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Effect of preceding crops and green manure on the fertility of clay loam soil

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Abstract. Influence of red clover (*Trifolium pratense* L.), sown lucerne (*Medicago sativa* L.), vetch and oat mixture (*Vicia sativa* L., *Avena sativa* L.) and green material of these legume crops used as green manure on the build up of biological N variation of soil properties and productivity of winter wheat (*Triticum aestivum* L.) was investigated on *Endocalcari-Endohypogleyic Cambisol (CMg-n-w-can)*, according to the texture – clay loam on silty clay. Experiments were carried out at the Joniskelis Research Station of the Lithuanian Institute of Agriculture over the period 1996–2000. It was revealed that lucerne and clover left the highest content of plant residues in the soil (13.7 t ha^{-1} and 9.2 t ha^{-1} of dry matter, respectively) which was 2.7 and 1.8 times more as compared to annual vetch and oat mixture. These perennial plants also determined accumulation of the highest content of biological N in roots and residues. According to N content applied with green manure, only lucerne aftermath was comparable to farmyard manure. Lucerne determined accumulation of the highest contents of total nitrogen (0.138%), humus (2.18%) and available phosphorus and potassium (130 and 279 mg kg^{-1} of soil, respectively) in the soil. Analysis of humus composition showed that its content in clay loam soil was rather stable, however, a slightly higher content of mobile humic acids was found after lucerne as a preceding crop when green manure or farmyard manure had been applied. When winter wheat was grown after lucerne as a preceding crop, the highest grain yield (on average 5.58 t ha^{-1}) was obtained, which was 18.5 and 28.3% higher than that after clover or vetch and oat mixture. Protein content in winter wheat grain was to a greater extent determined by legume crops rather than organic manure.

Key words: clay loam, legume crops, green manure, humus, winter wheat

INTRODUCTION

Experimental evidence of West European and Baltic countries suggests that increasing the area of treated with mineral fertilisers in the rotation from 50 to 100% does not always result in a significant reduction of grain yield (Adamiak, 1992; Magyla, 1997; Petrauskas, 2000; Vyn et al., 1991). However, one of the key problems in agriculture is faced here which is breakdown of soil humus and its quality deterioration, which is determined by the reduction of organic carbon and total nitrogen content (Dabkowska–Naskret et al., 1997; Powlson et al., 1998; Svirskienė et al., 1997). In many latest publications it is recommended that cereals should be grown after legumes, which would enable using the accumulated biological N for their nutrition in a more rational way (Chalk, 1998; Kelner et al., 1997; Wivstad et al., 1996). Abundant nitrogen - rich residues of legume crops break down gradually, especially in clay soils, therefore nutrients are released slowly. Biological nitrogen can influence not only winter wheat yield formation throughout all stages of vegetative growth but also cultivation of cereals in longer sequences (Magyla, 1997; Rasmussen et al., 1998).

The objective of the present study was to ascertain the effect of different preceding crops of winter wheat: red clover, sown lucerne, vetch and oat mixture, as well as the effect of their green matter used as fertiliser on the productivity of winter wheat and on the variation of agrochemical and physical properties of a clay loam *Gleyic Cambisol*.

MATERIALS AND METHODS

Experiments were conducted at the Joniskelis Research Station of the Lithuanian Institute of Agriculture located in the northern part of Central Lithuania Lowland. According to the FAO soil classification system, the soil of the experimental site is characterised as *Endocalcari-Endohypogleyic Cambisol (CMg-n-w-can)*, according to the texture – clay loam on silty clay.

Trials involved the following design:

Factor A. Preceding crops for winter wheat:

1. Red clover, 2. Sown lucerne, 3. Vetch and oat mixture.

Factor B. Organic manure:

1. Without manures, 2. Green manure, 3. 40 t ha^{-1} of farmyard manure.

Three analogous multiple-factor experiments were set up in 1996, 1997 and 1999 and lasted for two years each. The soil agrochemical properties in the 0–20 cm layer after clover were as follows: pH_{KCl} – 6.4; humus – 2.04%; total nitrogen – 0.133%; plant available P_2O_5 and K_2O – 108 and 241 mg kg^{-1} of soil respectively, after lucerne: pH_{KCl} – 6.4; humus – 2.18%; total nitrogen – 0.138%; plant available P_2O_5 and K_2O – 130 and 279 mg kg^{-1} of soil, respectively; after vetch and oat mixture: pH_{KCl} – 6.4; humus – 2.08%; total nitrogen – 0.131%; plant available P_2O_5 and K_2O – 115 and 274 mg kg^{-1} of soil, respectively.

The experiments were carried out by the method of bifactorial field trial and involved four replications. The replications in factor A were arranged in blocks in two, and treatments in the replications by a randomised design. The initial plot size was 60 m^2, and that of record plots 30–40 m^2.

The following crops preceded winter wheat (*Triticum aestivum* L.): red clover of the second year of use (*Trifolium pratense* L. cv. 'Liepsna'), sown lucerne (*Medicago sativa* L.) (cv. 'Birute') of the fourth year of use and vetch and oat mixture (*Vicia sativa* L., *Avena sativa* L. cv. 'Baiciai' and 'Jaugila'). The legume crops were grown using conventional technology and were fertilised with 60 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O. Winter wheat (cv. 'Sirvinta 1') was sown at a seed rate of 200 kg ha^{-1} on 02.09.1996; 05.09.1997 and 06.09.1999. Cereals were grown using conventional soil and crop management practices and were thrashed on 06.08.1997, 01.08.1998, and 04.08.2000.

Details of fertilisation treatments: green manure was applied correspondingly to the crop: lucerne and clover aftermath (3.1 and 3.9 t ha^{-1} dry matter, respectively) at the beginning of plant flowering, and green material of vetch and oat mixture (3.5 t ha^{-1}

dry matter) on completion of pod formation. In treatment three, for the sake of comparison 40 t ha^{-1} of solid manure was ploughed down after it had been stored in the manure storage for a year. Green material of plants was chopped and at the time of manure spreading in the plots indicated in the experimental design disked in and all the plots were stubble broken by a moaldboard stubble breaker, and after 2 weeks the soil was ploughed at a depth of 25 cm. Cereals were not fertilised with mineral nitrogen, phosphorus and potassium fertilisers.

In order to determine the mass of plant residues we collected plant fallings and leaves present on the soil surface on the backgrounds of lucerne, clover and vetch and oat mixture before stubble breaking in six places. Then, using the method described by Kachinsky, we washed of roots from the soil monolith (0.25 m x 0.25 m x 0.25 m). The mass of all plants' residues was recalculated to dry matter (DM), and on determining the concentration (in %) of nitrogen, phosphorus and potassium we calculated the content of nutrients incorporated in the soil.

Soil samples for the determination of chemical composition were taken from the backgrounds of legume crops before applied organic manure and after cereal harvesting at a depth of 0–20 cm. Soil samples for $N_{min.}$ were taken in spring, after the renewal of winter wheat vegetative growth, from a depth of 0–40 cm. Total nitrogen was determined by the Kjeldahl method at the Lithuanian Institute of Agriculture (LIA) analytical laboratory. Plant available P_2O_5 and K_2O were determined in the soil by the A-L method, mineral nitrogen (NO_3+NH_4) by the distillation and colorimetry (in KCl extraction) method at the Agrochemical Research Centre of the LIA (Agrochemical methods of soil Research, 1975). Humus content was determined after picking out visible rootlets from the soil samples by the Tjurin method, and humus composition by the Tjurin method modified Ponomariova – Plotnikova (Ponomariova & Plotnikova, 1980).

Number of plants (in spring after renewal of vegetative growth) and productive stems (before harvesting) were determined in each plot in 4 places of 0.25 m^{-2} stationary sites. The number of grains per ear and their weight were determined in the average sample composed of 20 ears taken from each plot. 1 kg samples of each plot were made at harvesting for the determination of dry matter content in grains, their quality and 1000 grain mass.

Nitrogen content in the green material of legume crops, their plant residues, farmyard manure and winter wheat grain and straw were determined by Kjeldahl method (Official methods of analysis, 1984), phosphorus by colorimetry methods (with ammonium molibdate), and potassium by flame photometry method (Razumov, 1982). Protein content (%) in the grain was calculated as nitrogen content (%) x 5.7.

Weather conditions of plant vegetative growth period are described by one of the most informative agrometeorological indicators the hydrotermal coefficient (HTK) (Kelchevskaja, 1971). It is calculated by the formula HTK = $\Sigma p/0.1\Sigma_t$, where Σp is the sum of precipitation (mm) during the period whose temperature is above 10°C; Σ_t is the sum of active temperatures of the same period (°C) (if HTK $\geq$ 1.6 the period is excessively wet, HTK = 1…1.5 – optimally wet, 0.9…0.8-weak drought, HTK = 0.7…0.6-medium drought, HTK = 0.5…0.4 – severe drought, HTK < 0,4 – a very severe drought). The hydrothermal regime (HTC) of the winter wheat vegetative growth period (April – August) was characterised as optimally wet in 1997 and 1998 and weak drought in 2000. The experimental data were processed by methods of dispersion and correlation analysis, applying the programmes ANOVA (for bi-factorial experiment) and STATENG for statistical data treatment (Tarakanovas, 1999).

RESULTS AND DISCUSSION

Chemical composition of plant residues and organic manure and their effect on soil properties. Legume plants differing in chemical composition, root system and content of nutrients in the phytomass, were selected as preceding crops for winter wheat. The yield of legume plants, red clover, sown lucerne, vetch and oat mixture, according to averaged data was 7.8, 12.0 and 5.0 t ha^{-1} of dry matter, respectively. Plant residues and roots left in the soil accounted for on average 50.0–54.1% of the total phytomass accumulated in the agrocenoses. The greatest amount of plant residues in the soil was left by perennial legume plants - lucerne and clover, (13.7 and 9.2 t ha^{-1} dry matter *i.e.* 2.7 and 1.8 times more as compared with vetch and oat mixture) (Table 1). An increase in this yield occurred in line with an increase in the mass of plant residues. It was determined that the greatest amount of nutrients was introduced into the soil with lucerne residues, while the least amount with vetch and oat mixture, which in turn was determined by the mass of residues and their chemical composition. According to averaged data, lucerne left in the soil 234.6 kg ha^{-1} of nitrogen, *i.e.* 2.4 times more than clover and 6.4 times more than vetch and oat mixture. The highest content of phosphorus was introduced into the soil with clover and lucerne residues (40.8 and 52.5 kg ha^{-1} P_2O_5, respectively), while the lowest content – with vetch and oat mixture (14.6 kg ha^{-1} P_2O_5). The residues of all preceding crops almost identically replenished potassium supplies in the soil.

Table 1. Amount of nutrients applied in the soil with plant residues of preceding crops and with organic manure. Average data of 1996, 1997, 1999.

Factor A – preceding crops	**Factor B –**organic manure	Dry matter, t ha^{-1}	Nutrients, kg ha^{-1} N	P_2O_5	K_2O
Red clover	Without manure	9.2	99.4	40.8	135.5
	Green manure	12.4	179.0	56.3	221.7
	40 t ha^{-1} of farmyard manure	17.0	238.2	121.8	452.5
Sown lucerne	Without manure	13.7	234.6	52.5	184.2
	Green manure	17.6	349.0	72.4	301.8
	40 t ha^{-1} of farmyard manure	21.6	373.4	133.6	501.2
Vetch and oat mixture	Without manure	5.0	36.6	14.6	106.0
	Green manure	8.8	75.8	28.5	213.5
	40 t ha^{-1} of farmyard manure	12.8	175.4	95.7	423.0
LSD_{05} A		1.41	32.53	11.41	51.87
LSD_{05} B		1.62	37.56	13.17	59.89
LSD_{05} AB		2.81	65.05	22.82	103.73

However, less nutrients were introduced into the soil with the overground mass of legume crops than with their plant residues. The greatest amount of nitrogen (114.4 kg ha^{-1}) was introduced into the soil with lucerne aftermath, which was 1.4 and 2.9 times more than with the aftermath of clover or green material of vetch and oat mixture. Experimental findings showed that according to the amount of nitrogen introduced into the soil, a high yielding lucerne aftermath was identical with a conventional organic fertiliser - farmyard manure. All types of green manure were poor in phosphorus (13.9–19.9 kg ha^{-1} P_2O_5), but rich in potassium (86.2–117.6 kg ha^{-1} K_2O). Out of organic manure, farmyard manure gave the highest increase in soil nutrients, especially in phosphorus and potassium (81.1 and 317.0 kg ha^{-1}, respectively). Residues of the legume plants studied are characterised by the following carbon and nitrogen ratio (C : N): of lucerne – 18, clover – 24, vetch and oat mixture – 35, and that of winter wheat it was as high as 55. Experimental findings suggest that C : N ratio of clover and lucerne green material is narrower (12 and 10, respectively), while that of vetch and oat mixture is much wider (31).

Due to a longer period of soil dormancy and systematic introduction of necrotic fine rootlets the highest content of total nitrogen and humus before experiment was found in the soil after lucerne cultivation. Here the content of total nitrogen and humus was 0.138% and 2.18%, respectively, *i.e.* by 3.8; 5.3% and 6.9; 4.8% higher than after clover or vetch and oat mixture. After winter wheat harvesting the highest humus content (2.17%) in the soil remained in the plots where cereals had been grown after lucerne (Table 2). Different organic fertilisers tended to increase humus content (green manure – 1.9, farmyard manure – 2.4%), however, the differences were insignificant as compared with not fertilised treatment. Of all green manure types, lucerne aftermath had the greatest positive effect on humus accumulation. Under the effect of interaction of the preceding crops and organic fertiliser, the highest humus content was found after lucerne as preceding crop, when fertilising with its aftermath – 0.22 percentage units and manure – 0.18 percentage units, which is significantly (by 11.0 and 9.0%) higher than in unfertilised clover field.

In clay loam soil fulvic acids accounted for the largest share in soil humus (39.3–44.8 %), while humic acids and humin accounted for a smaller share (26.6–31.4%). The highest content of humic acids was determined after vetch and oat mixture (on average by 30.2 %) and in the plots fertilised with farmyard manure (30.1%) (Table 2). Analyses of humic acids composition revealed that the fraction of mobile humic acids (HA-1), which is attributed to active forms of humus and is characterised by an increased content of hydrogen and nitrogen, accounted for a small share from the sum total of humic acids (HA total). After all the legume crops studied, the highest content of these acids (HA-1) (11.0% from the total content of HA) accumulated after lucerne and the lowest (8.5 %) after vetch and oat mixture. Green manure increased their content by 4.4%, however less than farmyard manure. The rest of the larger part of humic acids comprised acids bound with Ca and strongly bound with clay particles (HA-2 and HA-3). They are attributed to stable or inert humus forms, which are more resistant to decomposition and show a higher level of soil cultivation. The highest content of humic acids bound with Ca was found after clover (43.3%). The content of fulvic acids (FA total), which have a negative effect on plant growth and soil properties, under the effect of individual preceding crops and organic fertilisers differed insignificantly when wheat was grown. Humus quality is defined by the ratio of humic and fulvic acids (C_{HA} : C_{FA}). In our experiments it did not differ much after various legume crops, but a highest after lucerne – (0.71). When fertilising by farmyard manure, this ratio tended to increase. Due to earlier described humus composition indicators, the humus of clay loam soil can be characterized as low mobile and tightly bound.

Table 2. Effect of legume crops and organic manure on humus composition in the soil when growing winter wheat. Average data of 1997, 1998, 2000.

Treatment	Humus, %	Humus composition indicators from the total amount of carbon C, %						
		total humic acids (HA)	including			total fulvic acids (FA)	humin	HA/FA
			free (HA-1)	bound with Ca (HA–2)	strongly bound with clay particles (HA–3)			
Average after preceding crops **(factor A)**								
Red clover	2.02	27.2	9.0	43.3	47.7	40.8	31.9	0.67
Sown lucerne	2.17	29.5	11.0	38.9	50.1	41.6	29.0	0.71
Vetch and oat mixture	2.06	30.2	8.5	36.3	53.2	43.4	26.0	0.69
Average after organic manure **(factor B)**								
Without manure	2.06	28.4	9.1	40.1	50.1	41.6	30.2	0.68
Green manure	2.10	29.3	9.5	39.3	50.5	42.6	28.2	0.68
40 t ha^{-1} farmyard manure	2.11	30.1	10.2	38.5	50.6	42.0	27.4	0.70
LSD_{05} A	0.035	1.78	1.30	3.19	2.48	2.03	3.39	0.043
LSD_{05} B	0.041	2.05	1.50	3.69	2.86	2.35	3.91	0.050
LSD_{05} AB	0.070	3.56	2.59	6.38	4.95	4.07	6.78	0.087

When growing winter wheat in clay loam soil, slow mineralisation of organic matter and diverse hydrothermal conditions in different years determined a negligible variation in mineral nitrogen content ($N_{min.}$) in the 0–40 cm layer. Not every year there was a significant correlation between the content of mineral nitrogen in the soil and biological N applied with plant residues and organic manure, however, a strong linear – direct correlation with soil humus ($r = 0.723–0.786$) was established every year.

After comparing legume crops among themselves, it was determined that a significantly higher content of available P_2O_5 and K_2O in the 0–20 cm layer before experiment accumulated in the plots of lucerne is characterised by a deep root system. Obviously, deep-rooted plants lift up the nutrients from deeper soil layers into the surface, which is also reported by other authors (Teit, 1990). Few data are found in the literature on the effect of legume plant residues and green manure on phosphorus and potassium nutrition of cereals grown after them. Some researchers consider that plant residues and green manure are not rich in potassium and especially phosphorus, however, they improve soil physical properties and at the same time stimulate microbiological activity, which makes available phosphorus and potassium in the soil more readily available to plants. In harvested winter wheat grown after different preceding crops, the highest contents of available phosphorus and potassium remained after lucerne and vetch and oat mixture as preceding crops. On average, after all the legume crops the content of available phosphorus and potassium increased when fertilizing with green manure by 0.8 and 6.5 %, respectively, and when fertilising with farmyard manure by 11.8 and 18.8 %, respectively. Plant nutrition by phosphorus and potassium from the soil, plant residues and organic fertilisers was also modified by meteorological conditions.

Winter wheat grain yield formation and quality. After different leguminous preceding crops winter wheat yield elements formed diversely at different growth stages. Better physical and chemical properties of soil after perennial grasses determined more favourable growth and wintering conditions for winter wheat. The number of plants in all the treatments after lucerne was on average by 11.6% higher, and after vetch and oat mixture by 3.6 % lower as compared with clover as preceding crop (Table 3). The stand was a bit denser when fertilised by farmyard or green manure (on average by 6.3 and 4.5% respectively).

The number of winter wheat productive stems was highest after lucerne (on average 399 stems m^{-2}), while the smallest number after vetch and oat mixture (328 stems m^{-2}), *i.e.* by 18.0% more and 3.0% less, respectively, than in clover field. Organic manure was less effective as to the number of productive stems. Green manure application after all the legume crops studied increased the number of productive stems by 5.8 %, while in the case of farmyard manure the increase was only 5.3%, as compared to unfertilised treatment. Clover and lucerne aftermath gave the greatest increase in the number of productive stems. Of all the farmyard manure treatments the highest number of productive stems (413 m^{-2}) was found after lucerne.

The number of winter wheat grains per ear due to legume crops and organic manure varied negligibly. The highest grain number per ear (on average 29.7 grains) was found after clover. After vetch and oat mixture it declined significantly (7.7 %), and after lucerne a trend of reduction in the number of grains per ear (1.3%) was established. Green manure and farmyard manure tended to increase the number of grains per ear, but the increase was insignificant.

In winter wheat 1000 grain mass was the highest (51.1 g) when it was grown after lucerne, significant differences made up 4.1% and 5.1% as compared to clover and vetch and oat as preceding crops. Under the effect of organic fertilisers the 1000 grain weight of winter wheat fertilised with organic fertiliser increased as compared to winter wheat grown in unfertilised soil.

The results of correlation – regression analysis show that the relationship of winter wheat grain yield with structural elements was significantly strong: with the plant number ($r = 0.959$), productive stems number ($r = 0.923$) and 1000 grain weight ($r = 0.940$); the direct relationship is described by a linear equation. The relationship of grain yield relationship with ear productivity elements was not so obvious.

Table 3. The influence of preceding crops and organic manure on the winter wheat productivity. Average data of 1997, 1998, 2000.

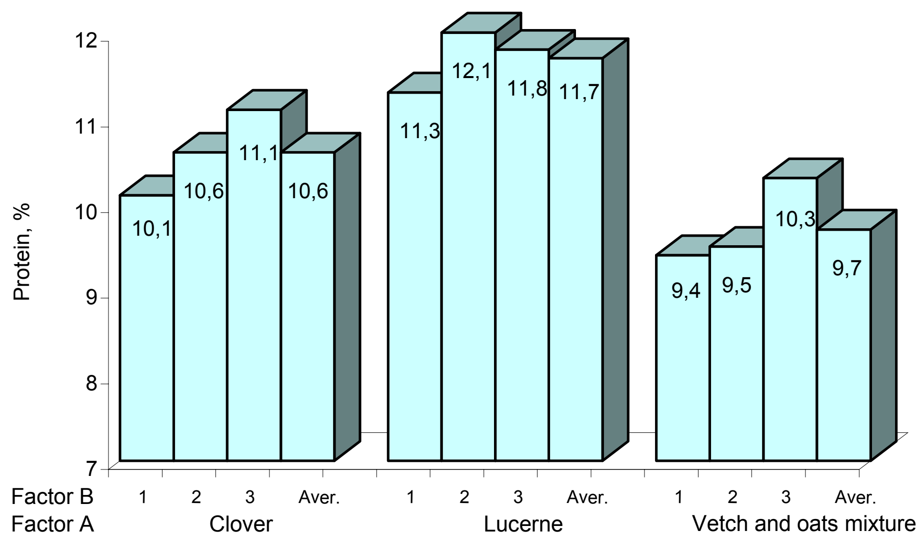
Treatment	Number of plants per m^2	Productive stems per m^2	Grains per ear	1000 grain mass, g	Grain yield, t ha^{-1}
Preceding crop – red clover					
Without manure	213	324	29.6	48.7	4.35
Green manure	232	364	29.5	49.1	4.85
40 t ha^{-1} farmyard manure	231	325	30.0	49.6	4.93
Preceding crop – sown lucerne					
Without manure	245	382	28.2	50.9	5.35
Green manure	252	401	29.2	51.5	5.69
40 t ha^{-1} farmyard manure	255	413	30.6	50.9	5.71
Preceding crop – vetch and oat mixture					
Without manure	212	320	26.7	48.0	4.16
Green manure	214	322	27.8	48.6	4.18
40 t ha^{-1} farmyard manure	225	341	27.8	49.2	4.72
Average after preceding crop **(factor A)**					
Red clover	225	338	29.7	49.1	4.71
Sown lucerne	251	399	29.3	51.1	5.58
Vetch and oat mixture	217	328	27.4	48.6	4.35
Average after organic manure **(factor B)**					
Without manure	223	342	28.2	49.2	4.62
Green manure	233	362	28.8	49.7	4.91
40 t ha^{-1} farmyard manure	237	360	29.5	49.9	5.12
LSD_{05} *A*	16.1	59.6	1.49	0.64	0.189
LSD_{05} *B*	20.6	38.1	1.38	0.73	0.186
LSD_{05} *AB*	35.9	68.7	2.33	1.23	0.330

Winter wheat produced the highest grain yield (5.58 t ha^{-1}) in all fertilisation treatments after lucerne, a significant grain yield increase made up 0.87 and 1.23 t ha^{-1}, or by 18.5 and 28.3 % more than after clover and vetch and oat mixture. After all legume crops a significant grain yield increase occurred through organic fertilisation. The different content of nitrogen in green manure and diverse mineralisation intensity determined a different increase in grain yield. The greatest increase in grain yield (11.5 and 6.4%, respectively) occurred when nitrogen-rich clover and lucerne aftermaths were used as fertilisers, while the lowest increase (0.5%) was obtained when the green matter of vetch and oat mixture was used, as compared with unfertilised treatment of respective preceding crop. The greatest increase in wheat yield under the effect of farmyard manure occurred when it was applied after clover (13.3%) and after vetch and oat mixture (13.5%), and yield increase was lowest (6.7%) after lucerne. Under the interaction of legume crops and organic manure the highest wheat grain yield increase (1.34 and 1.36 t ha^{-1}) was obtained after lucerne when fertilising by its aftermath or farmyard manure, as compared with unfertilised clover field. Winter wheat grain yield depended on the amount of nutrients applied with plant residues and organic manure in the soil (Table 4).

Table 4. Winter wheat grain yield t ha^{-1} (y) in relation to the amount of nutrients applied with plant residues and organic manure. Average data of 1997, 1998, 2000.

Years	Indicators	Regression equation	ŋ or r	Determin-ation coef. %
1997	N	y=5.26+0.003x	0.915**	84
1998		y=2.01+0.008x	0.866**	75
2000		y=4.49+0.005x	0.927**	86
Average		y=3.91+0.005x	0.971**	94
1997	P_2O_5	y=5.30+0.009x	0.745**	56
1998		$y=-1.53+0.23x-0.003x^2+0.0x^3$	0.779**	13
2000		y=4.62+0.014x	0.727**	53
Average		y=4.20+0.010x	0.668*	45
1997	K_2O	y=5.21+0.003x	0.694*	48
1998		y=2.73+0.001x	0.292	9
2000		y=4.86+0.002x	0.591*	35
Average		y=4.21+0.002x	0.578*	33

*-correlation reliable at 95 % probability level
**-correlation reliable at 99 % probability level.



Factor A – preceding crops.
Factor B – organic manure: 1. Without manure; 2. Green manure; 3. 40 t ha^{-1} farmyard manure. LSD_{05} A – 0.65; LSD_{05} B – 0.5; LSD_{05} AB – 1.29.

Fig 1. Effect of legume crops and organic manure on winter wheat protein content. Average data of 1997, 1998, 2000.

When estimating the effect of legume crops according to nitrogen accumulation in the winter wheat produce, it was revealed that the nitrogen content in grain and straw was significantly higher when cereals had been grown after lucerne as preceding crop, while the lowest N content was found after vetch and oat mixture. Of organic fertilisers a significant increase in winter wheat grain nitrogen content was shown by lucerne aftermath and farmyard manure. Nitrogen, slowly released from plant residues and organic manure, created favourable conditions for nitrogen nutrition and accumulation of total protein in grain (Fig. 1).

The highest protein content 11.7% was determined in ground grain of wheat which had been grown after lucerne; this was (by 10.4%) significantly higher as compared with wheat grown after clover. After vetch and oat mixture, the protein content was significantly lower. After all legume crops the protein content was significantly increased also by farmyard and green manure fertilisation (7,7%, as compared with the unfertilised treatment). The highest protein content (12.1%) was determined in the grain of winter wheat grown after lucerne, it was by 19.8% higher than in the unfertilised clover treatment. Results of correlation–regression analysis suggest that protein content (%) in winter wheat grain was significantly dependent on nitrogen applied with plant residues and organic manure.

CONCLUSIONS

1. Legume plants and green manure are important factors for the maintenance the potential fertility of clay loam soils and winter wheat productivity.

2. The greatest amount of nitrogen – rich plant residues was left in the soil after sown lucerne (13.7 t ha^{-1} DM) and after red clover (9.2 t ha^{-1} DM), which is 2.7 and 1.8 times more than after annual mixture of vetch and oat. These perennial plants determined accumulation of the highest content of biological nitrogen (234.6 and 99.4 kg ha^{-1}, respectively) in the soil.

3. Overground mass of lucerne and clover used as green manure was rich in nitrogen and potassium, and the green material of vetch and oat mixture was rich only in potassium. Lucerne green material gave the same amount of nitrogen as was applied with farmyard manure, however, the latter surpassed all types of green manure 4.1–5.8 times according to the phosphorus content applied, and 2.7–3.7 times according to potassium content applied.

4. Various legume plants had a diverse effect on the agrochemical properties of clay loam soil. The highest content of humus (2.18%) and nitrogen (0.138%) was found after sown lucerne. A significantly higher content of plant available phosphorus and potassium was determined after this legume crop. Analyses of humus composition showed that in clay loam soil humus is rather stable, however a slightly higher mobile humic acids content was found when winter wheat had been grown after lucerne as a preceding crop and had been given organic manure.

5. Lucerne determined more favourable soil properties, and this had a positive effect on the formation of yield elements of winter wheat grown after lucerne, which enabled to obtain on average 5.35 t ha^{-1} of grain without mineral and organic manure, which was 23.0% and 28.6%, respectively more as compared with winter wheat grown after red clover or vetch and oat mixture.

Overground mass of perennial legume plants ploughed in as green manure increased winter wheat yield: lucerne aftermath – 6.4%, clover aftermath – 11.5% vetch and oat mixture by 0.5%, as compared with the unfertilised treatments of these preceding crops.

6. Coefficients of regression suggest that the content of nutrients, especially nitrogen ($r^2 = 0.97$), incorporated with plant residues and organic manure are important factors in increasing the productivity of agrosystems.

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