Agronomy Research **8** (Special Issue II), 409–414, 2010

The influence of the expansion of winter crop proportion in the rotation structure on soil biological activity

D. Janušauskaitė[1] and A.Velykis[2]

[1]Plant Pathology and Protection Department, Lithuanian Research Centre for Agriculture and Forestry Akademija, Dotnuva, Kedainiai District, Lithuania, LT-58344; e-mail: daliaj@lzi.lt

[2]Joniskelis Experimental Station, Lithuanian Research Centre for Agriculture and Forestry, Joniskelis, Pasvalys District, Lithuania, LT-39301; e-mail: velykisalex@gmail.com

Abstract. The effect of the expansion of the winter crop proportion in the crop rotation structure under conditions of conventional (ploughing) and sustainable (reduced) soil tillage on soil biological properties was investigated on a clay loam *Gleyic Cambisol* at the Joniskelis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry over the period 2004–06. The effect of a different proportion of winter crop in the rotation on microbial populations in soil was influenced primarily by the weather conditions during the growing seasons. In different years, the number of ammonificators ranged from 5.68 to 28.37 mln g^{-1}, the number of mineralizators ranged from 8.23 to 37.01mln g^{-1}, fungi from 28.55 to 101.46 thousand g^{-1} of soil. The soil microbial amount was higher under wetter conditions. The numbers of microbes differed between soil tillage systems and had diverse impact. The number of ammonificators did not differ markedly between the soil tillage treatments; however, the number of microbes in the conventionally tilled plots exceeded that in the sustainable tillage system by 5.57%. The sustainable tillage system was positive for N assimilators and fungi. Increasing the winter crop in the rotation did not exert any strong positive effect on all microbes. Increasing the winter crop proportion was favourable for micromycetes. More bacteria were found in the rotation with 25% of winter crop, more mineral N assimilators were found in the rotation with 25% and 50% of winter crop, and fungi max under 50%, 75% and 100% of winter crop in the rotation.

Key words: Clayey *Cambisol*, crop rotation, winter crops, soil tillage, soil microbes

INTRODUCTION

Soil microbes decompose the plant and animal residues entering the soil and convert them into soil organic matter, which influences soil physical, chemical and biological properties and creates a complimentary medium for biological reactions and life support in the soil environment. Agricultural management can affect soil organic matter chemistry and the microbial community as well as soil biota influenced by land use and management techniques; changing management practices could have significant effects on the soil microbial properties and processes. One of the methods of maintaining soil fertility is applying crop rotation, returning more material to the soil or perennial crop, which activates soil organisms due to new carbon compounds.

Perennial cropping systems may achieve significant improvement over annual systems in the synchrony between crop nutrient demands and nutrient supplies (Crews, 2005). In bulk soil, the growth of microbes normally is limited by a shortage of carbon and energy while the continuous release of organic nutrients in the plant rhizosphere facilitates the activity and multiplication of a large variety of microorganisms. A perennial or winter crop, due to the length of root survival, would be the most beneficial for a maintenance relationship between plants and soil microbes (Atkinson & Watson, 2000). Rational crop rotation in the field economy is one of the main factors enabling an increase in the resources of organic matter and nutrients or in maintaining them at a proper level (Rychcik et al., 2004). Crop rotation is a central component of all sustainable farming systems. Crop rotations have positive effects on soil properties related to the higher C inputs and the diversity of plant residues returned to soils in comparison with continuous systems (Moore et al., 2000), including increased soil microbial activity, which may increase nutrient availability. Soil microbes are typically C-limited, and lower microbial biomass in soils from conventional agroecosystems often is caused by reduced organic C content in the soil (Flieβbach & Mäder 2000). As compared with conventional management, adoption of sustainable tillage can protect soils from biological degradation and maintain soil quality. Compared to the alternative minimum tillage system, a conventional plough tillage system increases the humus content and the hydro stable aggregate content. The sustainable tillage system could be considered as an effective management practice due to its improvement of soil physical and biochemical quality and soil C sequestration, increasing the contents of microbial biomass. Results of many researchers indicated the importance of reducing tillage as a means of increasing soil biological activity of the topsoil. (Zibilske & Bradford, 2003; Mijangos, et.al., 2006; Müler et.al., 2009).

The objectives of the current research are to study the impact of the expansion of the proportion of winter crops in crop rotations under conditions of conventional and reduced soil tillage on the soil microbial population.

MATERIALS AND METHODS

Soil and site. Complex research was conducted at the Lithuanian Institute of Agriculture's Joniskelis Experimental Station during the period 1998–2006 on drained clay loam on silty clay with deeper lying sandy loam *Endocalcari-Endohypogleyic Cambisol*, whose parental rock is glacial lacustrine clay on morainic loam. This paper presents the results of the final experimental period (2004–06).

Experimental design and parameters. The experiments were carried out according to the following design: **Factor A. Crop rotations with different proportion of winter and spring crops:** 1. without winter crops: vetch and oats, spring wheat, spring triticale, spring barley. 2. 25% winter crops: red clover and timothy, spring wheat, spring triticale, spring barley. 3. 50% winter crops: red clover and timothy, winter wheat, spring triticale, spring barley. 4. 75% winter crops: red clover and timothy, winter wheat, winter triticale, spring barley. 5. 100% winter crops: red clover and timothy, winter wheat, winter triticale, winter barley. **Factor B. Soil tillage systems:** 1. Conventional (ploughing). 2. Sustainable (ploughing after grasses for wheat, ploughless – after all cereals). All crops were grown every year in four replicates.

Herbicides of a selective mode of action were applied to cereals. The soil was ploughed at 23−25 cm depth and, in the case of ploughless tillage, was loosened by a universal stubble breaker at the same depth.

Measurements and assessments. Soil samples for microbial characterization were collected on July 2, 2004, June 30, 2005, and August 31, 2006. Each sample represented a composite from three replicates taken at depths of 0–15 cm and from 15–25 cm from an experiment incorporating different treatments. The dilution plate technique was employed to enumerate the most important groups of soil fungi and bacteria as colony forming units (cfu). For this purpose, different media were used: for ammonificators – Soy Tryptic agar; for bacteria using mineral N, as mineral N assimilators, starch nitrate agar media were used and total fungal counts were determined on malt extract agar. The plates were incubated at 25º C and bacterial and fungal counts were made after 4 and 7 days, respectively. Cfu were corrected for moisture content of the soil before the final counts were expressed as the number of culturable bacterial and fungal cells per 1 g of dry soil. Soil moisture content was the highest (18.44%) in 2004 and the lowest (12.51%) in 2005; in 2006 it was 16.79%. The data were subjected also to ANOVA, and variances between treatments were compared according to the Duncan multiple range test.

RESULTS AND DISCUSSION

The highest relative and significant differences of overall mean of bacteria were attributable to the factor 'year'. The population of total heterotrophic bacteria between years was 19.87×10^6, $15.50 \text{ x } 10^6$ and 8.8×10^6 cfu g^{-1} of dry weight soil in 2004, 2005 and 2006, respectively; N assimilators were 30.83×10^6, 21.88×10^6 and 12.62×10^6 cfu g^{-1} of dry weight soil; fungi 62.20×10^3, 36.94×10^3 and 74.51×10^3 cfu g^{-1} of dry weight soil, respectively in 2004, 2005 and 2006 (Table 1). It indicated a decline in population size during the dry season. Population decline during the drier season may result from both desiccation stress and a lack of substrate availability for energy maintenance of the population. Lower abundance of microbes in 2006 was due to a later sampling date.

Less variation was caused by 'crops' and 'sampling depth'. In most cases, a higher amount of microorganisms was revealed in the soil with the conventional tillage system at the 0–15 cm depth. However, in some cases the data are inconsistent. Generally, the microbial soil population had been scattered across the different treatments. The differences of microbial populations varied between depth distributions after both tillage practices. In general, a 2.8% higher amount of ammonificators was found in the upper 0-15 cm depth. The content of N assimilators was also by 5.47% higher in the upper soil layer. In addition, some authors suggest that the number of bacteria decreased in soil sampled from 10–20 cm layers (Zou Li et al., 2000). However, the amount of fungi had reduced by 6.69% in the upper soil layer as compared to the 15–25 cm depth.

Our results showed that the microbial population was different in soils with different proportions of winter crops, but only few significant effects were observed in relation to the rotation treatment. The highest density of ammonifying bacteria was observed under a 25% winter crop, the lowest in 100% winter crop. The population of mineral N assimilators only slightly increased in the plots with 25% and 50% of winter crop. The results of fungi show that max population was in the rotation with 50%, 75% and 100% of winter crop. Differences between winter crop proportions in the experiment could reflect differences in soil organic matter content and be due to limited microbial activity. The decomposition can differ more in separate plots, because large differences in microbial population amount were detected within the treatments. For example, in the 0–15 cm soil layer in the conventional tillage system the amount of ammonificators varied from 10.7 to 26.7 × 10^6 cfu g^{-1} of dry weight soil. In the same layer in sustainable tillage, it varied from 10.6 to 29.7 × 10^6 cfu g^{-1} of dry weight soil. Those differences in the plots with different proportions of winter crop occurred only in 2004, when climatic conditions were favourable for microbial activity due to high soil moisture (18.44%).

Table 1. Data of soil microbe amount (cfu) sorted by tillage treatment and crop rotation.

Variation	*Bacteria*		*Mineral N assimilators*		*Fungi*	
	Soil tillage systems		Soil tillage systems		Soil tillage systems	
Proportion of winter crops %	Conventional	Sustainable	Conventional	Sustainable	Conventional	Sustainable
			2004			
0	22.13b	16.42a	19.72a	36.52bc	33.46a	75.99ab
25%	28.37c	26.65b	34.42bcd	34.84bc	44.03bcd	71.24a
50%	12.92a	18.50a	32.63bcd	26.10a	40.01ab	73.11a
75%	21.66b	19.82a	36.76d	25.66a	38.84ab	94.25bcd
100%	16.75ab	15.40a	24.6ab	37.01c	49.66d	101.46d
LSD_{05}	5.4	5.82	10.56	7.23	8.6	12.03
			2005			
0	18.35e	13.47a	18.65a	25.73b	42.48ab	38.08c
25%	16.94cde	19.82b	19.12a	21.88ab	39.28ab	29.42abc
50%	12.26a	15.60a	23.86c	22.44ab	44.82ab	31.18abc
75%	15.51bc	15.55a	24.76c	21.51ab	47.94b	28.55a
100%	13.81ab	13.71a	19.70a	21.12ab	38.91ab	28.77abc
LSD_{05}	1.94	3.05	3.57	4.68	11.47	8.96
			2006			
0	11.37bc	8.56bc	18.74c	9.83b	100.35c	41.44a
25%	11.17bc	5.68a	15.68bc	8.54a	82.40abc	48.10a
50%	12.31c	10.33c	15.34bc	13.78bcd	77.72abc	83.85d
75%	6.70a	6.42a	8.30a	13.39bcd	97.03bc	77.90bcd
100%	6.94a	9.29bc	8.23a	15.37d	68.15a	68.15b
LSD_{05}	2.71	1.68	4.16	4.72	28.32	14.04

Means in columns followed by the same letter are not significantly different from each other at the 5% level of significance according to Duncan's multiple range tests.

During the crop growing season, N limitation may affect the efficiency of microbes depending on the pre-crop due to different plant residue quality. Frequent growing of the winter crop may promote a more effective accumulation of organic matter in the soil and improve quality parameters. Thus, a perennial or winter cover crop creates a combination of conditions optimal for the creation and maintenance of well-aggregated soil. When large quantities of readily decomposable organic matter are added to agricultural soils every year as crop residues or animal wastes, they have a significant outcome on soil microbial activity. The plant species growing on the soil also influence the population and function of the soil microbes (Groffman et al., 1996). Conversely, cropping sequences that involve annual plants and extensive cultivation provide less vegetative cover and organic matter, and usually result in a rapid decline in soil aggregation. Otherwise, soil structure affects microbial activity (Černý et al., 2008).

In the experiment, there was no clear relationship between the different soil tillage systems and microbial numbers. In some cases, these findings suggested positive differences in soil microbial population of the sustainable system compared with the conventional system, but showed no clear trend in the plots with increasing winter crop proportion. In general, the impact of soil tillage on the abundance of microbial population was inconsistent, even when the data were averaged across all the sites. With regard to soil tillage systems, the ammonificator amount tended to be by 5.57% higher but was not significant in the conventional system. The differences in the amounts of ammonificators and N assimilators among the rotations were not large, owing to the relative homogeneity of the treatments, which may be due–to the properties of clay loam soils. The results of mineral N assimilators show that the sustainable soil tillage system had a slightly positive impact on all experiments. In general, N assimilators were significantly higher under the sustainable tillage system by 8.13 and 6.2% in 2004 and 2005, respectively. However, the amount of N assimilators decreased by 10.6% in the sustainable system in 2006. Tillage can be beneficial or harmful to biologically active soil, depending on the type and timing of tillage used. Tillage, especially when it includes mouldboard ploughing, can be one of the dominant causes of soil organic carbon reductions (Reicosky et al., 1995). Extensive tillage stimulates microbial activity by providing soil microorganisms with the oxygen they need to break down or consume organic matter. However, as microorganisms actively decompose any amendments or crop residues, organic matter does not normally accumulate in the soil under these conditions (Karlen et al., 1994).

Whilst tillage had little impact on the overall bacterial community, the proportion of fungi in the soil increased twice in the sustainable tillage system in 2004 compared with the conventional system. Conversely, the amount of fungi decreased by 36.8 and 33.2% in 2005 and 2006, respectively. This variability is the result of a complex interaction of the weather, crop residue, previous crop, and time of sampling date. Fungi benefit soil structure by producing exudates that bind soil particles together along with their hyphae. Breaking fungal hyphae by mouldboard ploughing is detrimental to soil fungi and increases the potential for erosion. Increased microbial activity follows increased annual C and N inputs in cropping systems (Chirinda et al., 2008). The carbon compounds from roots drive the development of microbial populations in the rhizosphere, although the compounds lost from different plant species can vary markedly in quality and quantity (Morgan et al. 2005). A high content of easily decomposable organic C can lead to fast growth of soil microbes.

Our results agree with those obtained from this experiment during the period 1998–2002. Previously it had been concluded that the sustainable soil tillage system favoured increasing amounts of the microorganisms. Expansion of the winter crop area in the rotation had a less positive effect on soil biological properties compared with the effects of soil tillage systems (Velykis et.al, 2004).

CONCLUSIONS

The experimental data of soil microbial activity under the influence of the proportion of winter crops in the rotation structure and different soil tillage systems were inconsistent among the treatments. The highest relative and significant differences of overall mean of bacteria were related to the year factor. In most cases, there were higher amounts of microorganisms in the soil with the conventional tillage system in the 0–15 cm depth. Increasing the winter crop proportion in the rotation had no strong positive effects on all microbes. Marked effects were shown to have taken place on the bacterial populations under 25% winter crop, mineral N assimilators under 25% and 50% and fungi max less than 50%, 75% and 100%.

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