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EFFECT OF BUCKWHEAT AND POTATO AS FORECROPS ON SOIL MICROBIAL PROPERTIES IN CROP ROTATION

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*Field trials were carried out at the experimental cereal breeding fields in Stende (Latvia), an area characterized by a northern temperate climate. The soil had been under short-term organic or conventional crop management and was then subjected to crop rotation, using buckwheat (*Fagopyrum esculentum *Moench.) and potato (*Solanum tuberosum *L.) as the forecrops; wheat (*Triticum aestivum *L.) and oat (*Avena sativa *L.) as the following crops; and two fertilizer regimes under common organic and conventional practices. As the evaluation criteria of the soil quality, physico-chemical (pH value, organic matter, N, P, K) were tested. In addition, the following biological properties were estimated: plate counts of different physiological groups of microorganisms, soil microbial respiration, enzymatic activity (urease, dehydrogenase and fluoresceine diacetate hydrolysis) of soil microorganisms. Soil microbial respiration activity, FDA hydrolysis and urease activity showed a tendency to decrease in the soil after potato cultivation as the forecrop. The number of bacteria was higher in plots with wheat, and the actinomycete count was lower after oat cultivation. The number of bacteria, actinomycetes, fungi, as well as soil microbial respiration and enzymatic activity, fluctuated due to weather seasonality.*

Key words: *crop rotation, buckwheat, potato, soil enzymatic activity, soil respiration.*

INTRODUCTION

Maintaining a high level of soil health is the ultimate goal in the search for a sustainable production system. A better understanding of soil ecology could lead to more precise management of soil organisms for beneficial purposes in agriculture. Management and cropping systems varying in soil mobilisation rates and plant-residue inputs can have profound effects on the biological properties of the soil (Govaerts *et al*., 2008; Silva *et al*., 2010). The soil microbial biomass is fundamental to maintaining soil function, as it represents the main source of soil enzymes that regulate the transformation processes of elements in soils. It also controls the build up and break down of organic matter, the decomposition of organic residues, and is an early indicator of changes in soil management and of fertiliser practices (Shannon *et al*., 2002; Tu *et al*., 2006; Martinez-Salgado *et al*., 2010)

Soil microorganisms play an important role in soil development and function, and therefore, they are one of the indicators of soil fertility. The large and active soil microbial biomass is critically important for sustainable productivity of soils in organic farming systems. Plant growth in organic farming systems depends on the functions performed by soil microbes, particularly in nutrient supply. In comparison with conventional farming, organic farming has potential benefits in promoting soil structure formation, enhancing soil microbiological biodiversity and can improve yield (Grandy *et al*., 2006; Tu *et al*., 2006a). The impact of the farming system chosen is reflected as changes in soil biological activity, which is one of the most important indicators of soil quality. Many studies indicate that soil from conventional agro-ecosystems has a lower microbial biomass and diversity in comparison to biological farming techniques. The most important factors affecting microbial activity and community structure are the quantity and quality of organic inputs (Parkinson and Coleman, 1991; Mäder *et al*., 2002; Tu *et al*., 2006a).

Moreover, soil microbiological activity depends on plant-microbe interactions. Plants can affect the composition and activity of the microbial community around their root systems through the selective exudation of specific carbohydrates, carboxylic and amino acids. These microbial communities can be cultivar-specific. (Parmar and Dardarwal, 1999; Sturz and Christie, 2003).

Crop rotation efficiently cycles nutrients from season to season and promotes microbial diversity. However, a complicated picture emerged from the analysis of crop-rotation and succession systems (Franchini *et al*., 2007). Different sequences and rotations with plants showing varied C : N ratios that qualitatively and quantitatively affected immobilisation and mineralisation processes, making the picture unclear in terms of microbial biomass parameters. In some cases, reducing N availability in the soil may even result in N deficiency for subsequent crops in non-stabilised systems (Silva *et al*., 2010).

In order to improve both the sustainability of the agricultural system and the physical and biological condition of the soil, intensively managed potato production systems often utilise conservation practices with short-term rotations, (Carter *et al*., 2009). Buckwheat is becoming more and more popular as a forecrop in Latvia. It decreases the spread of plant diseases, soil acidification, and it is valuable as a green fertiliser (Rancāne u.c., 2009). At the same time, potatoes and buckwheat are incompatible cultures and they should not be grown in the same crop rotation (Lejins and Lejina, 2008).

Quantifying the changes of soil quality generated by agricultural operations is difficult, because, on the one hand, there is no clear concept regarding soil quality, and, on the other hand, there is no universally accepted methodology for evaluating changes in soil quality (Trasar-Cepeda *et al*., 2008). The general biochemical parameters most commonly used to estimate changes in soil quality include carbon associated with the microbial biomass, dehydrogenase activity and N mineralization capacity, while the most commonly used specific parameters include phosphatase (acid or alkaline), ß-glucosidase and urease activities (Trasar-Cepeda *et al*., 2008). FDA is hydrolysed by proteases, lipases, esterases and other enzymes produced by heterotrophic microorganisms. The enzymatic activity of microorganisms depends on many factors, such as the physiological state of the microorganisms and the chemical composition and physical properties of the environment. Respiration intensity summarises the activity of different soil organisms (bacteria, fungi, *Protozoa*) and also plant root respiration. Soil microbiological activity also depends on plant-microbe interactions. Through the selective exudation of specific metabolites, plants are able to influence the composition and activity of the microbial community around their root systems (Brooke, 2001; Pell *et al*., 2005).

The aim of this study was to evaluate the effect of buckwheat and potato as the forecrops in crop rotation in biological and conventional farming, using different physiological groups of soil microorganisms as well as microbial respiration and enzymatic activity as the evaluation criteria.

MATERIALS AND METHODS

Crop cultivars. In the crop rotation experiments, buckwheat and potato were the forecrops followed by wheat and oat in the next cropping season. The oat cultivar 'Laima' in 2009, wheat cultivars 'Ufo' and 'Fredis' (winter) in 2010, buckwheat cultivar 'Aiva', and potato cultivars 'Adretta' in 2009 and 'Borodjanski rozovij' in 2010 were used.

Experimental site and design. The field experiments were set up at the State Stende Cereal Breeding Institute, Talsi District, Latvia. Fields with organic and conventional management systems were included in the experiments. The systems differed in fertilisation methods and protection strategies against diseases, weeds and pests.

The experiment was designed with six experimental plots (Table 1) to compare the effect of buckwheat and potato as the forecrop on soil biological activity in organic and conventional management systems.

Table 1

THE SCHEME OF CROP ROTATION

Forecrop	Crop / tillage	Year	Plot No.
Buckwheat	Wheat / conventional	2010	1
	Wheat / organic	2010	2
Potato	Wheat / organic	2010	3
Buckwheat	Oats / conventional	2009	4
	Oats / organic	2009	5
Potato	Oats / conventional	2009	6

In the organic management system (three plots) the field soil was harrowed in the autumn and spring. In the 2nd and 5th experimental plots, buckwheat was used as a green manure, and in the 3rd experimental plot, potato was grown as a forecrop. Buckwheat was ploughed into the soil at the beginning of flowering, but in the field with potatoes, the soil was prepared only with potato post-harvesting residues. On these fields, oat and wheat were cultivated without mineral fertilisers and chemical plant protection.

Fertilisation with NPK 16:16:16 at 500 kg ha-1 were used in the conventional management system (1st, 4th and 6th plots). The dressing fertiliser contained ammonium nitrate 120 kg ha-1. The herbicide Mustang was used as recommended by the manufacturer. Oat and wheat were cultivated on these fields. Crop management included buckwheat or potato as the forecrop, followed by wheat or oats (Table 1).

Soil samples were collected at 0–20-cm depth four times per vegetation period. Composite soil samples consisted of 20 random sub-samples per plot. Soil samples were stored in plastic bags at 4 °C for further testing within one week after collecting samples. Soil dry weight (DW) was determined by drying of the soil at 105 °C for 24 h. At the beginning of the experiment, the soil pH value, organic matter and concentrations of mineral elements were determined in the Laboratory of the State Cereals Breeding Institute. Basic parameters are shown in Table 2.

Plate counts of various physiological groups of microorganisms and soil microbial respiration were determined at the Institute of Soil and Plant Sciences, Latvia University of

Table 2

PHYSICO-CHEMICAL CHARACTERISTICS OF SOIL IN PLOTS

Plot No.	Forecrop	Crop / tillage	pH (1n KCl)	Organic matter (%)	N (mg 100 g^{-1})	P (mg 100 g^{-1})	K (mg 100 g^{-1})
1	Buckwheat	Wheat / conventional	6.2	4.88	300	12.9	24.6
2		Wheat / organic	6.1	2.44	100	10.3	12.3
3	Potato	Wheat / organic	6.0	2.08	130	11.9	16.9
4	Buckwheat	Oat / conventional	5.82	2.12	120	9.2	13.4
5		Oat / organic	5.91	4.41	250	9.8	7.7
6	Potato	Oat / conventional	5.85	2.28	110	8.3	9.9

Agriculture. Soil enzymatic activity was tested at the Institute of Microbiology and Biotechnology, University of Latvia.

Plate counts of the physiological groups of microorganisms. Populations of selected components of the soil microbial community were tested by the plate count techniques (Tate, 1995). Bacteria were cultivated on Nutrient agar, actinomycetes on Actinomycete agar and fungi on Sabouraud Chloramphenicol agar (Scharlau, Spain). The results were expressed as Colony Forming Units (CFU) per gram of dry weight.

Asessment of soil enzymatic and respiration activity. Fluoresceine diacetate hydrolysis (FDA) activity was determined by hydrolysis of fluoresceine diacetate in 0.06 M phosphate buffer pH 7.6 at +37 °C (Chen *et al.*, 1988; Adam and Duncan, 2001). Dehydrogenase activity was determined according to Hayano (1997) by the reduction of 2-p-iodo-3-nitrophenyl-5-phenyltetrazolium chloride to iodonitrophenylformazan at 28 °C. Soil urease activity was determined colorimetrically as NH_4^+-N formation in urea-amended soil samples at 28 °C (Kandeler and Gerber, 1988). All determinations were performed in four replicates and for each soil sample the average values of the four replicates were expressed per gram DW.

Soil biological activity was characterised by the intensity of soil basal respiration. Soil basal respiration was determined by an incubation-alkaline absorption method according to Pell *et al.* (2005). Briefly, 50 g of field moisture soil and 5 mL of 0.1 M KOH was placed into 500 mL sealed jars and incubated 24 h in darkness at 30 °C and titrated with 0.1 M HCl.

RESULTS

Weather conditions monitored during the experiment. Weather conditions sufficiently influence plant growth and soil microbial activity. Therefore, air temperature and rainfall were monitored during the experiment. Most of the rain fell during the period from June to July in 2009 and from July to August in 2010, respectively. In both years the highest temperature was recorded in July (Table 3). The comparison of data on temperature and rainfall amounts (Table 3) showed that the vegetation periods in 2009 and 2010 were quite comparable in terms of weather conditions for the field experiments with oat (2009) and wheat (2010) as the 2nd year crop.

Table 3

CHARACTERISTICS OF WEATHER CONDITIONS DURING THE EXPERIMENT

Month	2009		2010	
	Temperature (C)	Precipitation (mm)	Temperature (C)	Precipitation (mm)
April	6.6	11.5	5.6	26.6
May	11.2	28.8	11.4	73.9
June	13.5	94.3	14.4	35.3
July	17.1	147.5	20.6	88.3
August	15.7	83.4	18.1	211.4
September	13.2	66.6	11.3	85.1
Mean	12.9	72.0	13.6	87.8
Sum of precipitation		432.1		520.6

However, soil moisture, which was sampled monthly from the experimental plots, did not always correlate with the average temperature and precipitation for the sampling period. Moreover, soil samples taken from three experimental fields during one day differed in moisture content. For example, the moisture of the soil sampled at the 1st experimental plot, was up to 7–11 % higher compared to those in the 2nd and 3rd experimental plots, and this difference was observed at all four sampling times (Fig. 1). The spatial distribution of soil moisture in the field is often related to the heterogeneity of soil hydraulic and other physical properties (Archer *et al.*, 1999).

Plate counts of physiological groups of microorganisms. A comparison of wheat and oat as the 2nd year crop by the CFU number of soil microorganisms in physiological groups showed that the number of bacteria was higher in plots with wheat, and number of actinomycetes in oat plots. The number of microscopic fungi did not differ among the variants mentioned above (Fig. 2).

The seasonal changes in the number of actinomycetes during 2009 could be explained by weather patterns, i.e., humidity and temperature, conditions. In the middle of summer the number of actinomycetes decreased, followed by an increase in autumn (Fig. 2D). The results obtained in this experiment indicated the seasonal character of actinomycete

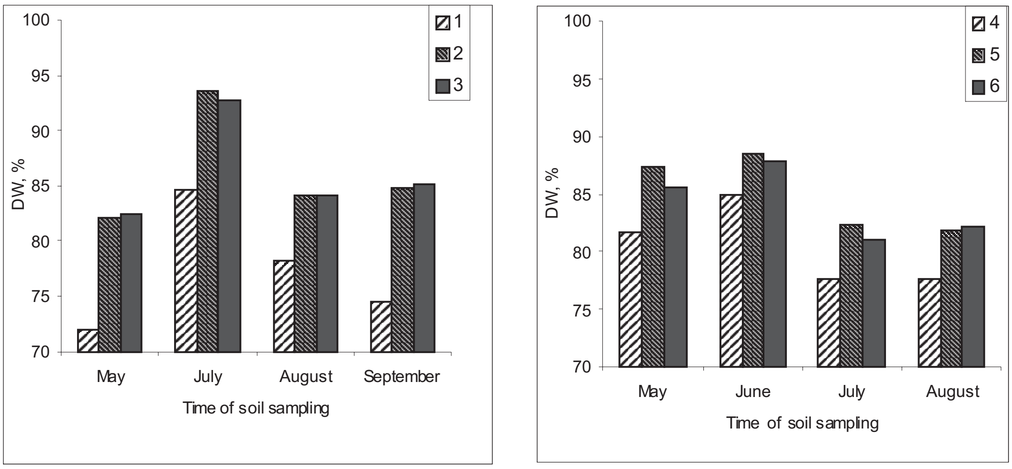

Fig. 1. Soil moisture during the experiment. 1, 2, 3 – 2010; 4, 5, 6 – 2009.

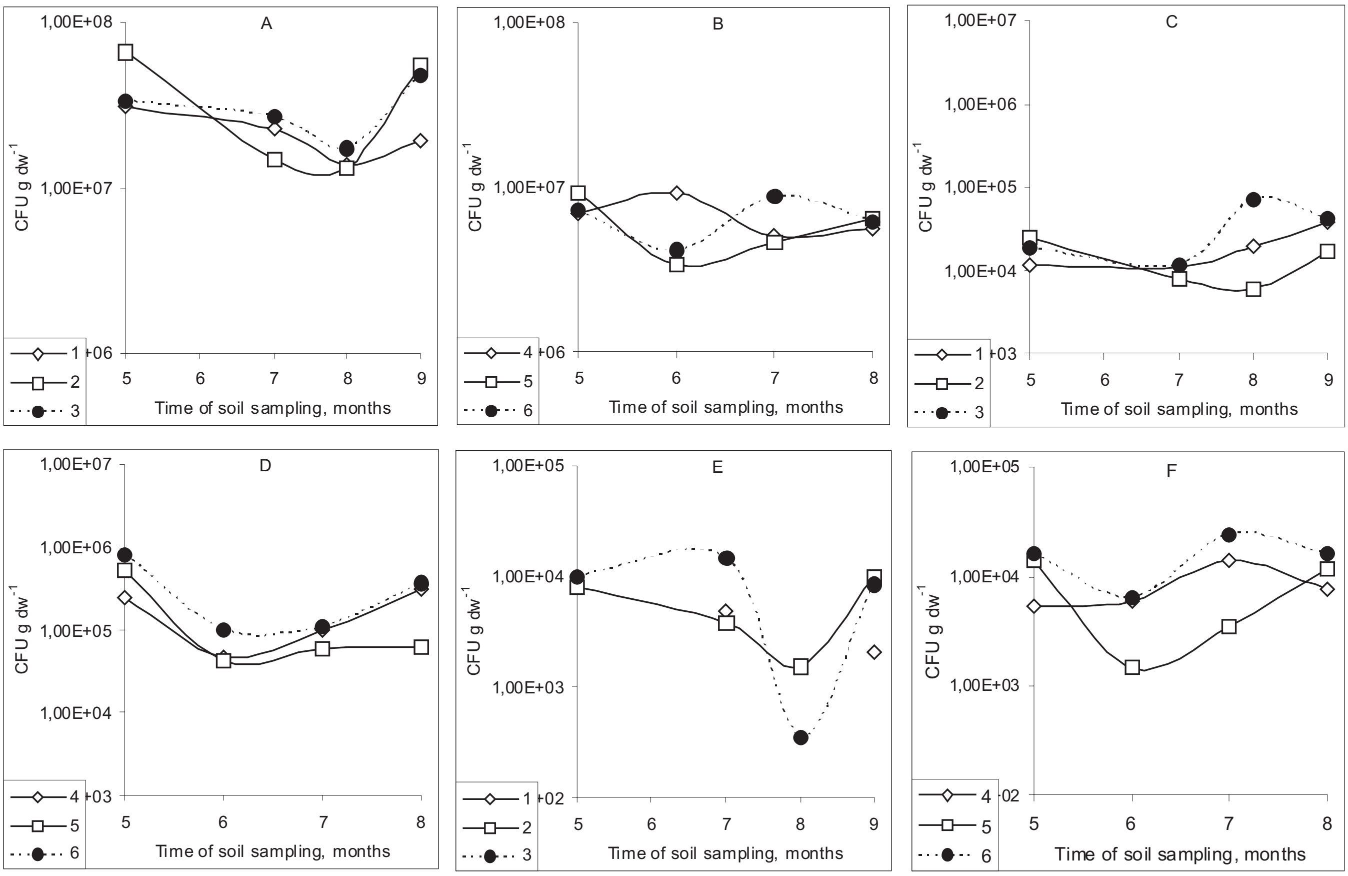

Fig. 2. Number of soil bacteria and actinomycetes during wheat (1, 2, 3) and oat (4, 5, 6) cultivation. A, B – bacteria; C, D – actinomycetes; E, F – fungi.

activity in the soil. A promoting effect of the potato as forecrop was found on actinomycetes (Fig. 2 C, D). The total number of microorganisms was highest in the spring and autumn of the research period, which can be explained by higher amounts of mineral and organic nutrients.

Soil microbial respiration. The results obtained in this study demonstrated seasonal fluctuation of soil respiration intensity (Fig. 2). The highest soil respiration intensity was observed in 2009 and 2010 in oat and wheat crop soil where buckwheat was the forecrop. Fluctuations in soil respiration intensity in these variants were higher in comparison with those in which potato was used as a forecrop.

The highest microorganism respiration rate occurred in the conventional wheat field at the end of vegetation period (Fig. 3 A, plot 1). A higher microorganism respiration rate was observed in the organic oats field at the beginning of the vegetation period (Fig. 3, B, plots 2, 3, 5). Comparison of the two forecrops tested in this study showed that buckwheat supported higher activity of microorganisms, as compared to the potato crop. The trend observed in this experiment did not depend on the cultivated plant or the tillage system (Fig. 3).

Enzymatic activity of soil microorganisms. In this study the enzymatic activity of soil microorganisms was evaluated

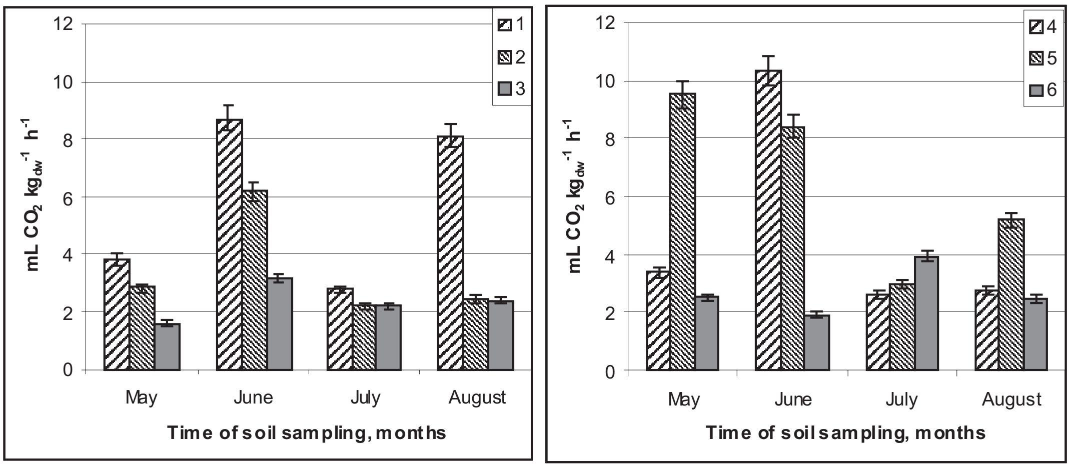

Fig. 3. Soil microbial respiration during wheat (A) and oat (B) cultivation.

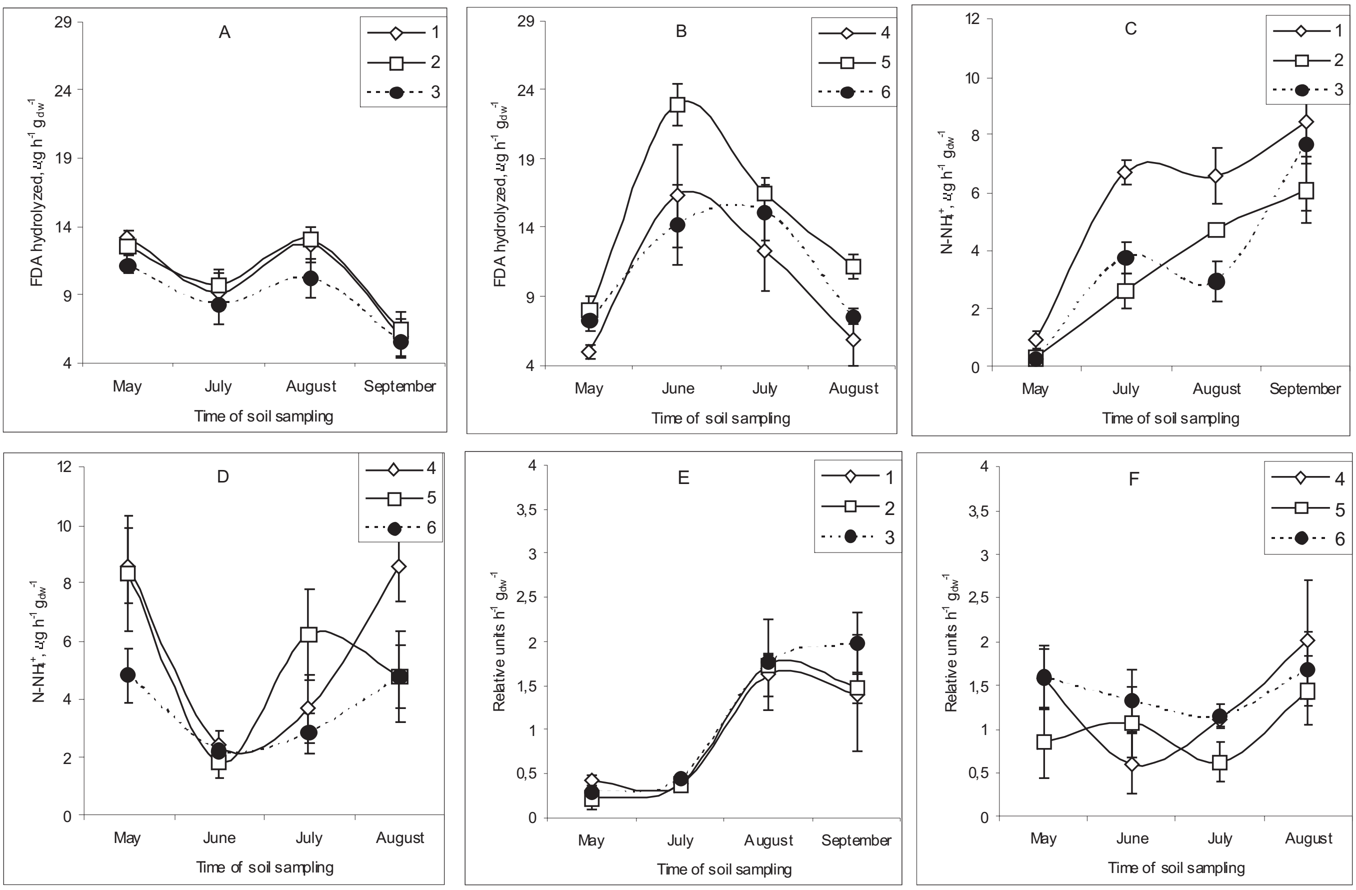

Fig. 4. Enzymatic activity of soil microorganisms. A, B – fluoresceine diacetate hydrolysis; C, D – urease activity; E, F – dehydrogenase activity. A, C, E and B, D, F – wheat and oat as the 2^{nd} year crop, respectively. Error bars represent the standard deviation at a 5% level of significance.

using FDA hydrolysis, urease, and DHA activity. Figure 4 shows that fluctuation of enzymatic activity was generally due to climate seasonality. An increase of urease activity in 2010 (wheat as the 2nd year crop) was detected already in July in all three experimental plots. FDA hydrolysis and dehydrogenase activity increased later, i.e., in August (Fig. 4, A, C, E). In July and August of 2010, the average temperature was 20.6 °C and 18.1 °C and rainfall was 88.3 mm and 211.4 mm, respectively (Table 3).

The results of the experiment with oat performed in 2009 demonstrated a maximum of FDA hydrolysis activity in June, whereas urease activity in June was considerably decreased, compared to that in May (Fig. 4, B, D).

FDA hydrolysis and urease activity was lower in soil after potato cultivation as a forecrop, when compared to plots win which buckwheat was used as a forecrop This was found for both of the following crops cultivated, i.e. wheat and oat. The same tendency was shown also for respiration activity (Fig. 3). FDA hydrolysis activity was higher in soil with oat cultivation, compared to that in soil with wheat (Fig. 4).

The differences in soil microbial enzymatic activity, tested by different enzymatic groups, can be explained by the relation of the given enzymatic group to physiological processes occurring in the microbial community. An increase of hydrolytic enzymes is more related to a larger microbial pool.

DISCUSSION

The number of microorganisms and their activity during plant vegetation period are variable. The seasonal changes in the number of soil microorganisms could be explained by weather patterns, i.e., humidity and temperature, conditions. The total number of microorganisms was highest in the spring and autumn of the research period, which can be explained by higher amounts of mineral and organic nutrients. The obtained data contrast with result obtained by Natywa *et al.* (2010), and this difference can be explained with larger and split nitrogen doses used in their experiments.

The results obtained in this experiment indicated the seasonal character of actinomycete activity in the soil and are in good agreement with the data previously obtained for Latvian weather conditions (Павловича, 1978). A promoting effect of the potato as forecrop was found on actinomycetes. The favourable effect of potatoes as the forecrop on the growth of actinomycetes in Latvian conditions has been reported earlier (Павловича, 1978; Клинцаре, 1983).

The differences in soil microbial enzymatic activity, tested by different enzymatic groups, can be explained by the relation of the given enzymatic group to physiological processes occurring in the microbial community. Data obtained by different authors usually related with local climatic conditions, cultivated plants and soil. The activity of dehydrogenase is characterised by organic matter oxidation, as it catalyses aerobic respiration, intervening in the electron transport chain (Zagal *et al*., 2009). An increase of hydrolytic enzymes is more related to a larger microbial pool than to its higher physiological capacity (Lagomarsino *et al*., 2009). Urease activity can vary in dependence on management practice (Bolton *et al*., 1985). Also, soil microbial activity and composition may vary considerably with plant growth stage, soil coverage, etc. (Franchini *et al*., 2007; Stark *et al*., 2006; Hungria *et al.,* 2009).

According to other authors (Carter *et al*., 2009), the management effects on some of the above biological properties may not be measurable in the short-term (i.e. years), necessitating the need for long-term experimentation.

Further investigations of the influence of crop rotation on soil properties, crop quality and microbial processes in soil and their dependence of environmental conditions are suggested.

Based on the results of this study, the following conclusions can be made:

- The numbers of bacteria, actinomycetes and fungi as well as respiration and enzymatic activity in all tested soil samples fluctuated due to climate seasonality.

- Soil microbial properties did not show any significant differences between organically and conventionally fertilised soils, indicating that seasonality, crop rotation and plant type had a larger influence on microbial biomass and enzyme activity.

- A comparison of two crops, i.e., wheat and oat, revealed that the number of bacteria was higher in plots with wheat, and actinomycete counts were higher in fields with oat. The number of microscopic fungi did not differ among the variants mentioned.

- Soil microbial respiration activity, as well as the FDA hydrolysis and urease activity showed a tendency to decrease in soil after potato cultivation as the forecrop. This effect was found for both cultivated crops, i.e. wheat and oat.

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PRIEKŠAUGU GRIĶU UN KARTUPEĻU EFEKTIVITĀTES VĒRTĒJUMS GRAUDAUGU MAIŅĀ

Izmēģinājumi iekārtoti Valsts Stendes Graudaugu selekcijas institūta pētījumu laukos. Graudaugi kvieši (*Triticum aestivum* L.) un auzas (*Avena sativa* L.) audzēti konvencionālajā un bioloģiskajā augu audzēšanas sistēmā. Kā priekšaugi izmantoti griķi (*Fagopyrum esculentum* Moench.) un kartupeļi (*Solanum tuberosum* L.). Noteikti augsnes fizikāli ķīmiskie (pH, organisko vielu daudzums, N, P, K) rādītāji. Augsnē analizētas mikroorganismu dažādu fizioloģisko grupu (baktēriju, aktinomicētu un mikroskopisko sēņu) daudzums 1 g gaissausas augsnes. Noteikta augsnes elpošanas intensitāte, kā arī augsnes enzīmu (ureāze, dehidrogenāze) aktivitāte un fluoresceīna diacetāta (FDA) hidrolīzes intensitāte. Elpošanas aktivitātei, FDA un ureāzes aktivitātei ir izteikta tendence palielināties variantos, kur priekšaugs ir kartupeļi. Baktēriju skaits lielāks ir variantā ar kviešiem, bet aktinomicētu — variantā ar auzām. Graudaugu ietekmi uz mikroskopisko sēņu skaitu, kā arī būtisku atšķirību augsnes aktivitātes galvenajos rādītājos starp konvencionālo un bioloģisko variantu nenovēroja. Mikroorganismu biomasu un enzīmu aktivitāti ietekmē priekšaugs un laukaugu maiņā audzētais graudaugs.