2) the creation of a narrow transplanting furrow without disturbing the surrounding mulch using a slower in-line tiller. The T-GM strategy involved: (1) ASC mowing and/or chopping, (2) incorporation of the ASC pieces into the soil by tillage, and (3) preparation of the seedbed. Further information about the experimental design and agronomic management in each trial is provided in Appendix S1 in Supporting Information.

2.3. Cropping system performance indicators

We used a set of ecological, environmental, and agronomic indicators with a system comparison approach to compare the performance of NT-RC and T-GM. In addition to a set of common indicators evaluated in all experiments, we selected a number of tailored indicators which were used according to the site-specific aims and conditions of the different experiments.

2.3.1. Ecological and environmental indicators

We investigated the effects of ASC management on the soil system by analysing its impact on soil arthropod fauna and soil enzyme activity. We followed the concept of ecological indicators *sensu* McGeoch (1998) because the functions represented by these indicators are of significance to agriculture (Niemelä, 2000). The impact of the ASC management strategies on the soil fauna was assessed by evaluating the activity density of ground (Carabidae) and rove (Staphylinidae) beetles and spiders (Araneae). These soil taxa have been shown to be sensitive to agricultural input and practices, including tillage, and are often used to typify the effect of agricultural practices on organisms living on the soil surface (Pretorius et al., 2018; Rivers et al., 2017). The activity densities (AD) of the Carabidae, Staphylinidae and Araneae were assessed using pit-fall traps. Specific details of pit-fall trapping, number and duration of sampling periods in each trail are provided in Appendix S2. In each trial, soil arthropod AD was calculated as the mean of the abundance of each taxonomic group in all samples divided by the number of traps and the number of days that traps were operative. The AD was normalised to seven days:

$$\mathrm{AD} = \frac{n}{T} \cdot \frac{7}{d}$$

where n is the total abundance of each taxon, T is the number of traps, and d is the number of days that traps were operative.

The effect of the ASC management strategy on soil quality was assessed using beta-glucosidase enzyme activity. This enzyme has known sensitivity to soil tillage, irrespective of pedo-climatic conditions, and can, therefore, provide rapid information regarding changes in soil properties (Ekenler & Tabatabai, 2003; Knight & Dick, 2004). In BE-INAGRO and DK beta-glucosidase was assessed using the method described in Alef and Nannipieri (1995), while in IT was determined by the procedure described by Fornasier and Margon (2007).

In the FtA trials, soil mineral nitrogen was measured by colorimetry at cash crop harvest as an indicator of the nitrogen leaching potential (N leaching).According to Hutchings and Kristensen (1995), it can be assumed that the remaining soil mineral nitrogen at the end of the growing season, which coincides with the beginning of the leaching season, will be leached during the winter. The potential recycling of material and energy within the cropping system was calculated using the concept of potentially recyclable energy (PRE) as an output of the cropping system in the energy-use efficiency indicator (PRE-EUE) (Navarro-Miró, Iocola, et al., 2019). The PRE incorporates all the energy that can potentially be recycled within a cropping system, including the energy contained in ASCs, weeds, and cash crop residues (comprising discarded yield and other plant matter). The PRE-EUE indicator was calculated dividing the PRE by the total energy inputs of the cropping system (human labour, diesel consumption, electricity, water for irrigation, ASC seeds, cash crop plantlets, organic fertilizers and organic soil amendments, crop protection inputs, and the machinery-embodied energy fraction estimated on the basis of the machinery weight and economic life). This indicator provides insight into the capacity of the cropping system to transform inputs into potentially recyclable energy. A description of the agronomic operations carried out in the evaluated trials, and the energy equivalents of the inputs and outputs used is provided in Navarro-Miró, Iocola, et al. (2019).

Further details of beta-glucosidase enzyme activity determination and the assessment of soil mineral nitrogen at harvest of the cash crop are provided in Appendix S2.

2.3.2. Agronomic indicators

We evaluated the effects of the ASC management strategies on two indicators: the cash crop marketable yield, and the cash crop quality. The cash crop marketable yield indicator was assessed using the dry biomass of the marketable cash crop yield, whereas the cash crop quality indicator included different measurements of the cash crop marketable parameters, specific to each crop (cabbages - head diameter;

pepper - fruit length; butternut squash - fruit weight; tomato - fruit total soluble solids with refractometric index, °Brix; cauliflower - marketable head dry matter weight), as indicated in Appendix S2.

The energy efficiency of the marketable production was determined by the energy-use efficiency indicator (M-EUE) (Barut, Ertekin, & Karaagac, 2011). For M-EUE, we considered the marketable yield of the cash crop as the output and was divided by the total energy inputs of the cropping system. Further details of the agronomic operations and the energy equivalent calculations can be found in Navarro-Miró, Iocola, et al. (2019). Weed control was analysed by determining weed density (individuals m^{-2}). To account for all the potential competition effects on the cash crop, we included the number of germinated and regrown weed plants and ASC species at an early stage of cash crop growth, before the first weeding operation. Specific details of weed sampling (i.e., the number of samples per plot) and timing are provided in Navarro-Miró, Blanco-Moreno, et al. (2019).

2.4. Statistical analysis

Each trial was conducted under its own particular pedo-climatic conditions and experimental design. Thus, instead of pooling the raw data from all the different trials, we fitted a statistical model for each trial and indicator. We used a meta-analytic approach to combine the *P*-values and assess the effect of the ASC management strategies on each indicator for all the trials. This approach is known to be almost as powerful as approaches based on data combination (Zaykin, 2011).

Statistical models for each partner were fitted according to the experimental variables evaluated and the experimental layout, and included all the experimental variables evaluated in each trial in order to rule out their effect on the dependent variable. The levels of the experimental variables included in each model are presented in Table 1. Total dry biomass (ASCs and weeds) was used as a covariate, calculated by pooling the different ASCs included in each trial and the weeds present prior to ASC termination. For the BE-ILVO, BE-INAGRO, BE-CRA-W, DK, EE, FR, IT, and SI trials, we used linear mixed-effects models and defined random effects according to the specific experimental layout of each trial, as detailed in Table 1. However, for ES, given that the experimental layout was influenced by the need to facilitate the movement of machinery between plots, we introduced spatial correlation structures in the generalised linear models to account for the lack of independence between samples (Pinheiro & Bates, 2000). Thus, we established the best model for each dependent variable comparing different classes of spatial correlation structures as well as a model with no spatial correlation structure using likelihood ratio tests and Akaike's information criterion. Data were transformed when necessary to ensure the normality and homoscedasticity of the residuals. All statistical analyses were performed with R software (R Core Team, 2018). For linear mixed-effects models, we used the `lme` function of the R `nlme` package (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2017), except for BE-CRA-W and IT-N leaching and IT-beta-glucosidase enzyme activity models, for which we used the `lmer` function of the R `lme4` package (Bates, Mächler, Bolker, & Walker, 2015). For the IT trial, the AD of ground and rove beetles and spiders was analysed using the `glmer.nb` function of the `lme4` package (Bates et al., 2015). For the ES trial, we fitted the models with spatial correlation structures using the `gls` function. Then, the statistical significance of the effect of the management strategy on a specific indicator for all the trials was analysed using the weighted Z-test, which is essentially a weighted version of Stouffer's method, as in Zaykin (2011):

$$p_Z = 1 - \Phi\left(\frac{\sum_{i=1}^{k} w_i Z_i}{\sqrt{\sum_{i=1}^{k} w_i^2}}\right)$$

where $Z_i = \Phi^{-1}(1-p_i)$; pi is the *P*-value from the i-th study out of a total of k studies; w_i is the weight selected for the study; and Φ and Φ^{-1} are are the standard normal cumulative distribution function and its inverse, respectively. For this study, we weighted *Zi* using the standardised effect size:

$$w_i = \frac{|\mu_i|}{SE_i}$$

where μ_i is the coefficient estimate, and SE_i is its standard error. To test for the same alternative hypothesis, individual *P*-values were converted to one-sided values before combining as follows:

$$p_{one-sided} = \begin{cases} \frac{p_{two-sided}}{2}, \text{if the direction of the effect coincides with the alternative hypothesis} \\ 1-\frac{p_{two-sided}}{2}, \text{otherwise.} \end{cases}$$

Independence between *P*-values is required for the weighted Z-test. Thus, we analysed the data from the two consecutive years of each trial simultaneously and obtained the average effect of the termination strategy in each trial after taking into account the effect of the year.

3. Results

3.1. Environmental and ecological indicators

The statistical analysis showed that the ASC management strategy significantly affected soil arthropod AD and PRE-EUE (Figure 1), whereas it had no significant effect on the beta glucosidase indicators or N-leaching across the trials, except for the BE-CRA-W trial where the N leaching potential was significantly affected (Table 2).

According to the weighted Stouffer's test, the Carabidae AD was significantly higher under NT-RC compared to T-GM across the trials (Figure 1) except in SI-FtA under NT-RC where a significantly lower AD was observed (Table 2). The weighted Stouffer's test showed that Staphylinidae AD was also significantly higher under NT-RC compared to T-GM (Figure 1). We observed a significantly higher

Staphylinidae AD under NT-RC in IT-FtA and IT-FtB whereas in BE-ILVO-FtA and SI-FtA, the Staphylinidae AD was significantly lower (Table 2). Spider AD was lower under NT-RC than T-GM across the trials (Figure 1), but only significantly so in two out of the five evaluated trials (Table 2). The energy recycling efficiency of the ASC management strategies (evaluated using the PRE-EUE indicator) was significantly higher across trials under NT-RC compared to T-GM (Figure 1). The PRE-EUE was significantly higher under NT-RC in four out of eight trials, and was significantly lower only in IT-FtB (Table 2).

The ranges (i.e., maximum and minimum) of the environmental and ecological indicators for each trial are presented in Appendix S3.

3.2. Agronomic indicators

All agronomic performance indicators were significantly affected by the ASC management strategy (Table 3). Weed density under NT-RC was lower than under T-GM (Figure 1) and declined significantly in seven out of nine trials (Table 3). According to the weighted Stouffer's test, both yield descriptors (i.e., cash crop marketable yield and quality) were lower under NT-RC compared to T-GM (Figure 1). Similarly, the energy-use efficiency of the ASC management strategies evaluated using marketable yield as the output of the cropping system was lower under NT-RC compared to T GM (Figure 1), and was significantly lower in four out of eight trials. However, energy use efficiency under NT-RC was significantly higher in ES-FtA and IT-FtA (Table 3).

The ranges (i.e., maximum and minimum) of the agronomic indicators for each trial are presented in Appendix S3.

4. Discussion

The system comparison approach between NT-RC and T-GM shows the importance of multidimensional analysis for evaluating the advantages and disadvantages of agricultural practices from an environmental, ecological, and agronomic perspective before they can be promoted by advisors and policymakers, and implemented by organic vegetable farmers. We acknowledge that our study reports only on the overall trend of the differences between management systems. Although we cannot make inference on the distribution or the magnitude of the effects on the different indicators beyond the study locations without further research, we provide a strong support, derived from several experiments, for the trends presented. Our results show that each of the ASC management strategies affected the performance of the agronomic, environmental, and ecological indicators differently. Thus, the multidimensional analysis showed that none of the ASC management strategies analysed can address all the most frequent limitations and criticisms of organic farming.

The overall results indicate that, in spite of some differences between trials, NT-RC enhanced weed control in the early growing season, and the AD of ground and rove beetles as well as the potential recycling of energy within the system when compared to T-GM. However, compared to T-GM, NT-RC lowered cash crop yield and quality, the energetic efficiency of production, and the AD of spiders in the vegetable crops and under the different soil and climatic conditions in the representative European countries.

The consistent effectiveness of NT-RC on reducing weed density across countries validates this approach as an effective strategy for European organic farmers to manage weeds during the early stages of vegetable growth. It is worth noting that other studies on the reduction of tillage intensity in organic farming analysed the effect of both ASC management strategies on weed density, weed species richness, and community composition (Navarro-Miró, Blanco-Moreno, et al., 2019). Implementation of NT-RC may lead to a decrease in the dependence on tillage for managing weeds, which in turn may result in less soil disturbance in organic vegetable systems. Moreover, the AD of ground and rove beetles were higher under NT-RC plots, which are generally sensitive to soil disturbance (Pretorius et al., 2018; Rivers et al., 2017; Tamburini et al., 2016). Our results agree with previous studies regarding the effects of ASC termination on soil functional diversity (Depalo et al., 2020; Magagnoli et al., 2018). The NT-RC strategy has been shown to reduce the direct impact of tillage (for ASC incorporation and weeding operations) on organisms living in the upper soil layers (Roger-Estrade et al., 2010; Sommaggio, Peretti, & Burgio, 2018) and to create favourable conditions (i.e., physical refuges and prey provision) for these groups during the cash crop cycle (Roger-Estrade et al., 2010; Sunderland & Samu, 2000). These soil-dwelling taxa play an important role in agroecosystem functioning, as they include pest and weed-seed predators and detritivores. For these reasons, their conservation and promotion may enhance the provision of ecosystem services (Pretorius et al., 2018).

In our study, spider AD was lower under NT-RC compared to T-GM across trials. This finding contradicts a growing body of work indicating the positive effects on spider abundance of straw mulch (Sunderland & Samu, 2000), and of conservation tillage (Tamburini et al., 2016). The lack of a clear pattern between ASC termination strategy and spider populations calls for further studies to improve knowledge of how flattened mulch may affect macrofauna based on body size, movement, behaviour, guild, and dispersal methods (Baatrup, Rasmussen, & Toft, 2018; Cardoso, Pekár, Jocqué, & Coddington, 2011; Jiménez-Valverde, Baselga, Melic, & Txasko, 2010).

Our NT-RC findings do not counter some of the main criticisms of this termination strategy regarding the yield and production efficiency of organic systems. Our results indicate that there is a consistent pattern of decreasing vegetable cash crop yield and marketable fruit quality under certain pedo-climatic conditions and crops. The reduction of the cash crop yield is one of the main drawbacks of no-till management, specifically when organic fertilisers are applied (Pittelkow et al., 2015). Overall, greater variability and lower cash crop yields are one of the factors hindering a more widespread adoption of no-till practices by European organic farmers (Casagrande et al., 2016; Vincent-Caboud et al., 2017). The negative effect of NT-RC on crop yield was related to limited N availability in the DK trial (Hefner, Gebremikael, et al., 2020). Similarly, other published literature links the yield gap and fall in marketable quality under NT-RC in organic vegetable systems to N shortages during cash crop development (Ciaccia, Montemurro, et al., 2015; Diacono, Persiani, Canali, & Montemurro, 2018; Diacono et al., 2017). Therefore, this line of evidence points to the need for improvement of fertilisation strategies to overcome this constraint in combination with the species chosen as the agroecological service crop as shown in the DK trial (Hefner, Canali, et al., 2020). Additionally, NT-RC was less efficient than T-GM in transforming inputs into marketable outputs. A reduction in M-EUE can be related to higher cash crop yields and/or lower energy input consumption (Mohammadi & Omid, 2010). In our study, the greater input consumption required by T-GM for tillage and weeding operations (Canali et al., 2013; Diacono et al., 2018) could be compensated by the higher yield and better quality observed with this management strategy.

Implementation of NT-RC improved the environmental performance in terms of the energy that could potentially be recycled within the cropping system. Flattening the ASCs and avoiding tilling prior to cash crop transplantation has been shown to increase the efficiency of the cropping system in terms of the potentially recyclable energy generated per unit of input invested (Navarro-Miró, Iocola, et al., 2019). Although future energy and nutrient input savings might result in the long term due to the higher retention of energy within the agroecosystem, the higher PRE observed in NT-RC plots was mainly caused by a higher non-marketable yield rate, which is not agronomically desirable. Therefore, more research is required to analyse whether the likely input savings would compensate for the higher proportion of non-marketable yield observed under NT-RC in the long term. Regarding beta-glucosidase activity, no clear conclusion could be drawn in the short term from the findings of the present study. Similarly, the leaching of mineral N as a potential environmental indicator was only significantly affected by the ASC management strategies in one of five trials, and there was no common significant pattern across trials.

In this study, the response of agroecosystem functioning to the different ASC management strategies was evaluated immediately after their implementation. Similarly to what is found in other agricultural systems (Cooper, Baranski, et al., 2016) the benefits from all forms of reduced and conservation tillage are cumulative and accrue over many years, so a single year of observations is likely to underestimate not only the benefits of these particular approaches, but also the broader ecological consequences. Therefore, longer-term studies are required to improve our understanding of the processes associated with organic NT-RC, and to evaluate whether this strategy is effective as a continuous long-term management approach.

5. Conclusions

In this study, we evaluated the consequences of a change in the management of organic vegetable production, from an agronomic, environmental, and ecological perspective. This study provides the first evidence that NT-RC alleviates some limitations of organic systems, mainly ecological and to lesser extent environmental and agronomic indicators in different vegetable crops and soils, and under different climatic conditions in Europe. However, compared to T-GM, NT-RC affects negatively some ecological and many agronomic indicators. Therefore, our results highlight the need to simultaneously evaluate different agronomic, environmental, and ecological aspects as a means of providing a clearer overview of the effect of ASC management strategies on agroecosystem functioning. Further research is thus required to determine how to reduce the yield gap under NT-RC via the use of new fertilisation strategies during cash crop development or in specific vegetable breeding programs. Additionally, studies performing economic analyses should be run to assess whether the costs associated with NT-RC compensate the reduction in cash crop yield and quality. Therefore, it is clear that for the promotion of any agricultural system it is necessary to undertake a thorough analysis of a multi-faceted set of indicators.

Authors contributions:

David Navarro-Miró designed the work, collected and analysed the data, interpreted the results, and drafted the article. **Ileana Iocola, Corrado Ciaccia, Elena Testani, Laura Depalo, Giovanni Burgio, Hanne Lakkenborg Kristensen, Margita Hefner, Kalvi Tamm, Ingrid Bender, Alessandro Persiani, MariangelaDiacono, Francesco Montemurro, KoenWillekens, Hélène Védie, Martina Bavec, Martina Robačer, DonatienneArlotti, Pauline Deltour, Stefaan De Neve, Mesfin Tsegaye Gebremikael, Lourdes Chamorro, Berta Caballero-López, and Alejandro Pérez-Ferrer** contributed to the design and management of the experiments and the data collection in each country. **Stefano Canali** (SoilVeg project coordinator) conceived the transnational, multisite, and multi-season dimensions of the whole experiment and contributed to its design. **José M. Blanco-Moreno and F. Xavier Sans** played a major role in the conception and design of the work, the data analysis and the interpretation of the results, and also helped draft the article. All authors critically revised the final manuscript.

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Data Availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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Table 1. Environmental conditions, cash crops, ASC and factors analysed in each trial. European Climatic Zones according to Metzger et al. (2005).

Country	Trial	European Climatic Zones	Temperature rainfall (annual mean)	Soil type	Cash crop	ASC composition	Explanatory variables in the models	Experimental design	Repetitions per treatment
BE-CRA-W	FtA	Atlantic Central	1Y: 10.99 °C; 538 mm	Silt loam	Red cabbage	L or G	T; B	S-P	Four
BE-ILVO	FtA	Atlantic Central	1Y: 11.1 °C; 898 mm 2Y: 11.3 °C; 822 mm	Sandy loam	White cabbage	L and G	T; B; Y	SS-P	Four
BE-INAGRO	FtA	Atlantic Central	1Y: 11.0 °C; 860 mm 2Y: 11.3 °C; 697 mm	Sandy loam	White cabbage	L or G	T; Y; A	S-P	Four
DK	FtA	Atlantic North	1Y: 9.3 °C; 614 mm 2Y: 9.1 °C; 673 mm	Sandy loam	White cabbage	L or G	T; B; Y	S-P	Three
EE	FtA	Nemoral	1Y: 6.0 °C; 825 mm 2Y: 5.8 °C; 694 mm	Sandy clay loam	White Cabbage	L or G	T; B; Y; F	ST-P	Three
ES	FtA	Mediterranean North	1Y: 16.5 °C; 406 mm 2Y: 16.1 °C; 409 mm	Loamy	Green pepper	L or G	T; B; Y	R-S-P	Four
	FtB	Mediterranean North	1Y: 16.1 °C; 344 mm 2Y: 16.5 °C; 406 mm	Loamy	Savoy cabbage	L or G	T; B; Y	R-S-P	Four
FR	FtA	Mediterranean North	1Y: 15.5 °C; 521 mm 2Y: 15.3 °C; 558 mm	Clay loamy	Butternut squash	L or G	T; B; Y	R-S-P	Three
IT	FtA	Mediterranean North	1Y: 16.7 °C; 539 mm 2Y: 16.5 °C; 402 mm	Clay	Tomato	L and G	T; B; Y; F	SS-P	Three
	FtB	Mediterranean North	1Y: 16.6 °C; 470 mm 2Y: 16.7 °C; 539 mm	Clay	Cauliflower	L or G and B	T; B; Y	SS-P	Three
SI	FtA	Alpine South	1Y: 10.9 °C; 1009 mm 2Y: 11.1 °C; 961 mm	Loam	Cauliflower	L or G	T; B; Y; F	SS-P	Four

FtA: Spring-summer cash crop; FtB: Autumn-winter cash crop. BE: Belgium; DK: Denmark, EE: Estonia, ES: Spain; FR: France; IT: Italy, and SI: Slovenia. 1Y: first year; 2Y: second year of experimentation. ASC composition: L: Legumes; G: Grasses; B: Brassicaceae. Explanatory variables: T: Termination; B: Total biomass; Y: Year; F: Fertilization; A: ASC composition. Experimental design: SS-P: Split-split-plot randomized complete block design; S-P: Split-plot randomized complete block design; ST-P: Strip-plot randomized complete block design; R-S-P: Randomized strip-plot.

Table 2. Ecological and environmental indicators. Estimates (± standard error) and their statistical significance taken from the models evaluating the environmental performance that compared T-GM to NT-RC. Variable transformation codes: †: logarithmic; ††: square root; †††: cube root. Significance codes: 'N.S.' P > 0.05; '*' P ≤ 0.05; '**' P ≤ 0.01; '***' P ≤ 0.001.

		Ecological indicators			Environmental indicators		
Country	Trial	Carabidae AD	Staphylinidae AD	Araneae AD	PRE-EUE	N leaching	Beta-glucosidase
BE-CRA-W	FtA					1.93 ± 0.91 *	
BE-ILVO	FtA	11.2 ± 2.63 **	-1.29 ± 0.43 *		† 0.37 ± 0.06 ***		
BE-INAGRO	FtA					1.39 ± 1.27 N.S.	0.06 ± 0.05 N.S.
DK	FtA	††† 0.58 ± 0.17 **	-0.92 ± 1.69 N.S.	-3.58 ± 1.06 **	0 ± 0 N.S.	3.43 ± 1.19 N.S.	-5.4 ± 6.49 N.S.
EE	FtA				-0.01 ± 0.01 N.S.	†† -0.2 ± 0.17 N.S.	
ES	FtA				0.02 ± 0.01 *		
	FtB			2.82 ± 2.58 N.S.	0 ± 0 N.S.		
FR	FtA				† 0.02 ± 0 ***		
IT	FtA	0.53 ± 0.23 *	0.79 ± 0.26 **	-0.17 ± 0.1 N.S.	0 ± 0 *	-0.32 ± 2.51 N.S.	0.34 ± 0.36 N.S.
	FtB	0.37 ± 0.13 **	0.71 ± 0.13 ***	-0.09 ± 0.1 N.S.	-0.02 ± 0 **		
SI	FtA	-26.25 ± 4.95 ***	† -0.66 ± 0.27 *	-8.97 ± 3.08 *			

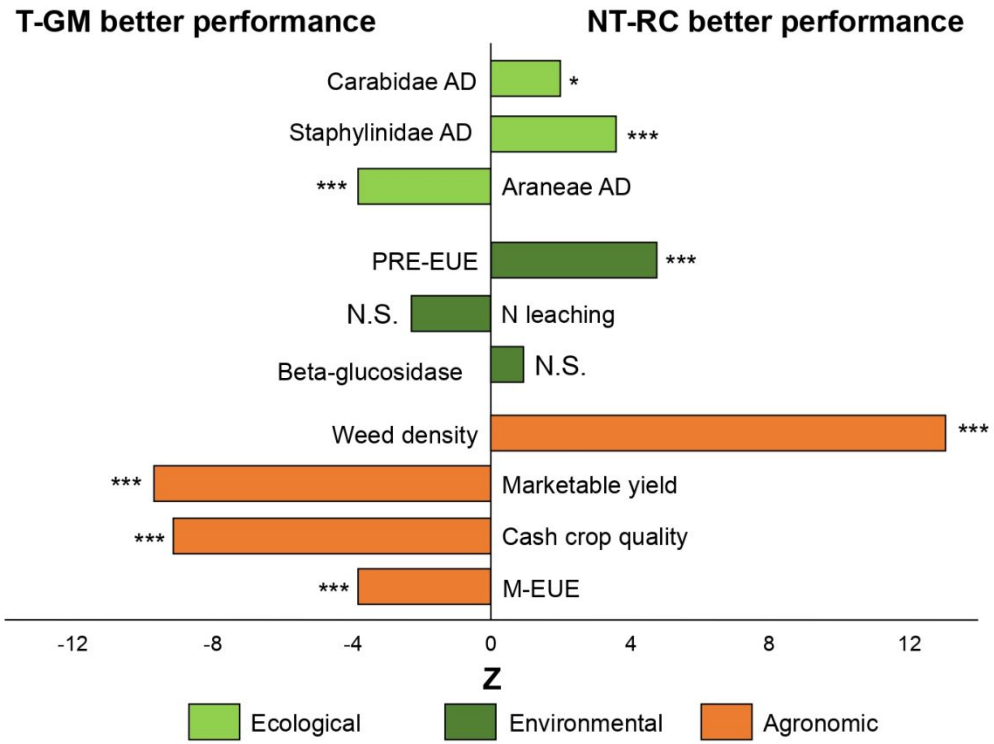
Country abbreviations as in Table 1. Ecological indicators: Carabidae AD: activity density of ground beetles; Staphylinidae AD: activity density of rove beetles; Araneae AD: activity density of spiders; Environmental indicators: PRE-EUE: energy-use efficiency using the potentially recyclable energy as the output of the cropping system; N leaching: nitrogen leaching potential. The estimate represents the average difference in the response variable (or its transformation) between NT-RC and T-GM. Positive values imply higher value of the response in NT-RC than in T-GM.

Table 3. Agronomic indicators. Estimates (± standard error) and their statistical significance in the models evaluating the agronomic performance that compared T-GM to NT-RC. Variable transformation codes: †: logarithmic; ††: square root. Significance codes: 'N.S.' P > 0.05; '*' P ≤ 0.05; '**' P ≤ 0.01; '***' P ≤ 0.001.

		Agronomic indicators			
Country	Trial	Weed density	Marketable yield	Cash crop quality	M-EUE
BE-CRA-W	FtA	-785.13 ± 85.32 ***	-0.22 ± 0.19 N.S.	-44.52 ± 3.48 ***	
BE-ILVO	FtA				0.04 ± 0.2 N.S.
BE-INAGRO	FtA		-4.12 ± 0.15 ***		
DK	FtA	-474.94 ± 39.13 ***	† -0.2 ± 0.04 **		†† -0.17 ± 0.03 **
EE	FtA	-140.08 ± 41.38 **	†† -0.27 ± 0.08 **	†† -1.77 ± 1.14 N.S.	†† -0.19 ± 0.06 **
ES	FtA	†† -10.98 ± 5.27 *	0.26 ± 0.15 N.S	0.55 ± 0.43 N.S.	0.14 ± 0.05 *
	FtB	† -0.77 ± 0.1 ***	-1.3 ± 0.4 **	1.37 ± 1.17 N.S.	-0.34 ± 0.1 **
FR	FtA	† -1.68 ± 0.26 ***	-1.91 ± 0.24 ***	-0.93 ± 0.15 ***	-0.44 ± 0.11 **
IT	FtA	† 0.12 ± 0.16 N.S.	† 0.32 ± 0.15 N.S.	-0.26 ± 0.08 **	† 0.37 ± 0.15 *
	FtB	25.44 ± 12.79 N.S.	-0.23 ± 0.12 N.S.	-0.01 ± 0.4 N.S.	-0.11 ± 0.07 N.S.
SI	FtA	†† -8.99 ± 0.34 ***			

Country abbreviations as in Table 1. Agronomic indicators: M-EUE: energy-use efficiency using the marketable yield as the output of the cropping system. The estimate represents the average difference in the response variable (or its transformation) between NT-RC and T-GM. Positive values imply higher value of the response in NT-RC than in T-GM.

Figure 1. Graphical representation of the statistical support for the differences in environmental and agronomic performance between T-GM and NT-RC. The bars represent the Z value obtained from the weighted Stouffer's test across trials for each indicator. Significance codes: 'N.S.' $P > 0.05$; '*' $P \leq 0.05$; '**' $P \leq 0.01$; '***' $P \leq 0.001$.



ASC management strategies: no-till roller crimping (NT-RC) and green manuring (T-GM). Ecological indicators: Carabidae AD: activity density of ground beetles; Staphylinidae AD: activity density of rove beetles; Araneae AD: activity density of spiders; Environmental indicators: PRE-EUE: energy-use efficiency using the potentially recyclable energy as the output of the cropping system; N leaching: nitrogen leaching potential; Beta-glucosidase enzyme. Agronomic indicators: M-EUE: energy-use efficiency using the marketable yield as the output of the cropping system.

Appendix S1. Trial details

This Appendix describes all experiments carried out in all trials located in all seven European countries. Our study compared only the no-till roller crimping (NT-RC) and tilling as green manure (T-GM) of agroecological service crop (ASC) management strategies.

Belgium - Walloon Agricultural Research Center (BE-CRA-W)

Field experiment type A

Experimental design

The field trial was newly established at the Walloon Agricultural Research Center located in Gembloux, Belgium (BE-CRA-W) (50° 36' 35.45" N and 4° 57' 14.91" E). This location represented the Atlantic Central European climatic zone. During experimentation, the mean annual temperature and rainfall were 10.99 °C and 538 mm, respectively. The trial soil had a silt loam texture and 0.91 % organic carbon content.

In this trial, only data from the second cycle (2016–2017) were gathered. During the first cycle (2015–2016), poor weather conditions delayed cabbage planting by 8 weeks which caused a significant decline in the survival and quality of the cabbage seedlings. Owing to the challenge of obtaining new cabbage seedlings quickly, and in consideration of financial loss to the farmer, the first year of the trial was abandoned.

The experimental field was located in an area managed according to European organic farming regulations since 1995. The previous crop was a mixture of oat (*Avena sativa* L.) and pea (*Pisum sativum* L.). The trial design was a split-plot with four replications, where ASC composition was the subplot factor, and the whole-plot factor was ASC management (Figure 1).

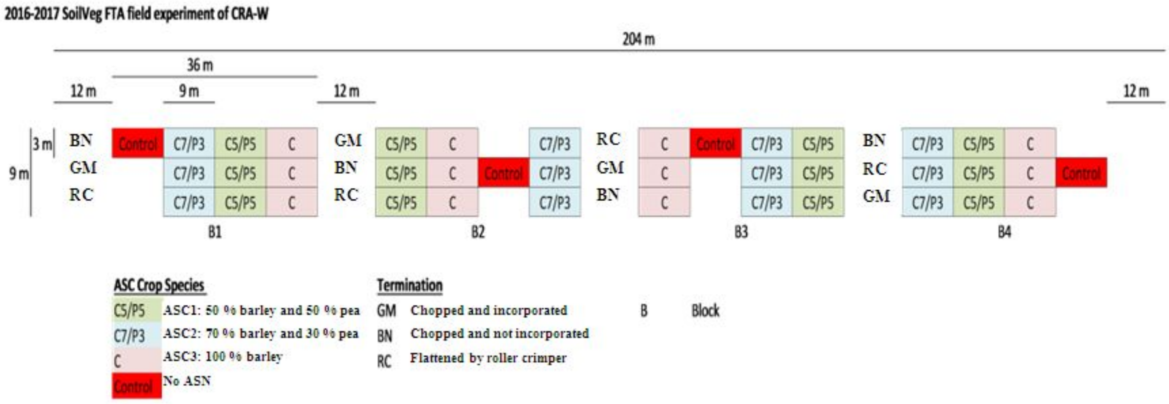
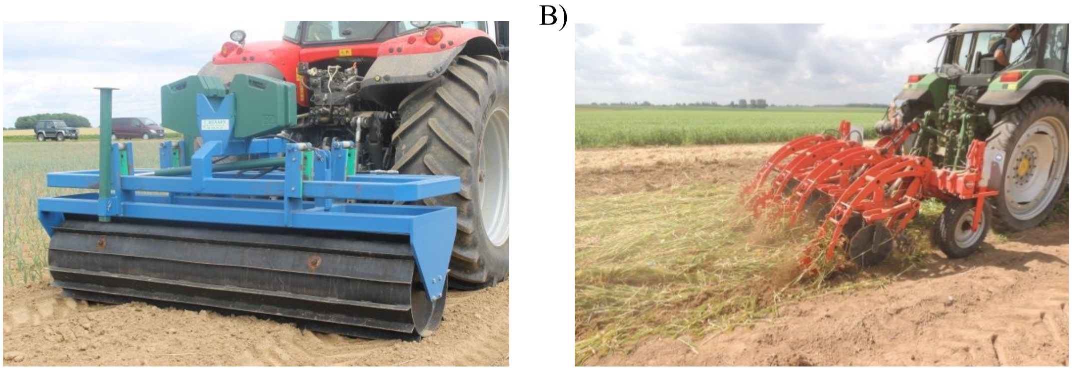


Figure 1. Experimental design of Walloon Agricultural Research Center (BE-CRA-W) trial. ASC composition: C5/P5 (green)- 50 % barley (*Hordeum vulgare* L.) + 50 % pea (*Pisum sativum* L.); C7/P3 (blue)- 70 % barley (*H. vulgare*) + 30 % pea (*P. sativum*); C (pink) – 100 % barley (*H. vulgare*); and Control (red) - No ASC. Termination: GM - Chopped and incorporated (T-GM); BN - Chopped and not incorporated; RC - Flattened by roller crimper (NT-RC).

The three ASC compositions were ASC1: 50 % barley (*Hordeum vulgare* L.) + 50 % pea (*Pisum sativum*), ASC2: 70 % barley (*H. vulgare*) + 30 % pea (*P. sativum*), and ASC3: 100 % barley (*H. vulgare*). The three ASC management strategies were: (1) chopped and incorporated into the soil by tillage as green manure (T-GM), (2) chopped and not incorporated into the soil (BN), and (3) flattened by roller-crimping (NT-RC). In parallel, a control treatment without plant cover (bare soil, BS) was established. The roller crimper was 3 m wide and weighed 1,720 kg (Picture 1.A). In the NT-RC plots, furrows for cash crop transplanting were created using an in-line tillage (Picture 1.B). Plot size was 3 × 9 m. The cash crop was red cabbage (*Brassica oleracea* var. *capitata* L. f. rubra).

A) B)



Picture 1. Machinery used for NT-RC management in the Walloon Agricultural Research Center (BE-CRA-W) trial. A - Roller crimper; B - In-line tiller.

Agronomic management

On the 25th August 2016, before ASC sowing, 20 t ha^{-1} of cow manure (82 kg total N ha^{-1}) was applied as fertiliser. The ASCs were sown on the 15th September 2016. In BS plots, four weed control operations, using a rotary harrow, were carried out during the ASC growth period. To simulate farmer practise, ASC termination was carried out on different dates, depending on the ASC management strategy: T-GM on May 5th, CNI on May 23rd, and NT-RC on May 31st, 2017.

Red cabbage was transplanted on the 31st May 2017, with a row spacing of 0.60 m and a plant spacing of 0.40 m (Picture 2). This cash crop was fertilised during planting, using commercial organic fertiliser containing 60 kg ha^{-1} of nitrogen and 33 kg ha^{-1} of phosphorous. Manual weed control was performed during growth of the cash crop on the 14th July 2017 only in T-GM and BS plots. The mulch in CNI and NT-RC plots provided acceptable weed control. The cash crop did not require irrigation and was harvested manually on the 25th and 26th of October 2017.

Picture 2. View of the red cabbage cash crop in the Walloon Agricultural Research Center (BE-CRA-W) trial.

More information about this trial can be found in Arlotti, Lakkenborg Kristensen, Canali, De Neve, Huyghebaert, et al. (2019), Arlotti, Lakkenborg Kristensen, Canali, De Neve, Sans Serra, et al. (2019) and Hefner, Canali, et al. (2020).

Belgium - Research Institute for Agriculture, Fisheries and Food (BE-ILVO)

Field experiment type A

Experimental design

The field trial was newly established at the Research Institute for Agriculture, Fisheries and Food (ILVO) in Merelbeke, Belgium (BE-ILVO) (50° 59′ 38″ N and 3° 44′ 46″ E), located in the Atlantic Central European climatic zone. During the first (2015–2016) and second (2016–2017) cycles, the mean annual temperature and rainfall were 11.1 °C and 898 mm, and 11.3 °C and 822 mm, respectively. The trial soil had a sandy loamy texture.

The experiment was repeated on the same plots during both years. The trial had a split-split-plot randomised complete block design with two factors and four replications. The main plot was the ASC management strategy, and the application of compost was the subplot factor (Figure 2).

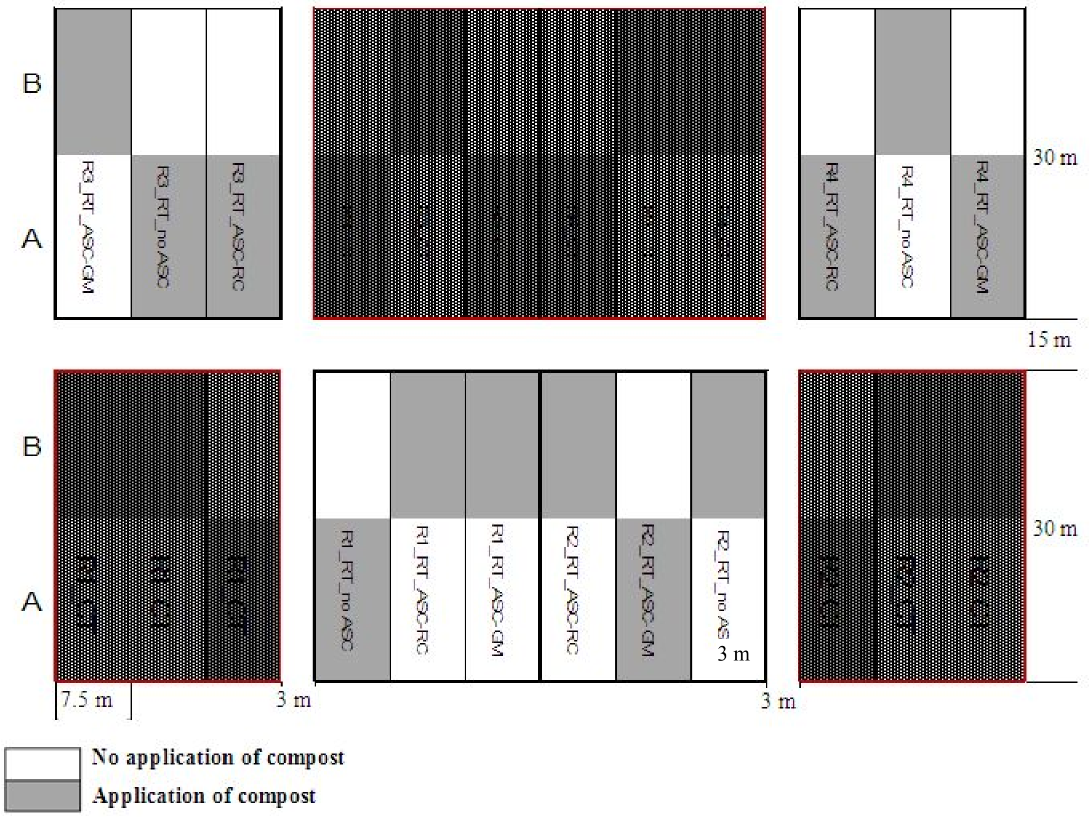


Figure 2 Experimental design of the Research Institute for Agriculture, Fisheries and Food (BE-ILVO) trial. Termination: R_RT_ASC-GM = ASC chopped and incorporated into the soil (T-GM); R_RT_ASC-RC = ASC

flattened by a roller crimper (NT-RC); and R_RT_noASC = Control treatment without ASC. Compost factor: White - No application of compost; Grey - Application of compost.

The ASC termination strategies were: (1) roller-crimped (NT-RC), (2) chopped with a flail mower and incorporated into the soil by non-inversion tillage (T-GM). The roller crimper was 3.1 m wide, weighed 1,720 kg when filled with oil, and was designed and constructed by ILVO (Picture 3). In the NT-RC plots, furrows for cash crop transplanting were created with a harrow tooth. The ASC was a mixture of 40 % rye (*Secale cereale* L.) and 60 % pea (*Pisum sativum*). Plot size was 7.5 × 15 m. The cash crop was white cabbage (*Brassica oleracea* var. *capitata* L.).

Picture 3. The roller crimper flattening the ASC in the Research Institute for Agriculture, Fisheries and Food (BE-ILVO) trial.

Agronomic management

The ASC was sown on the 5^{th} October 2015, and the 24^{th} November 2016. In T-GM plots, the ASC was terminated by flail mowing on the 20^{th} April 2016 and the 7^{th} May 2017, and by superficial tillage on the 4^{th} May 2016 and the 8^{th} May 2017. The NT-RC plots were terminated on the 26^{th} May 2016 and the 16^{th} June 2017. The cash crop was transplanted and fertilised using a planting machine on the 27^{th} May 2016, and the 21^{st} June 2017 (Picture 4). Mechanical weeding was carried out on the 6^{th} June, 6^{th}, 26^{th}, and 27^{th} July 2016, and on the 13^{th}, 17^{th}, and 27^{th} July 2017. Manual weeding was carried out during the periods: 6^{th} to 22^{nd} July, 28^{th} July to 4^{th} August, and 5^{th} to 14^{th} September 2016, and on the 14^{th}, 27^{th}, and 28^{th} July 2017. Cash crop irrigation was only required during the second year and was conducted manually twice during the crop cycle. The cash crop harvest was performed on the 3rd and 4th November 2016, and the 7th November 2017.

Picture 4. Transplanted white cabbage in an NT-RC plot in the Research Institute for Agriculture, Fisheries, and Food (BE-ILVO) trial.

More information about this trial can be found in Witvrouw (2016), Navarro-Miró, Iocola, et al. (2019) and Hefner, Canali, et al. (2020).

Belgium - INAGRO (BE-INAGRO)

Field experiment type A

Experimental design

The field trial was newly established at the INAGRO organic farm station in Roeselare, Belgium (BE-INAGRO) (50° 90' 68" N and 3° 12' 72" E), located in the Atlantic Central European climatic zone. During the first (2015–2016) and second (2016–2017) cycles, the mean annual temperature and rainfall were 11.0 °C and 860 mm, and 11.3 °C and 697 mm, respectively. The trial soil had a sandy loamy texture and a 1.12 % organic carbon content.

The experiment was not repeated on the same plots in both years, and was moved to an adjacent area for the 2016–2017 cycle. The INAGRO trial farm has been managed according to organic farming regulations since 2003 and has a rotation over six years (grass-clover, leek, carrot/celeriac, cereals, cabbage, and potato). The trial design was a split plot with four replications. The experimental design was modified each year (Figures 3 and 4).

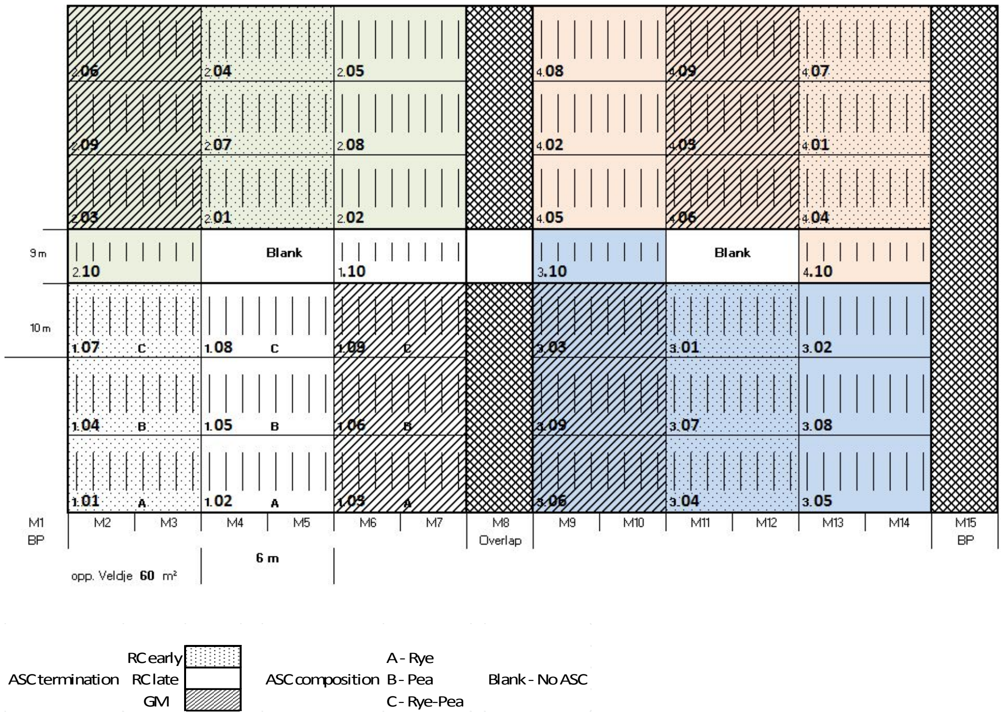


Figure 3. Experimental design at the INAGRO (BE-INAGRO) organic farm station during the first year. Termination: RC early - Roller crimper early termination; RC late - Roller crimper late termination; and GM - Mill cutting and non-inversion tillage (T-GM). ASC composition: A - winter rye (*Secale cereale*), B - pea (*Pisum sativum*); C - rye-pea mixture; and Blank - No ASC.

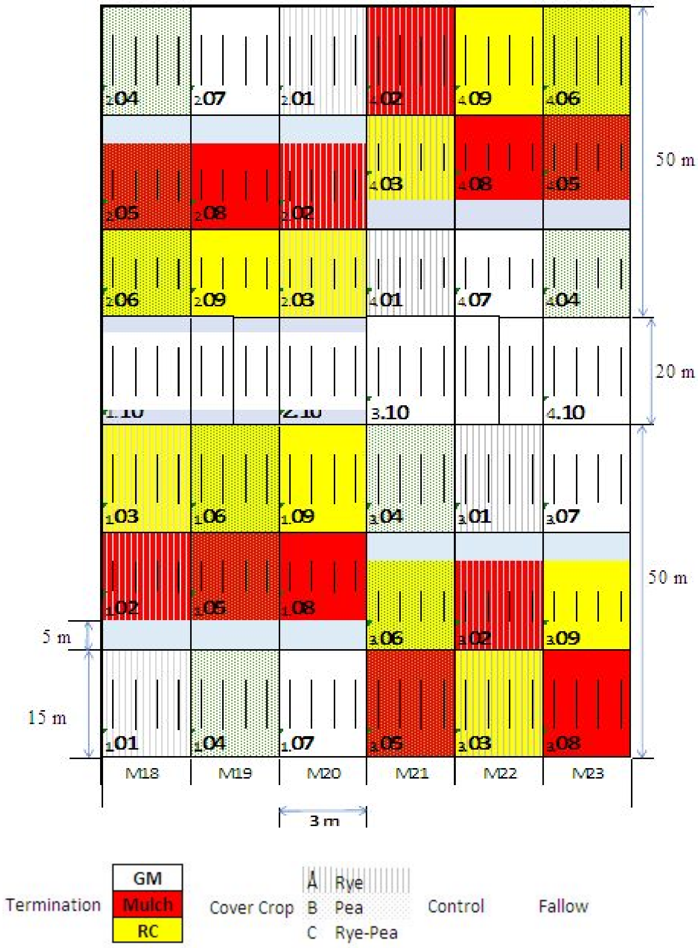


Figure 4. Experimental design at the INAGRO (BE-INAGRO) organic farm station during the second year. Termination: GM (white) - Incorporation by mill cutting one month before planting (T-GM); Mulch (red) - Mulching by flail mowing at planting (not-incorporated); and RC (yellow) - Roller crimper (NT-RC). ASC composition: A (vertical lines) - Winter rye (*Secale cereale*); B (small dots) - Winter pea (*Pisum sativum*); and C (no pattern) Rye-pea mixture.

The ASC compositions were A: winter rye (*Secale cereale*), B: winter pea (*Pisum sativum*) and C: a rye-pea mixture. The second factor was the ASC management strategy. During the first year, the ASC management strategies analysed were: (1) roller crimper early termination, (2) roller crimper late termination, and (3) mill cutting and non-inversion tillage, one month before planting (T-GM). The roller crimper early termination treatment was scheduled to coincide with the time of pea flowering (i.e., one week before cash crop transplanting) and the roller crimper late termination treatment, at the time of rye flowering (i.e., one day before planting of the cash crop). In the second year, the ASC management strategies studied were: (1) incorporation by mill cutting (MC) one month before planting (T-GM), (2) mulching by flail mowing at planting (not-incorporated), and (3) roller crimping (NT-RC). In this trial, the roller crimper used for ASC management was the same as in the ILVO trial (Picture 5.A) and furrows for cash crop transplanting were created by in-line tillage (Picture 5.B). Additionally, during both years, a control treatment that did not use ASC and standard soil management was set-up. Plot size was 6 × 10 m (except the fallow plots: 6 × 9 m) during the first year and 3 × 15 m during the second year. The cash crop was white cabbage (*Brassica oleracea* var. *capitata*).

A) B)

Picture 5. Machinery used for NT-RC management at the INAGRO (BE-INAGRO) organic farm station. A - Roller crimper; B - In-line tiller.

Agronomic management

The trial was fertilised with composted farm yard manure (10 ton ha $^{-1}$) on October 12th, 2015, and with commercial organic fertiliser (Organic plant feed (OPF) granulate 11-0-5, Plant Health Cure B.V., Nederland) on March 16th, 2017. The ASC was sown on October 13th, 2015 and October 28th, 2016. During the first year, the ASC was terminated with the T-GM strategy on April 28th, 2016 and with the NT-RC strategy on May 23rd, 2016. During the second year, termination happened on April 18th, 2017 in the T-GM plots, and on May 24th, 2017 in the NT-RC plots.

White cabbage was transplanted, with a row spacing of 0.70 m and a plant spacing of 0.30 m, using a planting machine on May 25th, 2016 and on May 30th, 2017 (Picture 6). The cabbages were fertilised with 50 kg N ha^{-1} commercial organic fertiliser (OPF granulate 11-0-5) on July 8th, 2016, during the first cycle, and on May 31st, 2017 during the second cycle. The cash crop was irrigated on August 24th, and 31st, 2016, and only once at the time of cash crop transplantation in 2017. In NT-RC plots, weeding operations were not required during the cash crop cycle. In T-GM plots, in the first year, weeding operations during the cash crop cycle were carried out by hoeing (June 8th, 2016) harrowing (June 9th, 2016) and manually (July 20th, and 22nd, 2016). In the second year, T-GM plots were weeded by mechanical weed control (June 15th, 2017) and manually (June 15th, and July 6th, 2017). The cash crop harvest was performed on November 21st, 2016 and November 7th, 2017. More information about this trial can be found in Hefner, Canali, et al. (2020).

Picture 6. Transplanting of white cabbage using a planting machine at the INAGRO (BE-INAGRO) organic farm station.

Denmark (DK)

Field experiment type A

Experimental design

The field trial was newly established at the Department of Food Science research centre of Aarhus University, located in Årslev, Denmark (55º 18′ N and 10º 27′ E), in the Atlantic North European climatic zone. The mean annual temperature was 9.3 °C and the mean annual rainfall, 614 mm during the first cycle (2015–2016), and 9.1 °C and 673 mm during the second cycle (2016–2017), respectively. The soil had a sandy loamy texture and a 1 % organic carbon content.

The experiment was not repeated on the same plots in both years, and was moved to an adjacent area for the 2016–2017 cycle. The two locations had been managed according to Danish organic farming regulations since 1996 and 2014, respectively. The previous crop grown in the area was barley (*Hordeum vulgare* L.). The trial had a split-plot randomised complete block experimental design with three replications, where ASC management was the whole-plot factor and ASC composition, the subplot factor. The experimental design was modified each year (Figures 5 and 6).

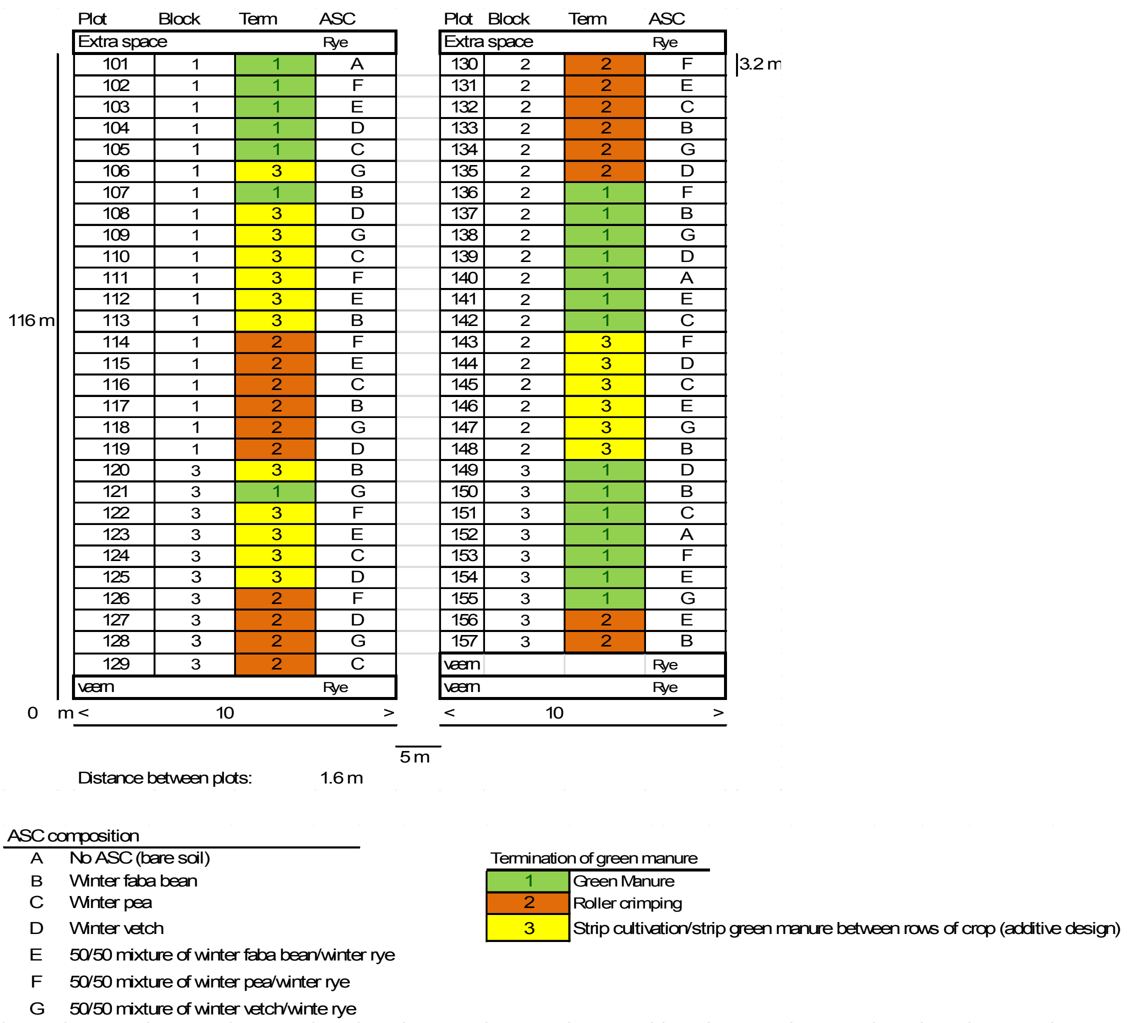


Figure 5. Experimental design of the organic farm station of the Department of Food Science research center of Aarhus University (DK) during the first cycle (2015–2016). Termination: 1 (green) - Chopped with a flail mower and incorporated into the soil with a cultivator as green manure (T-GM); 2 (orange) - Roller-crimped (NT-RC); and 3 (yellow) - Strip cultivation/strip green manure between rows of crop. ASC composition: A - No ASC, winter fallow (bare soil); B - Winter faba bean; C - Winter pea, D - Winter vetch; E - 50/50 mixture of winter rye and winter faba bean; F - 50/50 mixture of winter rye and winter pea; and G - 50/50 mixture of winter rye and winter vetch.

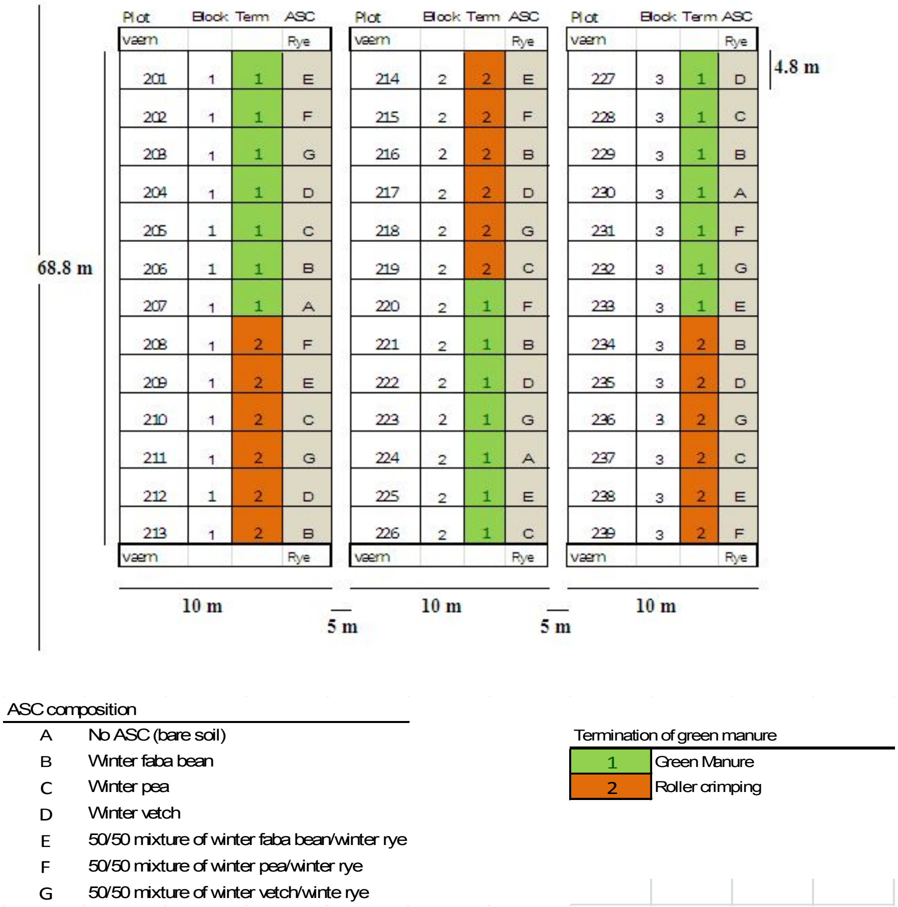
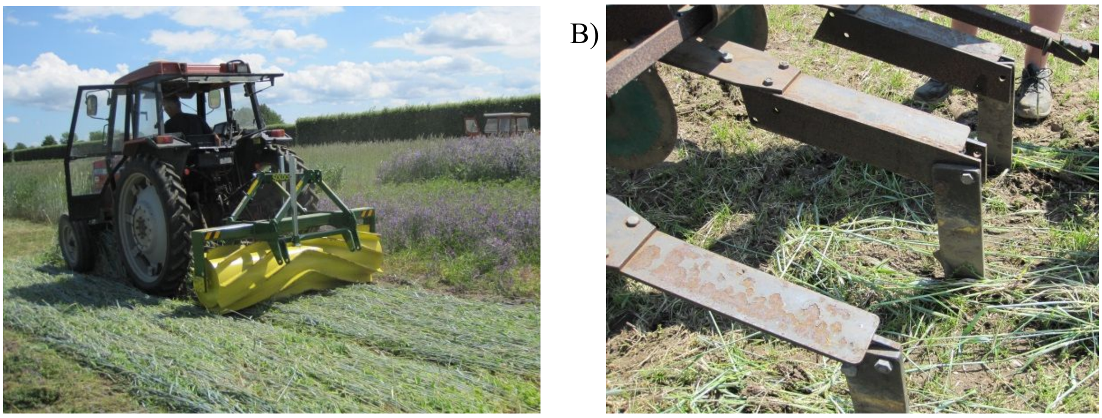


Figure 6. Experimental design of the organic farm station of the Department of Food Science research center of Aarhus University (DK) during the second cycle (2016–2017). Termination: 1 (green) - Chopped with a flail mower and incorporated into the soil with a cultivator as green manure (T-GM); 2 (orange) - Roller-crimped (NT-RC). ASC composition: A - No ASC, winter fallow (bare soil); B - Winter faba bean; C - Winter pea, D - Winter vetch; E - 50/50 mixture of winter rye and winter faba bean; F - 50/50 mixture of winter rye and winter pea; and G - 50/50 mixture of winter rye and winter vetch.

The ASC termination strategies were: (1) chopped with a flail mower and incorporated into the soil with a cultivator as green manure (T-GM), (2) roller-crimped (NT-RC), and (3) strip cultivation/strip green manure between crop rows (additive design). The roller crimper was 2 m wide and weighed 932 kg. It was designed and constructed by Soldo Macchine Agricole (Grassano, Italy) (Picture 7.A). Furrows for cash crop transplanting in the NT-RC plots were created with a harrow tooth (Picture 7.B). The ASC species composition was: B: winter faba bean (*Vicia faba* L.), C: winter pea (*Pisum sativum*), D: winter vetch (*Vicia sativa* L.), E: 50/50 mixture of winter rye (*Secale cereale*) and winter faba bean, F: 50/50 mixture of winter rye and winter pea, and G: 50/50 mixture of winter rye and winter vetch (Picture 8). A control treatment of winter fallow (bare soil) was also included. Plot size was 3.2 × 10 m during the first year and 4.8 × 10 m during the second year. The cash crop was white cabbage (*Brassica oleracea* var. *capitata*).

A) B)



Picture 7. Machinery used for NT-RC management in the DK trial. A - Roller crimper; B - Harrow tooth used to create the cash crop transplanting furrows.

Agronomic management

The trial was fertilised with 200 kg ha^{-1} of feather meal pellets (N-P-K: 13-0-0.4) (26 kg N ha^{-1}) on September 9th, 2015 and September 28th, 2016. The ASCs were sown on October 5th, 2015 and October 9th, 2016 and terminated on June 10th, 2016 and May 30th, 2017 (Picture 8).

Picture 8. View of DK field trial before ASC termination.

White cabbage was transplanted using a three-row planting machine on July 1st, 2016, and on June 21st, 2017, with a row spacing of 0.5 m and a plant spacing of 0.5 m. Weed management was carried out in T-GM plots using a weed-brush machine in inter-rows on July 27th–29th and August 19th, 2016, and July 17th–19th, 2017, and manually with a hoe in inter-rows and intra-rows on September 26th–30th, 2016 and August 10th–22nd, 2017. In NT-RC plots, weeding operations consisted of the manual removal of above ground biomass of large weeds. During the first year, cabbages were fertilised with 50 kg N ha^{-1} feather meal pellets on August 25th, 2016. During the second year, cash crop fertilisation with 100 kg N ha^{-1} feather meal pellets was carried out a week before cabbage transplantation. Thirty kg N ha^{-1} lupine seeds (N-P-K: 4.5-0.4-0.9) were applied on June 15th, 2017, and 80 kg N ha^{-1} feather meal pellets on August 24th, 2017. Cash crop irrigation was only required during the first year and was conducted twice (in August and September) with sprinklers. The cabbage crop was harvested on November 11th, 2016, and November 2nd, 2017.

More information about this trial can be found in Navarro-Miró, Iocola, et al. (2019) Navarro-Miró, Blanco-Moreno, et al. (2019), Hefner, Gebremikael, et al (2020) and Hefner, Canali, et al. (2020).

Estonia (EE)

Field experiment type A

Experimental design

The field trial was newly established in an experimental organic research field at Jõgeva in eastern Estonia (EE) (58° 44' N and 26° 24' E), located in the Nemoral European climatic zone. In the first cycle (2015–2016), the mean annual temperature was 6.0 °C and the mean annual rainfall, 825 mm, and in the second cycle (2016–2017) these environmental factors were 5.8 °C and 694 mm, respectively. The trial soil had a clay loamy texture and a 3 % organic carbon content.

The experiment was not repeated in the same plots in both years, and was moved to an adjacent area for the 2016–2017 cycle. The trial was established in an area certified organic from 2005. The previous crop grown in the area was red clover (*Trifolium pratense* L.). The trial had a strip-plot design with ASC strips and ASC management strategies crossed with a fertiliser factor, and three replicates per treatment (Figure 7).

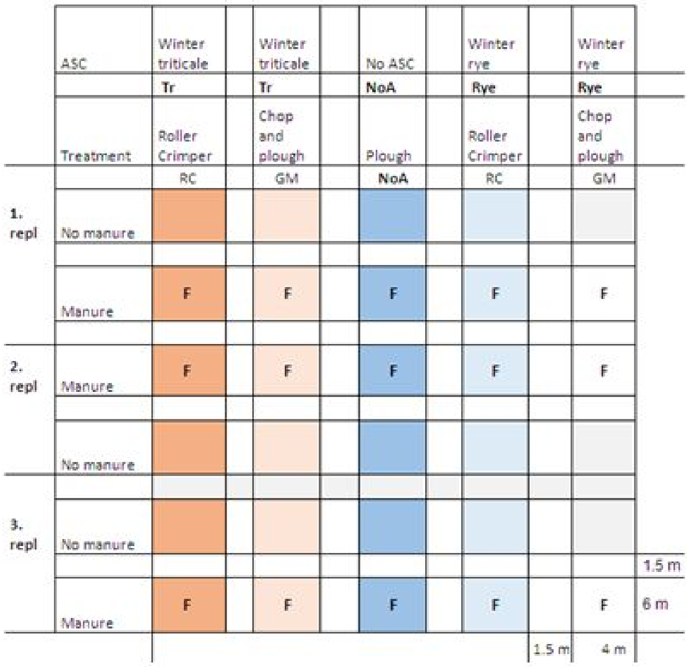


Figure 7. Experimental design of the research field at the organic farm station at Jõgeva in eastern Estonia (EE). Termination: RC - Roller-crimped (NT-RC); and GM - Chopped by a flail mower, then ploughed and levelled by a cultivator (T-GM). ASC composition: ASC1 - 100 % Winter rye; and ASC2 - 100 % Winter triticale. NoA - Control treatment without ASC (No ASC). Fertiliser factor: 1) Application of 30 t ha^{-1} solid cattle manure; 2) Not fertilised.

The two ASC termination strategies were: (1) roller-crimped (NT-RC), and (2) chopped by a flail mower, then ploughed, and levelled by a cultivator (T-GM). The roller crimper was 2 m wide and weighed 800 kg during the first year ASC termination, and 1,200 kg during the second, and was designed and constructed by Soldo Macchine Agricole (Grassano, Italy) (Picture 9). In the NT-RC plots, furrows for cash crop transplanting were created by in-line tillage (Picture 9). The ASC species composition was: ASC1 - 100 % winter rye (*Secale cereale*) (180 kg ha^{-1}), and ASC2 - 100 % winter triticale (× *Triticosecale blaringhemii* A.Camus) (155 kg ha^{-1}). The fertilisation factor consisted of: (1) application of 30 t ha^{-1} solid cattle manure (153 kg ha^{-1} N, 57 kg ha^{-1} P, and 81 kg ha^{-1} K), and (2) no fertiliser. Plot size was 6 × 4 m. The cash crop was white cabbage (*Brassica oleracea* var. *capitata*).

Picture 9. Machinery used for NT-RC management in the organic research field at Jõgeva in eastern Estonia (EE). A tractor equipped with a roller crimper and an in-line tiller.

Agronomic management

Fertiliser was applied to the fertiliser treatment plots before the ASCs were planted. During the second year, in addition to the fertilisation factor, all plots were fertilised with 12 t ha^{-1} of horse manure compost (12 kg ha^{-1} N, 1.2 kg ha^{-1} P, and 4.8 kg ha^{-1} K). During the first cycle, the ASCs were sown on August 25th, 2015 and terminated by NT-RC on June, 6th and June 9th, 2016, and by T-GM on June 10th, 2016. During the second cycle, the ASCs were sown in September 2016 and managed by T-GM on June 16th, 2017 and by NT-RC on June 19th, 2017. White cabbage was manually transplanted in the first year from the 13th to 16th June 2016, and in the second year on June 19th, 2017, with a row spacing of 0.65 m and a 0.50 m plant spacing (Picture 10). Manual weeding was carried out in all treatments on August 27th, 2016 and July 27th, 2017.

Picture 10. View of the organic farm station field at Jõgeva in eastern Estonia (EE) during growth of the cash crop.

During the first year, the cash crop was not irrigated, whereas during the second year, all plants were watered once in mid-July with a humic solution (0.0003 kg ha^{-1} N, 0.0001 kg ha^{-1} P, and 0.0002 kg ha^{-1} K). The cash crop harvest was performed on October 7th, 2016, and from October 4th to 6th, 2017.

More information about this trial can be found in Tamm, Bender, Nugis, Edesi, & Võsa, (2018), Navarro-Miró, Iocola, et al. (2019), Navarro-Miró, Blanco-Moreno, et al. (2019) and Hefner, Canali, et al. (2020).

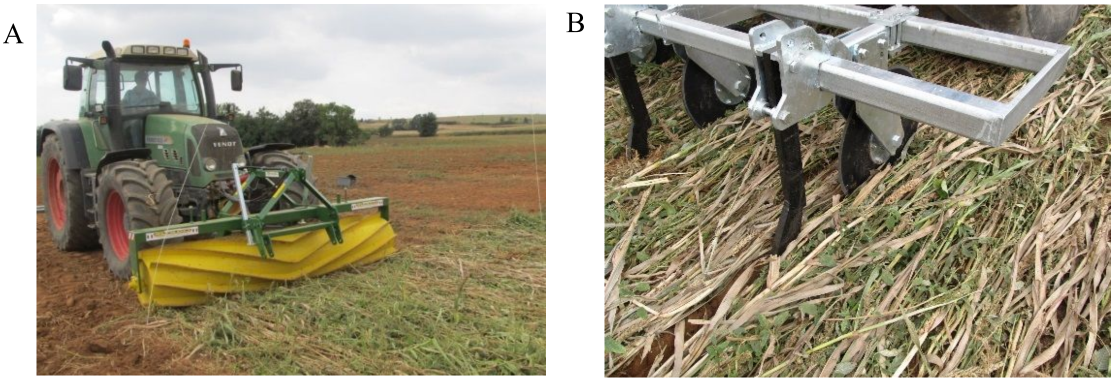
Spain (ES)

Experimental design

Both parallel field experiments type A (FtA) and type B (FtB) were newly established in the Gallecs Area of Natural Interest, Barcelona, Spain (ES) (41° 33' N and 2° 12' E), located in the Mediterranean North European climatic zone. In FtA, during the first cycle (2015–2016), the mean annual temperature was 16.5 °C and the mean annual rainfall, 406 mm, and during the second cycle (2016–2017), 16.1 °C and 409 mm, respectively. In FtB, during the first cycle (2014–2015), the mean annual temperature was 16.1 °C and the mean annual rainfall, 344 mm, and in the second cycle (2015–2016), 16.5 °C and 406 mm, respectively. The trial soil had a loamy texture and contained an average of 0.95 % organic carbon content.

In both trials, the field experiments were repeated in the same area in both years. Conversion of the experimental area to organic farming began in 2005, and the previous crop grown in the area was wheat. The experimental design of the FtA and FtB trials was a randomised strip-plot with two factors (ASC composition and ASC management strategy) and four replicates. The different treatments were defined in randomly distributed parallel bands, and within each band, four plots (6 × 4 m) were established. The experimental layout was designed to facilitate traffic of machinery between plots and to enable the agricultural practices to be performed in the same direction.

In FtA and FtB, the two ASC termination strategies were: (1) ASCs flattened by a roller crimper (NT-RC), and (2) ASCs mown and chopped and incorporated into the soil as green manure using a chisel plough (T-GM). The roller crimper was 3 m wide and weighed 800 kg when filled with oil, and was designed and constructed by Soldo Macchine Agricole (Grassano, Italy) (Picture 11.A). In the NT-RC plots, furrows for cash crop transplanting were created by in-line tillage (Picture 11.B). Both termination methods were compared to a control treatment without ASC (bare soil).



Picture 11. Machinery used for NT-RC management in the Gallecs Area of Natural Interest, Barcelona, Spain (ES). A - Roller crimper. B - In-line tiller.

Field experiment type A

In FtA, three ASC compositions and one No ASC treatment were established: ASC1 – 100 % cereal mixture (81 % *Avena byzantina* K.Koch and 19 % *Hordeum vulgare*) (200 kg ha^{-1}), ASC2 - 70 % cereal mixture (140 kg ha^{-1}) + 30 % *Vicia sativa* (75 kg ha^{-1}), ASC3 - 50 % cereal mixture (100 kg ha^{-1}) + 50 % *V. sativa* (125 kg ha^{-1}), and No ASC - spontaneous vegetation without sowing any ASC (Figure 8) . The cash crop was green pepper (*Capsicum annuum* L.)

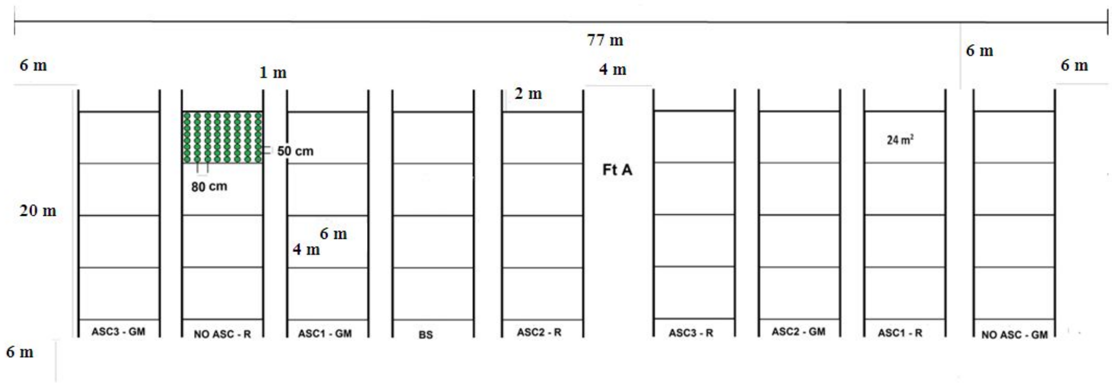


Figure 8. Experimental design of field experiment type A established in the Gallecs Area of Natural Interest, Barcelona, Spain (ES). Termination: ASC-R - Flattened by roller crimper (NT-RC); and ASC-GM - mowed, chopped and incorporated into the soil as green manure using a chisel plough (T-GM). ASC composition: ASC1 – 100 % cereal mixture (81 % *Avena byzantina* and 19 % *Hordeum vulgare*); ASC2 - 70 % cereal mixture + 30 % *Vicia sativa*; and ASC3 - 50 % cereal mixture + 50 % *V. sativa*; and No ASC - spontaneous vegetation without sowing any ASC. BS - control treatment maintaining the soil without plant cover (bare soil).

Field experiment type B

In FtB, the ASC compositions were: ASC1 - 100 % *Vigna unguiculata* (L.) Walp., ASC2 - 70 % *V. unguiculata* + 30 % *Sorghum bicolor* (L.) Moench, ASC3 - 50 % *V. unguiculata* + 50 % *S. bicolor*, and No ASC - spontaneous vegetation without sowing any ASC (Figure 9). The cash crop was savoy cabbage (*Brassica oleracea* L. var. *sabauda*).

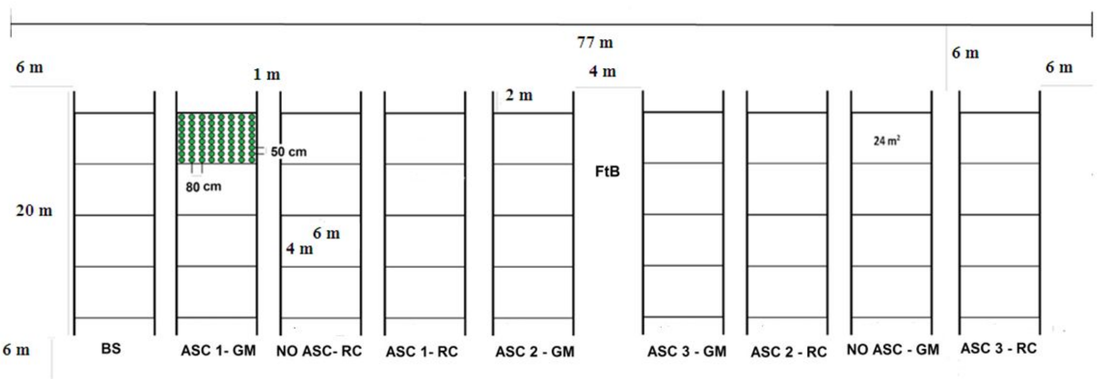


Figure 9. The experimental design of the FtB field experiment established in the Gallecs Area of Natural Interest, Barcelona, Spain (ES). Termination: ASC-R - Flattened by roller crimper (NT-RC); and ASC-GM - mowed, chopped and incorporated into the soil as green manure using a chisel plough (T-GM). ASC composition: ASC1 - 100 % *Vigna unguiculata*; ASC2 - 70 % *V. unguiculata* + 30 % *Sorghum bicolor*; ASC3 - 50 % *V. unguiculata* + 50 %

S. bicolor; and No ASC - spontaneous vegetation without sowing any ASC. BS - control treatment maintaining the soil without plant cover (bare soil).

Agronomic management

Field experiment type A

The ASCs were sown on November 19th, 2015 and January 9th, 2016. In the NT-RC plots, ASC management was carried out on May 4th, 2016 and May 18th, 2017, and creation of the transplanting furrows was carried out along with the NT-RC by in-line tillage on June 24th, 2016 and June 13th, 2017.

In the T-GM plots, ASC chopping was carried out on May 4th, 2016 and May 18th, 2017, and the incorporation of the plant material into the soil was performed on May 18th, 2016 and June 1st, 2017. The green pepper crop were transplanted on May 26th, 2016, and on June 20th, 2017, with a row spacing of 0.80 m and a 0.50 m plant spacing (Picture 12). The cash crop was fertilised just after transplantation with 170 kg ha^{-1} N using commercial organic fertiliser and the green pepper plants were drip-irrigated according to their needs. During the first year, T-GM plots were weeded four times, whereas NT-RC plots only required two weeding operations. During the second year, all plots required three weeding operations. In the first year, the cash crop harvest was performed weekly from July 18th to October 3rd, 2016, whereas in the second year the harvest took place from August 21st to October 2nd, 2017.

Picture 12. View of the FtA field experiment established in the Gallecs Area of Natural Interest, Barcelona, Spain (ES) during growth of the cash crop.

Field experiment type B

The ASCs were sown on April 30th, 2015 and on May 4th, 2016, and irrigated with sprinklers during their development. During the first cycle, the ASCs were managed by two passes of NT-RC on July 23rd and 27th, 2015 and one operation combining NT-RC and in-line tillage on July 29th, 2015. In the T-GM plots, the ASCs were chopped on July 23rd, 2015 and incorporated into the soil using a chisel plough on July, 28th, 2015. During the second cycle, NT-RC management was carried out on August 26th, 2016, and the creation of the transplanting furrows was carried out along with the NT-RC by in-line tillage on September 6th, 2016. In the T-GM management plots, chopping of the ASC was carried out on August 26th, 2016, and incorporation of plant material into the soil was performed on September, 6th, 2016. The savoy cabbages were transplanted on August 4th, 2015, and September 20th, 2016, with a row spacing of 0.80 m and a 0.50 m plant spacing (Picture 13). The cash crop was fertilised with 100 kg ha^{-1} N in both years. During the first year, the commercial organic fertiliser was split into two applications: (1) just after savoy cabbage transplantation and (2) during savoy cabbage development. During the second year, the commercial organic fertiliser was applied just after the savoy cabbage was transplanted. The cabbages were drip irrigated according to the crop needs. In the first cycle, all plots were weeded only once during the cash crop development, whereas in the second year, two weeding operations were required. The savoy cabbages were harvested on December 2nd, 2015, and February 22nd, 2017.

Picture 13. Transplanted savoy cabbage in a NT-RC plot in the FtB field experiment established in the Gallecs Area of Natural Interest, Barcelona, Spain (ES).

More information about this trial can be found in Navarro-Miró *et al.* (2017), Navarro-Miró, Iocola, et al. (2019), and Navarro-Miró, Blanco-Moreno, et al. (2019).

France (FR)

Field experiment type A

Experimental design

The field experiment was newly established at the experimental organic research centre of the Groupe de Recherche en Agriculture Biologique (GRAB) in Avignon, southern France (FR) (43° 54' 23.8" N and 4° 53' 06.4" E). This location represented the Mediterranean North European climatic zone. During the first cycle (2015–2016), the mean annual temperature was 15.5 °C and the mean annual rainfall, 521 mm, and in the second cycle (2016–2017) these environmental factors were 15.3 °C and 558 mm, respectively. The trial soil had a clay loam texture and a 1.86 % organic carbon content.

The experiment was repeated on the same plots in both years, but with some changes in the second year. The selected experimental field had been under organic farming management from 2000. The previous crops grown were diversified varieties of squash (*Cucurbita* sp.). The trial had a randomised strip-plot experimental design with three replicates during the first year and four during the second year, where ASC management strategy (i.e., NT-RC or T-GM) was the strip factor, and the ASC composition was the subplot factor (i.e., six different ASC compositions). The experimental design was modified each year (Figures 10 and 11).

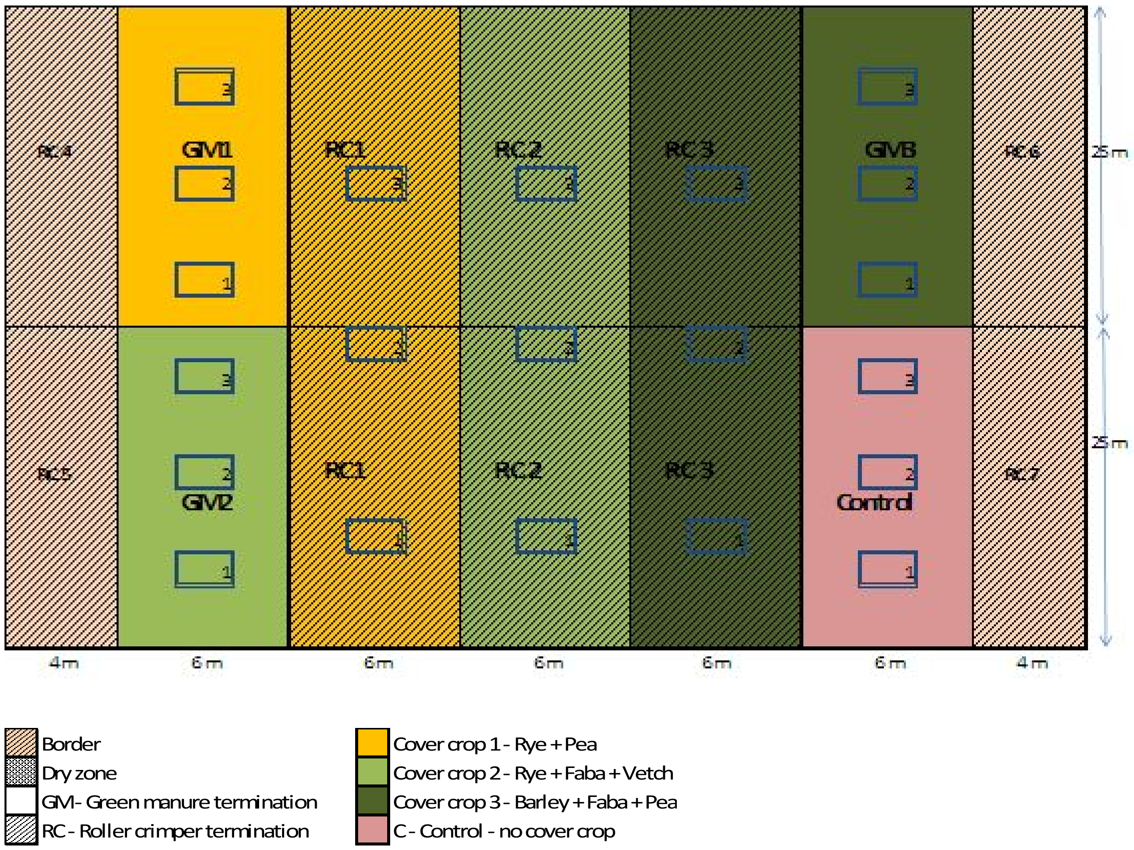


Figure 10. First cycle (2015–2016) experimental design of the trial established at the experimental organic research centre of the Groupe de Recherche en Agriculture Biologique (GRAB) in Avignon (FR). Termination: RC - Cover crop flattened by a roller crimper + in-line tillage to create the transplanting furrows (NT-RC); and GM - Termination as a green manure by mowing, chopping, and incorporation of the cover crop into the soil (T-GM). ASC composition: ASC1 - 50 % *Secale cereale* + 50 % *Pisum sativum*; ASC2 - 30 % *S. cereale* + 40 % *Vicia faba* + 40 % *Vicia villosa*; ASC3 - 50 % *Hordeum vulgare* + 37 % *V. faba* + 40 % *P. sativum*; and Control - Control treatment maintaining the soil without plant cover (bare soil).

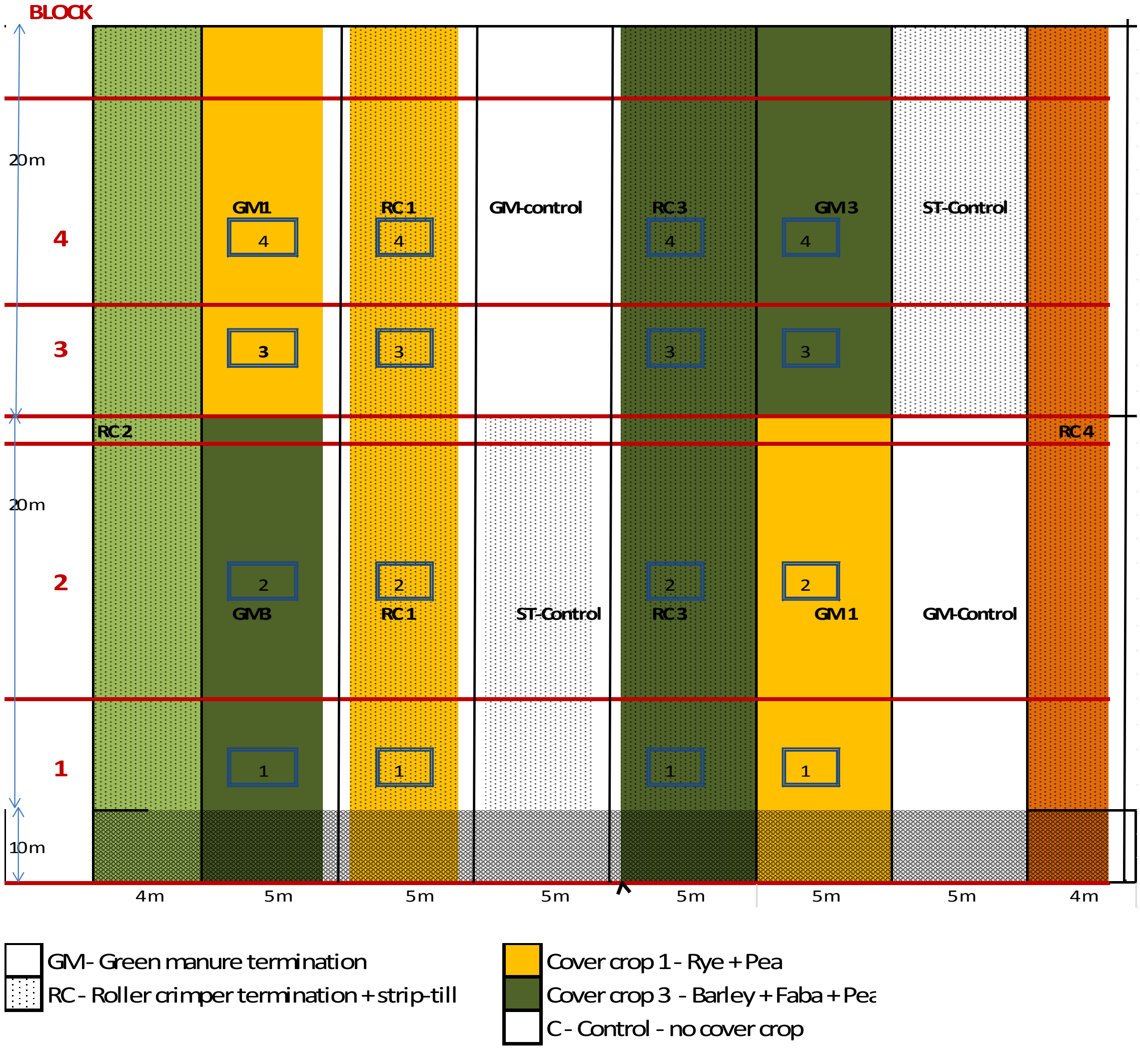


Figure 11. Second cycle (2016–2017) experimental design of the trial established at the experimental organic research centre of the Groupe de Recherche en Agriculture Biologique (GRAB) in Avignon (FR). Termination: RC - Cover crop flattened by a roller crimper + in-line tillage to create the transplanting furrows (NT-RC); and GM - Termination as a green manure by mowing, chopping, and incorporation of the cover crop into the soil (T-GM). ASC composition: ASC1 – 50 % *Secale cereale* + 50 % *Pisum sativum*; and ASC3 - 50 % *Hordeum vulgare* + 37 % *Vicia faba* + 40 % *P. sativum*. Additionally, two Control treatments maintaining the soil without plant cover (bare soil) were established: ST-control - Strip tillage before cash crop transplantation; and GM-control.

The two ASC termination strategies were: (1) cover crop flattened by a roller crimper (NT-RC) + in-line tillage to create the transplanting furrows, and (2) termination as a green manure by mowing, chopping, and incorporation of the cover crop into the soil (T-GM). The roller crimper was 2.21 m wide and weighed 600 kg. During the second cycle, four blocks of concrete (i.e. 70 kg each) were added to increase the weight of the roller to 920 kg (Picture 14). The roller crimper used in the FR trial was self-built in co-operation with *L'atelier Paysan*. During the first year, the ASC species composition was: ASC1: 50 % *Secale cereale* (60 kg ha^{-1}) + 50 % *Pisum sativum* (80 kg ha^{-1}), ASC2: 30 % *S. cereale* (40 kg ha^{-1}) + 40 % *Vicia faba* (80 kg ha^{-1}) + 40 % *Vicia villosa* Roth (20 kg ha^{-1}), and ASC3: 50 % *Hordeum vulgare* (50 kg ha^{-1}) + 37 % *V. faba* (73 kg ha^{-1}) + 40 % *P. sativum* (67 kg ha^{-1}). In the second year, only two of the previous ASC compositions were sown: ASC1 - 50 % *S. cereale* (60 kg ha^{-1}) + 50 % *P. sativum* (80 kg ha^{-1}), and ASC3 - 50 % *H. vulgare* (50 kg ha^{-1}) + 37 % *V. faba* (73 kg ha^{-1}) + 40 % *P. sativum* (67 kg ha^{-1}). Plot size was 10 × 6 m during the first year and 10 × 5 m during the second year. The cash crop was butternut squash (*Cucurbita moschata* Duchesne cv. 'Ariel').

Picture 14. Machinery used for NT-RC management at the experimental organic research centre of the Groupe de Recherche en Agriculture Biologique (GRAB) in Avignon (FR). A tractor equipped with a roller crimper and an in-line tiller.

Agronomic management

The trial was fertilised with 2 t ha^{-1} of organic commercial fertiliser (AB'Flor, N-P-K: 6-7-10) and 6 t ha^{-1} of compost (with approximately 65 % green waste and 35 % horse manure). ASCs were sown on October 1st, 2015 and October 11th, 2016. ASCs were terminated on April 26th, 2016 in the T-GM plots and April 28th, 2016 in the NT-RC plots, and on April 18th, 2017 in the T-GM plots, and on April 19th, 2017 in the RC3 plots and May 16th, 2017 in the RC1 plots. The butternut squash were manually transplanted on June 9th, 2016 and June 8th, 2017, with a row spacing of 2 m and a 0.5 m plant spacing (Picture 15). The cash crop plants were fertilised with commercial organic fertiliser (Dix® 9.2.2+1 MgO Italpollina). In the first year, 80 kg ha^{-1}

N was applied with the commercial organic fertiliser on June 6th, 2016. In the second year, 72 kg ha^{-1} N was applied with the commercial organic fertiliser on May 31st, 2017 (i.e., before soil tillage and cash crop transplantation) in the T-GM treatments, and localised in the strip-till lines on June 6th, 2017 in the NT-RC treatments. During both years, butternut squash was irrigated by drip irrigation according to crop needs.

Picture 15. View of the field trial during growth of the cash crop at the experimental organic research centrer Groupe de Recherche en Agriculture Biologique (GRAB) in Avignon (FR).

In the first year, weeding operations were performed in the inter-rows of the T-GM1 and T-GM2 plots using a rototiller on June 22nd, 2016, and manual weeding was performed three times in all treatments on the 23rd of June, 12th of July and 9th of August, 2016. During the second year, manual weeding was performed twice in all treatments on the 23rd of June, and 5th of July 2017. The cash crop was manually harvested on September 7th, 2016, and September 11th, 2017. More information can be found in Navarro-Miró, Iocola, et al. (2019).

Italy (IT)

Both parallel field experiments Type A (FtA) and Type B (FtB) were newly established at the Experimental Farm of Metaponto belonging to the Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT) (40º 24′ N and 16° 48′ E). This location represented the Mediterranean North European climatic zone. In FtA, during the first cycle (2015–2016), the mean annual temperature was 16.7 °C and the mean annual rainfall, 539 mm, and during the second cycle (2016–2017) these environmental factors were 16.5 °C and 402 mm, respectively. In FtB, during the first cycle (2014–2015) the mean annual temperature was 16.6 °C and the mean annual rainfall, 470 mm, and during the second cycle (2015–2016), these environmental factors were 16.7 °C, and 539 mm, respectively. The trial soil had a clay texture and contained on average 1.1 % organic carbon content.

In both trials, the field experiments were not repeated on the same plots in both years and were moved to an adjacent area for the second cycle. Plot size was 6 × 4 m. The two ASC management strategies were: (1) roller-crimped (NT-RC) + in-line tillage to create the transplanting furrows, and (2) chopped and ploughed under and incorporated into the soil by milling (T-GM). The roller crimper was 2.25 m wide and weighed 550 kg and was designed and constructed by Soldo Macchine Agricole (Grassano, Italy) (Picture 16). In the NT-RC plots, furrows for cash crop transplanting were created by in-line tillage (Picture 16).

Picture 16. Machinery used for NT-RC management at the Experimental Farm of Metaponto belonging to the Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT). A tractor equipped with a roller crimper and in-line tiller.

Experimental design

Field experiment type A

The previous crop grown in the area was fennel (*Foeniculum vulgare* Mill.). The experimental layout consisted of a split-split-plot with main plots arranged as a randomised complete block design, with three factors and three replications. The main plot was the ASC factor, and the subplot was assigned to the ASC management strategy, and the split-plot to the fertilisation factor (Figure 12).

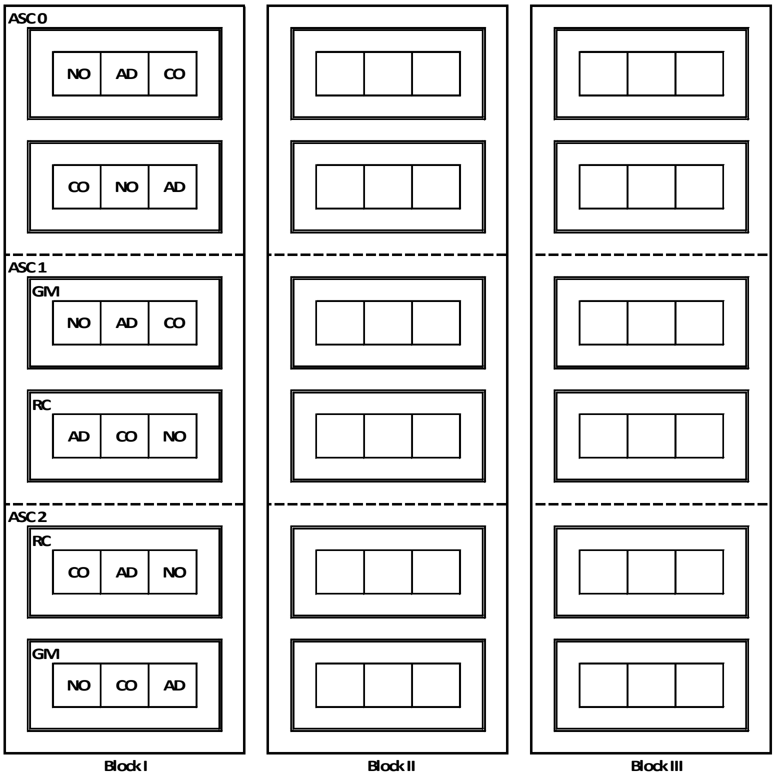


Figure 12. The FtA experimental design at the Experimental Farm of Metaponto belonging to the Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT). Termination: RC - Roller crimper + in-line tillage to create the transplanting furrows (NT-RC); and GM - ASC chopped, ploughed under and incorporated into the soil by milling (T-GM). ASC composition: ASC0 - Control treatment maintaining the soil without plant cover (bare soil); ASC1 - 20 % *Hordeum vulgare* + 80 % *Vicia sativa*; and ASC2 - 20% *H. vulgare* + 80 % *Vicia faba* var. *minor*. Fertilisation factor: NO - no fertiliser; CO - Commercial organic mineral fertiliser allowed in organic farming; and AD - Anaerobic digestate from cattle residues.

The ASC species composition was: ASC1 - *Hordeum vulgare* 20 % + 80 % *Vicia sativa*, and ASC2 – *H. vulgare* 20 % + 80 % *Vicia faba* var. *minor*. The fertilisation factor consisted of: (1) no fertiliser (NO), (2) commercial organic mineral fertiliser allowed in organic farming (CO), and (3) anaerobic digestate from cattle residues (AD). The cash crop was tomato (*Solanum lycopersicum* L.).

Field experiment type B

The previous crop was wheat (*Triticum aestivum* L.). The trial had a split-plot with the main plots arranged as a randomised complete block design, with two factors and three replications (Figure 13). The main plot was assigned to the ASC composition and the subplot to the ASC management strategy.

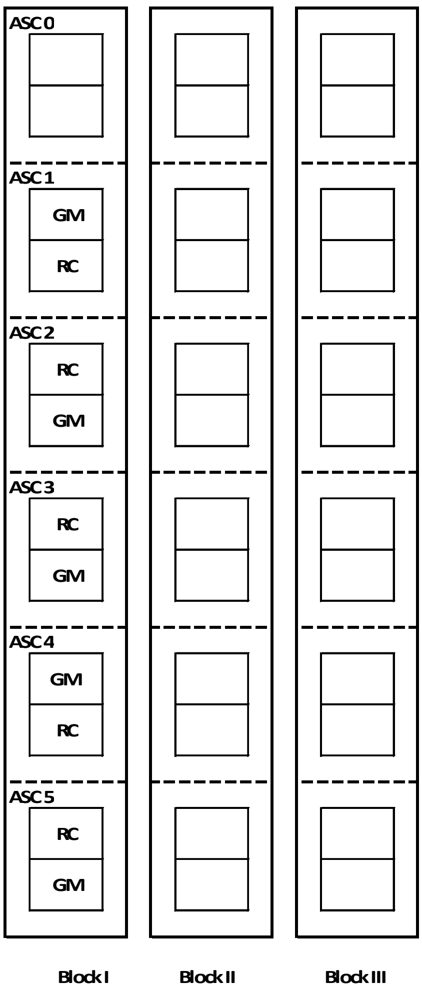


Figure 13. The FtB experimental design at the Experimental Farm of Metaponto belonging to the Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT). Termination: RC - Roller crimper + in-line tillage to create the transplanting furrows (NT-RC); and GM - ASC chopped, ploughed under and incorporated into the soil by milling (T-GM). In 2015, the ASC compositions were: ASC1 – 100 % *Vigna unguiculata*; ASC2 - 70 % *V. unguiculata* + 30 % *Pennisetum glaucum*; ASC3 - 50 % *V. unguiculata* + 50 % *P. glaucum*; and ASC4 - 40 % *V. unguiculata* + 30 % *P. glaucum* + 30 % *Raphanus raphanistrum* subsp. *sativus*. In 2016, the ASC compositions were: ASC1 - 100 % *V. unguiculata*; ASC2 - 100 % *Vigna radiata*; ASC3 - 100 % *Fagopyrum esculentum*; and ASC4 - 35 % *V. unguiculata* + 35 % *V. radiata* + 30 % *F. esculentum*. Additionally, a control treatment (ASC0) maintaining the soil without plant cover (bare soil) was established.

In 2015, ASC compositions were: ASC1 - 100 % cowpea (*Vigna unguiculata* (L.) Walp.), ASC2 - 70 % cowpea + 30 % pearl millet (*Pennisetum glaucum* (L.) R.Br.), ASC3 - 50 % cowpea + 50 % pearl millet, and ASC4 - 40 % cowpea + 30 % pearl millet + 30 % radish (*Raphanus raphanistrum* subsp. *sativus* (L.) Domin). In 2016, ASC compositions were: ASC1 - 100 % cowpea, ASC2 - 100 % mung bean (*Vigna radiata* (L.) R.Wilczek), ASC3 - 100 % buckwheat (*Fagopyrum esculentum* Moench), and ASC4 - 35 % cowpea + 35 % mung bean + 30 % buckwheat. The cash crop was cauliflower (*Brassica oleracea* var. *botrytis* L.).

Agronomic management

Field experiment type A

ASCs were sown on November 4th, 2015, and December 29th, 2016. Fertiliser was applied to plots belonging to the fertilisation treatments on April 8th, 2016 and April 26th, 2017 as follows: 12 t ha^{-1} of anaerobic digestate from cattle residues in the AD plots and 3.5 t ha^{-1} of commercial organic mineral fertiliser allowed in organic farming in the CO plots (Figure 12). In the T-GM treatments, ASCs were chopped on April 8th, 2016 and April 26th, 2017 and ploughed under and incorporated into the soil by milling on the 18th and 19th of April 2016 and April 28th, 2017. In the NT-RC treatments, the ASCs were flattened by roller crimper on April 15th, 2016 and April 26th, 2017. The tomato crop was manually transplanted on April 28th, 2016 and May 5th, 2017, with a row spacing of 1 m and a 0.40 m plant spacing (Picture 17). In the NT-RC system, ASC re-growth was mowed twice on May 10th, and 23rd, 2016. No further weed management was carried out during growth of the cash crop, whereas in the second year, inter-row weed control by mowing was carried out on the 12th of July 2017. The cash crop was drip irrigated weekly. The cash crop harvest was performed from July 7th to August 25th, 2016, and from July 18th to August 25th, 2017.

Picture 17. View of the FtA trial during growth of the cash crop at the Experimental Farm of Metaponto belonging to the Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT).

Field experiment type B

ASCs were sown on April 21st, 2015 and April 19th, 2016, and were irrigated on emergence. Commercial organic fertiliser (150 kg ha^{-1} N, 450 kg ha^{-1} P_2O_5, and 150 kg ha^{-1} K_2O) was applied just before the ASC termination, whereas in the second year, fertiliser was applied during cash crop development. ASC management was carried out on July 29th, 2015, whereas in the second year, the ASC was terminated by T-GM on July 27th, 2016, and by NT-RC on July 28th, 2016.

The cauliflower crop was transplanted on August 3rd in both years, with a row spacing of 1.0 m and a 0.45 m plant spacing. During the first year, the NT-RC plots were mowed every two weeks to reduce ASC regrowth biomass, whereas only two weeding operations were carried out in the T-GM plots. During the second year, only two ASC regrowth mowing operations were required, whereas no weed control was carried out in the T-GM plots. The cash crop was irrigated by micro-sprinklers according to crop requirements. The cash crop harvest was performed from November 23rd to December 15th, 2015, and November 28th, 2016.

More information about this trial can be found in Navarro-Miró et al. (2017), Navarro-Miró, Iocola, et al. (2019) and Navarro-Miró, Blanco-Moreno, et al. (2019).

Slovenia (SI)

Field experiment type A

Experimental design

The field trial was newly established at the University of Maribor (Pivola), Faculty of Agriculture and Life Sciences (UM), Slovenia (SI) (46° 30' N and 15° 37' E). This trial represented the Alpine South European climatic zone. During the first cycle (2015–2016), the mean annual temperature was 10.9 °C and the mean annual rainfall, 1,009 mm, and during the second cycle (2016–2017) these environmental factors were 11.1 °C and 961 mm, respectively. The trial soil had a loam texture with an average 2.66 % organic carbon content.

The experiment was not repeated in the same plots in both years, and was moved to an adjacent area for the 2016–2017 cycle. The previous crop grown in the area was barley. The trial had a split-split-plot design with plots arranged in a randomised complete block design, with three factors and four repetitions (Figure 14).

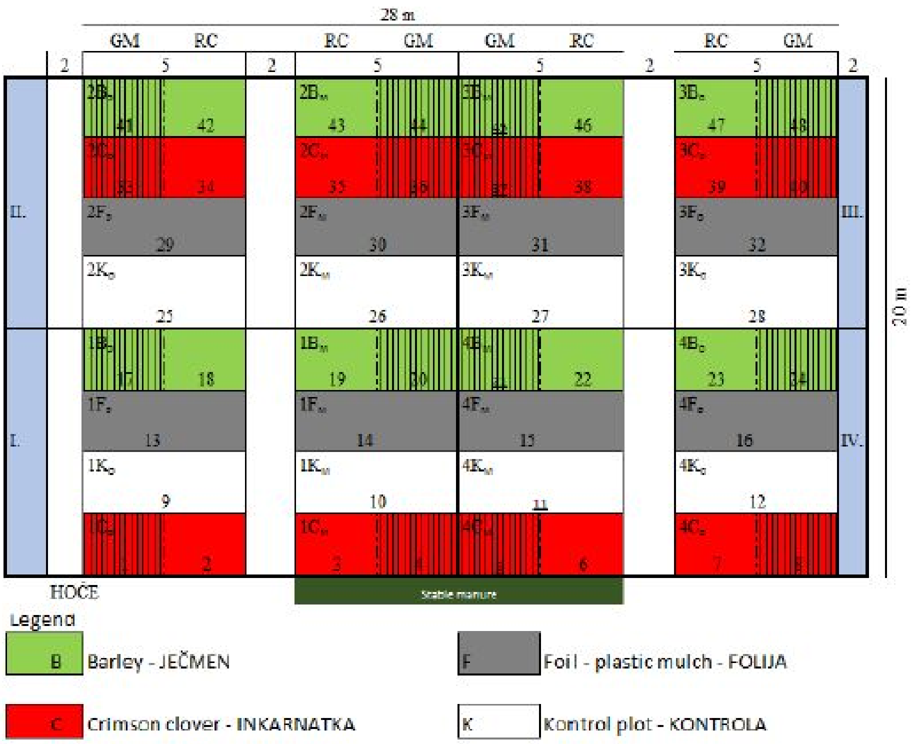


Figure 14. Experimental design of the trial established at the University of Maribor (Pivola), Faculty of Agriculture and Life Sciences (UM), Slovenia (SI). ASC compositions were: ASC1 (green) - 100 % *Hordeum vulgare*; and ASC2 (red) - 100 % *Trifolium incarnatum*; and two different controls: 1) No ASC (white) and 2) Black foil (grey). The two ASC termination strategies were: RC - ASC terminated with a roller crimper + in-line tillage (NT-RC); and GM - ASC mulched and incorporated into the soil and seedbed prepared with a rotary harrow (T-GM). Fertilisation factor: M - Application of livestock manure (30 t ha^{-1}) before sowing ASC; and O - Without manure application.

The ASC species composition was: 100 % *Hordeum vulgare* (220 kg ha-1), ASC2: - 100 % *Trifolium incarnatum* L. (35 kg ha^{-1}), and two different controls: (1) no ASC and (2) black foil. The two ASC termination strategies were: (1) cover crop terminated with a roller crimper + in-line tillage (NT-RC), and (2) ASC mulched and incorporated into the soil and seedbed prepared with a rotary harrow (T-GM). The roller crimper was 2.5 m wide and weighed 700 kg and was created through co-operation between the Faculty of Agriculture and Life Sciences, Department of Organic Agriculture, Crops, Vegetables and Ornamental Plants and Gorenc d.o.o. from Spodnji Brnik in Slovenia (Picture 18). In the NT-RC plots, furrows for cash crop transplanting were created by in-line tillage (Picture 18). The fertilisation factor had two levels: M application of livestock manure (30 t ha^{-1}) before sowing the ASCs, and O - no manure application. Plot size was 2.5 × 2.5 m. The cash crop was cauliflower (*Brassica oleracea* var. *botrytis* L.).

Picture 188. Machinery used for NT-RC management in the trial established at the University of Maribor (Pivola), Faculty of Agriculture and Life Sciences (UM), Slovenia (SI). A tractor equipped with a roller crimper and in-line tiller.

Agronomic management

The fertilisation treatment was performed using livestock manure (30 t ha^{-1}) on August 27th, 2015 and on August 24th, 2016. ASC1 was sown on August 31st, 2015 and on August 25th, 2016, whereas ASC2 was sown on October 26th, 2015 and October 25th, 2016. The ASCs were managed in the T-GM plots on May 19th, 2016 and on May 20th, 2016 in the NT-RC plots. During the second cycle, all plots were managed on May 18th, 2017.

The cauliflower crop was transplanted on June 3rd, 2016, and May 24th, 2017 with a row spacing of 0.6 m and a 0.40 m plant spacing (Picture 19). During the cash crop cycle, all plots were fertilised using commercial organic fertilisers when the cash crop was transplanted (70 kg ha^{-1} N), and during cash crop development (70 kg ha^{-1} N). During the second year, the cash crop was irrigated twice using micro-sprinklers. Weed management was performed manually in all treatments. During the first cycle, three weeding operations were carried out in the T-GM and control plots on June 29th, 2016, July 19th, 2016, and August 11th, 2016. In the NT-RC plots, only one operation was required (August 12th, 2016). During the second cycle, four weeding operations were carried out in the T-GM and control plots (June 19th, 2017, July

5th, 2017, July 26th, 2017, and August 17th, 2017), whereas in the NT-RC plots, two operations were required (July 5th, 2017 and August 9th, 2017). The cash crop harvest was performed on September 29th, 2016 and September 5th, 2017.

Picture 19. The cauliflower cash crop in the trial was established at the University of Maribor (Pivola), Faculty of Agriculture and Life Sciences (UM), Slovenia (SI).

More information can be found in Bavec, Robačer, Bavec, et al. (2017), Bavec, Robačer, Lisec, et al. (2017) and Navarro-Miró, Blanco-Moreno, et al. (2019).

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Appendix S2. Details of sampling procedures for Carabidae, Staphylinidae and Araneae, N leaching, beta-glucosidase, marketable yield and cash crop quality carried out in each trial.

1. Carabidae, Staphylinidae and Araneae trapping methodology

The activity densities of the Carabidae, Staphylinidae and Araneae were assessed using pit-fall traps.

Belgium - Research Institute for Agriculture, Fisheries and Food (BE-ILVO)

Field experiment type A

The pit-fall traps were placed in the middle of each sub-plot to avoid interference between treatments. Pit-fall traps contained diluted formaldehyde. All traps were emptied every two weeks over a five-month period, starting two weeks after the cabbage was planted and continuing until just before harvesting. After collection, arthropods were conserved in alcohol in the laboratory at room temperature until determination.

Denmark (DK)

Field experiment type A

The pit-fall station consisted of two pit-fall traps connected with a 10-cm-wide and 1-m- long metal barrier. In both years, two sampling periods (from August–October) of 14 days each were carried out. Pit-fall traps were filled with propylenglycol (40 %). After collection, biological material was rinsed and stored in 70 % alcohol until determination.

Italy (IT)

Field experiment type A and type B

Each trap consisted of two collecting cups (600 mL; 10-cm diameter) connected by a 10-cm-high and 1-m-long Plexiglas barrier. Cups were filled with 40 % aqueous solution of propylene glycol as a killing and preservative agent.

In FtA, traps were active for seven out of 21 days from early June to late July in 2016 and 2017. Trapped arthropods were collected four times.

In FtB, traps were continuously active for the whole growing season, i.e. from early September to the end of December in 2015 and 2016. Traps were checked every three weeks and arthropods were collected four times.

Slovenia (SI)

Field experiment type A

The pit-fall station consisted of two pit-fall traps connected by a 10-cm-wide and 1-m- long metal barrier. In the first year, five sampling periods (end of June to end of August) of two weeks each were performed. In the second year, there were six sampling periods (beginning of June to end of August) of two weeks each with the exception of the first sampling after 15 days. Pit-fall traps were filled with propylenglycol (40 %). After collection, biological material was rinsed and stored in 70 % alcohol and checked and identified in the laboratory.

Spain (ES)

Field experiment type B

In Spain, we only studied the activity density of spiders in the FtB trial. The pit-fall station consisted of two pit-fall traps connected by a 10-cm-wide and 1-m-long plexiglas barrier. In the first year, eight sampling periods (from August to December) of 13–18 days each were carried out. In the second year, we carried out seven sampling periods (from September to December) of 12–22 days. Pit-fall traps were filled with propylenglycol (40 %). After collection, biological material was rinsed and stored in 70 % alcohol and checked and identified in the laboratory.

2. Beta-glucosidase

The effect of the ASC management on soil quality was assessed using beta-glucosidase enzyme activity as an indicator.

Belgium - INAGRO (BE-INAGRO)

Field experiment type A

The activity of beta-glucosidase was assessed using the method described in Alef and Nannipieri, (1995). In short, 4 ml of modified universal buffer (pH 6.0) and 1 ml of 25 mM p-nitrophenyl-β-D-glucospyranoside solution was added to one gram of the pre-incubated moist soil. The soil suspensions were incubated for 1 h at 37 °C. After incubation, 1 ml of $CaCl_2$ and 4 ml of Tris buffer (pH 12.0) were added. If needed, soil suspensions were diluted twice with Tris buffer (pH 10.0) to make the filtrates fit the range of the p-nitrophenol standard series. The colour intensity of the filtrates and standard series was measured at 400 nm with a Cary 50 UV-Visible spectrophotometer (Varian Inc., Palo Alto, United States).

Denmark (DK)

Field experiment type A

Beta-glucosidase activity was measured by adding 1 ml of 25 mM p-nitrophenyl-β-D-glucoside solution and 4 ml of modified universal buffer to two technical replicates of 1 g of sieved soil (fresh weight). The samples were incubated at 37 °C for 1 h. P-nitrophenyl-β-D-glucoside solution was added to the control samples after incubation. Subsequently, 1 ml of 0.5 M $CaCl_2$ and 4 ml of Tris-buffer pH 12 were added to the samples, which were then filtered immediately using Whatman nº. 5 papers. Released p-nitrophenol in the extract was determined by measurement of the optical density with a Varian Cary 50 spectrophotometer at 400 nm. Beta-glucosidase activity was determined as the difference between experimental and control samples.

Italy (IT)

Field experiment type A

The activity of beta-glucosidase was determined by a heteromolecular exchange procedure described by Fornasier and Margon (2007).

3. N leaching

The nitrogen leaching potential (N leaching) was measured using as an indicator the soil mineral nitrogen at harvest of the cash crop (Hutchings & Kristensen, 1995)**.**

Belgium - Walloon Agricultural Research Center (BE-CRA-W)

Field experiment type A

The mineral nitrogen content was assessed using a soil depth of 0.3 m because the dry weather did not allow us to sample more deeply. Six samples were collected per plot area and mixed into one composite sample. Soil mineral nitrogen, measured when the cash crop was harvested, was extracted by 0.5 M KCl (1:5, w/v) and measured by continual flow colourimetry according to QuickChem® Method 12-107-06-3-B and QuickChem® Method 12-107-04-1-B for NH_4^+-N and NO_3^--N, respectively.

Belgium - INAGRO (BE-INAGRO)

Field experiment type A

Soils were sampled with a hand-driven auger with a 13-mm inner diameter to depths of 0–0.3 m, 0.3–0.6 m and 0.6–0.9 m. Four subsamples were taken per plot and combined into one composite sample per soil layer. Soil N_{min} was determined by the extraction of nitrate and ammonium in 1-M KCl for 1 h and by analysis of the supernatant using standard colourimetry.

Denmark (DK)

Field experiment type A

Soil samples for N leaching were taken to a depth of 2.5 m in November. Ten sub-samples were randomly taken in each subplot by a machine-driven soil piston auger with a 14-mm inner-diameter at depths of 0–0.25 m, 0.25–0.5 m, 0.5–1 m, 1–1.5 m, 1.5–2 m and 2–2.5 m and then mixed into a composite sample for each depth. Soil samples were frozen until mineral N analysis. After thawing, the subsamples (each 100 g fresh weight) were extracted in 1-M KCl for 1 h (1 soil: 2 solution). The soil extract was centrifuged and the supernatant was subjected to

NH_4^+ and NO_3^- analyses using standard colorimetric methods with an AutoAnalyzer 3 (Bran+Luebbe, Germany).

Estonia (EE)

Field experiment type A

For soil mineral nitrogen, measured when the cash crops were harvested, four subsamples were taken per plot and mixed into one composite sample. Soil N_{min} was determined by the extraction of nitrate and ammonium in 2-M KCl (1:10, w/v) for 1 h and by analysis of the supernatant using standard colourimetry. The analysis of the supernatant was performed twice to control for intra-laboratory variability.

Italy (IT)

Field experiment type A

Soil mineral nitrogen, measured when the cash crop was harvested, was extracted in 2-M KCl (1:10, w/v) and measured using continual flow colourimetry according to Krom (1980) and Henriksen and Selmer-Olsen (1970) for NH_4^+-N and NO_3^--N, respectively. All the soil laboratory tests were carried out in triplicate to control for intra-laboratory variability.

4. Marketable yield

The indicator of the cash crop marketable yield was assessed using the dry biomass of the marketable yield of the cash crop.

Belgium - Walloon Agricultural Research Center (BE-CRA-W)

Field experiment type A

The cabbage marketable yield was estimated on two days (October 25th and 26th, 2017) by evaluating 21 cabbages per plot selected in the centre of the plot along three central lines. The marketable heads was assessed by measuring the dry matter (t ha^{-1}; 60 °C until constant weight). The minimum diameter of the cabbage head considered as marketable was 130 mm.

Belgium - INAGRO (BE-INAGRO)

Field experiment type A

Cabbage yield at harvest was obtained by hand-harvesting two rows × 2 m. Plant samples were divided into marketable yield; crop residues and fresh and dry weights were calculated.

Denmark (DK)

Field experiment type A

Cabbage marketable yield was assessed by harvesting 16–18 plants (two crop rows × 4.5 m) per plot at harvest (October).

Estonia (EE)

Field experiment type A

In both years, we estimated the cabbage marketable yield by sampling five randomly chosen plants per plot.

Spain (ES)

Field experiment type A

In the first year, we estimated the pepper marketable yield by analysing eight random plants per plot during twelve weekly samplings. In the second year, we assessed five random plants per plot during five biweekly samplings. In both years, we calculated the accumulated yield per plot.

Field experiment type B

In both years, we estimated the cabbage marketable yield by assessing five randomly chosen plants per plot.

France (FR)

Field experiment type A

In both years, we measured the yields of 10 plants per plot × 4 plots per treatment.

Italy (IT)

Field experiment type A

At harvest, in the first year, tomatoes were collected from three randomly selected plants (in the centre of the rows in each elementary plot) at three different times in July and August 2016, and marketable and total yields (t ha^{-1}) were recorded. In the second year, tomatoes were collected from three different plants at four different times in July and August 2017, and marketable and total yields (t ha^{-1}) were recorded.

Field experiment type B

At harvest, in both years, cauliflower heads were collected from three randomly selected plants (in the centre of the rows in each elementary plot), and marketable and total yields (t ha^{-1}) were calculated.

5. Cash crop quality

The cash crop quality indicator included different measurements of the marketable parameters of the cash crop depending on the crop and trial.

Belgium - Walloon Agricultural Research Center (BE-CRA-W)

Field experiment type A

To assess the marketable yield, the cash crop quality was estimated measuring the head diameter (mm) of 21 cabbages collected from the centre of the selected plot. The minimum head diameter considered as marketable was 130 mm.

Estonia (EE)

Field experiment type A

In both years, cabbage quality was assessed by measuring the head diameter of five randomly chosen plants per plot.

Spain (ES)

Field experiment type A

In the first year, we estimated the cash crop quality by measuring the length of each pepper when harvesting of eight random plants per plot in twelve weekly samplings. In the second year, we used the same procedure, except that we chose five plants at random per plot and five biweekly samplings.

Field experiment type B

In both years, cabbage quality was assessed by measuring the head diameter of five randomly chosen plants per plot.

France (FR)

Field experiment type A

The cash crop quality of butternut squash was measured by calculating the average weight of the fruit.

Italy (IT)

Field experiment type A

At harvest, in both years, tomato quality was assessed by measuring the total soluble solids (refractometric index, °Brix) of the fruits.

Field experiment type B

At harvest, in both years, cauliflower head quality was assessed by measuring the dry matter weight ($t\ ha^{-1}$; 70 °C until constant weight) of marketable heads.

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Appendix S3. Minimum and maximum value of each variable in each trial.

This Appendix shows the minimum and maximum value of each variable in each trial. Our study compared the no-till roller crimping (NT-RC) and tilling as green manure (T-GM) of agroecological service crop (ASC) management strategies. We combined results from 11 organic arable vegetable field trials located in Belgium (BE), Denmark (DK), Estonia (EE), France (FR), Italy (IT), Slovenia (SI), and Spain (ES). In BE, three different trials were set up across the country (BE-ILVO, BE INAGRO, and BE-CRA-W). Two parallel field experiment types were carried out: FtA - Spring-summer cash crop and FtB- Autumn-winter cash crop.

			Ecological indicators			Environmental indicators			Agronomic indicators			
Country	Trial	Termination	Carabidae AD	Staphylinidae AD	Araneae AD	PRE-EUE	N leaching	Beta-glucosidase	Weed density	Marketable yield	Cash crop quality	M-EUE
BE-CRA-W	FtA	T-GM					4.8 - 8.2		1 - 4	0 - 0.9	59.5 - 144.3	
		NT-RC					5.1 - 9		0 - 5	0 - 0	40.8 - 109	
BE-ILVO	FtA	T-GM	2.2 - 9	0.1 - 1.4		0.03 - 0.03						0.54 - 1.22
		NT-RC	1.8 - 14.2	0.2 - 1.3		0.05 - 0.08						0 - 0.54
BE-INAGRO	FtA	T-GM					7.7 - 27.8	67 - 236.4		3.4 - 5.4		
		NT-RC					6.4 - 32.6	75.9 - 186.3		0 - 4.3		
DK	FtA	T-GM	0.3 - 41.5	0 - 4.5		0.05 - 0.14	5.1 - 20.9	86.5 - 116.9	309 - 1498	0 - 6.6		0 - 2.56
		NT-RC	6.3 - 55.5	0 - 2.5		0.04 - 0.14	7.4 - 21.9	77.1 - 123.9	89 - 665	0 - 6.1		0 - 2.49
EE	FtA	T-GM				0.04 - 0.16	8.6 - 19.5		108 - 341	0 - 1.1	582.6 - 777.9	0 - 0.58
		NT-RC				0.06 - 0.14	5.8 - 22.5		31 - 101	0 - 0.5	461.6 - 765.2	0 - 0.22
ES	FtA	T-GM				0.13 - 0.18			95 - 1090	2.2 - 3.7	17.1 - 20	0.7 - 1.05
		NT-RC				0.1 - 0.21			0 - 605	2.5 - 4.2	15 - 22	0.81 - 1.31
	FtB	T-GM			10.8 - 23.6	0.04 - 0.14			110 - 1440	0.3 - 3.5	5 - 18.2	0.07 - 0.96
		NT-RC			10.8 - 31.8	0.05 - 0.18			10 - 2585	0 - 3.5	6.5 - 17.6	0 - 0.81
FR	FtA	T-GM				0.06 - 0.12			44 - 1078	2.9 - 5.3	1 - 1.5	1.19 - 2.32
		NT-RC				0.08 - 0.16			8.5 - 164	1.3 - 3.2	0.9 - 1.3	0.65 - 1.68
IT	FtA	T-GM	0 - 12.7	0 - 3.7	0 - 52.2	0.04 - 0.14	0.5 - 44.4	0.9 - 4.6	4 - 124	0.6 - 5.5	3.6 - 6	0.18 - 2.48
		NT-RC	0 - 25.2	0 - 5.2	0.7 - 22.5	0.04 - 0.13	2.4 - 36.9	1.4 - 4.9	4 - 146	1 - 10.9	3.8 - 5.8	0.48 - 3.91
	FtB	T-GM	2.1 - 42.7	0.7 - 14.9	3 - 20.7	0.06 - 0.17			24 - 220	0.3 - 1.9	7.4 - 13.7	0.17 - 1.06
		NT-RC	18.3 - 45.3	0.7 - 23.4	3.8 - 23.8	0.05 - 0.15			64 - 339.2	0 - 1.5	6.7 - 14.8	0 - 0.96
SI	FtA	T-GM	8.9 - 91.9	0.3 - 10	20.3 - 55				74 - 880			
		NT-RC	7 - 42.9	0.1 - 8.8	10.9 - 43.1				16 - 352			

Ecological indicators (Carabidae AD, Staphylinidae AD, Araneae AD) (individuals per 7 days); Environmental indicators: PRE-EUE: energy-use efficiency using the potentially recyclable energy as the output of the cropping system; N leaching: nitrogen leaching potential (BE-CRA-W: kg N ha^{-1}; BE-INAGRO, DK, EE and IT: mg N kg^{-1}); Beta-glucosidase (BE-INAGRO and

DK: μg PNP g^{-1} h^{-1}; IT: nmol 4-MUF g^{-1} h^{-1}). Agronomic indicators: Weed density (individuals m^{-2}); Marketable yield (t ha^{-1}); Cash crop quality (cash crop quality indicator included different measurements of the cash crop's marketable parameters, given in Appendix 2); M-EUE: Energy-use efficiency using the marketable yield as the output of the cropping system.