POSSIBILITIES OF USING COVER CROPS IN CLAY LOAM SOILS OF NORTHERN LITHUANIA

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Abstract. *A range of experiments were conducted at Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry in 2010-2014 with the view of establishing the possibilities of cover crop cultivation and utilization in clay loam Cambisol. The influence of the main and cover crop combinations, straw and fertilization intensity; organic, sustainable and intensive cropping systems with cover crops in the soils of different humus content and reduced tillage combinations with cover crops on plant productivity was investigated. It was established that the most abundant yield was achieved when growing field pea after white mustard which can reduce the amount of free nitrogen in soil and stimulate the fixation of biological field pea nitrogen. The maximum yield of spring oilseed rape was obtained while fertilizing with mineral NPK fertilizer. The straw used as fertilizer reduced plant productivity, the cover crop cultivation mitigated its negative effect inducing straw degradation and nitrogen fixation in organic compounds. The incorporation of cover crop mass in combination with farmyard manure in the sustainable cropping system determined a significant increase in field pea yield compared with the organic system. The yields of winter wheat and field pea were higher in the intensive cropping system compared with the organic one. The yields of winter wheat and field pea in the soil of moderate humus content were higher compared with that in the soil of low humus content. Leaving of cover crops as mulch over winter without any tillage in autumn resulted in the decrease of field pea yield compared with ploughless tillage alone. Spring oilseed rape was less sensitive to the reduction of tillage in the combinations with cover crops compared with field pea.*

Key words: *cover crops, crop yield, cropping systems, fertilization intensity, tillage.*

INTRODUCTION

The abundance of clay particles in the clay loam soils of limnoglacial origin determines greater sorptive capacity and higher stability of nutritive elements and the productivity of crop rotation plants compared with light soils [1]. However, the global climate change and the effects of intensive agriculture on the environment invite to become worried about soil matching economic benefit with the management and conservation of natural resources [2]. One of the remedies is cover crop cultivation. In Lithuania soil is covered with the main crops only for 60-70% of the warm period. During the rest of the time the soil uncovered with plants is damaged by different environmental factors: dried by the sun and wind, the structure is damaged by heavy rainfall. Due to the above reasons microbiological processes in soil are suppressed, nutrients migrate downwards and weeds, especially perennial ones, prevail [3]. Cover crop cultivation improves nutrient management [4] and reduces the losses of nitrogen and other elements into the environment [5], it allows the reduction of mineral fertilizer rates [6] and improves the phytosanitary condition of crops [7]. These plants can loosen biologically a densified, mechanically unloosened soil layer by strong roots and thus improve soil structure [8]. However, the influence of cover crops on the productivity of crop rotation plants is not homologous. It depends on various factors. The mass of cover crop plants, the amount of nutrients (especially that of nitrogen) accumulated in it, the depth, ways and time of its incorporation into soil, soil and climate conditions determine the intensity of plant mass decomposition, release of chemical elements and other various biochemical processes in soil [9]. Additional yield can be expected only when the release of nutrients from the incorporated plant mass agree with the needs of plants grown with the main crops under the minimal activity of other biochemical processes taking place in soil.

The objective of this research was to establish the influence of the combinations of different types of plants grown as the main and cover crops, fertilization intensity and tillage methods on plant productivity.

MATERIALS AND METHODS

Experimental site and soil

Field experiments were conducted at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry (LRCAF) in 2010-2014. The station is situated in the northern part of Central Lithuania's lowland (40-60 m above the sea level; latitude: 56°12" N; longitude: 24° 20"). Northern Lithuania has a climate mid-way between maritime and continental. The climate is changeable, with mild, wet summers and cold winters. Annual precipitation is 500-600 mm. The soil of the experimental site is *Endocalcaric Endogleyic Cambisol* (*Siltic*, *Drainic*). The soil according texture is clay loam on silty clay with deeper lying sandy loam. The parent material is glacial lacustrine clay, which at 70-80 cm depth transits into morainic loam. Clay (< 0.002 mm) in the Ap horizon (0-30 cm) account for 27.0%, in the B_w horizon (31-51 cm) 59.6%, in the B_k horizon (52-76 cm) 51.6%, in the C_1 horizon (77-105 cm) 10.7%, in the C2 horizon (106-135 cm) 11.0%. Soil bulk density in the plough layer (0-25 cm) is 1.3-1.4 Mg m^{-3}, total porosity is 40-45%, and air-filled porosity is 8-10%. At the beginning of the experiments, soil agrochemical properties at the 0-20 cm layer varied: pH –6.1-7.1, available phosphorus (P_2O_5) – 115-182 mg kg^{-1}, available potassium (K_2O) – 172-268 mg kg^{-1} (content of P_2O_5 and K_2O was determined by Egner-Riehm-Domingo (A-L) method), humus 1.90-2.91%.

Influence of cover crops, straw and fertilizing intensity on plant productivity

Seeking to ascertain the effects of various main and cover crop combinations, straw and fertilization intensity on main crops productivity was done in a three-factor experiment set up in 2013, and the effects of measures used was monitored for successive year 2014. *Experimental design:* factor A – main and cover crop combinations: 1) spring barley (*Hordeum vulgare* L.) without cover crop – spring oilseed rape (*Brassica napus* L. (Partim)); 2) spring barley with undersown red clover (*Trifolium pratense* L.) – spring oilseed rape; 3) spring barley without cover crop – field pea (*Pisum sativum* L. (Partim)) ; 4) spring barley with post sown white mustard (*Sinapis alba* L.) – field pea ; factor B – straw use: 1) removed, 2) spread (+N_{40}); factor C – fertilization intensity: 1) unfertilised, 2) sustainable fertilizing, 3) intensive fertilizing. Red clover cv.'Vyliai' (seed rate 15 kg ha^{-1}) was undersown into spring barley in spring. After cereal harvesting straw was removed or chopped and spread. White mustard cv. 'Signal' (seed rate 18 kg ha^{-1}) was sown on the day of spring barley harvesting. For optimal growth of white mustard (when straw was removed or chopped and spread) and for straw mineralization, ammonium nitrate (40 kg ha^{-1} N) was applied. Late in autumn, due to better incorporation of cover crops, their biomass was chopped by disk stubble breaker and ploughed in at the 25 cm depth. The effect of cover crops mass were investigated in the following year for field pea cv. 'Tinker' (seed rate 380 kg ha^{-1}) and spring oilseed rape 'Kaldera' (seed rate 6 kg ha^{-1}). Fertilization rates were calculated according to agrochemical soil properties and the planned crop yield. The experimental plots were laid out in a complete three-factor randomised block design in four replicates.

Influence of cropping systems on plant productivity in soils of different humus content

Organic, sustainable and intensive cropping systems on a soil with different humus content, their effects on the sustainability of major crop productivity in the crop rotation – spring barley + undercrop → perennial grass (red clover) → winter wheat (*Triticum aestivum* L.) → field pea were investigated. *Experimental design:* soil humus content – factor A: low (1.90-2.01%); moderate (2.10-2.40%). Cropping systems – factor B: Organic*:* red clover cv. 'Vyliai' (15 kg seed ha^{-1}) mass as green manure was applied for winter wheat cv. 'Ada' (240 kg seed ha^{-1}), winter wheat straw was applied as manure and the cover crop – blue lupine (*Lupinus angustifolius* L.) cv. 'Boruta' (120 kg seed ha^{-1}) in a mixture with oilseed radish (*Raphanus sativus* var. *Oleiferus* Metzg.) cv. 'Rufus' (20 kg seed ha^{-1}) was cultivated as green manure for field pea cv. 'Pinochio' (380 kg seed ha^{-1}). Sustainable: farmyard manure (40 Mg ha^{-1}) was applied for winter wheat, winter wheat straw was applied as manure + mineral N fertilizer (N_{30}) in the form of ammonium nitrate for straw decomposition in autumn and white mustard cv. 'Sinus' (20 kg seed ha^{-1}) in a mixture with buckwheat (*Fagopyrum esculentum* Moench.) cv. 'Smuglianka' (80 kg seed ha^{-1}) was cultivated as green manure for field pea. Intensyve: red clover biomass as green manure + mineral fertilizer $N_{30}P_{60}K_{60}$ was applied for winter wheat, winter wheat straw as manure + mineral N fertilizer (N_{30}) for straw decomposition in autumn and mineral fertilizer $N_{10}P_{40}K_{60}$ in spring was applied for field pea. The experimental plots were laid out in a complete two-factor randomised block design in four replicates.

Effect of cover crop management under reduced tillage conditions

The experiment examined the effects of reduced tillage ant its combinations with cover crop management on main crop productivity. *Experimental design:* 1) ploughless tillage at 10-12 cm depth; 2) ploughless tillage at 10-12 cm depth with cover crop incorporation for green manure; 3) cover crop for winter mulch without tillage in autumn. Main crop rotation: field pea → winter wheat → spring oilseed rape → spring barley. The pre-crop (spring barley for field pea and winter wheat for spring oilseed rape) straw was chopped during harvesting and incorporated into the soil at 8–10 cm depth during stubble cultivation. Post-harvest cover crops were the mixture of white mustard cv. 'Braco' (10 kg seed ha^{-1}) and oilseed radish cv. 'Rufus' (13 kg seed ha^{-1}) for field pea after spring barley and the mixture of field pea cv. 'Klif' (90 kg seed ha^{-1}), common vetch (*Vicia sativa* L.) cv. 'Aisiai' (50 kg seed ha^{-1}) and blue lupine cv. 'Boruta' (60 kg seed ha^{-1}) for spring oilseed rape after winter wheat. Cover crops were sown after stubble cultivation. Cover crop fertilization – N_{30}. Cover crop for green manure was incorporated into soil by a combined stuble cultivator in autumn. Cover crop for winter mulch was left during winter without any tillage in autumn and its frost killed residues covered the soil surface. Field pea (360 kg seed ha^{-1}) cv. 'Tinker' and spring oilseed rape (7 kg seed ha^{-1}) cv. 'Fenjac' were grown as a main crops. Main crop fertilization: field pea – $N_{30}P_{90}K_{60}$, spring oilseed rape – $N_{120}P_{90}K_{60}$. The trial was arranged as a randomized single row design in four replicates.

Experimental parameters

A randomised plot design was used with the main plot size of 100 m^2 (20.0 m long and 5.0 m wide) and harvested plot size of 32.2 m^2 (14.0 m long and 2.3 m wide).

Plant analyses

The investigated crops plots were harvested using a small plot combine harvester. Grain yield was harvested when the majority of crops had reached hard dough stage (BBCH 87). Plant productivity was established by weighing. Dry matter (DM) content in the organic matter was determined by drying the sample at 105 °C to a constant weight. The grain yield (Mg ha^{-1}) is presented: field pea and winter wheat at 14.0%; spring oilseed rape at 9.0% standard moisture (w/w).

Statistical analyses

The research data were processed by analysis of variance using the program package Selekcija [10]. Sigificant differences are indicated by *$P < 0.05$ and ** $P < 0.01$.

Table 1

Influence of different cover crops, straw and fertilizing intensity on field pea and spring oilseed rape productivity Mg ha^{-1}, 2014

Fertilization intensity (C)	Without cover crop		Cover crops ▼	
	straw use (B)			
	removed	spread (+N_{40})	removed	spread (+N_{40})
Field pea				
Unfertilised (control)	4.90	3.92**	5.07	4.19**
Sustainable fertilizing	5.02	4.23**	5.15	4.64
Intensive fertilizing	5.00	4.03**	5.15	4.61
Mean	4.97	4.06**	5.12	4.48**
LSD_{05}: A – 0.195; B – 0.195; C – 0.238; AxB – 0.275; AxC – 0.337; BxC – 0.337; AxBxC – 0.477.				
Spring oilseed rape				
Unfertilised (control)	1.11	1.10	1.20	1.18
Sustainable fertilizing	1.64**	1.26	1.51**	1.34*
Intensive fertilizing	1.74**	1.46**	1.75**	1.55**
Mean	1.50	1.27**	1.49	1.36**
LSD_{05}: A – 0.088; B – 0.088; C – 0.108; AxB – 0.125; AxC – 0.153; BxC – 0.153; AxBxC – 0.216				

Note: ▼- for field pea - white mustard, for spring oilseed rape - red clover

RESULTS AND DISCUSSION

Influence of cover crops, straw and fertilizing intensity on plant productivity

The cultivation of cover crops and the utilization of their mass and straw as fertilizer had significant influence ($P < 0.01$) on field pea grain productivity (Table 1).

The incorporation of white mustard mass as fertilizer increased field pea grain productivity by 6.3% on average compared with the plot without cover crops. Due to the favourable mass C and N ratio (C:N = 25) white mustard decomposition intensity was low and it released a low amount of soil mineral nitrogen. Soil microorganisms used this nitrogen for decomposing straw and a decreasing amount of mineral nitrogen in soil could determine higher fixation of field pea biological nitrogen and the yield increase. This statement is supported by the fact that the negative influence of straw was substantially lower when field pea had been grown after the incorporation of white mustard mass compared with the cultivation without cover crops. The utilization of spring barley straw as fertilizer reduced pea grain productivity by 15.5% on average. A significant positive influence of phosphorus and potassium fertilizers was established when field pea had been grown after white mustard. An additional yield was higher by 10.5% on average compared with the unfertilized plot (without cover crop). The highest pea grain yield was obtained while growing it after white mustard with spring barley straw removed from the field and having fertilized with PK fertilizer.

Straw, fertilization with mineral fertilizer NPK ($P < 0.01$) and the interaction of these factors ($P < 0.05$) had a significant effect on spring oilseed rape yield. According to the mean data red clover mass only had a tendency of increasing spring oilseed rape yield. Due to narrow C and N ratio (C:N = 15) leguminous grass mass decomposes fast [9]. In accordance with the authors' other research data the incorporation of straw together with red clover mass increased the amount of mineral nitrogen in soil significantly during two years in spring [11]. More pronounced differences of spring oilseed rape yield compared with the incorporation of red clover mass were established only in the plots unfertilized with mineral fertilizer: the yield increased by 8.1% after straw removal from the field and – by 6.3% after spread compared with the control plot. Yield increase tendencies were established through the interaction between the cover crops and straw in the plots fertilized with mineral fertilizer. It can be proposed that some part of the *Fabaceae* mass nitrogen was incorporated into microbial biomass or organic soil compounds. The use of straw as a fertilizer reduced spring oilseed rape productivity by 11.9% on average compared with the plot without straw.

The highest spring oilseed rape yield was achieved by fertilizing with NPK fertilizer: sustainable fertilization – 25.1%, intensive fertilization – 41.4% compared with the unfertilized plot (average data). The highest spring oilseed rape yield was obtained having removed straw from the field and fertilized with the largest NPK rates irrespective of the cover crops.

Influence of cropping systems on plant productivity in soils of different humus content

The red clover mass as green manure and the application of farmyard manure and mineral fertilizers influenced the yield of winter wheat significantly only among the cropping systems ($P < 0.01$). According to the average data of four crop rotation fields due to slow mineralization of organic materials in clay loam soils fertilization with farmyard manure in the sustainable cropping system did not increase winter wheat grain yield significantly compared with the organic system (Table 2). The significantly highest winter wheat grain yield was achieved in the intensive cropping system where both green manure and mineral $N_{30}P_{60}K_{60}$ fertilizer were applied on winter wheat. In this cropping system the winter wheat grain yield in the soils of low and moderate humus content was 15.6 and 16.6% higher respectively compared with the yield in organic system. The winter wheat yield in the soil of higher humus content had an increasing tendency: on average the winter wheat grain yield in all cropping systems was 6.5% higher compared with the soil of low humus content, however, the differences were not significant.

Winter wheat straw was incorporated into soil; after that during the post-harvest period the cover crops were grown in the organic cropping system – low field pea yields were obtained. The straw which had been incorporated into soil was rich in lignin and slow to mineralize: that fact could have had influence as the straw utilized the nitrogen present in the soil as well as according to other authors low phosphorus content of the soil is a limiting factor for nitrogen fixation [1].

The field pea yield varied in terms of the humus content groups ($P < 0.05$) and the cropping systems ($P < 0.01$), there was no interaction between the both factors (A x B). A higher level of humus content had the significant positive 10.4% influence on field pea grain yield in all cropping systems compared with the soil of low humus content. The incorporation of cover crop mass in combination with farmyard manure in the soil of moderate humus content had a more marked influence on the field pea yield: in the sustainable cropping system which included growing white mustard together with buckwheat it increased by 11.1 and 32.0% respectively compared with the organic cropping system. In the intensive cropping system both in the soils of low and moderate humus content a significantly highest field pea yield was established – it constituted 34.0 and 26.7% compared with the organic cropping system.

Table 2

Influence of cropping systems on winter wheat and field pea grain yield Mg ha^{-1}, Mean 2010-2013

Cropping systems (factor B)	Soil humus content (factor A)		Mean factor B
	low	moderate	
Winter wheat			
Organic (control)	4.97	5.05	5.01
Sustainable	4.97	5.27	5.12
Intensive	5.74**	5.88**	5.81**
Mean factor A	5.19	5.37	5.28
LSD_{05}: A – 0.197, B – 0.279, AxB – 0.394			
Field pea			
Organic (control)	1.65	1.72	1.69
Sustainable	1.66	2.27**	1.97*
Intensive	2.21**	2.18**	2.19**
Mean factor A	1.83	2.02*	1.93
LSD_{05}: A – 0.083, B – 0.145, AxB – 0.221			

Effect of cover crop management under reduced tillage conditions

The influence of cover crop utilization and tillage combinations on the field pea grain yield depended on the conditions of a certain year. In 2010 and 2012 which were the years more favourable for field pea cultivation, application of cover crop for winter mulch without any soil tillage in autumn resulted in significantly lower pea grain yield by 19.5 and 37.3%, respectively compared with ploughless tillage alone (Table 3). In 2011, the year which was less favourable for field pea cultivation its grain yield was lower (36.5%) both in the cases of leaving the cover crop mulch over winter without tillage in autumn and also lower (17.8%) having incorporated the cover crop mass in autumn during ploughless tillage. The causes of such yield reduction could be considered to be the sensitivity of field pea to the reduction of tillage and tillage quality in heavy soils. In late autumn the clayey soils covered with cover crops are wetter compared with ones without cover crops. Therefore, under such conditions when green manure is incorporated tillage quality suffers.

Table 3

Effect of tillage and cover crop management on field pea and spring oilseed rape yield, Mg ha^{-1}

Tillage and cover crop management	Year		
	2010	2011	2012
Field pea			
Ploughless tillage	3.89	3.37	4.26
Ploughless tillage with cover crop for green manure	3.59	2.77*	4.09
Cover crop for winter mulch without tillage	3.13*	2.14*	2.67*
LSD_{05}	*0.343*	*0.315*	*0.340*
Spring oilseed rape			
Ploughless tillage	1.98	2.44	1.66
Ploughless tillage with cover crop for green manure	1.85	2.44	1.70
Cover crop for winter mulch without tillage	1.82	2.38	1.48*
LSD_{05}	*0.183*	*0.137*	*0.162*

Our research proved that spring oilseed rape was less sensitive to reduced tillage compared with field pea. Only in 2012 having left cover crop as mulch without any tillage in autumn the yield of spring oilseed rape decreased significantly by 10.8% compared with ploughless tillage alone (Table 3). Therefore, while cultivating spring oilseed rape under reduced tillage conditions more successful utilization of cover crops can be applied.

CONCLUSIONS

1. The field pea grain yield was increased significantly (6.3% on average) by the incorporated white mustard mass compared with the plots without cover crop. It can reduce the amount of free nitrogen in soil and stimulate field pea to fixate biological nitrogen. The highest yield of spring oilseed rape was achieved by applying intensive fertilization with NPK – the additional yield was 41.4% higher compared with the unfertilized plot. The straw used as fertilizer reduced crop productivity: field pea – by 15.5% and spring oilseed rape – by 11.9% compared with the treatment when the straw had been removed from the field. The cultivation of cover crops mitigated its negative impact by stimulating straw decomposition and nitrogen fixation in organic soil compounds.

2. The winter wheat grain yield in the intensive cropping system was significantly higher compared with that in the organic system. A higher level of soil humus content had essential impact on the winter wheat grain yield (increased by 10.0%) compared with that of low humus content soil. The incorporation of cover crop mass in combination with farmyard manure had a marked influence on the field pea yield in the soil of moderate humus content: in the sustainable cropping system where white mustard had been grown together with buckwheat the field pea yield increased by 32.0% compared with the organic cropping system. In the intensive cropping system both in the soils of low and moderate humus content the field pea yield was significantly higher – by 34.0 and 26.7% respectively compared with the organic cropping system.

3. Having left the cover crop as mulch over winter without any tillage in autumn reduced field pea yield by 19.5-37.3% in all years of the investigations compared with only ploughless tillage applied. The incorporation of cover crop as green manure in autumn during ploughless tillage reduced pea yield by 17.8% only in the year less favourable for field pea growing. Due to cover crop utilization as mulch without any tillage in autumn the yield of spring oilseed rape decreased by 10.8% only during one year of the three investigation years. Spring oilseed rape is less sensitive to the reduction of tillage compared with field pea. Therefore, the use of cover crops under the reduced tillage conditions of heavy soil is easier to apply in cultivating spring oilseed rape compared with field pea.

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