REPORTS 165

CHARACTERISTICS OF VARIOUS CATCH CROPS IN THE ORGANIC VEGETABLE PRODUCTION IN NORTHERN CLIMATE CONDITIONS – RESULTS FROM AN ON-FARM STUDY

SARI IIVONEN, PIRJO KIVIJÄRVI AND TERHI SUOJALA-AHLFORS
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CONTENTS

ABSTRACT ........................................................................................................................................................................... 7
TIIVISTELMÄ......................................................................................................................................................................... 9

INTRODUCTION ................................................................................................................................................................... 9

MATERIAL AND METHODS .................................................................................................................................................. 10
Experimental design and crop management .................................................................................................................. 10
Soil sampling and analyses ............................................................................................................................................... 10
Plant sampling and analyses ........................................................................................................................................... 12
Climatic data ....................................................................................................................................................................... 12

RESULTS AND DISCUSSION................................................................................................................................................ 14
Dry matter yield and nutrient content of catch crops ...................................................................................................... 14
Autumnal impacts of catch crops on soil soluble N ......................................................................................................... 16
Impacts of catch crops on soil fertility and on the yield of a succeeding carrot crop ......................................................... 18

CONCLUSIONS .................................................................................................................................................................. 23

REFERENCES ...................................................................................................................................................................... 24

TABLES
Table 1. Typical properties of the different catch crop species tested in the field trial ...................................................... 10
Table 2. Results of the soil analysis before sowing of the catch crops ............................................................................. 11
Table 3. Nutrient concentrations in above-ground catch crop biomasses on the 9th of October .............................. 15
Table 4. Nutrient contents in above-ground catch crop biomasses on the 9th of October .............................................. 16
Table 5. The total amount of soil soluble N at a soil depth of 0–50 cm on different dates .............................................. 18
Table 6. Nutrient concentrations of carrot roots and shoots at harvest time in the control and Italian ryegrass treatment ....................................................................................................................................................... 21

FIGURES
Figure 1. Illustration of the experimental design ............................................................................................................... 11
Figure 2. Average monthly air temperature during experiment period in 2014-2015 and long-term average monthly air temperature .................................................................................................................. 13
Figure 3. Monthly precipitation and average long-term monthly precipitation ........................................................................... 13
Figure 4. Dry mass yield of various catch crops on the 9th of October ........................................................................... 14
Figure 5. Soluble N contents at a soil depth of 0–10 cm in various catch crop and control treatments ........................................... 17
Figure 6. Soluble N contents at a soil depth of 10–25 cm in various catch crop and control treatments ........................................... 17
Figure 7. Soluble N contents at a soil depth of 25–50 cm in various catch crop and control treatments ........................................... 17
Figure 8. Ammonium-N contents in the carrot field at soil depths of 0–25 cm (A) and 25–50 cm (B) in early June and late July 2015 ........................................................................................................................................... 19
Figure 9. Nitrate-N contents in the carrot field at soil depths of 0–25 cm (A) and 25–50 cm (B) in early June and late July 2015 ........................................................................................................................................... 19
Figure 10. Marketable and total yield (fresh mass) of carrot roots. Data are means (± SD) of three replicates ........................................................................................................................................................................... 20
Figure 11. Root/shoot -ratio of carrots at harvest time after different catch crop treatments.......................................... 22
ABSTRACT

Catch crops are generally grown during the period between two main crops to prevent nutrient leaching and thus reduce nutrient losses from the system. Catch crops in Finnish organic vegetable farms are sown after the incorporation of green manure crop to the soil or after the harvesting of vegetable crops with early harvesting times. Knowledge on the ability of various catch crops in preventing nutrient leaching in vegetable farms located in northern latitudes is still scarce. We also have very limited knowledge of the effect of catch crops on the yield of the succeeding vegetable crop.

The aim of our on-farm study was to investigate the ability of contrasting catch crops, i.e. Italian ryegrass (*Lolium multiflorum*), phacelia (*Phacelia tanacetifolia*), white mustard (*Sinapis alba*) and radish (*Raphanus sativus*) in producing above-ground biomass, collecting nutrients and preventing leaching after broccoli (*Brassica oleracea var. italica* L.) harvesting in a commercial organic vegetable farm. Our second aim was to study the effects of various catch crops on the yield and nutrient status of a succeeding organic carrot (*Daucus carota subsp. sativus* L.) crop.

Our results show differing capabilities of various catch crop species in producing above-ground biomass and preventing nitrogen leaching. White mustard reached the highest aboveground dry matter yield, 1416 kg/ha, which was higher than that of Italian ryegrass, phacelia and radish. The dry mass of phacelia (933 kg/ha) was also clearly higher than that of Italian ryegrass and radish, which yielded only 291 kg/ha and 277 kg/ha, respectively. Mustard, phacelia and Italian ryegrass could prevent autumnal nitrogen leaching by 40–49 kg/ha. The weak performance of the radish catch crop after broccoli cultivation was an unexpected phenomenon. This experiment should be repeated to confirm the suppressive effect of broccoli on radish growth. The catch crop effect on the succeeding organic carrot crop was most negative for Italian ryegrass, and varied from negative (phacelia) to neutral (mustard) for the other tested catch crop species. Our study suggests that the utilization of efficient catch crops during crop rotation prevents soluble nutrient leaching from the organic field, but may have negative impacts on the productivity of succeeding vegetable crops.
TIIVISTELMÄ

KERÄÄJÄKASVILAJIEN VERTAILUA LUOMUVIHANNESTILALLA – TILAKOKEEN TULOKSIA SUOMEN KASVUOLOISSA

Kerääjäkasvilla tarkoitetaan kasvustoa, joka kerää biomassaansa viljelykasvin maahan jättämää ja viherlannoituksesta vapautuvia ravinteita ja suojaa maata lisäämällä kasvipeitteisyyttä. Luomuvihannestiloilla kerääjäkasvit kylvetään yleensä viherlannoituskasvuston päätämisen tai varhaisvihannesten sadonkorjuun jälkeen. Suomen kasvuloisissa tuotettua tietoa eri kerääjäkasvilajien hyödyistä ravinteiden kerääjinä ja niiden esikasvivaikutuksen seuraavana vuonna kasvatettavalle vihannekselle on olemassa vain vähän.

Tämän tilatutkimuksen tavoitteena oli tutkia kerääjäkasviksi kylvetyn italianraiheinän (Lolium multiflorum), hunajakukan (Phacelia tanacetifolia), valkosinapin (Sinapis alba) ja öljyretikan (Raphanus sativus) maanpäällisen biomassan tuottoa, ravinteiden sitomiskykyä ja liukoisen typpen huuhtoutumisen estovaikutusta heinäkuussa korjauttuun luomuparsakaalin jälkeen. Toisena tavoitteena oli tutkia kerääjäkasvisen esikasvivaikutusta seuraavana vuonna kasvatettavalle luomuporkkanalle.

Tulokset osoittavat, että testatut kerääjäkasvit eroavat selvästi kyyvissä kasvatettua maanpäällistä biomassaa ja estää liukoisen typpen huuhtoutumiseta. Valkosinappi tuotti suurimman maanpäällisen kuivamassan, 1416 kg/ha. Hunajakukan kuivamassaa (933 kg/ha) oli myös selvästi korkeampi kuin italienrheiheinän ja öljyretikan, jotka tuottivat 291 kg/ha ja 277 kg/ha maanpäällistä kuivamassaa. Valkosinappi, hunajakukka ja italianrheiheinä pystyivät estämään liukoisen typpen huhtoutumista maasta syksyllä 40–49 kg/ha. Öljyretikka taimetti erittäin heikosti tuottaa vaatimattoman maanpäällisen biomassan. Öljyretikan heikko taimettuminen paraskaalin jälkeen on ilmiö, joka saattaa johtua parasakaalin sadonkorjuujätteiden negatiivisesta vaikutuksesta öljyretikan siemenen itämiseen.

INTRODUCTION

Catch crops are generally grown during the period between two main crops to prevent nutrient leaching. In Finnish organic vegetable farms catch crops are sown after the incorporation of green manure crop to the soil or after the harvesting of vegetable crops with early harvesting times. If climate change proceeds as expected in northern latitudes, a warmer winter period with higher wintertime precipitation will lead not only to increasing nutrient leaching but also to water erosion of the agricultural land uncovered by vegetation such as catch crops (ICPP 2007). Nitrogen losses from the open-field vegetable farming systems can be moderate to high (Di and Cameron 2002, Torstensson and Sandin 2010, Cameron et al. 2013) and there is need to improve the nutrient use efficiency of the system. Although organic farming systems avoid the use of mineral nitrogen (N) fertilizers, N leaching occurs because a high amount of N can be released from the organic matter by nitrogen mineralization. Nutrient management in organic systems could be improved by optimizing nutrient utilization and recycling in the system and by minimizing nutrient losses from the system with the aid of catch crops (Thorup-Kristensen et al. 2012).

Properties of catch crops differ in their capacity to produce above- and belowground biomass, growth rate, the depth and structure of the root system, nutrient uptake capacity and the carbon/nitrogen (C/N)-ratio of the biomass. All these properties have an impact on the efficiency of the catch crop in preventing nutrient leaching along with its ability to release nutrients for the succeeding main crop. In general, a rapid establishment of a deep root system has been considered a feature of an efficient catch crop (Thorup-Kristensen 2001, Thorup-Kristensen et al. 2009), although the size of the root system does not solely determine its nutrient uptake capacity. The rapid formation of above-ground biomass with the capacity to compete with weeds is also a valuable property of the catch crop, especially in an organic vegetable farm.

In northern latitudes, the growing period is characterized by a relative small sum of degree-days and a long day length. These climate conditions determine the framework for the vegetable production system, allowing a relatively limited period for catch crop utilization. Knowledge is still scarce concerning the ability of various catch crops in preventing nutrient leaching on vegetable farms located in northern latitudes.

The catch crop effect on the succeeding main crop varies from positive to negative, being determined by several factors such as rooting depth of the catch crop and the succeeding vegetable crop, the overall demand of the succeeding vegetable for nutrients and its growth rhythm (Pedersen et al. 2009, Thorup-Kristensen 2006b). A negative effect can be achieved when a catch crop is incorporated into the soil late in spring, shortly before the sowing or planting of the succeeding main crop (Williamson and Thorup-Kristensen 2001, Thorup-Kristensen and Dresboll 2010). This is due to the slow net mineralization of nutrients included in the incorporated biomass. The net mineralization rate of nitrogen from the incorporated biomass depends on the nitrogen content of the biomass (Jensen et al. 2005), the carbon/nitrogen (C/N) -ratio of biomass along with soil biological activity, which is closely related to soil temperature and moisture. In general, the lower the C/N -ratio, the greater the net release of N (Constantin et al. 2011). For example, leguminous plants typically have a low C/N -ratio, while mustards, oil radish and phacelia have intermediate and ryegrasses have high C/N -ratios (Constantin et al. 2011).

Substantial nutrient losses may occur during winter in cold-winter regions. The repeated freezing-thawing cycles in the agricultural fields without permanent snow cover accelerate the releasing of nutrients from the catch crop residues. Various plant species exhibit clear differences in frost resistance. For example, brassicas, such as white mustard and oilseed radish, more readily release nutrients after frost compared to phacelia (Liu et al. 2013).

The aim of our on-farm study was to investigate the ability of contrasting catch crops (Table 1), i.e. Italian ryegrass, phacelia, white mustard and radish in producing aboveground biomass and in collecting nutrients and preventing leaching after broccoli harvesting in a commercial organic vegetable farm. The second aim was to study the effects of various catch crops on the yield and nutrient status of the succeeding organic carrot crop.
MATERIAL AND METHODS

EXPERIMENTAL DESIGN AND CROP MANAGEMENT

The study site was located on a commercial organic vegetable farm in the South-Savo region of eastern Finland. The soil type was fine sand moraine (according to the Finnish soil classification scheme) with 6–12% of organic matter. The field has been managed according to organic farming practices since 1995. The catch crop experiment was established on a field plot where broccoli was harvested in mid-July 2014. The broccoli residues were mixed into the soil using a rototiller on the 31st of July, and the soil was ploughed before sowing of the catch crops.

On the 18th of August four catch crop treatments and a control bare fallow treatment were established on five neighbouring strips running 201 m in length and 12 m in width (control 6 m in width) under uniform soil conditions (Figure 1.). Four different plant species were chosen for the catch crop testing (Table 1.). Seeding rates were 25 kg ha⁻¹ for Italian ryegrass (Lolium multiflorum ‘Meroa’; germination rate 96%), 15 kg ha⁻¹ for phacelia (Phacelia tanacetifolia L. ‘Balo’; germination rate 54%), 20 kg ha⁻¹ for white mustard (Sinapis alba L. var. Achilles; germination rate 91%) and 15 kg ha⁻¹ for radish (Raphanus sativus var. oleiformis ‘Farmer’; germination rate 82%).

Catch crop residues were ploughed into the soil to a 20-cm depth on the 12th of May. Boron fertilizer was applied at a rate of 100 kg/ha and harrowed into the soil. Carrot varieties were sown (seeding density 60 seeds per row metre) to the field plot on the 1st of June and harvested on the 3rd of September. Carrot rows were located perpendicular to the catch crop strips so as to cross the strips. In our study the measurements focused on the ‘Excelso’ variety, which was sown in 40 rows. The first row was located at a 30-m distance and the last row at a 60-m distance from the field edge.

SOIL SAMPLING AND ANALYSES

Soil sampling was conducted by compiling a pooled sample from seven points (forming the letter W) of the field plot at the beginning of August before establishment of the catch crops (Table 2). After the catch crop strips were established, soil sampling was systematically performed for each catch crop treatment in September and October from strip plot points measured at distances of 20, 40, 60, 80 and 100 m from the field edge along the strip centres. The soil samples were taken from each sample point at 0–10 cm, 10–25 cm and 25–50 cm depths using an auger with a diameter of 3 cm. The 5–7 soil samples of each depth were pooled, mixed and frozen until analysed.

<table>
<thead>
<tr>
<th>Catch crop</th>
<th>Root depth</th>
<th>Carbon/Nitrogen -ratio of biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italian ryegrass</td>
<td>Shallow</td>
<td>High</td>
</tr>
<tr>
<td>Phacelia</td>
<td>Intermediate</td>
<td>Intermediate</td>
</tr>
<tr>
<td>White mustard</td>
<td>Deep</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Radish</td>
<td>Deep</td>
<td>Low</td>
</tr>
</tbody>
</table>
Table 2. Results of the soil analysis before sowing of the catch crops. Description is based on Finnish soil quality classification terminology (Aaltonen 1997).

<table>
<thead>
<tr>
<th>Nutrient element</th>
<th>Soil depth 0–10 cm</th>
<th>Soil depth 10–25 cm</th>
<th>Soil depth 25–50 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg l⁻¹*</td>
<td>Description</td>
<td>mg l⁻¹*</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.08</td>
</tr>
<tr>
<td>Soluble N</td>
<td>16.5</td>
<td>11.8</td>
<td>9</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>2000</td>
<td>good</td>
<td>1600</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>21</td>
<td>good</td>
<td>19</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>270</td>
<td>good</td>
<td>130</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>200</td>
<td>good</td>
<td>160</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>31</td>
<td>good</td>
<td>13</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>1.1</td>
<td>good</td>
<td>1.2</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>6.4</td>
<td>good</td>
<td>8.1</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>5.2</td>
<td>acceptable</td>
<td>4.9</td>
</tr>
<tr>
<td>pH</td>
<td>6.5</td>
<td>good</td>
<td>6.5</td>
</tr>
</tbody>
</table>

* except pH and N. N is marked as percentage.
PLANT SAMPLING AND ANALYSES

The above-ground biomass samples of the catch crops were taken on the 10th of October 2014 just prior to the first below-freezing night. Catch crop samples were systematically taken for each treatment from strip plot points measured at distances of 20, 40, 60 and 80 m from the field edge along the strip centres using a 0.25-m² frame (Figure 1). Plant samples were collected by cutting plants at the soil surface.

Each sample was first divided into catch crops and weeds, then separately weighed and dried at 60 °C for two days before dry matter determination. Nutrient concentrations of the catch crop biomass were determined from the pooled sample for each species by a commercial and accredited laboratory (Eurofins Viljavuuspalvelu Ltd) using the ISO/IEC 17025 method.

The carrot crop yield samples were systematically collected from three different points in each catch crop treatment. The sampling points (2 row meter) were evenly spaced out ten metres apart from each other and running along the strip centres (Figure 1). The yield samples were sorted into marketable and non-marketable carrots. Non-marketable carrots included small (diameter <2 cm), cracked, diseased or pest-damaged vegetables. Total root yield (kg ha⁻¹) was counted by summing the non-marketable and marketable yields.

Seven carrots were randomly sampled from the same rows near the yield samples for root nitrate and nutrient analyses. Above- and below-ground masses were weighed separately and dried at 60 °C for two days before dry matter determination. Nutrient concentrations of the carrot canopy and roots were determined from the pooled samples of each catch crop treatment by a commercial and accredited laboratory (Eurofins Viljavuuspalvelu Ltd) using the ISO/IEC 17025 method.

CLIMATIC DATA

The weather data were collected from the official weather station of the Finnish Meteorological Institute at Mikkeli, which is situated in the same region (Figures 2-3).
Figure 2. Average monthly air temperature during experiment period in 2014-2015 and long-term average monthly air temperature. The weather data were collected from the official weather station of the Finnish Meteorological Institute at Mikkeli.

Figure 3. Monthly precipitation and average long-term monthly precipitation. The weather data were collected from the official weather station of the Finnish Meteorological Institute at Mikkeli.
RESULTS AND DISCUSSION

DRY MATTER YIELD AND NUTRIENT CONTENT OF CATCH CROPS

Catch crop species developed at different rates in autumn. By harvest time white mustard had reached the pre-flowering stage and the crop was fully stocked. Phacelia was concurrently fully stocked with some foliage leaves. Italian ryegrass had reached tillering stage by harvest time, but the crop was still relatively low. The fodder radish crop was still very sparse due to very weak emergence of seedlings.

The above-ground dry matter yield differed remarkably between the catch crop species as a consequence of differences in their development rates. White mustard reached the highest above-ground dry matter yield, 1416 kg/ha (Fig. 4). The dry mass of phacelia (933 kg/ha) was also clearly higher than that of Italian ryegrass and radish, which yielded only 291 kg/ha and 277 kg/ha, respectively. Contrary to several other studies (Stivers-Young 1998, Thorup-Kristensen 2001), the biomass production of radish remained extremely low due to very weak germination. It is well-documented that during their decomposition cruciferous plant residues can excrete compounds that have allelopathic or toxic properties capable of inhibiting the seed germination of certain species (Oleszek 1987). Broccoli residues in the soil have also been shown to be phytotoxic to other horticultural plants such as cruciferous cauliflower (Santos and Leskovar 1997) and lettuce (Patrick et al. 1963). We suggest that the weak establishment of the oil radish crop could have been a consequence of harmful allelochemicals produced by broccoli residues. These results indicate that oil radish cannot be recommended for use as a catch crop after broccoli harvest without reservation.

Knowledge of the biomass accumulation of catch crops in organic rotations in Finnish climate conditions is very scarce. However, some studies from more favourable climate conditions could be considered as references. The above-ground dry matter production of phacelia with an equal length of growth period was over three times higher (3000 kg/ha) in more favourable weather conditions in Poland (Zaniewicz-Bajkowska et al. 2013). White senf mustard (Brassica hirta) and phacelia sown after a lettuce harvest in early September produced 2200 kg/ha and 1400 kg/ha dry matter by mid-November in western New York (US) (Stivers-Young 1998). White mustard sown in mid-July after an organic potato harvest produced 6415 kg/ha of biomass by early November in south Sweden (Larsson et al. 2010). An estimated dry matter yield of white mustard in our study would be approximately 1300 kg/ha when biomass is converted to dry matter using a dry matter percent of 20%. In 2010 we con-

![Figure 4.](image-url)  
Dry mass yield of various catch crops on the 9th of October 2014 (sown on the 18th of August). Data are means ± SD of four replicates.
ducted a catch crop experiment on a conventional Finnish vegetable farm. Oat and a seed mixture of mustards and oil radish were sown in mid-July after harvesting of iceberg lettuce. Green mass samples were collected in mid-October. The dry matter yields were 3200 and 7000 kg/ha, respectively (Tuomola et al. 2012). It is obvious that an earlier sowing date would have facilitated a higher biomass yield of mustard, phacelia and Italian ryegrass in our study.

Nitrogen contents of the catch crop biomasses differed clearly. Biomass production did not solely predict nitrogen accumulation to the biomass because of varying capacities of the catch crop species in taking up nutrients. White mustard and radish had clearly higher N concentrations (4.1–5.3 %) compared to Italian ryegrass (3.3%) and phacelia (3.6%). However, these nitrogen concentrations were all high enough to allow direct N mineralization and N release from the biomass (Lewis 1986). Other studies have reported much lower nitrogen concentrations in catch crops. The mean N concentration in the shoots of phacelia was 1.55%, and 1.47% for yellow mustard grown as a catch crop after spring wheat (Herrera et al. 2010). The high N concentrations in the catch crops can be explained by their short growing time, and thus the juvenile developmental stage of the crop at sampling time. Very high nutrient availability in the soil after the broccoli crop could be another explanation. Nitrogen accumulation in white mustard, phacelia and Italian ryegrass above-ground biomasses in our study amounted to 57 kg/ha, 33 kg/ha and only 9.5 kg/ha, respectively. Salo et al. (1998) documented a nitrogen yield of 10–30 kg/ha in the ryegrass crop sown after a cauliflower harvest in August in Finland. A much higher nitrogen yield, 50 kg N/ha, has earlier been measured in a phacelia catch crop in Finland (Boberg 1997), which also confirms our results.

Our study lacks the examination of biomass and nutrient allocation to the root system. Below- and above-ground biomass allocation patterns are known to be species-specific. Phacelia has an extensive root type, and as much biomass can be allocated to the root system compared to the above-ground organs (Liu et al. 2013). Biomass allocation to the root system is more extensive in phacelia compared to white mustard (Liu et al. 2013). Italian ryegrass as a catch crop can allocate a remarkable amount (35%) of its total biomass to the root system (Thorup-Kristensen 2001, Thomsen et al. 2010), and root growth can continue for a long time in autumn in northern climatic conditions (Pietola & Alakukku 2005).

Macro- and micronutrient concentrations in catch crop biomasses varied depending on plant species (Table 3). All tested macro- and micronutrient contents in above-ground biomasses on the harvesting date (9th of October) were affected by the catch crop species. N, phosphorus (P), potassium (K), calcium (Ca), boron (B) and copper (Cu) contents were higher in phacelia and white mustard crops compared to the Italian ryegrass and radish crops (Table 4.). The significantly highest contents of N, K, sulphur (S) and zinc (Zn) were reached in

<table>
<thead>
<tr>
<th>Nutrient element</th>
<th>Italian ryegrass</th>
<th>Phacelia</th>
<th>White mustard</th>
<th>Radish</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>g kg⁻¹ dry mass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>32.5</td>
<td>35.8</td>
<td>40.6</td>
<td>52.8</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>4</td>
<td>6.2</td>
<td>5</td>
<td>5.6</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>27</td>
<td>50</td>
<td>49</td>
<td>41</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>4</td>
<td>32</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>2.1</td>
<td>4.3</td>
<td>3.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>2.6</td>
<td>3.3</td>
<td>8.5</td>
<td>6.2</td>
</tr>
<tr>
<td><strong>mg kg⁻¹ dry mass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>2100</td>
<td>260</td>
<td>260</td>
<td>520</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>4.7</td>
<td>23</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>13</td>
<td>12</td>
<td>6.6</td>
<td>7</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>77</td>
<td>34</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>43</td>
<td>23</td>
<td>54</td>
<td>42</td>
</tr>
</tbody>
</table>
the white mustard crop. Cruciferous catch crops, such as mustard, have a higher demand of S and therefore also the ability to deplete soil sulphate during the autumn and prevent S leaching (Eriksen and Thorup-Kristensen 2002).

**AUTUMNAL IMPACTS OF CATCH CROPS ON SOIL SOLUBLE N**

We did not directly measure nutrient leaching in our experiment. Soluble inorganic N soil concentration was used as an indirect indicator of the effect of growing catch crops in the prevention of nitrogen leaching, as in many previous studies (Stivers-Young 1998, Thorup-Kristensen 2006b). The soluble N fraction consists of ammonium- and nitrate-N. The ammonium concentration in most soils is usually low because it can rapidly be converted to nitrate, and nitrate is the N form most susceptible to leaching (Di and Cameron 2001).

<table>
<thead>
<tr>
<th>Nutrient element</th>
<th>Italian ryegrass</th>
<th>Phacelia</th>
<th>White mustard</th>
<th>Radish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>9.5</td>
<td>33.4</td>
<td>57.5</td>
<td>14.6</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>1.2</td>
<td>5.8</td>
<td>7.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>7.9</td>
<td>46.7</td>
<td>69.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>1.1</td>
<td>29.9</td>
<td>24.1</td>
<td>6.6</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>0.6</td>
<td>4.0</td>
<td>4.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>0.8</td>
<td>3.1</td>
<td>12.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>0.6</td>
<td>0.2</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>0.001</td>
<td>0.021</td>
<td>0.028</td>
<td>0.006</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.004</td>
<td>0.011</td>
<td>0.009</td>
<td>0.002</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.022</td>
<td>0.032</td>
<td>0.033</td>
<td>0.009</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>0.013</td>
<td>0.021</td>
<td>0.076</td>
<td>0.012</td>
</tr>
</tbody>
</table>

We examined the autumnal development of soil soluble N contents at three different soil depth layers. At a soil depth of 0–10 cm, soluble N content increased in the control and radish treatments until mid-September, and thereafter decreased reaching the same level as all the other catch crop treatments (Fig. 5). At a soil depth of 10–25 cm, soluble N content reached its highest level in the radish treatment, while the second highest level was reached in the control treatment in mid-September (Fig. 6). At a soil depth of 25–50 cm, soluble N concentration was highest in the control and radish treatments in mid-September and remained at a higher level compared to other catch crop treatments until mid-October (Fig. 7). The total amounts of soil soluble N at a soil depth of 0–50 cm in mid-September were 108 kg/ha and 117 kg/ha in the control and radish treatments, respectively (Table 5). In other catch crop treatments, the amount of soil soluble N varied between 59 kg/ha and 68 kg/ha in mid-September.
CHARACTERISTICS OF VARIOUS CATCH CROPS IN THE ORGANIC VEGETABLE PRODUCTION IN NORTHERN CLIMATE CONDITIONS – RESULTS FROM AN ON-FARM STUDY – SARI IIVONEN, PIRJO KIVIJÄRVI AND TERHI SUOJALA-AHLFORS

Figure 5. Soluble N contents at a soil depth of 0–10 cm in various catch crop and control treatments.

Figure 6. Soluble N contents at a soil depth of 10–25 cm in various catch crop and control treatments.

Figure 7. Soluble N contents at a soil depth of 25–50 cm in various catch crop and control treatments.
several factors affect the net mineralization rates of the succeeding crop is an optimal target. However, biomass synchronized with the nutrient demand of Well-balanced nutrient release from the catch crop A SUCCEEDING CARROT CROP FERTILITY AND ON THE YIELD OF IMPACTS OF CATCH CROPS ON SOIL

Table 5. The total amount of soil soluble N at a soil depth of 0–50 cm on different dates.

<table>
<thead>
<tr>
<th>Date</th>
<th>Control</th>
<th>Italian ryegrass</th>
<th>Phacelia</th>
<th>White mustard</th>
<th>Radish</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th of August</td>
<td>57</td>
<td>57</td>
<td>57</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>12th of September</td>
<td>108</td>
<td>66 (-42)</td>
<td>59 (-49)</td>
<td>68 (-40)</td>
<td>117 (+9)</td>
</tr>
<tr>
<td>9th of October</td>
<td>53</td>
<td>49 (-4)</td>
<td>45 (-8)</td>
<td>53 (+0)</td>
<td>74 (+21)</td>
</tr>
</tbody>
</table>

The total amount of soil soluble N at a soil depth of 0–50 cm on different dates.

The maximum soil depth during the soil examination was 50 cm, which is deeper than the mean root depth of the examined catch crops sown in August that had such short growing times in earlier studies. Herrera et al. (2010) reported a mean rooting depth of 39–42 cm for phacelia and white mustard, developed when the cumulative growing degree days of the catch crops varied from 1122 to 1072. The estimated temperature sum (daily average above 0 °C) needed for the catch crops to reach a rooting depth of 50 cm varied from 600 d.d. for phacelia to 950 d.d. for Italian ryegrass (Thorup-Kristensen 2001). In our experiment the cumulative degree days from catch crop sowing until harvesting were 494 d.d., which may indicate that the majority of the root system was located in soil at a depth of less than 50 cm.

Concentrations of soil soluble N tended to increase in the control (bare fallow) and radish plots by mid-September, whereas they remained at lower levels in the white mustard, phacelia and Italian ryegrass plots. This indicates that white mustard, phacelia and Italian ryegrass were capable of taking up potentially leachable nitrogen from the soil. The decrease in soil inorganic N concentrations in bare fallow and oilseed radish plots may indicate N leaching to deeper soil layers and probably also leaching losses during the autumn. According to these results, the potential leaching losses of soluble N to lower soil layers where it is unreachable by short-rooted plants could be approximately 40–50 kg/ha. This is of the same order of magnitude as for catch crops measured at a conventional vegetable farm in Finland. According to Tuomola et al. (2012), the catch crop sown in mid-July after iceberg lettuce harvesting could decrease the soil N content at a depth of 0–60 cm by 50 kg/ha in the autumn.

IMPACTS OF CATCH CROPS ON SOIL FERTILITY AND ON THE YIELD OF A SUCCEEDING CARROT CROP

Well-balanced nutrient release from the catch crop biomass synchronized with the nutrient demand of the succeeding crop is an optimal target. However, several factors affect the net mineralization rates of nutrients in the soil system, and therefore the catch crop effect on the succeeding main crop varies.

We examined the effects of catch crops on the amount of soil ammonium-N and nitrate-N in early and mid-summer. The amount of ammonium-N at soil depths of 0–25 varied from 7.5–12.5 kg/ha in early June (Fig. 8A). The amount of ammonium-N at soil depths of 25–50 varied from 5–10 kg/ha in early June, being lowest in the Italian ryegrass plot and highest in the oil radish plot (Fig. 8B). The variation in content is so small that it is impossible to see any remarkable differences. In addition, these results are produced using one pooled soil sample only per treatment and therefore results need to be interpreted with caution.

Amount of nitrate-N at soil depths of 0–25 varied from 22.5–27.5 kg/ha in early June (Fig. 10A). The lowest value (22.5 kg/ha) represents the lowest detectable value given by a commercial laboratory, and thus the real value can be lower than that in practice. The highest amount (27.5 kg/ha) was measured in the radish treatment.

Ammonium- and nitrate-N contents were quite uniform in all treatments at the beginning of June. This indicates that an incorporation of catch crops did not cause a remarkable surge in the inorganic N pool. No clear differences were observed between the catch crops with various C/N-rations or in their sensitivity to wintertime frost. Substantial nutrient losses are known to potentially occur during winter in cold-winter regions. Repeated freezing-thawing cycles in the agricultural fields without permanent snow cover accelerate the releasing of nutrients from the catch crop residues. Clear differences are also seen in frost resistance between plant species. Brassicas, such as white mustard and oilseed radish, can more readily release nutrients after frost compared to Phacelia (Liu et al. 2013).

The absence of differences in ammonium- and nitrate-N contents may result in low soil temperature during early summer. Average air temperature was approximately 10 °C at the beginning of June, which limits soil warming and soil microbial activity. Variations in soil temperature vary greatly between the soil surface and deeper layers, and the
Figure 8.
Ammonium-N contents in the carrot field at soil depths of 0–25 cm (A) and 25–50 cm (B) in early June and late July 2015.

Figure 9.
Nitrate-N contents in the carrot field at soil depths of 0–25 cm (A) and 25–50 cm (B) in early June and late July 2015.
temperature at a depth of 0–25 cm is clearly higher than at deeper soil layers. Van Schöll et al. (1997) have studied responses of nitrogen release from an incorporated catch crop material to soil temperatures. They showed that mineralization and nitrification do proceed at temperatures as low as 1 °C, but very slowly. At a soil temperature of 1 °C, 20% of the total added organic N was mineralized after ten weeks of incubation, whereas the corresponding value was 39% at a soil temperature of 15 °C. Certain different trends in soil soluble N contents are observable later in summer once soil temperature had increased.

The amount of ammonium-N at a soil depth of 0–25 cm increased in all treatments until the end of July, being clearly highest in the white mustard and radish plots. At the end of July, the amount of nitrate-N remained at the same level in all treatments, being 22.5 kg nitrate-N or lower. In the deeper soil layer, at 25–50 cm, the amount of nitrate-N was higher in the white mustard and radish treatments compared to the other treatments in early June. Contrastingly, a comparable high amount of nitrate-N (35–40 kg/ha) was measured in the Italian ryegrass and white mustard treatments in late July.

At the end of July, during a time of intensive carrot root formation, nitrate-N contents appeared to be higher at soil depths of 25–50 cm (Fig. 9B) in the Italian ryegrass and white mustard treatments compared to the other treatments. Reasons for this phenomenon are not easily interpreted because of the limitations in our experimental design.

Farmers are interested in the effects of catch crops on the marketable yield of vegetable crops. In this study the marketable carrot yield varied from 39 228 kg/ha to 51 513 kg/ha depending on the catch crop treatment (Fig. 10). The highest marketable yield was reached with the control treatment without a catch crop and the lowest yield with the Italian ryegrass treatment. The marketable yield was clearly lower in Italian ryegrass plots compared to the control plots, and a trend for a lower crop yield after a successful catch crop, such as phacelia and white mustard, was also observable. Total carrot yield varied from 44 520 kg/ha to 55 311 kg/ha. When considering total yields, the differences between catch crop treatments and the control treatment were smaller. None of the catch crops used in our study had a positive effect and Italian ryegrass had a negative effect on the carrot yield. The absence of positive effects of several catch crops on the carrot yield have been documented earlier and Italian ryegrass actually slightly decreased the carrot yield compared to the control treatment in the study by Thorup-Kristensen (2006a), which confirms our results.

It was surprising that Italian ryegrass had a slightly negative effect on the carrot yield as its biomass production and nitrogen allocation to the above-ground biomass was so low, only 9.5 kg N. We are missing the N content of the root system, but its maximum N content could be estimated to be of the same magnitude. This means that Italian ryegrass could have taken up approximately 20 kg N from the soil in autumn, which is slowly mineralized again. The carrot is a relatively deep-rooted crop with an intermediate demand for nutrients, and the period of high nutrient demand begins two months after sowing when intensive root formation begins.

![Figure 10. Marketable and total yield (fresh mass) of carrot roots. Data are means (± SD) of three replicates.](image-url)
Nutrient concentrations in the root and shoot tissues were compared to analyse whether this negative effect on carrot yield was due to lower availabilities of various nutrients after Italian ryegrass. Comparisons of the nutrient concentrations of carrot roots and shoots (Table 6) indicate that an availability of all measured nutrients in the Italian ryegrass treatment was not remarkably lower in relation to the referred control crop without a catch crop. This may indicate that a nutrient deficiency per se was not a reason for the lower carrot yield after Italian ryegrass catch crop cultivation. The nutrient analysis of the crop was performed at the harvest time and it does no show nutrient deficiencies at the earlier growth stages because nutrient accumulation in carrot typically occurs in situations with high amounts of available nutrients prior to harvest.

We do not have any available nutrient analysis data measured during the early stages of the growing season. It is therefore possible that nutrient availability was not as well-synchronized with the demand of plants for nutrients in the Italian ryegrass treatment as in the control treatment. In general, higher root yields of carrots tend to be associated with larger shoots (Hole et al. 1987). Average shoot dry weights in the control and Italian ryegrass treatments in our study were 4.5 g and 3.3 g, respectively. When comparing the root/shoot -ratio of carrots at harvest time we found that dry matter was allocated more to the roots compared to the shoots in the Italian ryegrass and phacelia treatments (Fig. 11). The allocation pattern of dry matter in carrot during the growing season has been studied previously (Hole et al. 1984, Korolev et al. 2000). Biomass accumulates to carrot shoots during the first two months after sowing and thereafter remains constant during the intensive period of root growth (Korolev et al. 2000). In our study, a lower dry matter accumulation to the carrot shoots after Italian ryegrass and phacelia catch crops may have been a consequence of insufficient nutrient availability during the intensive period of shoot development. The C/N -ratio is typically higher in Italian ryegrass and phacelia compared for example to white mustard. A higher C/N -ratio retards the decomposition process and delays nutrient mineralization from the green manure. This delay in early summer could be stronger in northern conditions than in warmer climate conditions, affecting the timing of various phenological phases and consequently the allocation of biomass to different plant organs during growing season.

In our study, the smaller shoots with lower leaf area could have limited the allocation of photosynthates to the taproot, thus decreasing the carrot yield.

Table 6. Nutrient concentrations of carrot roots and shoots at harvest time in the control and Italian ryegrass treatment.

<table>
<thead>
<tr>
<th>Nutrient element</th>
<th>Nutrient concentration of carrot shoots (g kg⁻¹ dry mass)</th>
<th>Nutrient concentration of carrot roots (g kg⁻¹ dry mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Italian ryegrass</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>18.9</td>
<td>22.1</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Kalium (K)</td>
<td>48</td>
<td>54</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>3.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient concentration of carrot shoots (mg kg⁻¹ dry mass)</th>
<th>Nutrient concentration of carrot roots (mg kg⁻¹ dry mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>170</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>29</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>41</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>&lt; 20</td>
</tr>
</tbody>
</table>
Carrot belongs to a vegetable group with a relatively low nutrient demand and capability of taking up nutrients from the lower soil layers (Sørensen 1993, Sørensen and Thorup-Kristensen 1993, Thorup-Kristensen 2006a). Therefore the negative effect of Italian ryegrass on the marketable yield of carrot was surprising.

Figure 11. Root/shoot-ratio of carrots at harvest time after different catch crop treatments.
CONCLUSIONS

Our study was conducted as an on-farm trial to generate results with direct application to current farming practices. The experimental design had to be kept very simple. Therefore we had no possibility of designing a randomized complete block design that would have been scientifically valid. In this arrangement the sampling points were not randomized. Due to our experimental design we cannot fully separate out the possible variation caused by soil fertility differences between strips from the treatment effects. However, we have tried to minimize variation by establishing the experiment on uniform ground and keeping the distances between sampling points within each treatment strip as long as possible.

Results show that the capability of various catch crop species in producing above-ground biomass and preventing nitrogen leaching varies. Mustard, phacelia and Italian ryegrass can prevent nitrogen leaching by 40–49 kg/ha in the autumn. The weak performance of the radish catch crop after broccoli harvest was an unexpected phenomenon. The experiment should be repeated to confirm this suppressive effect of broccoli on radish growth. The catch crop effect on the succeeding organic carrot crop was most negative for Italian ryegrass, and varied from negative (phacelia) to neutral (mustard) for the other tested catch crop species. All the tested catch crops in our study were non-leguminous crops. According to earlier studies deep-rooted vegetables, such as carrot, utilize leguminous N more efficiently (Thorup-Kristensen 2006). It would be important to continue testing to investigate whether a catch crop species or a mixture of catch crop species could prevent nutrient leaching in the autumn and wintertime and have a positive effect on the marketable yield of carrot.
REFERENCES


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