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Effect of sowing methods on the productivity of catch crops and soil nitrogen leaching

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Abstract. The field experiment was carried out at the Lithuanian Institute of Agriculture's Joniskelis Experimental Station in clay loam *Cambisol* from 2003–2005 to identify the most effective sowing method of catch crops: red clover(*Trifolium pratense* L.), mixture of white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.), and white mustard (*Sinapis alba* L.) in combination with different straw incorporation methods during the post–harvest period, to control mineral nitrogen content and nitrate leaching. 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 aboveground mass of aftercrop white mustard was formed in the plots of the treatments in which the seed was sown into stubble–broken soil or direct-sown into the stubble (2.43 and 2.53 t ha^{-1} of dry matter, respectively). Undersown legume crops during the post–harvest period produced the largest reduction in mineral nitrogen in the soil: red clover – 14.4%, white clover and Italian ryegrass mixture – 16.6%, compared with the treatment without catch crops. After incorporating cereal stubble shallowly at 10–12 cm by stubble-breaker, the contents of mineral nitrogen declined 5.9%, compared with that in the treatment with unbroken stubble. However, after incorporating by a stubble- breaker not only stubble but also straw, and having applied nitrogen fertilizer (N_{45}) for its mineralization, the content of mineral nitrogen increased by 14.9%, compared with the treatment where the plots were stubble–broken without straw. While incorporating straw with the addition of mineral nitrogen fertilizer, 9.5% lower $N_{min.}$ content in the soil was found in the treatment where catch crop white mustard was sown as the post–crop. In spring, higher contents of $N_{min.}$ in the soil and filtration water were found in the treatments in which nitrogen–rich biomass of legume crops had been incorporated in the autumn. With simultaneous incorporation of straw, nitrate nitrogen content in the soil filtration water declined (9.8%).

Key words: catch crops, sowing methods, $N_{min.}$ accumulation, nitrogen leaching

INTRODUCTION

The European Union's agricultural development strategy envisages increasing cereal productivity in Lithuania up to 5.5 t ha^{-1} by the year 2015 by abandoning crop production on unproductive soils and by intensifying it on fertile soils. Due to environmental regulations the amount of mineral fertilizers will be limited, therefore more attention will have to be paid to the maintenance of soil productivity by exploiting the post–harvest period for the accumulation of assimilants in catch crops (Rinnofner et al., 2005; Tripolskaja, 2005; Loges et al., 2006; Thorup–Kristensen, 2006). In Lithuania the post–harvest period is not long but is longest after winter wheat. Since in the tall–growing crops of winter wheat undersown crops do not perform adequately, it is advisable to sow aftercrops on clay soils. However, because of their hard surface (Arlauskiene & Maiksteniene, 2005), clay soils often present a problem for seed placement during the post–harvest period. Some authors suggest stubble-breaking or other loosening of the soil surface before aftercrop sowing; others look for more sophisticated sowing machines whose coulters could penetrate deeper into the soil surface and create better conditions for seed placement (Dryslova & Prochazkova, 2002; Dorsainvil et al., 2005). Experiments seeking to identify the most effective sowing method for undersown crops and aftercrops grown as catch crops during the post–harvest period were carried out at the Lithuanian Institute of Agriculture's Joniskelis Experimental Station.

MATERIALS AND METHODS

Two analogous trials were carried out at the Lithuanian Institute of Agriculture's Joniskelis Experimental Station in 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. 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.

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

The effect of cover crops and straw was monitored by growing spring barley (*Hordeum vulgare* L.). The experiment was conducted in the following rotation sequence: winter wheat + cover crop; spring barley. Winter wheat 'Ada' and spring barley 'Ula' were grown following conventional technology and fertilized by N_{60}, P_{60}, K_{60}. Various sowing methods of catch crops were studied: undersowing – by undersowing perennial grasses into winter wheat in spring; undersowing–broadcast – by spreading the seed of white mustard at winter wheat wax maturity; aftercrops – after harvesting direct drilling into stubble and into the surface loosened by combined breakers. In order to adequately place the seed of catch crops into clay loam soil, the wedge-type coulters of the *Amazone D7* sowing machine were fitted with special additions to make a deeper furrow, resulting in better seed placement.

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 leveling the soil surface. 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. The seed rate when sowing white mustard by the sowing machine *Amazone D7* was 18 kg ha^{-1}; broadcast sowing broadcast increased the rate 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}. Soil samples for $N_{min.}$. determination were taken before incorporation of catch crops and straw into the soil and, in spring, before barley sowing from the soil profile layer 0–40 cm. Mineral nitrogen ($NO_3 + NH_4$) was measured by distillation and the colorimetry method (in 1 N KCl extraction). To measure nutrient leaching, well–piezometers were set up after cereal harvesting in each background in two replications to collect filtration water. In water samples $N–NO_3$ content were determined by cadmium reduction methods.

The rate of rainfall during August–September 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 September–November 2004, after the incorporation of straw and plant biomass, the rate of precipitation was by 43,0% higher than the long–term mean. Winter 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. The experimental data were processed by ANOVA and STAT ENG.

RESULTS AND DISCUSSION

In the agrocenoses on the soils satiated with soil–depleting cereals, catch crops during the post–harvest period additionally accumulate organic matter and biogenic elements, utilise the growing season more effectively and protect the soil from degradation. The cereal crop thinned out by 21.6–23.2% (Table 1) when perennial legumes, red clover or white clover and Italian ryegrass mixture had been sown with special additions to the wedge–type coulters of the sowing machine after resumption of winter wheat vegetative growth, when the soil was sufficiently dry. Although the cereals tended to increase the number of productive tillers (4.8%), the winter wheat yield after undersown crops was significantly lower.

At winter wheat productive density of 432–524 plants m^{-2} the number of undersown plants was on average 149 plants m^{-2}. While assessing sowing methods of white mustard as a catch crop it was found that significantly fewer plants emerged when white mustard had been broadcast-sown compared with the treatments in which the seed was buried.

The best seed emergence was noted for the treatment in which the seed had been sown by wedge–type coulters with special additions into stubble–broken soil: the number of seedlings was 3.4 times higher compared with broadcast sowing and 10.4% higher compared with direct–drilling. 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 aboveground mass of white mustard aftercrop, amounted to on average 2.22 t ha^{-1} and was by 12.9% lower than that of red clover.

Table 1. The effect of the sowing methods on the emergence of catch crops and productivity of agrocenose, means of 2003–2004.

Catch crops and their sown methods (B)	Winter wheat		Catch crop		Productivity of agrocenose DM t ha^{-1}
	plants m^{-2}	grain yield t ha^{-1}	plants m^{-2}	biomass DM t ha^{-1}	
Without catch crop, stubble not broken	310	7.3	-	-	11.9
Without catch crop, stubble broken	285	7.1	-	-	11.7
Undersown catch crop – red clover	243	6.8	110	2.55	13.9
Undersown catch crop – mixture of white clover and Italian ryegrass	238	6.7	188	2.27	13.8
Undersown catch crop – white mustard broadcast–sown into winter wheat at wax maturity stage	315	7.0	44	1.70	13.2
Aftercrop catch crop – white mustard direct–sown into stubble	310	7.2	134	2.53	14.0
Aftercrop catch crop – white mustard direct–sown into stubble–broken soil	302	7.2	148	2.43	14.1
$LSD_{05\,(B)}$	30.2	0.29	42.2	0.23	0.68

The largest amount of white mustard aboveground mass was formed in the plots of the treatments in which the seed was sown into stubble–broken soil or direct-sown into the stubble 2.43 and 2.53 t ha^{-1} of dry matter, respectively. When growing catch crops in cereal crop rotations the productivity of agrocenose increased an average of 15.7%, compared with the control treatment.

Previous research conducted on a heavy–textured *Cambisol* in a cereal crop rotation suggests that higher contents of mineral nitrogen in the soil during the post–harvest period are found after spring rather than after winter cereals (Arlauskiene & Maiksteniene, 2005). Cultivation of catch crops as undersowings or postcrops and their incorporation into the soil as green manure makes it possible to include mineral nitrogen into the biological nutrient turnover cycle by retaining it in the plough layer (Table 2). Measurements 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 through all experimental treatments was on average 6.78 mg kg^{-1}, and in a 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. $N_{min.}$ tended to increase (on average 2.8%) by spreading mineral nitrogen fertilizer on the background of straw. Higher mineral nitrogen content on the background of straw was determined by ammonia nitrogen. Straw spread *on*, but not incorporated *into* the soil partly protected the soil from large temperature variations and conserved productive moisture reserves thus creating a favourable climate for catch crops' emergence and development.

Having incorporated cereal roots and stubble shallowly at 10–12 cm by stubble breaker, the contents of mineral nitrogen declined, which determined a reduction in mineral nitrogen content of 5.9%, 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 14.9%, compared with the treatment in which the plots were stubble–broken without straw.

Table 2. Effect of catch crops sowing and straw using methods on the soil mineral nitrogen content (mg kg^{-1} soil) in autumn before incorporating biomass of catch crop, means of 2003–2004.

Catch crops and their sown methods (B)	Straw using methods (A): straw removed from the field		straw chopped and incorporated		means for factor B	
	$N_{min.}$ mg kg^{-1}	relative number %	$N_{min.}$ mg kg^{-1}	relative number %	$N_{min.}$ mg kg^{-1}	relative number %
Without catch crop, stubble not broken	7.00	100	7.58	108.3	7.29	100
Without catch crop, stubble broken	6.59	94.1	7.57	108.1	7.08	97.1
Undersown catch crop – red clover	6.00	85.7	6.47	92.4	6.24	85.6
Undersown catch crop – mixture of white clover and Italian ryegrass	6.33	90.4	5.83	83.3	6.08	83.4
Undersown catch crop – white mustard broadcast–sown into winter wheat at wax maturity stage	6.54	93.4	6.55	93.6	6.55	89.8
Aftercrop catch crop – white mustard direct–sown into stubble	7.02	100.3	7.23	103.3	7.13	97.8
Aftercrop catch crop – white mustard direct–sown into stubble–broken soil	7.30	104.3	6.85	97.9	7.08	97.1
Means for factor A	6.68	100	6.87	102.8	6.78	

$LSD_{05\ (A)} = 0.303$; $LSD_{05\ (B)} = 0.566$; $LSD_{05\ (AB)} = 0.801$

White mustard was sown as an aftercrop to reduce nitrogen accumulation in the soil, which increases the risk of leaching. On the background without straw, having broken stubble and having applied mineral nitrogen fertilizer for the start growth of mustard, the content of mineral nitrogen was the highest: its content increased by 4.3 and 10.8%, respectively, compared with the check and stubble–broken treatments. In the analogous treatment, only incorporating 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. White mustard undersown at cereal wax maturity (including the starting dose of mineral nitrogen fertilizer), was at intensive nutrient utilization stage (Thorup–Kristensen, 2006), therefore more effectively utilized both soil and mineral fertilizer nitrogen and reduced $N_{min.}$ in the soil by 6.4%, compared with the check treatment. However, mineral nitrogen tended to increase when mustard was sown into the stubble after harvesting, especially in the soil where straw had been spread.

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 more effectively utilized nitrogen remaining in the soil compared with white mustard as aftercrop, moreover they do not need mineral nitrogen fertilizers.

Table 3. Effect of catch crops and straw using methods on the nitrate nitrogen ($N–NO_3$) leaching from the soil in winter-spring period, means of 2004–2005.

Catch crops and their sown methods (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 catch crop	6.11	100	7.80	127.7	6.96	100
Undersown catch crop – red clover	15.50	253.7	12.0	196.4	13.75	197.6
Aftercrop catch crop – white mustard	13.1	214.4	8.16	133.6	10.63	152.7
Means for factor A	11.57		9.32		10.44	
$LSD_{05\ (A)} = 3.14$; $LSD_{05\ (B)} = 4.44$; $LSD_{05\ (AB)} = 6.28$						

After incorporation of the catch crops biomass there was less mineral nitrogen on the background without straw where red clover was grown, with straw – white clover and Italian ryegrass mixture, which made up 14.3 and 16.7% less, compared with the check treatment.

Mineral nitrogen content in the soil profile in spring had some effect on nitrogen concentration in soil filtration water (Table 3). On both straw utilization backgrounds the nitrate nitrogen content in 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 catch crops biomass, and according to 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).

The use of straw for fertilization reduced (on average 9.8%) nitrate nitrogen content in the filtration soil solution. With incorporation of 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 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 incorporation of catch 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 – 6.79 mg kg^{-1} soil or 34.0 kg ha^{-1} (Table 4). The data of the trials conducted in Austria indicate that after catch 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 incorporation of the biomass of red clover and white clover and ryegrass mixture. This is due to the fact that in autumn, winter and early spring, during the breakdown of the incorporated biomass of legumes, higher content of nitrogen is released compared with that after incorporation of non–legume catch crops.

Table 4. Effect of catch crops sowing and straw-using methods on the soil (0–40 cm) mineral nitrogen content (mg kg^{-1} soil) in spring, means of 2004–2005.

Catch crops and their sown methods (B)	Straw using methods (A)					
	straw removed from the field		straw chopped and incorporated		means for factor B	
	$N_{min.}$ mg kg^{-1}	relative number %	$N_{min.}$ mg kg^{-1}	relative number %	$N_{min.}$ mg kg^{-1}	relative number %
Without catch crop, stubble not broken	7.45	100	6.92	92.9	7.19	100
Without catch crop, stubble broken	6.79	91.1	6.81	91.4	6.80	94.6
Undersown catch crop – red clover	7.10	95.3	6.68	89.7	6.89	95.8
Undersown catch crop – mixture of white clover and Italian ryegrass	7.38	99.1	6.12	82.1	6.75	93.9
Undersown catch crop – white mustard broadcast–sown into winter wheat at wax maturity stage	6.19	83.1	6.45	86.6	6.32	87.9
Aftercrop catch crop – white mustard direct–sown into stubble	6.71	90.1	6.05	81.2	6.38	88.7
Aftercrop catch crop – white mustard direct–sown into stubble–broken soil	7.65	102.7	6.66	89.4	7.15	99.4
Means for factor A	7.04	100	6.53	92.8	6.78	

$LSD_{05\ (A)} = 0.225$; $LSD_{05\ (B)} = 0.421$; $LSD_{05\ (AB)} = 0.595$

After the 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%, compared with analogous data in autumn. After incorporation of the 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); this concurs with studies by other authors (Reents et al., 2000).

The greatest reduction in mineral nitrogen content occurred having incorporated straw into broken and unbroken stubble (8.7 and 10.0%, respectively), compared with the respective data obtained in the autumn. A reduction of 16.3% 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 a larger share (59.6%) than nitrate nitrogen (40.4%) of total mineral nitrogen. After straw incorporation a significant reduction in mineral nitrogen contents occurred compared with the treatments in which straw was removed. Here the content of mineral nitrogen was by 7.2% lower, compared with 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, compared with the check treatment, or by 1.6 and 1.9%, respectively compared with the treatment in which straw was spread in the autumn. The highest content of mineral nitrogen was found on the background without straw, e.g., in the autumn, when white mustard was sown into broken stubble. The non–legume catch crop white mustard significantly reduced mineral nitrogen content in the soil, whereas legumes tended to increase mineral nitrogen.

CONCLUSIONS

The largest amount of aboveground mass 2.55 t ha^{-1} of dry matter was produced by undersown red clover (*Trifolium pratense* L.) with a longer growing season. The largest aboveground mass of the post-sown–crop white mustard (*Sinapis alba* L.) was formed in the plots of the treatments in which the seed was direct–sown into stubble–broken soil or into the stubble (2.43 and 2.53 t ha^{-1} of dry matter, respectively). Undersown legume crops during the post–harvest period produced the largest reduction in mineral nitrogen in the soil: red clover – 14.4%, white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) mixture – 16.6%, compared with the treatment without catch crops. With incorporation of cereal stubble shallowly at 10–12 cm by stubble breaker, the contents of mineral nitrogen declined by 5.9%, 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 fertilizer (N45) for its mineralization, the content of mineral nitrogen increased by 14.9%, compared with the treatment in which the plots were stubble–broken without straw. While incorporating straw with the addition of mineral nitrogen fertilizer, 9.5% lower $N_{min.}$ content in the soil was found in the treatment in which the catch crop white mustard was sown as post–crop. In spring, higher contents of $N_{min.}$ in the soil and filtration water were found in the treatments in which the nitrogen–rich biomass of legume crops had been incorporated in the autumn. Having incorporated it together with straw, nitrate nitrogen content in the soil filtration water declined (9.8%).

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