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Biomass production and nutrient binding of catch crops

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Abstract

The trials were carried out during the 2008–2010 growing seasons at the Estonian University of Life Sciences' Department of Field Crop Husbandry. The experiments were performed to measure the amount of biomass produced by catch crops and how effectively they bind the soil nutrients. The experiment was performed four times on a *Stagnic Luvisol* (*LVst*). The catch crops were white mustard, fodder radish, faba bean, winter oil rape, winter oil turnip, Italian ryegrass, pea, rye and phacelia. The amount of biomass that catch crops produced differed significantly from year to year. Sowing time had a great effect on biomass production, with August having the greatest sum of effective temperatures. The best nutrient binders were pea and beans. In better growth years these crops bound 50–100 kg ha^{-1} N, 7–10 kg ha^{-1} P, 40–60 kg ha^{-1} K. Of *Brassicaceae*, white mustard and fodder radish produced the highest biomass, used up to 9 kg ha^{-1} P and up to 82 kg ha^{-1} K (2010, fodder radish) in the biological cycle of organic matter. The catch crops did not reduce soil NO_3-N and NH_4-N content compared to the control fields without catch crops variant.

Key words: catch crops, biomass, nitrogen, potassium, phosphorus, C:N ratio, spring wheat yield.

Introduction

In recent years, many research groups from various countries have taken an interest in finding new ways of reducing the loss of plant-accessible soil nutrients during vegetation-free periods. It is known that the mineralization of organic matter takes place in periods before or after growing seasons (Powlson, 1993; Vos, Van der Putten, 2001); autumn ploughing also increases the risk of reducing nitrogen amounts because of leaching (Davies et al., 1996).

One way to reduce nitrogen leaching is to use a crop rotation system which leaves some of the fields covered with plants for the winter. Along with growing winter cereals or perennial grasses, one could also grow intermediate crops, i.e. catch crops.

The research interest in growing catch crops and green manures is not new, but the use of such crops has decreased (Renius, Entrup, 2002). A catch crop may absorb residual N up to 200 kg ha^{-1} N and thus reduce N available for leaching and denitrification. The N uptake by the catch crop may depend on plant species, sowing date (determined by the harvest time of the previous crop), amount of available soil N and weather conditions (Van Dam, 2006).

In addition to reducing nutrient leaching, catch crops improve soil quality by adding organic matter (Lord, Mitchell, 1998), avoiding topsoil erosion (Thorup-Kristensen et al., 2003), reducing the loss of organic matter, inhibiting pest/disease infestation and reducing weeds. Plants from the *Brassicaceae* family are able to produce glycosinolates (both in their roots as well as their above-ground parts), which inhibit root rot (Ilumäe et al., 2007). Therefore growing catch crops in a crop rotation system with cereals is of great importance, because it reduces the environmental stress on the soil and disrupts the disease development cycles. However, when choosing catch crops, it is important to avoid growing biologically similar species together too often, to prevent transferring common pests and diseases. Recently, it has also been speculated that catch crops may influence the degradation potential of the soil for pesticides (Thorup-Kristensen et al., 2003).

The most common catch crops are *Brassicaceae*: fodder radish, white mustard, oilseed rape and turnip, but also cereals (rye), Italian ryegrass and phacelia. These catch crops are able to bind free nitrogen in the soil. Leguminous plants, which have the added advantage of binding nitrogen from the air, are also grown as catch crops. The efficiency of binding air nitrogen depends on the length of the growing season, crop rotation system and manuring (Peoples et al., 2001).

Catch crops are usually sown late in the summer, immediately after main crop harvesting and usually after cereals, but it is becoming more common to sow them on early vegetable and legume (bean, pea) fields as well. The earlier the catch crops are sown, the more effective they are. Their growing period requires at least 50 days, a daily temperature of 9°C and a total amount of precipitation of 150–200 mm per growing season for their normal development (Küpper, 2000).

The catch crops are ploughed into the soil shortly before the ground freezes. After incorporation of the crop into the soil, N mineralization starts, so that, with good timing, part of the mineralized N may become available for the next main season crop allowing reduction of the N application for that crop (Vos, Van der Putten, 2001). Some researchers (Stenberg et al., 1999) have found that late autumn ploughing or spring ploughing reduces the risk of N leaching.

Experiments were performed in the trial fields to study the amount of biomass formed by catch crops, how they bind nutrients and their effect on the plant available N in the soil. The purpose was to find the most optimal catch crop species for Estonian conditions.

Materials and methods

The trials were carried out during the 2008–2010 growing seasons in the Department of Field Crop Husbandry at the Estonian University of Life Sciences (EMU), Institute of Agricultural and Environmental Sciences (58°23′ N, 26°44′ E). The trial was repeated four times on a *Stagnic Luvisol* (*LVst*) (by WRB classification), the humus layer of which has the following characteristics: 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 depth of ploughing layer was 27–29 cm. Soil analyses were carried out at the laboratories of the Department of Soil Science and Agrochemistry, EMU.

Barley cv. ‘Inari’ was used as the preceding crop. The field was prepared and catch crops were sown with a Kongskilde sowing machine (row width 12.5 cm) immediately after the barley harvesting: on 25 August in 2008, 14 August in 2009 and 2 August in 2010.

The catch crops were sown according at the following rates: winter oil turnip (*Brassica rapa* L. var. *silvestris*) cv. ‘Largo’ and winter oilseed rape (*Brassica napus* L. var. *oleifera*) 8 kg ha^{-1}, fodder radish (*Raphanus sativus oleiformis*) cv. ‘Adios’ 22 kg ha^{-1}, white mustard (*Sinapis alba* L.) cv. ‘Condor’ 18 kg ha^{-1}, pea (*Pisum sativum* L.) cv. ‘Clarissa’ 180 kg ha^{-1} (80 seed m^{-2}), faba bean (*Vicia faba* L.) cv. ‘Jõgeva’ 280 kg ha^{-1} (40 seeds m^{-2}), Italian ryegrass (*Lolium multiflorum* Lam.) cv. ‘Talvike’ 25 kg ha^{-1}, rye (*Secale cereale* L.) 210 kg ha^{-1} and phacelia (*Phacelia tanacetifolia* Benth.) cv. ‘Stala’ 11 kg ha^{-1}. The aboveground biomass of catch crops and the root mass were measured before ploughing. Samples of above-ground biomass were taken from 1 m^{-2} and the root mass from 0–30 cm depth (4 replications). The samples were dried and weighed. According to the length of the growing period, the catch crops were ploughed into the soil in the 2nd–3rd ten-day period of October. Ploughing depth was 22–24 cm. Before ploughing, the catch crops were neither ground nor crushed.

Soil samples to measure NO_3-N and NH_4-N content were taken during the catch crop growing period and in the spring before tillage (Table 2) from the 20 cm depth. NO_3-N and NH_4-N were determined in 2 M KCl soil extracts by “FIAstar 5000”.

The effect of catch crops was monitored by growing spring wheat cv. ‘Mooni’ (2009, 2010). Plant analyses were conducted at the Department of Soil Science and Agrochemistry of EMU. Acid digestion by sulphuric acid solution (Methods of soil…, 1986) was used to determine P and K content in the plant material. Total nitrogen, carbon and sulfur content of oven-dried samples (separately in undeground and aboveground biomass) were determined by dry combustion method on a “vario MAX CNS” elemental analyzer (“Elementar”, Germany).

Research data was processed by using analysis of variance and correlation analysis. The differences between treatments are shown as standard error. To describe the growth period, the sum of effective temperatures (above 5°C) and precipitation average (mm) was used (Table 1).

Table 1. The sum of effective temperatures and precipitation during catch crops’ growth period

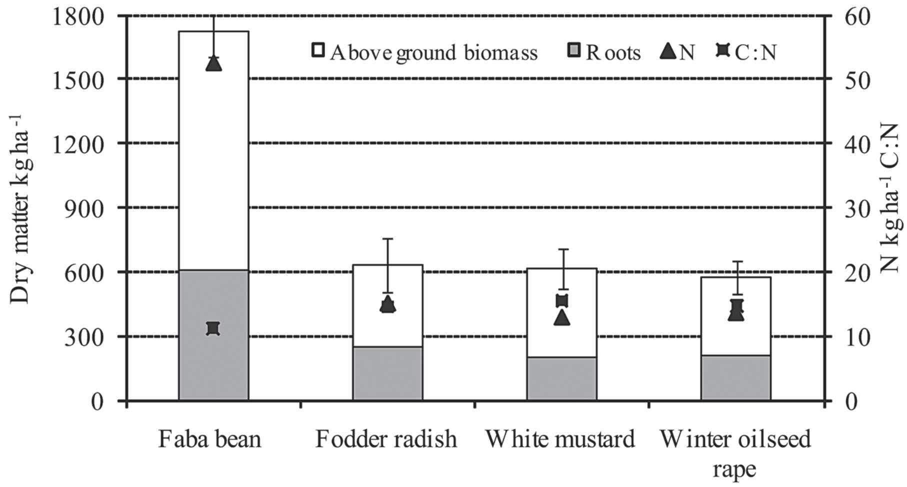
Year	Sum of effective temperatures, degree-days	Precipitation mm	Growth period/days
2008	352	134	72
2009	427	207	60
2010	602	225	72

Results and discussion

Since cereals are prevalent in modern crop rotation systems, barley cv. ‘Inari’ was chosen as the preceding crop before the catch crop for Estonian conditions. As a cultivar of medium height, it provides a sufficiently long growing period for the catch crop.

From year to year, there were great fluctuations in the quantity of catch crop biomass produced and depended on the sum of effective temperatures during the growing season (R = 0.63). Especially significant positive correlations were detected between biomass of fodder radish and sum of effective temperatures (R = 0.88). In 2008, because of the weather conditions, the crop was harvested at the end of August. As the sum of effective temperatures was low in August and September (about 30ºC lower than the average from 1948–2007), the catch crops produced a modest amount of biomass. The rather long duration of the growing period (until the end of October) did not compensate for the low temperatures. The total biomass of catch crops varied from 570 kg ha^{-1} for winter oil rape to 1720 kg ha^{-1} for faba bean, which bound 13–52 kg ha^{-1} N (Fig. 1). In fodder radish, 39% of the total biomass consisted of roots; for other crops the roots had a smaller share in the resulting biomass. Previous research (Thorup-Kristensen, 2001) has shown that fodder radish forms a strong taproot with a well-spread system of side roots, which enables it to uptake water and nutrients from lower soil layers and to improve soil structure.

The decomposition of organic matter depends largely on the C:N ratio and their overall amount. 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 (Kumar, Goh, 2002). The C:N ratio of the applied organic matter varied from 13 (bean) to 18 (white mustard and winter oilseed rape). When organic matter is decomposed by microorganisms in the conditions like these, no soil nitrogen is used in the decomposition process and nitrogen is immediately available for the main (following) crop.



Note. Vertical bars denote standard deviation.

Figure 1. Biomass of catch crops, N and C:N ratio in 2008

The ability of catch crops to bind P and K nutrients for the main crop has been less studied. Although both catch crops and green manure have an effect on nitrogen loss and its availability for catch crops, long term studies of catch crops and green manure in the context of nutrient depletion have shown that they cannot improve access to phosphorus and potassium in poorer soils (Pedersen et al., 2005; Jensen et al., 2006). This may be a result of smaller biomass production by catch crops on poor soils. Nevertheless, it has been shown (Thorup-Kristensen et al., 2003), that catch crops and green manures take up soil P and thus convert it from inorganic to organic form. Some species may have especially high P uptake capability, e.g., by forming particularly long root hairs. Upon incorporation of the residues into the soil the plant P is released slowly and is not as susceptible to leaching and precipitation as inorganic P fertilizers.

In 2008, field bean was the most effective binder of phosphorus and potassium in the experiment – 4.5 kg ha^{-1} P and 33 kg ha^{-1} K (Fig. 2). The phosphorus and potassium amounts did not change significantly and were 1.8–2.1 kg ha^{-1} P and 10.8–11.6 kg ha^{-1} K, accordingly.

Vos and Van der Putten (2000) have found that rye and fodder radish bound between 4 and 9 kg ha^{-1} P and 21–45 kg ha^{-1} K when grown as catch crops, if their biomass was 400 to 900 kg ha^{-1}. Bigger biomass enables them to bind more nutrients. The levels of P and K in a plant depend on species, growth stage and part of the plant. There is more potassium in young parts and more phosphorus in aboveground parts than in the roots.

In 2009, field bean had the largest biomass – 2160 kg ha^{-1} (35% was roots) but pea biomass was not significantly smaller (20% roots). Fodder radish (38% roots) and white mustard (28% roots) had an equal biomass – 1600 kg ha^{-1}. Winter oil turnip had a biomass of 1395 kg ha^{-1} (40% roots). The biomass of Italian ryegrass was significantly smaller. *Brassicaceae* returned into soil 28–37 kg ha^{-1} N. Legumes that are able to bind nitrogen from the air as well, deliver about 67 kg ha^{-1} N into soil (Fig. 3), but their disadvantage was high seed rate and price.

The C:N ratio in the biomass that was ploughed to the soil varied from 13 (bean and pea) to 33 (Italian ryegrass). Depending on crop type and amount of biomass, in 2009 catch crops returned to the nutrient cycle from 12 (Italian ryegrass) to 51 kg ha^{-1} K (bean) and 7.3 kg ha^{-1} P (pea). In 2009, Italian ryegrass was the least effective in binding phosphorus (total biomass only 620 kg ha^{-1}) – 1.6 kg ha^{-1} P (Fig. 4).

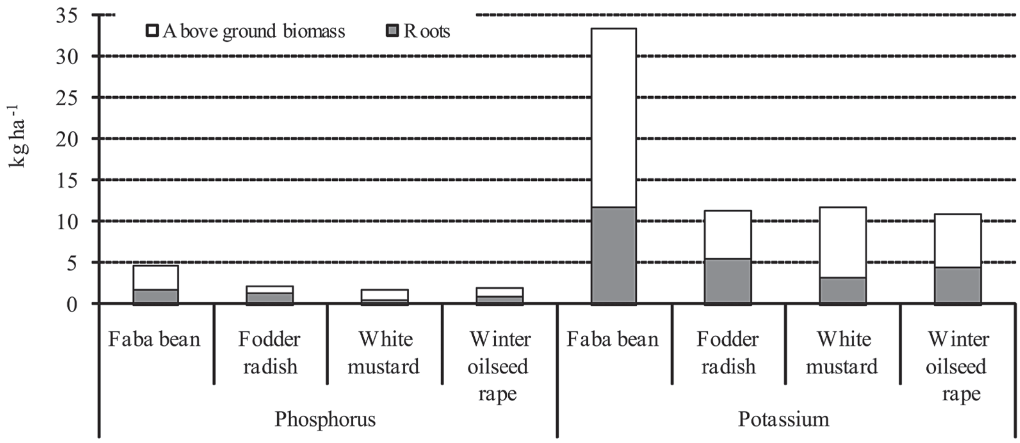
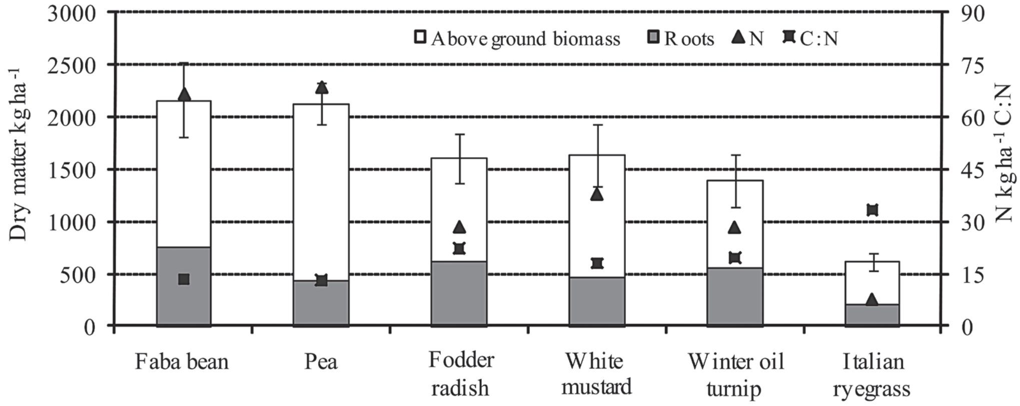


Figure 2. Quantities of P and K in 2008 (ploughed into soil with catch crops biomass)



Note. Vertical bars denote standard deviation.

Figure 3. Biomass of catch crop, N and C:N ratio in 2009

In 2009, the sulfur levels in plants were also measured. Sulfur is known to have a positive effect on nitrogen uptake and plant viability. Plants with sufficient sulfur give bigger yields with better quality. Sulfur deficiency has become an important feature of most North European arable cropping systems, due to the greatly reduced sulfur emissions from fossil fuels. Sulfur behaves very similarly to nitrogen in the soil system, and it can easily be lost by leaching in the form of sulfate. Few studies have focused specifically on the effects of catch crops on sulfur retention and availability (Thorup-Kristensen et al., 2003).

Eriksen and Thorup-Kristensen (2002) have found that *Brassicaceae* species, which usually have a high plant S concentration, showed high uptakes of 22–36 kg ha^{-1} S, compared to only 8 kg ha^{-1} S taken up by Italian ryegrass. Data from the current experiment does not support these results. The biggest uptake of sulfur was by pea 7.8 kg ha^{-1} S. Although bean biomass was relatively large, the amount of sulfur uptake was similar to that of *Brassicaceae* catch crops. Biomass from Italian ryegrass returned only 1.5 kg ha^{-1} S to the soil (Fig. 4).

The weather conditions of 2010 made it possible to harvest the barley and sow the following catch crops quite early. The growing period for the catch crops was 72 days, with a total sum of 602 degrees of effective temperatures, resulting in the biggest catch crop biomass for the whole experiment.

In 2010, the total biomass of catch crops (aboveground parts + roots) added from 930 (Italian ryegrass and rye) to 3550 kg ha^{-1} (fodder radish) of organic matter to the soil. Although in previous years white mustard produced about the same amount of biomass as fodder radish, the results were different in 2010. White mustard is a long-day plant; if it is sown early (in the beginning of August), it quickly starts flowering. Flowering reduces root activity and nutrient uptake.

Phacelia is generally considered to be a good catch crop (Brant et al., 2009). Phacelia should be able to create a considerable amount of root mass in a relatively short time, uptaking large amounts of nitrogen. Current results did not support this idea. Although both winter oil turnip and phacelia produced equal amounts of biomass, their root percentages were different: 41% in winter oil turnip, 26% in phacelia. Also, despite the same biomass amount, phacelia bound 1.6 times less nitrogen than winter oil turnip (Fig. 5). Earlier studies (Eichler-Löbermann et al., 2008) have also shown that phacelia contributed to the P supply of the main crops, because it significantly increased the P uptake as well as the readily available P contents in soil.

The amount of nitrogen that was contributed to the soil varied from 10 (Italian ryegrass) to 100 (pea) kg ha^{-1}. Of all *Brassicaceae* crops, fodder radish was the biggest contributor of nitrogen to the soil. The C:N ratio stayed below 30 for all the catch crops, except for Italian ryegrass.

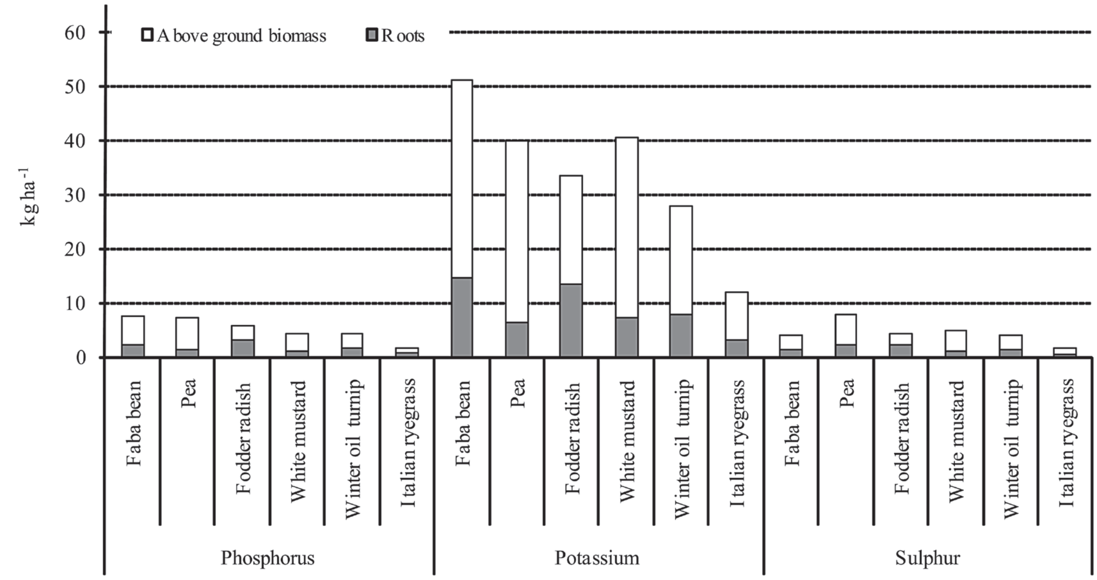
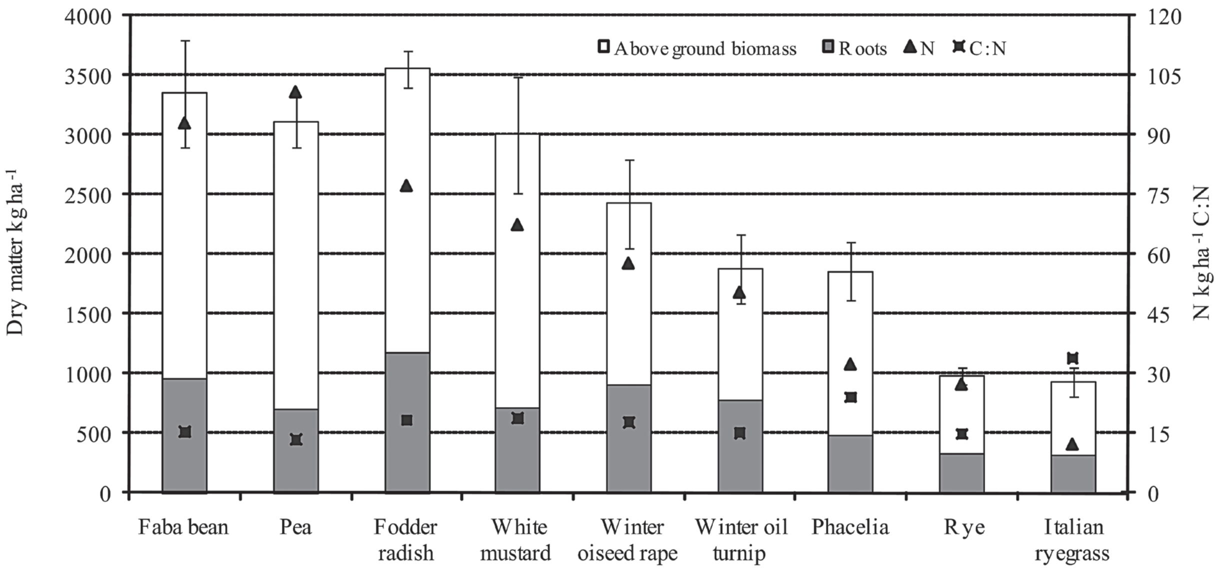


Figure 4. Quantities of P, K and S in 2009 (ploughed into soil with catch crops biomass)



Note. Vertical bars denote standard deviation.

Figure 5. Biomass of catch crop, N and C:N ratio in 2010

In relation to biomass amount, in 2010 the catch crops contributed up to 82 kg ha^{-1} K (fodder radish) and up to 9.9 kg ha^{-1} P (pea) (Fig. 6) to the soil.

In 2009, beans had the greatest effect on the following spring wheat yield, compared to N_0 control field; the spring wheat yield was 590 kg ha^{-1} bigger. Although beans contributed more nitrogen to the soil, the following wheat yield was not significantly different from the wheat yield after growing *Brassicaceae* catch crops. In 2010, the catch crop did not affect grain yields significantly (Fig. 7). An experiment carried out in Sweden also showed that the catch crop did not reduce grain yields significantly in any of the studied years (Stenberg et al., 1999). Muller et al. (1989) found a negative effect of the catch crop on the biomass production of the following crop.

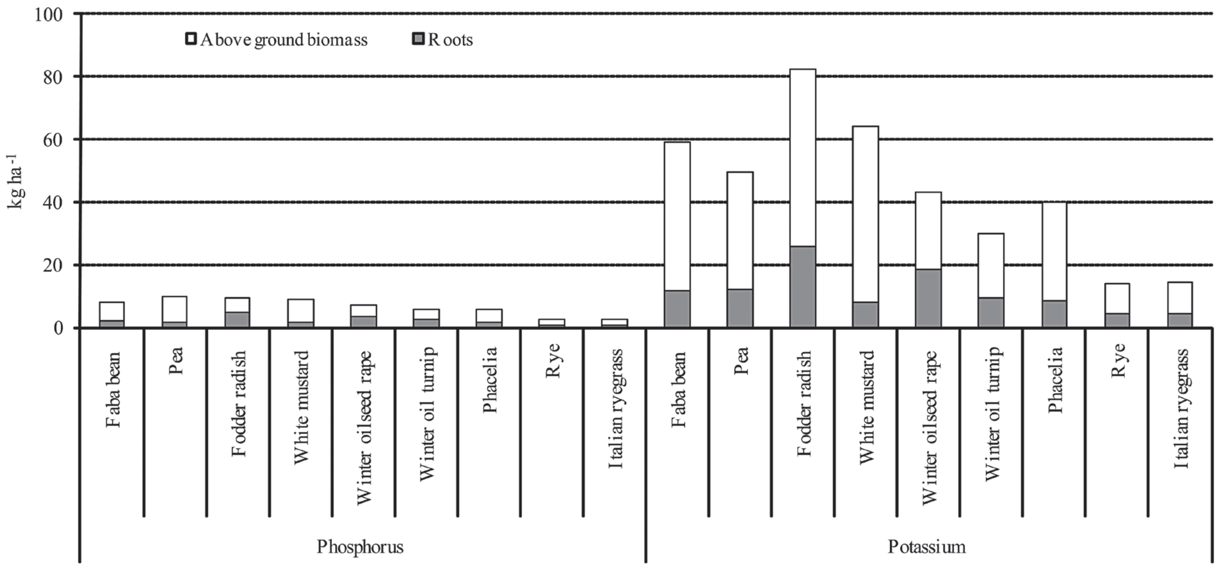
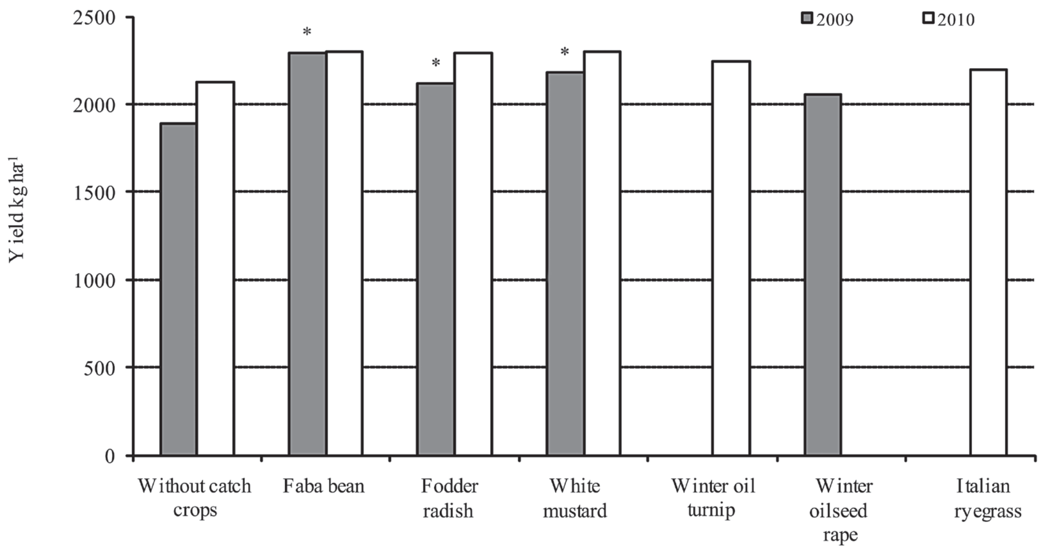


Figure 6. Quantities of P and K in 2010 (ploughed into soil with catch crops biomass)



Note. * – significantly different at $p > 0.05$ significant level, $LSD_{0.05}$ 2009 – 174, 2010 – 259

Figure 7. Grain yield of spring wheat cv. 'Mooni' in 2009, 2010

Soil ammonium and nitrate N content may vary greatly, influenced by soil type and measuring time and cannot be considered a reliable indicator of soil fertility (Kärblane, 1996). The soil cannot retain NO_3-, which is therefore susceptible to leaching. Catch crops should be able to bind available nutrients and biologically usable nitrogen should not leach out during vegetation-free periods. In all soil samples, NO_3-N and NH_4-N content was low when measured.

The nitrate and ammonium nitrogen content that was measured while the catch crops still grew was relatively similar for all the catch crops, but was significantly different for the control treatment. According to literature (Thorup-Kristensen, Nielsen, 1998), catch crops bind soil nitrogen, which should decrease mineral nitrogen content. Conversely, Stenberg et al. (1999) have found that if the growth of catch crops is hindered, nitrate concentrations at 60 cm were higher than those expected in the catch crop treatments. After catch crops, the concentration of available soil N is normally higher in the topsoil layers, with higher amounts of inorganic N in the uppermost soil layers and less in the deeper soil layers (Thorup-Kristensen, Van den Boogaard, 1999). In the current experiment, catch crops did not decrease soil NO_3- and NH_4- content, compared to the control treatment (Table 2).

The reducing effect of a catch crop on nitrate-N leaching is associated with the amount of nitrogen accumulated in the catch crops (Vos, Van der Putten, 2004). Macdonald et al. (2005) have found that catch crops are most likely to be effective when grown on freely drained sandy soils where the risk of nitrate leaching is greatest.

Table 2. Amounts of nitrate N and ammonium N in the soil during the growing period of catch crops and in the spring before tillage

Treatments (2009)	19th October, 2009		21st April, 2010	
	NO_3-N mg kg^{-1}	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}	NH_4-N mg kg^{-1}
Faba bean	7.5*	12.5*	9.2*	3.6*
White mustard	6.2	8.8*	5.7	1.7*
Fodder radish	6.3*	9.4*	6.0*	1.0
Italian ryegrass	x	x	5.3	1.2
Control (without catch crops)	4.7	0.7	3.8	0.5

* – significantly different at $p > 0.05$ significance level; x – not determined

Conclusions

1. The effectiveness of catch crops depends on the choice of species, sowing time and main crop harvesting time, as well as on weather conditions during the autumn and winter period. Italian ryegrass and rye produced the least biomass. They also bound less nitrogen than *Brassicaceae* and leguminous crops.

2. Of all the *Brassicaceae* catch crops, the most effective were fodder radish and white mustard, which produced the most biomass and therefore drove more nutrients into the soil.

3. The best nutrient binders were legumes pea and bean. In more favourable growing years (2009–2010) they bound 50–100 kg ha^{-1} N, 7–10 kg ha^{-1} P, 40–60 kg ha^{-1} K. Their disadvantage was high seed rate and establishment costs.

4. The levels of soil nitrogen in nitrates and ammonium were relatively consistent for all the catch crops; growing catch crops did not decrease soil NO_3-N and NH_4-N content compared to the treatment without catch crops.

5. Fodder radish and white mustard proved to be the most optimal catch crops under Estonian weather conditions.

Acknowledgements

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Tarpinių augalų biomasės augimas ir maisto medžiagų kaupimas

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Estijos gyvybės mokslų universiteto Žemės ūkio ir aplinkos mokslų institutas

Santrauka

Bandymai vykdyti 2008–2010 m. vegetacijos laikotarpiu Estijos gyvybės mokslų universiteto Augalininkystės skyriuje. Siekta nustatyti tarpinių augalų užaugintos biomasės kiekį ir dirvožemio maisto medžiagų kaupimo efektyvumą. Bandymas kartotas 4 kartus stagniniame dirvožemyje (IDj). Auginti šie tarpiniai augalai: baltosios garstyčios, pašariniai ridikai, pašarinės pupos, žieminiai rapsai, žieminiai turnepsai, gausiažiedės svidrės, žirniai, rugiai ir facelijos. Įvairiais tyrimų metais augalų užaugintos biomasės kiekis smarkiai skyrėsi. Sėjos laikas turėjo didelę įtaką biomasės augimui, nes rugpjūčio mėnesį buvo didžiausia efektyvių temperatūrų suma. Daugiausia maisto medžiagų sukaupė žirniai ir pupos. Palankesniais augti metais šie augalai sukaupė 100 kg ha^{-1} azoto (N), 7–10 kg ha^{-1} fosforo (P) ir 40–60 kg ha^{-1} kalio (K). Iš bastutinių (*Brassicaceae*) augalų daugiausia biomasės užaugino baltosios garstyčios ir pašariniai ridikai, biologiniame cikle sunaudoję iki 9 kg ha^{-1} P ir 82 kg ha^{-1} K (2010 m. pašariniai ridikai) organinės medžiagos. Tirti tarpiniai augalai dirvožemyje NO_3-N ir NH_4-N kiekio nesumažino, palyginti su laukais be tarpinių augalų.

Reikšminiai žodžiai: tarpiniai pasėliai, biomasė, azotas, kalis, fosforas, C:N santykis, vasarinių kviečių derlius.