Agronomy Research **14**(4), 1274–1284, 2016

Soil microbiological activity depending on tillage system and crop rotation

L. Dubova*, A. Ruža and I. Alsiņa

Institute of Soil and Plant Sciences, Faculty of Agriculture, Latvia University of Agriculture, Liela iela 2, LV-3001 Jelgava, Latvia
*Correspondence: laila.dubova@llu.lv

Abstract. Soil management practices include various tillage systems that influence plant growth and activity of microorganisms. Minimum tillage without soil inversion is increasingly being used because the conventional soil tillage with soil inversion is a more energy-consuming operation and affects the biodiversity of agroecosystems. The present study was aimed to estimate the effect of conventional and minimum tillage systems on soil microbiological activity. The trials were established in the experimental fields of the Latvia University of Agriculture. The intensity of soil respiration and the ratio of microbial biomass between minimum tillage and conventional tillage were calculated from 2011 to 2013, and cellulose degradation intensity – from 2012 to 2014. The conventionally tilled plots were ploughed to the depth of 23 cm, but minimum tillage was done at the depth of 10–12 cm without soil inversion. Soil samples were collected at two depths: 0–10 cm, and 11–20 cm. The crops were cultivated both in a monoculture (winter wheat) and using crop rotation (winter wheat–rape). Soil microbiological activity was characterised by soil respiration, cellulose degradation intensity, and biomass of soil microorganisms. The results suggest that microbial biomass of soil increased in the fields under minimum tillage compared to those under conventional tillage. It was found that crop rotation had no significant effect on the microbial biomass and soil respiration intensity. Although the upper soil layer has a higher potential of microbiological activity, the cellulose degradation intensity showed a tendency to decrease at both soil depths in the experimental plots without crop rotation.

Key words: cellulose degradation, soil minimum tillage, soil respiration.

INTRODUCTION

Soil use influences the quality of soil since it can deteriorate, stabilize, or improve the soil ecosystem. Soil quality affects micro- and macroorganisms that live in the soil, but ecological factors such as water content, temperature, and aeration of soil modify the intensity of soil microbiological processes (Feng et al., 2003; Han et al., 2007). The qualitative and quantitative changes in the population of soil microorganisms reflect the changes in soil quality (Sharma et al., 2010). Soil tillage practices affect the soil microbial community in various ways, with possible consequences for nitrogen (N) losses, plant growth, and soil organic carbon (C) decomposition. At the same time, soil microorganisms are involved in biochemical processes that include the decomposition of plant residues and the transformations of organic matter, affect the mineralization of plant available nutrients, and influence the efficiency of nutrient cycles (Singh et al., 2011; Jackson et al., 2012; Tiemann et al., 2015).

A growing interest in soil management that could prevent decrease in soil quality has been observed throughout the world. Therefore, farmers replace the conventional soil tillage with alternative techniques of crop cultivation and soil management defined as conservation agriculture that include no-tillage (conservation tillage) or reduced tillage. Reduced tillage is increasingly being used to save soil quality and to decrease soil mechanical disturbance, erosion, and agricultural production costs (Andrade et al., 2003; Morris et al., 2010). Investigations of various tillage systems under all climatic conditions have not been carried out equally intensively. Reduced tillage, especially no-tillage, methods are widespread throughout the North and South America but are less used in Europe, where intermediate forms of the non-ploughing or non-inversion tillage have been adopted much more readily than no-till farming system; however, some advantages and disadvantages are being studied more extensively (Soane et al., 2012; Avižienyte et al., 2013; Brennan et al., 2014).

The weather conditions have a significant effect on the crops grown using non-inversion tillage (Brennan et al., 2014), so that plant residues on soil surface influence the soil properties and the efficiency of utilisation of fertilizers, pesticides, and other inputs. As pointed by some authors, soil tillage affects the abundance and diversity of weed species and the survivability of plant pathogens (Gaweda, 2007; Morris et al., 2010; Brennan et al., 2014). The minimum tillage increases the amount of plant residues on the soil surface. Plant residue decomposition is slow due to the partial contact between crop residues and soil. Equally important, the soil microbiological activity is influenced also by other site-specific factors (Andrade et al., 2003). The accumulation of plant debris in soil or on its surface may increase the biodiversity of agroecosystems; at the same time, there is a risk that various pathogens may retain their viability until the succeeding crop is grown. Crop rotations and cover crops are considered to be essential components in the reduction of weeds (Soane et al., 2012).

The conversion from conventional to conservation tillage introduces changes in the distribution of organic matter within soil profile and increases the amount of organic matter and microbial biomass in the soil surface layer (Šimon et al., 2009). Both the soil tillage system and the soil type affect the amount of mineral elements in different soil layers, which, in its turn, influences the development of plants and the number and activity of microorganisms (Feiza et al., 2010).

Mikanova et al. (2009) have found that soil biological activity, particularly the activity of microorganisms, is a significant indicator of the soil quality and fertility. Different agroecosystem management practices differently influence the soil nutrient availability and potential enzyme activity. Research findings about the effect of agroecosystem management on the number of soil bacteria and fungi are contradictory. For example, Bowles et al. (2014) have not detected its major effect on soil microbial community. Their research suggests that the growth rates of saprophytic fungi and bacteria were unaffected by tillage practice. Greonigen et al. (2010) have noted that reduced tillage treatment increased the biomass of both microbial groups in the topsoil layer, whereas Frey et al. (1999) have reported that the fungal and bacterial biomass ratio increased under no-till systems. The observed differences may be explained by a higher degree of soil disruption in reduced tillage systems compared to strict no-till systems.

Plant residues left on the soil surface may increase the fungal population. On the other hand, growth rates are more strongly affected by environmental factors in the short term than the biomass of microbes and their metabolites such as enzymes and biologically active components. Soil tillage may also affect the composition of soil amino sugar pool, which dynamics represents an important component of the carbon (C) and nitrogen (N) cycles (Greonigen et al., 2010). The activity of soil respiration and enzymes can be a sensitive indicator of the changes occurring in the soil biological activity and fertility in response to various soil management practices. Gajda & Martyniuk (2004) have reported a lower microbial biomass C and N content, soil respiration intensity and enzyme activity for the soil of conventional winter wheat monoculture compared to organic management and conventional short-rotation farming system. Assessment of the microbial biomass and activity can reveal changes in the content of soil organic matter before these changes are detected in the total soil organic matter (Andreda et al., 2003).

The aim of the current research was to assess the effect of soil tillage methods and crop rotation on the activity of soil microorganisms.

MATERIALS AND METHODS

The description of experimental site. A stationary field experiment (established in 2009) was carried out at the Study and research farm 'Peterlauki' of the Latvia University of Agriculture. The data were obtained in the experimental period 2011–2014. The soil was *Cambic Calcisol*, pH KCl 6.8, according to WRB 2014. The soil agrochemical properties and the evaluation of the amount of mineral elements are presented in Table 1.

Table 1. Soil agrochemical properties at the depth of 0–20 cm

Index	Values		Evaluation*
	mean	±	
Humus, g kg^{-1}	22.0	2.0	low
P_2O_5, mg kg^{-1}	134.5	25.3	sufficient
K_2O, mg kg^{-1}	245.3	22.5	sufficient
Ca, mg kg^{-1}	1,809.0	92.5	sufficient
Mg, mg kg^{-1}	483.6	43.6	high

* According to Fertiliser Recommendations for Agricultural Crops, 2013.

Agrotechniques of experimental site. Two soil primary tillage treatments were investigated: conventional tillage (CT) – ploughing at the depth of 22–23 cm with a mouldboard plough; and minimum shallow tillage (MT) – at the depth of 10–12 cm with a disc harrow. The crops were cultivated without crop rotation (plots No. 1 and No. 2) and with crop rotation (plots No. 3 and No. 4). The scheme of crop rotation and soil tillage methods used in the experimental plots by years is presented in Table 2. Each plot size was 24×100 m. Each experimental variant was designed in two replications.

Table 2. The scheme of crop rotation and soil tillage in the experimental plots

Year	Minimum tillage (MT)	Conventional tillage (CT)		Minimum tillage (MT)
	Plot 1	Plot 2	Plot 3	Plot 4
2010	winter wheat	winter wheat	winter rape	winter rape
2011	spring wheat	spring wheat	spring wheat	spring wheat
2012	winter wheat	winter wheat	winter wheat	winter wheat
2013	winter wheat	winter wheat	winter rape	winter rape
2014	winter wheat	winter wheat	winter wheat	winter wheat

In 2011, fertilization of all experimental plots was done in August – with complex NPK 7–24–24 kg ha^{-1}. CT and MT were performed in September. In May 2012, all plots were additionally fertilized with ammonium nitrate at the dose of N 50 kg ha^{-1}. In the autumn of 2012, after soil tillage, complex fertilizer NPK 7–20–28 was applied at the dose of 300 kg ha^{-1}. In 2013, ammonium nitrate was additionally applied in April and May: to winter wheat – N 80 kg ha^{-1} and N 70 kg ha^{-1}, respectively; and to winter rape – N 80 kg ha^{-1} and N 80 kg ha^{-1}, respectively.

Weather conditions. In the vegetation period of 2011, the average temperature was 0.2–3.6 degrees higher than the long-term average. Dry weather prevailed from April to November, except May, July, and August, when precipitation was 40.5%, 40.0%, and 60.4% higher, respectively, than the long-term average. In 2012, the average monthly temperature was lower, but the amount of precipitation was higher than in the previous year. In 2013, spring was cooler than the long-term average, but the vegetation period was mostly warm and dry. Meteorological conditions throughout the vegetation period of 2014 were characterized by larger precipitation amounts than the long-term average (123–220% from long-term data) (Figs 1 and 2).

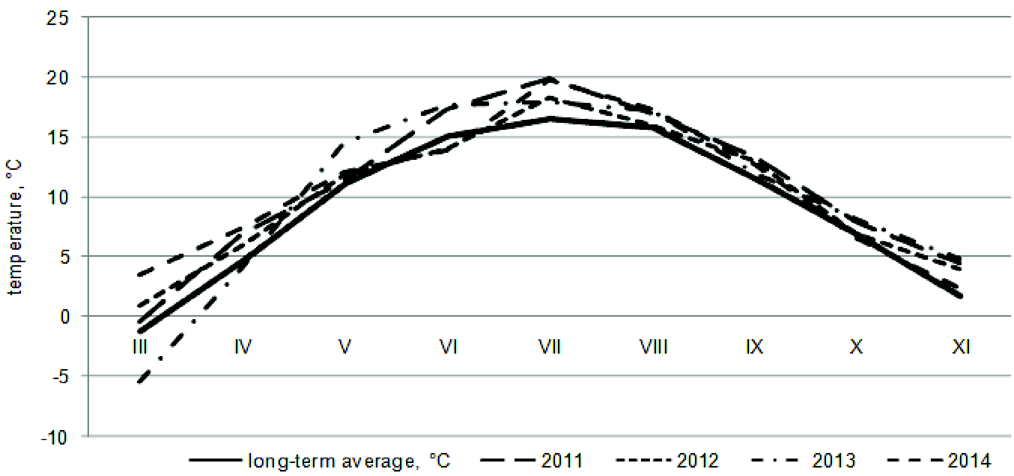

Figure 1. Temperature in the experimental period.

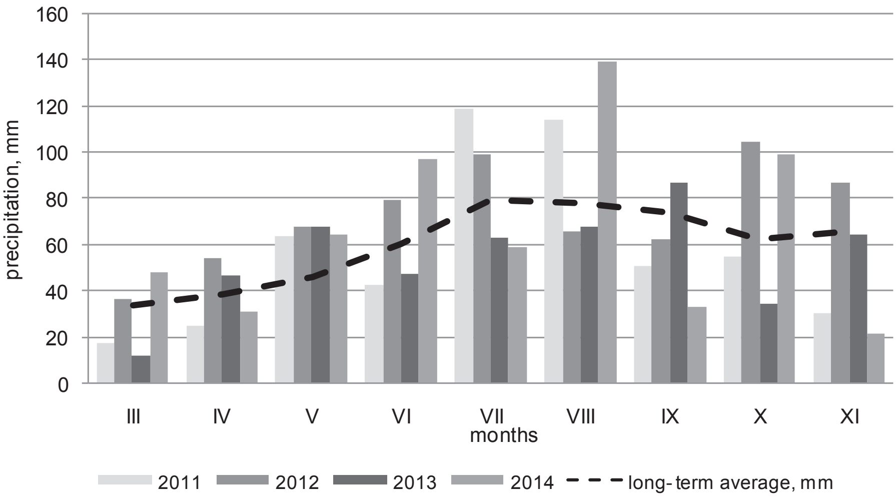

Figure 2. Precipitation in the experimental period.

Soil sampling and assessment of biological activity. The soil was sampled four times from each plot during the vegetation period. Soil samples were taken from two soil layers (at the depths of 0–10 cm and 10–20 cm) using an auger with a 2 cm diameter. A composite sample of 10–15 drillings was taken from each plot. Field-moist samples were stored in plastic bags at 4 °C for soil biological activity analysis.

Soil basal respiration was determined by placing 50 g of field-moist soil and a beaker containing 5 mL of 0.1 M KOH solution into a 500-mL jar; the jar was sealed and placed in the dark at the temperature of 30 °C for 24 hours. Afterwards, the KOH solution was removed and titrated with 0.1 M HCl to determine the amount of CO_2 evolved with the soil microbial respiration (Pell et al., 2005). The soil moisture was determined by drying the sample for 24 hours at 105 °C. Soil microbial biomass carbon (microbial biomass-C) was calculated by substrate-induced respiration results according to LVS ISO 14240-1:1997. For the assessment of substrate-induced respiration, 2 mg of glucose were added to 1 gram of a soil sample.

In May of 2012, 2013 and 2014, cellulose degradation activity was determined using linen pieces. A soil sample from each plot was placed in two containers (volume – 1 L); in each container, three weighed linen pieces were placed. All containers were stored in field conditions. After six weeks, the linen pieces were removed from the sampled soil and weighed. The degree of degradation was expressed as percentage of linen degradation.

The experimental data were analysed by the two-factor analysis of variance. The data were processed using software *ANOVA*. The parameters were considered as significant at $P < 0.05$.

RESULTS AND DISCUSSION

The biomass of soil microorganisms. Soil microorganisms indicate the living and dynamic component of soil organic matter. Despite the fact that microbes are only a few percent of soil organic matter, they can affect crop production and are significant for sustainable agroecosystems. However, the microbial biomass can be affected by the factors that change the water or carbon content of soil and include soil type, climate, and management practices. The soil properties that usually affect the microbial biomass are soil pH, content of clay, and organic matter. To compare the effect of tillage and crop rotation on the biomass of microorganisms, the ratio $C_{MT} : C_{CT}$ was calculated. Changes in the ratio of microbial biomass-C ($C_{MT} : C_{CT}$) at the depth of 0–10 cm and 10–20 cm in conventionally tilled and minimum-tilled soil are shown in Table 3.

Table 3. The ratio of microbial biomass-C between minimum-tilled soil and conventionally tilled soil without crop rotation (plots No. 1 and No. 2) and with crop rotation (plots No. 3 and No. 4)

Year	Plot No.	April	June	August	November	On average
	$C_{MT} : C_{CT}$ at soil depth 0–10 cm					
2011	1 : 2	1.32	1.08	1.47	1.06	1.23
	4 : 3	1.02	1.17	1.06	1.17	1.11
2012	1 : 2	1.08	1.20	0.94	0.91	1.03
	4 : 3	1.19	1.21	0.79	0.97	1.04
2013	1 : 2	1.73	1.66	1.26	0.92	1.39
	4 : 3	1.67	1.62	1.55	0.97	1.45
	$C_{MT} : C_{CT}$ at soil depth 10–20 cm					
2011	1 : 2	1.23	0.86	1.42	0.81	1.08
	4 : 3	0.93	0.92	1.06	0.95	0.97
2012	1 : 2	1.02	0.88	0.96	1.14	1.00
	4 : 3	1.02	0.95	1.11	1.00	1.02
2013	1 : 2	1.34	1.06	1.34	0.65	1.10
	4 : 3	1.12	1.48	0.79	1.27	1.17

The results show that MT, contrary to CT, increased the biomass of microorganisms. Each year during the vegetation period, the value of the biomass of microorganisms fluctuated, and a statistically different (F = 0.74 > F crit = 0.006) value of the ratio $C_{MT} : C_{CT}$ was only in the year 2013 – at the depth of 0–10 cm and 10–20 cm. The results are in accordance with Andrada et al. (2003) and Groenigen et al. (2010) who have noted that reduced tillage or no tillage increased the amount of microorganisms in the upper soil layer, whereas the impact of crop rotation on the biomass of microorganisms was insignificant. The response of soil microbial biomass to tillage varied because of the climatic conditions, sampling depth, and cropping system.

Soil respiration intensity. The obtained data show that weather conditions significantly affected the activity of microorganisms. The average soil respiration intensity during the experiment is shown in Fig. 3. In 2013, the lowest soil respiration intensity was observed in the 0–10 cm soil layer. The year 2013 was characterized by high air temperatures and little precipitation, which may explain the low level of soil respiration intensity observed under both tillage methods. In 2011 and 2012, a significantly higher soil respiration intensity was determined in the upper layer of minimum-tilled soil compared to conventionally tilled soil. Accumulation of plant residues in upper soil layers and sufficient moisture stimulate the activity of microorganisms. Yao et al. (2011) suggest that temperature and moisture are important environmental factors influencing the soil microbial growth and activity. Also heterotrophic organisms are largely dependent on the amount of organic matter presented in the soil. On the other hand, plant residue distribution in the whole plough layer at CT provides an unfluctuating activity of microorganisms throughout the vegetation period. Our results demonstrate that soil respiration intensity when using CT was not so strongly affected by environmental factors, especially at the depth of 10–20 cm. This suggests that under MT system, the upper-soil-layer microorganisms are more exposed to the weather conditions.

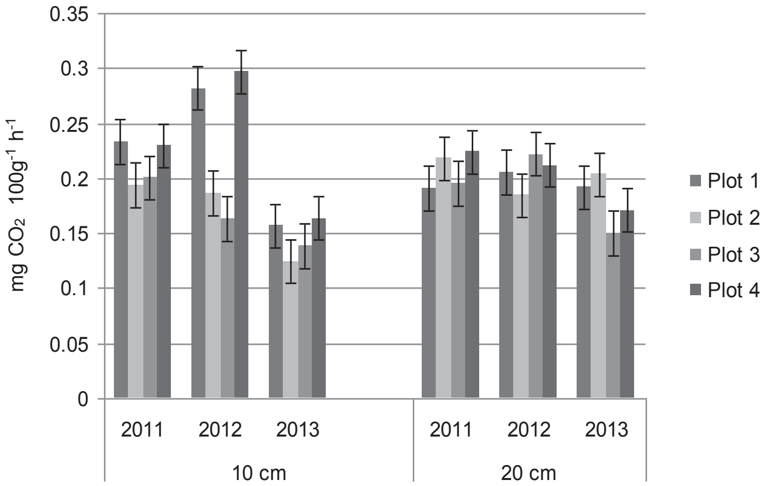

Figure 3. Soil respiration intensity in the experimental period (bars present LSD).

The results of the assessment of microbial activity during the 2011–2013 vegetation period are shown in Fig. 4.

In 2011, the highest soil respiration intensity was observed in April; then it decreased and fluctuated between 0.1 and 0.25 mg CO_2 100 g^{-1} h^{-1}. No statistically significant fluctuations in soil respiration intensity were detected in deeper soil layers. The research suggests that tillage had a significant effect on upper soil layers. This could be explained by the rather warm air temperatures and abundant precipitation, which affected plant residue decomposition in the upper soil layer.

In the second part of the 2012 vegetation period, a significant increase in soil respiration intensity was observed in minimum-tilled plots – on average, two times higher than in conventionally tilled plots. This may be due to the accumulation of plant residues in the upper soil layer and the heavy rainfalls in July, which stimulated the activity of microorganisms.

Large fluctuations in the intensity of soil respiration were observed in August 2013, when soil respiration drastically increased in both soil layers. This might have been influenced by the increase in precipitation after the long dry and warm period in the first part of vegetation. No significant effect of crop rotation on soil respiration intensity was detected.

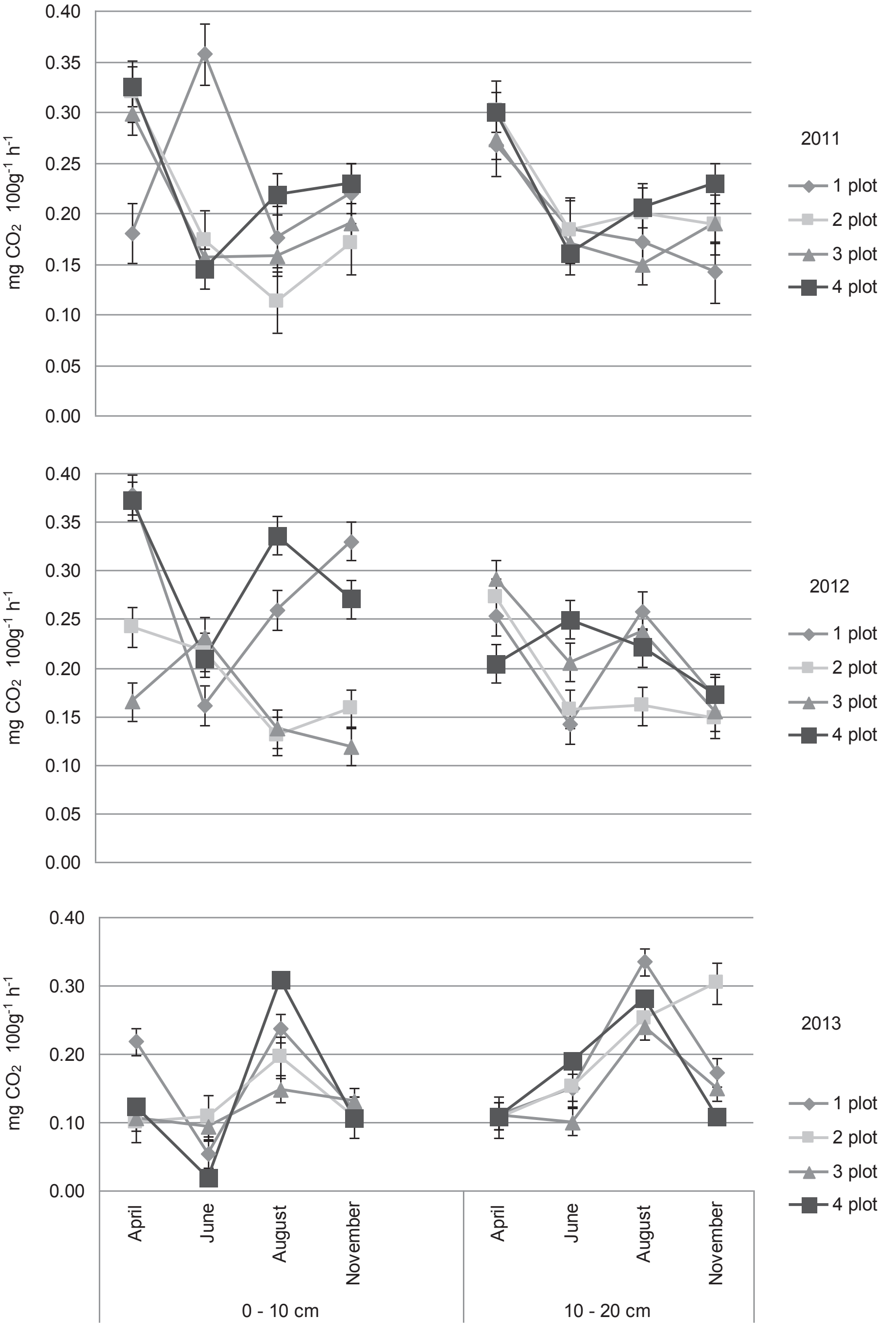

Figure 4. Soil respiration intensity during the vegetation period of 2011, 2012, and 2013.

Cellulose degradation intensity. The data obtained in 2012 revealed significant differences between the soil layers. In the upper soil layer, cellulose degradation intensity was 2–2.5 times higher compared to the 10–20 cm soil depth (Figs 5–7). This corresponds to the data obtained by other researchers (Andrade et al., 2003; Šimon et al., 2009). In 2013, no fluctuations between tillage method and soil sampling depth were observed. In 2014, a difference between the reduced and conventional tillage methods was established. In all experimental period, except the year 2012, it was detected that in conventionally tilled plots, the activity of cellulose degrading bacteria was similar at both soil depths.

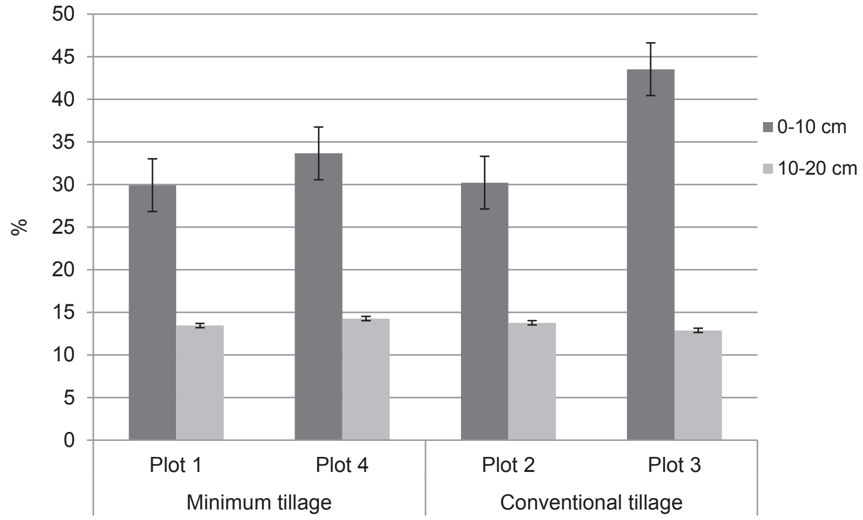

Figure 5. Cellulose degradation intensity in 2012.

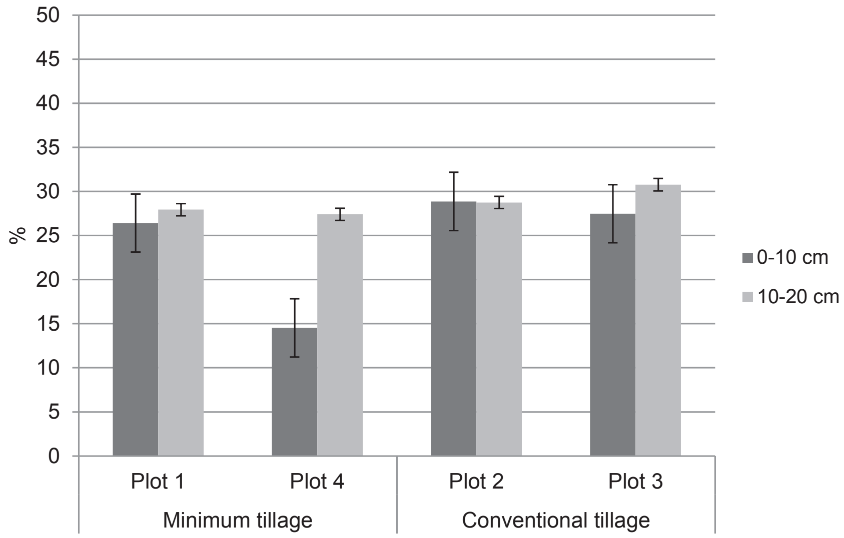

Figure 6. Cellulose degradation intensity in 2013.

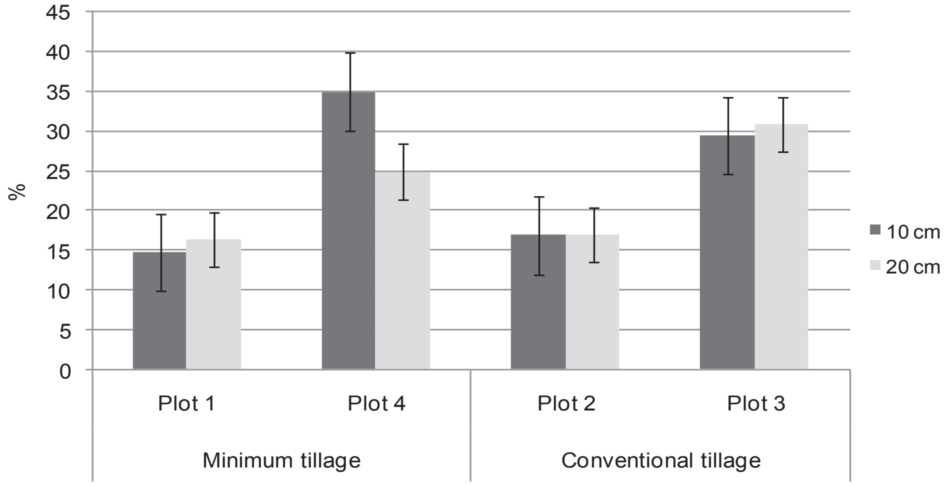

Figure 7. Cellulose degradation intensity in 2014.

Cellulose degradation intensity had a tendency to decrease at both soil depths in the experimental plots without crop rotation. Although the upper soil layer has a higher potential for microbiological activity because it accumulates more plant debris, it is more exposed to the influence of weather conditions.

CONCLUSIONS

Minimum tillage (MT), contrary to conventional tillage (CT), increased the biomass of microorganisms. A statistically significant difference was detected between soil sampling depths, whereas crop rotation showed no significant effect on soil respiration intensity. Although the 0–10 cm soil layer has a higher potential of microbiological activity, the minimum soil tillage does not provide an even decomposition of plant residues because the upper layers are more influenced by the weather conditions.

ACKNOWLEDGEMENT. The research was supported by the State research program 'Agricultural Resources for Sustainable Production of Qualitative and Healthy Foods in Latvia', Project No. 1 'Sustainable use of soil resources and abatement of fertilization risks (SOIL)'.

REFERENCES

Andrade, D.S., Colozzi-Filho, A. & Giller, K.E. 2003. The soil microbial community and soil tillage. In: El Titi A. (ed.). *Soil Tillage in Agroecosystems*, pp. 51–82.

Avižienytė, D., Romaneckas, K., Palyškytė, R., Bogužas, V., Pilipavičius, V., Šarauskis, E., Adamavičienė, A. & Vaiciukevičius, E. 2013. The impact of long-term reduced primary soil tillage on maize (*Zea mays* L.) productivity. *Zemdirbyste-Agriculture* **100**(4), 377–382.

Brennan, J., Hackett, R., McCabe, T., Grant, J., Fourtune, R.A. & Forristal, A.C. 2014. The effect of tillage system and residues management on grain yield and nitrogen use efficiency in winter wheat in cool Atlantic climate. *European Journal of Agronomy* **54**, 61–69.

Bowles, T.M., Acosta-Martinez, V., Calderon, F. & Jackson, L.E. 2014. Soil enzyme activities, microbial communities, and carbon and nitrogen availability in organic agroecosystems across

an intensively-managed agricultural landscape. *Soil Biology and Biochemistry* **68**, 252–262.
Feiza, V., Feizienė, D., Auškalnis, A. & Kadžienė, G. 2010. Sustainable tillage: results from long-term field experiments on *Cambisol*. *Zemdirbyste-Agriculture* **97**(2), 3–14.
Feng, Z., Motta, A.C., Reeves, D.W., Burmester, C.H., Van Santen, E. & Osborne, J.A. 2003. Soil microbial communities under conventional-till and no-till continuous cotton systems. *Soil Biology and Biochemistry* **35**, 1693–1703.
Fertiliser Recommendations for Agricultural Crops. 2013. Ed. by A. Karklins and A. Ruza. Jelgava, LLU, 55 pp.
Frey, S.D., Elliot, E.T. & Paustian, K. 1999. Bacterial and fungal abundance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. *Soil Biology and Biochemistry* **31**, 573–585.
Gajda, A. & Martyniuk, S. 2005. Microbial biomass C and N and activity of enzymes in soil under winter wheat grown in different crop management systems. *Polish Journal of Environmental Studies* **14**(2), 159–163.
Gaweda, D. 2007. Winter wheat weeds infestation under conditions of various tillage systems. *Acta Agrophysica* **10**, 317–325.
Greonigen, K.J., Bloem, J., Baath, E., Boeck, P., Rousk, J., Bode, S., Forristal, D. & Jones, M. 2010. Abundance, production and stabilization of microbial biomass under conventional and reduced tillage. *Soil Biology and Biochemistry* **42**(1), 48–55.
Han, G., Zhou, G., Xu, Z., Yang, Y., Liu, J. & Shi, K. 2007. Biotic and abiotic factors controlling the spatial and temporal variation of soil respiration in an agricultural ecosystem. *Soil Biology and Biochemistry* **39**(2), 418–425.
Jackson, L.E., Bowles, T.M., Hodson, A.K. & Lazcano, C. 2012. Soil microbial-root and microbial-rhizosphere processes to increase nitrogen availability and retention in groecosystems. *Current Opinion in Environmental Sustainability* **4**, 517–522.
LVS ISO 14240-1:1997. Soil quality – determination of soil microbial biomass. Part 1: Substrate-induced respiration method.
Mikanova, O., Javurek, M., Šimon, T., Friedlova, M. & Vach, M. 2009. The effect of tillage systems on some microbial characteristics. *Soil and Tillage Research* **105**, 72–76.
Morris, N.L., Miller, P.C.H., Orson, J.H. & Fround-Williams, R.J. 2010. The adoptation of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment – a review. *Soil and Tillage Research* **108**, 1–15.
Pell, M., Stenström, J. & Granhall, U. 2005. Soil respiration. In: Bloem J. *et al*. (eds). Microbiological methods for assessing soil quality, pp. 117–126.
Sharma, S.K., Ramesh, A., Sharma, P., Joshi, O., Govaerts, B., Steenwerth, K.L. & Karlen, D.L. 2010. Microbial community structure and diversity as indicator for evaluating soil quality. In: E. Lichtfouse (ed.). *Biodiversity, Biofuels, Agroforestery and Conservation Agriculture, Sustainable Agriculture Reviews*, 5, Springer Science+Business Media, pp. 317–347.
Singh, J.S., Pandey, V.C.. & Singh, D.P. 2011. Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development. *Agriculture, Ecosystems and Environment* **140**, 339–353.
Soane, B.D., Ball, B.C., Arvidsson, J., Basch, G., Moreno, F. & Roger-Estrade, J. 2012. No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. *Soil and Tillage Reaserch* **118**, 66–87.
Šimon, T., Javurek, M., Mikanova, O. & Vach, M. 2009. The influence of tillage systems on soil organic matter and soil hydrophobicity. *Soil and Tillage Research* **105**, 44–48.
Tiemann, L.K., Grandy, A.S., Atkinson, E.E., Marin-Spiotta, E. & McDaniel, M.D. 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. *Ecology Letters*, doi: 10.1111/ele.12453.
Yao, H., Bowman, D. & Shi, W. 2011. Seasonal variations of microbial biomass and activity in warm- and cool-season turfgrass systems. *Soil Biology and Biochemistry* **43**, 1536–1543.