removal of potassium by 11.31kg. Single introduction of phosphoric fertilizers decreased the removal of potassium from 217.43 kg ha^{-1} (P_{60}) to 188 kg ha^{-1} with (P_{180}).
The level of the total removal of nutrients is determined generally by the crop yields of DM of alfalfa, and less depended on the chemical composition.

Conclusions

Use of NPK fertilizers is the most effective influencing factor on the crop yield of alfalfa, which is cultivated for feed. With optimal doses of fertilizers ($N_{20}P_{120}K_{160}$), the average yield of dry matter was 8.10 t ha^{-1}.
Mineral fertilizers favour the increase of the total protein. The most significant impact is shown by paired combinations of NP and PK fertilizers – with higher doses the increase of protein increased by 1.5 times.
With the application of $N_{20}P_{120}K_{160}$, alfalfa removes from the soil with the yield of dry matter 226 kg ha^{-1} of N; 55 kg ha^{-1} of P_2O_5 and 271 kg ha^{-1} of K_2O.

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LUCERNAS RAŽĪBA UN KVALITĀTE VELĒNU PODZOLĒTĀ AUGSNĒ PIE DAŽĀDIEM MINERĀLMĒSLU LĪMEŅIEM

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Rakstā apkopoti LLU aģentūras Zemkopības zinātniskā institūta lucernas 5-gadīgie pētījumu rezultāti. Pētījumi veikti velēnu podzolētā augsnē ar dažādām NPK mēslojumu devām. Minerālmēslojums būtiski palielināja lucernas zaļās masas ražu. Pie optimālā NPK mēslojuma attiecības ($N_{20}P_{120}K_{160}$) ieguva 8.10 t ha^{-1} sausnas.
Minerālmēslojums sekmēja arī kopējā proteīna ieguvi, pie paaugstinātas devas $N_{20}P_{120}K_{160}$, proteīna ieguve palielinājās 1.5 reizes.Mēslojot lucernu ar $N_{20}P_{120}K_{160}$, iegūtā lucernas sausnas raža no augsnes iznes N-226 kg ha^{-1}, P_2O_5 – 55 kg ha^{-1} un K_2O – 271 kg ha^{-1}.

THE EFFECTS OF COVER CROPS AND STRAW ON SOIL MINERAL NITROGEN DYNAMICS AND LOSSES FROM ARABLE LAND

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Abstract

Seeking to estimate the effects of biological measures – various cover crops in combination with different straw incorporation methods on the reduction of soil mineral nitrogen and nitrogen leaching complex research was conducted at the Lithuanian Institute of Agriculture‘s Joniskelis Experimental Station on clay loam *Gleyic Cambisol* during the period 2003–2005. Undersown legume crops during the post–harvest period gave the largest reduction in mineral nitrogen in the soil: red clover (*Trifolium pratense* L.) – 15.1 %, white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) mixture – 16.4 %, compared with the treatment without cover crops. However, having incorporated by a stubble breaker not only stubble but also straw and having applied nitrogen fertiliser (N 45) for its mineralization, the content of mineral nitrogen increased by 15.2 %, compared with the treatment where the plots were stubble–broken without straw. Having incorporated straw with the addition of mineral nitrogen fertiliser, 9.2 % lower $N_{min.}$ content in the soil was found in the treatment where cover crop white mustard (*Sinapis alba* L.) was sown as a post–crop. In heavy–textured *Cambisol* in spring, higher contents of $N_{min.}$ in the soil and filtration water were found in the treatments where the biomass of legume crops was incorporated in the autumn. Having incorporated it together with straw, the $N_{min.}$ content in the soil significantly declined (9.8 %).

Key words: clay loam soil, cover crops, mineral nitrogen, nitrogen leaching

Introduction

Intensive agriculture where the nutritional needs of plants are met by mineral fertilisers, poses a threat to ecological balance (Buciene, 2003). Most research findings suggest that 50–60 % of nitrogen present in surface water is of agricultural origin. Numerous studies have been done and recommendations have been provided on the most suitable fertiliser forms and rates, application timing and methods. However, research on the effects of the technologies used on nutrient, especially nitrogen, immobilisation in the soil after the harvesting of the main crops, when the soil during the post–harvest period stays without any plant cover for a long time, is rather scanty. It was found that intensive crop fertilisation results in increased $N_{min.}$ content in the autumn (Arlauskiene and Maiksteniene, 2005). Mineral nitrogen build–up and dynamics in the soil depend on soil texture and humus content, conditions of the growing period, crop and soil management technologies, especially fertilisers used (mineral and organic), their rates and application method (Antil *et al*., 2005). Seeking to reduce environmental pollution, adequate selection of preventive measures is very important when including the nutrients not utilised by plants into the biological turnover cycle. With this end in view, technologies with cover crops that accumulate and localize in the soil the nutrients left in the biomass at the end of summer – during the autumn (winter) period, and during the most intensive leaching complex that prevent the nutrients from being leached, are widely used in Western Europe. Under the effect of biological transformation the incorporated biomass in the following year becomes the nutrient source for crops grown (Reents and Moller, 2000; Thorup–Kristensen, 2006). However, after the incorporation of the nitrogen–rich biomass of cover crops (especially those with a narrow carbon to nitrogen ratio), intensive mineralization during the early spring period is possible, when the content of N_{min} increases and there is a risk of its leaching into ground water (Farthofer *et al*., 2004; Loges *et al*., 2006). An effective way to prevent nutrient migration into deeper layers during the autumn – is early spring nitrogen inclusion into the soil's organic compounds. It is the incorporation of the nitrogen-rich biomass of the cover crops into the soil together with carbon –rich cereal straw (Dryslova and Prochazkova, 2002). Experiments carried out in Denmark show that the proper use of straw not only reduces mineral nitrogen excess in the soil but also restores soil humus and increases the stable humic matter content (Luxhoi *et al*., 2007).
The study was designed to estimate the effects of various cover crops in combination with different straw incorporation methods on the reduction of soil mineral nitrogen and nitrogen leaching complex in clay loams.

Materials and Methods

Two analogous trials were carried out at the Lithuanian Institute of Agriculture's Joniskelis Experimental Station during the periods: 2003–2004 (I experiment) and 2004–2005 (II experiment). The soil of the northern part of Central Lithuania's lowland is *Endocalcari–Endohypogleyic Cambisol*, according to texture – clay loam on silty clay with deeper lying sandy loam (p2 / m2 / p1). The soil agrochemical properties in the 0–20 cm layer were as follows: pH_{KCl} –

6.4, humus content of 21–22 g kg^{-1}, plant available P and K – 0.052 and 0.220 g kg^{-1} of soil respectively.

Experimental design:

Factor A. Winter wheat (*Triticum aestivum* L.) straw management methods: I. Straw – removed from the field; II. Straw – chopped and incorporated.

Factor B. Stubble breaking and cover crops: 1. Without cover crop, stubble not broken; 2. Without cover crop, stubble broken; 3. Undersown cover crop – red clover (*Trifolium pratense* L.); 4. Undersown cover crop – mixture of white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.); 5. Undersown – cover crop – white mustard (*Sinapis alba* L.) broadcast–sown into winter wheat at wax maturity stage; 6. Aftercrop cover crop – white mustard direct–sown into stubble; 7. Aftercrop cover crop – white mustard direct–sown into stubble–broken soil.

The experiment was conducted in the fallowing rotation sequence: winter wheat + cover crop; spring barley. The effect of cover crops and straw was monitored by growing spring barley (*Hordeum vulgare* L.). Winter wheat 'Ada' and spring barley 'Ula' were grown following conventional technology and fertilised by N 60, P 26.4 and K 49.8. The sowing time of cover crops was for undersown red clover and a mixture of white clover and Italian ryegrass – beginning of April, for broadcast – undersown white mustard – end of July, for aftercrop white mustard – beginning of August (the very day after the cereal harvest). According to the experimental design the winter wheat stubble was broken by a combined breaker composed of goose feet coulters cutting 10–12 cm soil layer, disks incorporating plant residues and straw and bar rollers levelling the soil surface. Various sowing methods of cover crops were studied: undersowing – by drilling perennial grasses into winter wheat in spring; broadcast undersowing – by spreading the seeds of white mustard at winter wheat wax maturity; aftercrops – by direct drilling into stubble and into the surface loosened by a combined stubble breaker after harvesting. In order to adequately place the seeds of cover crops into the clay loam soil, the wedge – type coulters of the *Amazone D7* sowing machine were fitted with special additions to make a deeper furrow and to achieve better placement of seed. The seed rate when sowing white mustard by the sowing machine *Amazone D7* was 18 kg ha^{-1}, when sowing broadcast the rate was increased by 30 %. The seed rate of undersown red clover was 15 kg ha^{-1}, of white clover mixed with Italian ryegrass 8 + 7 kg ha^{-1}. Mineral nitrogen fertilisers (N 45) were applied after winter wheat harvesting: in background – straw removed from the field (I) to white mustard and in background – straw chopped and incorporated (II) for straw mineralisation – in all treatments excluding undersown red clover and mixture of white clover and Italian ryegrass). Soil samples for mineral nitrogen ($N_{min.}$) determination were taken before the incorporation of cover crops and straw into the soil and early in spring before barley sowing from the soil profile layer 0–40 cm. Mineral nitrogen (NO_3 + NH_4) was measured by the distillation and colorimetry method (in 1 N KCl extraction). To measure nutrient leaching, wells-piezometers were set up (depth 0–80 cm) after winter wheat harvesting in each background in two replications to collect the filtration water. In water samples the N–NO_3 content were determined by cadmium reduction methods.

The rate of rainfall during the August–September period in 2003 accounted for 63.7 % of the long–term mean, however sufficient rainfall after crop emergence determined good crop establishment and growth. In winter and early spring (2004) the rate of precipitation was lower compared with the long–term mean, as a result, the probability of nutrient leaching was low. During the September–November period of 2004 after the incorporation of straw and plant biomass, the rate of precipitation was 43 % higher than the long–term mean. The winter of 2004–2005 was milder (especially in January, when the air temperature was 4.3 °C higher) than usual. However, the winter was long and the weather became warmer only in April before crop sowing. The experimental data were processed by ANOVA and STAT ENG.

Results and Discussion

In the agrocenoses on the soils satiated with soil–depleting cereals cover crops during post–harvest period additionally accumulate organic matter and biogenic elements, better utilise the growing season and protect the soil from degradation. The largest amount of aboveground mass 2.55 t ha^{-1}

of dry matter was produced by undersown red clover with a longer growing season. The largest amount of white mustard aboveground mass was formed in the plots of the treatments where the seed was sown into stubble–broken soil or directly sown into the stubble 2.43 and 2.53 t ha^{-1} of dry matter, respectively.

Experiments carried out early in October before the incorporation of cover crops into the soil show that the content of mineral nitrogen in the upper 0–40 cm soil profile was on average through all experimental treatments 0.0067 g kg^{-1}. Nitrate and ammonia nitrogen accounted for 45.9 and 54.1 % of its content. On the background of straw, having spread mineral nitrogen fertiliser for its more rapid mineralization, $N_{min.}$ tended to increase (on average 1.5 %) (Table 1). The higher mineral nitrogen content on the background of straw was determined by ammonia nitrogen. Spread on the soil but not incorporated into the soil straw partly protected the soil from large temperature variations and conserved productive moisture reserves thus creating favourable a climate for the emergence and development of cover crops.

Table 1. Effect of cover crops sowing and straw using methods on the soil (layer 0–40 cm) mineral nitrogen content (g kg^{-1} soil) in autumn before the incorporation of the biomass of the cover crop (mean date from 2003–2004)

Cover crops and their sown methods (B)	Straw using methods (A)					
	straw removed from the field		straw chopped and incorporated		means for factor B	
	$N_{min.}$, g kg^{-1}	relative number, %	$N_{min.}$, g kg^{-1}	relative number, %	$N_{min.}$, g kg^{-1}	relative number, %
Without cover crop, stubble not broken	0.0070	100	0.0076	108.6	0.0073	100
Without cover crop, stubble broken	0.0066	94.3	0.0076	108.6	0.0071	97.3
Undersown cover crop – red clover	0.0060	85.7	0.0065	92.9	0.0062	84.9
Undersown cover crop – mixture of white clover and Italian ryegrass	0.0063	90.0	0.0058	82.9	0.0061	83.6
Undersown cover crop – white mustard broadcast–sown into winter wheat at wax maturity stage	0.0065	92.9	0.0066	94.3	0.0066	90.4
Aftercrop cover crop – white mustard direct–sown into stubble	0.0070	100.0	0.0072	102.9	0.0071	97.3
Aftercrop cover crop – white mustard direct–sown into stubble–broken soil	0.0073	104.3	0.0069	98.6	0.0071	97.3
Means for factor A	0.0067	100	0.0068	101.5	0.0068	

LSD_{05} (A) = 0.00030; LSD_{05} (B) = 0.00057; LSD_{05} (AB) = 0.00080

Having incorporated cereal roots and stubble shallowly at 10–12 cm by the stubble breaker, the contents of the mineral nitrogen declined, which created a reduction in the mineral nitrogen content of 5.7 %, compared with that in the treatment with unbroken stubble. However, having incorporated by a stubble breaker not only stubble but also straw and having applied nitrogen fertiliser (N 45) for its mineralization, the content of mineral nitrogen increased by 15.2 %, compared with the treatment where the plots were stubble–broken without straw.

Seeking to reduce nitrogen accumulation in the soil, which increases the risk of leaching, white mustard was sown as an aftercrop. On the background without straw having broken stubble and having applied mineral nitrogen fertiliser for the start growth of mustard, the content of mineral nitrogen was the highest, its content increased by 4.3 and 10.6 %, respectively, compared with the check and stubble–broken treatments. In an analogous treatment only having incorporated straw into the topsoil by a stubble breaker nitrogen fixation increased and there was less mineral nitrogen in the soil. The effect of white mustard as an aftercrop on mineral nitrogen content in the soil depended on the sowing method of white mustard. White mustard undersown at cereal early wax maturity (and having incorporated the start dose of mineral nitrogen fertiliser), was at the intensive nutrient utilisation stage (Thorup–Kristensen, 2006), therefore better utilised both soil and mineral fertiliser nitrogen and reduced $N_{min.}$ in the soil by 7.1 %, compared with the check treatment. However, mineral nitrogen tended to increase having sown mustard into stubble after harvesting, especially in the soil where straw had been spread.

On both backgrounds undersown legumes significantly increased the revivification of mineral nitrogen in the soil profile. Literature sources indicate that in autumn cover crops can reduce mineral nitrogen content in the soil by 20–25 kg ha^{-1} (Farthofer *et al*., 2004). Undersown grasses grown as cover crops have a well–developed root system, as a result, after cereal harvesting they better utilise the nitrogen remaining in the soil compared with white mustard as an aftercrop, moreover they do not need mineral nitrogen fertilisers. After the incorporation of the cover crops biomass there was less mineral nitrogen on the background without straw where red clover was grown, with straw – white clover and ryegrass mixture, which made up 14.3 and 17.1 % less, compared with the check treatment.

The mineral nitrogen content in the soil profile in spring had some effect on the nitrogen concentration in the soil filtration water (Table 2). On both straw utilisation backgrounds nitrate nitrogen content in the soil filtration water was significantly increased by the biomass of legume crops incorporated in the autumn. As literature sources indicate, nitrate nitrogen depends on the nitrogen content accumulated in the cover crops biomass, and according to the nitrogen content in the soil solution the plants can be ranked in the following order: legumes > legume and non–legume mixture > non–legumes (Rinnofner *et al*. 2005).

Table 2. Effect of cover crops and straw using methods on the nitrate nitrogen (N–NO_3) leaching from the soil in spring period (mean data from 2004–2005)

Cover crops (B)	Straw using methods (A)					
	straw removed from the field		straw chopped and incorporated		means for factor B	
	mg l^{-1}	relative number, %	mg l^{-1}	relative number, %	mg l^{-1}	relative number, %
Without cover crop	6.11	100	7.80	127.7	6.96	100
Undersown cover crop – red clover	15.50	253.7	12.0	196.4	13.75	197.6
Aftercrop cover crop – white mustard	13.1	214.4	8.16	133.6	10.63	152.7
Means for factor A	11.57	100	9.32	80.6	10.44	
LSD_{05} (A) = 3.141; LSD_{05} (B) = 4.440; LSD_{05} (AB) = 6.282						

The use of straw for fertilisation reduced (on average 9.8 %) nitrate nitrogen content in filtration soil solution. Having incorporated straw, after legume crops, the content of nitrate nitrogen in filtration water declined by 11.3 %, white mustard by 18.9 %, compared with analogous treatments without straw. This nitrate nitrogen concentration in soil filtration water is not high. The data of long–term experiments conducted in Lithuania suggest that the average nitrate nitrogen concentration in lysimetric water of different soils ranged from 49.2 to 83.7 mg l^{-1} (Tyla, 1995).

In spring after the incorporation of the cover crops biomass and straw the content of nitrogen in heavy-textured soil at the 0–40 cm layer was found to be almost the same as in autumn – 0.0068 g kg^{-1} soil or 34.0 kg ha^{-1} (in average) (Table 3). The data of the trials conducted in Austria indicate that after the cover crops incorporation, in spring the content of mineral nitrogen markedly increases (in the 0–30 cm layer – 60 kg ha^{-1}, in the 0–120 cm layer – 120 kg ha^{-1}) (Farthofer *et al*., 2004). At the beginning of the plant growing season mineral nitrogen varied in a slightly different way than in autumn. The greatest increase in $N_{min.}$ content in the soil occurred after the incorporation of red clover and white clover and the ryegrass mixture. This results from the fact that during the period of autumn, winter and early spring during the breakdown of incorporated biomass of legumes, a higher content of nitrogen is released compared with that after incorporation of non–legume cover crops. After red clover and white clover with ryegrass mixture, $N_{min.}$ increased by 18.3 and 17.5 %, straw incorporation reduced its content by 3.1 and 5.2 %, compared with analogous data in autumn. Having incorporated non–legume crop – white mustard the content of mineral nitrogen declined on both backgrounds (except for the treatment where mustard was sown into broken stubble), which is indicated by other authors (Reents *et al*., 2000).

Table 3. Effect of cover crop sowing and straw using methods on the soil (0–40 cm) mineral nitrogen content (g kg^{-1} soil) in spring (mean data from 2004–2005)

Cover crops and their sowing methods (B)	Straw using methods (A)					
	straw removed from the field		straw chopped and incorporated		means for factor B	
	$N_{min.}$, g kg^{-1}	relative number, %	$N_{min.}$, g kg^{-1}	relative number, %	$N_{min.}$, g kg^{-1}	relative number, %
Without cover crop, stubble not broken	0.0075	100.0	0.0069	92.0	0.0072	100.0
Without cover crop, stubble broken	0.0068	90.7	0.0068	90.7	0.0068	94.4
Undersown cover crop – red clover	0.0071	94.7	0.0067	89.3	0.0069	95.8
Undersown cover crop – mixture of white clover and Italian ryegrass	0.0074	98.7	0.0061	81.3	0.0068	94.4
Undersown cover crop – white mustard broadcast–sown into winter wheat at wax maturity stage	0.0062	82.7	0.0065	86.7	0.0063	87.5
Aftercrop cover crop – white mustard direct–sown into stubble	0.0067	89.3	0.0061	81.3	0.0064	88.9
Aftercrop cover crop – white mustard direct–sown into stubble–broken soil	0.0077	102.7	0.0067	89.3	0.0072	100.0
Means for factor A	0.0071	100	0.0065	91.5	0.0068	
LSD_{05} (A) = 0.00023; LSD_{05} (B) = 0.00042; LSD_{05} (AB) = 0.00060						

The greatest reduction in mineral nitrogen content occurred having incorporated straw into broken and unbroken stubble (10.5 and 9.2 %, respectively), compared with the respective data obtained in the autumn. A reduction of 15.3 % in mineral nitrogen was also recorded having direct–sown mustard into stubble with straw, compared with respective data in the autumn.

In spring ammonia nitrogen accounted for the largest share (59.6 %) than nitrate nitrogen (40.4 %) in total mineral nitrogen. After straw incorporation a significant reduction in mineral nitrogen contents occurred compared with the treatments where the straw was removed. Here the content of the mineral nitrogen was 8.0 % lower, compared with the check treatment. Autumn stubble breaking with and without straw tended to reduce mineral nitrogen content in the soil 9.3 %, compared with the check treatment, or by 1.4 %, compared with the treatment where straw was spread in the autumn. The highest content of mineral nitrogen was found on the background without straw, like in the autumn having incorporated white mustard sown into broken stubble. The non–legume cover crop, white mustard, significantly reduced the mineral nitrogen content in the soil, whereas legumes tended to increase mineral nitrogen.

Conclusions

Undersown legume crops during the post–harvest period gave the largest reduction in mineral nitrogen in the soil: red clover (*Trifolium pratense* L.) – 15.1 %, white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) mixture – 16.4 %, compared with the treatment without the cover crop. Having incorporated cereal straw and having applied nitrogen fertiliser (N 45) for its mineralization, the content of mineral nitrogen increased by 15.2 %, compared with the treatment where the plots were stubble–broken without straw. While incorporating straw with the addition of mineral nitrogen fertiliser (N 45), 9.2 % lower $N_{min.}$ content in the soil was found in the treatment where cover crop white mustard was sown as the aftercrop. In spring, higher contents of $N_{min.}$ in the soil and filtration water were found in the treatments where the biomass of legume crops was incorporated in the autumn. Having incorporated it together with straw, the nitrate nitrogen content in the soil filtration water declined (9.8 %).

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UZTVĒRĒJAUGU UN SALMU EFEKTIVITĀTE AUGSNES MINERĀLĀ SLĀPEKĻA DINAMIKĀ ARAMZEMĒ

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Lai noskaidrotu dažādu uztvērējaugu un to kombināciju ar salmiem bioloģiskās iespējas samazināt augsnes minerālā slāpekļa izskalošanos minerālaugsnēs, Lietuvas Zemkopības institūta Jonišķeļu izmēģinājumu stacijā smilšmāla augsnē *Gleyic Cambisol* periodā no 2003.-2005. gadam tika ierīkoti kompleksi izmēģinājumi. Tauriņziežu pasēja pēcnovākšanas periodā nodrošināja lielāko minerālā slāpekļa samazinājumu: salīdzinājumā ar kontroli, sarkanais āboliņš (*Trifolium pratense* L.) par 15.1 %, baltā āboliņa (*Trifolium repens* L.) un daudzziedu airenes (*Lolium multiflorum* Lamk.) maisījums- par 16.4 %. Taču, atliekās iekļaujot ne tikai rugājus, bet arī salmus un to mineralizācijai lietojot slāpekļa mēslojumu (N 45), minerālā slāpekļa saturs pieauga par 15.2 %, salīdzinot ar rugāju variantu bez salmiem. Iekļaujot salmus ar minerālā slāpekļa mēslojuma piedevu, par 9.2 % zemāks $N_{min.}$ saturs augsnē tika konstatēts apstrādē, kur kā uztvērējaugs tika sēta baltā sinepe (*Sinapis alba* L.) Smagās *Cambisol* augsnēs pavasarī augstāks $N_{min.}$ saturs augsnē un filtrācijas ūdenī tika konstatēts variantos, kur rudenī tika iekļauta tauriņziežu biomasa. Iekļaujot to kopā ar salmiem, $N_{min.}$ saturs augsnē būtiski samazinājās (9.8 %).