ORIGINAL ARTICLE

The effects of pure and undersowing green manures on yields of succeeding spring cereals

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Abstract
A field experiment was conducted in 2004–2006 to investigate the effect of green manure treatments on the yield of oats and spring barley. In the experiment, different green manure crops with undersowing and pure sowing were compared for amounts of N, C, and organic matter driven into soil and their effect on cereal yield. The spring barley field had a total of 41.7–62.4 kg N ha⁻¹ and 1.75–2.81 Mg C ha⁻¹ added to the soil with straw, weed, and roots, depending on the level of fertilisation; with red clover, and both common and hybrid lucerne undersowing, with barley straw and roots, the values were 3.45–3.96 Mg C ha⁻¹ and 139.9–184.9 kg N ha⁻¹. Pure sowings of these three leguminous green manure crops had total applications of 3.37–4.14 Mg C ha⁻¹ and 219.7–236.8 kg N ha⁻¹. The mixed and pure sowing of bird’s-foot trefoil provided considerably less nitrogen and carbon to the soil with the biomass than with the other leguminous crops. Application of biomass with a high C/N ratio reduced the yield of the succeeding spring cereals. Of the green manures, the most effective were red clover and both common and hybrid lucerne, either as undersowing or as pure sowing. Undersowings with barley significantly increased the N supply for the succeeding crop without yield loss of the main crop compared with the unfertilised variant. Compared with ploughing-in of green manure in autumn, spring ploughing gave a 0.2–0.57 Mg ha⁻¹ larger grain yield.

Keywords: Biomass, carbon, grain yield, green manure crops, nitrogen, phytoproductivity.

Introduction
Efficient and economic utilisation of natural resources is crucial in farming systems (Granstedt, 2000). Each farming system determines the nutrient inputs and balance of soils (Kätterer et al., 2004; Montemurro et al., 2006), nutrient availability and sequestration in the soil (Schaldach & Alcamo, 2006), nutrient leaching (Hansen et al., 2000; Kutra & Aksamaitiene, 2003) as well as the general state of the environment and agro-ecosystem productivity (Waldon et al., 1998; Eltun et al., 2002).

The present global area of organically managed land exceeds 31.5 million hectares (The World of Organic Agriculture . . ., 2007). Since the beginning of the 1990s, organic farming has rapidly developed in European countries: across the EU, more than 6.4 million hectares, representing 3.5% of the utilised agricultural area (The World of Organic Agriculture . . ., 2007), are under organic management. By the end of 2005, the agricultural area occupied by organic farming in Estonia was 59 862 hectares, or 7.2% of total agricultural land.

Organic fertilisers play the central role in sustaining soil fertility and crop productivity in organic farming. In specialised crop farms where the use of animal manure is limited, green manures provide the most effective way to improve the N supply for succeeding crops (Thorup-Kristensen et al., 2003). Organic crop farming in Estonia is mainly centred on the islands of Hiiumaa and Saaremaa and on the

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west and south-eastern mainland, where soil fertility is relatively low, and is infrequently employed in the fertile soils of central Estonia. The yield level of crops throughout Estonia is lower than in other European countries (Roostalu et al., 2000), partly due to the insufficient use of fertilisers; Astover et al. (2006) determined that the low input of plant nutrients limits the actual yield level.

One limiting factor is low humus content – below 2% – especially in 40–60% of the total cultivated area of southern Estonia (Jarvan et al., 1996). Currently, in Estonia’s small farms, animal manure and mineral fertilisers are used considerably less than in large-scale agricultural production, resulting in a negative soil humus balance (Roostalu et al., 2000). Thus, both soil fertility and crop productivity depend largely on the use of organic fertilisers in both organic and conventional cultivation; consequently, green manure crops have an increasingly important role in crop husbandry.

Organic matter has a favourable effect on the soil biota and the biological activity of soil, improving their humus condition, which in turn improves soil structure and its physical and hydrophysical characteristics. The concentration of organic C and N are good indicators of soil quality and productivity, affecting those characteristics (Reeves, 1997). The C and N pools in the soil play an important role in nutrient cycling, plant productivity and the quality of the environment. The content and balance of soil C and N can be influenced by various management practices, such as rate of fertilisation, soil tillage, the cultivation of different field crops and crop rotation. A common practice for guaranteeing maximally high and stable yields of field crops in contemporary intensive agriculture is the use of comparatively large quantities of mineral and organic fertilisers, including green manures. However, the application of high fertiliser norms can lead to appreciable nutrient losses from the soil, which affects the quality of groundwater and contributes to the eutrophication of water bodies (Tilman et al., 2002). To obtain a balance between agronomic, economic and environmental targets, the know-how of green manure management is essential. The aim of the present study was to investigate the influence of various green manures on the yield of oats and spring barley.

Methods and materials

The trials were carried out during the 2004–2006 growing seasons at the Department of Field Crop Husbandry in the Estonian University of Life Sciences (EMU), Institute of Agricultural and Environmental Sciences (58° 23’ N, 26° 44’ E). Random block-placement in 4 replications was used (Hills & Little, 1972). The size of each test plot was 30 m². The soil type of the experiment area was sandy loam Stagnic Luvisol in the WRB 1998 classification. The mean characteristics of the humus horizon were as follows: Corg 1.1–1.2%, Ntot 0.10–0.12%, P 110–120 mg kg⁻¹, K 253–260 mg kg⁻¹, pHKCl 5.9, soil bulk density 1.45–1.50 Mg m⁻³. The thickness of the ploughing layer was approximately 27–29 cm. Soil analyses were carried out at the laboratories of the Department of Soil Science and Agrochemistry, EMU. Air-dried soil samples were passed through a 2 mm sieve. Various methods were used to determine the following soil characteristics: pHKCl; organic carbon by the Tjurin method (Soil Survey Laboratory Staff, 1996); P and K by the Mehlich-3 method (Extracting Reagent 0.2N CH₃CO₂H; NH₄NO₃; 0.015N 0.001M EDTA) (Handbook on..., 1992); the Kjeldahl method was used to determine the total-N content of soil (Benton & Jones, 2001). Plant analyses were conducted at both the Department of Soil Science and Agrochemistry of EMU and the Estonian Agricultural Research Centre laboratories. Acid digestion by sulfuric acid solution (Methods of Soil..., 1986) was used to determine N, P, K content in plant material. The Dumas Combustion method was used to determine the content of carbon in the plant biomass.

The field experiment was established in 2004 using the following variants of green manure crops and fertilisation:

- **Variant A**) legume pure sowings (i) red clover (*Trifolium pratense*), (ii) lucerne (*Medicago sativa*), (iii) hybrid lucerne (*Medicago media*), (iv) bird’s-foot trefoil (*Lotus corniculatus*), (v) pea (*Pisum sativum*);
- **Variant B**) spring barley (*Hordeum vulgare* L.) with undersowings of (i) red clover, (ii) lucerne, (iii) hybrid lucerne, (iv) bird’s-foot trefoil, (v) pea, (vi) westervold ryegrass (*Lolium multiflorum westervoldicum*);
- **Variant C**) spring barley with dairy manure applied on 25 October 2004 (60 Mg ha⁻¹);
- **Variant D**) spring barley with mineral fertiliser rates (i) *N₀* – the control variant (ii) *N₅₀*; (iii) *N₁₀₀* (every year with cereal sowing).

The 2004 cover crop was spring barley cv. “Arve”, sown on 30 April. Succeeding crops were, in 2005, oats (*Avena sativa* L.) cv. “Jaak” (3 May), and, in 2006, spring barley (*Hordeum distichon* L.) cv. “Inari” (2 May). The seed rate of germinating grains of cereals was 500 m⁻¹ every year. Green manure pure crops were sown according to the following norms: red clover 15 kg ha⁻¹, lucerne 13 kg ha⁻¹, hybrid lucerne 20 kg ha⁻¹, bird’s-foot trefoil 12 kg ha⁻¹, westervold ryegrass 10 kg ha⁻¹, pea 220 kg ha⁻¹. The seeding rates for undersowings were reduced by...
half. In all variants, barley straw and the biomass of legumes were ploughed into the soil (20–22 cm). The biomass of legume pure sowings (variant A) was ploughed into the soil in two variants – (i) autumn (end of October) and (ii) spring (end of April) (exception: pea was ploughed into the soil only in autumn). Autumn ploughing alone was carried out with the other variants. In autumn 2005, straw of the oat crop was ploughed into the soil. Samples of aboveground biomass were taken before harvesting of the cereals and the root mass was taken from 10–60 cm in depth. In variants with undersowings (B), the mean biomass of green manure crops was measured twice: first, during harvesting; secondly, the aftermath mass was taken before autumn ploughing. The aboveground biomass of pure sowings and the root mass of leguminous crops were measured before ploughing.

The experimental area belongs to the south-Estonian upland agroclimatic region, where the average annual sum of active air temperatures is 1750–1800°C and total precipitation is 550–650 mm. The period of active plant growth (mean diurnal temperature continuously above 10°C) ranges usually from 115 to 135 days (Tarand, 1999). The amount of precipitation during the vegetation period (from May to September) compared with the average varied through the trial: it was greater than average in 2004, similar in 2005, but lower in 2006 (Table I).

Analysis of variance (ANOVA) was used to evaluate the impact of the experimental variants on the grain yield. The significance of differences between grain yields of the variants was calculated using the Fischer test, and the levels of significance \( p < 0.05 \) and \( p < 0.01 \) were used. The software STATISTICA 7.0 (StatSoft, Inc., 2005) was used for the statistical data analysis.

Results

The barley yield in 2004, the year the trial was established, was 0.38–0.64 Mg ha\(^{-1}\) higher in the mixed sowings with leguminous green manure crops than for the unfertilised control variant (Figure 1). The grain yield of barley was higher with undersowings of pea and bird’s-foot trefoil, but the ryegrass yield did not differ from the control variant (\(N_0\)). The mineral nitrogen fertiliser norms \(N_{50}\) and \(N_{100}\) increased the barley yield by 1.78 and 2.50 Mg ha\(^{-1}\), respectively.

The total phytomass of pure sowings of barley constituted 6.55–11.54 Mg of dry matter per hectare depending on the nitrogen fertiliser norm, of which the root mass constituted 17.7–20.4% and the grain yield 37.3–43.2%. The total phytomass of mixed sowings varied within the range 8.13–12.13 Mg ha\(^{-1}\), the root mass comprising 18.6–33.3% and the grain yield 22.9–31.4%. The smallest total phytomass of legume pure sowings was bird’s-foot trefoil at only 4.64 Mg ha\(^{-1}\), while those of red clover, lucerne, and hybrid lucerne were 8.91, 8.40, and 9.43 Mg ha\(^{-1}\), respectively. The root mass constituted 42.2–51.6% of the total biomass in these legume pure sowings.

The amount of organic material left in the soil was affected by the crop grown: The highest was left in the soil with pure sowing of legumes, and the lowest with pure sowing of nonfertilised barley (Figure 2). The larger total quantity of aboveground dry matter (\(x, \text{kg ha}^{-1}\)) that was formed [Equation (1)] the smaller was the proportion of the aboveground phytomass of weeds (\(y, \%\)).

\[
y = -0.0039x + 37.441; \quad R^2 = 0.62; \quad p < 0.05 \tag{1}
\]

Both the nitrogen content and the C/N ratio of the applied organic matter varied considerably. The variance in the nitrogen content of barley straw,

Table I. Weather conditions for 2004–2006 (according to the Erika weather station) and the average for 1966–1998* in Tartu (Jaagus, 1999).

<table>
<thead>
<tr>
<th>Month</th>
<th>Air temperatures, °C</th>
<th>Precipitation, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2004</td>
<td>2005</td>
</tr>
<tr>
<td>January</td>
<td>-7.6</td>
<td>-1.7</td>
</tr>
<tr>
<td>February</td>
<td>-4.5</td>
<td>-7.3</td>
</tr>
<tr>
<td>March</td>
<td>-0.4</td>
<td>-4.9</td>
</tr>
<tr>
<td>April</td>
<td>5.6</td>
<td>5.0</td>
</tr>
<tr>
<td>May</td>
<td>12.7</td>
<td>10.8</td>
</tr>
<tr>
<td>June</td>
<td>13.4</td>
<td>14.5</td>
</tr>
<tr>
<td>July</td>
<td>16.4</td>
<td>19.5</td>
</tr>
<tr>
<td>August</td>
<td>17.0</td>
<td>16.5</td>
</tr>
<tr>
<td>September</td>
<td>11.9</td>
<td>12.7</td>
</tr>
<tr>
<td>October</td>
<td>5.7</td>
<td>6.7</td>
</tr>
<tr>
<td>November</td>
<td>-0.7</td>
<td>2.6</td>
</tr>
<tr>
<td>December</td>
<td>-0.1</td>
<td>-3.2</td>
</tr>
</tbody>
</table>
The shoot-to-root ratio (S/R) was 4.46 depending on the nitrogen fertiliser norm, with roots comprising 31–35% of the total returned organic matter. Depending on the mineral nitrogen fertiliser norm, the annual C inputs constituted 1.75–2.81 Mg ha\(^{-1}\) with straw and 0.91–1.11 Mg ha\(^{-1}\) without straw.

In the second year of the trial (2005), oats, the succeeding crop on unfertilised soil, gave a grain yield of 2.95 Mg ha\(^{-1}\). However, the mineral nitrogen fertiliser norm N\(_{100}\) produced a yield increase of 51% (Table II). The effect of the biomass of the mixed sowings with red clover and hybrid lucerne was significant, giving a yield increase of 39–47%. By contrast, the oat yield in 2005 decreased by 22% (0.65 Mg ha\(^{-1}\)) as a result of the application of barley straw and ryegrass biomass into the soil, compared with the control variant. The effect of green manure pure sowings of leguminous crops was

\[
y = 42.977x^{-1.0035}; \quad R^2 = 0.99; \quad p > 0.000 \quad (2)
\]

The barley straw had a C/N ratio of 60–70; it was 12–18 in the aboveground biomass of leguminous crops. Taking into account the total quantity of organic matter applied to the soil, 41.7–236.8 kg N ha\(^{-1}\) was applied to the soil depending on the variant (Figure 3).

The straw, weeds, and roots that were applied to the unfertilised barley field produced only 41.7 kg N ha\(^{-1}\), approximately half of which comprised nitrogen from the aboveground parts of weeds. The mean nitrogen content of the organic matter applied to soil was 1.02% and the C/N ratio was 41.9; the mean quantity of carbon applied was 1.75 Mg C ha\(^{-1}\). The quantity of nitrogen applied to the soil was also small in the mixed sowing of barley and ryegrass – 46.3 kg N ha\(^{-1}\); the average biomass nitrogen content was low – 0.98%; the C/N ratio was 43.5, and the quantity of carbon applied into the soil was 2.02 Mg C ha\(^{-1}\). In barley mixed sowings with red clover, lucerne, and hybrid lucerne, 3.45–3.96 Mg C ha\(^{-1}\) and 139.9–184.9 kg N ha\(^{-1}\) were applied to soil; the average nitrogen content of biomass was 1.76–2.02%. The carbon and nitrogen inputs from pure sowings of legumes were 3.37–4.14 Mg ha\(^{-1}\) and 219.7–236.8 kg ha\(^{-1}\), respectively, and the nitrogen content of the organic matter was 2.42–2.73%. Considerably less nitrogen, 93.1–94.1 kg ha\(^{-1}\), and marginally less carbon, 1.96–2.86 Mg ha\(^{-1}\), were added to the soil with the biomass of mixed and pure sowing of bird’s-foot trefoil than from the other leguminous crops.

The shoot-to-root ratio (S/R) was 4.46 depending on the nitrogen fertiliser norm, with roots comprising 31–35% of the total returned organic matter. Depending on the mineral nitrogen fertiliser norm, the annual C inputs constituted 1.75–2.81 Mg ha\(^{-1}\) with straw and 0.91–1.11 Mg ha\(^{-1}\) without straw.

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dependent on when the biomass was ploughed into the soil. Autumn ploughing produced an increase in the oat yield of 31–62%, red clover and hybrid lucerne having the greatest effect. The effect of green manure was even higher when applied the following spring. The spring ploughing of green manure compared with the autumn version gave a 4–15% extra yield. The effect of leguminous green crops on the yield of oats is 2–2.5-times greater than that of manure norm 60 Mg ha\(^{-1}\) applied in the autumn.

Barley was grown again in 2006, the control variant (N\(_0\)) producing a yield of 2.10 Mg ha\(^{-1}\). Undersowings of the biomass with red clover and hybrid lucerne that had been applied to soil in autumn 2004 still had a significant effect, although it resulted in approximately half the grain yield two years later. The decrease in the cereal yield was to some extent due to nitrogen-deficient biomass, which was applied with the mixed sowing of barley and ryegrass. The rest of the mixed legume sowings had a relatively small after-effect on the barley yield. The second-year after-effect of the pure sowings of leguminous crops on the barley yield was 2–3-times greater than the effect of the straw and green manure crops ploughed into soil through the mixed sowings with red clover and hybrid lucerne. The yields of second-year succeeding crops revealed that the spring ploughing-in of the biomass gave a 0.21–0.54 Mg ha\(^{-1}\) greater cereal yield than did the autumn ploughing of green manure crops.

**Discussion**

The quantity of organic matter that is added to soil in an agroecosystem depends on the following factors: the plant species, pedoclimatic conditions, and the agricultural engineering applied (Bolinder et al., 1997; Pietola & Alakukku, 2005). Mean S/R ratios for annual crops were the highest for small-grain cereals and lowest for forages, but the ratio varies greatly. For example, depending on farming conditions, the S/R ratio may vary from 2–17 for barley (Bolinder et al., 2007). The S/R ratios depend on the nitrogen fertiliser norm, with roots comprising 31–35% of the total returned organic matter.

Studies have shown that in the case of 4.6 Mg ha\(^{-1}\) barley grain yield, with the straw being left in the field after harvest, the estimated annual C input to the soil is 2.79 Mg ha\(^{-1}\). If the straw is removed from the field, then the estimated annual C input would be reduced by 26% (Bolinder et al., 1997). In our experiment, depending on the mineral nitrogen fertiliser norm, the annual C inputs constituted 1.75–2.81 Mg ha\(^{-1}\) with straw and 0.91–1.11 Mg ha\(^{-1}\) without straw. Considering the fact that under Estonian conditions 20% of the carbon that was applied to soil is transformed into humus, and that 1–2% of the soil humus or carbon stores (45.3 Mg C ha\(^{-1}\)) are mineralised per year (Piho, 1973), it is also evident that with the application of straw to soil, the humus balance remains negative if the barley

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**Table II. Grain yield of succeeding crops depending on nitrogen fertiliser norm and green manure application.**

<table>
<thead>
<tr>
<th>Variants in 2004</th>
<th>Oats</th>
<th></th>
<th>Barley</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield in 2005, Mg ha(^{-1})</td>
<td>Yield increase, Mg ha(^{-1})</td>
<td>Yield in 2006, Mg ha(^{-1})</td>
<td>Yield increase, Mg ha(^{-1})</td>
</tr>
<tr>
<td>Barley N(_0) (control variant)</td>
<td>2.95</td>
<td>–</td>
<td>2.10</td>
<td>–</td>
</tr>
<tr>
<td>Barley N(_{50})</td>
<td>4.04**</td>
<td>1.09</td>
<td>3.19**</td>
<td>1.09</td>
</tr>
<tr>
<td>Barley N(_{100})</td>
<td>4.44**</td>
<td>1.49</td>
<td>3.89**</td>
<td>1.79</td>
</tr>
<tr>
<td>Barley + manure 60 Mg ha(^{-1})</td>
<td>3.77**</td>
<td>0.82</td>
<td>2.44</td>
<td>0.54</td>
</tr>
<tr>
<td>Pea</td>
<td>3.45*</td>
<td>0.50</td>
<td>2.38</td>
<td>0.28</td>
</tr>
<tr>
<td>Barley + pea</td>
<td>3.13</td>
<td>0.18</td>
<td>2.24</td>
<td>0.14</td>
</tr>
<tr>
<td>Barley + westervold ryegrass</td>
<td>2.30*</td>
<td>– 0.65</td>
<td>1.98</td>
<td>– 0.12</td>
</tr>
<tr>
<td>Barley + red clover</td>
<td>4.34**</td>
<td>1.39</td>
<td>2.70**</td>
<td>0.69</td>
</tr>
<tr>
<td>Barley + bird’s-foot trefoil</td>
<td>3.02</td>
<td>0.07</td>
<td>2.27</td>
<td>0.17</td>
</tr>
<tr>
<td>Barley + lucerne</td>
<td>3.32</td>
<td>0.37</td>
<td>2.45</td>
<td>0.35</td>
</tr>
<tr>
<td>Barley + hybrid lucerne</td>
<td>4.11**</td>
<td>1.16</td>
<td>2.65**</td>
<td>0.55</td>
</tr>
</tbody>
</table>

**Autumn ploughing**

| Red clover | 4.77** | 1.82 | 3.20** | 1.10 |
| Bird’s-foot trefoil | 3.87** | 0.92 | 2.65** | 0.55 |
| Lucerne | 4.00** | 1.05 | 3.17** | 1.07 |
| Hybrid lucerne | 4.58** | 1.63 | 3.46** | 1.36 |

**Spring ploughing**

| Red clover | 5.08** | 2.13 | 3.41** | 1.31 |
| Bird’s-foot trefoil | 4.44** | 1.49 | 3.19** | 1.09 |
| Lucerne | 4.53** | 1.58 | 3.42** | 1.32 |
| Hybrid lucerne | 4.78** | 1.83 | 3.67** | 1.57 |

\(^*\) Significant at level \(p < 0.05\) and \(p < 0.01\), respectively. \(^b\) Mineral nitrogen 50 kg ha\(^{-1}\). \(^b\) Mineral nitrogen 100 kg ha\(^{-1}\).
yield is low. On a cereals farm, where only stubble and plant roots are ploughed into the soil after harvesting, the humus decrease is 2- to 3-times greater than the increase of humus from fresh organic matter. Thus, both in organic and conventional cereal farming, where animal manure is not used, green manures are the only means for retaining and improving soil fertility.

The bioproduction, nitrogen uptake, and C/N ratio of green manure crops vary greatly depending on the plant species, soil, and agricultural engineering applied (Wivstad et al., 1996). The bioproduction of green manure crops may, under favourable conditions, exceed 10 Mg ha$^{-1}$, of which 2–3 Mg ha$^{-1}$ of humus is formed as a result of the humification process (Piho, 1973). Nitrogen fixation by leguminous crops can be 200–300 kg N ha$^{-1}$ per year (Tonitto et al., 2006). In the case of barley undersowings with red clover, lucerne, and hybrid lucerne, the estimated annual C and N inputs to the soil were 3.45–3.96 Mg C ha$^{-1}$ and 140–185 kg N ha$^{-1}$, respectively. In the current experiment, pure sowings of these three crops resulted in applications of 3.37–4.14 Mg C ha$^{-1}$ and 220–237 kg N ha$^{-1}$ into the soil.

The decomposition of organic matter in soil is largely determined by its C/N ratio. The smaller the C/N ratio of organic matter and the greater its nitrogen content, the more nitrogen is mineralised into soil from green manure (Chaves et al., 2004). Nitrogen is either immobilised by micro-organisms during the decomposition of organic matter or it is mineralised into soil as ammoniacal nitrogen. We confirmed the finding that the application of biomass with a high C/N ratio (i.e., ryegrass) reduces the yield of the succeeding crop (Thorup-Kristensen et al., 2003). The consumption of carbon is more important for micro-organisms than is the consumption of nitrogen (McGill & Cole, 1981). Since the decomposition of organic matter and the uptake of nitrogen by micro-organisms are dependent on soil temperature (Andersen & Jensen, 2001), it is crucial from the standpoint of nitrogen loss to optimise the time of the green manure application. According to numerous studies, green manure should be ploughed into the soil in late autumn or early spring, thus decreasing the leaching of nitrogen and increasing the effect on the yield of succeeding crops (Wivstad et al., 1996). The results of the present trial attest that with spring ploughing, the efficiency of green manure is 0.2–0.6 Mg ha$^{-1}$ greater on the yield of cereals grown as succeeding crops than with the autumn ploughing-in of green manure. Andersen and Olsen (1993) have not found any second-year after-effect and Schröder et al. (1996) found only a slightly increasing after-effect of green manures on barley yield. However, in our study there was a significant positive second-year after-effect on the barley yield with pure sowings of leguminous crops and in undersowings of red clover and hybrid lucerne as green manures.

Green manure helps to improve the fertility of soil in organic and conventional plant production where animal manure is not used or is used in limited quantities. Undersowings with barley provide a significant increase in the N supply for the succeeding crop without any yield loss of the main crop compared with the unfertilised variant (N0). The bioproduction of pure sowings of red clover, lucerne, and hybrid lucerne reaches 8.5–9.5 Mg ha$^{-1}$ in dry matter; the quantity of nitrogen applied to the soil is 220–240 kg ha$^{-1}$. The biomass (including straw) applied to soil with the mixed sowings of barley with red clover or lucerne and hybrid lucerne has nearly the same quantity of dry matter, but its C/N ratio is considerably larger: the input to soil is 140–180 kg N ha$^{-1}$ with organic matter. The effect of nitrogen applied to the soil with green manure on succeeding crops depends on the C/N ratio of the applied organic matter and the time of application. Green manure of high nitrogen content should be ploughed into soil in spring, thereby decreasing the leaching potential of nitrogen and environmental pollution.

References
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