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The effect of soil pH and natural fertilizers on the productivity of different mixtures and nitrogen accumulation in plant biomass

R. Butkutė[1], N. Daugėlienė[2] and E. Butkuvienė[1]

[1]Vėžaičiai Branch, Lithuanian Institute of Agriculture, Gargždų 29, LT-96216, Vėžaičiai, Klaipėda District, Lithuania;phone no.: +370 46 458233, fax no.: +370 46 458777; e-mail: ruta@vezaiciai.lzi.lt
[2]Faculty of Forestry and Ecology, Lithuanian University of Agriculture, Studentų 11, LT-53356, Akademija, Kaunas District, Lithuania

Abstract. Research aimed at comparing the productivity and nitrogen (N) accumulation in plant biomass of different mixtures and permanent meadow grown in soils with different pH was performed. Most of the N was accumulated in permanent meadow grass biomass. Barley/lupine and barley/pea mixtures accumulated considerably less N. In most cases, soil pH had no significant effect on N accumulation. In fact, N accumulation strongly depended on plant productivity. In 2008, there was a more significant decrease in the productivity of barley/lupine mixture, compared to that of 2007. Permanent meadow was a more stable agroecosystem compared with annual mixtures; therefore different agroclimatic conditions had little effect on yield formation (somewhat bigger in 2008, but insignificantly), whereas increase in grass productivity was obtained. Average data for 2007 and 2008 showed that barley/pea mixture was the most productive.

Key words: soil pH, natural fertilizers, productivity, N accumulation.

INTRODUCTION

The resistance to anthropogenic factors depends on the abundance and activity of soil biota, as they are participating in metabolism of nutrients and energy, decomposing organic matter (Lockwood & Pimm, 1994; Eitminavičiūtė, 2001). To decrease the negative anthropogenic influence on environment restore the ecological balance and maintain soil fertility in acid soils liming should be performed first. Half of the calcium and magnesium compounds are mobile in acid soils, therefore they leach easily (Čiuberkienė & Ežerinskas, 2000; Mažvila et al., 2004; Butkute, 2006; Mesić et al., 2007). From the ecological point of view, adjustment and maintenance of soil pH is crucial, as productivity of agricultural crops strongly depends on proper pH and nutrient levels. Research carried out in acid soils has proven, that phosphorus and potassium compounds in grassland soils release when pH is $\geq$ 6.0 (Daugėlienė, 2002; Daugeliene & Butkute, 2008).

Legumes are of primary importance in agroecosystems, as legumes not only derive nitrogen from N_2 fixation, but also transfer it to cereals and ameliorate soil (Schulze, 2004; Trydeman Knudsen et al., 2004; Jensen et al., 2005). Fixed nitrogen is nature friendly, does not contaminate environment and its amounts within components of any farming system (organic farming is no exception) are not regulated by EU directives (Lapinskas, 2008). Cereals serve as prop; legumes grow higher and receive more sunlight. Therefore, intercropping of legumes and cereals is getting more popular, especially in organic farming system, where nitrogen supply is problematic (Jensen et al., 2005; Knoden et al., 2005; Hauggaard-Nielsen et al., 2008). Thus, nutrients and growth conditions are used more efficiently, so intercropping may enhance and stabilize yields and improve quality (Dahlamann, Fragstein, 2006; Jensen et al., 2005; Malezieux et al., 2008).

The research was performed with the aim to determine the effects of soil pH on the productivity and N accumulation in plant biomass of permanent meadow and mixtures of barley with legumes.

MATERIALS AND METHODS

The experiment was performed in Western Lithuania in 2007–2008. The soil of the research area was *Haplic Luvisol*, soil texture – light loam. Plot size was 50.4 m^2. Treatments were replicated threefold. Randomised design was used. Liming and fertilization till the beginning of the experiment established two pH_{KCl} levels: 5.1–5.5, and ~6.4. Limestone dust ($CaCO_3$ 98.5%) had been applied and introduced into the topsoil (10 cm depth) before sward sowing in spring 1991. Limestone rate was calculated according to the titration curves (Remezov method), neutralizing soil with 0.033 N of $CaCl_2$ solution. Primary soil acidity and planned pH level determined limestone rates varying from 3.4 to 27.8 t ha^{-1}. Over the period 2003–2006, the annual inputs of Ca and Mg from natural fertilizers were 55.8 kg ha^{-1} and 14.8 kg ha^{-1}, respectively.

Two field trials on a meadow with different fertilization rates ($P_{60}K_{60}$ and $N_{120}P_{60}K_{60}$) were observed. Barley/lupine and barley/pea mixtures were fertilized with $P_{60}K_{60}$. Fertilizers used were as follows: 'Provita' (14% N), phosphorite powder (20% P) and Patentkali/potassium magnesium (28% K_2O). 'Provita' was applied to meadow in equal parts twice after the 1st and 2nd cuts. PK fertilizers were applied early in spring before grass vegetation had resumed, and before sowing to the plots where barley/legume mixtures were grown. During the trial period nutrient amounts in the arable layer of soil were 0.10–0.17% N_{total}, 120–184 mg P_2O_5 kg^{-1} and 111–209 mg K_2O kg^{-1}.

The following mixture was sown: 35% of white clover (*Trifolium repens* L.), 40% of timothy (*Phleum pratense* L.) and 25% of meadow-grass (*Poa pratensis* L.). Long-term fertilization during the 15 years of use had formed two different sward types: white clover and meadow-grass sward in the plots fertilized with $P_{60}K_{60;}$ and sward, in which meadow-grass prevailed, where $N_{120}P_{60}K_{60}$ had been applied. Mixtures of spring barley (*Hordeum vulgare* L.) cv. *'Annabell'* with field pea (*Pisum sativum* L.) cv. *'Pinochio'* or narrow-leafed lupine (*Lupinus angustifolius* L.) cv. *'Boruta'* for silage were grown in 2007–2008. Sowing rate was 150 kg ha^{-1} of legumes and 50 kg ha^{-1} of barley.

Dry matter (DM) yields and sward botanical composition of three cuts were determined annually by weighing method. Mixture samples were collected from every plot, and from the two marked 0.25 m^2 spots to evaluate root and above-ground DM yields. Later on, metabolizable energy (ME) was re-calculated from DM yields using the coefficients: meadow – 10.0, barley/pea – 13.0, barley/lupine – 12.5 (Jankauskas *et al.*, 2000). Soil pH_{KCl} was determined ionometrically each autumn. Root yields were established by Kachinsky's weighing method (washing out and weighing the roots obtained from soil columns of 0.25 m^2 from 10 cm depth). N accumulation in plant root and above-ground biomass was evaluated determining the amounts of N_{total} by the Kjeldahl method.

Meteorological conditions during the study period 2007–2008 were contrasting and not sufficiently suitable for plant germination and development. Hail of 15 May 2007 (30.8 mm with 20 mm diameter ice pieces) had a strong negative effect on barley/legume crops. In spring 2007, a lack of moisture occurred, while there was a lot of rain in June and especially in July (251 mm of precipitation, i.e.three long-term average norms). The period April to September 2008 was distinguished by precipitation deficiency, especially in May and September, when only 23% and 24%, respectively, of long-term average precipitation had fallen. However, a wetter-than-average August 2008 had 183 mm of precipitation (double long-term average norm). Soil moisture in May-June varied from 9.5% to 11.6% in the plots, where barley/legume mixtures were grown. Monthly average temperatures of the period 2007-2008 were similar to the long-term average temperatures with some exceptions: by 1.0-2.3°C higher in May, June and August 2007 and by 2.0°C higher in April 2008..

Statistical analysis. The analysis was performed by using the SELEKCIJA software package, programme STAT_ENG for EXCEL vers. 1.55. Standard errors of the mean ($S\bar{x}$) were calculated. To determine the significance of the differences, F-test was used (Tarakanovas & Raudonius, 2003).

RESULTS AND DISCUSSION

Productivity. According to the obtained average data, the most productive (ME by 6.7–19.1 GJ ha^{-1} higher) of all the plants was the barley/pea mixture grown for silage (Table 1). Accumulated ME in permanent meadow was higher in 2008 compared with 2007. However, barley/legume mixtures accumulated less ME in 2008. In 2008 barley/lupine ME significantly (by 22.5–24.8 GJ ha^{-1}) decreased, compared to 2007. Irrespective of soil pH barley/pea mixtures accumulated by 8.0 GJ ha^{-1} lower ME amounts. The drought in spring 2008 was the main cause of poor germination of legumes, especially that of lupine. Therefore, lupine was suppressed by barley, and considerably lower barley/lupine yields were obtained.

Decrease in soil acidity from 5.1 to ~6.4 pH had no considerable effect on barley/pea mixture productivity, whereas the productivity of barley/lupine mixture tended to increase in less acidic soil. In almost every case the permanent meadow grown in ~6.4 pH soil accumulated by 2.3–5.4 GJ ha^{-1} higher ME, compared to the meadow grown in 5.1–5.5 pH soil. Fertilization with N_{120} increased ME accumulation in permanent grass.

Table 1. Metabolizable energy (GJ ha^{-1}) of agricultural crops grown in soil with different pH and fertilization (figures are means ME± $S\bar{x}$).

Soil pH_{KCl}	Metabolizable energy, GJ ha^{-1}			
	meadow $P_{60}K_{60}$	meadow $N_{120}P_{60}K_{60}$	barley/pea mixture	barley/lupine mixture
		2007		
5.1–5.5	32.5±3.50	40.8±2.90	57.6±4.80	54.2±2.69
6.4	34.8±4.82	46.2±2.97	58.7±3.11	59.2±1.65
		2008		
5.1–5.5	37.8±6.74	44.0±5.17	50.8±2.25	31.7±1.92
6.4	35.5±5.85	48.9±4.18	50.0±3.18	34.4±5.04
		2007–2008 average		
5.1–5.5	35.2±3.60	42.4±2.74	54.2±2.82	42.9±5.24
6.4	35.2±3.39	47.6±2.37	54.3±2.78	46.8±6.03

Table 2. N_{total} amounts accumulated in biomass of permanent meadow, barley/pea and barley/lupine mixtures, kg ha^{-1} (figures are means N_{total}± $S\bar{x}$).

Soil pH_{KCl}	N_{total} amounts accumulated in biomass			
	meadow $P_{60}K_{60}$	meadow $N_{120}P_{60}K_{60}$	barley/pea mixture	barley/lupine mixture
		in roots		
		2007		
5.1–5.5	124±7.23	-	3.77±0.50	6.52±0.98
6.4	119±4.84	-	5.56±1.19	6.88±0.56
		2008		
5.1–5.5	95±1.74	-	2.72±0.18	6.00±0.45
6.4	75±7.47	-	3.62±0.51	4.50±0.44
		in above-ground biomass		
		2007		
5.1–5.5	66±9.66	89±9.21	73.11±11.80	72.82±5.60
6.4	69±12.46	107±6.08	68.99±8.19	82.69±13.06
		2008		
5.1–5.5	92±19.74	108±20.38	62.88±3.72	66.63±7.56
6.4	92±19.20	124±11.00	69.29±5.44	54.12±5.63
		in roots + above-ground biomass		
		2007		
5.1–5.5	190±16.74	-	76.88±12.27	79.34±6.05
6.4	188±15.92	-	74.55±9.24	89.57±13.58
		2008		
5.1–5.5	187±18.03	-	65.59±3.79	72.63±7.11
6.4	167±12.98	-	72.91±5.90	58.62±5.94

Nitrogen accumulation in biomass. Continuous metabolism of nutrients and energy occurs in the soil. Microorganisms decompose plant residues, releasing and combining nitrogen. Plants draw nitrogen – it passes into different parts of the plant and accumulates in the biomass. As indicated in Table 2, N_{total} amounts in dry matter (DM) yield of permanent meadow (roots + above-ground biomass) were the highest of all the plants studied. Major part of N_{total} (~65%) accumulated in roots (2007) and the rest of it in above-ground biomass of all 3 cuts. However, in 2008 roots and above-ground mass accumulated similar N_{total} amounts. Fertilization with $N_{120}P_{60}K_{60}$ led to higher N_{total} accumulation in above-ground biomass by 23–38 kg ha^{-1} in 2007 and by 16-32 kg ha^{-1} in 2008, compared to the meadow fertilized with $P_{60}K_{60}$.. Root biomass was not determined in meadow fertilized with nitrogen, thus, we cannot derive tendencies towards N_{total} accumulation in roots. However, it is supposed that higher nitrogen amounts would accumulate, in the above-ground biomass of grass compared with the roots, in the meadows not fertilized with nitrogen.

Soil pH had no significant influence on nitrogen accumulation in roots, or its effect was indeterminate both in 2007 and 2008. Barley/legume mixtures, unlike the meadow, accumulated the major part of N_{total} in the above-ground biomass. Due to the strong effect of meteorological conditions in 2008, less nitrogen accumulated in mixture biomass compared with 2007. Both mixtures grown in soil with pH values between 5.1 and 5.5 accumulated similar N_{total} amounts. In 2007, when mixtures grew in soil with pH ~6.4, the barley/lupine accumulated by 15 kg ha^{-1} higher N_{total} amount than the barley/pea biomass. In 2008, however, inverse data were obtained.

In 2007, N_{total} amount in barley/pea biomass was not affected by soil pH, while considerably higher N_{total} amounts were determined in barley/lupine biomass. It was influenced by increased nitrogen accumulation in barley biomass. In 2008, similar nitrogen amounts accumulated in barley in soils of both pH values, and N_{total} in whole barley/lupine mixture was by 14 kg ha^{-1} lower.

Thus, we can speculate that the years 2007 and 2008 differed a lot on meteorological conditions, which were one of the major factors that determined legume germination, mixture productivity formation and nitrogen accumulation in biomass. From the point of view of soil protection, the best means to capture nitrogen is to grow permanent meadows, as major part of nitrogen accumulates in grass roots. Annual mixtures accumulated most of the nitrogen in above-ground biomass, thus agroecosystems lose it with the yield. However, barley/legume mixtures are high-yielding and nutritious; legumes fix atmospheric nitrogen and can transfer it to barley. Thus, barley/legume mixtures are good rotational crops, especially for organic farms.

CONCLUSIONS

Average data of the research showed that barley/pea mixture was the most productive of crops. Different agroclimatic conditions first of all affected barley/lupine yield. Permanent meadow productivity was similar in 2007 and 2008. Nitrogen fertilization with ‘Provita’ N_{120} resulted in significantly higher meadow productivity both in 5.1–5.5 and in ~6.4 pH soil. Decreased soil acidity (from pH 5.1…5.5 up to ~6.4) positively affected barley/lupine and meadow productivity, especially that of the meadow fertilized with $N_{120}P_{60}K_{60}$..

Most of N_{total} was accumulated in permanent meadow biomass. Barley/lupine and barley/pea mixtures accumulated considerably less N_{total}. In permanent meadow agroecosystem the majority of N_{total} accumulated in roots, however in case of barley/legume mixtures – in the above-ground biomass. More N_{total} was accumulated in lupine roots compared with pea (9% and 1.5%, respectively, from total accumulated nitrogen amount in under- and above-ground biomass). In most cases soil pH did not significantly affect accumulation of nitrogen, or its effect was indeterminate both in 2007 and 2008.

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