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The Effect of Sustainable and Organic Farming Systems on the Balance of Biogenic Elements and Changes of Agrochemical Properties in Gleyic Cambisol

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1. Introduction

In clay loam soils of glacial lacustrine origin, the abundance of clay particles results in higher sorption capacity and nutrient stability compared with light soils. However, even in these soils the level of various agrosystems' functioning is largely determined by cropping systems. When making the shift from intensive cropping system to alternative ones and replacement of fertilization systems it is important to quantify the changes in soil productivity qualitative parameters and to ascertain the effects of environmentally safe agricultural practices on crop productivity. With a higher focus on organic fertilization and reduction or complete abandonment of mineral fertilization, the content of organic carbon increases in the soil, however, this poses a problem for versatile plant nutrition (Gale & Gilmour, 1988; Deng, Motore & Tabatabai, 2000). In alternative cropping systems, when there is a shortage of specific nutrients, plants experience stress, which results in a marked reduction in crop productivity. But this will not suppress the demand for viable developmental processes and the potential collateral effects in order to avoid resource depletion. Where natural resources exist, it must be determined to what degree the environment is capable of absorbing the impact of the development. As agricultural soil is the foundation for nearly all land uses, soil quality stands as a key indicator of sustainable land use. Second, land use and its mismanagement of arable areas by farmers and grazing areas by livestock is addressed as one of the major causes of soil degradation (Zuazo et al., 2011). This discourages the development of organic agriculture, and low organic production volumes are a meagre reserve for safe food. In alternative cropping systems, plant demand for major nutrients is compensated by soil nutrient reserves and nutrients released from organic matter. With no use of mineral fertilization in alternative cropping systems, on a clay loam *Cambisol* of glacial lacustrine origin, the problem of phosphorus shortage becomes most apparent, since low phosphorus content is a genetic characteristic of this soil type.

Anthropogenic activity has a clear effect on ecosystems, because it stimulates domination of components, useful for human beings. In intensive farming, fertilization system targeted at yield increase is based on the plant nutrition needs, but little attention is paid to the

maintenance of ecosystem productivity (Hoffmann & Johnsson, 2000; Nieder et al., 2003). Intensive use of chemical plant protection products and mineral fertilizers intended for crops productivity enhancement results in the atrophy of natural, self-regulation processes in soil. Rational soil management in combination with maintaining of ecological balance helps to increase fertility and to keep its potential productivity. In order to reduce environment pollution and to maintain safe environment, it is important to select prevention means appropriately by including nutrients, not absorbed by plants, into biological circulation (Di et al., 2002; Arlauskienė, Maikštėnienė & Šlepetienė, 2009; Arlauskienė, Maikštėnienė & Šlepetienė, 2011). Anthropogenic activity must be directed towards the increase of stability in farming system by improving the state of crops and fauna. The process of biologization in agriculture is one of the main factors, maintaining the natural productivity of soil as well as stability of ecosystem (Hoffmann & Johnston, 2000).

In order to protect ecosystems from effect of chemical means, alternative agricultural systems are being developed. However, these agricultural systems must often solve the problems of nutrients balance, because the issue of versatile plants nutrition arises. Mineral fertilizers help in forming the appropriate balance of nutrients ratio more easily than in cases when sustainable and organic farming is applied, where plant nutrition is solved by organic manure and limited content of mineral fertilizers (Bhogal et al., 2000). Seeking to preserve nutrients, especially readily migration nitrogen, in the ploughlayer, to reduce nutrient leaching losses and to provide as long as possible protection of the soil surface from the direct adverse effect of the atmospheric phenomena, promoting soil degradation, we cultivated after crops after the main crops in the farming systems. Under Lithuania's conditions, during the warm period, the soil is covered with crops for only 3-4 months in a year, while in autumn with a prolonged rainy period, the risk of nutrient leaching during main crops' post-harvest arises. Catch crops accumulate in their biomass the nutrients that are left in soil after the main crops, and what is the most important, keep nitrogen in the topsoil layer (Stopes & Philipps, 1994; Marcinkevičienė et al., 2008).

The aim of this study was to estimate the effects of organic and sustainable farming systems on the balance of biogenic elements and changes of agrochemical properties in clay loam *Gleyic Cambisol*.

2. Experimental design and field management

Two bi-factor field experiments were conducted in Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry during 2006–2009 on a clay loam *Endocalcari-Endohypoglejic Cambisol* (CMg-n-w-can). The soil texture is clay loam (clay particle <0.002 mm in Ap horizon 0–30 cm make up 27.0 %) on silty clay with deeper lying sandy loam. Parental rock is limnoglacial clay on morenic clay loam. Research was done in the northern part of Central Lithuania's lowland (56°21'N, 24°10'E).

The crop rotation, expanded in time and space, consisted of perennial grasses – red clover (*Trifolium pratense* L.) and meadow fescue (*Festuca pratensis* Huds.), winter wheat (*Triticum aestivum* L.), pea (*Pisum sativum* L.) and spring barley (*Hordeum vulgare* L.) with undersown perennial grasses. The investigated measures – farming systems were assessed in the grass-cereals sequence: perennial grasses (aftermath for green manure) → winter wheat + catch crops (for green manure) → pea.

The field experiment was arranged according to the following design:

Soil humus content (based on the humus content scale developed by several authors - Пестряков, 1977; Amacher, Neill & Perry, 2007) – **factor A:** 1) – low (1.90–2.01 %); 2) – moderate (2.10–2.40 %).

Farming systems – factor B: organic – I, organic – II, sustainable – I and sustainable – II, are presented in table 1.

Cropping system (Factor B)	Plants of the crop rotation sequence and fertilization		
	perennial grass	winter wheat	pea
Organic I (O I)	-	aftermath of perennial grass	straw + narrow-leaved lupine (<i>Lupinus angustifolius</i> L.) and oil radish (<i>Raphanus sativus</i> var. <i>Oleifera</i> L.)
Organic II (O II)	-	farmyard manure 40 Mg ha ⁻¹ + aftermath of perennial grass	straw + white mustard (<i>Sinapis alba</i> L.)
Sustainable I (S I)	-	farmyard manure 40 Mg ha ⁻¹	straw + N ₃₀ + white mustard and buckwheat (<i>Fagopyrum exculentum</i> Moench.)
Sustainable II (S II)	P ₆₀ K ₆₀	aftermath of perennial grass + N ₃₀ P ₆₀ K ₆₀	straw + N ₃₀ N ₁₀ P ₄₀ K ₆₀

Table 1. Cropping systems, plants of the crop rotation sequence and fertilization

The field experiment was arranged as a randomized single row design in four replicates.

2.1 Soil analyses

Soil sample for soil agrochemical properties were taken before experiment and of the end experiment in each plot treatment from the 0 – 20 cm layer. Soil samples for N_{min} (N-NH₄ + N-NO₃) estimation were taken from each plot at twenty positions, from the soil layer of 0 – 40 cm, taking average samples. Samples were taken in spring at the beginning of winter wheat vegetation, in autumn, before catch crop biomass incorporation and in spring before the sowing of peas.

Soil chemical analyses carried out by methods: pH_{KCl} – ionometrically (ISO 10390, 2005) method; the humus status – by Tyurin method; the mobile humic substance – by Tyurin method, modified by Ponamariova and Plotnikova (Пономарева & Плотникова, 1980) in 0,1 NaOH suspension; the available phosphorus (P₂O₅) and potassium (K₂O) – by Egner-Riehm-Domingo (A-L) method (GOST 26208-91:1993); N_{min}: the nitrate nitrogen (N-NO₃) ionometrically, the ammonia nitrogen (N-NH₄) photometrically (ISO 14256-2, 2005).

2.2 Plant analyses

Composite samples were taken at harvesting of the main crop in every field in main and secondary produce as well as the samples of over-ground biomass of catch crops. Crops yield was expressed by the content of absolutely dry matter Mg ha⁻¹. To determine the root biomass of catch crops, monoliths 0.25 x 0.25 x 0.24 m in size were dug out in the plots of each treatment replicated three times. The roots were washed and air-dry weight was determined. Samples of the aboveground and underground biomass were taken for the

determination of dry matter (dried to a constant weight at 105 °C), nitrogen, phosphorus and potassium.

In the biomass of main and secondary produce of rotation crops as well as in catch crops' biomass, nitrogen was determined by Kjeldahl method (ISO 20483: 2006), phosphorus was measured by spectrophotometric and potassium – by flame photometer methods.

Soil and plant analyses were done at the Laboratory of Chemical research at Lithuanian Research Centre for Agriculture and Forestry.

2.3 Statistical analysis

The statistical analysis of data was performed using ANOVA for two-factor experiment (Tarakanovas & Raudonius, 2003; Crawley, 2007; Ritz, 2009).

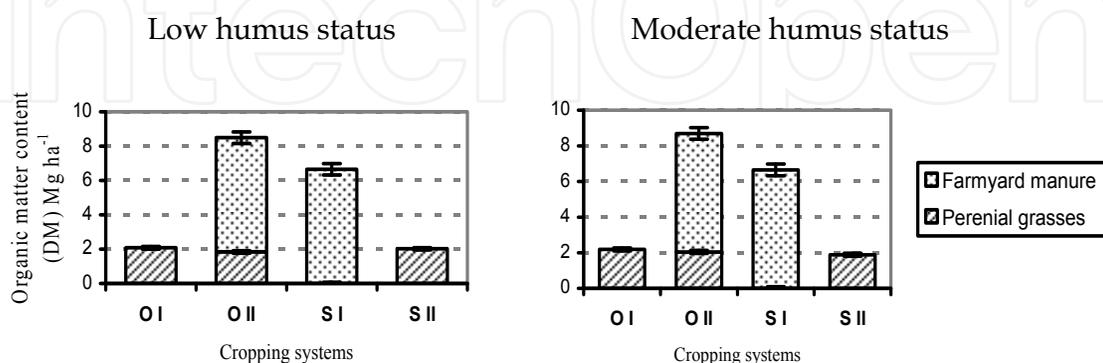
3. Results and discussion

3.1 Fertilization systems

3.1.1 Fertilization systems of winter wheat and analyses of biogenic elements

In a gleiyic *Cambisol* differing in humus status, seeking to determine the effects of various cropping systems, we used aftermath of perennial grass, farmyard manure and their combinations for winter wheat fertilization (Fig. 1). The data averaged over four years suggest that *Cambisol* received on average the lowest dry matter (DM) content of organic matter in organic I and sustainable II cropping systems, 2.1 and 2.0 Mg ha⁻¹ respectively, having used only aftermath of perennial grass for winter wheat fertilization. In organic II and sustainable I cropping systems, with farmyard manure fertilization the soil received by on average 4.0 and 3.1 times higher DM contents.

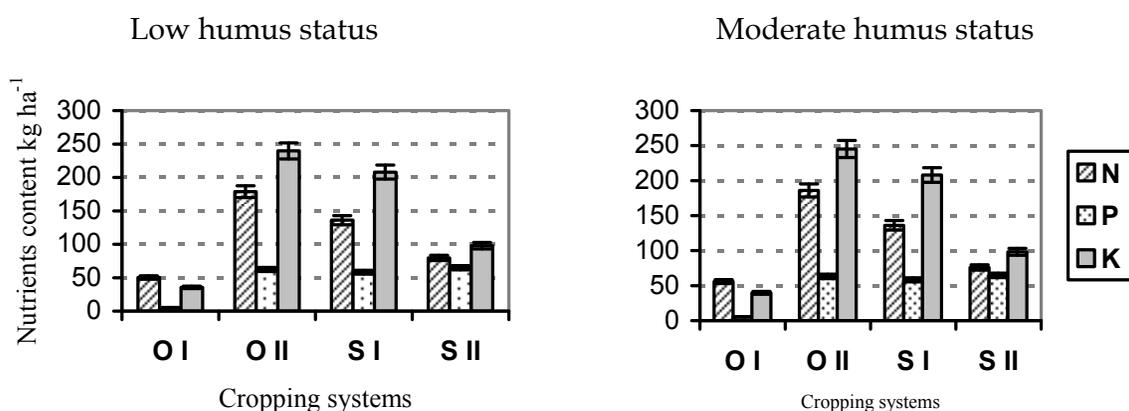
It is consistent, that in organic II cropping system using farmyard manure and biomass of perennial grass aftermath for winter wheat fertilization the soil received the highest content of biogenic elements (Fig. 1). In this cropping system, in the soil with low humus status for winter wheat there was incorporated 3.5 times more nitrogen, 12.1 times more phosphorus and 6.8 times more potassium compared with organic I cropping system. In sustainable I cropping system, in which only farmyard manure was used the content of NPK incorporated into the soil was by 2.7, 11.3 and 5.9 higher compared with organic I system, in which only green manure was used. In sustainable II cropping system, having applied aftermath of perennial grass for winter wheat fertilization the soil received inappreciably lower DM content than in organic I cropping system (Fig. 1).



LSD₀₅: A-0.10, B-0.18, AB-0.27

Fig. 1. Organic matter contents (DM) incorporated into the soil with aftermath of perennial grass and farmyard manure

However, in sustainable II system, having used mineral fertilizers for additional winter wheat fertilization, the NPK content was by 1.6; 12.7 and 2.8 times higher than in organic I cropping system (Fig. 2). In the soil with moderate humus status, winter wheat received inappreciably higher contents of biogenic elements with incorporated aftermath of perennial grass compared with those in the soil with low humus status. In organic II and sustainable I cropping systems, the content of biogenic elements incorporated into the soil was markedly higher than in organic I system: of nitrogen by 3.3 and 2.4 times, of phosphorus 11.7 and 10.7 times, and potassium 6.2 and 5.2 times. In sustainable II cropping system, having used aftermath of perennial grass and additional NPK fertilization for winter wheat the content of biogenic elements incorporated into the soil was significantly higher – of nitrogen 1.4 times, of phosphorus and potassium by 12.0 and 2.5 times, respectively, compared with organic I system.



LSD₀₅: N - A-0.53, B-0.92, AB-1.40; P - A-1.32, B-2.28, AB-3.48; K - A-2.78, B-4.81, AB-7.35

Fig. 2. Nutrient contents incorporated into the soil with aftermath of perennial grass, farmyard manure and mineral fertilizer

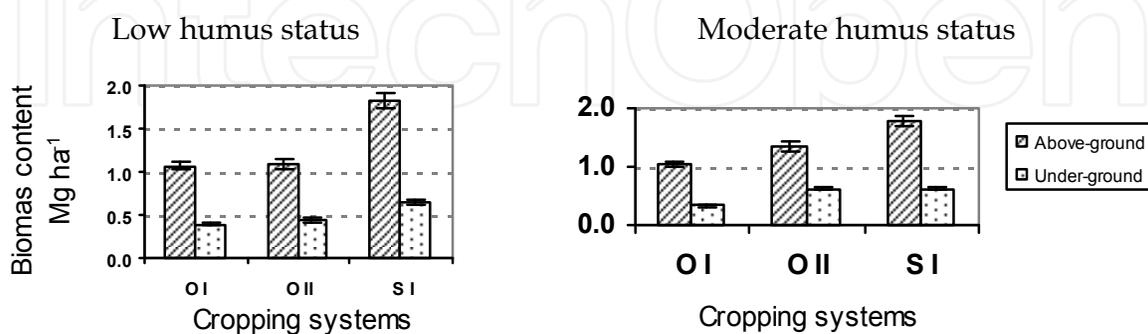
Nutrient content accumulated in the biomass of perennial grass, in the soil with higher humus status was not higher than that in the biomass of grass that grew in the soil with low humus status, since their development was negatively influenced by higher productivity of the cover crop and its suppressive power. In the soil of both humus levels, the trends of biogenic elements accumulation were similar. For winter wheat fertilization having used only perennial grasses' aftermath the soil received insignificant phosphorus content, per both humus levels it amounted to on average 5.3 kg ha⁻¹. These data show that in clay loam *Cambisols* whose genetic characteristic is low phosphorus level, green manure used for fertilization does not secure optimal phosphorus content in the soil for succeeding plants.

In summary, we can maintain that aftermath of perennial grasses used as green manure can meet plants' nutritional needs only for nitrogen and potassium, since only insignificant amounts of phosphorus are incorporated with their biomass.

3.1.2 Fertilization systems of pea and analyses of biogenic elements

For fertilization of pea was application biomass of catch corps and mineral fertility. Analysis of catch crops' above-ground biomass during winter wheat (pea pre-crop) post-harvest

period showed that markedly higher DM content was accumulated in sustainable I cropping system when growing white mustard in mixture with buckwheat compared with organic II system when growing only white mustard, the difference in low-humus status soil made up 67.0 % in moderate-humus status soil it made up 33.3 %. Such results might have been determined not only by the biological properties of catch crops but also low nitrogen rate N_{30} applied in sustainable I cropping system for straw mineralization, which promoted catch crops' development (Fig. 3).



LSD05 (above-ground): A-0.22, B-0.32, AB-0.50; LSD05 (under-ground): A-0.03, B-0.04, AB-0.07

Fig. 3. Above-ground and under-ground biomass (DM) content of catch crops, $Mg\ ha^{-1}$

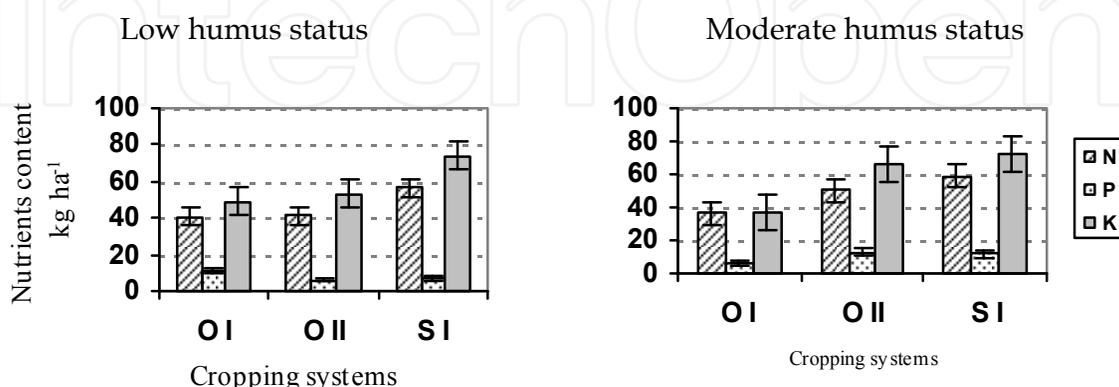
The lowest DM content in catch crops' above-ground biomass in the soil with low and moderate humus status was accumulated when growing narrow-leaved lupine in mixture with oil radish.

Similar results were obtained for catch crops' under-ground biomass (Fig. 3). In the soil low and moderate in humus status, DM content in the under-ground biomass of white mustard mixture with buckwheat was by 47.7 and 1.6 % higher than in organic II system, when growing only white mustard. The lowest DM content in the under-ground biomass in the soil low and moderate in humus status was accumulated when growing narrow-leaved lupine in mixture with oil radish as catch crops. Averaged over all cropping systems, the DM content in under-ground biomass of catch crops grown in the soil moderate in humus content was by 8.2 % higher than that in the soil low in humus status. It is consistent that both DM content accumulated in catch crops' biomass and biogenic elements content were markedly higher in sustainable I cropping system, in which a low nitrogen fertilizer rate N_{30} was applied for straw mineralization.

The above-ground biomass of white mustard and buckwheat mixture grown in the soil low and moderate in humus status had the highest nitrogen and potassium contents, compared with white mustard sole crop, the difference made up 36.1 and 15.7 % and 36.5 and 7.2 %, more, respectively (Fig. 4).

These data indicate that in the soil low in humus status, in worse nutrition conditions, the positive effects of catch crops' biological characteristics manifested themselves more tangibly. In sustainable I cropping system, the biomass of white mustard and buckwheat mixture contained by 40.0 % more nitrogen and by 46.4 % more potassium than in the biomass of narrow-leaved lupine and oil radish mixture in organic I cropping system. Although narrow-leaved lupine fixes nitrogen from the atmosphere and is superior to *Brassicaceae* family plants in organic agrosystems, according to its genetic origin it is a long-day plant, therefore shortening days in the autumn period have a greater negative impact.

In the soil low in humus status, when growing white mustard and buckwheat combination or white mustard as a sole crop, we established lower phosphorus content than in organic I cropping system when growing narrow-leaved lupine in combination with oil radish. However, in the soil moderate in humus status, the biomass of the latter catch crops accumulated the lowest phosphorus content. Higher soil humus status in most cases promoted more intensive biogenic elements' accumulation in the biomass of catch crops; however, the differences were not significant compared with the soil low in humus content.



LSD05: N - A-5,68, B-8,04, AB-12,71; P - A-1,16, B-1,64, AB-2,60; K - A-9,49, B-13,43, AB-21,24

Fig. 4. Nutrients accumulated in catch crops' above-ground and under-ground biomass

The under-ground biomass of catch crops accumulated considerably less nutrients compared with the above-ground biomass (Fig. 4). In the soil low in humus status, in sustainable I cropping system, with the biomass of white mustard and buckwheat mixture the soil received the highest content of nitrogen and potassium, which was by 37.6 and 45.7 %, respectively more compared with sole white mustard grown in organic II cropping system. In the soil moderate in humus status, nitrogen and potassium accumulation in catch crops' under-ground biomass varied in a similar pattern to that in the low-humus status soil.

Averaged over all cropping systems, in the soil moderate in humus content, catch crops' under-ground biomass accumulated more nutrients compared with low-humus status soil. With catch crops' under-ground biomass the soil received insignificant contents of phosphorus.

For pea, apart from catch crops' biomass we incorporated winter wheat straw with which the soil low in humus status received NPK on average 19.3, 3.7 and 27.0 kg ha⁻¹, respectively, and the soil moderate in humus status received 22.2, 4.3 and 30.4 kg ha⁻¹, respectively.

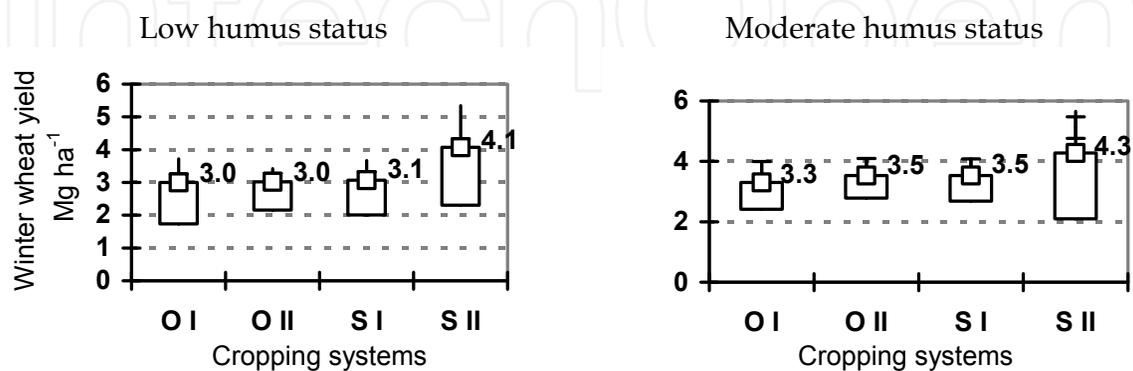
3.2 Productivity of the crops

3.2.1 Winter wheat grain yield and biogenic elements

In organic I cropping system, when using only aftermath of perennial grass for fertilization, winter wheat yield was rather low and uncharacteristic of productive soils; in the soil low in humus it amounted to 3.0, in the soil moderate in humus to 3.3 Mg ha⁻¹ DM, as a result, it accumulated rather low nutrient contents (Fig. 5).

Averaged over the four crop rotation fields, in clay loam soil, due to the slow organic matter mineralization, farmyard manure applied in organic II and sustainable I cropping systems

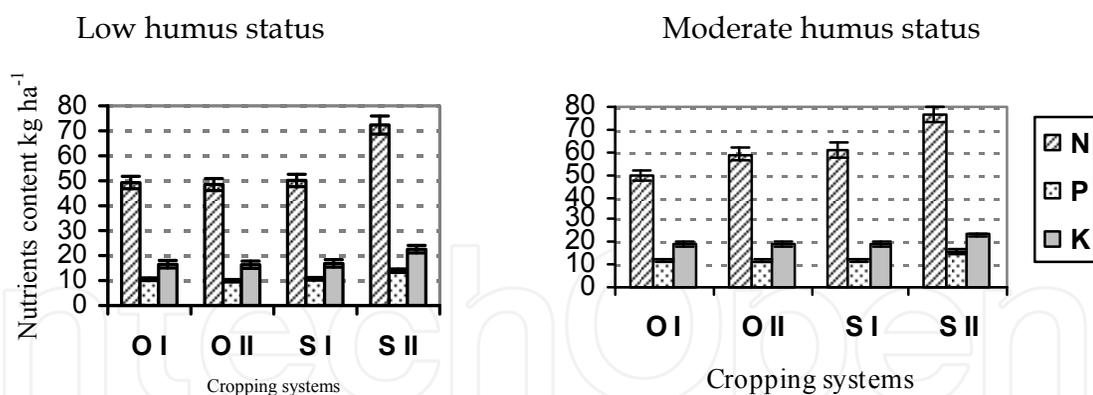
did not give a significant increase in winter wheat grain yield compared with organic I system. The highest grain yield was produced in the more intensive - sustainable II cropping system, in which besides green manure, wheat received mineral $N_{30}P_{60}K_{60}$ fertilization. In this system, grain yield in the soil low and moderate in humus status was by 35.7 and 29.7 % respectively higher than in the organic I system. In the soil moderate in humus, in separate cropping systems we established a consistent winter wheat yield increase (on average 11.2 %) compared with that produced on the soil low in humus status.



LSD05: A-0.14, B-0.25, AB-0.38

Fig. 5. The effect of fertilization on the grain yield of winter wheat

In the organic I cropping system, when using green manure, grain yield accumulated rather low contents of major biogenic elements, especially of phosphorus and potassium 11.3 and 17.8 kg ha⁻¹, respectively (Fig. 6).



LSD05: N - A-3.20, B-5.54, AB-8.46; P - A-0.67, B-1.16, AB-1.77; K - A-0.99, B-1.71, AB-2.07

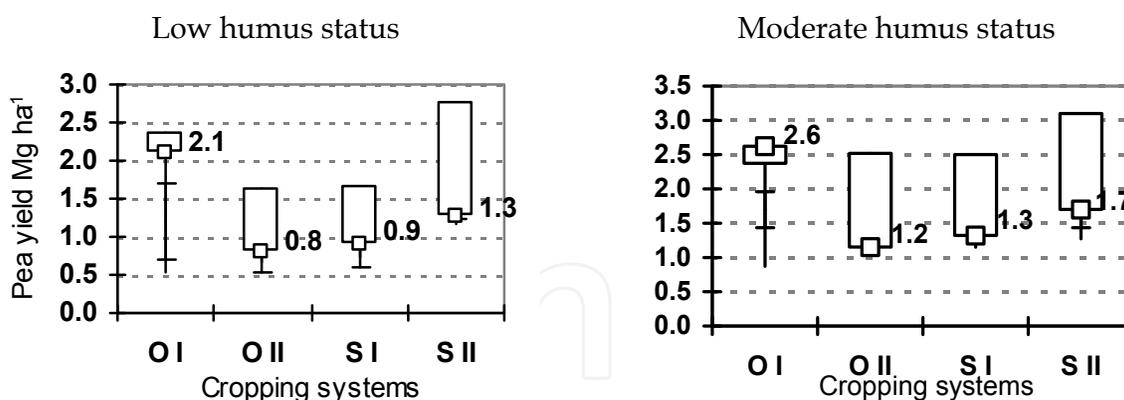
Fig. 6. Biogenic elements accumulated in winter wheat grain yield

In the soil low in humus status, the highest biogenic elements' content in winter wheat main produce was accumulated in sustainable II cropping system, with the use of moderate NPK rates in addition to green manure. In this cropping system, the contents of NPK accumulated in winter wheat yield were by 46.8, 32.1 and 36.4 % respectively higher, compared with the treatment applied with only perennial grasses' aftermath. In the soil moderate in humus status, like in that low in humus status, similar contents of biogenic elements were accumulated in winter wheat yield. Averaged over both humus levels,

significantly higher content of biogenic elements in winter wheat grain yield was in the sustainable II cropping system, where the highest grain yield was produced. Having used minimal NPK rates in addition to aftermath of perennial grass, grain yield was found to contain more N by 43.9 %, P by 32.2 %, and K by 28.3 % compared with the treatment fertilized with only aftermath of perennial grass. When fertilizing with farmyard manure or in combination with aftermath of perennial grass, the content of biogenic elements in winter wheat grain yield was markedly lower compared with that in the treatment applied with aftermath of perennial grass and additionally NPK fertilizers.

3.2.2 Grain yield of pea and biogenic elements

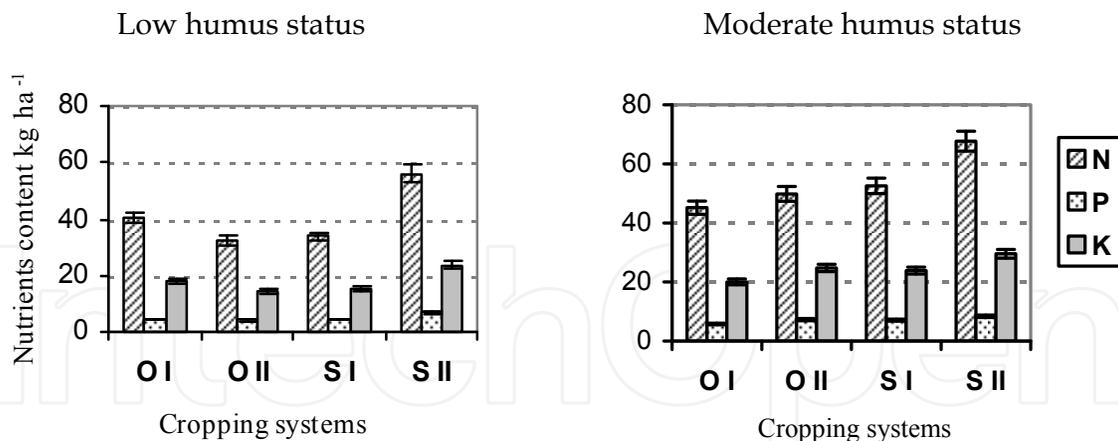
Having incorporated winter wheat straw into the soil, and growing catch crops during the post-harvest period, low yields of pea were produced in the organic cropping systems (Fig. 7). This was influenced by incorporated winter wheat straw containing much lignin and therefore exhibiting slow mineralization, which utilized nitrogen present in the soil. In the soil moderate in humus status, incorporation of catch crops' biomass exerted a more marked effect on pea yield. The highest positive impact on pea yield was exerted by white mustard grown as a sole crop or in mixture with buckwheat. Incorporation of their biomass, compared with narrow-leaved lupine and oil radish mixture increased pea grain yield by 23.0 and 19.4 %, respectively. In sustainable I cropping system, having applied N₃₀ for straw mineralization, pea yield significantly increased only in the soil moderate in humus status. The highest dry matter yield of pea was produced in the sustainable II cropping system, in the soil low in humus status and in the soil moderate in humus status, the yield increase amounted to 42.9 and 46.0 %, compared with the organic I system. The higher soil humus status had a significant (33.9 %) positive effect on grain yield, compared with the soil low in humus status.



LSD05: A-0.09, B-0.16, AB-0.24

Fig. 7. The effect of fertilization on the grain yield of pea

Nitrogen accumulation in grain was positively influenced by *Fabaceae* catch crops only in the soil low in humus status, compared with *Brassicaceae* catch crops (Fig. 8). In the soil low in humus status, phosphorus and potassium contents in grain were significantly higher only in the sustainable II cropping system, where straw had been incorporated for pea fertilization and N₃₀ was applied to promote straw mineralization, and minimal NPK fertilizer rates, the difference, compared with the organic I system, made up 45.9 and 32.9 %, respectively.



LSD05: N - A-4.04, B-6.99, AB-10.68; P - A-0.37, B-0.64, AB-0.98; K - A-1.09, B-1.89, AB-2.88

Fig. 8. Biogenic elements accumulated in pea grain yield

Different catch crops had a more marked effect on the accumulation of biogenic elements in pea grain in the soil moderate in humus status. The highest phosphorus and potassium contents were accumulated in the grain of pea crop for which biomass of sole white mustard had been incorporated, which were by 25.8 and 23.4 % respectively higher; or in combination with buckwheat by 23.4 and 19.0 % higher, compared with phosphorus and potassium contents accumulated in pea grain in the narrow-leaved lupine or oil radish treatment. In the soil moderate in humus status, the highest contents of biogenic elements were accumulated in the yield of peas grown in the sustainable II cropping system - the content of nitrogen was by 49.9 %, phosphorus by 45.6 % and potassium by 47.4 % higher compared with that in pea grain yield in the organic I system.

Averaged over all cropping systems, in the soil moderate in humus, biogenic elements' accumulation in the yield was significantly higher (of nitrogen by 32.4 %, of phosphorus 42.3 % and of potassium by 37.8 %) compared with the low humus status soil. In the soil low in humus status, incorporation of biomass of catch crops grown after winter wheat had a moderately strong effect $r=0.53$ $P<0.05$ on pea yield, while in the soil moderate in humus, this effect was weaker $r=0.44$ $P>0.05$.

3.3 Balance of nutrients incorporated into the soil and removed from the soil with the crops yield

When using organic fertilizers in the cropping systems it is rather complicated to balance the contents of nutrients incorporated into the soil and removed with the yield due to specific characteristics of loamy soils - high content of clay particles, determining slow organic matter mineralization and availability to plants. The nutrient contents accumulated in winter wheat by-produce and catch crops' biomass were returned into the soil, as a result, they were not included into the balance estimated, except for the nitrogen symbiotically fixed by narrow-leaved lupine grown as a catch crop in the organic I cropping system (Fig. 9). The balance between nitrogen introduced into the soil with organic and mineral fertilizers and that removed with the yield varied markedly between the different cropping systems. In the organic I cropping system, in both humus status levels, when using only aftermath of perennial grasses and catch crops' biomass, including nitrogen symbiotically fixed by *Fabaceae* plants, for fertilization, irrespective of

the fact that removal with winter wheat and pea yield was low, N balance was negative and plant needs were compensated by 48.6 and 46.9 %, respectively. In the organic II cropping system, in which green manure and farmyard manure were incorporated into the soil low in humus status, N balance was markedly excessive, the removal with the yield of the main produce of crop rotation sequence was compensated by 152.2 %. In the soil moderate in humus status, with better plant growth conditions that determined a higher yield of plants, especially that of winter wheat main produce, N was properly balanced. In the sustainable I cropping system, nitrogen content, incorporated with farmyard manure and catch crops' biomass, in the soil low in humus status compensated N content removed with yield by 120.3 %, in the soil moderate in humus status, where the yields of the main produce were higher, N compensation rate was 86.6 %. Averaged over both soil humus levels, the nitrogen compensation rate closest to 100 % was established in the sustainable I cropping system.

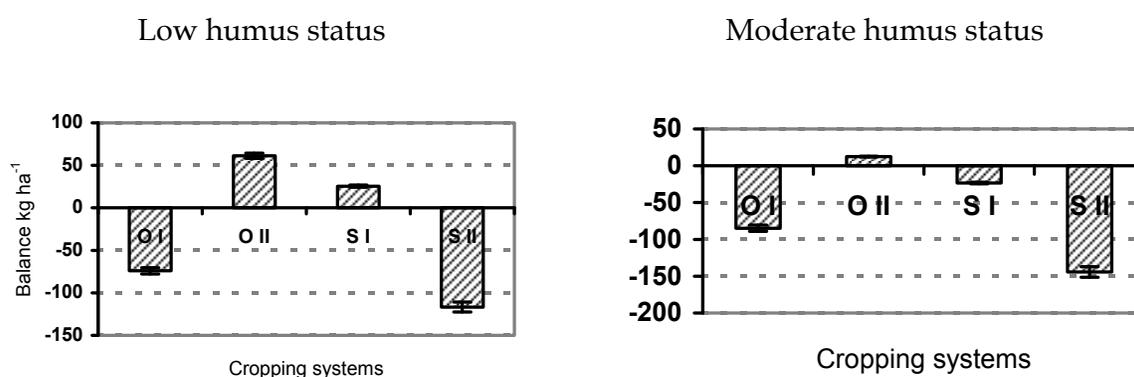


Fig. 9. N balance in the crop rotation sequence - perennial grass-winter wheat-pea

In the sustainable II cropping system, having applied mineral fertilizers for winter wheat and pea, the yield increased markedly, compared with those grown in the organic cropping systems, as is indicated when discussing yield productivity, and this resulted in higher nitrogen removal and its negative balance. In this cropping system, in the soil low and moderate in humus status, nitrogen content, incorporated with organic and mineral fertilizers, compensated the content of nitrogen removed with the yield by as little as 37.5 and 31.4 %, respectively.

Phosphorus incorporation with organic fertilizers and removal with the yield of main produce were rather low, therefore in all cropping systems, except for organic I, phosphorus balance was positive (Fig. 10). In the organic I cropping system, when only green manure was used for fertilization, phosphorus removal in the soil low in humus was compensated by 23.6 % and in the soil moderate in humus by 21.9 %. As a result, in this cropping system, in terms of phosphorus, the soil was depleted in both low and moderate humus levels; it's content in the soil over 4 years declined by 15.9 and 19.2 %, respectively. In organic II and sustainable I cropping systems, having incorporated farmyard manure for winter wheat, there was a well-marked phosphorus surplus. In these cropping systems, phosphorus removal with crop yield was compensated by phosphorus incorporation with fertilizers in the soil low in humus by 3.6 and 3.2 times; in the soil moderate in humus by 2.4 and 2.2 time, respectively.

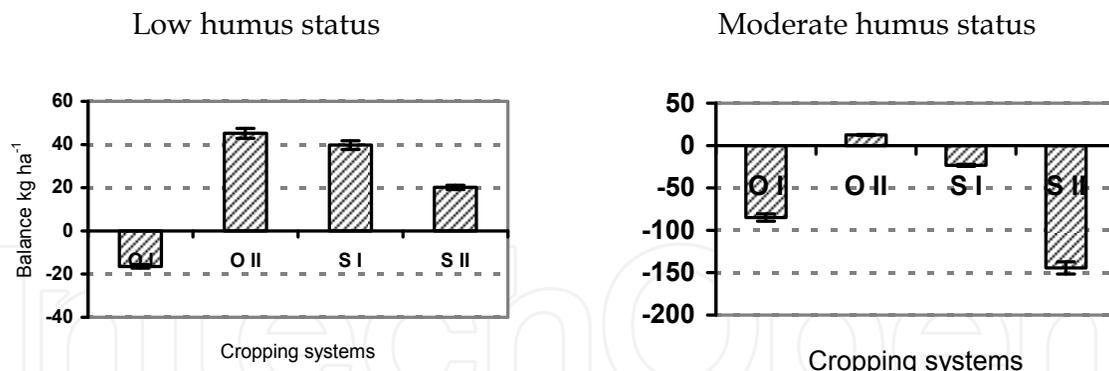


Fig. 10. P balance in the crop rotation sequence - perennial grass-winter wheat-pea

In the sustainable II cropping system, in both humus levels, organic fertilization was supplemented by mineral $N_{30}P_{60}K_{60}$ fertilization. Mineral fertilizers, due to readily plant available nutrients, gave the greatest increase in the yield of main produce and removal of nutrients. In this system, winter wheat main produce yield amounted to on average 4.2 Mg ha^{-1} ; of pea to 1.9 Mg ha^{-1} . However, P content removed with the yield was sufficiently well compensated by that incorporated with fertilizers both in the soil low in humus (171.1 %) and moderate in humus (152.0 %).

Both in the soil low and moderate in humus status, K content accumulated in the main produce of crops was markedly higher than that of phosphorus (Fig. 11).

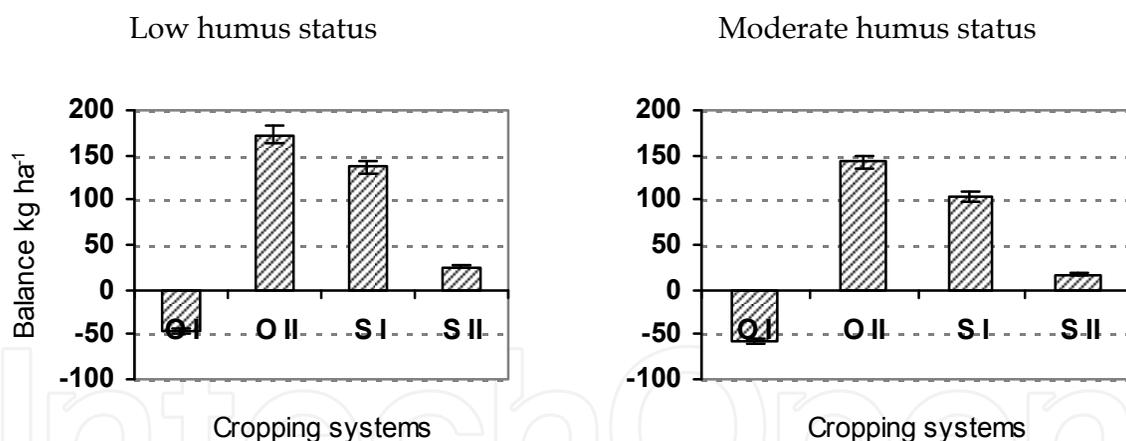


Fig. 11. K balance in the crop rotation sequence - perennial grass-winter wheat-pea

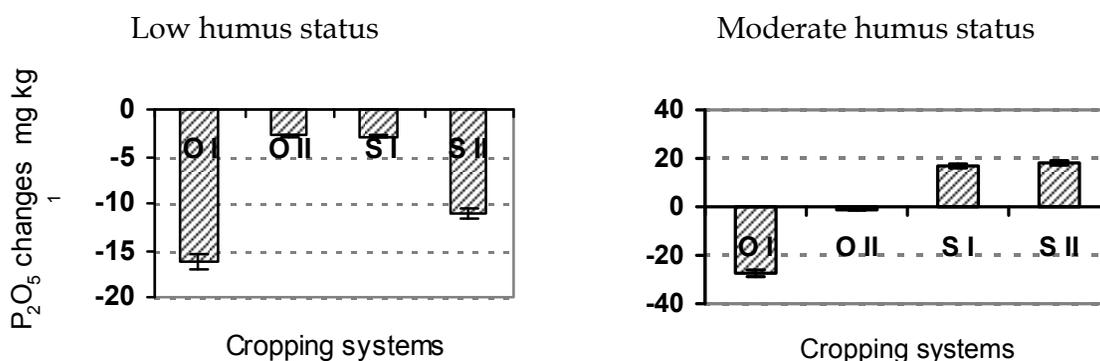
In organic I system, using only green manure for fertilization, potassium balance was strongly negative and plant needs for K in the soil low and moderate in humus were compensated by fertilizers by as little as 43.6 and 41.3 %. In this cropping system, the soil was being depleted, the content of available potassium in the soil low in humus, compared with K content at the beginning of research, declined over a 4-year period by 9.6 %, in the soil moderate in humus by 4.2 %. In the organic II and sustainable I cropping systems, in which green manure fertilization was supplemented by farmyard manure, K balance was strongly positive. In the organic II system, in the soil low and moderate in humus, K plant needs were compensated by fertilizers by 3.6 and 2.4 times, in the sustainable I system, with

higher K removal with yield, by 2.9 and 2.0 times, respectively. In the sustainable II cropping system, with the use of mineral fertilizers, crop yields and nutrient removal were markedly higher, therefore potassium balance was slightly surplus, in low and moderate humus status soils it amounted to 122.7 and 114.2 %.

3.4 The effect of cropping systems on the changes of main nutrients elements in the soil

3.4.1 Available phosphorus

From the environmental protection viewpoint, seeking to explore safer systems, by biologizing agricultural production, it is important to maintain sustainability of soil productivity parameters. In the soil low in humus, which was also low in phosphorus at the beginning of research, the investigated means in the cropping systems did not secure positive changes in available phosphorus (Fig. 12).



LSD05: A - 6.76, B - 11.70, AB - 17.88

Fig. 12. The effect of cropping systems on the changes in available phosphorus in the 0-20 cm soil layer, mg kg⁻¹

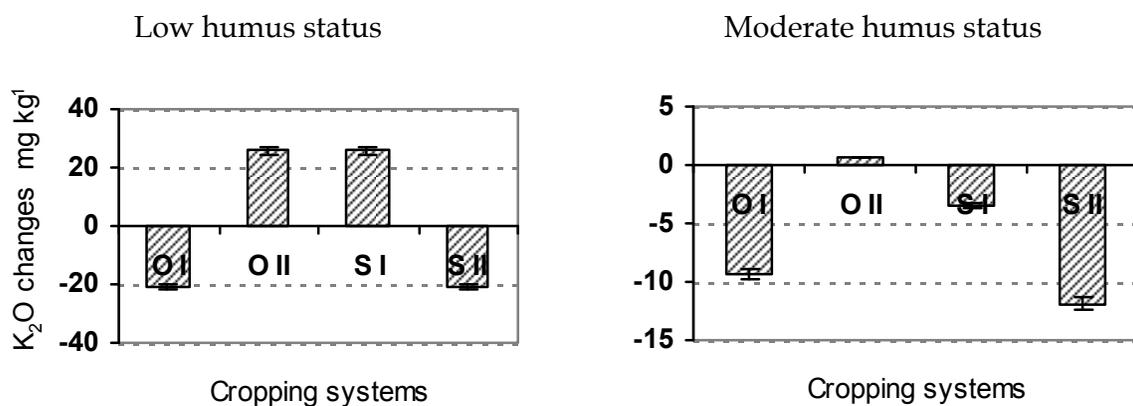
Compared with the initial data, the most marked reduction in available phosphorus content in the soil occurred in the organic I and sustainable II cropping systems, in which only green manure or moderate mineral NPK rates were used for fertilization - 16.2 and 11.0 mg kg⁻¹, respectively. In the cropping systems in which phosphorus contents removed with yield were compensated by those introduced with farmyard manure, the available phosphorus level in the soil remained close to initial.

In the soil moderate in humus, the initial phosphorus level was considerably higher compared with the soil low in humus. At the end of the sequence, in the organic I cropping system, we established a significant reduction in available phosphorus content by 27.4 mg kg⁻¹, compared with the initial level. In the organic II system, it remained close to initial. In the sustainable I and II cropping systems, a marked increase in available phosphorus content in the soil was determined, which was by 16.9 and 18.1 mg kg⁻¹ higher compared with that before trial establishment.

In the soil low in humus, the content of phosphorus accumulated in catch crops' biomass depended moderately on the content of available phosphorus in the soil $r=0.521$ ($P<0,05$). In the soil moderate in humus, the shortage of available phosphorous was less severe, therefore there was no relationship between phosphorus content accumulated in catch crops' biomass and available phosphorus content in the soil.

3.4.2 Available potassium

Heavy-textured soils are characterised by high potassium status, this shows that the soil constantly releases enough potassium compounds that are readily uptaken by plants, and the potassium content incorporated into the soil does not strongly influence plant nutrition. At the beginning of research, clay loam soil low in humus had high potassium content, and the soil moderate in humus had very high content of potassium (Fig. 13). In the soil low in humus, in organic I cropping system, using only green manure that compensated only 43.6 % of potassium removed with the yield, the changes in available potassium content were significantly negative - 21.0 mg kg⁻¹, compared with the initial level. Similar negative changes in available potassium were established in the sustainable II cropping system, in which only moderate mineral fertilizer rates were applied. In the cropping systems, farmyard manure applied once in the crop rotation determined significant positive changes in available potassium - 26.0 and 25.7 mg kg⁻¹ respectively, compared with the initial status.



LSD05: A - 2.85, B - 4.93, AB - 7.53

Fig. 13. The effect of cropping systems on the changes in available potassium in the 0-20 cm soil layer, mg kg⁻¹

In the soil moderate in humus, like in the soil low in humus, negative changes in available potassium were established in organic I and sustainable II cropping systems, by 55.2 and 42.6 % lower than in the soil low in humus. In organic II and sustainable I cropping systems, in which farmyard manure had been applied, the changes in available potassium were similar to initial levels. In the soil both low and moderate in humus, available potassium content weakly correlated with potassium content accumulated in catch crops' biomass.

4. Summary and conclusion

Having summarised the results of research into various alternative cropping systems, investigated over the 2006 - 2009 period in the crop rotation sequence - perennial grasses → winter wheat + catch crop → peas on a clay loam *Endocalcari-Endohypogleyic Cambisol* (CMg-*n-w-can*) with a different humus status, the following conclusions were made:

In the soil with low and moderate humus status, the lowest dry matters and nutrient content for winter wheat were incorporated in organic I farming system with aftermath of perennial grasses. With the application of farmyard manure 40 Mg ha⁻¹ in organic II farming system and aftermath of perennial grasses with mineral fertilizers N₃₀P₆₀K₆₀ in sustainable II

farming system, appropriate reserves of main nutrients – nitrogen, phosphorus and potassium – for optimal yields of winter wheat were incorporated.

Application of farmyard manure had not significant effect to increase the grain yield and accumulation of biogenic elements was not significantly higher than in cases, when only aftermath of perennial grasses was applied for manure. Farmyard manure due to low mineralization in clay loam *Cambisol*, it increased the yield of second rotation member (peas) more effectively, than that of the first rotation member (winter wheat yield).

Significantly higher content of accumulated biogenic elements in main production of winter wheat was observed in sustainable II farming system, when average NPK rates were applied N-43.9 %, P-28.8 % and K-28.3 % more than in cases when only aftermath of perennial grasses was applied for manure.

Catch crops', cultivated in post-harvest period as well as analysis of accumulated biogenic elements in them indicates, that the lowest content throughout averagely both humus backgrounds of accumulated dry matters and biogenic elements in their biomass was observed in mixture of narrow-leafed lupine and oil radish.

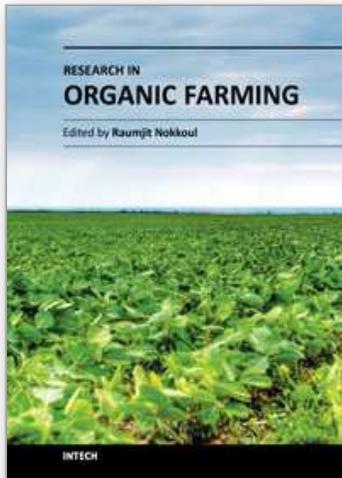
In a *Gleyic Cambisol* low and moderate humus content in the organic system with the application of organic manure – aftermath of perennial grasses for winter wheat, straw and catch crops' biomass for peas, the NPK balance was negative, despite of low removal with low crop yields.

In sustainable farming system, application of 40 Mg ha⁻¹ of farmyard manure for winter wheat and N₃₀ in the form of ammonium nitrate for straw mineralization, as well as catch crops' biomass for peas, NPK balance in the soil low in humus content, was positive and in the soil moderate humus status the nitrogen balance was negative, due to the better conditions for crop growth and higher removal with wheat yield. In sustainable farming system, with application of integrated system of fertilization, incorporation of aftermath of perennial grasses as well as N₃₀P₆₀K₆₀ for winter wheat and N₁₀P₄₀K₆₀ for peas, the wheat yield and accumulated content of biogenic elements in it for both humus environments were the highest; however the nitrogen balance was positive, while that of PK was insignificantly positive. Investigated farming systems demonstrates different character of available P₂O₅ and K₂O accumulation in the soil top layer during crop rotation.

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This book has emerged as a consequence of the difficulties we experienced in finding information when we first started researching. The goal was to produce a book where as many existing studies as possible could be presented in a single volume, making it easy for the reader to compare methods, results and conclusions. As a result, studies from countries such as Thailand, Spain, Sweden, Lithuania, Czech, Mexico, etc. have been brought together as individual chapters, and references to studies from other countries have been included in the overview chapters where possible. We believe that this opportunity to compare results from different countries will open a new perspective on the subject, allowing the typical characteristics of Organic Agriculture and Organic Food to be seen more clearly. Finally, we would like to thank the contributing authors and the staff at InTech for their efforts and cooperation during the course of publication. I sincerely hope that this book will help researchers and students all over the world to reach new results in the field of Organic Agriculture and Organic Food.

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