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Influence of crop rotation and catch crop for green manure on nitrogen balance in organic farming

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A field experiment was carried out in an organic certified field of the Experimental Station of the Lithuanian University of Agriculture in 2003–2007. The soil type was *Calc*(*ar*)*i Epihypogleyic Luvisol* (*LVg-p-w-cc*). Nitrogen balance was evaluated after four years of experiment. Four 7-year crop rotations with a different ratio of nitrogen fixing crops were compared: I – 43% (grass-clover; grass-clover; winter wheat; spring barley; peas; winter wheat; spring barley); II – 43% (grass-clover; winter wheat; peas; spring barley; grass-clover; winter wheat; spring barley); III – 29% (grass-clover; potato; oat; spring barley; peas; winter wheat; spring barley); IV – 14% (grass-clover; winter wheat; potato; spring barley; winter rape; winter wheat; spring barley). The catch crop was (1) included, (2) not included in rotations. The objective of our study was to evaluate the influence of crop rotations with a different nitrogen fixing crop percentage and catch crop (for green manure) on nitrogen balance in organic farming.

The least soil nitrogen loss (1.87 to 4.58 kg ha^{-1}) due to leaching to deeper soil horizons was established in crop rotations II and IV, in grass-clover and winter rape crop. The biggest nitrogen loss (40.7 to 74.8 kg ha^{-1}) was found in the soil of crop rotation I in peas and in the soil of crop rotation III in peas without a catch crop. Catch crop for green manure reduced nitrogen leaching by 94.9% in the soil of crop rotation III in comparison with the same crop rotation (III) without a catch crop. The amount of nitrogen leached to the deeper soil layers depended on nitrogen content in the soil.

During the experiment, a negative nitrogen balance was established in the soil of all crop rotations (–46.69 to –145.13 kg ha^{-1}). The nitrogen balance was influenced by nitrogen uptake from soil ($r = -0.77$, $P < 0.05$). The obtained data show that biological nitrogen suppliers are very important in organic farming.

Key words: nitrogen balance, crop rotation, catch crop, organic farming

INTRODUCTION

Crop rotations in organic farming must focus not only on the prevention of such problems as the spread of diseases, pests and weeds. N self-supply in soil through the use of N-fixing and catch crops is very important in organic farming (Askegaard et al., 2005).

Soil microbes release mineral nitrogen from organic matter. N-leaching is determined to a large degree by soil type, precipitation (rainfall), and N-concentration in soil (Zhao, 1993; Lewan, 1994). Catch crops undersown into the main crop or sown after their harvesting accumulate soil mineral N in underground and terraneous parts (biological acumulation of nitrates), and nitrate leaching from soil decreases. By the data of N. Lütke Entrup (1995), I. K. Thomsen and B. T. Christensen (1999) nitrogen leaching to deeper soil horizons was best decreased by common ryegrass versus other catch crops. Other authors indicate that postharvest catch crops, especially of the *Brassicaceae*, are very effective for biological nitrogen fixation (Köphe, 1994; Van Dam, Leffelaar, 1998). Legumes are very important nitrogen suppliers in ecological farming systems. Scientists recommend to grow them with cereals to prevent the risk of nitrogen leaching (Torstensson et al., 1998; Olesen et al., 2000; Korsaeth, 2008). Investigations in Sweden revealed that in sandy loam soils without a catch crop during one-year period there leached 39.2 kg ha^{-1} N-NO_3 and with common ryegrass as a catch crop 10.3 kg ha^{-1}. M. Torstensson (2006) has reported that N leaching in a crop rotation with a catch crop was reduced by 13 kg ha^{-1} year^{-1} (34%) as compared with an identical crop rotation without a catch crop. Ross et al. (2008) indicate that the use of legumes, manure and N fertiliser affected soil N, but the most important factor was the legume crop ratio in the crop rotation.

The Helsinki Committee (HELCOM) February 6, 1992 recommendations No. 13/9 emphasize that it is necessary annually calculate the plant nutrient balance for the purpose of the economic and ecological evaluation of fertilization. It is considered positive if the amount of nutrients brought into soil is higher than nutrient uptake from the soil (Mašauskas ir kt., 2000).

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By the data of Š. Antanaitis, V. Mašauskas and S. Lazauskas (2007), in a bioorganic farming system when the nitrogen balance was supported with biological nitrogen by growing red clover, even without organic fertilisers (manure) during a five-year period the silt loam soil was not exhausted. Most of nitrate-N leached through drainage in arable soil; depending on the year, it varied from 1.7 to 43 kg ha^{-1}, meanwhile in grassland it did not exceed 5 kg ha^{-1}.

The objective of our study was to evaluate the influence of crop rotations with a different nitrogen-fixing crop percentage and catch crop (for green manure) on nitrogen balance in organic farming.

MATERIALS AND METHODS

A field experiment was carried out in an organic certified field of the Experimental Station of the Lithuanian University of Agriculture in 2003–2007. The experimental factors were: (1) the ratio of nitrogen-fixing crops in a crop rotation, (2) with and without a catch crop. Four 7-year crop rotations with a different ratio of nitrogen-fixing crops were compared: I – 43% (grass-clover; grass-clover; winter wheat; spring barley; peas; winter wheat, spring barley); II – 43% (grass-clover; winter wheat; peas; spring barley; grass-clover; winter wheat, spring barley); III – 29% (grass-clover; potato; oat; spring barley; peas; winter wheat, spring barley); IV – 14% (grass-clover; winter wheat; potato; spring barley; winter rape; winter wheat, spring barley). Catch crop was (1) included, (2) not included in crop rotations. Nitrogen balance was evaluated after four years of experiment.

The initial plot size was 126 m^2, with each plot replicated three times.

The catch crop in all crop rotations was white mustard *Sinapis alba* L. sown after the main crop. Straw of cereals and the yield of catch crop were chopped and ploughed into the soil in autumn.

To estimate nitrate leaching to deeper soil horizons, galvanized 0.25 m^2 tin lysimeters were installed at a depth of 40 cm in plots of all crop rotations with and without a catch crop. Lysimeters were incorporated by hoses with water-gathering containers. Lysimetric water was collected from May 1 to October 30. Data of the Meteorological Station of Kaunas Hydrometeorological Observatory were used for determining the precipitation in the same period.

We measured precipitation permeated through the soil (drainage water). The lysimetric method is based on the drainage principle, so rainfall water permeated through the soil can be established when a surplus in soil moisture occurs.

We determined the amounts of mineral (NO_{3-} and NH_{4-}) nitrogen in lysimetric and rainfall water by the colorimetric method using disulphophenolic acid.

We established the content of nitrogen in absolutely dry matter of grass-clover, peas and winter rape seeds. Crops for yield determination were harvested manually from square plots of 1 m^2. Grass-clover overground mass yield was expressed by the content of absolutely dry matter t ha^{-1}, peas – by 14% of humidity and absolutely clean grain mass, winter rape – by 8.5% of humidity and absolutely clean grain mass. The content of nitrogen (mg kg^{-1}) in absolutely dry matter was determined by the Kjeldhal method.

The N balance was calculated using Welte and Timmermann (1985), Claupein (1994) models.

The N balance model when legumes are grown is as follows: $B_N = (N_{symbiotically\ fixed} + N_{in\ precipitation}) - (N_{in\ yield} + N_{leached})$; the N balance model when legumes are not grown is as follows: $B_N = N_{in\ precipitation} - (N_{in\ yield} + N_{leached})$. The content of mineral nitrogen (ammonia and nitrate) in lysimeters and rainwater were determined by the colorimetric method using disulphophenolic acid; the content of nitrogen in absolutely dry matter of plants was determined by the Kjeldhal method. Symbiotically fixed atmospheric nitrogen was determined by the method of difference: $N_{fixed} = N_{in\ legumes} - N_{in\ comparables}$ (Rennie, 1984; Weaver, 1986).

Table 1. **Structure of four different seven-course crop rotations with and without catch crops**

Catch crop	Year	Crop rotation I	Crop rotation II	Crop rotation III	Crop rotation IV
Without	2003	Grass–clover	Grass–clover	Grass–clover	Grass–clover
	2004	Grass–clover	Winter wheat	Potato	Winter wheat
	2005	Winter wheat	Peas	Hulless oat	Potato
	2006	Spring barley	Spring barley	Spring barley	Spring barley
	2007	Peas	Grass–clover	Peas	Winter rape
	2008	Winter wheat	Winter wheat	Winter wheat	Winter wheat
	2009	Spring barley	Spring barley	Spring barley	Spring barley
With	2003	Grass–clover	Grass-clover / aftercrop for green manure	Grass–clover / aftercrop for green manure	Grass–clover / aftercrop for green manure
	2004	Grass–clover / aftercrop for green manure	Winter wheat / white mustard	Potato	Winter wheat / white mustard
	2005	Winter wheat / white mustard	Peas / white mustard	Hulless oat / white mustard	Potato
	2006	Spring barley / white mustard	Spring barley	Spring barley / white mustard	Spring barley
	2007	Peas	Grass–clover	Peas	Winter rape
	2008	Winter wheat / white mustard	Winter wheat / white mustard	Winter wheat / white mustard	Winter wheat / white mustard
	2009	Spring barley	Spring barley	Spring barley	Spring barley

Note. A slash (/) indicates catch crop after the main crop.

Statistical analyses. The mean values were compared by the least significant difference test at $P_{(level)} < 0.05$ using SYSTAT 10. To estimate the relationships between N leaching and N concentration in the soil, N leaching and N uptake by the crops, N balance in the soil and N uptake from the soil, regression analyses were performed using SYSTAT 10 (SPSS Inc., 2000).

RESULTS AND DISCUSSION

Calculations of nutrients requirement for an optimal crop yield must be not limited only by estimating nitrogen removal with harvest. It must be based on a full-scale analysis including all essential nutrient inputs and removals in the plant–soil system.

A summarized nitrogen balance in the soil during the experimental period (May–October 2007) is presented in Table 2. The atmospheric N deposition with rainfall to soil was 7.86 kg ha^{-1}.

The annual atmospheric nitrogen deposition with rainfall was 10 to 15 kg ha^{-1} per year (http://www.ktl.mii.lt/aa/dir43.html).

There are nitrogen inputs from symbiotic N fixation in crop rotations with legumes. Schmidke and Rauber (1993) indicate that the content of symbiotic fixed nitrogen in the above-ground part of clover is 53.3–89.6%, and Schnotz (1995) indicates 68.6%. Our experimental data showed that symbiotic fixed nitrogen reached in clover 47.2 to 56.0% and in peas 12.4 to 21.8%. In crop rotation IV, grass-clover additionally derived from the atmosphere 95.2 to 97.4 kg ha^{-1} nitrogen. In crop rotations I and III, peas additionally derived from the atmosphere 9.07 to 14.1 kg ha^{-1} nitrogen. Asymbiotically fixed nitrogen in the soil reached less than 1 kg ha^{-1} per year (Lamb et al., 1987).

Nitrogen content in grass-clover over-ground mass (two harvests) reached 99.1 to 99.2%, in pea seeds 46.3 to 94.4%, in winter rape seeds 95.2 to 97.6% of all assimilated and irreversible nitrogen in soil.

The least losses of nitrogen (1.87 to 4.58 kg ha^{-1}) through leaching to deeper soil horizons were established in soil of crop rotations II and IV where grass-clover and winter rape were grown. In the latter crop rotations, catch crops for green manure had no influence on nitrogen leaching. The biggest nitrogen losses (40.7 to 74.8%) through leaching to deeper soil horizons were established in crop rotation I where peas were grown, and in crop rotation III where peas were grown without a catch crop for green manure. The amount of nitrogen leached to deeper soil horizons was 35.8–53.7% of all nitrogen losses. In the soil of crop rotation III, the catch crop decreased by 94.9% the amount of nitrogen leached to deeper soil horizons as compared without a catch crop in the same crop rotation.

Table 2. **Influence of crop rotation and catch crop for green manure on nitrogen balance in soil**

Nitrogen components	Crop rotations							
	I		II		III		IV	
	Without CC	CC for green manure	Without CC	CC for green manure	Without CC	CC for green manure	Without CC	CC for green manure
N input (kg ha^{-1})	7.86	7.86	7.86	7.86	7.86	7.86	7.86	7.86
1. Rainfall								
2. Fixed by N-fixing crops	9.07	12.3	95.2	97.4	11.7	14.1	–	–
Total	**16.93**	**20.16**	**103.06**	**105.26**	**19.56**	**21.96**	**7.86**	**7.86**
N uptake (kg ha^{-1})								
1. Crop yield	72.9	69.6	246.3	200.3	64.6	64.8	114.9	90.2
2. Leaching to deeper soil horizons	40.7	49.6	1.89	1.87	74.8	3.85	2.84	4.58
Total	**113.6**	**119.2**	**248.19**	**202.17**	**139.4**	**68.65**	**117.74**	**94.78**
N balance in soil, kg ha^{-1}	**–96.67**	**–99.04**	**–145.13**	**–96.91**	**–119.84**	**–46.69**	**–109.88**	**–86.92**

Note: CC – catch crop. Crop rotations with different ratio of nitrogen fixing crops: I – 43% (grass–clover; grass–clover; winter wheat; spring barley; peas; winter wheat, spring barley); II – 43% (grass–clover; winter wheat; peas; spring barley; grass–clover; winter wheat, spring barley); III – 29% (grass–clover; potato; oat; spring barley; peas; winter wheat, spring barley); IV – 14% (grass–clover; winter wheat; potato; spring barley; winter rape; winter wheat, spring barley).

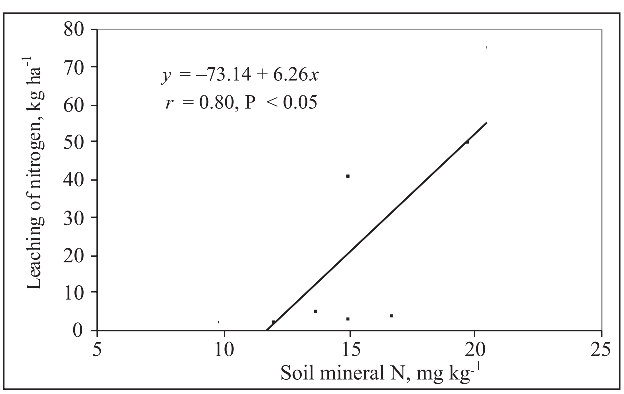

Fig. 1. Relationship between N leaching and mineral N content in soil

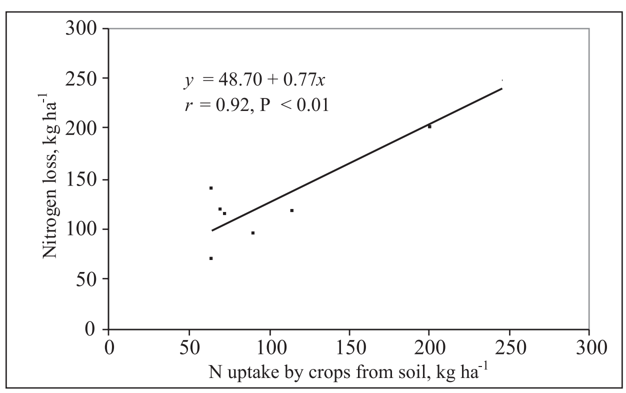

Fig. 2. Relationship between N loss and N-uptake by the crops from the soil

The amount of nitrogen leached to deeper soil horizons depends on mineral nitrogen content in soil; a positive, strong significant correlation between these indexes was established (Fig. 1.)

The more nitrogen was assimilated from soil by agricultural plants, the bigger loss of nitrogen was established. A positive, very strong significant correlation was established between nitrogen assimilation from soil by agricultural plants and nitrogen loss (Fig. 2).

We established a negative nitrogen balance in the soil of all crop rotations during the experimental period – from 46.69 to145.13 kg ha^{-1}. Nitrogen balance in the soil was influenced by removed from soil nitrogen amount ($r = -0.77, P < 0.05$). A negative, strong, significant correlation between nitrogen balance in the soil and nitrogen removed from soil was calculated (Fig. 3).

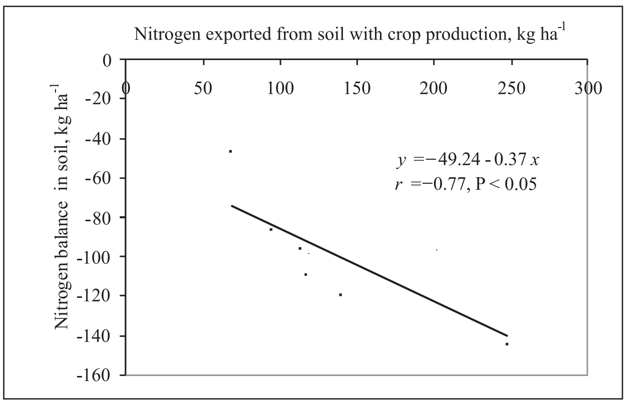

Fig. 3. Relationship between N balance in soil and N exported from soil with crop production

CONCLUSIONS

The least nitrogen loss (1.87 to 4.58 kg ha^{-1}) due to leaching to deeper soil horizons was found in crop rotations II and IV, where respectively grass-clover and winter rape were grown. The biggest nitrogen loss in the soil (40.7 to 74.8 kg ha^{-1}) was established in crop rotation I where peas were grown, and in crop rotation III under the pea crop without a catch crop. Catch crop for green manure decreased the content of leached nitrogen by 94.9% as compared with no catch crop in crop rotation III. The content of nitrogen leached to deeper soil horizons depends on the content of mineral nitrogen in the soil ($r = 0.80, P < 0.05$).

We established a negative nitrogen balance in the soil in all crop rotations during the experiment period (from −46.69 to −145.13 kg ha^{-1}). Nitrogen balance was influenced by the nitrogen amount removed from soil ($r = -0.77, P < 0.05$). These data prove the importance of biological nitrogen support in organic farming.

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SĖJOMAINŲ IR TARPINIŲ PASĖLIŲ ŽALIAJAI TRĄŠAI ĮTAKA DIRVOS AZOTO BALANSUI EKOLOGINĖJE ŽEMDIRBYSTĖJE

Santrauka

Tyrimai atlikti 2003–2007 m. Lietuvos žemės ūkio universiteto Bandymų stotyje. Tyrimų lauko dirvožemis karbonatingas sekliai glėjiškas išplautžemis – *IDg8-k*. Azoto balansas buvo skaičiuotas po 4 metų nuo tyrimo pradžios. Tyrimo A veiksnys – 4 septynių narių sėjomainų rotacijos su skirtinga azotą fiksuojančių augalų dalimi: I – 43% (daugiametės žolės; daugiametės žolės; žieminiai kviečiai; vasariniai miežiai; žirniai; žieminiai kviečiai; vasariniai miežiai); II – 43% (daugiametės žolės; žieminiai kviečiai; žirniai; vasariniai miežiai; daugiametės žolės; žieminiai kviečiai; vasariniai miežiai); III – 29% (daugiametės žolės; bulvės; belukštės avižos; vasariniai miežiai; žirniai; žieminiai kviečiai; vasariniai miežiai); IV – 14% (daugiametės žolės; žieminiai kviečiai; bulvės; vasariniai miežiai; žieminiai rapsai; žieminiai kviečiai; vasariniai miežiai). B veiksnys – tarpinis pasėlis: 1) su tarpiniu pasėliu; 2) be tarpinio pasėlio. Tyrimų tikslas – įvertinti sėjomainų rotacijų su skirtinga azotą fiksuojančių augalų dalimi ir tarpinių pasėlių žaliajai trąšai įtaką azoto balansui dirvoje ekologinėje žemdirbystėje.

Mažiausi azoto nuostoliai (nuo 1,87 iki 4,58 kg ha^{-1}) dėl išplovimo į gilesnius dirvožemio horizontus nustatyti II ir IV sėjomainų dirvoje, kurioje augo atitinkamai raudonųjų dobilų ir pašarinių motiejukų mišinys ir žieminiai rapsai. Didžiausi azoto nuostoliai (nuo 40,7 iki 74,8 kg ha^{-1}) nustatyti I sėjomainos dirvoje, kurioje augo žirniai, ir III sėjomainos dirvoje, kurioje augo žirniai ir nebuvo augintas tarpinis pasėlis žaliajai trąšai. III sėjomainos dirvoje tarpinis pasėlis žaliajai trąšai, lyginant su jo nenaudojimu, 94,9%. sumažino išplauto azoto kiekį. Į gilesnius dirvožemio horizontus išplauto azoto kiekis priklausė nuo dirvoje esančio mineralinio azoto kiekio (r = 0,80, P < 0,05). Tiriamuoju laikotarpiu visų sėjomainų dirvoje nustatytas neigiamas azoto balansas – nuo –46,69 iki –145,13 kg ha^{-1}. Azoto balansui dirvoje turėjo įtakos išnešto iš dirvos azoto kiekis (r = –0,77, P < 0,05). Šie duomenys įrodo, kad ekologinėje žemdirbystėje yra labai svarbūs biologiniai azoto tiekėjai.

Raktažodžiai: azoto balansas, sėjomainų rotacijos, tarpiniai pasėliai, ekologinė žemdirbystė