Green manure as a nutrient source for succeeding crops

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ABSTRACT

The trials were carried out in the Estonian University of Life Sciences (58°23'N, 26°44'E), and studied to what extent green manure crops bind nutrients and the effect and stability of biologically fixed nitrogen (N). Our research covered more species than most of the earlier studies in the Nordic countries. Compared with biomass from unfertilized barley, legume undersowing, straws plus roots added up to 4 times more N, 2.8 times more phosphorus (P) and 2.5 times more potassium (K) returning to the soil. Red clover, hybrid lucerne and white melilot as pure sows produced the highest biomass, amounts of N, P, and K being up to 206, 24 and 144 kg/ha, respectively. The effect of additional N in soil was measured by weighing successive grain yields. In the first test year, 1 kg of N from green manure had the effect of producing 8.6 kg grain and this relation did not change even for higher N amounts. Green manure had a significant effect even in the third year after the green manure was ploughed into soil.

Keywords: biomass; biologically fixed nitrogen; phosphorus; potassium; grain yield

Crop yield, soil nutrient content, amount of agricultural production and their environmental effects are all influenced by fertilizer use. Decreased soil fertility and increased mineral fertilizer prices made legumes a popular option as organic fertilizers. Organic fertilizers have an important role in improving soil fertility. Manures are most often not sufficiently available in organic arable farming, and this necessitates the use of other sources of N for fully fertilizing high yielding cereals under organic farming in Northern Europe (Olesen et al. 2009). One option is to use green manure. Correctly managed, green manures can replace some or all of the N required for non-leguminous succeeding crops (Guldan et al. 1997). The average amounts of N accumulated by green manures can entirely substitute for mineral fertilizer N at current average application rates. It was often observed that legumes, in contrast to cereals, have a beneficial effect on grain yield of subsequent cereal crops (Olesen et al. 2007).

Soil fertility is especially affected by soil organic matter, which depends on biomass input to compensate mineralization. Higher biomass return to the soil can increase soil organic carbon and soil total N. N is the most studied nutrient, but P and K levels are also important. Askegaard and Eriksen (2008) reported that in organic farming, K deficiency may become a significant problem. Perennial legumes such as lucerne, with their deep root systems, import additional nutrients (P, K, Ca) (Teit 1990) to the soil that are accessible to succeeding crops (Witter and Johansson 2001). Some researchers consider that plant residues and green manure are not rich in K and especially P (Maiksteniene and Arlauskiene 2004), but they improve the physical characteristics and stimulate microbial activity of the soils. After decomposition, the organic P and K bound in the green manure crop may provide an easily accessible form of P and K to succeeding crops (Askegaard and Eriksen 2008, Eichler-Löbermann et al. 2009).

For maximum yield and crop quality, big amounts of fertilizers are used. However, application of high mineral fertilizer amounts can bring about considerable nutrient losses from the soil, which affects the quality of surface- and groundwater. With green manure also, large amounts of N are applied into soil, but nutrients are released from green manure at a slower rate; also, N from N-fixing bacteria becomes accessible over a long time span. These processes grant steady sources of N for succeeding crops (Freyer 2003).

Our research concentrates on determining the effects of growing various legumes as green manure crops in Nordic conditions. Crucial parts of this research are studies of biologically fixed N and its efficiency. There are not many preceding studies about these effects. Our research covered more species than most of the earlier studies in Nordic countries. The purpose of the experiment was to study (i) to what extent the green manure crops fix nutrients and (ii) the duration of release of fixed N.

METHOD AND MATERIALS

The trials were carried out during the 2004–2009 growing seasons in the Estonian University of Life Sciences (58°23'N, 26°44'E). The experiment was designed in fully randomized blocks with 4 replicates. The size of each test plot was 30 m^2. The soil type of the experiment area was sandy loam Stagnic Luvisol according to the WRB 2006 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, K 253–260 mg/kg, pH_{KCl} 5.9, soil bulk density 1.45–1.50 g/cm^3. The ploughing layer was 27–29 cm. Soil organic carbon was determined by the Tjurin method, P and K by the Mehlich III method, and the total-N content by the Kjeldahl method.

Two field experiments were constructed to study the effects of green manures. The first field experiment was established in 2004 using the following variants of green manure crops and fertilization:

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

(B) spring barley (*Hordeum vulgare* L.) with undersowing of red clover, lucerne, hybrid lucerne, bird's-foot trefoil;

(C) spring barley without mineral fertilizer rates N_0 – the control variant and with mineral fertilizer N_{50}, N_{100} (every year with cereal sowing).

The undersown main crop was spring barley cv. Arve. Succeeding crops were, in 2005, oats (*Avena sativa* L.) cv. Jaak, in 2006, spring barley (*Hordeum distichon* L.) cv. Inari, and, in 2007 oats cv. Jaak.

The second field experiment was established in 2007 using the same variants of green manure crops and fertilization, but white melilot (*Melilotus albus* Med) was added in variant A and B. The cover crop was spring barley cv. Arve. Succeeding crops were, in 2008, spring wheat (*Triticum aestivum* L.) cv. Vinjet, in 2009, spring barley (*Hordeum distichon* L.) cv. Inari.

The seed rate of germinating grains of cereals was 500 seeds per m^2 every year. Green manure pure crops were sown according to the following norms: red clover 15 kg/ha, lucerne 13 kg/ha, hybrid lucerne 20 kg/ha, bird's-foot trefoil 12 kg/ha, white melilot 30 kg/ha. The seeding rates for undersowing were reduced by half.

Biomass (shoots + roots + weeds) of cereals was measured before harvesting. The aboveground biomass (shoots + weeds) of undersown crops was measured at cereal harvest and before autumn ploughing. The aboveground biomass (shoots + weeds) of pure legumes were measured before ploughing. The root mass (0–60 cm in depth, frame 10 × 25 cm) of leguminous crops were measured before ploughing. Roots were sampled by washing roots from soil. Aboveground biomass was taken by cutting below the surface, allocated weeds and all plant samples were dried (80°C). In all variants, barley straw and the biomass of legumes were ploughed into the soil (20–22 cm) in the end of October.

Acid digestion by sulphuric acid solution was used to determine P and K content in plant material. Total N and C content of oven-dried samples were determined by dry combustion method on a varioMAX CNS elemental analyzer (ELEMENTAR, Hanan, Germany).

The experimental area belongs to the South-Estonian upland agroclimatic region. During the experimental period, rainfall and air temperature were recorded daily at a meteorological station located within the experimental area (Table 1).

The software STATISTICA 10 (StatSoft Inc., Tulsa, USA) was used for the statistical data analysis. The trial data were processed using descriptive statistics. The means are presented with their standard errors (± SE), $P < 0.05$. The significance of differences between grain yields of the variants was calculated using the Fischer's test, the level of significance $P < 0.05$.

RESULTS

Biomass formation and nutrient absorption. On average, pure barley sows produced 4.18–6.34 t/ha of ploughable (straws, stubble, roots) dry matter, determined by the amount of added nitrogen

Table 1. Monthly precipitation and average temperature during the experiment

Month	Air temperatures (°C)						Precipitation (mm)					
	2004	2005	2006	2007	2008	2009	2004	2005	2006	2007	2008	2009
January	−7.6	−1.7	−5.5	−7.1	−1.3	−3.4	6	114	5	29	22	10
February	−4.5	−7.3	−8.7	−6.6	0.6	−4.9	18	0	8	23	34	7
March	−0.4	−4.9	−3.5	−2.4	0.4	−1.5	36	4	13	26	8	22
April	5.6	5.0	6.2	4.2	7.1	5.3	8	22	15	33	27	14
May	12.7	10.8	11.9	11.6	10.6	11.5	34	114	34	55	27	13
June	13.4	14.4	16.2	15.1	14.4	13.8	210	54	47	66	110	137
July	16.4	19.5	18.7	16.7	16.1	16.9	113	22	16	72	54	55
August	17.0	16.5	17.1	15.6	17.7	15.4	116	92	80	79	118	89
September	11.9	12.7	13.6	10.4	9.8	12.8	99	59	35	66	46	49
October	5.7	6.7	8.1	5.7	8.2	4.1	61	38	111	52	68	116
November	−0.7	2.6	5.3	0.3	2.3	2.3	25	30	10	48	49	36
December	−0.1	−3.2	3.8	−4.2	−1.1	−3.8	27	17	38	40	24	41

(Table 2). Barley roots yield was 1.36–2.15 t/ha. Barley roots and straws returned to soil 39–59 kg N, 8–14 kg P and 55–102 kg K/ha. Organic matter in soil left after barley harvest was relatively low in N content, the C/N ratio was 42–47. Barley grains removed 39–80 kg N, 7–13 kg P and 15–31 kg K/ha. As the soil humus layer contained 430 kg of plant-available P and 1050 kg of similarly usable K – and 80% of all nutrients are taken from humus layer – then we can conclude that in a single year, barley

Table 2. Average dry matter yield (t/ha) of shoots, roots and weeds of pure spring barley with three N fertilization rates, five legume species undersown in spring barley and legumes grown as pure crops in 2004 and 2007

	Quantities of dry matter (t/ha) applied into soil (mean ± SE)			
	barley straw	shoots	roots	weed
Barley N_0	2.10 ± 0.09^c	×	1.36 ± 0.08^c	0.71 ± 0.07^b
Barley N_{50}	3.27 ± 0.12^b	×	1.70 ± 0.08^b	0.41 ± 0.13^c
Barley N_{100}	3.86 ± 0.13^a	×	2.15 ± 0.12^b	0.33 ± 0.05^c
Undersown legumes				
Red clover	2.25 ± 0.10^c	2.52 ±0.39^b	3.29 ± 0.43^a	0.25 ± 0.03^c
Bird's-f. tr-l*	2.46 ± 0.29^c	0.26 ± 0.05^d	2.57 ± 0.77^a	1.43 ± 0.20^a
Lucerne	2.45 ± 0.17^c	1.50 ± 0.19^c	3.05 ± 0.32^a	0.46 ± 0.15^c
Hybrid lucerne	2.29 ± 0.20^c	2.01 ± 0.53^b	2.69 ± 0.14^a	0.27 ± 0.08^c
White melilot	2.17 ± 0.05^c	2.36 ± 0.09^b	2.91 ± 0.14^a	0.25 ± 0.05^c
Legume pure sowings				
Red clover	×	4.09 ± 0.36^a	3.28 ± 0.57^a	0.24 ± 0.8^c
Bird's-f. tr-l*	×	1.72 ± 0.35^c	2.30 ± 0.28^{ab}	0.92 ± 0.24^b
Lucerne	×	3.36 ± 0.14^a	3.80 ± 0.26^a	0.45 ± 0.11^c
Hybrid lucerne	×	3.67 ± 0.37^a	4.11 ± 1.18^a	0.24 ± 0.07^c
White melilot	×	3.63 ± 0.36^a	3.64 ± 0.12^a	0.35 ± 0.01^c

Means followed by different letters in the same column are significantly different at $P < 0.05$. Bird's-f. tr-l* – Bird's-foot trefoil

Table 3. Estimated means and standard errors of N, P, and K (kg/ha) in barley grains and incorporated biomass (shoots and roots), and C/N of the biomass in two trials in 2004 and 2007

Variant	Barley grain			Biomass remained at field			
	N	P	K	N	P	K	C/N
Barley N_0	39 ± 1.27	7 ± 0.29	15 ± 0.48	40 ± 1.85	8 ± 0.30	55 ± 2.06	44
Barley N_{50}	63 ± 2.32	12 ± 0.58	25 ± 1.04	46 ± 2.35	9 ± 0.49	68 ± 2.32	47
Barley N_{100}	80 ± 2.65	13 ± 0.59	31 ± 1.13	60 ± 1.36	14 ± 1.24	102 ± 9.96	42
Undersown legumes							
Red clover	47 ± 2.59	10 ± 0.55	17 ± 1.23	165 ± 10.6	19 ± 1.59	153 ± 8.87	25
Bird's-foot tr-l	55 ± 1.77	12 ± 0.37	19 ± 0.59	93 ± 5.07	17 ± 0.84	98 ± 2.12	31
Lucerne	47 ± 2.90	10 ± 0.62	14 ± 0.97	136 ± 5.19	20 ± 1.70	114 ± 5.51	26
Hybrid lucerne	48 ± 3.20	10 ± 0.68	16 ± 1.07	139 ± 17.61	16 ± 1.85	118 ± 12.3	24
White melilot	43 ± 1.05	9 ± 0.22	14 ± 0.35	177 ± 1.59	20 ± 0.25	112 ± 2.03	27
Legume pure sowings							
Red clover	×	×	×	196 ± 1.74	20 ± 1.25	144 ± 13.09	17
Bird's-foot tr-l	×	×	×	114 ± 8.42	17 ± 1.32	89 ± 3.32	19
Lucerne	×	×	×	191 ± 13.9	19 ± 0.64	120 ± 12.02	16
Hybrid lucerne	×	×	×	195 ± 15.9	24 ± 1.22	123 ± 13.95	18
White melilot	×	×	×	206 ± 3.51	22 ± 0.39	104 ± 2.86	17

used up 2–4% of P and 4–7% of K in the humus layer. With undersown barley, where green manure biomass was used as an addition to barley straws and roots, the total amount of dry matter produced varied from 6.72–8.31 t/ha. Roots yielded 2.57–3.29 t/ha. Thus, 93–177 kg N/ha, 16–20 kg P and 98–153 kg K/ha was returned to soil. The C/N ratio of the total biomass was 24–31 (Table 3). Therefore undersown legumes improve the C/N ratio in organic matter, which creates better conditions for organic matter decomposition in soil. Growth period, aftermath formation and competitiveness all had an influence on biomass production. The lowest amount of biomass was from undersown bird's-foot trefoil, where bird's-foot trefoil remained in the lower growth layer and its aboveground biomass was only 0.26 t/ha. The biggest biomass from undersowing was from red clover – 8.32 t/ha, of which 40% were roots and 27 cereal straws (Tables 2 and 3).

Total dry matter yield (shoots and roots, including weeds) of pure legume crops were: bird's-foot trefoil 4.94 t/ha, red clover and common lucerne 7.60 t/ha, white melilot 7.61 t/ha and hybrid lucerne 8.02 t/ha. Roots yielded 2.30–4.11 t/ha, which was 45–57% of total mass. N, P, and K yields of the total

Table 4. Yield increase of succeeding crops (kg/ha) depending on green manure application compared with unfertilized cereal

Green manure	Undersown legumes			Legume pure sowings		
	1st year	2nd year	3rd year	1st year	2nd year	3rd year
Red clover	1206*	608*	219*	1725*	1086*	305*
Bird's-foot tr-l	123	238	98	1128*	724*	108
Lucerne	659*	555*	335*	1292*	1143*	494*
Hybrid lucerne	1017*	697*	234*	1540*	1345*	365*
White melilot	1106*	603*	×	1969*	1198*	×

*significant at level $P < 0.05$; × – yield was not measured. Unfertilized cereal yield in 1st year 2897; 2nd year 2025; 3rd year 1967 kg/ha biomass were 113–206 kg, 17–24 and 89–144 kg/ha. K content in roots was lower than in above-ground biomass. The C/N ratio was 16–19 (Tables 2 and 3). Considering the total amount of biomass that was added to soil, legume pure sowings have up to three times narrower C/N ratio than cereals.

Nitrogen efficiency for succeeding crops. The effect of additional N in soil was measured by weighing successive grain yields. Still in the third year, pure and undersown red clover, lucerne and hybrid lucerne had a significant effect (Table 4). Grain yields of three succeeding cereal crops was increased with increasing N yield of the first experimental year. In the first year, after organic matter was added to the soil, the relationship between cereal yield and the amount of N in biomass was linear ($P < 0.00$). The response of 1 kg of N was 8.6 kg of grains. Also in the next year, the response of 1 kg of N was 6.8 kg of grains ($P < 0.000$). The relationship between cereal yield and biomass N content stayed linear in the third year ($P < 0.000$), although the relationship was much weaker than in previous two years. The response of 1 kg of N was 2.0 kg of grains (Figure 1).

100 kg N/ha added to soil in biomass (pure and undersowing), resulted in 43, 34, and 10% increase in grain yield of the first, second and third succeeding cereal respectively, compared to the unfertilized control field.

DISCUSSION

Earlier experiments showed that the amount of biomass depends on plant species, tillage methods and environment (Kumar and Goh 2002, Talgre et al. 2009). Current study showed that also lucerne and white melilot can be successfully used for green manure, in addition to the most popular green manure crops in Northern Europe, red and white clover. Compared with other legumes, bird's-foot trefoil had a less prominent effect. Thereby it was proved that bird's-foot trefoil is not suitable as a green manure crop. Red clover, hybrid lucerne and white melilot produced the highest biomass. Undersown legumes produced less biomass and absorbed less N than pure legumes, but the total biomass, legumes and cereal together, increased compared to pure cereal crops. The C/N ratio of incorporated biomass decreased in context of undersowing, compared to pure cereal crop. This is in accordance with Dordas and Lithourgidis (2011) and with Jørgensen et al. (1999). High C/N ratio of cereal straw have a negative effect on N availability (Taylor et al. 1989, Nygaard Sorensen and Thorup-Kristensen 2011).

According Becker et al. (1995), even with a short growth period of 45–60 days, green manure legumes can fix 80–100 kg N/ha of which the major portion (about 80%) is derived from biological N_2 fixation. Therefore – biomass from legume green manure crops can add a huge amount of N and C to the soil, which improves soil humus characteristics. Legumes can absorb nutrients from lower soil layers, with their well developed and deep root systems and return the nutrients to upper soil layers with their biomass. The relocation of plant nutrients (especially P and K) is particularly useful in organic farming.

As P and K are relatively stable in soil, their leaching losses are almost nonexistent and most of these elements are removed with the crop. We found that barley grains removed 7–13 kg P and 15–31 kg K/ha, which is in accordance with Kirchmann et al. (2008) who reported that around 10 kg P and

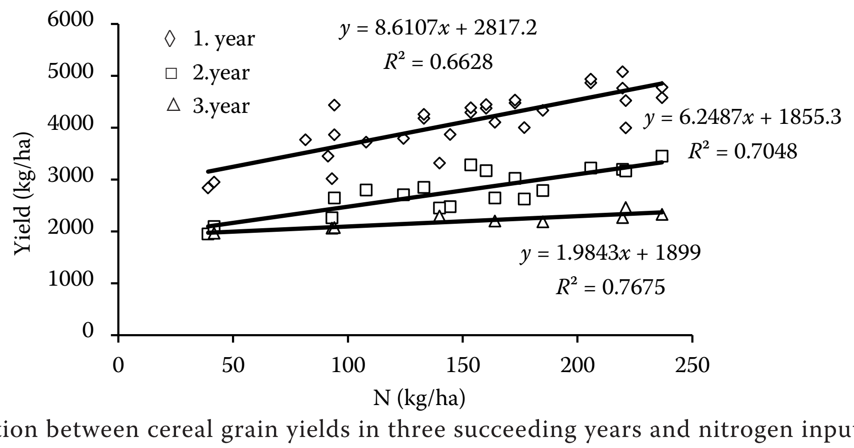

Figure 1. Correlation between cereal grain yields in three succeeding years and nitrogen input through organic matter. y – cereal yield (t/ha); x – nitrogen amount in biomass (kg N/ha); R^2 – relationship between cereal yield and the amount of nitrogen in biomass. In the 1st year $R^2 = 0.66$; $P < 0.00$; 2nd year $R^2 = 0.70$; $P < 0.000$ and 3rd year $R^2 = 0.77$; $P < 0.000$

15 kg K/ha is removed from the field every year in organic farming. This rate of phosphorus and potassium use is usual, considering the amount of nutrients in soil and the amount of fertilizer needs. Green manure biomass ploughed in can release nutrients needed by cereal crop. Our tests showed that K content in roots was lower than in the above-ground biomass. Mengel (1982) found that root K content normally constitutes less than 10% of the total plant K content. The release of nutrients depends on the nutrient concentration of the organic matter and the C-to-nutrient ratio (Nygaard Sorensen and Thorup-Kristensen 2011). Martin and Cunningham (Ha et al. 2008) found that up to 40 and 60% of P in residues is water-soluble and rapidly released after incorporation into soil. Depending on biomass size, pure and undersown green manure crops fixed up to 153 kg K/ha and up to 20 kg P/ha. It was shown that with careful management of manure and the effective use of legumes, and by using permitted inputs for P and K, organic farms can be managed sustainably.

N is the key element in obtaining a high yield with good quality. It is involved in all of the plant's metabolic processes, its rate of uptake and partition being largely determined by supply and demand during the various stages of plant growth (Delogua et al. 1998). Research showed that the yield effect of green manure in soil depends on the amount of N in biomass, its release rate, the C/N ratio in organic matter (Kumar and Goh 2002), soil N content and climate. Our experiments showed the beneficial effects on succeeding crops. The first year after effects were studied by Hanly and Gregg (2004), Tonitto et al. (2006) who confirm our results. As the soil in our experimental field was relatively low at humus content and the general amount of N in the humus layer was only 0.10–0.12%, N from green manure crops in soil was very effective. The succeeding crop yield in the first year after pure red clover and hybrid lucerne sows was even higher than when 100 kg N/ha was used as a mineral fertilizer. In contrast, Harris and Hesterman (1990) found that lucerne residues did not provide significant amounts of N to a succeeding barley crop explaining it with high C/N ratio in roots, leading to slow decomposition and later N availability. There is little information regarding the response of second – and third year succeeding crop. Andersen and Olsen (1993) did not find any second year after-effect of green manures on barley yield. In our study in the second year, the positive after-effect of green manure was found. According to Viil and Võsa (2005) 16–18% of red clover's after effect becomes apparent in the second year; it is up to 28% for white melilot. In our study, still in the third year, green manure from red clover, lucerne and hybrid lucerne all had a significant effect, but the effect of N in their organic matter on yield increase was three times lower than in the first year. Yield results of the present study showed that N is slowly released from green manure, which may decrease lodging and yield loss. Mineral fertilizers work quickly, and in a soil with high N content fertilization rate of 60 kg/ha N, may cause crop flattening in 1–2 years out of ten (Roostalu et al. 2003).

Biomass from pure green manure legume undersowing adds a considerable amount of nitrogen to the soil, but is released over long time. Because of that, green manure had a significant effect even in the third year after the green manure was ploughed into soil.

Undersown legumes produced less biomass and absorbed less N than pure legumes, but the total biomass, legumes and cereal together, increased compared to pure cereal crops. With undersown lee gumes, 93–177 kg N/ha, 16–20 kg P and 98–153 kg K/ha was returned to soil. In the tested common green manure legumes as pure sows, 114–196 kg N, 17–24 kg P and 89–144 kg K/ha was returned to soil every year. Green manures with high nutrient concentrations and low C/N ratios have a great impact on their value as fertilizer in crop production. Compared with other legumes, bird's-foot trefoil is not suitable as a green manure crop.

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