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AGROECOSYSTEMS TO DECREASE DIFFUSE NITROGEN POLLUTION IN NORTHERN LITHUANIA

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Abstract. The paper presents the research conducted at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry on a clay loam *Gleyic Cambisol* during the period of 2006–2010. The research investigated the changes of mineral nitrogen in soil growing catch crops during the winter wheat post-harvest period and incorporating their biomass into the soil for green manure. Green manure implications for environmental sustainability were assessed. The studies were carried out in the soil with a low (1.90–2.00%) and moderate (2.10–2.40%) humus content in organic and sustainable cropping systems. The crop rotation, expanded in time and space, consisted of red clover (*Trifolium pretense* L.) → winter wheat (*Triticum aestivum* L.) → field pea (*Pisum sativum* L.) → spring barley (*Hordeum vulgare* L.) with undersown red clover. Investigations of mineral nitrogen migration were assessed in the crop rotation sequence: winter wheat + catch crops → field pea. Higher organic matter and nitrogen content in the biomass of catch crops were accumulated when *Brassisaceae* (white mustard, *Sinapis alba* L.) was grown in a mixture with buckwheat (*Fagopyrum esculentum* Moench.) or as a sole crop, compared with oilseed radish (*Raphanus sativus* var. *Oleiferus* Metzg.) grown with the long-day legume plants blue lupine (*Lupinus angustifolius* L.). Mineral nitrogen concentration in soil depended on soil humus status, cropping system and catch crop characteristics. In late autumn there was significantly higher mineral nitrogen concentration in the soil with moderate humus content, compared with soil with low humus content. The lowest mineral nitrogen concentration in late autumn in the 0–40 cm soil layer and lower risk of leaching into deeper layers was measured using organic cropping systems with catch crops. The highest mineral nitrogen concentration was recorded in the sustainable cropping system when mineral nitrogen fertilizer (N_{30}) was applied for winter wheat straw decomposition. In the organic cropping system, the incorporation of catch crop biomass into soil resulted in higher mineral nitrogen reserves in soil in spring than in the sustainable cropping system, (mineral nitrogen fertilizer (N_{30}) applied for straw decomposition in autumn and no catch crop grown). Applying organic cropping systems with catch crops is an efficient tool to promote environmental sustainability.

Keywords: environmental sustainability, low and moderate soil humus content, organic and sustainable cropping systems, catch crops, straw, biomass, mineral nitrogen.

Introduction

In intensive agriculture, mineral fertilization intended to meet plant nutritional needs poses a threat to ecological balance. Much research has been completed and recommendations have been presented about the best-suited plant fertilizer forms and rates, application timing and methods. However, there is little research into the effects of technologies on nutrients, especially nitrogen (N) immobilization in soil and leaching after harvesting of the main crops, when the soil during the post-harvest period stays bare for a prolonged period. Intensive fertilization results in significant increases in mineral N in soil in autumn, which poses a threat of groundwater contamination (Shevtsova *et al.* 2003). The largest quantities of N are leached from light soils. However, in heavy soils, conditions are created for N migration into deeper layers and groundwater contamination (Arlauskienė *et al.* 2011). Contributory factors include increased stickiness resulting in the appearance of vertical rills during crop growing season and due to low soil permeability resulting

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in higher runoff from ploughed soil. Nutrient leaching is also promoted by uneven distribution of rainfall during the growing season and more frequent downpours fuelled by global warming. Mineral nitrogen accumulation and dynamics in soil depend on soil texture and humus content, weather during the growing season and soil and crop management technologies, especially the fertilizers used (mineral and organic), their rates and application methods (Tonitto *et al.* 2006; Diacono, Montemurro 2010). However, even organic agriculture poses some risk of nitrate leaching, due to abundant accumulation of organic matter and mineralization (Loges *et al.* 2006; Torstensson *et al.* 2006).

Seeking to alleviate environmental pollution, it is important that appropriate preventive measures are chosen for inclusion of nutrients which are not utilized by plants into biological cycling (Di *et al*. 2002). For this, technologies involving catch crops that accumulate nutrients remaining in the soil during the most intensive leaching period in the end of summer-autumn (winter) and prevents them from leaching, are widely used in West Europe (Dawson *et al*. 2008; Torstensson *et al.* 2006; Komatsuzaki, Ohta 2007; Möller *et al.* 2008). Moreover, cover crop management, manure application and no-tillage practices during the cereal post-harvesting period reduce evaporation and CO_2 and N_2O emission from humus-rich clay soils (Komatsuzaki, Ohta 2007). Rapid and constant cover of soils with crops during the growing season and autumn protects it from the negative effects of direct atmospheric phenomena (Tonitto *et al.* 2006; Fullen *et al.* 2011).

It is suggested that under favourable weather conditions the biomass of catch crops incorporated into the soil starts to decompose in autumn (Lahti, Kuikman 2003). The higher the decomposition rate, the more mineral N is accumulated in soil (Vinther *et al.* 2004; Tripolskaja 2005; Stadler *et al*. 2005). If it is not bound into soil organic compounds or not utilized by growing plants, losses may occur during the winter-early spring period (Hasegawa, Denison 2005). The rate of mineralization of organic matter incorporated into the soil and N losses can be reduced by delaying the incorporation of catch crops biomass, by cultivating winter catch crops (whose choice is rather limited today) or by leaving catch crops as a frozen mulch over winter and incorporating it in spring (Crandall *et al.* 2005; Larsson *et al.* 2005). Researchers have reported that with straw incorporated together with N-rich catch crop biomass binds excess mineral N in soil, restores soil humus, increases the amount of stable humic substances and improves aeration (Arlauskienė *et al.* 2010). The technique may also improve soil physical state. Incorporation results in improved structure and increased amount of water stable soil aggregates, which is especially relevant for soils containing high silt contents (Velykis, Satkus 2008).

There are contrasting opinions that, in the case of continuous cultivation of winter cereals, during an average five-year period, the content of nitrates in the soil solution was found to be lower compared with the treatments grown with cereals alternating in growing season with catch crops (Catt *et al.* 1998). Research at the Lithuanian Institute of Agriculture's Joniškėlis Experimental Station on a fine-textured soil established that having incorporated N-rich biomass of lucerne and red clover as green manure, early in spring the soil 0–40 cm layer had a low mineral N (30–40 kg ha^{-1}) content. However, a significantly higher cereal grain yield was obtained (Arlauskienė, Maikštėnienė 2010; Arlauskienė *et al.* 2011), which suggests slower mineralization of organic fertilizers incorporated into fine-textured soils.

When making the shift from intensive cropping to alternative systems and replacement of fertilization systems it is important to quantify changes in soil productivity parameters. In alternative cropping systems, plant demand for major nutrients is compensated by soil reserves and nutrients released from organic matter. Thus, the present research was designed to ascertain the effects of catch crops, cultivated in the winter wheat post-harvest period and the impact of their biomass incorporated for green manure on mineral N dynamics in autumn and spring in clay loam *Cambisol* in organic and sustainable cropping systems. The impacts of these changes on environmental sustainability were assessed.

1. Material and methods

Experimental site and soil. Field experiments were conducted at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry (LRCAF). The station is situated in the northern part of Central Lithuania's lowland (40–60 m above the sea level; latitude: 56°12" N; longitude: 24° 20"). Northern Lithuania has a climate mid-way between maritime and continental. The climate is changeable, with mild, wet summers and cold winters. Annual precipitation is 500–600 mm. The soil of the experimental site is *Endocalcari–Endohypogleyic Cambisol*, whose texture is clay loam on silty clay with deeper lying sandy loam. The parent material is glacial lacustrine clay, which at 70–80 cm depth transits into morainic loam. Clay (<0.002 mm) in the Ap horizon (0–30 cm) account for 27.0%, in the B_w horizon (31–51 cm) 59.6%, in the B_k horizon (52–76 cm) 51.6%, in the C_1 horizon (77–105 cm) 10.7%, in the C_2 horizon (106–135 cm) 11.0%. Soil bulk density in the plough layer (0–25 cm) is 1.3–1.4 Mg m^{-3}, total porosity is 40–45%, and air-filled porosity is 8–10%. Investigations were performed in soil with the following chemical characteristics in the plough layer: pH_{KCl} 6.6, available P_2O_5 in the soil low in humus was 75–101, in the soil moderate in humus 111–134 mg kg^{-1}. The corresponding values for available K_2O were 207–235 and 221–240 mg kg^{-1}, respectively.

Field experiment. The field experiment was arranged according to the following design:

Soil humus content – *factor A*:

1) *low* (1.90–2.01%); 2) *moderate* (2.10–2.40%).

Cropping systems – *factor B*:

Organic I (O I): red clover biomass as green manure was applied for winter wheat, winter wheat straw was applied as manure and the catch crop (blue lupine, *Lupinus angustifolius* L.) in a mixture with oilseed radish (*Raphanus sativus* var. *Oleiferus* Metzg.) was cultivated as green manure for field pea.

Organic II (O II): red clover biomass as green manure and farmyard manure (40 Mg ha^{-1}) was applied for winter wheat, winter wheat straw was applied as manure and white mustard (*Sinapis alba* L.) was cultivated as green manure for field pea.

Sustainable I (S I): farmyard manure (40 Mg ha^{-1}) was applied for winter wheat, winter wheat straw was applied as manure + mineral N fertilizer (N_{30}) in the form of ammonium nitrate for straw decomposition in autumn and white mustard in a mixture with buckwheat (*Fagopyrum esculentum* Moench.) was cultivated as green manure for field pea.

Sustainable II (S II): red clover biomass as green manure + mineral fertilizer $N_{30}P_{60}K_{60}$ was applied for winter wheat, winter wheat straw as manure + mineral N fertilizer (N_{30}) for straw decomposition in autumn and mineral fertilizer $N_{10}P_{40}K_{60}$ in spring was applied for field pea.

The field experiment was arranged as a randomized single row design in four replicates. The crop rotation, expanded in time and space, and consisted of red clover (*Trifolium pretense* L.) cv. 'Vyliai' → winter wheat (*Triticum aestivum* L.) cv. 'Ada' → field pea (*Pisum sativum* L.) cv. 'Pinochio' → spring barley (*Hordeum vulgare* L.) cv. 'Luokė' with undersown red clover. The investigated cropping systems were assessed in winter wheat + catch crops (for green manure) → field pea.

In the sustainable II cropping system, in autumn, before sowing mineral fertilizer $P_{60}K_{60}$ was applied for winter wheat, and in spring after resumption of winter wheat growth, mineral N fertilizer (N_{30}) was applied in the form of ammonium nitrate. After winter wheat harvesting, the stubble was broken by a combined breaker and chopped straw was simultaneously incorporated into the soil. In the sustainable system I and sustainable system II, winter wheat straw decomposition was promoted with the addition of mineral N fertilizer (N_{30}) in the form of ammonium nitrate. Catch crops were sown: a mixture of blue lupine (cv. 'Boruta') and oilseed radish (cv. 'Rufus') at a seed rate of 150 and 20 kg ha^{-1}, respectively; white mustard (cv. 'Sinus') at 22 kg ha^{-1}, and when grown in mixture with buckwheat (cv 'Smuglianka') at 15 and 80 kg ha^{-1}, respectively.

Plant analyses. Biomass of catch crops was established by weighing. Dry matter (DM) content in the biomass was determined by drying samples at 105 °C to constant weight. The yield of catch crop biomass is presented in absolutely dry matter Mg ha^{-1}. Analyses of N content were performed on samples taken from the catch crop biomass before incorporation into the soil. The biomass of catch crops was analysed for the concentration (%) of N using the standard macro-Kjeldahl procedure (Koutroubas *et al.* 2008). N content was recalculated in kg ha^{-1}. Chemical analyses of plants were made at the Agrochemical Research Laboratory of the LRCAF.

Soil chemical properties. Soil samples for the determination of soil chemical characteristics of the plough layer (0–25 cm) were collected before the establishment of the experiment. Available P_2O_5 and K_2O in the soil were determined by ammonium lactate extraction Egner-Riem-Domingo (A-L), and pH_{KCl} by electro-potensiometric methods. The effect of the investigated measures on mineral N dynamics was estimated in autumn before catch crops biomass incorporation by ploughing and in the spring of the following year before the sowing of field pea. Twenty soil samples were used for the determination of changes in mineral N within each plot. Each of the 20 samples was taken from different places within the plot from the 0–40 cm depth and composite samples were formed. Mineral N was determined: N-NH_4 by the spectrophotometric method and N-NO_3 by the ionometric method. Soil chemical analyses were made at the Chemical Research Laboratory of the Institute of Agriculture of LRCAF.

Meteorological conditions. The mean daily air temperature and precipitation are presented for more important experimental periods (Fig. 1). In 2006, during the growing season of the main crops (May–July), when cereals grow intensively and utilize nutrients from the soil, there was also a moisture deficit. The rainfall that fell during that period accounted for only 38.9% of the long-term mean (Table 1). Meanwhile, the mean daily temperature in June and July was higher by 0.7 and 3.7 °C, respectively. The yield of the main crops was low. However, the growing season of catch crops (August–October 2006) was the most favourable for catch crop growth compared with the other growing seasons of catch crops. Minimum daily temperature dropped <10 °C only in the second half of September. Moreover, in August, September and October the mean daily air temperature exceeded the long-term mean by 1.5, 2.9 and 3.1 °C, respectively. During the growing season of catch cops, precipitation exceeded the long-term mean by 85.5 mm, and there was ample rainfall in August and October. The period from November 2006 to April 2007 was warmer than usual, except for February. The mean daily temperature of the months was >0 °C. Precipitation amount accorded with the long-term mean. Only in

January there was relatively more precipitation. Early in spring (March and April) there was little precipitation.

After the dry year of 2006, the growing season of the main crops (May–July 2007) was relatively warm and wet. Thus, conditions were especially favourable for cereal grows. Catch crops sown after cereal harvesting grew poorly. In August, September, October the mean daily temperature was higher than the long-term mean, the minimum daily air temperature dropped <10 °C by late August and persisted all through September, although the days were relatively warm. Poor plant emergence and establishment were determined by the droughty first half of August, and heavy rain only fell on August 20. The period from November 2007 to April 2008 was one of the warmest and wettest. The winter months were especially warmer (by 4.2–6.9 °C compared with the long-term mean). Spring months (March and April) were distinguished by higher precipitation amounts (when the amount of precipitation exceeded the long-term mean by 16.8 and 17.2 mm, respectively).

In 2008, the mean daily air temperature during the main crop growing season differed little from the long-term mean. However, this period was one of the driest recorded. Plants were already short of moisture at the early growth stages (May and June). This impeded plant nutrient uptake from the soil. The growing season of catch crops was rather wet. However, precipitation was distributed very unevenly. In August rainfall exceeded the long-term mean by 48.6 mm, and in October by 29.3 mm. September was extremely dry (rainfall was only 6.5 mm).

The period from November 2008 to April 2009 was 1.8 °C warmer than the long-term mean. However, it was wet. Much precipitation fell in December and March (63.1 and 51.7 mm, respectively). Dry weather in April and May 2009 suppressed the germination and establishment of the main crops. However, June and July were very wet. October was cooler, with rainfall 27.1 mm more that the long-term mean. In 2009, November and December were wet with rainfalls of 11.2 and 23.8 mm, respectively, higher that the long-term mean.

Winter 2010 was cold. In January, air temperature was 6.6 °C lower and precipitation was 14.7 mm lower that

Table 1. Precipitation and long-term (30 years) mean air temperature

Months	April	May	June	July	August	September	October
Temperature °C	6.2	12.3	15.6	17.1	17.1	12.0	6.3
Rainfall mm	37.4	45.6	59.4	69.2	67.9	57.9	45.5

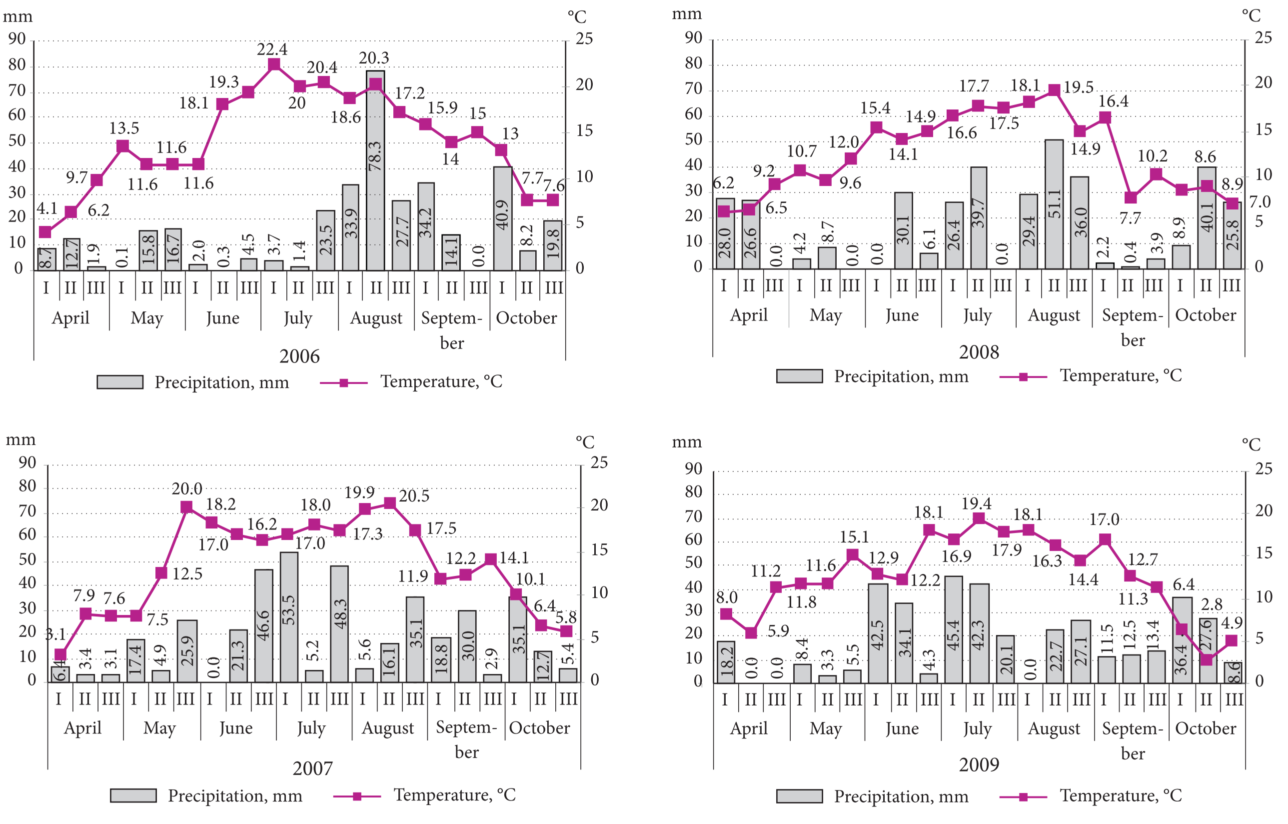


Fig. 1. Precipitation and mean air temperature during the experimental periods

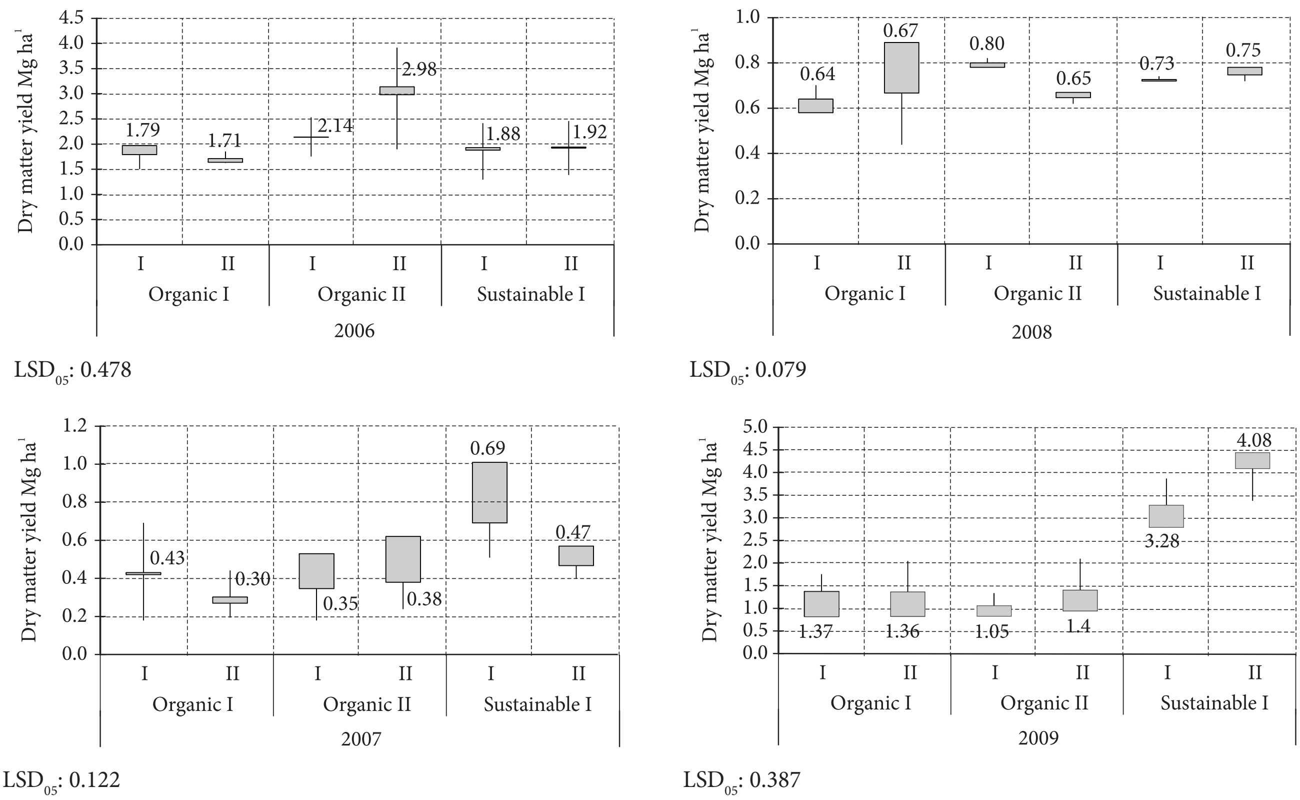
the long-term mean. In spring, the mean daily temperature was close to the long-term mean, but rainfall was higher in March and May (by 2.5 and 23.7 mm, respectively). The high amount of rainfall had negative affects throughout the 2010 growing season.

Statistical analysis. The research data were statistically processed by a two-factor analysis of variance and correlation-regression analysis using the program package Selekcija (Tarakanovas, Raudonius 2003), as well as "R" statistical software after Crawley (2007).

2. Results and discussion

Dry matter yield of catch crops. In the experiment established in 2006, there was a moisture deficit during the growing season of the main crop (winter wheat). Thus, most nutrients in soil were not utilized by the crop. After cereal harvesting, during the warm and wet autumn, catch crops grew rapidly by effectively utilizing nutrients left in the soil. In the soil with low and moderate humus content, when the conditions for catch crop growth were favourable, the largest dry matter yield was produced in the organic cropping system by short-vegetation plants (white mustard). The dry matter yield was 16.7 and 76.5% more, respectively, than the longer-vegetation blue lupine combined with oilseed radish and 5.6 and 11.8% more, respectively, than in the sustainable cropping system of white mustard combined with buckwheat (Fig. 2).

In 2007, due to the rainy and warm period, the main crops developed intensively and thus utilized most available nutrients. Moreover, the post-harvest period was droughty. Therefore all catch crops accumulated little dry matter yield, with a mean of ~0.25 of that produced in 2006. In the soil low in humus, the largest dry matter yield was accumulated by the combined white mustard-buckwheat sustainable cropping system. Yield was 40.0% more than white mustard grown as a sole crop. Such results might have been influenced by the low mineral N



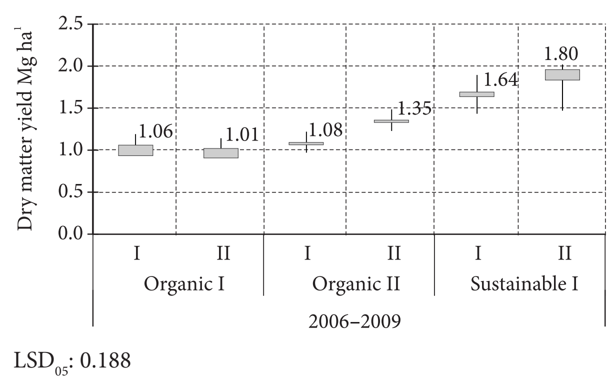


Fig. 2. Dry matter yield of catch crops

Notes: Ɪ – Standard error;
I – low humus content in the soil;
II – moderate humus content in the soil.

fertilizer (ammonium nitrate) rate (N_{30}) applied to promote winter wheat straw decomposition and by the buckwheat specific root system due to which it can assimilate more varied nutrient forms.

The literature indicates that although buckwheat roots mass is much smaller than that of some cereals, its sucking power can be 2.7–14.0 times greater, due to its long root hair. Moreover, buckwheat roots exude formic, acetic and citric acids capable of dissolving stable compounds present in the soil, especially those of phosphorus (P), which is of special relevance in fine-textured soil deficient in P (Marcinkonis *et al.* 2007).

In the soil with moderate humus content the same trend of catch crop dry matter yield variation persisted. The largest dry matter yield was accumulated in the sustainable cropping system with the white mustard–buckwheat combination. This was 25.0% more than in the organic cropping system where only white mustard was grown. In 2006, in the soil low and moderate in humus content, much greater dry matter yield was accumulated by white mustard grown in combination with buckwheat compared with that of mustard grown as a sole crop. These results were determined in the sustainable cropping system by mineral N fertilizer (N_{30}) applied to promote straw decomposition and which created better establishment nutritional conditions for catch crops during the droughty post-harvest period than for those grown in the organic cropping system. Moreover, in the year less favourable for catch crop growth, higher crop productivity was achieved when growing them in binary agroecosystems (mixtures).

The literature indicates that plants possessing biologically different root nutrition assimilate nutrients at different rates and intensities, which enables plants to better exploit various soil and environmental conditions (Möller *et al.* 2008). Blue lupine grown in the organic cropping system combined with oilseed radish, as a crop with a longer growing season, develop more slowly and, due to the small leaf area, accumulate a low content of assimilates. Thus, although lupine fixed atmospheric N when grown in mixture, it accumulated less dry matter yield than white mustard-buckwheat mixture.

In the 2008, although the growing season of the main crop (winter wheat) was dry, it removed little nutrients from the soil. However, in rainy August leaching was pronounced, since nearly double the monthly mean amount of rain fell. Catch crops developed poorly and, due to the prolonged drought, dry matter yield was small. However, the mean yield was 1.6 times larger compared with catch crops grown in 2007. In the soil with low humus content, more dry matter yield accumulation was noted in the organic cropping system for white mustard grown as a sole crop or in the sustainable cropping system grown in combination with buckwheat. Their dry matter yields, compared with that of the blue lupine-oilseed radish mixture were 33.3 and 16.7%, respectively, higher. In the soil with moderate humus content, there were no significant differences between the dry matter yield accumulated by catch crops grown in the organic and sustainable cropping systems. The differences might have been alleviated by better nutritional conditions.

In the 2009 growing year, which was similar in weather respect to the 2007, analysis of catch crop dry matter yield showed that markedly higher biomass contents accumulated in the sustainable I cropping system when growing white mustard-buckwheat compared with the organic II system when only growing white mustard. The difference in low humus soil was 2.4-fold and in moderate humus soil was 2.9-fold.

According to the mean data of 2006–2009, analysis of catch crop dry matter yield during the winter wheat (field pea pre-crop) post-harvest period showed that markedly higher dry matter yield accumulated in the sustainable I cropping system when growing white mustard mixed with buckwheat compared with the organic II system when growing only white mustard. The difference in low humus content was 54.7% and in moderate humus content soil was 33.3%. Such results may have been influenced both by the biological properties of catch crops and the low N rate (N_{30}) applied in the sustainable I cropping system for straw mineralization, which promoted catch crop development. The least dry matter yield of catch crops in the soil with low and moderate humus content was accumulated when growing blue lupine mixed with oil radish.

Analysis of the data from separate years suggests the catch crop white mustard grown as a sole crop or mixed with buckwheat under the conditions of cereal post-harvest period produced greater dry matter yields compared with the blue lupine-oilseed radish system. The data showed that the complex effects of environmental factors in Lithuania not favourable for post-harvest catch crop growth and development every year. By late summer with days becoming shorter lighting of plant parts actively participating in the process of photosynthesis decreases along with above-ground mass and roots. Consequently, catch crop development and accumulation of nutrients in biomass is largely determined by weather conditions (temperature, precipitation amount and distribution, solar radiation intensity and cloudiness). Due to unfavourable conditions during the initial growth stages, catch crops accumulate less biomass, and later with days becoming shorter, they form generative organs (Mattson, Erwin 2005; Odhiambo, Bomke 2007).

Having applied catch crops after winter wheat, fertilizer efficacy differed between years. Efficacy was related to rainfall during the growing season, which influenced the mineralization of organic fertilizers. The strength of the correlation between catch crop dry matter yield and rainfall amount was related to the soil humus status and fertilizer applications.

In the soil with low humus content, in the organic I and II cropping systems, the relationship between catch crop dry matter yield and precipitation was stronger ($r = 0.628^{**}$ and 0.871^{**}, respectively) than that in the soil with moderate humus content ($r = 0.616^{**}$ and 0.815^{**}, respectively; all $n = 16$, $^{**} = P < 0.01$). Consequently, results were affected by the application of manures in the organic cropping systems. In turn, mineralization rate and nutrient release for plant nutrition largely depend on soil water content. With the prolonged dry growing season, manures release few nutrients and thus have little influence on catch crop yield.

In the soil with both low and moderate humus contents, in the sustainable I cropping systems, incorporated N_{30} had positive effects on catch crop growth and development. Therefore, there was no significant correlation between dry matter yield of catch crops and rainfall.

Table 2. Nitrogen concentration and nitrogen uptake in the above-ground biomass of selected catch crops

Cropping system (Factor B)	Catch crops and fertilization	Soil humus content (Factor A)				Mean factor B	
		low		moderate			
		concentration g kg^{-1}	uptake kg ha^{-1}	concentration g kg^{-1}	uptake kg ha^{-1}	concentration g kg^{-1}	uptake kg ha^{-1}
		2006					
Organic I	blue lupine + oilseed radish	34.3	61.6	35.9	61.3	35.1	61.4
Organic II	white mustard	37.6	80.6	34.5	102.7	36.1	91.7
Sustainable I	white mustard + buckwheat + N_{30}	36.2	67.6	37.3	71.0	36.7	69.3
Sustainable II	N_{30}	–	–	–	–	–	–
	Mean factor A	36.0	69.9	35.9	78.3	36.0	74.1
LSD$_{05}$: A – 1.71; B – 2.09; AB – 2.96							
		2007					
Organic I	blue lupine + oilseed radish	20.0	9.8	19.4	4.1	19.7	6.9
Organic II	white mustard	21.9	7.7	20.1	7.2	21.0	7.5
Sustainable I	white mustard + buckwheat + N_{30}	20.2	13.3	22.2	10.3	21.2	11.7
Sustainable II	N_{30}	–	–	–	–	–	–
	Mean factor A	20.7	10.2	20.6	7.2	20.6	8.7
LSD$_{05}$: A – 2.57; B – 3.15; AB – 4.45							
		2008					
Organic I	blue lupine + oilseed radish	23.0	14.8	21.2	10.9	22.1	12.8
Organic II	white mustard	17.5	13.9	19.3	12.4	18.4	13.2
Sustainable I	white mustard + buckwheat + N_{30}	20.6	14.9	25.4	18.4	23.0	16.7
Sustainable II	N_{30}	–	–	–	–	–	–
	Mean factor A	20.3	14.5	22.0	13.9	21.2	14.2
LSD$_{05}$: A – 2.62; B – 3.21; AB – 4.54							
		2009					
Organic I	blue lupine + oilseed radish	22.5	31.4	21.3	29.3	21.9	30.4
Organic II	white mustard	17.8	18.6	16.7	23.9	17.3	21.2
Sustainable I	white mustard + buckwheat + N_{30}	20.5	69.1	15.6	72.1	18.1	70.6
Sustainable II	N_{30}	–	–	–	–	–	–
	Mean factor A	20.3	39.7	17.9	41.8	19.1	40.7
LSD$_{05}$: A – 1.48; B – 2.10; AB – 3.31							
		Mean 2006–2009					
Organic I	blue lupine + oilseed radish	25.0	29.4	24.5	26.4	24.7	27.9
Organic II	white mustard	23.7	30.2	22.7	36.6	23.2	33.4
Sustainable I	white mustard + buckwheat + N_{30}	24.4	41.2	25.1	43.0	24.8	42.1
Sustainable II	N_{30}	–	–	–	–	–	–
	Mean factor A	24.3	33.6	24.1	35.3	24.2	34.5
LSD$_{05}$: A – 8.639; B – 12.217; AB – 19.316							

Nitrogen uptake in the biomass of catch crops. Experiments conducted over four years showed that in different cropping systems N concentration in the above-ground biomass of catch crops during the post-harvest period was highest in 2006. This proved favourable for catch crop growth. In the soil with moderate humus content, the highest N concentration in the above-ground biomass was established in the sustainable cropping system. In the white mustard-buckwheat mixture, in the soil low in humus, the data were inconsistent (Table 2). In 2006, during the favourable post-harvest period, catch crops intensively used the remaining nutrients and produced much biomass and accumulated high N contents. In the soil low and moderate in humus content, the highest N content accumulated in the white mustard grown as a sole crop was 30.8 and 67.5%, respectively, more than the organic I cropping system, when growing blue lupine mixed with oilseed radish. In the sustainable I cropping system, a low mineral N fertilizer rate (N_{30}) did not have any significant effect on white mustard and buckwheat biomass N content.

In 2007, during the main crop post-harvest period, during the catch crop growing season, there was little rainfall in August and September; 11.1 and 6.2%, respectively, less than the long-term mean, both in the organic and sustainable cropping systems catch crops developed poorly and accumulated little biomass and N.

In soil with both low and moderate humus contents, N concentration in above-ground biomass of catch crops and their mixtures varied from 19.4–22.2 g kg^{-1}. There was a slightly higher N uptake in the sustainable cropping system in the white mustard-buckwheat combination, where mineral N fertilizer (N_{30}) had been applied. The largest amount of N was incorporated in the sustainable cropping system with the biomass of catch crops. In the white mustard and buckwheat mixture in soil with low and moderate humus N was 35.7% and 2.5 times more, respectively, than when growing blue lupine with oilseed radish.

In 2008, after sowing catch crops, at the seedling stage, heavy rainfall in August (almost double the mean monthly total at 116.5 mm) caused high N leaching. The dry September had a negative effect on catch crop development and their biomass accumulated little N. In soil with both low and moderate humus contents, white mustard grown as a catch crop in the organic cropping system had the lowest N concentration. This was reflected in the lower total N uptake in biomass. During the droughty, unfavourable period for catch crop growth, higher N uptake was noted for the white mustard-buckwheat mixture. This was reflected in significantly higher (68.8%) N content in blue lupine and oilseed radish in soil with moderate humus content. It is consistent that catch crop biomass and N content were markedly higher in the sustainable I cropping system, in which N fertilizer N_{30} was applied. September 2009 had a prolonged warm spell. Buckwheat developed intensively, thus the largest amount of N accumulated in the biomass of white mustard-buckwheat mixture. In the soil with low and moderate humus contents, N was by 2.2 and 2.5 times more, respectively, than blue lupine mixed with oilseed radish and 3.7 and 3.0 times more, respectively, than only white mustard.

During the warm and favourable growing season for catch crops in 2006 and 2009, when soil organic matter (SOM) mineralization was intensive, higher N uptake in biomass was noted in the organic cropping system. This was especially the case in soil with moderate humus content, for white mustard as short-season catch crop.

According to the mean data of 2006–2009, the biomass of the white mustard-buckwheat mixture grown in the soil with low and moderate humus contents had the highest N contents, compared with white mustard as a sole crop. The difference was 36.4 and 19.4% more, respectively. These data indicate that in the soil low in humus content, in poor nutrition conditions, the positive effects of catch crop biological characteristics manifested themselves more tangibly.

In the sustainable I cropping system, in soil with low and moderate humus contents, the biomass of the white mustard-buckwheat mixture contained 40.1 and 62.9%, respectively, more N than the biomass of blue lupine-oil radish mixture in the organic I cropping system. Although blue lupine fix N from the atmosphere and is superior to *Brassicaceae* family plants in organic agrosystems, according to its genetic origin it is a long-day plant. Therefore shortening days in autumn have marked negative impacts.

Higher soil humus status in most cases promoted more intensive N uptake in the biomass of catch crops. However, differences were not significant compared with the soil low in humus content. However, in dry periods in the growing season, more N was accumulated by binary catch crops. Usually, the white mustard-buckwheat mixture was superior to the blue lupine-oilseed radish mixture. During autumn, catch crops can reduce nitrate losses in soil by 10–20 kg ha^{-1}, by accumulating N in biomass (Xu *et al.* 2006; Zhao *et al.* 2012). The more N-rich the biomass incorporated into the soil is, the greater the risk of nitrate leaching (Vinther *et al.* 2004; Möller *et al.* 2008).

Mineral nitrogen content in soil before catch crop incorporation for green manure by ploughing in autumn. With climate warming and increasing risks of N leaching, after growing the main crops, it is vital to estimate N uptake in soil and plant residues and to apply appropriate crop and soil management practises (Ergstöm, Linden 2009). In autumn, cultivation of catch crops and incorporation of their biomass (green manure) makes it possible to include mineral N into biological nutrient cycling, retain it in the plough layer and prevent leaching. Hao *et al.* (2001) suggested leaving straw on the soil surface over winter and incorporating into soil only in spring, like mineral N fertilizer, otherwise nitrous oxide emission will increase.

In experiments (2006), catch crops produced much biomass. However, in warm and normally wet autumns, organic matter mineralization was intensive and before autumn ploughing, mineral N concentration in soil (0–40 cm depth) remained rather high and varied from 8.07–10.67 mg kg^{-1} soil (Table 3). These results were influenced by the dry growing season of the main crops and the sufficiently wet and warm growing season of catch crops in 2006. After harvest of the main crops, intensive SOM mineralization processes in soil caused comparatively high mineral N release.

Significantly more (mean 1.21 mg kg^{-1} soil or 13.8%) mineral N was present in soil with moderate humus content compared with soil with low humus content. When estimating only catch crops, it was found that residual mineral N from the soil was utilized less by white mustard sole crop. When growing white mustard only, mean mineral N concentration in soil with moderate and

Table 3. Effects of catch crops and applications of mineral nitrogen fertilizer on the mineral nitrogen content in soil before autumn ploughing, mg kg^{-1}

Cropping system (Factor B)	Catch crops and fertilization	Soil humus content (Factor A)		Mean factor B
		low	moderate	
			2006	
Organic I	blue lupine + oilseed radish	8.80	10.19	9.50
Organic II	white mustard	8.07	8.80	8.44
Sustainable I	white mustard + buckwheat + N_{30}	8.59	10.21	9.40
Sustainable II	N_{30}	9.59	10.67	10.13
	Mean factor A	8.76	9.97	9.37
	LSD_{05}: A – 1.044; B – 1.476; AB – 2.088			
			2007	
Organic I	blue lupine + oilseed radish	6.38	6.00	6.21
Organic II	white mustard	5.29	7.32	6.30
Sustainable I	white mustard + buckwheat + N_{30}	6.07	8.44	7.27
Sustainable II	N_{30}	7.42	8.64	8.03
	Mean factor A	6.30	7.61	7.00
	LSD_{05}: A – 0.318; B – 0.450; AB – 0.636			
			2008	
Organic I	blue lupine + oilseed radish	3.39	3.89	3.64
Organic II	white mustard	3.33	4.50	3.91
Sustainable I	white mustard + buckwheat + N_{30}	4.05	4.90	4.47
Sustainable II	N_{30}	6.89	7.57	7.23
	Mean factor A	4.41	5.21	4.81
	LSD_{05}: A – 0.685; B – 0.968; AB – 1.369			
			2009	
Organic I	blue lupine + oilseed radish	3.31	3.51	3.41
Organic II	white mustard	3.44	3.32	3.38
Sustainable I	white mustard + buckwheat + N_{30}	3.43	3.58	3.51
Sustainable II	N_{30}	4.14	4.15	4.15
	Mean factor A	3.58	3.64	3.61
	LSD_{05}: A – 0.103; B – 0.178; AB – 0.272			
			Mean 2006–2009	
Organic I	blue lupine + oilseed radish	5.47	5.90	5.69
Organic II	white mustard	5.03	5.99	5.51
Sustainable I	white mustard + buckwheat + N_{30}	5.54	6.78	6.16
Sustainable II	N_{30}	7.01	7.76	7.39
	Mean factor A	5.76	6.61	6.19
	LSD_{05}: A – 0.198; B – 0.343; AB – 0.524			

low humus content was significantly less (11.2 and 10.2%, respectively), compared with mixtures of blue lupine- oilseed radish and white mustard-buckwheat. The highest soil mineral N content was in plots where to promote straw decomposition N_{30} was applied in the form of ammonium nitrate and no catch crops were grown. In 2007, during the main crop post-harvest period, catch crops developed and grew poorly, accumulated little biomass and used little soil N. Before the incorporation of catch crop biomass in soil the mean mineral N content was 25.3% less than 2006, in soils with both low and moderate humus contents. However, the main patterns of mineral N variation remained the same as in the favourable year (2006). Significantly more mineral N (mean 20.8%) was in the soil with moderate humus content compared with the soil with low humus content. This trend might have been influenced by more intensive organic matter mineralization processes in soil with more humus. The highest content of mineral N before autumn ploughing was in the sustainable II cropping system. In this system, straw mineralization was promoted by applying N_{30} in the form of ammonium nitrate and no catch crops were grown. However, significant mineral N differences in the sustainable II compared with the organic I system were only identified in the soil with a low humus content. In the soil with moderate humus content, the difference was alleviated by higher contents of N compounds released during the decomposition of organic matter. These data disagree with Bučienė (2003), who suggested that N applied for straw decomposition is effectively utilized and included in organic compounds.

In 2008, the heavy rainfall at the catch crops emergence stage (116.5 mm) promoted N leaching from soil, and the dry September inhibited soil microbiological processes. Consequently, mineral N concentration in the soil was a mean 48.7 and 31.3% less, respectively, compared with 2006 and 2007. However, changes due to agricultural practices remained similar. The highest mineral N contents before autumn ploughing were in the sustainable cropping system having applied mineral N fertilizer (N_{30}) to promote straw decomposition, in both soils with low and moderate humus contents. In 2008, the positive effect of catch crops on decreased mineral N leaching during the winter period was evident, since significantly less mineral N remained having applied N_{30} and with catch crop cultivation in the sustainable I cropping system compared with the same N rate applied without catch crops in sustainable II cropping system. The differences in the soil with low and moderate humus contents were 41.2 and 35.3%, respectively.

In the autumn 2009, during the period of intensive organic matter mineralization, before autumn ploughing, mineral N concentration in the 0–40 cm soil layer was 3.3–4.2 mg kg^{-1} soil. In the soil in the sustainable II cropping system with low and moderate humus contents, mineral N concentration was 25.1 and 18.2%, respectively, higher than in the organic I system. This higher mineral N concentration was influenced by applications of ammonium nitrate (N_{30}), applied to promote straw decomposition in soil.

According to the mean data of 2006–2009, in the autumn, during intensive organic matter mineralization before autumn ploughing, mineral N concentration in the 0–40 cm soil layer remained rather high and totalled 5.0–7.8 mg kg^{-1} soil. In the soil low in humus content, before the incorporation of catch crops into the soil, soil mineral N concentration was lower in the organic II cropping system compared with the organic I system. The highest mineral N concentration in the 0–40 cm soil layer (28.2% higher than in the organic I system) was in the sustainable II cropping system. In this system, the higher mineral N concentration was influenced by ammonium nitrate (N_{30}) applications. Before the incorporation of catch crops, during late autumn, significantly higher (14.8%) mineral N concentration was in soil with moderate humus content, compared with soil with low humus content. In the soil with moderate humus content, the trends of mineral N concentration were similar and significantly higher (by 31.5%) in the sustainable II system, compared with the organic I system.

Soil mineral nitrogen variation during the spring-autumn period. The data of changes in mineral N concentration in spring before sowing field pea compared with that in autumn before the incorporation of catch crops for green manure in the 0–40 cm soil layer are presented in Figure 3. In autumn 2006, after incorporation of N-rich catch crops, and with prolonged spells of mild weather in November and December (when mean monthly temperature was 4.4 and 4.2 °C, respectively), the soil did not freeze and conditions for mineral N migration in soil were favourable. Consequently, in spring 2007 before sowing field pea, a marked reduction in mineral N occurred compared with soil in autumn before the incorporation of catch crop for green manure by ploughing. N contents varied from 5.17–5.84 mg kg^{-1} and there were no significant differences between the cropping systems. However, analysis of mineral N losses from autumn to spring showed that the greatest reduction in N content occurred in the sustainable I and II cropping systems, where mineral N fertilizer (N_{30}) had been applied. Mineral N decreased most in the sustainable cropping system, where mineral N fertilizer (N_{30}) had been applied to promote straw decomposition and no catch crops had been grown. The mean N content was 16.7% higher on both low and moderate soil humus contents compared the treatment with the same fertilizer rate and catch crop. The least mineral N differences, compared with its status in autumn, were identified in the organic cropping system where white mustard was grown as a catch crop. Blue lupine mixed with oilseed radish had insignificant effects on

N retention in soil, since their biomass accumulated least N. In 2007, during the droughty post-harvest period, catch crops developed poorly, especially in the organic cropping system, and accumulated little biomass and low N content. Since there was little rainfall in August and September (11.1 and 6.2 mm, respectively, less than the long-term mean), in both treatments (with and without catch crops) soil mineral N content before autumn ploughing was similar. Thus, mineral N content in spring 2008 remained fairly consistent. Changes in soil mineral N concentration at 0–40 cm depth during the period from autumn 2007 to spring 2008 showed a similar trend to that in the previous year and the differences were not significant. The greatest difference between mineral N concentration in autumn and that remaining in spring was in the sustainable II cropping system, where ammonium nitrate was applied. In both low and moderate humus content soils, the mean N content was 0.92 mg kg^{-1}. In the organic cropping systems where catch crops had been grown, especially white mustard, which produced more biomass, an increase in mineral N concentration was evident in spring, however, only in soil with low humus content.

In spring 2009, there were the lowest mineral N concentrations in both the organic and sustainable cropping systems compared with earlier years. These results might have been influenced by the heavy rainfall in August 2008. At the catch crop emergence stage in late August there was nearly double the mean rainfall. Analysis of N losses shows that before the incorporation of catch crops losses were greatest where mineral N fertilizer (N_{30}) had been applied for straw decomposition without growing catch crop. Highest N losses were measured in spring and differences in N concentrations between treatments almost disappeared. This year (2009) the trend remained the same to that in the previous year, mineral N losses in the sustainable II cropping system, where mineral N fertilizer was applied for straw decomposition and with no catch crops amounted to a mean 2.29 mg kg^{-1} in soils with both low and moderate humus contents. In organic cropping systems, after catch crops, there was a slight increase in mineral N. Kramberger *et al.* (2009) discussed the high importance of weather conditions in influencing mineral N migration.

Although mineral N variations in separate years were highly affected by weather conditions, analysis of data in spring 2010 indicated positive trends of catch crops in reducing mineral N migration.

In the soil with low humus content, comparison of mineral N concentration in autumn before incorporating catch crops with that in spring before sowing field pea, changes were small in all cropping systems. In the soil with moderate humus content, in the organic II cropping system with white mustard grown as a sole crop, mineral N concentration in soil was higher in spring than autumn. In the organic cropping systems, the positive immobilization effect of catch crops on mineral N concentration in soil manifested itself during the late autumn-early spring period of intensive leaching. In the sustainable II cropping system, where mineral N fertilizer was applied for straw decomposition, in the next year's spring, before sowing field pea, mineral N concentration in soil markedly

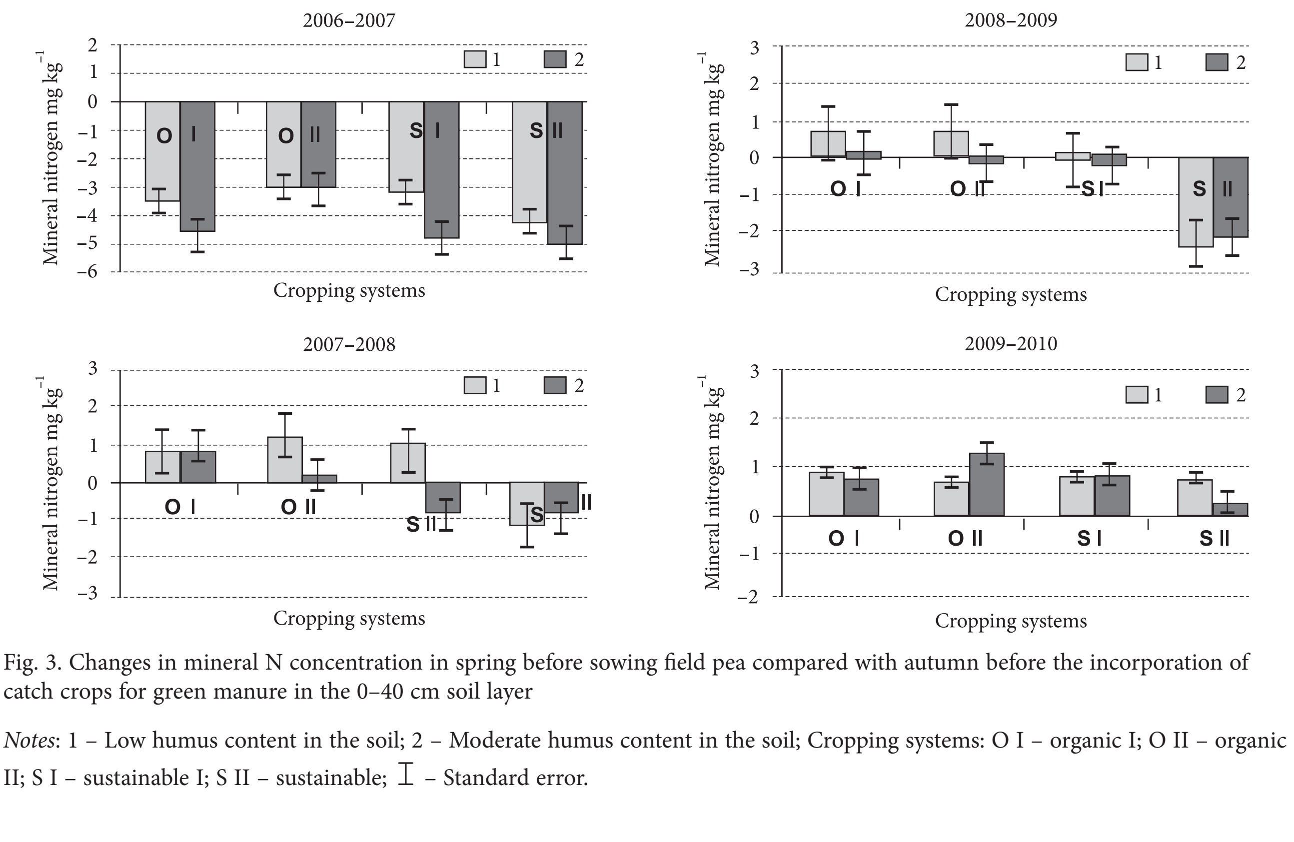


Fig. 3. Changes in mineral N concentration in spring before sowing field pea compared with autumn before the incorporation of catch crops for green manure in the 0–40 cm soil layer

Notes: 1 – Low humus content in the soil; 2 – Moderate humus content in the soil; Cropping systems: O I – organic I; O II – organic II; S I – sustainable I; S II – sustainable; I – Standard error.

declined, in soil with low and moderate humus contents, compared with organic cropping systems. In the sustainable II cropping system, although before autumn ploughing N concentrations were high, in the next year's spring it was markedly lower than in the systems in which catch crops were grown during the winter wheat post-harvest period. This shows that application of mineral N fertilizer for straw decomposition increased mineral N concentration in the 0–40 cm layer before autumn ploughing. N concentrations markedly declined until spring due to its rapid leaching into deeper soil layers. These results show that some applied N for winter wheat straw decomposition remains unbound to organic compounds and remain in soil in the form of mineral N in cropping systems without catch crops. Torstensson *et al.* (2006) and Möller *et al.* (2008) suggest that the most effective N utilization occurs in cropping systems with catch crops.

Conclusions

Investigations were conducted on organic and sustainable cropping systems over the period 2006–2010 on a clay loam soil with low and moderate humus contents. Catch crops grown during the winter wheat post-harvest period markedly influenced nitrogen dynamics both in soils and crops:

1. Markedly higher dry matter yield of catch crop accumulated in the sustainable I cropping system (white mustard mixed with buckwheat) compared with the organic II system (white mustard only). The difference in low-humus content soil was 54.7%, in moderate-humus content soil it was 33.3%.

2. Higher dry matter yield of catch crops and their N content were accumulated when white mustard (short-vegetation plant) was grown in a mixture with buckwheat or as a sole crop, compared with oilseed radish grown with blue lupine (long-day plant).

3. Mineral N concentrations in the 0–40 cm soil layer late in autumn were higher in soil with moderate humus content, compared with soil with low humus content. The highest mineral N concentration in soil with both low and moderate humus contents, late in autumn and the risk of leaching into deeper layers were recorded having incorporated mineral N fertilizer (N_{30}) for winter wheat straw decomposition. The lowest mineral N concentration was measured in organic cropping systems with catch crops.

4. In the organic cropping system, the incorporation of catch crops into soil resulted in higher mineral N reserves in soil in spring than in the sustainable cropping system, having applied mineral N fertilizer for straw decomposition in autumn.

Applying organic cropping systems with catch crops on a clay loam soil with low and moderate humus contents is an efficient tool to promote environmental sustainability.

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