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The effects of green manures on yields and yield quality of spring wheat

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Abstract. A field experiment was conducted in the period of 2004–2006 to investigate the effect of green manure treatments on the yield and yield quality of spring wheat. In the experiment, different green manure crops were compared for amounts of N, C and organic matter applied into soil and their effect on the yield and yield quality of succeeding cereals. The amount of organic matter applied into soil was dependent on the cultivated crop. The highest amount of organic matter was applied with hybrid lucerne, the lowest, with unfertilised oats. With sowings of red clover, lucerne and hybrid lucerne, 4.91–7.70 Mg C ha^{-1} and 341.9–379.1 kg N ha^{-1} were added to soil with green material and roots. The yield of spring wheat on unfertilised soil was 2.12 Mg ha^{-1}, but the treatment with hybrid lucerne as a preceding crop gave an extra yield of 1.45 Mg ha^{-1}. Green manure crops did not have a unilateral effect on the quality of spring wheat. Grain yield grew with the increased norm of mineral nitrogen, but there was no significant improvement in quality indicators.

Key words: biomass, green manure crops, spring wheat, nitrogen, grain yield, crude protein, gluten index

INTRODUCTION

Efficient and economic utilisation of natural resources is crucial in farming systems (Bade & Kruseman, 1998; Granstedt, 2000). In addition to conventional farming systems, increasingly more attention is being paid to organic farming, which secures an ecologically cleaner and healthier environment.

Some issues in organic farming include enrichment of soil with nutrients and growing wheat with good baking properties. Cultivation of leguminous green manure crops is the main possibility for soil enrichment with nutrients, especially with nitrogen. Nitrogen binding by leguminous crops reaches its peak in the period of blooming, and starts decreasing in the period of seed formation (Leinonen, 2000). The productivity of cereals depends on soil properties, meteorological factors, fertilisation, and especially humus content in soil. Ploughed-in green material enriches soil with organic matter, which as a result of microbiological processes releases nutrients for plants.

The largest amount of organic matter is left in the soil with the residues of perennial grasses, less with annual grasses, winter cereals, maize, spring cereals, grain legumes and others (Maiksteniene & Arlauskiene, 2004). According to Viil & Võsa

(2005), the amount of nitrogen left in soil in the sowing year of white sweet clover and red clover is 247 kg/ha and 160 kg/ha respectively.

The residues and ploughed-in green material of perennial grasses, as preceding crops, have a positive effect on the formation of productivity elements of cereal crops not only in the first year but also in the second year, which determines the productivity of the cereal link (Skuodienė & Nekrošienė, 2007). The results suggest that red clover is the optimum species for use as green manure (Stopes et al., 1996).

The nitrogen released from green manures can be used by succeeding crops (wheat in the experiment) throughout their growing period. Therefore, the nitrogen taken up in the later growing period increases the protein content of grains. Significant amounts of nitrogen are applied into soil with green manures, but nitrogen is released gradually with long-term decomposition of organic matter, thus decreasing the risk of leaching nutrients.

The aim of the present study was to investigate the influence of various green manures on the yield and yield quality of spring wheat.

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 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 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: pH_{KCl}; organic carbon by the Tjurin method (Soil Survey Laboratory Staff, 1996); P and K by the Mehlich-3 method (Extracting Reagent 0.2N CH_3COOH; NH_4NO_3; 0.015N NH4 HNO_3; 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 sulphuric acid solution (Method 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 crude protein (CP) concentration in feeds is determined using the Kjeldahl procedure. Wet gluten content (WGC) and gluten index (GI) were determined by ISO 21415-2:2006. Yield (Y), 1000 kernel weight (TKW) and volume weight (VW) was calculated as average of 8 replications.

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

Variant A) spring barley (*Hordeum vulgare* L.) with undersowings of (i) red clover (*Trifolium pratense)*, (ii) Lucerne *(Medicago sativa)*, (iii) hybrid Lucerne *(Medicago media)*, (iv) bird's-foot trefoil *(Lotus corniculatus)*.

Variant B) spring barley with mineral fertiliser 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*", sown on 30 April. Succeeding crops were, in 2005 after barley oats (*Avena sativa* L.) *cv.* "*Jaak*" (3 May), and, in 2006 spring wheat (*Triticum aestivum*) "Triso".

The seed rate of germinating grains of cereals was 500 m^{-1} every year. Green manure crops were sown according to the following norms: red clover 7.5 kg ha^{-1}, lucerne 6.5 kg ha^{-1}, hybrid lucerne 10 kg ha^{-1}, bird's-foot trefoil 6 kg ha^{-1}. In 2004 barley straw was removed. In autumn 2005, straw of the oat crop and the biomass of legumes were ploughed into the soil.

Samples of aboveground biomass were taken before harvesting the cereals and the root mass was taken from 0–60 cm in depth. In variants with undersowings (A) the aboveground biomass and the root mass of leguminous crops were measured before ploughing.

The experimental area belongs to the South Estonia upland agroclimatic region, where the sum of active air temperatures of the year is averagely 1750–1800°C and total precipitation is 550–650 mm. The period of active plant growth (average diurnal temperature continuously above 10°C) ranges usually from 115-135 days (Tarand, 2003).

During the vegetation period (May to September), the amount of precipitation was greater than average in 2004, similar to the average in 2005. The vegetation period of 2006 had a high temperature regime and low precipitation. The first half of the vegetation period (up to 31 July) was very dry, with only half of the average precipitation in Estonia (Table 1). The other half of the period (up to 31 October) also saw less than average precipitation. Due to dry weather, the vegetation period of crops shortened, affecting the yield and the quality of grains.

Table 1. Weather conditions during the vegetation period in 2004–2006 (according to the Erika weather station) and the average* of 1966–1998 in Tartu (Jaagus, 1999).

Month	Temperatures, °C				Precipitation, mm			
	2004	2005	2006	Average*	2004	2005	2006	Average*
May	12,7	10,8	11,9	11.6	34	114	34	55
June	13,4	14,4	16,2	15.1	210	54	47	66
July	16,4	19,5	18,7	16.7	113	22	16	72
Aug.	17,0	16,5	17,1	15.6	116	92	80	79
Sept.	11,9	12,7	13,6	10.4	99	59	35	66

The trial data were statistically processed using the single factor analysis of variance (ANOVA) and correlation analysis.

RESULTS AND DISCUSSION

In 2004, pure sowings of barley returned 11–24 kg ha^{-1} of nitrogen into soil with stubble and roots of barley depending on the nitrogen fertiliser norm, while 69–124 kg ha^{-1} N was removed from soil with grain yield and straw. The biomass returned into soil remained in the range of 1.3–2.3 Mg of dry matter ha^{-1}.

In 2005, in pure sowings of oats, the total biomass returned into soil constituted 5.1–7.8 Mg of dry matter per hectare depending on the nitrogen fertiliser norm, the root mass forming 40%–44%. The total biomass of leguminous green manure crops ploughed into soil varied between 10.3–17.2 Mg ha^{-1}, of which the root mass constituted 33%–48% (Figure 1). The total biomasses were as follows: 10.3 Mg ha^{-1} for bird's foot trefoil, 15.3 Mg ha^{-1} for red clover, 15.7 for lucerne and 17.2 Mg ha^{-1} hybrid lucerne. 4.91–7.70 Mg C ha^{-1} was applied into soil with green material and roots of red clover, lucerne and hybrid lucerne sowings.

The nitrogen content of the applied organic matter varied considerably. The nitrogen content of oats straw varied according to fertiliser norm in the range of 0.63%–0.67%. The nitrogen content of above-ground biomass of legumes, roots and the above-ground biomass of weeds was 2.43%–2.82%, 1.38%–2.73% and 1.88% respectively. In total, 39.2–379.1 kg N ha^{-1} was applied into soil with organic matter depending on the treatment (Figure 2).

In pure sowings of leguminous green manure crops, the efficiency of green manure depends on the time of biomass application (Talgre et Al., 2008). When growing spring cereals as preceding crops, it is practical to apply the green manure crop in late autumn or spring in order to minimise nitrogen loss. The risk of N loss depends on the N content of green manure crops. It is advisable to plough green manure fallows grown on cereal fields or having high N content as the last ones in autumn (Känkänen, 2001).

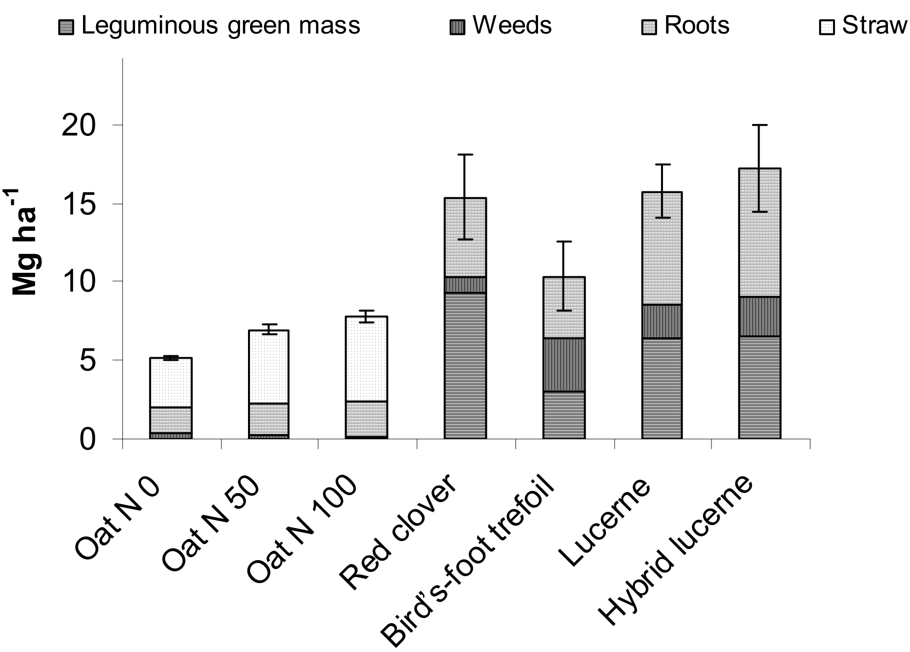

Fig. 1. Quantities of dry matter (Mg ha^{-1}) applied into soil in 2005.
Vertical bars denote confidence limits (CL 0.05 – level of statistical significance).

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 released into soil from green manure mineralisation (Kumar & Goh, 2002).

The relationship between the C/N ratio (y) and the nitrogen content (x, %) of the organic matter is reflected in the following regression equation:

$$y\ (C/N) = 42.977x^{-1.0035}$$
$$R^2 = 0.99$$

The C/N ratio of the applied organic matter varied significantly. The C/N ratio of oats straw and the biomass of leguminous crops was 50–57 and 18–23 respectively (Figure 2).

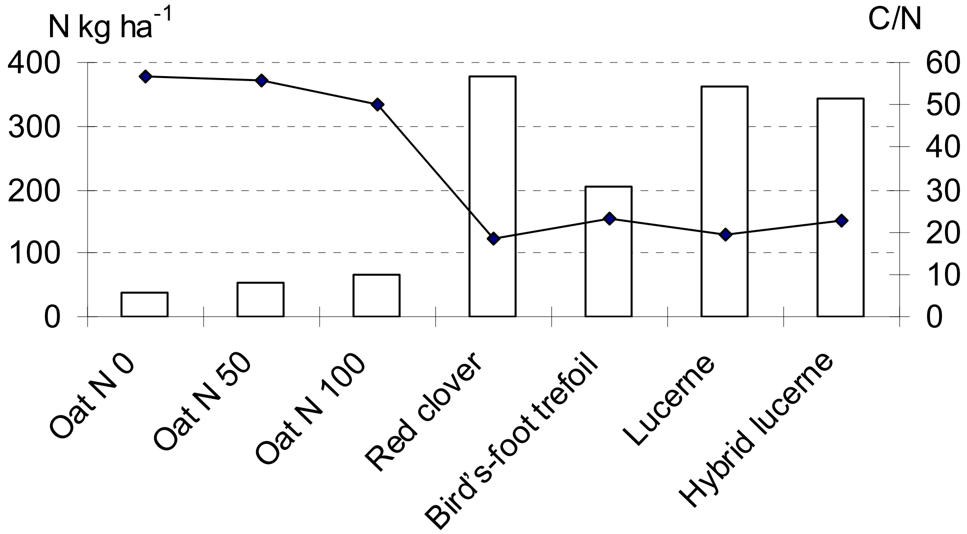

Fig. 2. Quantities of nitrogen (kg ha^{-1}) and the C/N ratio of organic matter at the application into soil with biomass in 2005.

In 2006, spring wheat was grown as a succeeding crop. Due to its weak roots, spring wheat requires a high level of humidity. Under the conditions of drought, soil may contain the optimum amount of nutrients, but there is no uptake by plants. The drought of July 2006 shortened the vegetation period of wheat, affecting its yield. The yield of spring wheat was 2.12 Mg ha^{-1} on unfertilised soil, whereas mineral nitrogen fertiliser norm N_{100} gave an extra yield of 1.33 Mg ha^{-1} (Table 2). The treatment with red clover as a preceding crop gave a wheat yield of 3.46 Mg ha^{-1} and 3.57 Mg $^{-1}$ after hybrid lucerne, which is 3% higher than after clover and fertilisation with norm N_{100}. Also Maiksteniene and Arlauskiene (2004) show that the highest wheat yield is attained when wheat is grown after lucerne as a preceding crop, the yield being 18.5% higher than after clover. Wheat yield was lower after bird's foot trefoil than after red clover and hybrid lucerne.

Fertilisation with nitrogen at a late stage is crucial in order to get high-quality wheat. Under normal humidity conditions, the optimum time for fertilisation is the heading phase because it fosters the increase of protein content. Nitrogen applied later than at the heading stage raises mostly wet gluten content (Järvan et al., 2007). If all nitrogen fertiliser is applied at once at the beginning of growing, it may cause excess vegetative growth, lodging, lower yields and lower yield quality (Brown et al., 2007). By using green manure crops, nitrogen is released over a long period. Thus, nitrogen uptake by crops remains balanced throughout the vegetation period, contributing to high quality of wheat.

Volume weight (test weight) is the oldest and one of the most often used wheat quality indexes. Test weight of wheat cultivars is an index of the density and soundness of kernels. As a general rule, the higher the test weight, the better. Test weight is influenced by many factors, including fungal infection, insect damage, kernel shape and density, foreign materials, broken and shrivelled kernels, agronomic practice and the climatic and weather conditions (Gaines et al., 1997). In the present trial, there is no systematic connection between volume weight and use of mineral fertiliser. Grain remained thin and volume weight low due to drought. Of leguminous crops, red clover has influenced the increase of volume weight.

The 1000-grain weight varies due to different weather conditions during grain formation and ripening stage and is affected by fertilisation and the number of plants per area unit (Plyčevaitienė, 2002). Year 2006 was not favourable for the formation of big grains. Hybrid lucerne as a preceding crop had the lowest 1000-grain weight. There was no plausible correlation between 1000-grain weight and yield.

Table 2. Yield and yield quality of spring wheat *Triso* depending on preceding crop

Preceding crop	Y/yield Mg ha^{-1}	TKW/ 1000 kernel weight g	VW/volume weight g/l	CP/crude protein %	WGC/wet gluten content %	GI/gluten index %
Oats N0	2.12	31.9	790.7	9.2	18.1	96.5
Oats N50	2.93*	33.5*	796.5*	10.0	21.9*	87.5
Oats N100	3.45*	33.2	775.0	12.5*	30.0*	71.0
Clover	3.46*	32.3	799.6*	13.1*	32.0*	77.0
Bird's foot trefoil	3.23*	30.9	796.8	10.9*	24.5*	92.0
Lucerne	3.33*	31.7	795.6	13.2*	33.0*	74.5
Hybrid lucerne	3.57*	30.8	797.9	13.5*	33.2*	76.0
LSD $_{0.05}$	0.18	1.46	8.8	0.14	0.12	1.24

* significant differences from the control at *P>0,05*.

Crude protein is a primary quality component of cereal grains. Protein concentration is influenced by both environmental and genotypic factors that are difficult to separate (Fowler et al., 1990; Garcia del Moral et al., 1995)**.** The protein content of wheat grains can vary from 6% up to as much as 25%, depending upon the growing conditions (Blackman & Payne, 1987). Wheat with good baking properties has a protein content of 13%–15%. Higher temperature in the period of grain maturation accelerates aging and maturation of leaves, causing higher protein content in grains. Higher grain yields are usually associated with lower protein concentration (Blackman & Payne 1987), but in the test year, the protein content increased with the growth of yield. Mineral nitrogen increased the protein content by 0.8%–3.3%. Protein content of grain was also significantly affected by leguminous green manures by 1.7%–4.3%. Wheat grain protein content reached 10.9%–13.5% with green manure crops, while the treatment with bird's foot trefoil as a preceding crop gave the lowest protein content.

Wet gluten is formed by mixing flour with water. The higher the wet gluten content in flour, the fluffier the bread. The minimum grain wet gluten content should be 26% (optimum is 28%–29%). Grain wet gluten content increased with fertilisation and the after-effect of green manure crops. WGC remained below the norm in the unfertilised treatment, with N_{50} and after bird's foot trefoil. Research has shown (Kangor et al*.,* 2007) that the amount of wet gluten is increased with both fertilisation and intensive use of leaf fertilisers. The quality of wet gluten was determined by the genetic properties of the cultivar.

The optimum gluten index is 60%–90%. Gluten index over 90% decreases the flexibility and elasticity of wet gluten, which is unfavourable for the ready-to-use product. GI shows the effectiveness of wet gluten, which determines baking quality. Too low or high gluten index does not give good raising qualities. In the present trial, the GI was over 90% in the N_0 treatment of wheat and after bird's foot trefoil. GI remained in the range between 74.5%–77% after lucerne and red clover.

CONCLUSIONS

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. Green manure crops provide a significant increase in the N supply for the succeeding crop without any yield loss of the main crop compared to the unfertilised variant (N_0).

Spring wheat gave the lowest yield on unfertilised soil, but the treatment with hybrid lucerne as the preceding crop gave the biggest extra yield. Bird's foot trefoil as a preceding crop contributed to the growth of yield, but compared to other green manure crops, its effect remained less significant in terms of yield and quality indicators.

The effect of green manure crops on the quality of spring wheat was not unilateral. Red clover and lucernes had the most significant effect as preceding crops, improving the protein content, wet gluten % and gluten index of grains. Grain yield was improved by increasing the mineral nitrogen norm, but there was no significant improvement in quality indicators.

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