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

By David Navarro-Miró, José M. Blanco-Moreno, Corrado Ciaccia, Elena Testani, Ileana Iocola, Laura Depalo, Giovanni Burgio, Hanne Lakkenborg Kristensen, Margita Hefner, Kalvi Tamm, Ingrid Bender, Alessandro Persiani, Mariangela Diacono, Francesco Montemurro, Koen Willekens, Hélène Védie, Martina Bavec, Martina Robačar, Donatienne Arlotti, Pauline Deltour, Stefaan De Neve, Mesfin Tsegaye Gebremikael, Lourdes Chamorro, Berta Caballero-López, Alejandro Pérez-Ferrer, Stefano Canali, Francesc Xavier Sans

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

3  
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47

## 48 **Abstract**

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

## 77 **Key words**

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

## 80 **1. Introduction**

81  
82 Agriculture provides multiple ecosystem services that are indispensable for human welfare and these  
83 depend on a network of supporting (e.g., soil fertility and nutrient cycling) and regulating (e.g., pest and  
84 weed control) services. However, the management of cropping systems can also generate disservices

85 that reduce productivity (e.g., pest damage), generate environmental issues (e.g., nutrient leaching), and  
86 affect both the maintenance and functioning of ecosystems and human well-being (Power, 2010; Zhang,  
87 Ricketts, Kremen, Carney, & Swinton, 2007).

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

97 Organic farming was originally promoted as a holistic farming system aimed at improving soil health,  
98 and environmental and social aspects of agricultural production (Seufert, Ramankutty, & Mayerhofer,  
99 2017). In recent decades, its conventionalisation has led to the intensification and specialisation of  
100 organic production (Buck, Getz, & Guthman, 1997; Darnhofer, Lindenthal, Bartel-Kratochvil, &  
101 Zollitsch, 2010), and several studies have questioned the environmental benefits and agronomic  
102 viability of organic farming (Seufert et al., 2017; Trewavas, 2001, 2004; Tuomisto, Hodge, Riordan, &  
103 Macdonald, 2012).

104 There are also agronomic limitations to the widespread implementation of organic farming, of which  
105 weed management is identified by organic farmers as one of the main constraints on organic arable  
106 vegetable production (Turner, Davies, Moore, Grundy, & Mead, 2007). For example, the dependence  
107 on frequent soil tillage for controlling weeds negatively affects the sustainability of soil management in

108 organic systems (Trewavas, 2001, 2004). This is because tillage is very energy-consuming and increases  
109 fossil fuel consumption (Alluvione, Moretti, Sacco, & Grignani, 2011). In addition, tillage has a direct  
110 impact on soil organisms (i.e., by directly killing or injuring them) and their habitat, and modifies inter-  
111 specific relationships (Roger-Estrade, Anger, Bertrand, & Richard, 2010). In particular, ground and  
112 rove beetles are known to be sensitive to soil disturbance (Pretorius et al., 2018; Rivers, Mullen, Wallace,  
113 & Barbercheck, 2017; Tamburini, De Simone, Sigura, Boscutti, & Marini, 2016). Moreover, the  
114 negative impact of tillage on certain groups of soil-dwelling predatory invertebrates also affects the  
115 biological pest-control potential of this cropping system (Tamburini et al., 2016). Finally, intensive  
116 tillage causes changes in the biological quality of the soil and, for example, affects the activity of  
117 enzymes (e.g., beta-glucosidase) that play important roles in organic matter degradation (Ekenler &  
118 Tabatabai, 2003).

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

131 natural water bodies (Trewavas, 2001). On the other hand, Trewavas (2004) highlighted the fact that  
132 recycling energy and nutrients within the cropping system cannot compensate for the absorption of  
133 nutrients by the cash crop. Therefore, this type of management can lead to a progressive depletion of  
134 these nutrients in the soil.

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

144 Traditionally, European organic farmers have managed ASCs as green manure (T-GM) by chopping up  
145 and incorporating plant material into the soil by tillage (Peigné et al., 2016). However, as stated above,  
146 tillage can negatively affect the soil system. In recent years, therefore, the use of no-till roller crimping  
147 (NT-RC) for ASC management has attracted the interest of European farmers and researchers  
148 (Casagrande et al., 2016; Vincent-Caboud, Peigné, Casagrande, & Silva, 2017) because it can improve  
149 weed management and reduce dependence on tillage in organic farming. The roller-crimper flattens the  
150 ASC, creating a dense layer of plant residue on the soil surface (i.e., mulch) without soil disturbance.  
151 The use of NT-RC for ASC management originated in Brazil (Kornecki, Price, Raper, & Arriaga, 2009),  
152 and this approach has been studied and developed mainly in Latin America, Canada, and the USA  
153 (Altieri et al., 2011; Carr, Gramig, & Liebig, 2013; Delate, Cwach, & Chase, 2012; Shirtliffe & Johnson,



154 2012). The few studies performed in European organic vegetable systems have concluded that NT-RC  
155 reduces weed abundance dramatically and requires less fossil fuel than the T-GM approach (Canali et  
156 al., 2013; Ciaccia, Testani, et al., 2015; Diacono et al., 2017). Nevertheless, both positive and negative  
157 effects have been observed on cash crop yields when NT-RC is implemented under Mediterranean  
158 conditions (Canali et al., 2013; Ciaccia et al., 2016; Diacono et al., 2017). In addition, few studies have  
159 examined the impact of cover crop termination on beneficial soil fauna (Depalo et al., 2020; Magagnoli  
160 et al., 2018), root growth, and soil nitrogen (Hefner, Canali, et al., 2020; Hefner, Gebremikael, et al.,  
161 2020).

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

171 In this study, we analysed effects of the ASC management strategies (NT-RC vs. T-GM) on organic  
172 vegetable cropping system performance by means of agronomic, environmental, and ecological  
173 indicators, in different vegetable crops, soils and climatic conditions across Europe. We compared NT-  
174 RC and T-GM using a system comparison approach to exemplify the need for multidimensional analysis  
175 to address some of the most frequent criticisms and constraints as mentioned above. We also aimed to  
176 show the importance of an appraisal of the environmental and ecological implications—as well as the

177 agronomic benefits to the agroecosystem—under different crop, soil, and climatic conditions to evaluate  
178 the pros and cons of the different management systems before promoting them to organic vegetable  
179 farmers, advisors, and policymakers. To this end, we combined results obtained over a two year period  
180 from eleven organic vegetable field trials located in seven European countries as part of the SoilVeg  
181 project (ERA-Net CORE Organic Plus).

182

## 183 **2. Material and methods**

### 184 **2.1. Locations and field trials**

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

190 Two parallel field experiment types were carried out during two crop cycles as part of the SoilVeg  
191 project. Field experiment type A (FtA) was established at all trial locations (BE-ILVO, BE-INAGRO,  
192 BE-CRA-W, DK, EE, ES, FR, IT, SI) and involved the introduction of cold-rainy season ASCs into the  
193 crop rotation, followed by a spring-summer cash crop. The first FtA cycle took place during 2015 and  
194 2016 and the second, during 2016 and 2017. Field experiment type B (FtB) was performed only at the  
195 IT and ES locations where the Mediterranean climatic conditions enabled introduction of the ASCs in  
196 the warm-dry season (i.e., summer) with irrigation, followed by the transplantation of an autumn-winter  
197 cash crop. The first FtB cycle took place during 2014 and 2015 and the second, during 2015 and 2016.  
198 The comparison between ASC management strategies (NT-RC vs. T-GM) was carried out within each

199 trial for both experiment types. In total, results from twenty-two original datasets were analysed (i.e.,  
200 from 11 field experiments carried out over two years) (Table 1).

## 201 **2.2. Trial management**

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

213

## 214 **2.3. Cropping system performance indicators**

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

219

220 2.3.1. Ecological and environmental indicators

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

$$234 \quad AD = \frac{n}{T} \cdot \frac{7}{d}$$

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

237 The effect of the ASC management strategy on soil quality was assessed using beta-glucosidase enzyme  
238 activity. This enzyme has known sensitivity to soil tillage, irrespective of pedo-climatic conditions, and  
239 can, therefore, provide rapid information regarding changes in soil properties (Ekenler & Tabatabai,  
240 2003; Knight & Dick, 2004). In BE-INAGRO and DK beta-glucosidase was assessed using the method  
241 described in Alef and Nannipieri (1995), while in IT was determined by the procedure described by  
242 Fornasier and Margon (2007).

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

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

### 261 262 2.3.2. Agronomic indicators

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

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

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

279

## 280 **2.4. Statistical analysis**

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

286 Statistical models for each partner were fitted according to the experimental variables evaluated and the  
287 experimental layout, and included all the experimental variables evaluated in each trial in order to rule  
288 out their effect on the dependent variable. The levels of the experimental variables included in each

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

$$309 \quad p_Z = 1 - \Phi \left( \frac{\sum_{i=1}^k w_i Z_i}{\sqrt{\sum_{i=1}^k w_i^2}} \right)$$

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

$$313 \quad w_i = \frac{|\mu_i|}{SE_i}$$

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

$$316 \quad p_{one-sided} = \begin{cases} \frac{p_{two-sided}}{2}, & \text{if the direction of the effect coincides with the alternative hypothesis} \\ 1 - \frac{p_{two-sided}}{2}, & \text{otherwise.} \end{cases}$$

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

## 320 **3. Results**

321

### 322 **3.1. Environmental and ecological indicators**

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

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



331 Staphylinidae AD under NT-RC in IT-FtA and IT-FtB whereas in BE-ILVO-FtA and SI-FtA, the  
332 Staphylinidae AD was significantly lower (Table 2). Spider AD was lower under NT-RC than T-GM  
333 across the trials (Figure 1), but only significantly so in two out of the five evaluated trials (Table 2).  
334 The energy recycling efficiency of the ASC management strategies (evaluated using the PRE-EUE  
335 indicator) was significantly higher across trials under NT-RC compared to T-GM (Figure 1). The PRE-  
336 EUE was significantly higher under NT-RC in four out of eight trials, and was significantly lower only  
337 in IT-FtB (Table 2).  
338 The ranges (i.e., maximum and minimum) of the environmental and ecological indicators for each trial  
339 are presented in Appendix S3.

### 340 **3.2. Agronomic indicators**

341 All agronomic performance indicators were significantly affected by the ASC management strategy  
342 (Table 3). Weed density under NT-RC was lower than under T-GM (Figure 1) and declined significantly  
343 in seven out of nine trials (Table 3). According to the weighted Stouffer's test, both yield descriptors  
344 (i.e., cash crop marketable yield and quality) were lower under NT-RC compared to T-GM (Figure 1).  
345 Similarly, the energy-use efficiency of the ASC management strategies evaluated using marketable  
346 yield as the output of the cropping system was lower under NT-RC compared to T-GM (Figure 1), and  
347 was significantly lower in four out of eight trials. However, energy use efficiency under NT-RC was  
348 significantly higher in ES-FtA and IT-FtA (Table 3).  
349 The ranges (i.e., maximum and minimum) of the agronomic indicators for each trial are presented in  
350 Appendix S3.

## 351 **4. Discussion**

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

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

369 The consistent effectiveness of NT-RC on reducing weed density across countries validates this  
370 approach as an effective strategy for European organic farmers to manage weeds during the early stages  
371 of vegetable growth. It is worth noting that other studies on the reduction of tillage intensity in organic  
372 farming analysed the effect of both ASC management strategies on weed density, weed species richness,  
373 and community composition (Navarro-Miró, Blanco-Moreno, et al., 2019). Implementation of NT-RC  
374 may lead to a decrease in the dependence on tillage for managing weeds, which in turn may result in

375 less soil disturbance in organic vegetable systems. Moreover, the AD of ground and rove beetles were  
376 higher under NT-RC plots, which are generally sensitive to soil disturbance (Pretorius et al., 2018;  
377 Rivers et al., 2017; Tamburini et al., 2016). Our results agree with previous studies regarding the effects  
378 of ASC termination on soil functional diversity (Depalo et al., 2020; Magagnoli et al., 2018). The NT-  
379 RC strategy has been shown to reduce the direct impact of tillage (for ASC incorporation and weeding  
380 operations) on organisms living in the upper soil layers (Roger-Estrade et al., 2010; Sommaggio, Peretti,  
381 & Burgio, 2018) and to create favourable conditions (i.e., physical refuges and prey provision) for these  
382 groups during the cash crop cycle (Roger-Estrade et al., 2010; Sunderland & Samu, 2000). These soil-  
383 dwelling taxa play an important role in agroecosystem functioning, as they include pest and weed-seed  
384 predators and detritivores. For these reasons, their conservation and promotion may enhance the  
385 provision of ecosystem services (Pretorius et al., 2018).

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

393 Our NT-RC findings do not counter some of the main criticisms of this termination strategy regarding  
394 the yield and production efficiency of organic systems. Our results indicate that there is a consistent  
395 pattern of decreasing vegetable cash crop yield and marketable fruit quality under certain pedo-climatic  
396 conditions and crops. The reduction of the cash crop yield is one of the main drawbacks of no-till  
397 management, specifically when organic fertilisers are applied (Pittelkow et al., 2015). Overall, greater

398 variability and lower cash crop yields are one of the factors hindering a more widespread adoption of  
399 no-till practices by European organic farmers (Casagrande et al., 2016; Vincent-Caboud et al., 2017).  
400 The negative effect of NT-RC on crop yield was related to limited N availability in the DK trial (Hefner,  
401 Gebremikael, et al., 2020). Similarly, other published literature links the yield gap and fall in marketable  
402 quality under NT-RC in organic vegetable systems to N shortages during cash crop development  
403 (Ciaccia, Montemurro, et al., 2015; Diacono, Persiani, Canali, & Montemurro, 2018; Diacono et al.,  
404 2017). Therefore, this line of evidence points to the need for improvement of fertilisation strategies to  
405 overcome this constraint in combination with the species chosen as the agroecological service crop as  
406 shown in the DK trial (Hefner, Canali, et al., 2020). Additionally, NT-RC was less efficient than T-GM  
407 in transforming inputs into marketable outputs. A reduction in M-EUE can be related to higher cash  
408 crop yields and/or lower energy input consumption (Mohammadi & Omid, 2010). In our study, the  
409 greater input consumption required by T-GM for tillage and weeding operations (Canali et al., 2013;  
410 Diacono et al., 2018) could be compensated by the higher yield and better quality observed with this  
411 management strategy.

412 Implementation of NT-RC improved the environmental performance in terms of the energy that could  
413 potentially be recycled within the cropping system. Flattening the ASCs and avoiding tilling prior to  
414 cash crop transplantation has been shown to increase the efficiency of the cropping system in terms of  
415 the potentially recyclable energy generated per unit of input invested (Navarro-Miró, Iocola, et al.,  
416 2019). Although future energy and nutrient input savings might result in the long term due to the higher  
417 retention of energy within the agroecosystem, the higher PRE observed in NT-RC plots was mainly  
418 caused by a higher non-marketable yield rate, which is not agronomically desirable. Therefore, more  
419 research is required to analyse whether the likely input savings would compensate for the higher  
420 proportion of non-marketable yield observed under NT-RC in the long term. Regarding beta-

421 glucosidase activity, no clear conclusion could be drawn in the short term from the findings of the  
422 present study. Similarly, the leaching of mineral N as a potential environmental indicator was only  
423 significantly affected by the ASC management strategies in one of five trials, and there was no common  
424 significant pattern across trials.

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

## 433 **5. Conclusions**

434 In this study, we evaluated the consequences of a change in the management of organic vegetable  
435 production, from an agronomic, environmental, and ecological perspective. This study provides the first  
436 evidence that NT-RC alleviates some limitations of organic systems, mainly ecological and to lesser  
437 extent environmental and agronomic indicators in different vegetable crops and soils, and under  
438 different climatic conditions in Europe. However, compared to T-GM, NT-RC affects negatively some  
439 ecological and many agronomic indicators. Therefore, our results highlight the need to simultaneously  
440 evaluate different agronomic, environmental, and ecological aspects as a means of providing a clearer  
441 overview of the effect of ASC management strategies on agroecosystem functioning. Further research  
442 is thus required to determine how to reduce the yield gap under NT-RC via the use of new fertilisation

443 strategies during cash crop development or in specific vegetable breeding programs. Additionally,  
444 studies performing economic analyses should be run to assess whether the costs associated with NT-  
445 RC compensate the reduction in cash crop yield and quality. Therefore, it is clear that for the promotion  
446 of any agricultural system it is necessary to undertake a thorough analysis of a multi-faceted set of  
447 indicators.

448

#### 449 **Authors contributions:**

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

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467  
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471

## 472 **Data Availability statement**

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

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682



**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

3  
4 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  
5 year of experimentation. ASC composition: L: Legumes; G: Grasses; B: Brassicaceae. Explanatory variables: T: Termination; B: Total biomass; Y: Year; F: Fertilization; A: ASC  
6 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  
7 block design; R-S-P: Randomized strip-plot.  
8

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

12

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

13

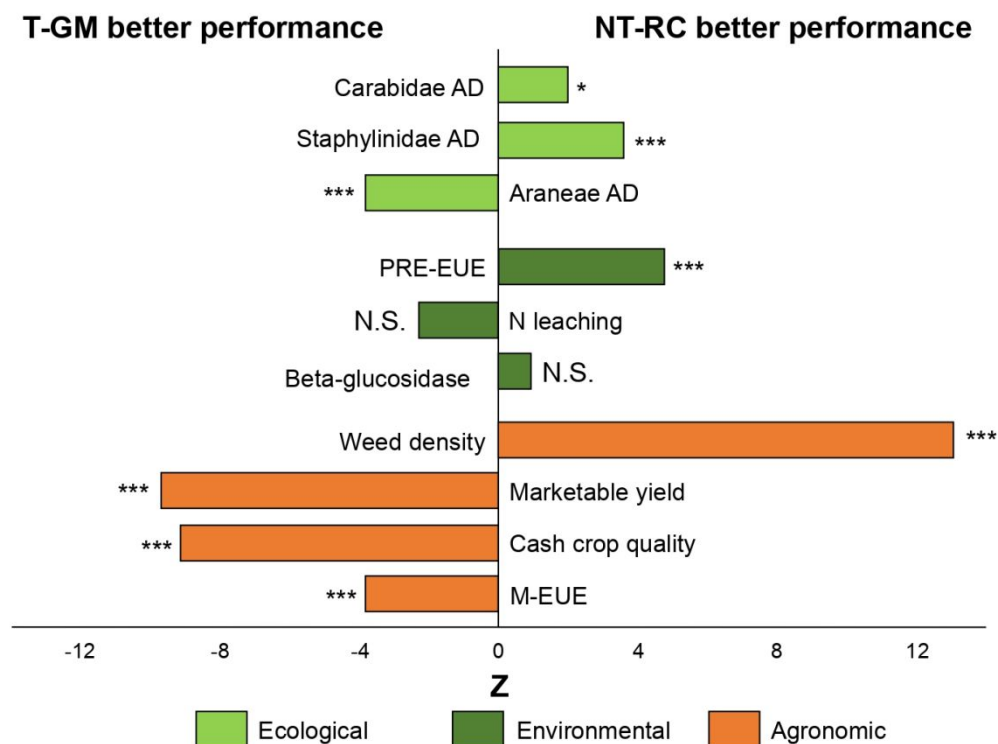
14 Country abbreviations as in Table 1. Ecological indicators: Carabidae AD: activity density of ground beetles; Staphylinidae AD: activity density of rove beetles; Araneae AD: activity  
 15 density of spiders; Environmental indicators: PRE-EUE: energy-use efficiency using the potentially recyclable energy as the output of the cropping system; N leaching: nitrogen leaching  
 16 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  
 17 NT-RC than in T-GM.

18 **Table 3.** Agronomic indicators. Estimates ( $\pm$  standard error) and their statistical significance in the models  
 19 evaluating the agronomic performance that compared T-GM to NT-RC. Variable transformation codes: †:  
 20 logarithmic; ††: square root. Significance codes: ‘N.S.’  $P > 0.05$ ; ‘\*’  $P \leq 0.05$ ; ‘\*\*’  $P \leq 0.01$ ; ‘\*\*\*’  $P \leq 0.001$ .  
 21

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

22 Country abbreviations as in Table 1. Agronomic indicators: M-EUE: energy-use efficiency using the marketable yield as the  
 23 output of the cropping system. The estimate represents the average difference in the response variable (or its transformation)  
 24 between NT-RC and T-GM. Positive values imply higher value of the response in NT-RC than in T-GM.  
 25  
 26  
 27

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



4  
 5  
 6

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

## 1 **Appendix S1. Trial details**

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

### 5 **Belgium - Walloon Agricultural Research Center (BE-CRA-W)**

#### 6 **Field experiment type A**

#### 7 **Experimental design**

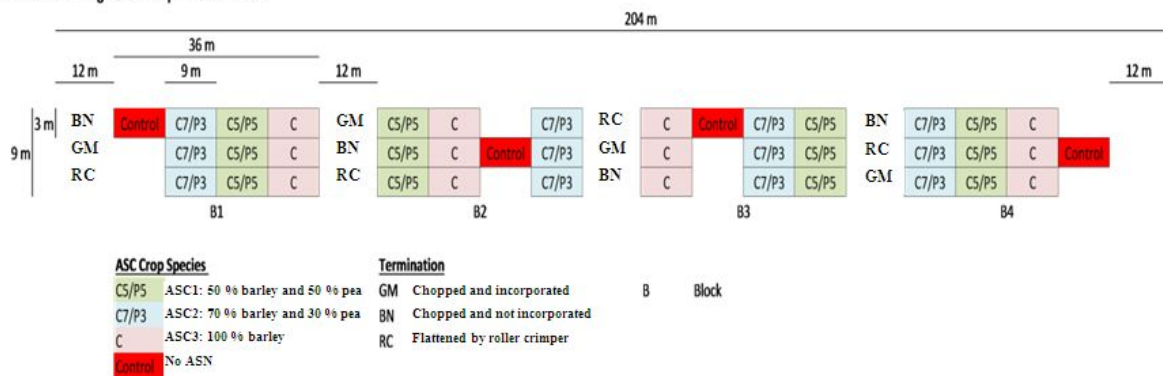
8 The field trial was newly established at the Walloon Agricultural Research Center located in  
9 Gembloux, Belgium (BE-CRA-W) (50° 36' 35.45" N and 4° 57' 14.91" E). This location  
10 represented the Atlantic Central European climatic zone. During experimentation, the mean  
11 annual temperature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

13 In this trial, only data from the second cycle (2016–2017) were gathered. During the first cycle  
14 (2015–2016), poor weather conditions delayed cabbage planting by 8 weeks which caused a  
15 significant decline in the survival and quality of the cabbage seedlings. Owing to the challenge  
16 of obtaining new cabbage seedlings quickly, and in consideration of financial loss to the farmer,  
17 the first year of the trial was abandoned.

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

22

2016-2017 SoilVeg FTA field experiment of CRA-W



23

24 **Figure 1.** Experimental design of Walloon Agricultural Research Center (BE-CRA-W) trial. ASC composition:

25 C5/P5 (green)- 50 % barley (*Hordeum vulgare* L.) + 50 % pea (*Pisum sativum* L.); C7/P3 (blue)- 70 % barley (*H.*

26 *vulgare*) + 30 % pea (*P. sativum*); C (pink) – 100 % barley (*H. vulgare*); and Control (red) - No ASC. Termination:

27 GM - Chopped and incorporated (T-GM); BN - Chopped and not incorporated; RC - Flattened by roller crimper

28 (NT-RC).

29 The three ASC compositions were ASC1: 50 % barley (*Hordeum vulgare* L.) + 50 % pea

30 (*Pisum sativum*), ASC2: 70 % barley (*H. vulgare*) + 30 % pea (*P. sativum*), and ASC3: 100 %

31 barley (*H. vulgare*). The three ASC management strategies were: (1) chopped and incorporated

32 into the soil by tillage as green manure (T-GM), (2) chopped and not incorporated into the soil

33 (BN), and (3) flattened by roller-crimping (NT-RC). In parallel, a control treatment without

34 plant cover (bare soil, BS) was established. The roller crimper was 3 m wide and weighed

35 1,720 kg (Picture 1.A). In the NT-RC plots, furrows for cash crop transplanting were created

36 using an in-line tillage (Picture 1.B). Plot size was 3 × 9 m. The cash crop was red cabbage

37 (*Brassica oleracea* var. *capitata* L. f. *rubra*).

38

A)



B)



39

40 **Picture 1.** Machinery used for NT-RC management in the Walloon Agricultural Research Center (BE-CRA-W) trial.

41 A - Roller crimper; B - In-line tiller.

## 42 **Agronomic management**

43 On the 25<sup>th</sup> August 2016, before ASC sowing, 20 t ha<sup>-1</sup> of cow manure (82 kg total N ha<sup>-1</sup>) was  
44 applied as fertiliser. The ASCs were sown on the 15<sup>th</sup> September 2016. In BS plots, four weed  
45 control operations, using a rotary harrow, were carried out during the ASC growth period. To  
46 simulate farmer practise, ASC termination was carried out on different dates, depending on the  
47 ASC management strategy: T-GM on May 5<sup>th</sup>, CNI on May 23<sup>rd</sup>, and NT-RC on May 31<sup>st</sup>,  
48 2017.

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



55

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

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

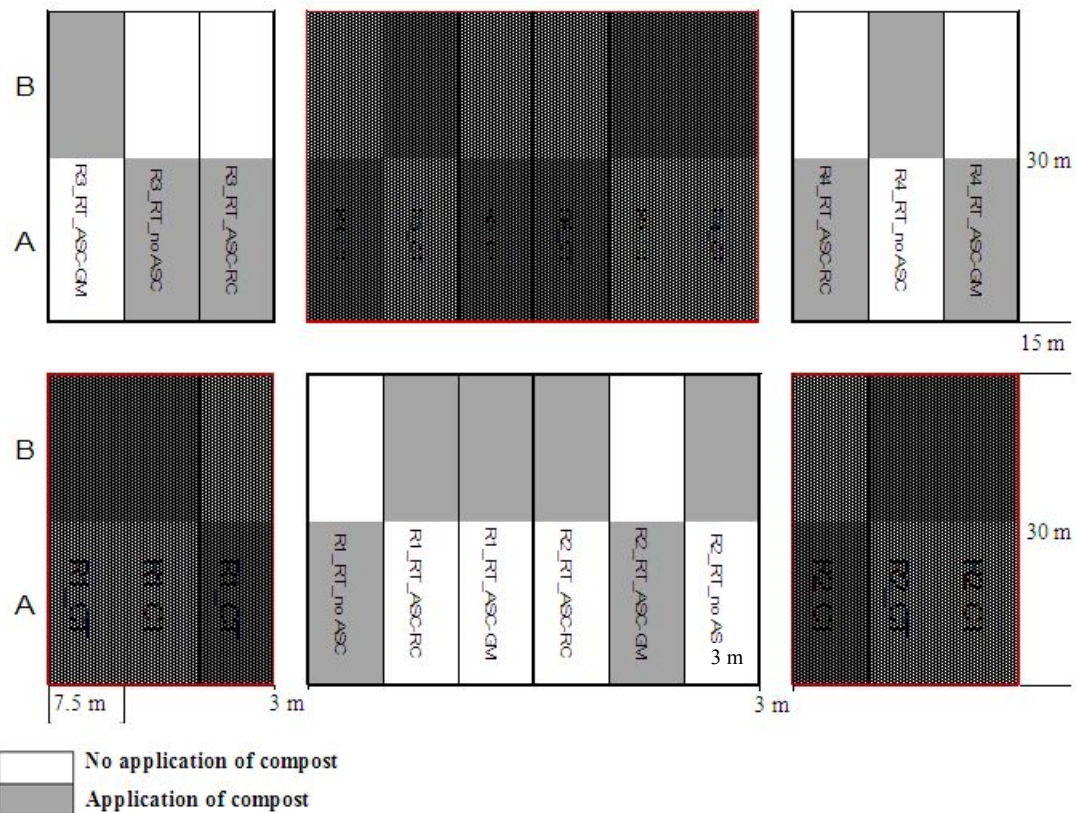
60 **Belgium - Research Institute for Agriculture, Fisheries and Food (BE-**  
 61 **ILVO)**

62 **Field experiment type A**

63 **Experimental design**

64 The field trial was newly established at the Research Institute for Agriculture, Fisheries and  
 65 Food (ILVO) in Merelbeke, Belgium (BE-ILVO) (50° 59' 38" N and 3° 44' 46" E), located in  
 66 the Atlantic Central European climatic zone. During the first (2015–2016) and second (2016–  
 67 2017) cycles, the mean annual temperature and rainfall were 11.1 °C and 898 mm, and 11.3 °C  
 68 and 822 mm, respectively. The trial soil had a sandy loamy texture.

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



73 **Figure 2** Experimental design of the Research Institute for Agriculture, Fisheries and Food (BE-ILVO) trial.

74 Termination: R\_RT\_ASC-GM = ASC chopped and incorporated into the soil (T-GM); R\_RT\_ASC-RC = ASC



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

77 The ASC termination strategies were: (1) roller-crimped (NT-RC), (2) chopped with a flail  
78 mower and incorporated into the soil by non-inversion tillage (T-GM). The roller crimper was  
79 3.1 m wide, weighed 1,720 kg when filled with oil, and was designed and constructed by ILVO  
80 (Picture 3). In the NT-RC plots, furrows for cash crop transplanting were created with a harrow  
81 tooth. The ASC was a mixture of 40 % rye (*Secale cereale* L.) and 60 % pea (*Pisum sativum*).  
82 Plot size was  $7.5 \times 15$  m. The cash crop was white cabbage (*Brassica oleracea* var. *capitata* L.).  
83



84  
85 **Picture 3.** The roller crimper flattening the ASC in the Research Institute for Agriculture, Fisheries and Food  
86 (BE-ILVO) trial.

### 87 **Agronomic management**

88 The ASC was sown on the 5<sup>th</sup> October 2015, and the 24<sup>th</sup> November 2016. In T-GM plots, the  
89 ASC was terminated by flail mowing on the 20<sup>th</sup> April 2016 and the 7<sup>th</sup> May 2017, and by  
90 superficial tillage on the 4<sup>th</sup> May 2016 and the 8<sup>th</sup> May 2017. The NT-RC plots were terminated  
91 on the 26<sup>th</sup> May 2016 and the 16<sup>th</sup> June 2017. The cash crop was transplanted and fertilised  
92 using a planting machine on the 27<sup>th</sup> May 2016, and the 21<sup>st</sup> June 2017 (Picture 4). Mechanical  
93 weeding was carried out on the 6<sup>th</sup> June, 6<sup>th</sup>, 26<sup>th</sup>, and 27<sup>th</sup> July 2016, and on the 13<sup>th</sup>, 17<sup>th</sup>, and  
94 27<sup>th</sup> July 2017. Manual weeding was carried out during the periods: 6<sup>th</sup> to 22<sup>nd</sup> July, 28<sup>th</sup> July to  
95 4<sup>th</sup> August, and 5<sup>th</sup> to 14<sup>th</sup> September 2016, and on the 14<sup>th</sup>, 27<sup>th</sup>, and 28<sup>th</sup> July 2017. Cash crop

96 irrigation was only required during the second year and was conducted manually twice during  
97 the crop cycle. The cash crop harvest was performed on the 3<sup>rd</sup> and 4<sup>th</sup> November 2016, and the  
98 7<sup>th</sup> November 2017.



99

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

102 More information about this trial can be found in Witvrouw (2016), Navarro-Miró, Iocola, et al.  
103 (2019) and Hefner, Canali, et al. (2020).

## 104 **Belgium - INAGRO (BE-INAGRO)**

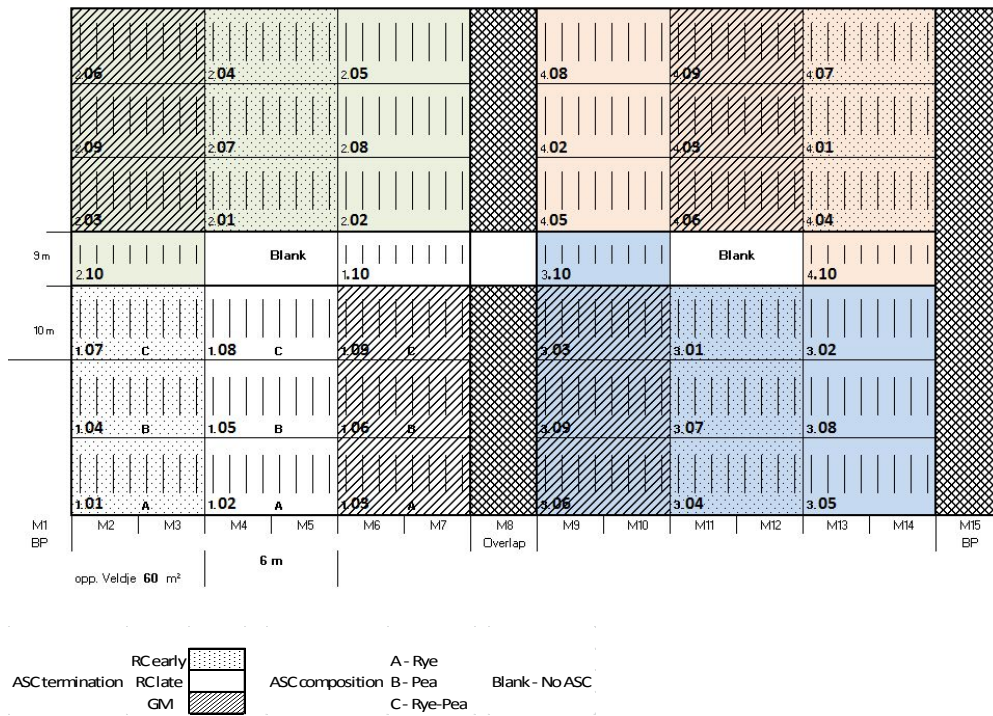
### 105 **Field experiment type A**

#### 106 **Experimental design**

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

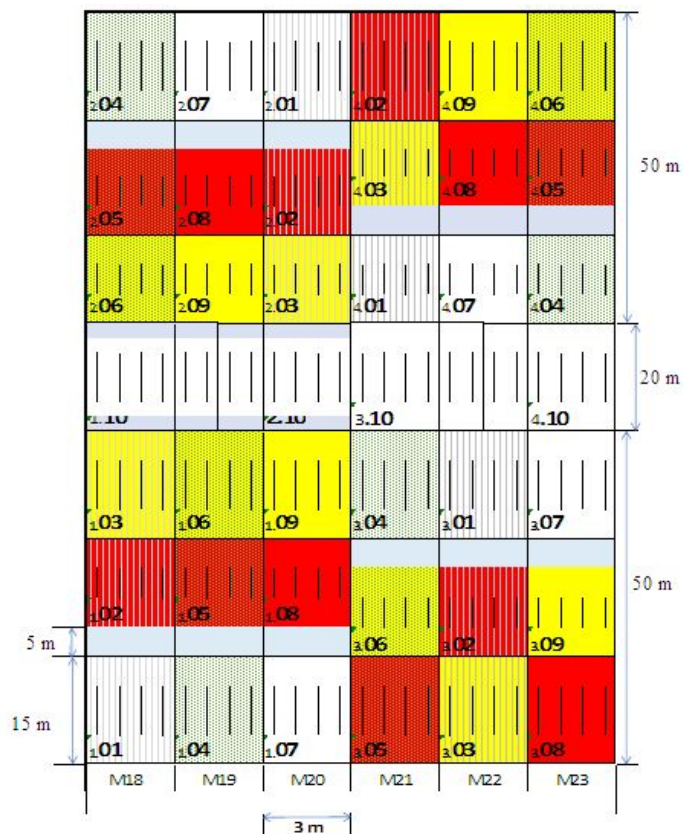
112 The experiment was not repeated on the same plots in both years, and was moved to an adjacent  
113 area for the 2016–2017 cycle. The INAGRO trial farm has been managed according to organic  
114 farming regulations since 2003 and has a rotation over six years (grass-clover, leek,

115 carrot/celeriac, cereals, cabbage, and potato). The trial design was a split plot with four  
 116 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.



124

125

126

**Figure 4.** Experimental design at the INAGRO (BE-INAGRO) organic farm station during the second year.

127

Termination: GM (white) - Incorporation by mill cutting one month before planting (T-GM); Mulch (red) - Mulching

128

by flail mowing at planting (not-incorporated); and RC (yellow) - Roller crimper (NT-RC). ASC composition: A

129

(vertical lines) - Winter rye (*Secale cereale*); B (small dots) - Winter pea (*Pisum sativum*); and C (no pattern) Rye-

130

pea mixture.

131

The ASC compositions were A: winter rye (*Secale cereale*), B: winter pea (*Pisum sativum*) and

132

C: a rye-pea mixture. The second factor was the ASC management strategy. During the first

133

year, the ASC management strategies analysed were: (1) roller crimper early termination, (2)

134

roller crimper late termination, and (3) mill cutting and non-inversion tillage, one month before

135

planting (T-GM). The roller crimper early termination treatment was scheduled to coincide with

136

the time of pea flowering (i.e., one week before cash crop transplanting) and the roller crimper

137

late termination treatment, at the time of rye flowering (i.e., one day before planting of the cash

138

crop). In the second year, the ASC management strategies studied were: (1) incorporation by

139

mill cutting (MC) one month before planting (T-GM), (2) mulching by flail mowing at planting

140 (not-incorporated), and (3) roller crimping (NT-RC). In this trial, the roller crimper used for  
 141 ASC management was the same as in the ILVO trial (Picture 5.A) and furrows for cash crop  
 142 transplanting were created by in-line tillage (Picture 5.B). Additionally, during both years, a  
 143 control treatment that did not use ASC and standard soil management was set-up. Plot size was  
 144  $6 \times 10$  m (except the fallow plots:  $6 \times 9$  m) during the first year and  $3 \times 15$  m during the second  
 145 year. The cash crop was white cabbage (*Brassica oleracea* var. *capitata*).



146  
 147 **Picture 5.** Machinery used for NT-RC management at the INAGRO (BE-INAGRO) organic farm station. A - Roller  
 148 crimper; B - In-line tiller.

### 149 **Agronomic management**

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

157 White cabbage was transplanted, with a row spacing of 0.70 m and a plant spacing of 0.30 m,  
 158 using a planting machine on May 25<sup>th</sup>, 2016 and on May 30<sup>th</sup>, 2017 (Picture 6). The cabbages  
 159 were fertilised with  $50 \text{ kg N ha}^{-1}$  commercial organic fertiliser (OPF granulate 11-0-5) on July  
 160 8<sup>th</sup>, 2016, during the first cycle, and on May 31<sup>st</sup>, 2017 during the second cycle. The cash crop  
 161 was irrigated on August 24<sup>th</sup>, and 31<sup>st</sup>, 2016, and only once at the time of cash crop

162 transplantation in 2017. In NT-RC plots, weeding operations were not required during the cash  
163 crop cycle. In T-GM plots, in the first year, weeding operations during the cash crop cycle were  
164 carried out by hoeing (June 8<sup>th</sup>, 2016) harrowing (June 9<sup>th</sup>, 2016) and manually (July 20<sup>th</sup>, and  
165 22<sup>nd</sup>, 2016). In the second year, T-GM plots were weeded by mechanical weed control (June  
166 15<sup>th</sup>, 2017) and manually (June 15<sup>th</sup>, and July 6<sup>th</sup>, 2017). The cash crop harvest was performed  
167 on November 21<sup>st</sup>, 2016 and November 7<sup>th</sup>, 2017. More information about this trial can be found  
168 in Hefner, Canali, et al. (2020).



169  
170 **Picture 6.** Transplanting of white cabbage using a planting machine at the INAGRO (BE-INAGRO) organic farm  
171 station.

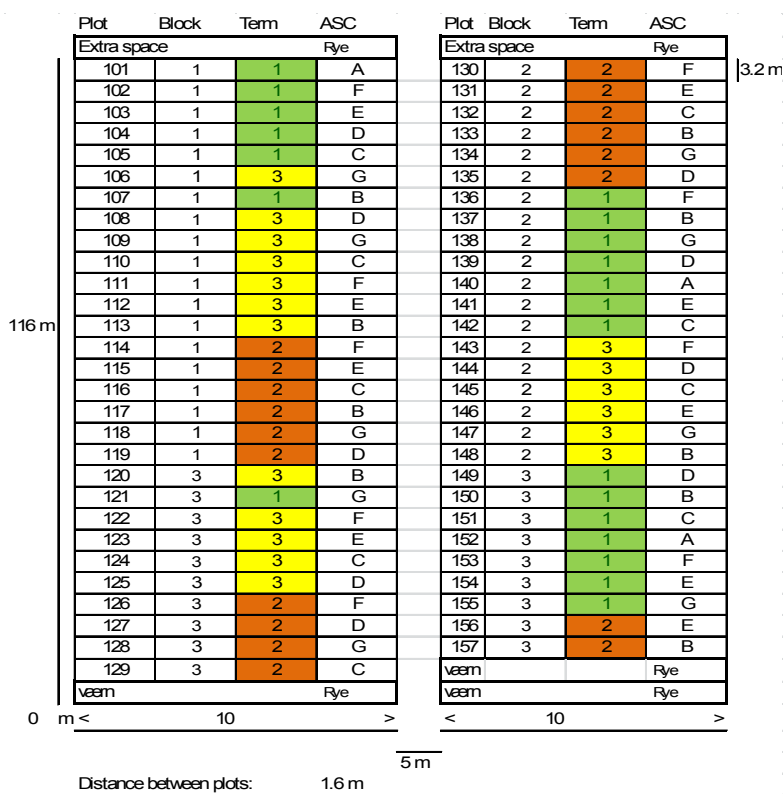
## 172 **Denmark (DK)**

### 173 **Field experiment type A**

#### 174 **Experimental design**

175 The field trial was newly established at the Department of Food Science research centre of  
176 Aarhus University, located in Årsløv, Denmark (55° 18' N and 10° 27' E), in the Atlantic North  
177 European climatic zone. The mean annual temperature was 9.3 °C and the mean annual rainfall,  
178 614 mm during the first cycle (2015–2016), and 9.1 °C and 673 mm during the second cycle  
179 (2016–2017), respectively. The soil had a sandy loamy texture and a 1 % organic carbon  
180 content.

181 The experiment was not repeated on the same plots in both years, and was moved to an adjacent  
 182 area for the 2016–2017 cycle. The two locations had been managed according to Danish organic  
 183 farming regulations since 1996 and 2014, respectively. The previous crop grown in the area was  
 184 barley (*Hordeum vulgare* L.). The trial had a split-plot randomised complete block experimental  
 185 design with three replications, where ASC management was the whole-plot factor and ASC  
 186 composition, the subplot factor. The experimental design was modified each year (Figures 5 and  
 187 6).



188

#### ASC composition

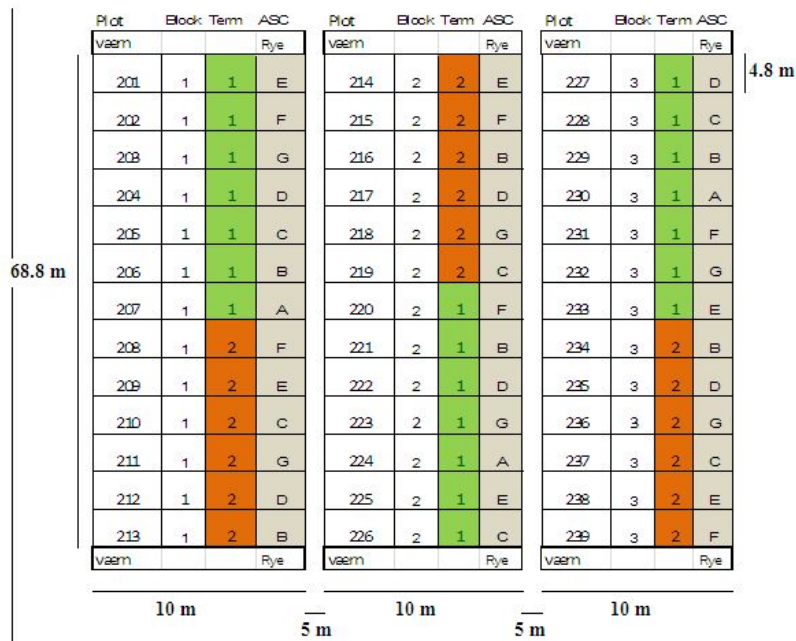
- A No ASC (bare soil)
- B Winter faba bean
- C Winter pea
- D Winter vetch
- E 50/50 mixture of winter faba bean/winter rye
- F 50/50 mixture of winter pea/winter rye
- G 50/50 mixture of winter vetch/winter rye

189

#### Termination of green manure

- 1 Green Manure
- 2 Roller crimping
- 3 Strip cultivation/strip green manure between rows of crop (additive design)

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



196

#### ASC composition

- A No ASC (bare soil)
- B Winter faba bean
- C Winter pea
- D Winter vetch
- E 50/50 mixture of winter faba bean/winter rye
- F 50/50 mixture of winter pea/winter rye
- G 50/50 mixture of winter vetch/winter rye

197

#### Termination of green manure

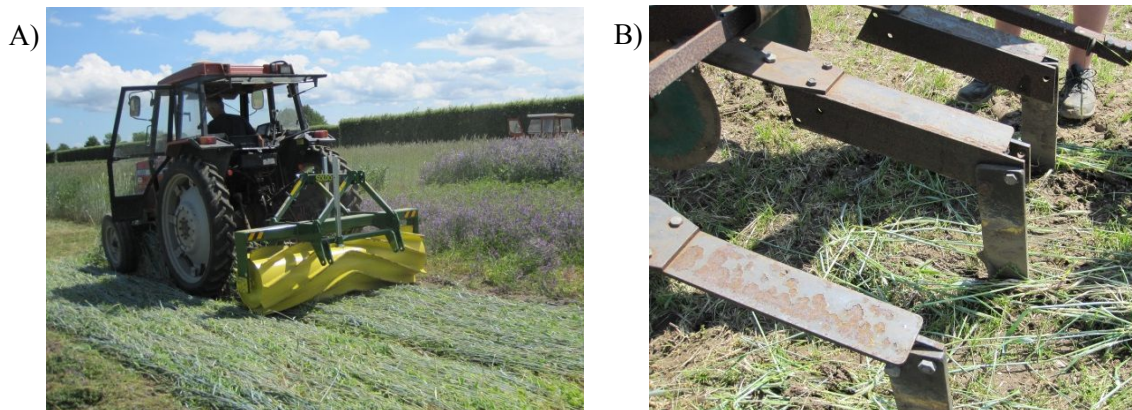
- |   |                 |
|---|-----------------|
| 1 | Green Manure    |
| 2 | Roller crimping |

198 **Figure 6.** Experimental design of the organic farm station of the Department of Food Science research center of  
 199 Aarhus University (DK) during the second cycle (2016–2017). Termination: 1 (green) - Chopped with a flail mower  
 200 and incorporated into the soil with a cultivator as green manure (T-GM); 2 (orange) - Roller-crimped (NT-RC). ASC  
 201 composition: A - No ASC, winter fallow (bare soil); B - Winter faba bean; C - Winter pea, D - Winter vetch; E -  
 202 50/50 mixture of winter rye and winter faba bean; F - 50/50 mixture of winter rye and winter pea; and G - 50/50  
 203 mixture of winter rye and winter vetch.

204 The ASC termination strategies were: (1) chopped with a flail mower and incorporated into the  
 205 soil with a cultivator as green manure (T-GM), (2) roller-crimped (NT-RC), and (3) strip  
 206 cultivation/strip green manure between crop rows (additive design). The roller crimper was 2  
 207 wide and weighed 932 kg. It was designed and constructed by Soldo Macchine Agricole  
 208 (Grassano, Italy) (Picture 7.A). Furrows for cash crop transplanting in the NT-RC plots were  
 209 created with a harrow tooth (Picture 7.B). The ASC species composition was: B: winter faba  
 210 bean (*Vicia faba* L.), C: winter pea (*Pisum sativum*), D: winter vetch (*Vicia sativa* L.), E: 50/50  
 211 mixture of winter rye (*Secale cereale*) and winter faba bean, F: 50/50 mixture of winter rye and



212 winter pea, and G: 50/50 mixture of winter rye and winter vetch (Picture 8). A control treatment  
 213 of winter fallow (bare soil) was also included. Plot size was  $3.2 \times 10$  m during the first year and  
 214  $4.8 \times 10$  m during the second year. The cash crop was white cabbage (*Brassica oleracea* var.  
 215 *capitata*).



216  
 217 **Picture 7.** Machinery used for NT-RC management in the DK trial. A - Roller crimper; B - Harrow tooth used to  
 218 create the cash crop transplanting furrows.

### 219 **Agronomic management**

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



223  
 224 **Picture 8.** View of DK field trial before ASC termination.

225 White cabbage was transplanted using a three-row planting machine on July 1<sup>st</sup>, 2016, and on  
 226 June 21<sup>st</sup>, 2017, with a row spacing of 0.5 m and a plant spacing of 0.5 m. Weed management

227 was carried out in T-GM plots using a weed-brush machine in inter-rows on July 27<sup>th</sup>–29<sup>th</sup> and  
228 August 19<sup>th</sup>, 2016, and July 17<sup>th</sup>–19<sup>th</sup>, 2017, and manually with a hoe in inter-rows and intra-  
229 rows on September 26<sup>th</sup>–30<sup>th</sup>, 2016 and August 10<sup>th</sup>–22<sup>nd</sup>, 2017. In NT-RC plots, weeding  
230 operations consisted of the manual removal of above ground biomass of large weeds. During the  
231 first year, cabbages were fertilised with 50 kg N ha<sup>-1</sup> feather meal pellets on August 25<sup>th</sup>, 2016.  
232 During the second year, cash crop fertilisation with 100 kg N ha<sup>-1</sup> feather meal pellets was  
233 carried out a week before cabbage transplantation. Thirty kg N ha<sup>-1</sup> lupine seeds (N-P-K: 4.5-  
234 0.4-0.9) were applied on June 15<sup>th</sup>, 2017, and 80 kg N ha<sup>-1</sup> feather meal pellets on August 24<sup>th</sup>,  
235 2017. Cash crop irrigation was only required during the first year and was conducted twice (in  
236 August and September) with sprinklers. The cabbage crop was harvested on November 11<sup>th</sup>,  
237 2016, and November 2<sup>nd</sup>, 2017.

238 More information about this trial can be found in Navarro-Miró, Iocola, et al. (2019) Navarro-  
239 Miró, Blanco-Moreno, et al. (2019), Hefner, Gebremikael, et al (2020) and Hefner, Canali, et al.  
240 (2020).

## 241 **Estonia (EE)**

### 242 **Field experiment type A**

#### 243 **Experimental design**

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

250 The experiment was not repeated in the same plots in both years, and was moved to an adjacent  
251 area for the 2016–2017 cycle. The trial was established in an area certified organic from 2005.  
252 The previous crop grown in the area was red clover (*Trifolium pratense* L.). The trial had a

253 strip-plot design with ASC strips and ASC management strategies crossed with a fertiliser  
 254 factor, and three replicates per treatment (Figure 7).

	ASC	Winter triticale	Winter triticale	No ASC	Winter rye	Winter rye	
		Tr	Tr	NoA	Rye	Rye	
Treatment		Roller Crimper	Chop and plough	Plough	Roller Crimper	Chop and plough	
		RC	GM	NoA	RC	GM	
1. repl	No manure						
	Manure	F	F	F	F	F	
2. repl	Manure	F	F	F	F	F	
	No manure						
3. repl	No manure						1.5 m
	Manure	F	F	F	F	F	6 m
							1.5 m   4 m

255

256 **Figure 7.** Experimental design of the research field at the organic farm station at Jõgeva in eastern Estonia (EE).

257 Termination: RC - Roller-crimped (NT-RC); and GM - Chopped by a flail mower, then ploughed and levelled by a  
 258 cultivator (T-GM). ASC composition: ASC1 - 100 % Winter rye; and ASC2 - 100 % Winter triticale. NoA - Control  
 259 treatment without ASC (No ASC). Fertiliser factor: 1) Application of 30 t ha<sup>-1</sup> solid cattle manure; 2) Not fertilised.

260 The two ASC termination strategies were: (1) roller-crimped (NT-RC), and (2) chopped by a  
 261 flail mower, then ploughed, and levelled by a cultivator (T-GM). The roller crimper was 2 m  
 262 wide and weighed 800 kg during the first year ASC termination, and 1,200 kg during the  
 263 second, and was designed and constructed by Soldo Macchine Agricole (Grassano, Italy)  
 264 (Picture 9). In the NT-RC plots, furrows for cash crop transplanting were created by in-line  
 265 tillage (Picture 9). The ASC species composition was: ASC1 - 100 % winter rye (*Secale*  
 266 *cereale*) (180 kg ha<sup>-1</sup>), and ASC2 - 100 % winter triticale (*× Triticosecale blaringhemii*  
 267 *A. Camus*) (155 kg ha<sup>-1</sup>). The fertilisation factor consisted of: (1) application of 30 t ha<sup>-1</sup> solid  
 268 cattle manure (153 kg ha<sup>-1</sup> N, 57 kg ha<sup>-1</sup> P, and 81 kg ha<sup>-1</sup> K), and (2) no fertiliser. Plot size was  
 269 6 × 4 m. The cash crop was white cabbage (*Brassica oleracea* var. *capitata*).



270

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

### 273 **Agronomic management**

274 Fertiliser was applied to the fertiliser treatment plots before the ASCs were planted. During the  
275 second year, in addition to the fertilisation factor, all plots were fertilised with 12 t ha<sup>-1</sup> of horse  
276 manure compost (12 kg ha<sup>-1</sup> N, 1.2 kg ha<sup>-1</sup> P, and 4.8 kg ha<sup>-1</sup> K). During the first cycle, the  
277 ASCs were sown on August 25<sup>th</sup>, 2015 and terminated by NT-RC on June, 6<sup>th</sup> and June 9<sup>th</sup>,  
278 2016, and by T-GM on June 10<sup>th</sup>, 2016. During the second cycle, the ASCs were sown in  
279 September 2016 and managed by T-GM on June 16<sup>th</sup>, 2017 and by NT-RC on June 19<sup>th</sup>, 2017.

280 White cabbage was manually transplanted in the first year from the 13<sup>th</sup> to 16<sup>th</sup> June 2016, and  
281 in the second year on June 19<sup>th</sup>, 2017, with a row spacing of 0.65 m and a 0.50 m plant spacing  
282 (Picture 10). Manual weeding was carried out in all treatments on August 27<sup>th</sup>, 2016 and July  
283 27<sup>th</sup>, 2017.



284

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

286 During the first year, the cash crop was not irrigated, whereas during the second year, all plants  
287 were watered once in mid-July with a humic solution (0.0003 kg ha<sup>-1</sup> N, 0.0001 kg ha<sup>-1</sup> P, and  
288 0.0002 kg ha<sup>-1</sup> K). The cash crop harvest was performed on October 7<sup>th</sup>, 2016, and from October  
289 4<sup>th</sup> to 6<sup>th</sup>, 2017.

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

## 293 **Spain (ES)**

### 294 **Experimental design**

295 Both parallel field experiments type A (FtA) and type B (FtB) were newly established in the  
296 Gallecs Area of Natural Interest, Barcelona, Spain (ES) (41° 33' N and 2° 12' E), located in the  
297 Mediterranean North European climatic zone. In FtA, during the first cycle (2015–2016), the  
298 mean annual temperature was 16.5 °C and the mean annual rainfall, 406 mm, and during the  
299 second cycle (2016–2017), 16.1 °C and 409 mm, respectively. In FtB, during the first cycle  
300 (2014–2015), the mean annual temperature was 16.1 °C and the mean annual rainfall, 344 mm,  
301 and in the second cycle (2015–2016), 16.5 °C and 406 mm, respectively. The trial soil had a  
302 loamy texture and contained an average of 0.95 % organic carbon content.

303 In both trials, the field experiments were repeated in the same area in both years. Conversion of  
304 the experimental area to organic farming began in 2005, and the previous crop grown in the area  
305 was wheat. The experimental design of the FtA and FtB trials was a randomised strip-plot with  
306 two factors (ASC composition and ASC management strategy) and four replicates. The different  
307 treatments were defined in randomly distributed parallel bands, and within each band, four plots  
308 (6 × 4 m) were established. The experimental layout was designed to facilitate traffic of  
309 machinery between plots and to enable the agricultural practices to be performed in the same  
310 direction.

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



324

325

326 **Picture 11.** Machinery used for NT-RC management in the Gallecs Area of Natural Interest, Barcelona, Spain

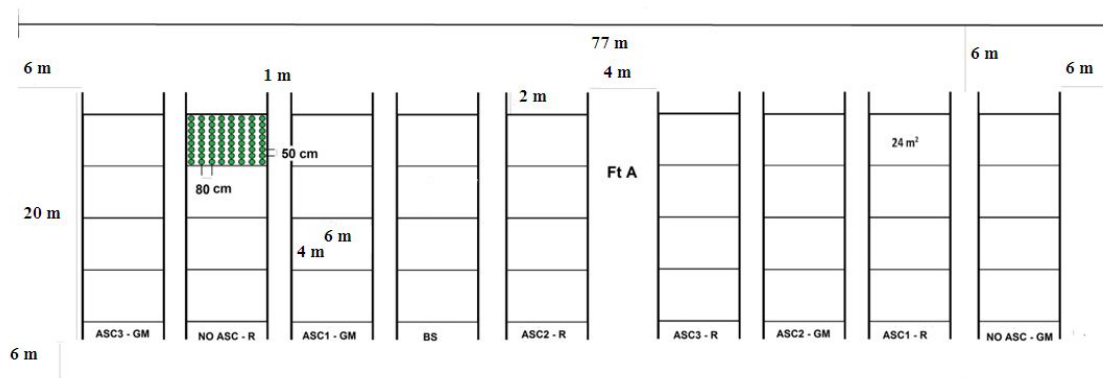
327

(ES). A - Roller crimper. B - In-line tiller.

328

### 328 **Field experiment type A**

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

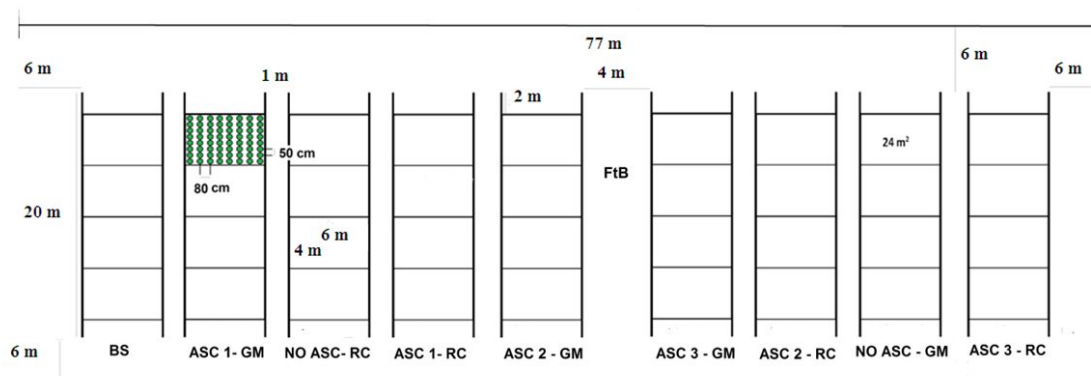


334

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

#### 341 Field experiment type B

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



346

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

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

### 353 **Agronomic management**

#### 354 **Field experiment type A**

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

359 In the T-GM plots, ASC chopping was carried out on May 4<sup>th</sup>, 2016 and May 18<sup>th</sup>, 2017, and the  
360 incorporation of the plant material into the soil was performed on May 18<sup>th</sup>, 2016 and June 1<sup>st</sup>,  
361 2017. The green pepper crop were transplanted on May 26<sup>th</sup>, 2016, and on June 20<sup>th</sup>, 2017, with  
362 a row spacing of 0.80 m and a 0.50 m plant spacing (Picture 12). The cash crop was fertilised  
363 just after transplantation with 170 kg ha<sup>-1</sup> N using commercial organic fertiliser and the green  
364 pepper plants were drip-irrigated according to their needs. During the first year, T-GM plots  
365 were weeded four times, whereas NT-RC plots only required two weeding operations. During  
366 the second year, all plots required three weeding operations. In the first year, the cash crop  
367 harvest was performed weekly from July 18<sup>th</sup> to October 3<sup>rd</sup>, 2016, whereas in the second year  
368 the harvest took place from August 21<sup>st</sup> to October 2<sup>nd</sup>, 2017.



369

370 **Picture 12.** View of the FtA field experiment established in the Gallecs Area of Natural Interest, Barcelona, Spain

371

(ES) during growth of the cash crop.



**372 Field experiment type B**

373 The ASCs were sown on April 30<sup>th</sup>, 2015 and on May 4<sup>th</sup>, 2016, and irrigated with sprinklers  
374 during their development. During the first cycle, the ASCs were managed by two passes of NT-  
375 RC on July 23<sup>rd</sup> and 27<sup>th</sup>, 2015 and one operation combining NT-RC and in-line tillage on July  
376 29<sup>th</sup>, 2015. In the T-GM plots, the ASCs were chopped on July 23<sup>rd</sup>, 2015 and incorporated into  
377 the soil using a chisel plough on July, 28<sup>th</sup>, 2015. During the second cycle, NT-RC management  
378 was carried out on August 26<sup>th</sup>, 2016, and the creation of the transplanting furrows was carried  
379 out along with the NT-RC by in-line tillage on September 6<sup>th</sup>, 2016. In the T-GM management  
380 plots, chopping of the ASC was carried out on August 26<sup>th</sup>, 2016, and incorporation of plant  
381 material into the soil was performed on September, 6<sup>th</sup>, 2016. The savoy cabbages were  
382 transplanted on August 4<sup>th</sup>, 2015, and September 20<sup>th</sup>, 2016, with a row spacing of 0.80 m and a  
383 0.50 m plant spacing (Picture 13). The cash crop was fertilised with 100 kg ha<sup>-1</sup> N in both years.  
384 During the first year, the commercial organic fertiliser was split into two applications: (1) just  
385 after savoy cabbage transplantation and (2) during savoy cabbage development. During the  
386 second year, the commercial organic fertiliser was applied just after the savoy cabbage was  
387 transplanted. The cabbages were drip irrigated according to the crop needs. In the first cycle, all  
388 plots were weeded only once during the cash crop development, whereas in the second year,  
389 two weeding operations were required. The savoy cabbages were harvested on December 2<sup>nd</sup>,  
390 2015, and February 22<sup>nd</sup>, 2017.



391

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

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

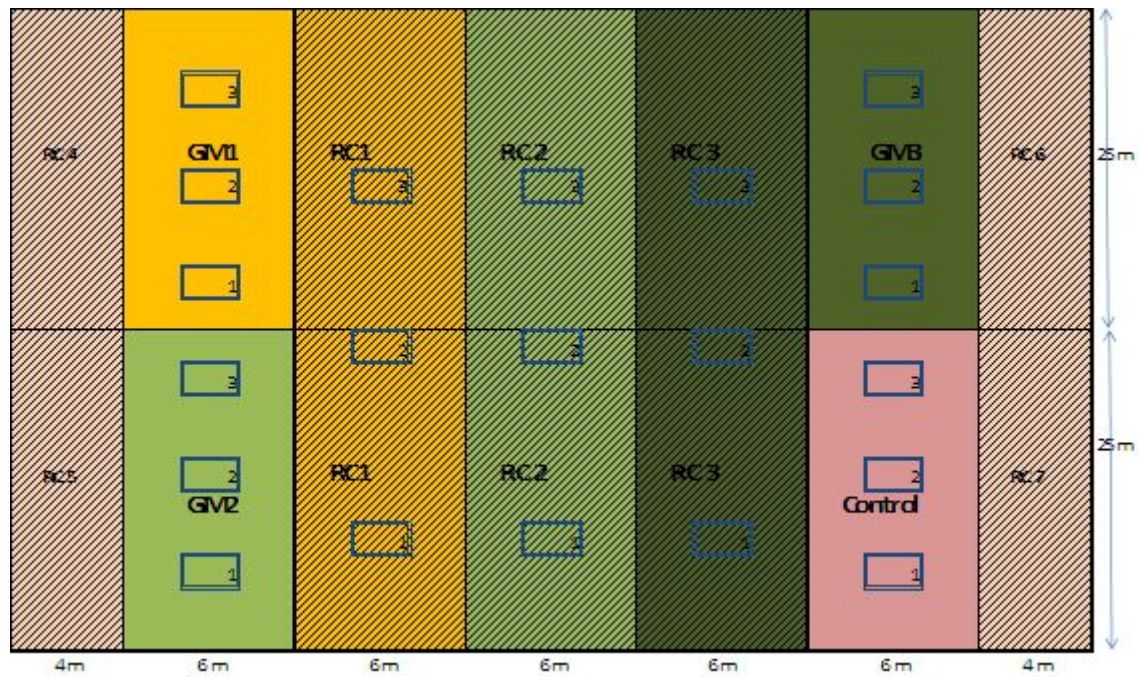
## 396 **France (FR)**

### 397 **Field experiment type A**

#### 398 **Experimental design**

399 The field experiment was newly established at the experimental organic research centre of the  
400 Groupe de Recherche en Agriculture Biologique (GRAB) in Avignon, southern France (FR)  
401 (43° 54' 23.8" N and 4° 53' 06.4" E). This location represented the Mediterranean North  
402 European climatic zone. During the first cycle (2015–2016), the mean annual temperature was  
403 15.5 °C and the mean annual rainfall, 521 mm, and in the second cycle (2016–2017) these  
404 environmental factors were 15.3 °C and 558 mm, respectively. The trial soil had a clay loam  
405 texture and a 1.86 % organic carbon content.

406 The experiment was repeated on the same plots in both years, but with some changes in the  
407 second year. The selected experimental field had been under organic farming management from  
408 2000. The previous crops grown were diversified varieties of squash (*Cucurbita* sp.). The trial  
409 had a randomised strip-plot experimental design with three replicates during the first year and  
410 four during the second year, where ASC management strategy (*i.e.*, NT-RC or T-GM) was the  
411 strip factor, and the ASC composition was the subplot factor (*i.e.*, six different ASC  
412 compositions). The experimental design was modified each year (Figures 10 and 11).

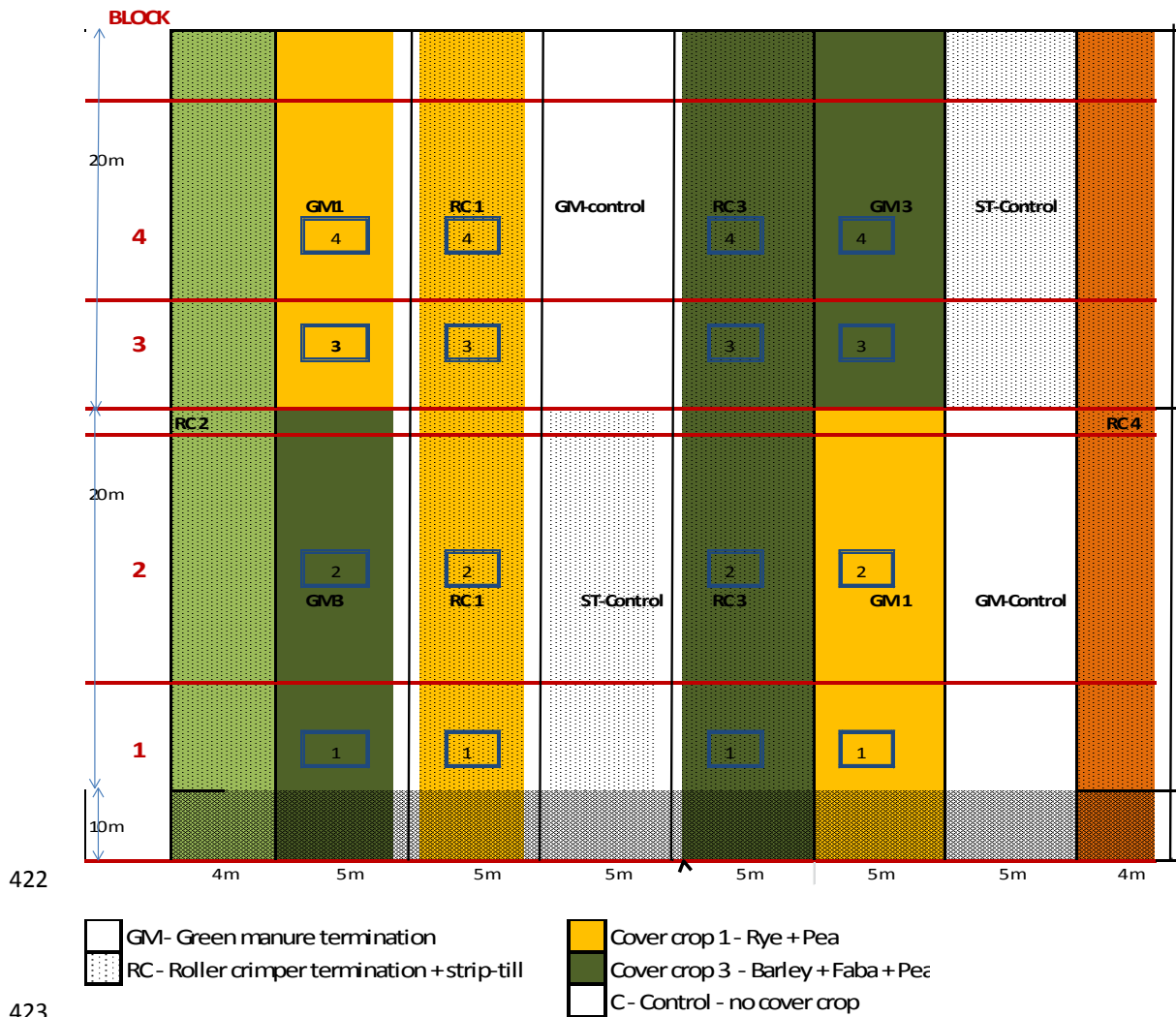


413

414

	Border		Cover crop 1- Rye + Pea
	Dry zone		Cover crop 2- Rye + Faba + Vetch
	GVI- Green manure termination		Cover crop 3- Barley + Faba + Pea
	RC- Roller crimper termination		C- Control - no cover crop

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



422  
423  
424 **Figure 11.** Second cycle (2016–2017) experimental design of the trial established at the experimental organic  
425 research centre of the Groupe de Recherche en Agriculture Biologique (GRAB) in Avignon (FR). Termination: RC -  
426 Cover crop flattened by a roller crimper + in-line tillage to create the transplanting furrows (NT-RC); and GM -  
427 Termination as a green manure by mowing, chopping, and incorporation of the cover crop into the soil (T-GM). ASC  
428 composition: ASC1 – 50 % *Secale cereale* + 50 % *Pisum sativum*; and ASC3 - 50 % *Hordeum vulgare* + 37 % *Vicia*  
429 *faba* + 40 % *P. sativum*. Additionally, two Control treatments maintaining the soil without plant cover (bare soil)  
430 were established: ST-control - Strip tillage before cash crop transplantation; and GM-control.  
431 The two ASC termination strategies were: (1) cover crop flattened by a roller crimper (NT-RC)  
432 + in-line tillage to create the transplanting furrows, and (2) termination as a green manure by  
433 mowing, chopping, and incorporation of the cover crop into the soil (T-GM). The roller crimper  
434 was 2.21 m wide and weighed 600 kg. During the second cycle, four blocks of concrete (i.e.  
435 70 kg each) were added to increase the weight of the roller to 920 kg (Picture 14). The roller  
436 crimper used in the FR trial was self-built in co-operation with *L'atelier Paysan*. During the

437 first year, the ASC species composition was: ASC1: 50 % *Secale cereale* (60 kg ha<sup>-1</sup>) + 50 %  
 438 *Pisum sativum* (80 kg ha<sup>-1</sup>), ASC2: 30 % *S. cereale* (40 kg ha<sup>-1</sup>) + 40 % *Vicia faba* (80 kg ha<sup>-1</sup>) +  
 439 40 % *Vicia villosa* Roth (20 kg ha<sup>-1</sup>), and ASC3: 50 % *Hordeum vulgare* (50 kg ha<sup>-1</sup>) + 37 % *V.*  
 440 *faba* (73 kg ha<sup>-1</sup>) + 40 % *P. sativum* (67 kg ha<sup>-1</sup>). In the second year, only two of the previous  
 441 ASC compositions were sown: ASC1 - 50 % *S. cereale* (60 kg ha<sup>-1</sup>) + 50 % *P. sativum* (80 kg  
 442 ha<sup>-1</sup>), and ASC3 - 50 % *H. vulgare* (50 kg ha<sup>-1</sup>) + 37 % *V. faba* (73 kg ha<sup>-1</sup>) + 40 % *P. sativum*  
 443 (67 kg ha<sup>-1</sup>). Plot size was 10 × 6 m during the first year and 10 × 5 m during the second year.  
 444 The cash crop was butternut squash (*Cucurbita moschata* Duchesne cv. 'Ariel').



445  
 446 **Picture 14.** Machinery used for NT-RC management at the experimental organic research centre of the Groupe de  
 447 Recherche en Agriculture Biologique (GRAB) in Avignon (FR). A tractor equipped with a roller crimper and an in-  
 448 line tiller.

#### 449 **Agronomic management**

450 The trial was fertilised with 2 t ha<sup>-1</sup> of organic commercial fertiliser (AB'Flor, N-P-K: 6-7-10)  
 451 and 6 t ha<sup>-1</sup> of compost (with approximately 65 % green waste and 35 % horse manure). ASCs  
 452 were sown on October 1<sup>st</sup>, 2015 and October 11<sup>th</sup>, 2016. ASCs were terminated on April 26<sup>th</sup>,  
 453 2016 in the T-GM plots and April 28<sup>th</sup>, 2016 in the NT-RC plots, and on April 18<sup>th</sup>, 2017 in the  
 454 T-GM plots, and on April 19<sup>th</sup>, 2017 in the RC3 plots and May 16<sup>th</sup>, 2017 in the RC1 plots.  
 455 The butternut squash were manually transplanted on June 9<sup>th</sup>, 2016 and June 8<sup>th</sup>, 2017, with a  
 456 row spacing of 2 m and a 0.5 m plant spacing (Picture 15). The cash crop plants were fertilised  
 457 with commercial organic fertiliser (Dix® 9.2.2+1 MgO Italtollina). In the first year, 80 kg ha<sup>-1</sup>

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



463

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

466 In the first year, weeding operations were performed in the inter-rows of the T-GM1 and T-  
467 GM2 plots using a rototiller on June 22<sup>nd</sup>, 2016, and manual weeding was performed three times  
468 in all treatments on the 23<sup>rd</sup> of June, 12<sup>th</sup> of July and 9<sup>th</sup> of August, 2016. During the second  
469 year, manual weeding was performed twice in all treatments on the 23<sup>rd</sup> of June, and 5<sup>th</sup> of July  
470 2017. The cash crop was manually harvested on September 7<sup>th</sup>, 2016, and September 11<sup>th</sup>, 2017.  
471 More information can be found in Navarro-Miró, Iocola, et al. (2019).

## 472 **Italy (IT)**

473 Both parallel field experiments Type A (FtA) and Type B (FtB) were newly established at the  
474 Experimental Farm of Metaponto belonging to the Consiglio per la Ricerca in Agricoltura e  
475 l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT) (40° 24' N and 16° 48' E). This  
476 location represented the Mediterranean North European climatic zone. In FtA, during the first  
477 cycle (2015–2016), the mean annual temperature was 16.7 °C and the mean annual rainfall, 539

478 mm, and during the second cycle (2016–2017) these environmental factors were 16.5 °C and  
 479 402 mm, respectively. In FtB, during the first cycle (2014–2015) the mean annual temperature  
 480 was 16.6 °C and the mean annual rainfall, 470 mm, and during the second cycle (2015–2016),  
 481 these environmental factors were 16.7 °C, and 539 mm, respectively. The trial soil had a clay  
 482 texture and contained on average 1.1 % organic carbon content.

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



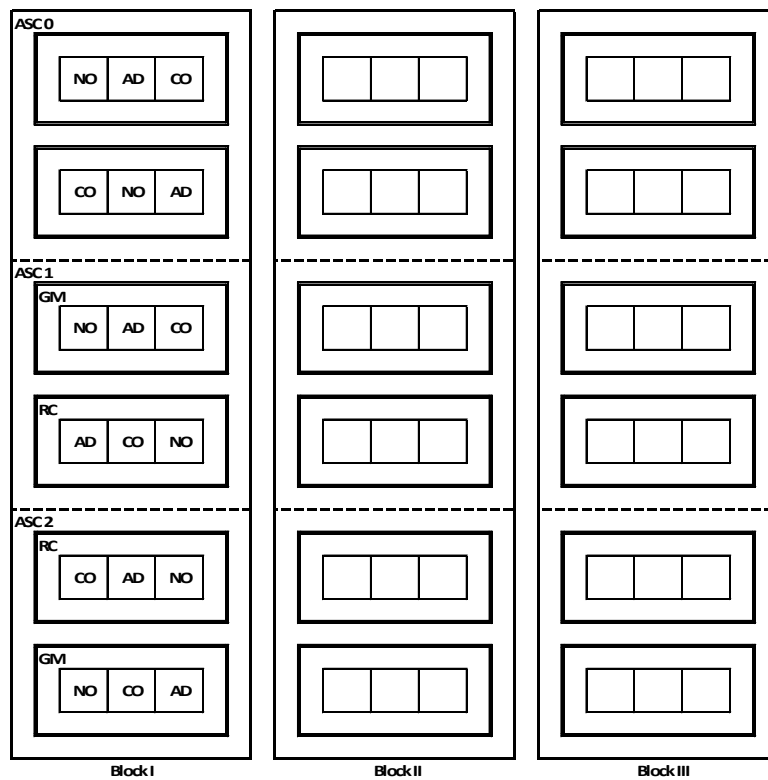
490  
 491 **Picture 16.** Machinery used for NT-RC management at the Experimental Farm of Metaponto belonging to the  
 492 Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT). A tractor  
 493 equipped with a roller crimper and in-line tiller.

## 494 **Experimental design**

### 495 **Field experiment type A**

496 The previous crop grown in the area was fennel (*Foeniculum vulgare* Mill.). The experimental  
 497 layout consisted of a split-split-plot with main plots arranged as a randomised complete block  
 498 design, with three factors and three replications. The main plot was the ASC factor, and the

499 subplot was assigned to the ASC management strategy, and the split-plot to the fertilisation  
 500 factor (Figure 12).



501

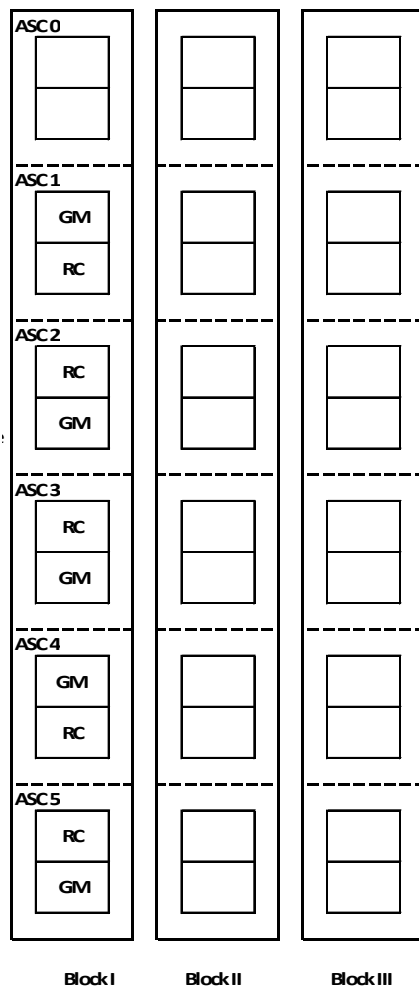
502 **Figure 12.** The FtA experimental design at the Experimental Farm of Metaponto belonging to the Consiglio per la  
 503 Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT). Termination: RC - Roller  
 504 crimper + in-line tillage to create the transplanting furrows (NT-RC); and GM - ASC chopped, ploughed under and  
 505 incorporated into the soil by milling (T-GM). ASC composition: ASC0 - Control treatment maintaining the soil  
 506 without plant cover (bare soil); ASC1 - 20 % *Hordeum vulgare* + 80 % *Vicia sativa*; and ASC2 - 20% *H. vulgare* +  
 507 80 % *Vicia faba* var. *minor*. Fertilisation factor: NO - no fertiliser; CO - Commercial organic mineral fertiliser  
 508 allowed in organic farming; and AD - Anaerobic digestate from cattle residues.

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

514 **Field experiment type B**



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



519

Block I

Block II

Block III

520 **Figure 13.** The FtB experimental design at the Experimental Farm of Metaponto belonging to the Consiglio per la  
 521 Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) in southern Italy (IT). Termination: RC - Roller  
 522 crimper + in-line tillage to create the transplanting furrows (NT-RC); and GM - ASC chopped, ploughed under and  
 523 incorporated into the soil by milling (T-GM). In 2015, the ASC compositions were: ASC1 – 100 % *Vigna*  
 524 *unguiculata*; ASC2 - 70 % *V. unguiculata* + 30 % *Pennisetum glaucum*; ASC3 - 50 % *V. unguiculata* + 50 % *P.*  
 525 *glaucum*; and ASC4 - 40 % *V. unguiculata* + 30 % *P. glaucum* + 30 % *Raphanus raphanistrum* subsp. *sativus*. In  
 526 2016, the ASC compositions were: ASC1 - 100 % *V. unguiculata*; ASC2 - 100 % *Vigna radiata*; ASC3 - 100 %  
 527 *Fagopyrum esculentum*; and ASC4 - 35 % *V. unguiculata* + 35 % *V. radiata* + 30 % *F. esculentum*. Additionally, a  
 528 control treatment (ASC0) maintaining the soil without plant cover (bare soil) was established.

529 In 2015, ASC compositions were: ASC1 - 100 % cowpea (*Vigna unguiculata* (L.) Walp.),  
530 ASC2 - 70 % cowpea + 30 % pearl millet (*Pennisetum glaucum* (L.) R.Br.), ASC3 - 50 %  
531 cowpea + 50 % pearl millet, and ASC4 - 40 % cowpea + 30 % pearl millet + 30 % radish  
532 (*Raphanus raphanistrum* subsp. *sativus* (L.) Domin). In 2016, ASC compositions were: ASC1 -  
533 100 % cowpea, ASC2 - 100 % mung bean (*Vigna radiata* (L.) R.Wilczek), ASC3 - 100 %  
534 buckwheat (*Fagopyrum esculentum* Moench), and ASC4 - 35 % cowpea + 35 % mung bean +  
535 30 % buckwheat. The cash crop was cauliflower (*Brassica oleracea* var. *botrytis* L.).

### 536 **Agronomic management**

#### 537 **Field experiment type A**

538 ASCs were sown on November 4<sup>th</sup>, 2015, and December 29<sup>th</sup>, 2016. Fertiliser was applied to  
539 plots belonging to the fertilisation treatments on April 8<sup>th</sup>, 2016 and April 26<sup>th</sup>, 2017 as follows:  
540 12 t ha<sup>-1</sup> of anaerobic digestate from cattle residues in the AD plots and 3.5 t ha<sup>-1</sup> of commercial  
541 organic mineral fertiliser allowed in organic farming in the CO plots (Figure 12). In the T-GM  
542 treatments, ASCs were chopped on April 8<sup>th</sup>, 2016 and April 26<sup>th</sup>, 2017 and ploughed under and  
543 incorporated into the soil by milling on the 18<sup>th</sup> and 19<sup>th</sup> of April 2016 and April 28<sup>th</sup>, 2017. In  
544 the NT-RC treatments, the ASCs were flattened by roller crimper on April 15<sup>th</sup>, 2016 and April  
545 26<sup>th</sup>, 2017. The tomato crop was manually transplanted on April 28<sup>th</sup>, 2016 and May 5<sup>th</sup>, 2017,  
546 with a row spacing of 1 m and a 0.40 m plant spacing (Picture 17). In the NT-RC system, ASC  
547 re-growth was mowed twice on May 10<sup>th</sup>, and 23<sup>rd</sup>, 2016. No further weed management was  
548 carried out during growth of the cash crop, whereas in the second year, inter-row weed control  
549 by mowing was carried out on the 12<sup>th</sup> of July 2017. The cash crop was drip irrigated weekly.  
550 The cash crop harvest was performed from July 7<sup>th</sup> to August 25<sup>th</sup>, 2016, and from July 18<sup>th</sup> to  
551 August 25<sup>th</sup>, 2017.



552

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

### 555 **Field experiment type B**

556 ASCs were sown on April 21<sup>st</sup>, 2015 and April 19<sup>th</sup>, 2016, and were irrigated on emergence.  
557 Commercial organic fertiliser (150 kg ha<sup>-1</sup> N, 450 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, and 150 kg ha<sup>-1</sup> K<sub>2</sub>O) was  
558 applied just before the ASC termination, whereas in the second year, fertiliser was applied  
559 during cash crop development. ASC management was carried out on July 29<sup>th</sup>, 2015, whereas in  
560 the second year, the ASC was terminated by T-GM on July 27<sup>th</sup>, 2016, and by NT-RC on July  
561 28<sup>th</sup>, 2016.

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

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

### 571 **Slovenia (SI)**

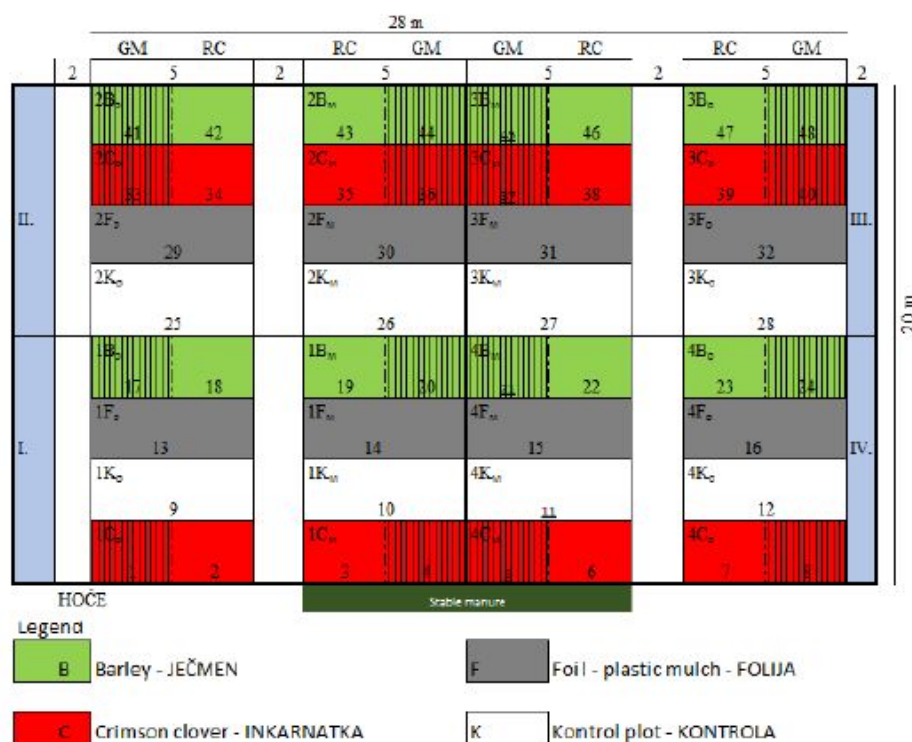
#### 572 **Field experiment type A**

**573 Experimental design**

574 The field trial was newly established at the University of Maribor (Pivola), Faculty of  
575 Agriculture and Life Sciences (UM), Slovenia (SI) (46° 30' N and 15° 37' E). This trial  
576 represented the Alpine South European climatic zone. During the first cycle (2015–2016), the  
577 mean annual temperature was 10.9 °C and the mean annual rainfall, 1,009 mm, and during the  
578 second cycle (2016–2017) these environmental factors were 11.1 °C and 961 mm, respectively.

579 The trial soil had a loam texture with an average 2.66 % organic carbon content.

580 The experiment was not repeated in the same plots in both years, and was moved to an adjacent  
581 area for the 2016–2017 cycle. The previous crop grown in the area was barley. The trial had a  
582 split-split-plot design with plots arranged in a randomised complete block design, with three  
583 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<sup>-1</sup>) before sowing ASC; and O - Without manure application.

584 The ASC species composition was: 100 % *Hordeum vulgare* (220 kg ha<sup>-1</sup>), ASC2: - 100 %  
 585 *Trifolium incarnatum* L. (35 kg ha<sup>-1</sup>), and two different controls: (1) no ASC and (2) black foil.  
 586 The two ASC termination strategies were: (1) cover crop terminated with a roller crimper + in-  
 587 line tillage (NT-RC), and (2) ASC mulched and incorporated into the soil and seedbed prepared  
 588 with a rotary harrow (T-GM). The roller crimper was 2.5 m wide and weighed 700 kg and was  
 589 created through co-operation between the Faculty of Agriculture and Life Sciences, Department  
 590 of Organic Agriculture, Crops, Vegetables and Ornamental Plants and Gorenc d.o.o. from  
 591 Spodnji Brnik in Slovenia (Picture 18). In the NT-RC plots, furrows for cash crop transplanting  
 592 were created by in-line tillage (Picture 18). The fertilisation factor had two levels: M application

593 of livestock manure (30 t ha<sup>-1</sup>) before sowing the ASCs, and O - no manure application. Plot  
594 size was 2.5 × 2.5 m. The cash crop was cauliflower (*Brassica oleracea* var. *botrytis* L.).



595

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

### 599 **Agronomic management**

600 The fertilisation treatment was performed using livestock manure (30 t ha<sup>-1</sup>) on August 27<sup>th</sup>,  
601 2015 and on August 24<sup>th</sup>, 2016. ASC1 was sown on August 31<sup>st</sup>, 2015 and on August 25<sup>th</sup>, 2016,  
602 whereas ASC2 was sown on October 26<sup>th</sup>, 2015 and October 25<sup>th</sup>, 2016. The ASCs were  
603 managed in the T-GM plots on May 19<sup>th</sup>, 2016 and on May 20<sup>th</sup>, 2016 in the NT-RC plots.  
604 During the second cycle, all plots were managed on May 18<sup>th</sup>, 2017.

605 The cauliflower crop was transplanted on June 3<sup>rd</sup>, 2016, and May 24<sup>th</sup>, 2017 with a row spacing  
606 of 0.6 m and a 0.40 m plant spacing (Picture 19). During the cash crop cycle, all plots were  
607 fertilised using commercial organic fertilisers when the cash crop was transplanted  
608 (70 kg ha<sup>-1</sup> N), and during cash crop development (70 kg ha<sup>-1</sup> N). During the second year, the  
609 cash crop was irrigated twice using micro-sprinklers. Weed management was performed  
610 manually in all treatments. During the first cycle, three weeding operations were carried out in  
611 the T-GM and control plots on June 29<sup>th</sup>, 2016, July 19<sup>th</sup>, 2016, and August 11<sup>th</sup>, 2016. In the  
612 NT-RC plots, only one operation was required (August 12<sup>th</sup>, 2016). During the second cycle,  
613 four weeding operations were carried out in the T-GM and control plots (June 19<sup>th</sup>, 2017, July

614 5<sup>th</sup>, 2017, July 26<sup>th</sup>, 2017, and August 17<sup>th</sup>, 2017), whereas in the NT-RC plots, two operations  
615 were required (July 5<sup>th</sup>, 2017 and August 9<sup>th</sup>, 2017). The cash crop harvest was performed on  
616 September 29<sup>th</sup>, 2016 and September 5<sup>th</sup>, 2017.



617

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

620 More information can be found in Bavec, Robačar, Bavec, et al. (2017), Bavec, Robačar, Lisec,  
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1 **Appendix S2.** Details of sampling procedures for Carabidae, Staphylinidae and Araneae, N  
2 leaching, beta-glucosidase, marketable yield and cash crop quality carried out in each trial.

3

#### 4 **1. Carabidae, Staphylinidae and Araneae trapping methodology**

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

7

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

##### 9 **Field experiment type A**

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

#### 15 **Denmark (DK)**

##### 16 **Field experiment type A**

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

#### 21 **Italy (IT)**

##### 22 **Field experiment type A and type B**

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

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

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

### 31 **Slovenia (SI)**

#### 32 **Field experiment type A**

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

### 39 **Spain (ES)**

#### 40 **Field experiment type B**

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

47

## 48 **2. Beta-glucosidase**

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

51

**52 Belgium - INAGRO (BE-INAGRO)****53 Field experiment type A**

54 The activity of beta-glucosidase was assessed using the method described in Alef and  
55 Nannipieri, (1995). In short, 4 ml of modified universal buffer (pH 6.0) and 1 ml of 25 mM p-  
56 nitrophenyl- $\beta$ -D-glucospyranoside solution was added to one gram of the pre-incubated moist  
57 soil. The soil suspensions were incubated for 1 h at 37 °C. After incubation, 1 ml of CaCl<sub>2</sub> and 4  
58 ml of Tris buffer (pH 12.0) were added. If needed, soil suspensions were diluted twice with Tris  
59 buffer (pH 10.0) to make the filtrates fit the range of the p-nitrophenol standard series. The  
60 colour intensity of the filtrates and standard series was measured at 400 nm with a Cary 50 UV-  
61 Visible spectrophotometer (Varian Inc., Palo Alto, United States).

**62 Denmark (DK)****63 Field experiment type A**

64 Beta-glucosidase activity was measured by adding 1 ml of 25 mM p-nitrophenyl- $\beta$ -D-glucoside  
65 solution and 4 ml of modified universal buffer to two technical replicates of 1 g of sieved soil  
66 (fresh weight). The samples were incubated at 37 °C for 1 h. P-nitrophenyl- $\beta$ -D-glucoside  
67 solution was added to the control samples after incubation. Subsequently, 1 ml of 0.5 M CaCl<sub>2</sub>  
68 and 4 ml of Tris-buffer pH 12 were added to the samples, which were then filtered immediately  
69 using Whatman n°. 5 papers. Released p-nitrophenol in the extract was determined by  
70 measurement of the optical density with a Varian Cary 50 spectrophotometer at 400 nm. Beta-  
71 glucosidase activity was determined as the difference between experimental and control  
72 samples.

**73 Italy (IT)****74 Field experiment type A**

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

77

**78 3. N leaching**

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

81

**82 Belgium - Walloon Agricultural Research Center (BE-CRA-W)****83 Field experiment type A**

84 The mineral nitrogen content was assessed using a soil depth of 0.3 m because the dry weather  
85 did not allow us to sample more deeply. Six samples were collected per plot area and mixed into  
86 one composite sample. Soil mineral nitrogen, measured when the cash crop was harvested, was  
87 extracted by 0.5 M KCl (1:5, w/v) and measured by continual flow colourimetry according to  
88 QuickChem® Method 12-107-06-3-B and QuickChem® Method 12-107-04-1-B for  $\text{NH}_4^+\text{-N}$   
89 and  $\text{NO}_3^-\text{-N}$ , respectively.

**90 Belgium - INAGRO (BE-INAGRO)****91 Field experiment type A**

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

**96 Denmark (DK)****97 Field experiment type A**

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

104  $\text{NH}_4^+$  and  $\text{NO}_3^-$  analyses using standard colorimetric methods with an AutoAnalyzer 3  
105 (Bran+Luebbe, Germany).

106 **Estonia (EE)**

107 **Field experiment type A**

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

113 **Italy (IT)**

114 **Field experiment type A**

115 Soil mineral nitrogen, measured when the cash crop was harvested, was extracted in 2-M KCl  
116 (1:10, w/v) and measured using continual flow colourimetry according to Krom (1980) and  
117 Henriksen and Selmer-Olsen (1970) for  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N, respectively. All the soil  
118 laboratory tests were carried out in triplicate to control for intra-laboratory variability.

119

120 **4. Marketable yield**

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

123

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

125 **Field experiment type A**

126 The cabbage marketable yield was estimated on two days (October 25<sup>th</sup> and 26<sup>th</sup>, 2017) by  
127 evaluating 21 cabbages per plot selected in the centre of the plot along three central lines. The  
128 marketable heads was assessed by measuring the dry matter ( $\text{t ha}^{-1}$ ; 60 °C until constant weight).

129 The minimum diameter of the cabbage head considered as marketable was 130 mm.

130 **Belgium - INAGRO (BE-INAGRO)**

131 **Field experiment type A**

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

134 **Denmark (DK)**

135 **Field experiment type A**

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

138 **Estonia (EE)**

139 **Field experiment type A**

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

142 **Spain (ES)**

143 **Field experiment type A**

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

148 **Field experiment type B**

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

151 **France (FR)**

152 **Field experiment type A**

153 In both years, we measured the yields of 10 plants per plot  $\times$  4 plots per treatment.

154 **Italy (IT)**

155 **Field experiment type A**

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

#### 161 **Field experiment type B**

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

165

#### 166 **5. Cash crop quality**

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

169

#### 170 **Belgium - Walloon Agricultural Research Center (BE-CRA-W)**

##### 171 **Field experiment type A**

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

#### 175 **Estonia (EE)**

##### 176 **Field experiment type A**

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

#### 179 **Spain (ES)**

##### 180 **Field experiment type A**



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

#### 185 **Field experiment type B**

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

#### 188 **France (FR)**

##### 189 **Field experiment type A**

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

#### 192 **Italy (IT)**

##### 193 **Field experiment type A**

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

##### 196 **Field experiment type B**

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

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

2 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-  
 3 GM) of agroecological service crop (ASC) management strategies. We combined results from 11 organic arable vegetable field trials located in Belgium (BE), Denmark (DK),  
 4 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  
 5 parallel field experiment types were carried out: FtA - Spring-summer cash crop and FtB- Autumn-winter cash crop.

Country	Trial	Termination	Ecological indicators			Environmental indicators			Agronomic indicators			
			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
ES	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
IT	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			

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

8 DK:  $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$ ; IT:  $\text{nmol 4-MUF g}^{-1} \text{ h}^{-1}$ ). Agronomic indicators: Weed density (individuals  $\text{m}^{-2}$ ); Marketable yield ( $\text{t ha}^{-1}$ ); Cash crop quality (cash crop quality indicator included  
9 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.