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Effect of magnesium fertiliser on Italian ryegrass (*Lolium multiflorum* Lam.) in different types of soil with different carbonate content levels

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Abstract

Pot experiments were conducted in 2008–2010. Italian ryegrass (*Lolium multiflorum* Lam.) plants were sown into pots filled with soil of different types and with different carbonate content levels, collected from different locations in Lithuania. Two rates of magnesium fertiliser were applied. A total of 9 experiments were performed. Plant available content of magnesium in the collected soil samples was determined using Egner-Riehm-Domingo, Mehlich 3 and Schachtschabel methods and potassium chloride, ammonium acetate and water extractions. Our research evidence suggests that magnesium fertilisation resulted in a statistically significant herbage yield increase in all the soil types tested in our experiments only in the conditions of hot summer with short showery rain. In that year, Mg_{20} rate increased the herbage yield on average by 12% and Mg_{40} by 14.1%. In favourable weather conditions, magnesium fertilisation practically did not increase the yield of annual ryegrass.

The correlation was established between the annual ryegrass yield and plant available magnesium, plant available calcium carbonates and humus content in soil. Six methods for determination of magnesium content in soil were compared. The yield increase resulting from magnesium fertilisation correlated most significantly with the plant available magnesium content in the soil determined by Egner-Riehm-Domingo method and in water extraction.

Magnesium content in the Italian ryegrass herbage yield was higher in the less productive year, characterised by high air temperatures. The herbage yield of the second cut contained lower levels of magnesium than that of the first cut. Magnesium fertilisation increased the content of magnesium in herbage; this was especially evident when Mg_{40} rate had been applied. Crude protein content in the dry matter of Italian ryegrass herbage yield in the first cut ranged from 6.19% to 13.88%, in the second cut from 3.19% to 4.75%. In most cases, magnesium fertilisation increased crude protein content in Italian ryegrass herbage. Italian ryegrass crop absorbed 24 kg ha^{-1} of magnesium on average, and 30 kg ha^{-1} when the crop was more productive or accumulated larger amounts of magnesium in the herbage yield.

Key words: *Lolium multiflorum*, magnesium fertiliser, magnesium in soil.

Introduction

Magnesium (Mg) is a macro-element playing an important role in plant nutrition process. This element is necessary for performance of the main physiological functions: it participates in a photosynthesis process as a constituent of a chlorophyll molecule; it is an important agent in the process of phosphorus transport within the plant; it takes part in the synthesis of sugars and transport of starch as well as in several other physiological and biochemical processes (Roemheld, Kirkby, 2007).

The results of an inter-laboratory research programme (12 laboratories from ten countries participated in this programme) organised by VDLUFA (Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten) revealed that European researchers have quite different views on the crop demand for magnesium as well as on the need for magnesium fertilisation (Fotyma, Dobers, 2008). The same soil samples were tested for magnesium content in the laboratories of different countries using the methods valid in the given country. The laboratories of Hungary, Latvia and Lithuania determined high levels of magnesium in the majority of the tested soil samples, while Estonian and Polish laboratories determined low levels of magnesium in the majority of the same soil samples. Each laboratory calculated the recommended magnesium fertilisation rates (kg ha^{-1} Mg) for one tone of the total crop yield (primary production like grain plus secondary production like straw) using the fertilisation calculation methods valid in the given country. This resulted in even bigger differences between the countries: the recommended magnesium fertilisation rate varied from 1.2 to 3.2 kg ha^{-1} Mg for winter wheat crop, from 4.5 to 6.0 kg ha^{-1} Mg for winter rape crop, and from 0 to 0.91 kg ha^{-1} Mg for potato crop. The recommended magnesium fertilisation rate in some of the European countries (including Lithuania) is based on the amount of readily available magnesium in soil instead of the specific demand of the crop grown (Fotyma, Dobers, 2008). For example, if the level of readily available magnesium content in soil is considered to be normal, the recommended rate of magnesium (MgO) fertilisers for the grass crops is: 15 kg ha^{-1} in Estonia, 20 – in Latvia and Norway, 25 – in Denmark, 40 – in France, Germany and Benelux countries, 30–50 (depending on the K:Mg ratio in soil) – in Austria (Ristimaki, 2007).

The level of readily available magnesium content in soil and thus the efficiency of magnesium fertiliser depends on soil texture, pH and humus content (Lietuvos dirvožemių..., 1998; Ristimaki, 2007; Staugaitis, Rutkauskienė, 2010). Magnesium deficiency in plants can be caused not only by the low level of readily available magnesium content in soil; competing cations – Ca^{2+} in calcareous soils, H^+, NH_4^+ and Al^{3+} in acid soils, and Na^+ in saline soils – can also prevent the uptake of magnesium by plants (Mengel, Kirkby, 2001; Shaul, 2002). Moreover, the uptake of magnesium by plants depends also on the ratio of the levels of exchange cations: calcium, magnesium, potassium, sodium and ammonium (Loide, 2004; Mažvila et al., 2006). Researchers indicate that the optimal ratios of Ca:Mg and K:Mg content in soil are 5–8:1 and <5:1, respectively (Ristimaki, 2007; Rehm, 2009). Magnesium fertilisation decreases the negative impact of some adverse processes taking place in soil on the crops grown, for example, the toxicity of the aluminium ions (Keltjens, Tan, 1993). Since the magnesium is an important element for the nitrogen compound metabolic process, magnesium deficiency might disturb the protein synthesis process. Magnesium fertilisation facilitates an increase in protein content in plants; higher protein content is an important factor in production of forage grain crops and grasses (Mayland, Wilkinson, 1989; Roemheld, Kirkby, 2007). Excessive potassium fertilisation results in decreased magnesium content in plants, therefore the rates of potassium fertilisers for forage grass crops should not be high (Jarvis, Fisher, 2007). Plants containing optimal magnesium levels are more resistant to the negative environmental factors, such as drought, heat, lack of light; such extreme weather events have become more frequent due to the global warming processes (Cakmak, Kirkby, 2007). Plants grown in the soils with low magnesium content levels (sandy soils are generally low in magnesium) accumulate less of this element; in such cases magnesium fertilisation is very efficient (Mayland, Wilkinson, 1989).

The recommended magnesium fertilisation rate in the Central and Eastern European countries is generally based on the amount of readily available magnesium in the soil as well as on the soil texture. As a result of that, there are different numbers of groups of soil richness in magnesium, which determine the content of magnesium in the soil: 10 in Slovenia, 12 in Latvia, 15 in Austria, Lithuania, Czech Republic and Slovakia, 20 in Poland, 25 in Germany and 50 in Hungary (Fotyma, Dobers, 2008). The determination of soil groups in Lithuania is conducted differently: the amount of readily available magnesium in soil is linked to the soil pH and thus the different soil types are divided into three groups: ≤6.0, 6.1–7.0, ≥7.1 pH.

These differences in evaluation of magnesium content in soil and calculation of recommended magnesium fertilisation rates encouraged us to reassess the effect of magnesium fertilisation on plants. The majority of scientific publications on this matter in Central and Eastern Europe were published in the middle of the last century. More recent researches have been conducted in other continents and on the plants which are not grown in Northern Europe (McNaught et al., 1968; Johnston, 2007; Dordos, 2009).

Italian ryegrass (*Lolium multiflorum* Lam.) was selected as an experimental plant for evaluation of the magnesium fertilisation effect on the yield in soils of different types and with different carbonate content levels as well as on the level of magnesium and crude protein content in herbage (these indicators are important for cattle feeding). Another area of interest was evaluation of the significance of different soil properties for the efficiency of magnesium fertilisation, since European countries are prioritising different indicators: plant available magnesium content in soil, soil texture, soil pH, content of carbonates in soil, humus content in soil, even the groups of plants cultivated (field crops, horticultural crops, grasses, etc.) (Fotyma, Dobers, 2008; Budnakova, Čermak, 2009).

The aim of this research was to assess the yield of Italian ryegrass and the content of magnesium and crude proteins in it as affected by magnesium fertilisation. We chose to conduct pot experiments (instead of filed experiments) in order to test a large enough number of different soil types for our research.

Materials and methods

The pot experiment (Mitscherlich type pots were used) was conducted in 2008–2010 at the Agrochemical Research Laboratory of the Lithuanian Research Centre for Agriculture and Forestry. Italian ryegrass (*Lolium multiflorum* Lam.) plants were fertilised using the following scheme: 1) not treated with Mg (Mg_0), 2) 20 kg ha^{-1} of Mg (Mg_{20}), 3) 40 kg ha^{-1} of Mg (Mg_{40}).

Cylinder-shaped plastic pots 17 cm in height and 22 cm in diameter were filled with 6 l of soil. The soil was thoroughly mixed, stones and plant residues were removed. Then it was sieved (mesh width 5 mm), poured into the pots by hand and evenly pressed to the mark of the selected soil volume. Mg_{20} rate was achieved by applying 0.075 g of magnesium per pot, and Mg_{40} – 0.15 g. The pots were irrigated with the solution of magnesium sulphate dissolved in water. Before sowing all pots were fertilised with $N_{80}P_{60}K_{107}$ (0.3 g N, 0.15 g P_2O_5 and 0.4 g K_2O per pot): the pots were irrigated with water solutions of urea, single superphosphate and potassium chloride. Every treatment had four replications. One experiment consisted of 12 pots in total. Two grams of seeds (calculated into 100% germination) of Italian ryegrass cv. 'Dilana' were sown per pot. The seeds were evenly distributed on the soil surface and then covered with 1 cm layer of soil. The ryegrass was sown on May 8–10 every year of the experiment. The first cut (booting stage) was taken on June 26–30, the second (beginning of inflorescence emergence stage) – on September 4 in 2008 and 2009, and on August 30 in 2010. The plants were cut 2 cm above the soil surface; the harvested herbage was weighed separately for each pot. During vegetative growth plants were manually watered with distilled water. Plant protection measures were not used during the whole experimental period.

Three separate experiments using soil of different types and with different carbonate content levels were conducted each year, thus in three years there were carried out 9 separate experiments on annual ryegrass magnesium fertilisation. Soil for each experiment was collected from the arable layer in specially selected areas where spring cereals had been grown. The soils were divided into three groups according to the soil quality requirements: 1) carbonate-poor*:* plant available magnesium content (A-L) <200 mg kg^{-1}, plant available calcium content (A-L) approx. 1000 mg kg^{-1}, pH$_{KCl}$ <5.0, content of carbonates <0.1%; 2) moderately-rich in carbonates*:* plant available magnesium content (A-L) 250–300 mg kg^{-1}, plant available calcium content (A-L) approx. 2000 mg kg^{-1}, pH$_{KCl}$ 5.1–6.0, content of carbonates 0.1–0.3%; 3) carbonate-rich*:* plant available magnesium content (A-L) >500 mg kg^{-1}, plant available calcium content (A-L) approx. 4000 mg kg^{-1}, pH$_{KCl}$ >6.5, content of carbonates >0.3%.

Our aim was to have all types of the aforementioned soils every experimental year.

Plant available content of magnesium in the collected soil samples was determined using 6 methods. 1. Egner-Riehm-Domingo method (abbreviated as A-L). The sample was extracted in the A-L buffer solution (1 M lactic acid, 3 M acetic acid and 1 M ammonium acetate, pH 3.7), soil to solvent ratio 1:20, stirred for 4 hours. 2. Mehlich 3 method (abbreviated as Me 3). The sample was extracted in Me 3 solution (0.2 M acetic acid, 0.015 M ammonium fluoride, 0.013 M nitric acid, 0.25 M ammonium nitrate, 0.001 M ethylenediaminetetraacetic acid, solution was prepared using all the listed reagents, its pH was 2.5), soil to solvent ratio 1:10, stirred for 5 minutes. 3. Calcium chloride or Schachtschabel method (abbreviated as $CaCl_2$). The sample was extracted in 0.0125 M calcium chloride solution, soil to solvent ratio 1:20, stirred for 1 hour. 4. Potassium chloride method (abbreviated as KCl). The sample was extracted in 1 M potassium chloride solution, soil to solvent ratio 1:10, stirred for 1 hour. 5. Exchangeable magnesium or magnesium determined in ammonium acetate extract (abbreviated as NH_4OAc). The sample was extracted in 1 M ammonium acetate solution (pH 7.0), soil to solvent ratio 1:10, stirred for 1 hour. 6. Water soluble magnesium (abbreviated as H_2O Mg) was determined by extracting the sample in water, soil to solvent ratio 1:5, stirred for 1 hour.

Soil pH$_{KCl}$ was determined using 1N KCl potentiometric method, plant available phosphorus, potassium and calcium – A-L method, carbonates – using calcimeter, calculation of humus content was based on the organic carbon amount determined by dry combustion. Total nitrogen content in Italian ryegrass herbage was determined using Kjeldahl method. Total nitrogen amount was multiplied by 6.25 and thus the crude protein content in grass was obtained. Magnesium amount in grass was determined by dry combustion using the “Analyst 200AA” spectrometer (“Perkin Elmer Inc.”, USA). Magnesium balance was calculated by subtracting the amount of magnesium taken up by the plants from the amount of magnesium supplied by fertiliser.

Soil. Properties of the soil types used in our pot experiments are presented in Tables 1 and 2. We selected the soils typical of Lithuania: *Luvisols* (*LV*), *Albeluvisols* (*AB*) and *Cambisols* (*CM*). The texture of soils was sandy loam or loam. Humus content was within a range of 1.69–3.86%, plant available phosphorus (P_2O_5) – 45–253 mg kg^{-1}, plant available potassium (K_2O) – 90–275 mg kg^{-1}. As one can see, five groups of soil richness in phosphorus and four groups of soil richness in potassium were represented by our soil samples.

Table 1. Properties of soil used in the experiments

Indicators	Experiment No.*								
	1^1	2^2	3^3	4^1	5^2	6^3	7^1	8^2	9^3
Year	2008			2009			2010		
Soil typology FAO**	*ABd*	*LVg-n-w-ha*	*CMg-n-h-cap*	*LVg-n-w-ha*	*LVh-gld-w*	*LVk-ha*	*LVh-gld-w*	*LVk-gld-w*	*CMg-n-h-cap*
Soil texture	Sandy loam	Loam	Loam	Sandy loam	Loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Sand (2–0.063 mm)	56.9	50.6	50.6	70.1	49.8	56.7	60.6	70.9	57.4
Silt (0.063–0.002 mm)	29.9	34.7	35.9	24.2	35.2	28.1	30.2	24.7	33.8
Clay (<0.002 mm)	13.2	14.7	13.5	5.7	15.0	15.2	9.2	4.4	8.8
pH$_{KCl}$	4.3	5.4	7.1	4.9	6.2	6.6	5.3	6.1	7.0
P_2O_5 (A-L) mg kg^{-1}	137	45	67	121	212	142	137	253	183
K_2O (A-L) mg kg^{-1}	143	90	92	186	176	153	275	132	156
Ca (A-L) mg kg^{-1}	912	2044	4162	937	1964	3496	1894	2035	8488
Carbonates %	0.00	0.17	0.50	0.08	0.08	0.58	0.00	0.08	0.33
Humus %	1.69	2.91	3.86	1.83	1.84	3.09	1.83	2.03	2.17
Ca:Mg (A-L)	6.8	8.0	6.2	6.2	6.9	6.3	6.9	8.0	6.2
K:Mg (A-L)	1.06	0.35	0.14	1.25	0.62	0.27	1.01	0.52	0.11
K:Mg (A-L:KCl)	2.17	0.60	0.34	2.78	0.90	0.56	1.91	1.08	0.99

* – conditional group of soil richness in carbonates is indicated: ^{1} – carbonate-poor, ^{2} – moderately-rich in carbonates, ^{3} – carbonate-rich. ** – *ABd – Dystric Albeluvisol*, *CMg-n-h-cap – Epicalcari-Endohypergleyic Cambisol*, *LVg-n-w-ha – Hapli-Endohypogleyic Luvisol*, *LVh-gld-w – Bathihypogleyi-Haplic Luvisol*, *LVk-gld-w – Bathihypogleyi-Calc(ar)ic Luvisol*, *LVk-ha – Hapli-Calc(ar)ic Luvisol*.

Table 2. Magnesium (Mg) content (mg kg^{-1}) in experimental soils determined using different methods

Method	Experiment No.								
	1^1	2^2	3^3	4^1	5^2	6^3	7^1	8^2	9^3
A-L	135	255	676	151	283	558	273	254	1360
Me-3	97	166	396	71	199	372	174	158	316
KCl	66	149	272	67	196	275	144	122	158
NH_4OAc	64	148	316	65	192	262	123	117	149
$CaCl_2$	93	170	286	70	191	287	169	141	182
H_2O Mg	11	25	31	9	17	32	61	23	53

^{1} – carbonate-poor, ^{2} – moderately-rich in carbonates, ^{3} – carbonate-rich

Due to our aim each year to carry out pot experiments using the soils representing all three groups of soil types: relatively poor, moderately-rich and rich in carbonates, the differences between the determined pH values as well as the content of carbonates, plant available calcium and magnesium were substantial: pH_{KCl} – 4.3–7.1, carbonates – 0.00–0.58%; calcium (Ca) – 912–8488 mg kg^{-1}, magnesium (Mg_{A-L}) – 135–1360 mg kg^{-1}. The content of plant available magnesium in soil depended on soil richness in carbonates. Larger differences in plant available magnesium content in the tested soils were obtained using A-L and Me 3 methods. The ratio of plant available calcium and magnesium content in soil was optimal – from 6.2 to 8.0. The ratio of plant available potassium and magnesium content in tested soils varied much more: K:Mg (A-L) – from 0.11 to 1.25, K:Mg (A-L:KCl) – from 0.34 to 2.17.

Weather conditions. In 2008 and 2009, the air temperature in May was close to the multi-annual average (Table 3). Precipitation level was lower than usual; plants were watered manually, germination and growth were good. In 2010, heavy rains occurred during emergence. This resulted in soil surface compaction and subsequently – low germination and weak growth.

Table 3. Means of the daily (24 hour) air temperature (°C) and precipitation level (mm) in 2008–2010 (Kaunas Weather Station)

Year	May				June				July				August			
	I	II	III	month	I	II	III	month	I	II	III	month	I	II	III	month
Means of the daily (24 hour) air temperature (°C) for ten days and for whole month																
2008	12.0	11.8	12.9	12.2	17.6	15.1	15.4	16.0	16.9	17.9	19.3	18.1	18.3	19.7	16.0	17.9
2009	11.4	11.7	14.8	12.7	12.7	13.5	18.4	14.9	18.0	19.3	18.0	18,4	18.4	16,6	15.7	16.9
2010	10.8	16.5	13.9	13.7	17.6	15.4	16.4	16.5	19.8	23.8	21.9	21.9	21.4	22.0	16.0	19.7
V.*				12.3				15.5				17.5				16.4
Precipitation (mm) per ten days and per whole month																
2008	6	9	20	35	0	38	45	83	22	17	5	44	35	36	28	99
2009	13	9	21	43	50	41	17	108	22	38	24	84	0	26	61	87
2010	15	60	21	96	59	27	41	127	14	22	60	96	35	19	113	167
V.*				54.1				62.8				81.1				80.2

V.* – multi-annual average for 1975–2009

In 2008, June was warmer than multi-annual average. In 2009, the first 20 days of June were cool and rainy, yet in general in both years June was favourable for the growth of Italian ryegrass which resulted in high herbage yield of the first cut. In 2010, an average monthly air temperature of June was by 1°C higher than multi-annual average; during the first 10 days of June intensive showers compacted the soil surface which resulted in weak growth and low yield of the first cut.

In 2008 and 2009, July and August were warmer than usual; an average air temperature was within 15.7–19.7°C, growth conditions were favourable, and the yield of the second cut was good. In 2010, July and August were substantially warmer than usual – 50 days from the beginning of July an average air temperature exceeded the multiannual average and was 19.8, 23.8, 21.9, 21.4, 22.0 °C for every 10 days respectively. The air temperature drop during the last ten days of August was followed by heavy rains – 113 mm of rainfall in ten days period. Experimental pots were soaked, plants lodged, and thus the cut was taken 5 days earlier than usual. In general, the weather conditions in 2008 and 2009 were favourable for Italian ryegrass growth, and in 2010 – not favourable because of the heavy rains and hot weather, especially after the first cut.

Results and discussion

Our research evidence suggests that magnesium fertilisation effect on the Italian ryegrass yield was contradictory (Table 4).

When the plants were fertilised with magnesium at Mg_{20} rate, an increase in the Italian ryegrass yield was statistically significant (LSD_{05}) in four experiments, in one experiment a statistically significant decrease of the yield was calculated, and in other four experiments a trend towards decrease was recorded (Table 5). When Mg_{40} rate was applied, an increase in the Italian ryegrass yield was statistically significant (LSD_{05}) in the same four experiments, in three experiments a statistically significant decrease of the yield was calculated, and in two experiments a yield increase trend was recorded.

Annual ryegrass yield increase was evident in 2010 characterised by high air temperatures and showers. Statistically significant yield increase was recorded in experiments No. 7, 8 and 9 when fertilisation rates Mg$_{20}$ or Mg$_{40}$ had been applied. In 2010, magnesium fertilisation increased the yield of Italian ryegrass grown in different soils with different agrochemical properties. Herbage yield increase, when compared to the not fertilised treatment, was obtained in the first as well as in the second cut. On average for the three experiments of 2010 the Mg$_{20}$ rate increased the herbage yield by 12.0% (the increase ranged from 7.9% to 20.2%), Mg$_{40}$ rate – by 14.1% (9.0–29.2%). Thus in hot weather conditions Mg$_{20}$ rate increased the herbage yield on average by 12.0%, and application of the larger Mg$_{40}$ rate resulted in a 2.1% yield increase.

In 2008 and 2009, the weather conditions were typical of Lithuania. Statistically significant herbage yield increase was obtained only in experiment No. 3, the largest increase was recorded when Mg$_{20}$ rate was applied. In experiments No. 4 and 6, when Mg$_{40}$ rate was applied, the yield increase trends were recorded; in some of the aforementioned experiments the herbage yield did not increase. Application of magnesium fertilisers in other experiments resulted in yield decrease or the trends of yield decrease were recorded. On average, in 2008 and 2009 (normal weather conditions) application of magnesium fertilisers did not increase the yield of Italian ryegrass.

In 2008 and 2009, application of Mg$_{40}$ rates increased the herbage yield or resulted in the yield increase trends in experiments Nos 3 and 6, where soil had higher levels of humus (3.86% and 3.09%, respectively) and the K:Mg ratio was low. It is likely that these soil properties were responsible for higher efficiency of magnesium fertilisers (as indicated by Mayland and Wilkinson, 1989). The correlation between the soil agrochemical properties and the Italian ryegrass yield revealed that the latter was higher when plants were grown in soils with higher pH and containing larger amounts of plant available magnesium, calcium, carbonates and higher humus content (Table 10).

Table 4. Annual ryegrass yield (g of dry matter per pot) as affected by the magnesium fertilisation

Rate	2008				2009				2010				2008–2010		
	Experiment No.														
	1	2	3	$\bar{x}$	4	5	6	$\bar{x}$	7	8	9	$\bar{x}$	1.4.7	2.5.8	3.6.9
1^{st} cut															
Mg$_0$	24.1	21.4	19.1	21.6	20.4	20.2	20.6	20.4	13.8	16.1	9.5	13.1	19.4	19.2	16.4
Mg$_{20}$	22.3	20.9	21.6	21.6	19.3	18.4	20.7	19.5	15.1	17.5	10.9	14.5	18.9	18.9	17.7
Mg$_{40}$	20.8	17.7	20.6	19.7	21.2	19.3	21.7	20.7	13.9	16.9	11.1	14.0	18.6	18.0	17.8
LSD$_{05}$	2.16	2.94	2.18		1.58	1.85	1.58		1.06	1.14	0.71		0.57	2.93	0.42
2^{nd} cut															
Mg$_0$	13.7	11.3	14.5	13.2	10.6	14.9	15.8	13.8	10.8	11.6	8.3	10.2	11.7	12.6	12.9
Mg$_{20}$	14.7	10.8	15.3	13.6	10.9	14.2	15.2	13.4	12.1	12.5	10.6	11.7	12.6	12.5	13.7
Mg$_{40}$	13.9	10.7	15.1	13.2	10.0	13.6	15.0	12.9	13.0	13.3	11.9	12.7	12.3	12.6	14.0
LSD$_{05}$	1.56	1.64	1.65		1.11	1.56	1.25		1.22	1.12	1.11		0.82	0.76	0.57
1^{st} and 2^{nd} cut															
Mg$_0$	37.8	32.7	33.7	34.7	31.0	35.1	36.3	34.1	24.6	27.7	17.8	23.4	31.14	31.83	29.26
Mg$_{20}$	36.9	31.7	36.8	35.2	30.2	32.7	35.9	32.9	27.3	29.9	21.4	26.2	31.47	31.44	31.38
Mg$_{40}$	34.7	28.5	35.7	32.9	31.1	32.9	36.8	33.6	26.9	30.2	23.0	26.7	30.91	30.59	31.81
LSD$_{05}$	1.46	3.21	1.81		1.82	1.91	2.16		1.91	2.01	1.05		1.14	2.57	0.272

Table 5. Annual ryegrass yield increase (+) or decrease (–) as affected by the magnesium fertilisation

Rate	Experiment No.								
	1	2	3	4	5	6	7	8	9
Mg$_{20}$	–	–	+*	–	–*	–	+*	+*	+*
Mg$_{40}$	–*	–*	+*	+	–*	+	+*	+*	+*

* – statistically significant (LSD$_{05}$)

We evaluated the effect of magnesium fertilisers on the annual ryegrass yield as influenced by soil richness in carbonates. In 2008–2010, when Mg$_{20}$ rate was applied, the increase in herbage yield of the 1st and 2nd cuts in carbonate-poor soils was 2.0%, in moderately-rich soils the yield decreased by 0.7%, and in carbonate-rich soils the yield increased by 9.4%. When Mg$_{40}$ rate had been applied the yield increased by 0.5% in carbonate-poor soils, decreased by 3.4 in moderately-rich soils and increased by 12.2% in carbonate-rich soils. Thus we did not get the expected result – that magnesium fertilisation would increase the annual ryegrass yield most in carbonate-poor soils, as some researchers had indicated (Lietuvos dirvožemių..., 1998; Bogdevitch, Mishuk, 2006). The largest annual ryegrass yields were obtained in carbonate-rich soils with high content of plant available magnesium determined not only by A-L method, but also by other methods. Yet, the yield increase correlated most significantly with the plant available magnesium content in soil determined using A-L method and water extraction, and with plant available calcium content.

The determined magnesium content in the Italian ryegrass yield was within the range of 0.13–0.30% (Table 6). Magnesium content in the herbage yield of the 2nd cut was lower. Magnesium content in herbage depended on the year: it was 0.18% in the herbage yield of the 1st cut of not fertilised plants in 2008, 0.21% in 2009 and 0.23% in 2010; in the herbage yield of the 2nd cut – 0.17, 0.17 and 0.19%, respectively. In 2010, characterised by high air temperatures and showers, magnesium content in the Italian ryegrass yield was higher.

Table 6. Magnesium (Mg) content (%) in annual ryegrass yield as affected by the magnesium fertilisation

Rate	2008				2009				2010				2008–2010		
	Experiment No.														
	1	2	3	$\bar{x}$	4	5	6	$\bar{x}$	7	8	9	$\bar{x}$	1.4.5	2.5.8	3.6.9
	1st cut														
Mg_0	0.13	0.21	0.20	0.18	0.14	0.19	0.25	0.21	0.24	0.22	0.23	0.23	0.17	0.21	0.23
Mg_{20}	0.15	0.23	0.23	0.20	0.16	0.19	0.25	0.20	0.27	0.21	0.21	0.23	0.20	0.21	0.23
Mg_{40}	0.16	0.24	0.23	0.23	0.21	0.18	0.27	0.22	0.30	0.23	0.23	0.25	0.22	0.21	0.24
LSD_{05}	0.025	0.020	0.003		0.009	0.018	0.077		0.107	0.063	0.018		0.038	0.011	0.031
	2nd cut														
Mg_0	0.13	0.20	0.19	0.17	0.15	0.17	0.20	0.17	0.17	0.21	0.19	0.19	0.15	0.19	0.19
Mg_{20}	0.15	0.22	0.20	0.19	0.19	0.18	0.20	0.19	0.19	0.22	0.18	0.20	0.17	0.20	0.19
Mg_{40}	0.19	0.22	0.20	0.20	0.20	0.18	0.19	0.18	0.23	0.25	0.20	0.22	0.20	0.22	0.20
LSD_{05}	0.01	0.006	0.032		0.031	0.053	0.039		0.018	0.077	0.053		0.006	0.023	0.022

Magnesium fertilisation increased the magnesium content in herbage: at Mg_{20} rate the magnesium content increase was statistically significant (LSD_{05}) in the herbage yield of the 1st cut of two experiments and in the herbage yield of the 2nd cut of four experiments; at Mg_{40} rate – in the herbage yield of both cuts of four experiments (Table 7). In other experiments, the trend of magnesium content increase was recorded, especially when Mg_{40} rate was applied.

The correlation analysis revealed that an increase in magnesium content in herbage depended mostly on plant available magnesium content in soil determined using KCl and $CaCl_2$ extractions, and on pH (Table 10). It depended less on the content of plant available calcium and carbonates in soil.

Table 7. Increase (+) or decrease (–) of magnesium content in annual ryegrass yield as affected by the magnesium fertilisation

Rate	Experiment No.								
	1	2	3	4	5	6	7	8	9
	1st cut								
Mg_{20}	+	+	+*	+*	0	0	+	–	–*
Mg_{40}	+*	+*	+*	+*	–	+	+	+	+
	2nd cut								
Mg_{20}	+*	+*	+	+*	+	+	+*	+	–
Mg_{40}	+*	+*	+	+*	+	–	+*	+	+

* – statistically significant (LSD_{05})

The determined content of crude protein in the herbage yield of the 1st cut was within the range of 6.19–13.88%, in the herbage yield of the 2nd cut – 3.19–4.75% (Table 8). The content of crude protein in the grass not fertilised with magnesium depended on the year: herbage yield of the 1st cut contained 7.24% of crude protein in 2008, 7.22% in 2009 and 10.86% in 2010; herbage yield of the 2nd cut contained 3.72% of crude protein in 2008, 3.57% in 2009 and 4.44% in 2010. Thus in hot weather conditions of 2010, the content of crude protein in herbage yield of the 1st cut was by 50.2% higher than that accumulated in herbage in 2008–2009, and in the herbage yield of the 1st cut – by 21.8% higher.

Magnesium fertilisation increased the crude protein content in plants in most cases: at Mg_{20} rate the crude protein content increase was statistically significant (LSD_{05}) in herbage yield of the 1st cut of four experiments, in other five experiments the trend of crude protein content increase was recorded (Table 9); as for the herbage yield of the 2nd cut, the trend of crude protein content increase was recorded in seven experiments, and in the other two experiments the crude protein content decreased (the decrease was statistically significant only for one experiment).

Table 8. Crude protein content (%) in Italian ryegrass yield as affected by the magnesium fertilisation

Rate	2008			2009			2010			2008–2010		
	Experiment No.											
	1	2	3	4	5	6	7	8	9	1.4.5	2.5.8	3.6.9
						1st cut						
Mg_0	7.06	7.31	6.19	6.31	7.13	8.22	9.81	12.56	10.22	7.73	8.99	8.21
Mg_{20}	7.09	7.81	6.27	6.34	7.63	9.28	10.5	13.88	11.08	7.98	9.77	8.88
Mg_{40}	6.38	7.19	6.25	6.45	7.93	10.09	10.5	13.66	11.81	7.78	9.59	9.44
LSD_{05}	0.87	0.79	0.63	0.66	0.90	0.76	0.38	0.98	0.37	0.07	0.36	0.22
						2nd cut						
Mg_0	3.69	3.75	3.72	3.50	3.34	3.88	4.75	4.28	4.28	3.98	3.79	3.96
Mg_{20}	3.97	3.81	3.31	3.84	3.41	3.91	4.75	4.09	4.56	4.19	3.77	3.93
Mg_{40}	3.63	4.28	3.59	3.69	3.19	3.78	4.44	4.44	4.22	3.92	3.97	3.87
LSD_{05}	0.48	0.33	0.29	0.48	0.11	0.61	0.44	1.09	0.55	0.15	0.42	0.40

Table 9. Increase (+) or decrease (–) of crude protein content in annual ryegrass yield as affected by the magnesium fertilisation

Rate	Experiment No.								
	1	2	3	4	5	6	7	8	9
					1st cut				
Mg_{20}	+	+	+	+	+	+*	+*	+*	+*
Mg_{40}	–	–	+	+	+	+*	+*	+*	+*
					2nd cut				
Mg_{20}	+	+	–*	+	+	+	+	–	+
Mg_{40}	+	+*	+	+	–*	+	–	+	–

* – statistically significant LSD_{05}

When Mg_{40} rate was applied, the crude protein content increase was statistically significant LSD_{05} in herbage yield of the 1st cut of four experiments, in other three experiments the trend of crude protein content increase was recorded; crude protein content in the herbage yield of the 2nd cut increased in the majority of experiments, yet there were several experiments where the decrease was recorded.

The correlation analysis revealed that dependence of crude protein content in plants on different agrochemical properties of soil was not significant. Weak correlation was determined between the crude protein content in grass and the humus and water soluble magnesium content in soil (Table 10).

Table 10. The correlation between the Italian ryegrass yield, magnesium and crude protein content in herbage and the agrochemical properties of soil

Agrochemical properties of soil x	y				
	yield	magnesium content	crude protein content	yield increase	
				Mg_{20}	Mg_{40}
Plant available magnesium content mg kg^{-1}:					
A-L	0.402	0.389	0.181	0.642**	0.727**
Me-3	0.618**	0.588**	0.074	0.362*	0.367*
KCl	0.691**	0.684**	0.217	0.093	0.074
NH_4OAc	0.596**	0.569*	0.301	0.092	0.048
$CaCl_2$	0.698**	0.685**	0.148	0.165	0.120
H_2O Mg	0.520*	0.588**	0.415	0.674**	0.625**
Plant available calcium content mg kg^{-1}	0.443	0.423	0.224	0.651**	0.726**
pH_{KCl}	0.745**	0.691**	0.109	0.431**	0.489**
Carbonate content %	0.481*	0.381	0.222	0.193	0.222
Humus content %	0.415	0.276	0.368	0.089	0.056

** – statistically significant (LSD_{01}), * – statistically significant (LSD_{05})

Italian ryegrass plants not treated with magnesium fertiliser accumulated in the herbage yield on average 59 mg of magnesium per pot during vegetative period (Table 11). This magnesium amount was taken up from the soil. 75 mg of magnesium was added to the soil in pots treated with Mg_{20}, thus the plants grown in these pots absorbed on average 23.6 kg ha^{-1} of magnesium (the amounts of absorbed magnesium calculated for the nine experiments ranged from 14.8 to 33.2 kg ha^{-1}). Crop demand for magnesium in experiments Nos 5 and 6 was 30 kg ha^{-1} and a bit higher than 30 kg ha^{-1}; in the three other experiments this demand was much lower – 14.8–19.6 kg ha^{-1}; in experiments Nos 1 and 4 it was lower due to the lower content of magnesium in herbage, and in experiment No. 9 – due to the lower productivity.

The amount of magnesium absorbed by the Italian ryegrass fertilised with Mg_{40} was much less than the amount of this element supplied with fertilisers, thus this fertilisation rate was excessive. An average amount of supplied and not absorbed magnesium was 33.2 kg ha^{-1}. It can be concluded that Italian ryegrass demand for magnesium was 24 kg ha^{-1} on average, and when herbage yield was higher or there were larger amounts of magnesium in the yield – 20 kg ha^{-1}. Mg_{20} fertilisation rate was correct from the balance point of view.

Table 11. Magnesium (Mg) balances (mg per pot) in experiments

Rate	Experiment No.									
	1	2	3	4	5	6	7	8	9	$\bar{x}$
Mg_0	−49 ± 1.7	−68 ± 0.9	−66 ± 2.7	−44 ± 0.8	−75 ± 5.3	−83 ± 1.7	−50 ± 2.9	−60 ± 1.3	−37 ± 1.1	−59 ± 2.0
Mg_{20}	20 ± 0.9	4 ± 3.4	−6 ± 1.0	23 ± 0.6	16 ± 2.0	−8 ± 0.8	11 ± 2.3	11 ± 0.4	33 ± 1.7	12 ± 1.5
Mg_{40}	91 ± 0.6	85 ± 0.8	73 ± 2.2	86 ± 0.4	94 ± 3.0	62 ± 3.1	79 ± 1.2	79 ± 3.8	102 ± 2.4	83 ± 1.9

Our research evidence suggests that in the majority of cases fertilisation of Italian ryegrass with magnesium did not increase the yield under favourable weather conditions; the results obtained from our experiments were not affected by the soil type, texture (sandy loam or loam) soil acidity or richness in plant available calcium and magnesium. On the other hand, in hot weather conditions magnesium fertilisation resulted in statistically significant herbage yield increase in all soil types tested in our experiments. This is an important finding in the light of climate change processes. Magnesium fertilisation increased the levels of magnesium and crude protein contents in the Italian ryegrass herbage; this is important from the cattle nutrition point of view in spite of the fact that magnesium fertilisation did not increase the crop productivity. The fact that Italian ryegrass herbage yield increase correlated most significantly with the plant available magnesium content in soil determined by A-L method and water extraction indicates the need for stronger solvents when the potential content of plant available magnesium has to be determined (since part of magnesium is released even from magnesium carbonates). On the other hand, the content of water soluble magnesium is very important as well: it indicates the magnesium amount that is readily available for plants (for this reason water extraction method is used in greenhouse soil tests). It is understandable why higher annual ryegrass yield was obtained in soils containing larger amounts of carbonates – these soils have higher pH values, they are richer in plant available calcium, magnesium and carbonates. Such soils are the most productive ones in Lithuania. Since soil magnesium content in Lithuania is determined using A-L method, the levels of determined magnesium content are high when compared to the results obtained using other methods. In addition to this, the majority of agricultural producers and experts in Lithuania believe fertilisation of grasses with magnesium is not necessary. This opinion is not supported by any scientific evidence since there were no appropriate scientific experiments conducted in Lithuania. Selection of A-L method was not scientifically supported either. Our research provided some scientific evidence on this issue. Based on the results of our experiments, we can question the magnesium fertilisation practice adopted in other European countries regarding the grass crop need for magnesium fertilisation as well as the recommended magnesium fertilisation rates (Fotyma, Dobers, 2008). As for today, the only reasonable argument for magnesium fertilisation is the fact that magnesium-fertilised grass contains higher levels of proteins and magnesium. The majority of the scientific literature on the issues of magnesium fertilisation and magnesium determination methods dates back to the 60's–90's of the last century. There is an obvious need for an updated evaluation and a search for new approaches regarding the magnesium fertilisation topic. Our research created a basis for further steps: elaboration of a problem and setting up of series of detailed experiments.

Conclusions

1. A significant increase in Italian ryegrass herbage yield in response to magnesium fertilisation was evident only in 2010, which was characterised by high air temperatures and short showery spells. In that year, Mg_{20} rate increased the herbage yield on average by 12%, and Mg_{40} – by 14.1%. Magnesium fertilisation in normal weather conditions (2008 and 2009) did not give any yield increase.

2. The largest Italian ryegrass yield was obtained in carbonate-rich soils with high contents of plant available magnesium ($Mg_{A\text{-}L}$ 558–1360 mg kg^{-1}), calcium ($Ca_{A\text{-}L}$ 3496–8488 mg kg^{-1}) and carbonates (0.33–0.58%) and with a pH_{KCl} value of 6.6–7.1. The correlation was found between the Italian ryegrass yield and plant available magnesium, plant available calcium carbonates and

humus content in the soil. Six methods for magnesium content determination in soil were compared, and the yield increase from magnesium fertilisation correlated most significantly with the plant available magnesium content in the soil determined using Egner-Riehm-Domingo (A-L) method and water extraction.

3. Magnesium content in the Italian ryegrass yield was within the range of 0.13–0.30%. The herbage yield of the 2nd cut contained lower levels of magnesium than that of the 1st cut. Magnesium content in the Italian ryegrass yield was higher in the less productive year, characterised by high air temperatures. Magnesium fertilisation increased the content of magnesium in leaves; this was especially evident when Mg_{40} rate was applied. An increase in magnesium content in leaves depended mostly on plant available magnesium content in the soil determined using KCl and $CaCl_2$ extractions and on pH. It depended less on the content of plant available calcium and carbonates in soil.

4. The content of crude protein in the Italian ryegrass herbage yield of the 1st cut ranged from 6.19% to 13.88%, in the yield of the 2nd cut from 3.19% to 4.75%. In hot summer conditions, the content of crude protein in herbage was higher. Magnesium fertilisation increased the crude protein content in Italian ryegrass in most cases.

5. Annual ryegrass absorbed 24 kg ha^{1} magnesium on average, and 30 kg ha^{-1} when the crop was more productive or accumulated larger amounts of magnesium in the yield.

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Magnio trąšų įtaka gausiažiedei svidrei (*Lolium multiflorum Lam.*) skirtingų tipų ir karbonatingumo dirvožemiuose

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Santrauka

2008–2010 m. Lietuvos agrarinių ir miškų mokslų centro Agrocheminių tyrimų laboratorijos vegetacinių bandymų aikštelėje iš įvairių Lietuvos vietų paimtuose skirtingų tipų ir karbonatingumo dirvožemio bandiniuose, supiltuose į vegetacinius indus, tirta magnio (Mg) trąšų normų įtaka gausiažiedei svidrei (*Lolium multiflorum* Lam.). Iš viso buvo atlikti 9 bandymai. Dirvožemiuose judriojo magnio kiekis tirtas Egnerio-Riehmo-Domingo (A-L) bei *Mehlich, Schachtschabel 3* metodais ir kalio chlorido, amonio acetato bei vandens ištraukose. Tyrimų duomenys parodė, kad magnio trąšos esmingai didino gausiažiedžių svidrių derlių tik karštais su trumpalaikėmis liūtimis metais. Tokiais metais visuose bandymuose derlių trąšos Mg_{20} padidino vidutiniškai 12 %, o Mg_{40} – 14,1 %. Esant gausiažiedėms svidrėms palankioms meteorologinėms sąlygoms, magnio trąšos derliaus dažniausiai nedidino. Nustatyta koreliacinė priklausomybė tarp gausiažiedžių svidrių derliaus ir judriojo magnio, judriojo kalcio, karbonatų bei humuso kiekio dirvožemyje. Esminė koreliacija tarp derliaus priedo ir tręšimo magniu gauta judriojo magnio kiekį dirvožemyje nustačius A-L metodu ir vandens ištraukoje (iš viso taikyti šeši magnio kiekio nustatymo metodai).

Gausiažiedės svidrės žolėje karštais ir mažiau derlingais metais magnio buvo daugiau; antro pjovimo žolės derliuje magnio buvo mažiau nei pirmojo. Magnio trąšos didino magnio kiekį žolėje, ypač patręšus pagal didesnę normą (Mg_{40}). Žalių baltymų kiekis sausosiose medžiagose gausiažiedės svidrės pirmo pjovimo žolės derliuje svyravo net nuo 6,19 iki 13,88 %, antrojo – nuo 3,19 iki 4,75 %. Karštais metais žalių baltymų žolėje buvo daugiau. Magnio trąšos daugelyje bandymų gausiažiedės svidrės augaluose didino žalių baltymų kiekį. Gausiažiedės svidrės magnio sunaudojo vidutiniškai 24 kg ha^{-1}, o esant didesniam derliui ir didesnei magnio koncentracijai augaluose – 30 kg ha^{-1}.

Reikšminiai žodžiai: *Lolium multiflorum*, magnio trąšos, magnis dirvožemyje.