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The effect of agronomic and meteorological factors on the yield of main and catch crops

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Abstract

Field experiments were conducted during the period 2006–2009 at the Joniškėlis Experimental Station of the Lithuanian Institute of Agriculture. The soil of the experimental site is *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*). The aim was to assess the dependence of catch crops' biomass accumulation on main crops' productivity and rainfall in the cropping systems differring in intensity. The studies were carried out in the soil with a low (1.90–2.00%) and moderate (2.10–2.40%) humus status in organic and sustainable cropping systems. Research was done in the following crop rotation – spring barley (*Hordeum vulgare* L.), perennial grasses (red clover (*Trifolium pretenses* L.) and meadow fescue (*Festuca pratensis* Huds.)), winter wheat *(Triticum aestivum* L.), and pea (*Pisum sativum* L.). The interrelationship between the main crops and catch crops and their relationship with the amount of precipitation were established when growing winter wheat and various catch crops during the wheat post-harvest period.

Grain yield in the soil low and moderate in humus status in the organic system was significantly lower than in the more intensive – sustainable cropping system in which besides green manure, wheat received mineral $N_{30}P_{60}K_{60}$ fertilization. In the soil low in humus status, in all cropping systems the relationship between winter wheat grain yield and amount of precipitation was stronger than that in the soil moderate in humus status. In the organic cropping systems, using only organic fertilizers, winter wheat grain yield was more strongly dependent on the amount of precipitation, than in the sustainable system, using integrated fertilization system. Averaged over all cropping systems, the dry matter content in the above-ground and under-ground biomass of catch crops grown in the soil moderate in humus was by 5.5% higher than that in the soil low in humus. A significant relationship between catch crops' phytomass and precipitation amount was established only in September, when it was relatively warm and plants effectively utilised moisture reserves. In the soil low in humus, in both organic cropping systems the dependence of catch crops' phytomass on the amount of precipitation was direct and strong, respectively; in sustainable I, in which N_{30} had been applied for straw mineralization, there was no relationship.

Key words: low and moderate soil humus status, organic and sustainable farming systems, main and catch crops, rainfall.

Introduction

In the intensive farming system, crop cultivation technology and fertilization system are often targeted at solely plant needs. Heavy use of mineral fertilizers (especially nitrogen) promotes even more intensive soil organic matter decomposition, which may disturb soil fertility self-regulation balance (Fliessbach et al., 2000; Hodge et al., 2000; Maikštėnienė et al., 2008; Marschner et al., 2008). The negative consequences resulting from intensive agricultural development prompt to seek greater harmony with nature by maintaining potential plant productivity and preserving healthy environment, consequently organic farming priorities are highlighted (Gliessman, 2007). However, its implementation is a complex and long process, since it is necessary to restore natural, biological properties of soil, which is a major component of an agrosystem producing plant nutrients (Bučienė, 2003; Kibblewhite et al., 2004). Organic farming is spreading more rapidly on unproductive soils. Although on such soils an opportunity to solve environmental and water pollution problems emerges, farmers fail to produce high yields of organic produce. Incentives and policies for ensuring the sustainability of agriculture and ecosystem are crucial if we are to meet the demands of improving yields without compromising environmental integrity or public health (Tilman et al., 2002).

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 et al. 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. This discourages the development of organic agriculture, and low organic production volumes are a meagre reserve for safe food (Tausojamoji žemdirbystė..., 2008). In alternative cropping systems, plant demand for major nutrients is compensated by soil nutrient reserves and nutrients released from organic matter (Tripolskaja, 2005; Agroekosistemų komponentų..., 2010). 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.

The consistent patterns of different ecosystems are changing due to climate change (Bučienė, 2003; Cedro, 2006). The influence of anthropogenic activities results in the longer growing season, with the possibility after the main crops to grow catch-crops, in order to take advantage of the solar radiation energy longer and keep the soil covered. Besides that, catch crops are one of the main sources of the organic fertilizers in the organic farming agro-systems.

The objective of the present study was to assess the dependence of catch crop biomass accumulation upon main crop productivity and rainfall in the cropping systems of different intensity.

Methods and materials

Two bi-factor field experiments were conducted at the Joniškėlis Experimental Station of the Lithuanian Institute of Agriculture during 2006–2009 on a clay loam *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*). In topsoil (0–25 cm), mobile P_2O_5 in the soil low in humus was 75–101 mg kg^{-1}, in the soil moderate in humus 111–134 mg kg^{-1} and K_2O 207–235 and 221–240 mg kg^{-1}, respectively. 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 morainic clay loam at the depth of 70–80 cm. Research was done in the northern part of Central Lithuania's lowland (56º21′ N, 24º10′ E).

The crop rotation, expanded in time and space, consisted of perennial grasses – red clover (*Trifolium pretenses* L.) cv. 'Vyliai' and meadow fescue (*Festuca pratensis* Huds.) cv. 'Dotnuva 1', winter wheat (*Triticum aestivum* L.) cv. 'Ada', pea (*Pisum sativum* L.) cv. 'Pinochio' and spring barley (*Hordeum vulgare* L.) cv. 'Luokė' with undersown perennial grasses. The investigated measures – cropping systems were assessed in the grass-cereals sequence: perennial grasses of the 1st year of use (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; Lietuvos dirvožemių..., 1998; Amacher et al., 2007) – *factor A*: 1) – low (1.90–2.01%), 2) – medium (2.10–2.40%);

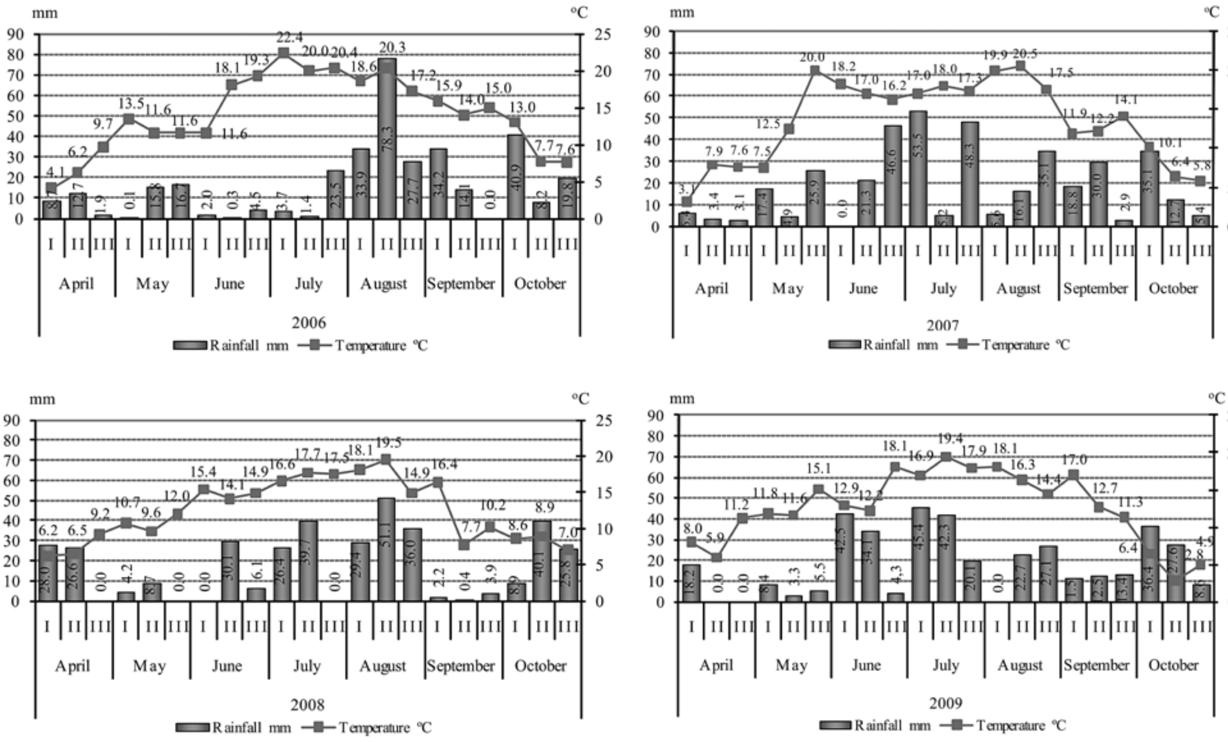
cropping systems – factor B: organic I (O I) – aftermath of perennial grasses, straw + narrow-leaved lupine (*Lupinus angustifolius* L.) and oil radish (*Raphanus satinus* var. *oleifera* L.), organic II (O II) – farmyard manure 40 Mg ha^{-1} + aftermath of perennial grasses, straw + white mustard (*Sinapis alba* L.), sustainable I (S I) – farmyard manure 40 Mg ha^{-1}, straw + N_{30} + white mustard and buckwheat (*Fagopyrum exculentum* Moench.) and sustainable II (S II) – aftermath of perennial grasses + $N_{30}P_{60}K_{60}$ straw + N_{30}. The field experiment was arranged as a randomized single row design in four replicates.

Plant and soil analyses. Composite samples were taken at harvesting of the main crop in every field in the main and secondary produce as well as the samples of above-ground biomass of catch crops. Crop 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 above-ground and underground biomass were taken for the determination of dry matter (dried to a constant weight at 105ºC).

Soil available phosphorus (P_2O_5) and potassium (K_2O) contents were measured by Egner-Riem-Domingo (A-L) method. Humus content was measured by Tyurin method. Soil and plant agrochemical analyses were made at the Chemical Research Laboratory of the Lithuanian Institute of Agriculture.

Statistical analysis. The research data were statistically processed by the correlation-regression analysis between the yield of main crop and catch crop biomass and the amount of rainfall, using the statistical package ANOVA for two-factor experiment (Tarakanovas, Raudonius, 2003).

Meteorological conditions. In 2005, the growing season of the main crops was distinguished by less rainfall in July compared with the long-term mean, therefore cereals matured early. In 2005, after cereal harvesting, September and October were warmer and wetter than usual (Fig. 1).



Parameters	Long-term average						
	Months						
	IV	V	VI	VII	VIII	IX	X
Temperature ºC	6.2	12.3	15.6	17.1	17.1	12.0	6.3
Rainfall mm	37.4	45.6	59.4	69.2	67.9	57.9	45.5

Figure 1. Meteorological conditions in the experimental period

In 2006, during the growing season of the main crops (May–July), when cereals grow intensively and utilize nutrients from the soil, there was also a shortage of moisture. The rainfall that fell during that period accounted for only 38.9% of the long-term mean. Meanwhile the mean daily temperature in June and July was by 0.7 and 3.7°C, respectively higher. The yield of the main crops was low. However, the growing season of catch crops (August–October 2006) was the most favourable for catch crops' growing compared with the other growing seasons. Minimal daily temperature dropped below 10°C only in the second half of September. Moreover, in August, September and October the mean daily air temperature exceeded the long-term mean by 1.5, 2.9 and 3.1°C. During the growing season of catch cops the amount of precipitation exceeded the long-term mean by 85.5 mm; there was a lot of rainfall in August and October.

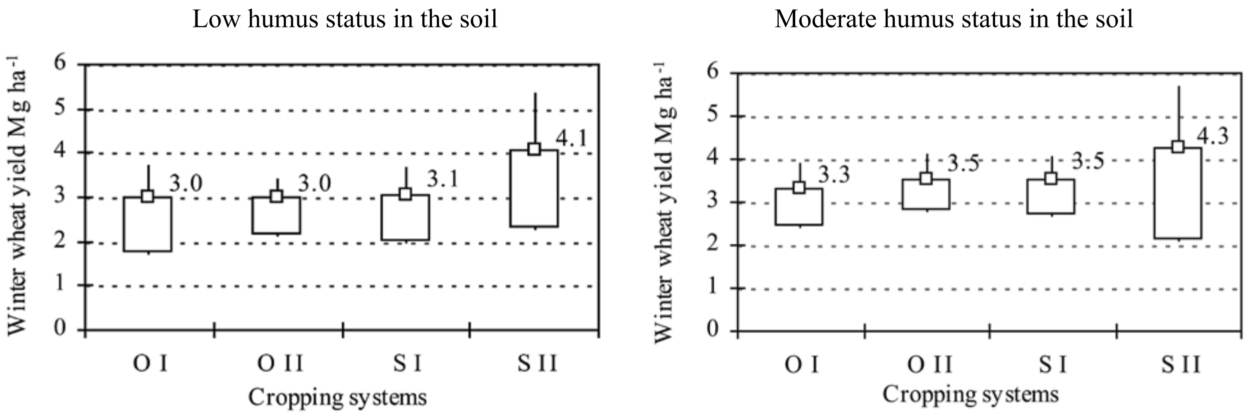
After the dry year 2006, the growing season of the main crops (May–July 2007) was relatively warm and wet. As a result, conditions were especially favourable for cereal growing. Catch crops sown after cereal harvesting grew poorly. In August, September, October the mean daily temperature was higher than the long-term mean, the minimal daily air temperature dropped below 10°C already at the end of August and persisted such all through September, although the days were relatively warm. Poor plant emergence and establishment were determined by doughtier first half of August, heavier rain occurred only on August 20.

In 2008, the mean daily air temperature during the main crops' growing season differed little from the long-term mean; however, this period was one of the driest ones. The plants were short of moisture already at early growth stages – May and June. This impeded plant nutrient uptake from the soil. Catch crops' growing season was rather wet. However, precipitation distributed very unevenly – in August the rainfall exceeded the long-term mean by 48.6 mm, in October by 29.3 mm. September was extremely dry (rainfall amounted to as little as 6.5 mm).

In November 2008–April 2009, the period was warmer by 1.8°C that usual, though wet. High precipitation was observed in December and March – 63.1 and 51.7 mm, respectively. Extremely dry April and May resulted in poor emergence and development of spring crops. However, June and July were very wet.

Results and discussion

Winter wheat grain yield. In our research, the data averaged over 4 rotation fields showed that in organic I cropping system, when using only aftermath of perennial grasses for fertilization, winter wheat yield was rather low, not typical of productive soils and was 3.0 t ha^{-1} of DM (Fig. 2). 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 throughout all cropping system the grain yield was significantly 12.1% higher than in soil with low humus content.



LSD$_{05}$: A – 0.142, B – 0.247, AB – 0.377

Figure 2. Winter wheat grain yield, 2006–2009

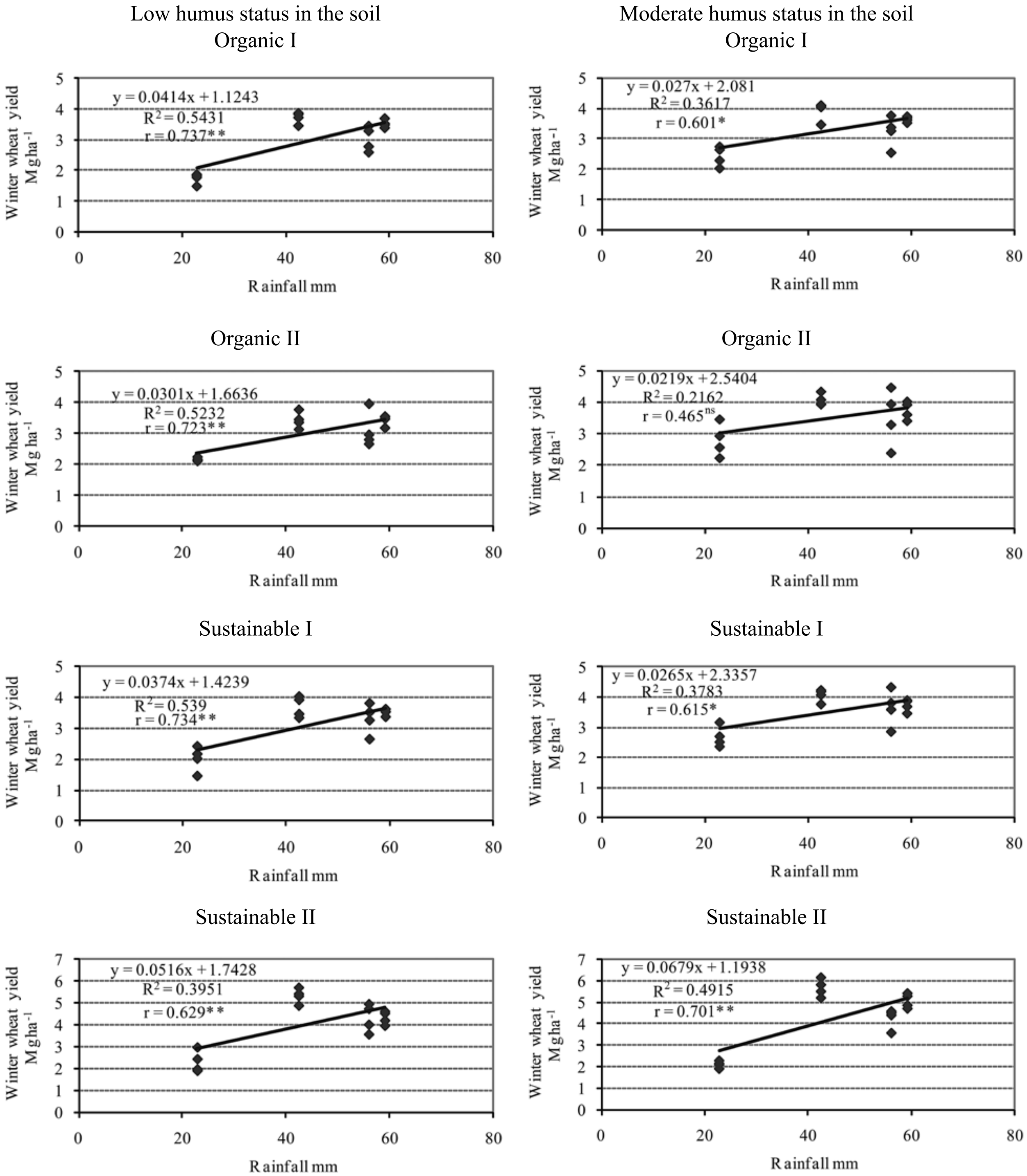
Having applied winter wheat with perennial grass aftermath, farmyard manure, mineral fertilizers or their combinations, fertilizer efficacy differed between years. It was largely dependent on the experimental years' amount of precipitation during the growing season, which determined mineralization intensity of organic fertilizers. The strength of the correlation between winter wheat grain yield and amount of precipitation depended on soil humus level and fertilizers used in the cropping systems (Fig. 3).

In the soil low in humus status, in all cropping systems the relationship between winter wheat grain yield and amount of precipitation was stronger than that in the soil moderate in humus status. In the organic I and II cropping systems, using only organic fertilizers, winter wheat grain yield was more strongly dependent on the amount of precipitation (r = 0.737** and 0.723**, respectively) than in the sustainable II system, using integrated fertilization system (r = 0.629**).

Such results were determined by the fact that in the organic cropping systems application of organic fertilizers, whose mineralization rate and at the same time nutrient release for plant nutrition are largely dependent on moisture conditions. During the dry growing season, organic fertilizers release little nutrients and their influence on crop yield is negligible.

In the soil moderate in humus status, in the organic I and II cropping systems, having used only perennial grass aftermath or in combination with 40 Mg ha^{-1} farmyard manure and in the sustainable I system having applied only farmyard manure for winter wheat fertilization grain yield moderately correlated with the amount of precipitation. In the sustainable II cropping system, in which perennial grass aftermath and minimal mineral fertilizer rates had been applied, wheat grain yield correlation with the amount of precipitation was strong. It is likely that in the soil moderate in humus status, in the case of higher precipitation, mineral fertilizers promoted humus mineralization and nutrient release, which improved plant nutrition and exerted a positive effect on the yield.

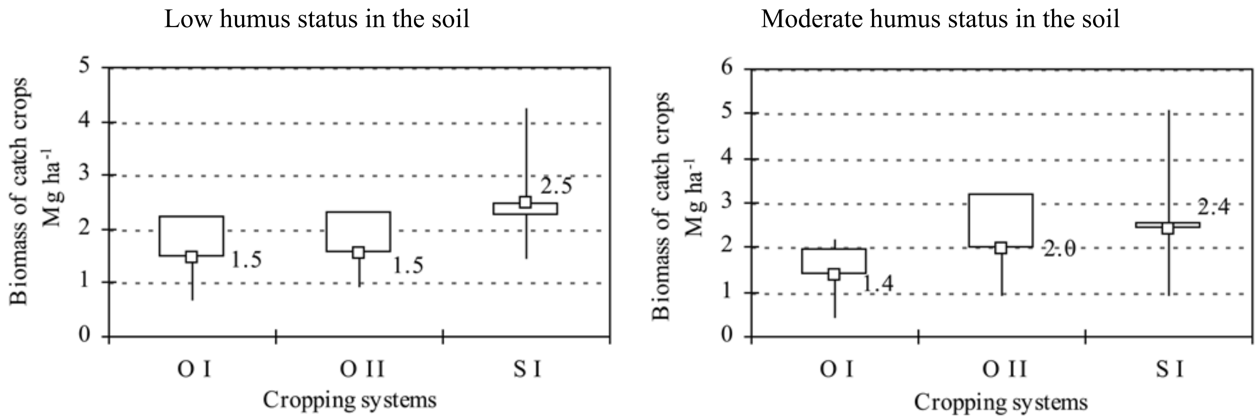
Above-ground and under-ground biomass contents of catch crops. After main crops cultivation during their post-harvest period, in order to keep remaining nutrients in the soil from migration to deeper layers of soil, catch crops are cultivated, which are the main source of organic manure (Tripolskaja, 2005; Tausojamoji žemdirbystė…, 2008). The researchers suggest that under favourable conditions the biomass of catch crops incorporated with straw into the soil start to decompose in the autumn (Lahti, Kuikman, 2003). The scientists of many countries estimated, that incorporation of catch crops biomass for green manure have different positive effect (Abdallahi, N'Dayegamiye, 2000; Kara, Penezoglu, 2000; Marcinkevičienė, Pupalienė, 2009).



Significance levels: * – $p < 0.05$, ** – $p < 0.01$; ns – not significant

Figure 3. The relationship between indicators of winter wheat grain yield and average of rainfall

Analysis of catch crops' above-ground and under-ground biomass during winter wheat (pea pre-crop) post-harvest period showed that markedly higher DM content was accumulated in the 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 60.8% in moderate-humus status soil it made up 23.4%. 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. 4). The lowest DM content in catch crops' above-ground and under-ground biomass in the soil with low and moderate humus status was accumulated when growing narrow-leaved lupine in mixture with oil radish.



LSD$_{05}$: A – 0.129, B – 0.182, AB – 0.288

Figure 4. Above-ground and under-ground biomass contents of catch crops (DM)

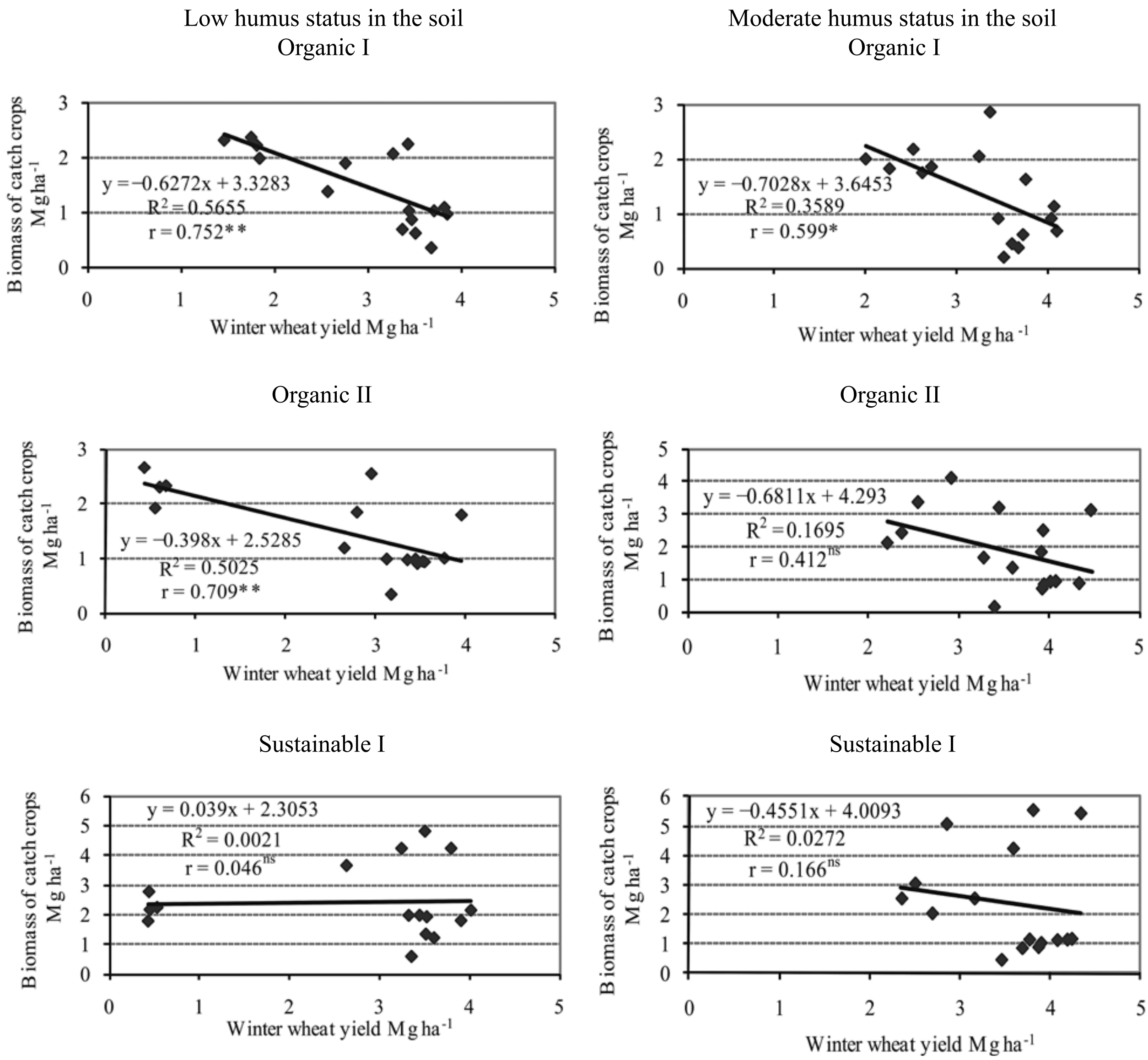
Averaged over all cropping systems, the DM content in above-ground and under-ground biomass of catch crops grown in the soil moderate in humus content was by 5.5% higher than that in the soil low in humus status. It is consistent that both DM content accumulated in catch crops' biomass content were markedly higher in sustainable I cropping system, in which a low nitrogen fertilizer rate N_{30} was applied for straw mineralization.

Figure 1 shows that winter wheat grain yield in different cropping systems substantially differed. This was determined by the amount of organic fertilizers, their chemical composition and mineralization rate. The more rainfall fell in the first half of the summer, the higher the winter wheat grain yield was and the more nutrients were removed from the soil. Figure 4 demonstrates how winter wheat grain yield and nutrients removed with it determined phytomass content of catch crops grown during wheat post-harvest period.

In the soil low in humus status, during the winter wheat post-harvest period, in the organic I and II cropping systems, the amount of phytomass of catch crops strongly inversely correlated with winter wheat grain yield – r = 0.752–0.709**; in the sustainable I cropping system, having incorporated N_{30} for straw mineralization, which had a positive effect on catch crops' growth and development, there was no correlation (Fig. 5).

In the soil moderate in humus status, in the organic I cropping system, in which only green manure had been used, the dependence of catch crops' phytomass on winter wheat yield was moderately strong r = 0.599*; in organic II, in which farmyard manure had been applied the relationship was weak, and in the sustainable I system, having used N_{30} for wheat straw mineralization there was no significant correlation with wheat yield.

The amount of precipitation during the growing season (August–October) of catch crops grown during winter wheat post-harvest period varied from 256.8 mm (in 2006) to 159.8 mm (in 2009). The deviation from the long-term mean precipitation (171 mm) in separate years made up to 50.2% more or 6.5% less. The correlation analysis showed that there was weak relationship between catch crops' phytomass accumulation and amount of precipitation during the August–October period. A significant relationship between catch crops' phytomass and precipitation amount was established only in September, when it was relatively warm and plants effectively utilised moisture reserves (Fig. 6).

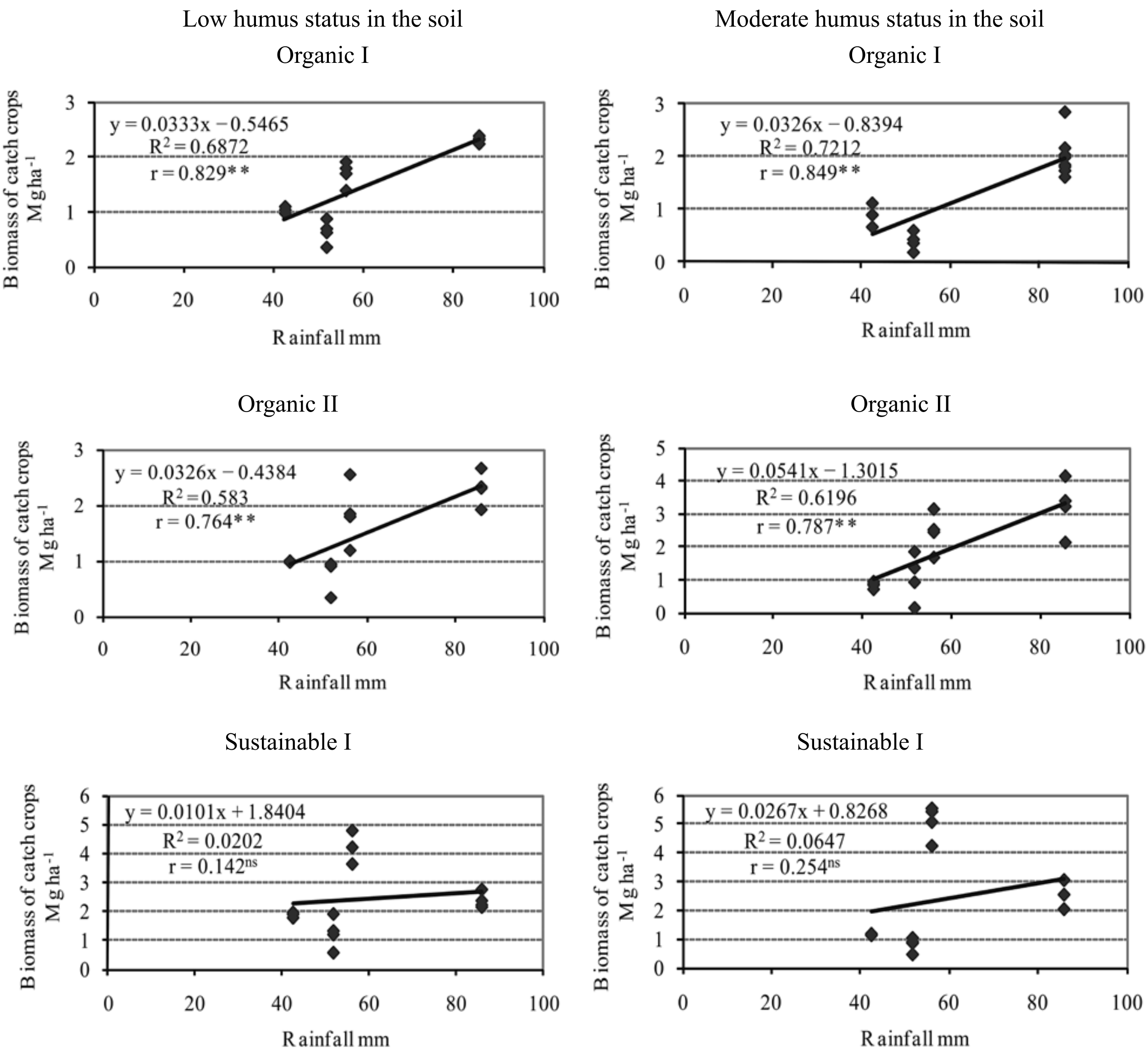


Note. Significance levels: * – $p < 0.05$, ** – $p < 0.01$; ns – not significant.

Figure 5. The relationship between indicators of above-ground and under-ground biomass content of catch crops and winter wheat grain yield

The relationship between phytomass of catch crops grown during wheat post-harvest period in different cropping systems and amount of precipitation in September was of different strength and depended on soil humus status and biological properties of plants.

In the soil low in humus status, in both organic cropping systems the dependence of catch crops' phytomass on the amount of precipitation was direct and strong r = 0.829** and 0.764**, respectively; in sustainable I, in which N_{30} had been applied for straw mineralization, there was no relationship. In the soil moderate in humus, like in that low in humus, the relationship was similar, in the organic cropping systems the relationship between catch crops' phytomass and amount of precipitation in September was direct and strong r = 0.849** and 0.787**, respectively; and in sustainable I system there was no significant relationship.



Significance levels: * – $p < 0.05$, ** – $p < 0.01$; ^{ns} – not significant.

Figure 6. The relationship between indicators of above-ground and under-ground biomass content of catch crops and average of rainfall

Conclusions

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

1. Grain yield in the soil low and moderate in humus status in the organic system was significantly low, than in the more intensive – sustainable cropping system in which besides green manure, wheat received mineral $N_{30}P_{60}K_{60}$ fertilization.

2. In the soil low in humus status, in all cropping systems the relationship between winter wheat grain yield and amount of precipitation was stronger than that in the soil moderate in humus status.

3. In the organic cropping systems, using only organic fertilizers, winter wheat grain yield was more strongly dependent on the amount of precipitation, than in the sustainable system, using integrated fertilization system.

4. Averaged over all cropping systems, the DM content in above-ground and under-ground biomass of catch crops grown in the soil moderate in humus content was by 5.5% higher than that in the soil low in humus status.

5. A significant relationship between catch crops' phytomass and precipitation amount was estab-

lished only in September, when it was relatively warm and plants effectively utilised moisture reserves. In the soil low in humus status, in both organic cropping systems the dependence of catch crops' phytomass on the amount of precipitation was direct and strong, respectively; in sustainable I, in which N_{30} had been applied for straw mineralization, there was no relationship.

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Agronominių ir meteorologinių veiksnių įtaka pagrindinių bei tarpinių pasėlių derliui

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Santrauka

Lauko bandymai vykdyti 2006–2009 m. Lietuvos žemdirbystės instituto Joniškėlio bandymų stotyje sunkaus priemolio giliau karbonatingame giliau glėjiškame rudžemyje (Rdg4-k2), *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*). Tyrimų tikslas – taikant skirtingo intensyvumo žemdirbystės sistemas nustatyti tarpinių pasėlių biomasės kaupimo priklausomumą nuo pagrindinių pasėlių produktyvumo ir kritulių kiekio. Tyrimai atlikti mažo (1,90–2,00 %) ir vidutinio (2,10–2,40 %) humusingumo dirvožemyje, taikant ekologinę ir tausojamąją žemdirbystės sistemas. Sėjomaina išskleista laike ir erdvėje – vasarinis miežis (*Hordeum vulgare* L.), daugiametės žolės (raudonasis dobilas (*Trifolium pratense* L.) ir tikrasis eraičinas (*Festuca pratensis* Huds.)), žieminis kvietys (*Triticum aestivum* L.), sėjamasis žirnis (*Pisum sativum* L.). Pagrindinių ir tarpinių pasėlių tarpusavio priklausomumas ir jų ryšys su kritulių kiekiu nustatytas auginant žieminius kviečius, o jų popjūtiniu laikotarpiu – skirtingus tarpinius pasėlius.
Taikant visas žemdirbystės sistemas, žieminių kviečių grūdų derliaus priklausomumas nuo kritulių kiekio buvo stipresnis mažo humusingumo dirvožemyje nei vidutinio. Ekologinėse žemdirbystės sistemose naudojant tik organines trąšas, žieminių kviečių grūdų derlius stipriau priklausė nuo kritulių kiekio nei tausojamosiose taikant integruotą tręšimo sistemą. Visose žemdirbystės sistemose tarpinių pasėlių fitomasės sausųjų medžiagų sukaupimas nustatytas vidutiniškai 5,5 % didesnis vidutinio humusingumo dirvožemyje nei mažo. Tarpinių pasėlių fitomasės sukaupimas silpnai priklausė nuo kritulių kiekio rugsėjo mėnesį, kai teigiamų temperatūrų suma dar pakankama augalams vystytis ir efektyviai panaudoti drėgmės atsargas. Taikant abi ekologinės žemdirbystės sistemas, mažo ir vidutinio humusingumo dirvožemyje tarpinių pasėlių fitomasės priklausomumas nuo kritulių kiekio buvo tiesioginis stiprus; tausojamojoje, kurioje šiaudų mineralizacijai panaudota N_{30}, ryšio nebuvo.

Reikšminiai žodžiai: mažo ir vidutinio humusingumo dirvožemis, ekologinė ir tausojamoji žemdirbystė, pagrindiniai ir tarpiniai pasėliai, krituliai.