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Phytomass formation and carbon amount returned to soil depending on green manure crop

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Abstract. The trials were carried out during the 2004–2006 growing seasons at the Department of Field Crop and Grassland Husbandry of the Estonian University of Life Sciences. Various green manures and ensuing cereals were studied in respect of phytomass formation and quantity of C returned to soil. The highest amount of organic matter was applied by red clover (8.91 Mg ha^{-1}) and lucerne (8.41 Mg ha^{-1}), and the lowest by unfertilized barley. The total phytomass of pure sowings of barley ranged, depending on the nitrogen fertilizer norm, from 6.55 to 11.54 Mg of dry matter per hectare, of which the grain yield constituted 37.3–43.2%. Sowings of lucerne and red clover added 3.44–3.82 Mg C ha^{-1} to soil, while sowing of bird's-foot trefoil supplemented 1.99 Mg C ha^{-1}. Preceding crop determined the phytomass of ensuing crops and the amount of C returned to soil. The amount of C of the oats grown after clover was 5.32 Mg C ha^{-1}, whereas 3.28 Mg C ha^{-1} was returned to soil. Lucerne pure sowing resulted in 3.17 Mg C ha^{-1} returned to soil. When oats were preceded by barley (without manure), 2.53 Mg C ha^{-1} was returned to soil.

Key words: green manure, soil fertility, carbon, soil organic matter, humus content

INTRODUCTION

One of the factors that limit the yield of field crops is low humus content, especially in South Estonia, where humus content is below 2% in 40–60% of the total cultivated area (Järvan et al., 1996). Among the most important factors influencing soil fertility is humus, the organic matter contained in soil. Soil fertility is closely linked to soil organic matter (Roose & Barthes, 2001) and depends to a large extent on the use of organic fertilizers, in both organic and conventional cultivation; green manure crops have an important role in crop rotation (Lauringson et al., 2000). In favourable conditions, bioproduction of green manure crops may 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). The organic matter applied to soils improves their humus condition, which in its turn improves soil structure as well as its physical and hydrophysical characteristics.

Organic matter has a favourable effect on the soil biota and the biological activity of soil. The concentration of organic C and N appear to be good indicators of soil quality and productivity (Reeves, 1997). Many agricultural systems in industrialized countries induce low contents of soil organic carbon (Dick & Gregorich, 2004; Riley & Bakkegard, 2006). The amount of carbon returned to soil depends on the quantities of nitrogen fertilizer and the crop (Talgre et al., 2009). The more organic matter and carbon is applied to soil, the more humus is formed.

Increasing the soil fertility and maintaining it at an optimum level is one of the key factors in sustainable agriculture. In organic farming, growing legumes would be the main method of enriching soil with nutrients. The green mass that has been ploughed in improves the soil with organic matter, and as a result of microbiological activity, nutrients consumable by plants are released.

The aim of the present study was to investigate the influence of various green manures and ensuing cereals in respect of phytomass formation and quantity of C returned to soil.

MATERIALS AND METHODS

The trials were carried out during the 2004–2006 growing seasons at the Department of Field Crop and Grassland Husbandry of the Estonian University of Life Sciences. Random block-placement in 4 replications was used (Hills & Little, 1972). The size of each test plot was 30 m^2. 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: C_{org} 1.1–1.2 %, N_{tot} 0.10–0.12%, P 110–120 mg kg^{-1}, K 253–260 mg kg^{-1}, pH_{KCl} 5.9, soil bulk density 1.45–1.50 Mg m^3. The thickness of the ploughed layer was approximately 27–29 cm. Soil analyses were carried out at the laboratories of the Department of Soil Science and Agrochemistry. Plant analyses were conducted at both the Department of Soil Science and Agrochemistry of EMU and at the laboratories of the Estonian Agricultural Research Centre. Acid digestion by sulphuric acid solution was used to determine the N 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 fertilization:

Variant A) legume pure sowings (i) red clover (*Trifolium pratense)*, (ii) lucerne *(Medicago sativa)*, (iii) bird's-foot trefoil *(Lotus corniculatus)*;

Variant B) spring barley (*Hordeum vulgare* L.) with undersowings of (i) red clover, (ii) lucerne, (iii) bird's-foot trefoil, (iv) Westerwold ryegrass *(Lolium multiflorum westerwoldicum)*;

Variant C) spring barley with mineral fertilizer rates (i) N_0 – the control variant (ii) N_{50}, (iii) N_{100} (every year with cereal sowing).

The 2004 cover crop was spring barley *cv. "Arve"*. Succeeding crops in 2005 were oats (*Avena sativa* L.) *cv.* "*Jaak*", and in 2006, spring barley (*Hordeum distichon* L.) *cv.* "*Inari"* in 2006. 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}, bird's-foot trefoil 12 kg ha^{-1}, Westerwold ryegrass 10 kg ha^{-1}. The seeding rates of undersowings were reduced by half. In all variants, barley straw and the biomass of legumes were ploughed into the soil (20–22 cm). Samples of aboveground biomass were taken before harvesting the cereals and the root mass was taken from 10–60 cm in depth. In variants with undersowings (B), the aboveground biomass of green manure crops was measured twice: first, during harvesting; and 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 (Tarand, 2003). The amount of precipitation during the vegetation period (from May to September), compared to the average, varied through the trial: it was above average in 2004, similar in 2005, but below average in 2006.
The analysis of variance (ANOVA) was used in the statistical analysis of trial results.

RESULTS AND DISCUSSION

The vegetation period and the competitiveness of the green manure crop influence the biomass of herbage. The total phytomass of pure sowings of barley constituted 6.55–11.54 Mg of dry matter per hectare depending on the nitrogen fertilizer norm, of which the root mass constituted 17.7–20.4% and the grain yield 37.3–43.2%. The phytomass of mixed sowings returned to soil varied from 7.72 to 8.25 Mg ha^{-1}, the root mass constituted 18.6–33.3%. The lowest total phytomass of legume pure sowings was observed in bird's foot trefoil with only 4.64 Mg ha^{-1}, while that of red clover and lucerne was 8.91 Mg ha^{-1} and 8.41 Mg ha^{-1}, respectively (Fig. 1). Root mass constituted 42.2–51.6% of the total phytomass in these legume pure sowings. Roots may also be important C sources to soils which contribute to soil C sequestration (Hogberg & Hogberg, 2002).

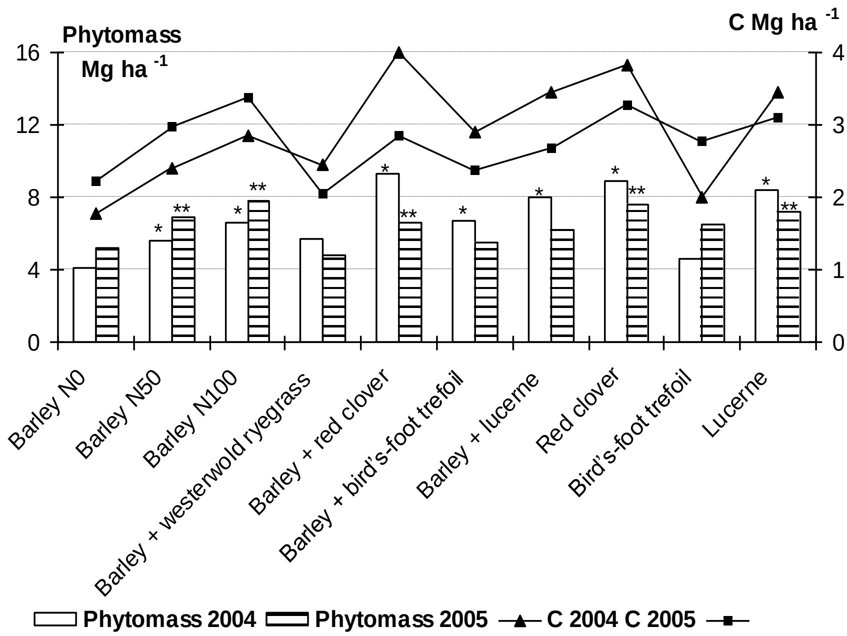

Fig. 1. Quantities of dry matter (Mg ha^{-1}) and carbon (Mg ha^{-1}) applied to soil in 2004, 2005.

* significant at $P<0.05$, respectively, in 2004 and ** significant at $P<0.05$, respectively, in 2005

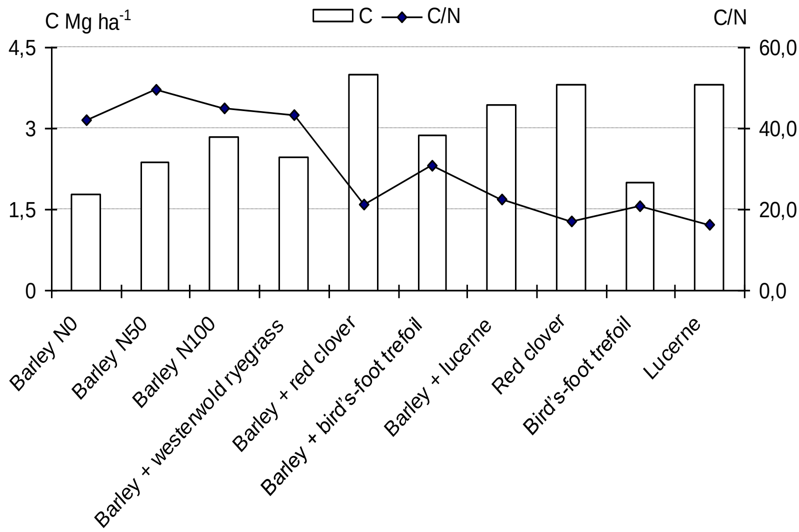

Fig. 2. Quantities of carbon (Mg ha^{-1}) and the C/N ratio of organic matter at the application into soil with biomass (2004).

In an unfertilized barley field, 1.75 Mg C ha$^{–1}$ was applied to soil with straw, weeds and roots, the biomass C/N ratio being 41.9. With undersowing of barley and ryegrass, 2.02 Mg C ha^{-1} was applied to soil, with the C/N ratio of 43.5. Undersowing of red clover and lucerne with barley straw and roots gave 3.45–3.96 Mg C ha^{-1} .With the pure sowing of leguminous green manure crops, 1.99–3.82 Mg C ha^{-1} was applied to soil (Figure 2). The amounts of carbon and nitrogen were significantly smaller with undersowing and pure sowing of bird's foot trefoil. Decomposition of organic matter in soil is largely determined by its C/N ratio. The usual recommended range for C/N ratios at the start of the composting process is about 30/1 (Ghaly et al., 2006). The C/N ratio of the organic matter varied considerably. The C/N ratio was more than 60 in barley straw and 18–23 in the biomass of legumes. The following year, oats were used as the succeeding crop. Its yield and capability to form biomass were dependent on the preceding crop and the amount of N applied to soil. The trial variant N_{100} gave the largest amount of oats biomass and carbon, with 3.4 Mg C ha^{-1} returned to soil. In the previous trial variant, 2.4 Mg C ha^{-1} was returned to soil with straw, which equals the amount of carbon returned to soil with unfertilized oats. The biomass of the undersowing of red clover and lucerne had a significant effect on the formation of oat biomass. Following the undersowing of clover and lucerne, the amount of carbon returned to soil with oat biomass was 2.8 Mg C ha^{-1} and 3.4 Mg C ha^{-1}, respectively. 3.3 Mg C ha^{-1} was returned to soil with straw and roots of oats after the pure sowing of clover (Fig. 1).

In the second year with barley as succeeding crop, 2.53–3.61 Mg C ha$^{–1}$ was returned to soil, depending on the trial variant. The amount of carbon returned to soil was up to 1.1 Mg ha^{-1} greater with mineral nitrogen and green manure as compared to unfertilized barley. As a result, it can be concluded that the organic matter remaining in soil from green manure crops has a long-lasting effect on soil fertility.

Considering the fact that 20% of the carbon that was applied to soil is incorporated into humus, and 1–2% of the soil humus or carbon stores (45.3 Mg C ha^{-1}) is mineralized per year (Piho, 1973), it is evident that in case straw is applied to soil, the humus balance remains negative if the barley yield is low. On a cereal farm where only stubble and roots are applied to soil after harvesting, two to three times more humus is lost than formed (Talgre et al. 2009).

CONCLUSION

The amount of organic material and C left in the soil was affected by the crop grown. It was the highest in the pure sowing of legumes: red clover – 8.91 Mg ha^{-1} dry matter and 3.82 Mg C ha^{-1} , and the lowest in the sowing of non-fertilized barley – 4.1 Mg ha^{-1} dry matter and 1.77 Mg C ha^{-1}. Taking into consideration the total input of biomass, leguminous green manure crops show a three times narrower C/N ratio of the organic matter compared to cereal crops or cereals undersown with ryegrass. Thus, in both organic and conventional cereal farming where animal manure is not used, green manures are the only means for retaining and improving soil fertility.

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