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Sustainable cropping system for the solution of environment protection problems

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To estimate the effects of biological measures – various catch crops in combination with different straw incorporation methods – on the reduction of soil physical degradation and nitrogen leaching complex, a research was conducted at the Lithuanian Institute of Agriculture Joniškelis Experimental Station on an *Endocalcari–Endohypogleyic Cambisol* during the period 2003–2005. Incorporation of straw and the biomass of catch crops, especially of white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) mixture, tended to improve soil physical state and decrease soil bulk density. Catch crops grown with undersown crops reduced soil moisture content, whereas surface loosening by stubble breaking tended to increase soil moisture. On incorporating straw, moisture content was found to be significantly higher (by 4.1%) compared with the control treament. Better soil moisture conditions, in the year of catch crop and straw incorporation aftereffect, were identified for barley in the treatments where catch crop biomass was incorporated in combination with straw.

In the autumn, with a high rainfall rate during the post-harvest period of primary crops, undersown red clover (*Trifolium pratense* L.) and a mixture of white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) reduced $N_{min.}$ content in the soil as well as the risk of leaching by 10.9% and 13.1%, respectively, as compared with the treatment without catch crops. On the background of shallow incorporation of straw and mineral N45 incorporation intended to accelerate straw mineralization, white mustard (*Sinapis alba* L.) grown as a catch crop reduced $N_{min.}$ content in the soil by 9.5%. In the year of aftereffect, in spring, after autumn-incorporated nitrogen-rich biomass of legumes grown as catch crops, and straw, $N_{min.}$ content in the soil and lysimetric water significantly declined.

Key words: clay loam, physical degradation of soil, nitrogen immobilisation, catch crops, nitrogen leaching

INTRODUCTION

Intensive agriculture, in which nutritional needs of plants are met by mineral fertilisers, poses a threat to ecological balance. Most research findings suggest that 50–60% of nitrogen present in surface water is of agricultural origin (Lygis, 1999). 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 harvesting of main crops, when the soil during the post-harvest period stays without any plant cover for a long time, is rather scanty. It has been found that intensive crop fertilisation results in increased N_{min} content in the autumn, since the content of nitrogen unutilised by crops amounts to 25 to 155 kg ha^{-1}, which poses a real threat of groundwater pollution (Hansen et al., 2000). The highest contents of nitrogen are leached from light soils; however, also on heavy soils nitrogen leaching can be rather significant due to soil stickiness, uneven distribution of rainfall during the growing season and the resulting vertical rills (Фокин, 1986). 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 (mineral and organic), their rates and application method (Cheshire et al., 1999; Antil et al., 2005).

To reduce environmental pollution, very important is an adequate selection of preventive measures, including incorporation of the nutrients not utilised by plants into the biological turnover cycle. With this end in view, technologies with catch crops that accumulate and localize in the soil the nutrients left in biomass at the end of summer and in the autumn/winter period and during the most intensive leaching 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 a nutrient source for crops (Sorensen, 1992; Vos et al., 1997; Thorup-Kristensen, 2003; Friedel et al., 2001). Experiments in Denmark have shown that due to the nutrients accumulated by catch crops, the yield of barley grown after the catch crops increased by 0.39 t ha^{-1}, and the content of nitrogen accumulated in the yield increased by 10 kg ha^{-1} (Hansen et al., 2000). However, after incorporation of nitrogen-rich biomass of catch crops (especially those with a close carbon-to-nitrogen ratio), intensive mineralization early in spring is possible, when the content of N_{min} increases and there is a risk of its leaching into groundwater (Van Scholl et al., 1997; Knappe et al., 2002). An effective way to prevent nutrient migration into deeper layers in autumn – early spring is nitrogen inclusion into soil organic compounds (Bremer, Kukiman, 1997), i. e. incorporation of nitrogen-rich biomass of catch crops into the soil together with carbon-rich cereal straw. Experiments carried out in Germany show that the proper use of straw not only reduces mineral nitrogen excess in the soil, but also restores soil humus, increases stable humic matter content, and improves aeration (Stumpe et al., 2000; Barzegar et al., 2002).

MATERIALS AND METHODS

Two bi-factorial trials designed to explore the feasibility of reducing nitrogen leaching and soil physical degradation through cultivation of catch crops and straw utilisation were carried out at the Joniškėlis Experimental Station of the Lithuanian Institute of Agriculture.

Experimental materials. The soil of the northern part of the Central Lithuanian Lowland is *Endocalcari–Endohypogleyic Cambisol* (*Cmg-n-w-can*), and according to texture it is heavy loam on silty clay with the underlying sandy loam (*p2/m2/p1)*. Illuvial horizons of these soils are characterised by formation of vertical rills (Fig. 1), which is determined by the abundance (27–30%) of clay particles smaller than 0.002 mm in size. This has a significant effect on the intensity of the regime of vertical water migration with dissolved nutrients. The role of vertical rills as enhancers of surface water migration increases when the soil which has been in the conditions of minimal moisture is most severely cracked and the rills on the surface are most widely open; the leaching complex becomes more intensive with heavy autumn rainfalls. On cracked heavy-textured soils, filtration water is localised in separate points of vertical rill configuration. A. Fokin has described a scheme of filtration water migration and its concentration in separate points of vertical rills of different configuration by the isotopic indicator method (Fig. 2).

Localisation of chemical substances of different concentration in separate points of the profile increases the risk of their migration into groundwater. Such localised accumulation of chemical substances, especially of nitrogen, has an important effect on their leaching, since their sorption occurs not in the whole mass of soil, but only in the walls of the rills. Experimental materials were heavy-textured soils, with improvement of their physical properties by increasing organic matter content by catch crops in combination with straw.

The soil agrochemical properties in the 0–20 cm layer were as follows: pH_{KCl} 6.4, humus 2.1–2.2%, plant available P_2O_5 and K_2O 118–120 and 240–265 mg kg^{-1} of soil, respectively.

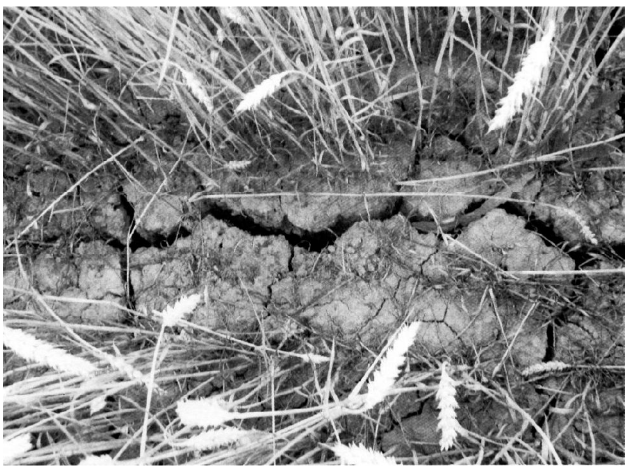

Fig 1. When the soil is rapidly drying after heavy rain, vertical rips form in sticky soils

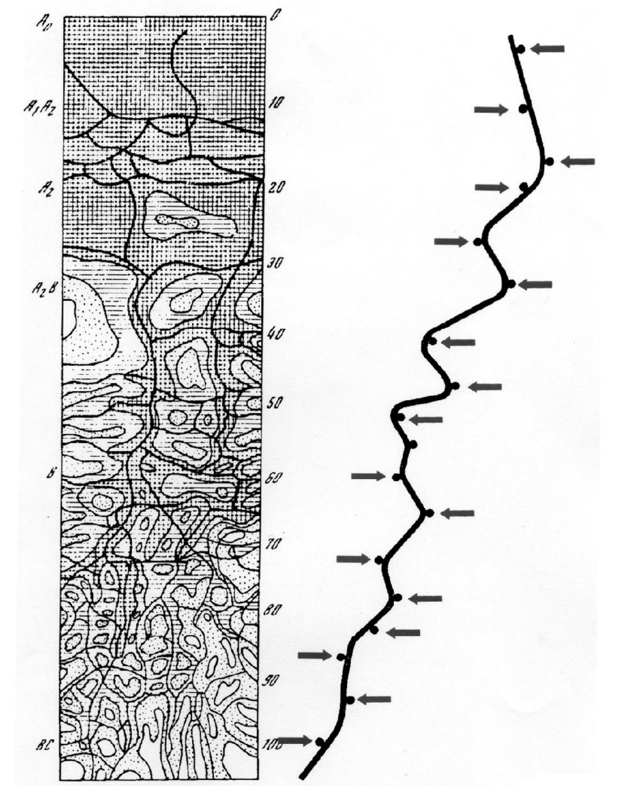

Fig 2. Washing off and localisation of rainfall water in clay soils after rip formation

Experimental design

Factor A: Straw management methods:

I. Straw – removed from the field

II. Straw – chopped and incorporated.

Factor B: Stubble breaking and catch crops:

1. Stubble not broken (check treatment)
2. Stubble broken by combined stubble breakers
3. Undersown catch crops – red clover (*Trifolium pratense* L.)
4. Undersown catch crops – white clover (*Trifolium repens* L.) and Italan ryegrass (*Lolium multiflorum* Lamk.) mixture.
5. Undersown catch crops – white mustard (*Sinapis alba* L.) broadcast-sown into winter wheat at wax maturity stage
6. Aftercrop catch crops – white mustard (*Sinapis alba* L.) direct-sown into stubble
7. Aftercrop catch crops – white mustard (*Sinapis alba* L.) undersown into stubble-broken soil.

The effect of catch crops and straw was monitored by growing spring barley. N45 was applied after winter wheat harvesting for the optimal growth and development of white mustard. To ensure optimal conditions for the mineralization of incorporated straw, 8 kg ha^{-1} of nitrogen was applied after straw chopping and spreading.

Experimental methods. For the determination of soil physical properties, samples were collected before incorporation of catch crops and in the year of effect before barley harvesting from each plot per replication at a depth of 0–10 and 10–20 cm. Soil moisture content was measured by drying a sample in a thermostat to a constant weight at a temperature of +105 °C. Soil samples for $N_{min.}$ determination were taken before incorporation of catch 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 after cereal harvesting in each background in two replications to collect filtration water. In water samples, N-NO_3 and N-NH_4 and total nitrogen contents were determined calorimetrically with a FIA Star 5012 analyser, NH_4-N – by the gas diffusion, total N (after organic matter mineralization with potassium persulfate) and N-NO_3 – by the cadmium reduction methods.

To determine the decomposition intensity of catch crop mass and straw, synthetic bags with the biomass of the test plants at a ratio of 1:1 (20 g of catch crops and 20 g of straw) were buried at the depth 10–15 cm after ploughing the experimental field. The bags were dug out in spring before soil preparation for barley sowing, and the content of undecomposed organic matter was determined by weighing.

The experimental data were processed by the methods of analysis of variance and correlation analysis, applying ANOVA and STATENG software (Tarakanovas, Raudonius, 2003).

Weather conditions. The rate of rainfall during August–September in 2001, 2002, 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. In September–November of 2004, after incorporation of straw and plant biomass, the rate of precipitation was by 43% higher than the long-term mean. The winter of 2004–2005 was milder (especially in January when the air temperature was by 4.3 °C higher) than usual. However, the winter was long and the weather became warmer only in April, before crop sowing.

RESULTS AND DISCUSSION

Soil physical properties and degradation. Alongside their advantages such as high potential productivity, heavy-textured Cambisols have also some disadvantages, such as high cohesion and stickiness. On sticky soils with a moderate humus content, when the soil rapidly dries off after heavy rains, vertical rills are formed, through which surface water with dissolved nutrients is leached into deeper layers. Cohesion and stickiness of heavy-textured cambisols tend to decline, and hydrophysical and sorption properties tend to improve with increasing the contents of organic matter in the soil. With declining cohesion and improvement in structure, the surface of clay soils is subject to lesser cracking, which in turn reduces the risk of leaching. The data found in the literature suggest that straw incorporation into soil is a valuable biological means increasing organic matter content in it (Wallgren, Linden, 1994). It has been reported that after straw incorporation in the direct-drilled plots N leaching declines by 16%, in the harrowed soil by 7.9%, and in ploughed soil by 40.4% (Stenberg et al., 1999). Other researchers indicate that with the process of straw decomposition soil structure improves and the content of water-stable soil aggregates increases, which is of special relevance for soils with a high silt fraction (Stumpe et al., 2000). Another means that helps improve soil physical state is continuous cultivation of crops by growing catch crops after primary crops, which protects against the negative effects of atmospheric phenomena.

Our experiments were designed to ascertain the effects of catch crops and straw incorporation and the combination of both on the improvement of the physical properties of heavy-textured cambisols, seeking to reduce their negative properties such as cohesion and cracking by increasing organic matter content in the soil, which would increase soil sorption capacity and prevent nutrient leaching. When undersown catch crops red or white clover are grown in mixtures with Italian ryegrass and the post-crop (white mustard) is sown by a drill with a wedge-type coulters fitted with special accessories, crops of optimal density are formed, with the overground biomass before incorporation into the soil up to 2.11; 2.29 and 2.45 t ha^{-1} dry matter, respectively. The crop of broadcast-sown white mustard at winter wheat wax maturity was much thinner and the biomass accumulated was significantly lower (by 44.4, 35.5 and 40.7%, respectively) compared with the earlier mentioned crops undersown by a drill. Various catch crops, their diverse root system and the chemical composition of incorporated biomass had different effects on soil physical properties.

Soil moisture. Depending on the catch crops, moisture content in the 0–10 cm soil layer at the end of the growing season varied. It was by 2.5% higher in the treatment where straw was spread and as a mulch protected the soil surface from drying (Table 1). A greater effect of catch crops on soil moisture was identified in the deeper ploughlayer (10–20 cm) where the root structure is situated, since plants of different development level and growth stage while forming phytomass differently utilise soil moisture reserves. A significantly lower moisture content (3.6 and 2.6%), was determined in the above-mentioned soil layer in treatments with undersown red clover and a white clover and Italian ryegrass mixture, compared with the check treatment. The effect of the white mustard aftercrop on soil moisture depended on the sowing method which determined diverse crop development conditions. The greatest reduction in soil moisture (7.7%) was found in the treatments where white mustard was sown into stubble-broken soil. Straw as a mulch did not have any significant effect on moisture accumulation in this soil layer (10–20 cm). In the subsoil of the soil tilled with stubble breakers, the highest content of moisture accumulated, and on incorporating straw, the moisture content significantly increased (4.1%) as compared with the check treatment.

After incorporation of catch crop biomass and straw when spring barley was grown in the year of effect, only trends of soil moisture variation were determined. In the topsoil layer (0–10 cm) on average through both backgrounds soil moisture was lower (by 4.4%) after white mustard biomass incorporation compared with the check treatment. Soil surface loosening by stubble breaking and breaking capillaries (with and without straw) helped maintain soil moisture not only in autumn but also in spring, especially in the deeper 10–20 cm soil layer (5.2%). However, direct (without stubble breaking) plough-in of straw tended to reduce soil moisture content in the ploughlayer. In the deeper soil layer, moisture content was higher on the background of incorporated straw (1.9%). Incorporation of catch crop biomass and straw increased soil moisture content by 6.3% compared with straw plough-in alone.

Table 1. **Effects of catch crops and their biomass and straw incorporated in the soil on the variation of moisture (%)**

Treatments (B)	Layer, cm	Before ploughing in of catch crops and straw			Year of influence		
		Without straw	Spray of chopped straw	Average	Without straw	Spray of chopped straw	Average
Stubble not broken	0–10	20.1	20.4	20.2	16.0	15.4	15.7
	10–20	19.5	19.7	19.6	15.5	15.3	15.4
Stulbe broken by combined breakers	0–10	20.6	20.5	20.5	16.6	15.8	16.2
	10–20	19.7	20.3	20.0	16.5	16.0	16.3
Catch crops – red clover	0–10	19.2	20.5	19.9	15.6	16.0	15.8
	10–20	18.4	19.1	18.8	15.4	15.9	15.6
Catch crops – white clover + Italian reygrass	0–10	19.9	20.3	20.1	16.7	15.0	15.8
	10–20	19.2	18.7	19.0	16.3	16.2	16.3
White mustard broadcast-sown	0–10	19.8	20.2	20.0	14.9	15.2	15.0
	10–20	19.3	19.0	19.1	16.0	16.0	16.0
White mustard direct-sown into stubble	0–10	20.2	20.4	20.3	15.2	15.8	15.5
	10–20	18.9	19.5	19.2	15.1	17.3	16.2
White mustard undersown into stubble broken soil	0–10	20.1	21.2	20.7	15.9	15.0	15.4
	10–20	18.4	17.5	18.0	16.4	16.8	16.6
Average	0–10	20.0	20.5	20.3	15.8	15.5	15.7
	10–20	19.1	19.1	19.1	15.9	16.2	16.1
LSD_{05} fact. A	0–10	0.56			2.28		
LSD_{05} fact. B		1.06			4.28		
LSD_{05} fact. AB		1.49			6.05		
LSD_{05} fact. A	10–20	0.30			1.58		
LSD_{05} fact. B		0.56			2.95		
LSD_{05} fact. AB		0.80			4.17		

Soil bulk density. In the autumn, at the end of catch crop growing season, soil bulk density was more affected by undersown crops than by post-crops, or by the methods of straw utilisation and stubble breaking (Table 2). On average, through both backgrounds, undersown red clover increased the bulk density of the topsoil layer (0–10 cm) by 4.4% and white clover and Italian ryegrass mixture by 2.2% as compared with the treatment without catch crops. The bulk density of the deeper plouhlayer varied in a similar way (Table 2).

More marked positive differences in soil bulk density both in the topsoil and subsoil as affected by straw incorporation were identified when in the year of effect spring barley was grown. On incorporating straw, on average through all treatments, soil bulk density in both soil depths (0–10 and 10–20 cm) was by 1.4% and 2.7% lower as compared with the background without straw. Catch crops inappreciably reduced the bulk density of the topsoil layer (0-10 cm), whereas autumn stubble breaking did not have any notable effect. More pronounced differences in soil bulk density were identified in the deeper soil layer in which catch crops reduced soil bulk density by 3.2% versus the treatment without catch crops. A significant reduction in soil bulk density occurred on incorporating white clover biomass in mixture with Italian ryegrass; the difference versus the check treatment was 5.9%. Stubble breaking and straw incorporation reduced soil bulk density more significantly, especially in the year of effect, the difference in the topsoil layer being 4.9% and in the deeper layer 2%.

Organic matter mineralisation. The rate of organic matter decomposition was monitored in model trials by digging out and weighing the nylon bags with the remaining organic matter. Our experimental evidence suggests that under field conditions during the period from early October to early May (7 months) nearly half (40.5%) of the underground and overground biomass of catch crops decomposes. The rate of biomass decomposition of catch crops with straw was much slower, as the bags contained 89.4% of undecomposed biomass of incorporated plants. The slowest decomposition was recorded for the biomass of white clover and Italian ryegrass together with straw.

Soil mineral nitrogen. A previous research conducted on heavy-textured cambisol in a cereal crop rotation suggests that the content of mineral nitrogen in soil during the post-harvest period is higher after spring rather than after winter cereals (Arlauskienė, Maikštėnienė, 2005). Cultivation of catch crops as undersowings or postcrops and their incorporation into the soil as green

Table 2. **Effects of catch crops, their biomass and straw on soil bulk density (Mg^{-3}) (0–20 cm)**

Treatments (B)	Layer, cm	Before ploughing in of catch crops and straw			Year of influence		
		Without straw	Spray of chopped straw	Average	Without straw	Spray of chopped straw	Average
Stubble not broken	0–10	1.38	1.36	1.37	1.42	1.37	1.39
	10–20	1.41	1.41	1.42	1.53	1.51	1.52
Stulbe broken by combined breakers	0–10	1.36	1.41	1.38	1.45	1.38	1.41
	10–20	1.41	1.41	1.42	1.52	1.49	1.51
Catch crops – red clover	0–10	1.43	1.42	1.43	1.40	1.34	1.37
	10–20	1.46	1.46	1.45	1.49	1.46	1.48
Catch crops – white clover + Italian reygrass	0–10	1.39	1.40	1.40	1.39	1.39	1.39
	10–20	1.45	1.45	1.46	1.45	1.42	1.44
White mustard broadcast-sown	0–10	1.37	1.40	1.38	1.38	1.38	1.38
	10–20	1.43	1.43	1.44	1.51	1.49	1.50
White mustard direct-sown into stubble	0–10	1.41	1.38	1.39	1.34	1.40	1.37
	10–20	1.45	1.45	1.44	1.52	1.43	1.48
White mustard undersown into stubble broken soil	0–10	1.36	1.37	1.37	1.44	1.40	1.42
	10–20	1.43	1.43	1.44	1.46	1.43	1.46
Average	0–10	1.38	1.39	1.39	1.40	1.38	1.39
	10–20	1.43	1.44	1.44	1.50	1.46	1.46
LSD_{05} fact. A	0–10	0.021			0.058		
LSD_{05} fact. B		0.039			0.109		
LSD_{05} fact. AB		0.056			0.154		
LSD_{05} fact. A	10–20	0.025			0.041		
LSD_{05} fact. B		0.047			0.070		
LSD_{05} fact. AB		0.067			0.108		

manure make it possible to include mineral nitrogen into the biological nutrient turnover cycle by retaining it in the ploughlayer (Table 3). Experiments carried out early in October before incorporation of catch 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 6.78 mg kg^{-1} and in the deeper soil profile (40–80 cm) 4.93 mg kg^{-1} soil. Nitrate and ammonia nitrogen accounted for 45.9% and 54.1% of its content. On the background of straw, on spreading mineral nitrogen fertiliser for its more rapid mineralization, $N_{min.}$ tended to increase. A higher mineral nitrogen content on the background of straw was determined by ammonia nitrogen whose content was by 5.0% higher as compared with that on the background without straw. 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 climate for catch crops to emerge and develop. On incorporating cereal roots and stubble at 10–12 cm by stubble breakers, the content of both nitrate and ammonia nitrogen declined and determined a reduction in mineral nitrogen content by 5.9% as compared with that in the treatment with unbroken stubble. How-ever, on incorporating with a stubble breaker not only stubble but also straw and on applying nitrogen fertiliser (N45) for its mineralization, the content of mineral nitrogen in-creased by 14.9% versus the treatment where the plots were stubble-broken without straw. Seeking to reduce nitrogen accumulation in soil, which increases the risk of leaching, white mustard was sown as a postcrop. On the background without straw, on breaking stubble and applying mineral nitrogen fertiliser for the start growth of mustard, the content of mineral nitrogen was the highest; its content increased by 4.3% and 10.8%, respectively, as compared with the check and stubble-broken treatments. In an analogous treatment, but with straw incorporated into the topsoil with a stubble breaker, nitrogen fixation increased and there was less mineral nitrogen in the soil.

On both backgrounds, undersown legumes significantly increased revivification of mineral nitrogen in the soil profile. Literature sources indicate that in autumn catch crops can reduce mineral nitrogen content in the soil by 20–25 kg ha^{-1} (Farthofer et al., 2004). Undersown grasses grown as catch crops have a well-developed root system, as a result, after cereal harvesting they better utilise nitrogen remaining in the soil compared with white mustard as a postcrop; moreover, they do not need mineral nitrogen fertilisers. After incorporation of catch crop biomass there was less mineral nitrogen on the background without straw where red clover was grown, and with straw – a white clover and ryegrass mixture which was by 14.3% and 16.7% less as compared with the check treatment. The effect of white mustard as a post crop on mineral nitrogen content in soil depended on the white mustard sowing method. White mustard undersown at cereal milk maturity (and on incorporating the starting dose of mineral nitrogen fertiliser) was at intensive nutrient utilisation stage, therefore it better utilised both soil and mineral fertiliser nitrogen and reduced N_{min} in the soil by 6.4% as compared with the check treatment. However, mineral nitrogen tended to increase on sowing mustard into stubble after harvesting, especially in the soil where straw had been spread.

In spring, after incorporation of catch crop biomass and straw, the content of nitrogen in heavy-textured soil in the 0–40 cm layer was found to be almost the same as in autumn – 6.79 mg kg^{-1} soil or 27.2 kg ha^{-1} (Table 4). Data of trials conducted in Austria indicate that after catch crop incorporation in spring the content of mineral nitrogen markedly increased (in the 0–30 cm layer by 60 kg ha^{-1} and in the 0–120 cm layer by 120 kg ha^{-1}) (Farthofer et al., 2004). At the beginning of the plant growth season, mineral nitrogen varied in a slightly different way than in autumn. The greatest increase in $N_{min.}$ content in the soil occurred after incorporation of red clover and white clover and ryegrass mixture, because in autumn, winter and early spring, during the breakdown of incorporated biomass of legumes, a higher content of nitrogen is released than after incorporation of non-legume catch crops. After red clover and white clover with ryegrass mixture, $N_{min.}$ increased by 18.3% and 16.6%, straw incorporation reduced its content by 3.2% and 5.0% as compared with analogous data in autumn. On incorporating a non-legume crop (white mustard) the content of mineral nitrogen declined on both backgrounds (except for the treatment where mustard had been sown into broken stubble), which is indicated by other authors (Reents et al., 2000). The greatest reduction in mineral nitrogen content occurred on incorporating straw into broken and unbroken stubble (8.7% and 10.0%, respectively), compared with the respective data obtained in autumn. A reduction of 16.3% in mineral nitrogen was also recorded on sowing mustard into stubble-broken soil with straw, compared with respective data in autumn.

In spring, ammonia nitrogen accounted for a larger share (59.6%) than nitrate nitrogen (40.4%) in total mineral nitrogen. After straw incorporation, a significant reduction in ammonia and nitrate nitrogen contents occurred versus treatments where straw was removed. Here the content of mineral nitrogen was by 7.2% lower than in the check treatment. Autumn stubble breaking with and without straw tended to reduce mineral nitrogen content in the soil by 8.6% and 8.9%, respectively, as compared with the check treatment, or by 1.6% and 1.9%, respectively, 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 autumn on incorporating white mustard sown into broken stubble. A non-legume catch crop, white mustard, significantly reduced mineral nitrogen content in the soil, whereas legumes tended to increase mineral nitrogen.

Mineral nitrogen content in the soil profile in spring had some effect on nitrogen concentration in soil filtration water (Table 5).

On both straw utilisation backgrounds, nitrate nitrogen content was significantly increased by the biomass of legume crops incorporated in autumn. As the literature sources indicate, nitrate nitrogen depends on the nitrogen content accumulated in catch crop biomass, and according to nitrogen content in soil solution the plants can be ranked in the following order: legumes > legume–non-legume mixture > non-legumes (Rinnofner et al., 2005). The use of straw for fertilisation reduced (19.0%) nitrate nitrogen content in filtration soil solution. On incorporating straw after legume crops, the content of mineral nitrogen in filtration water declined by 21.0%, white mustard by 26.0% as compared with analogous treatments without straw. This nitrate nitrogen concentration in soil filtration water is not high. Data of long-term experiments conducted in Lithuania showed that the average nitrate nitrogen concentration in lysimetric water of different soils ranged from 49.2 to 83.7 mg l^{-1} (Tyla, 1995).

Table 3. **Mineral nitrogen content (mg kg^{-1} soil) in soil (0–40 cm) before incorporation of catch crops biomass**

Treatments (B)	Without straw			Spray of chopped straw		
	NO_3	NH_4	$N_{min.}$	NO_3	NH_4	$N_{min.}$
Stubble not broken	3.34	3.66	7.00	3.17	4.41	7.58
Stulbe broken by combined breakers	3.02	3.57	6.59	3.63	3.95	7.57
Catch crops – red clover	2.75	3.25	6.00	2.99	3.49	6.47
Catch crops – white clover + Italian reygrass	2.94	3.39	6.33	2.73	3.10	5.83
White mustard broadcast-sown	3.27	3.27	6.54	2.80	3.75	6.55
White mustard direct-sown into stubble	3.12	3.90	7.02	3.33	3.91	7.23
White mustard undersown into stubble broken soil	3.26	4.05	7.30	3.14	3.71	6.85
Average	3.10	3.58	6.68	3.11	3.76	6.87
LSD_{05} fact. A	0.178	0.271	0.303			
LSD_{05} fact. B	0.333	0.507	0.566			
LSD_{05} fact. AB	0.471	0.718	0.801			

Table 4. **Effect of various catch crops and their biomass and straw on mineral nitrogen accumulation in soil (mg kg^{-1}) in spring (0–40 cm)**

Treatments (B)	Without straw			Spray of chopped straw		
	NO_3	NH_4	$N_{min.}$	NO_3	NH_4	$N_{min.}$
Stubble not broken	3.08	4.36	7.45	2.89	4.03	6.92
Stulbe broken by combined breakers	2.99	3.80	6.79	2.66	4.15	6.81
Catch crops – red clover	3.01	4.08	7.10	2.69	3.98	6.68
Catch crops – white clover + Italian reygrass	2.91	4.47	7.38	2.44	3.67	6.12
White mustard broadcast-sown	2.50	3.69	6.19	2.55	3.91	6.45
White mustard direct-sown into stubble	2.67	4.04	6.71	2.60	3.44	6.05
White mustard undersown into stubble broken soil	2.82	4.82	7.65	2.57	4.08	6.66
Average	2.85	4.18	7.04	2.63	3.89	6.53
LSD_{05} fact. A	0.181	0.185	0.225			
LSD_{05} fact. B	0.339	0.347	0.421			
LSD_{05} fact. AB	0.479	0.490	0.595			

Table 5. **Nitrogen leaching (mg l^{-1}) from the soil under various catch crops (0–80 cm)**

Treatments (B)	Without straw			Spray of chopped straw		
	NO_3	NH_4	$N_{min.}$	NO_3	NH_4	$N_{min.}$
Stubble not broken	6.11	0.013	6.12	7.80	0.88	8.68
Undersown legume catch crops	15.5	0.84	16.34	12.0	0.91	12.91
Aftercrop catch crops – white mustard	13.0	0.01	13.01	8.16	1.47	9.63
Average	11.5	0.29	11.83	9.32	1.09	10.41
$NO_3 LSD_{05}$ fact. A-2.649; fact. B-3.245; fact. AB-4.589						
$N_{min}.LSD_{05}$ fact. A-2.326; fact. B-2.849; fact. AB-4.029						

CONCLUSIONS

1. Different catch crops, incorporated biomass alone or in combination with straw, greatly influenced soil physical state. Catch crops, especially those undersown with crops with a longer growing season and high biomass yield, tended to reduce soil moisture as compared with the check treatment. Breakage of capillaries during soil loosening in the autumn retained a higher moisture content in the deeper soil layer, and more significantly in the treatment with straw incorporation (4.1%), compared with the check treatment. In the year of effect when barley was grown, better soil moisture conditions formed in the treatments where the biomass of catch crops was incorporated in combination with straw.

2. Straw, especially in combination with incorporated biomass of white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) mixture or white mustard (*Sinapis alba* L.) sown into broken stubble tended to reduce soil bulk density.

3. Catch crops with legume crops are an important preventive agromeans against nitrogen accumulation in the soil, and consequently, against its leaching into groundwater. Undersown legume crops during the post-harvest period gave the largest reduction in mineral nitrogen in the soil: red clover (*Trifolium pratense* L.) by 10.9%, white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) mixture by 13.1% as compared with the treatment without catch crops. However, when growing *Brassicaceae* plants, white mustard (*Sinapis alba* L.), and applying low doses of mineral nitrogen fertiliser for its start growing, $N_{min.}$ concentration in the soil was higher than in the check treatment.

4. Straw spread on soil surface as mulch but not incorporated into the soil did not reduce $N_{min.}$ content in the soil during the post-harvest period. On incorporating straw with addition of mineral nitrogen fertiliser, $N_{min.}$ content in the soil was 9.5% lower in the treatment where the catch crop white mustard (*Sinapis alba* L.) was sown as the post-crop.

5. Low contents of $N_{min.}$ are found in heavy-textured cambisols in spring, and higher contents of $N_{min.}$ in the soil and filtration water were found in the treatments where nitrogen-rich biomass of legume crops was incorporated in autumn; on incorporating it together with straw, $N_{min.}$ content in the soil significantly declined (5.9–17.1%).

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TAUSOJANTI ŽEMDIRBYSTĖS SISTEMA DIRVOSAUGOS PROBLEMOMS SPRĘSTI

S a n t r a u k a

Kompleksiniai tyrimai, siekiant išaiškinti biologinių priemonių – įvairių tarpinių pasėlių su skirtingais būdais įterptais šiaudais įtaką dirvožemio fizinės degradacijos bei azoto išsiplovimo mažinimui, atlikti 2000–2005 m. Lietuvos žemdirbystės instituto Joniškėlio bandymų stotyje giliau karbonatingame giliau glėjiškame rudžemyje. Įterptų šiaudų ir tarpinių pasėlių augalų, ypač baltųjų dobilų (*Trifolium repens* L.) ir gausiažiedžių svidrių (*Lolium multiflorum* Lamk.) mišinio, biomasė gerino dirvožemio fizinę būklę – mažino dirvožemio tankį. Tarpiniuose pasėliuose auginant į pagrindinius pasėlius įsėtus įsėlinius augalus, mažėjo dirvožemio drėgmė, tuo tarpu dėl paviršiaus supurenimo skutant ražienas jos daugėjo. Įterpus šiaudus, drėgmės buvo esminiai (4,1%) daugiau, palyginus su kontroliniu variantu. Po tarpinių pasėlių ir šiaudų įterpimo, poveikio metais auginant miežius, geresnės dirvožemio drėgmės sąlygos susiformavo ten, kur įterpta tarpinių pasėlių augalų biomasė su šiaudais.

Pagrindinių pasėlių popjūtiniame periode, rudenį esant stipriausiam išplaunamajam kompleksui, tarpiniuose pasėliuose įsėliniai raudonieji dobilai (*Trifolium pratense* L.) bei baltųjų dobilų ir gausiažiedžių svidrių mišinys $N_{min.}$ kiekį dirvožemyje ir išsiplovimo pavojų sumažino atitinkamai 10,9 ir 13,1%, palyginus su variantu be tarpinių pasėlių. Sekliai įterptų šiaudų ir greitesnei jų mineralizacijai įterptų mineralinių azoto trąšų N45 fone $N_{min.}$ kiekį dirvožemyje 9,5% sumažino tarpiniuose pasėliuose augintos baltosios garstyčios (*Sinapis alba* L.). Poveikio metais pavasarį, po rudenį įterptos tarpiniuose pasėliuose augintų ankštinių augalų azotingos biomasės, $N_{min.}$ kiekį dirvožemyje ir filtraciniuose vandenyse gerokai sumažino kartu su ja įterpti šiaudai.

Raktažodžiai: sunkus priemolis, fizinė dirvožemio degradacija, azoto imobilizavimas, tarpiniai pasėliai, azoto išsiplovimas