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BIOMASS OF SPRING BARLEY (*Hordeum vulgare* L.) IN RELATION TO FERTILISING

BIOMASA JĘCZMIENIA JAREGO (*Hordeum vulgare* L.) JAKO FUNKCJA NAWOŻENIA

Abstract: The study was aimed to determine the effect of the fertilizer dose on growth of barley. In the experiment we used calcium sulphate, which is a waste during gas desulphurisation in heat and power stations. We assumed that dihydrate calcium sulphate would react with aluminium and form insoluble $AlSO_4^+$. We weighed the biomass of barley, underground and aboveground parts separately, determined the content of chlorophyll and the change in soil reaction caused by the applied doses of fertilisers. The vase experiment with barley of the brewery variety Propino was conducted in a setting of sub-blocks with fertilizing as the one changing factor. One experimental block included 5 variants in 5 repetitions. During growth period we conducted detailed observations of growth and development of barley. Calcium sulphate has positive effect on the growth of biomass and chlorophyll content in leaves of barley. Application of a double dose of calcium sulphate did not bring measurable increase in the growth of biomass and the height of barley stems.

Keywords: biomass, mineral fertilization, grain yield, *Hordeum vulgare*

Cereals are strategic products in national and international economy, because of their multipurpose utility. Besides consumption by man, cereals are also widely use as a feed for animals. Barley grain is used specifically for production of malt, which is used in fermentation, bakery and pharmaceutical trade. The largest amounts of barley are used in brewing industry.

Mineral fertilisation is one of the most important factors that affect the size of crop. Fertilizing is efficient at maximum level only if other factors that determine its activity are optimally adjusted by agrochemical practices. Many studies showed the influence of fertilizing with nitrogen on crops of cereals, including spring barley [1–4]. Nitrogen not

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only improves productive layerage of plants but also the number of grains in an ear, which is additional factor that increases crop. Unsustainable fertilisation without supplementation with calcium leads to strong acidification of soil and considerable loss of quality of cultivated plants. Using calcium sulphate in agriculture and gardening is not a standard practice in Poland. Calcium sulphate is a waste from gas desulphurisation by both wet and semi-dry methods. The semi-dry method of gas desulphurisation is more economic than the wet methods because it uses less water. But the waste from the wet method (synthetic $CaSO_4$), which is used as a substitute of the natural calcium (VI) sulphate has buyers. Thus the chemical content of waste from gas desulphurisation will be decisive for its commercial use in agriculture.

This study was aimed to determine the effect of the type and the dose of fertilizers on the biomass of barley. The study included measurements of overground parts of plants, including the ear and grains, and of their root systems. We also determined the content of chlorophyll in leaves of plants, and tested soil for changes in its reaction and in the content of exchangeable aluminium in the effect of the used doses of fertilizers.

Material and methods

We started the two-year vase experiment with barley of the variety Propino in 2014. During the first year of study the experiment was designed as five variants in three repetitions. In the second year we modified the experiment by increasing the number repetitions to five. We used three repetitions of the experiment to assess the biomass of plants (of overground parts and roots) produced by the beginning of barley flowering. We collected the remaining plants when they were fully mature in the third decade of July, and we measured the length of ear and the number and the mass of grains. We dosed fertilisers according to the methods of vase experiments. At the base of the control (variant I), which was low-intensity cultivation without fertilizing, we set up four other variants (II, III, IV and V), in which we used mineral fertilizing by NPK fertilisers in proportions 4 : 12 : 12 at a dose of 20 g/12 dm^3 of soil. In variants III, IV and V we additionally applied fertilising by ammonium nitrate (NH_4NO_3) at two doses of 6 g/12 dm^3 of soil, one before the start of growth and before the start of growth and the second one during stem formation. Variants IV and V were fertilized with calcium sulphate ($CaSO_4 \cdot 2H_2O$) at doses of 15 and 30 g/12 dm^3 of soil, respectively [5].

Soil used in the experiment was collected from the arable layer of podsolic soil of the granulometric content of a light clay sand. Soil dried in the air was sifted through a sieve with holes of 2 mm diameter and moved to vases of the volume 12 dm^3 each. During growth of plants we maintained constant humidity of soil at the level of 60% f.w.c. (field water capacity). We sowed material of the score K1 treated with preparation Premis Universal 275 FS. We sowed barley by hand at a density of 300 seeds per 1 m^2. We kept equal distances between grains by using a previously prepared template during sowing. Sowing material was placed in the soil at the depth of 3 cm. Each time we sowed barley in the first decade of April. During the experiment, in the phase of an ear formation, the plants were sprayed against aphids with preparation

Rapid 060 CS. During growth the relative content of chlorophyll in plants was measured using chlorophyll meter CCM 200.

Before the plants formed ears, we measured the height, the length of the root (measurement of the longest root in a bundle) and biomass of the overground and underground parts of each individual in 15 vases. We used the July harvest of plants from the remaining 10 vases to estimate the crop of grains. The content of the dry mass was determined by drying and weighing plant material in 105°C until the mass was stable. We measured reaction (pH) and the content of exchangeable aluminium in soil using the method of Sokolow.

Results and discussion

During the period of growth detailed observations of development and growth of barley while constant humidity of soil was maintained. Density of plants was determined directly after germination (z_0) and after the experiment was finished (z_1). The relative density was between 0.83 and 1.0. (Table 1). Germination was similar in the control variant and in variant IV, the weakest germination was recorded in the variant where ammonium nitrate was applied (variant III). The number of individuals did not change until the end of the experiment.

Table 1

Relative density of individuals

Repetitions	Density of individuals in relation to maximum density									
	VARIANTS									
	I		II		III		IV		V	
	z_0	z_1	z_0	z_1	z_0	z_1	z_0	z_1	z_0	z_1
1	0.94	0.94	0.94	0.94	0.88	0.88	1.00	1.00	0.94	0.94
2	0.94	0.94	0.88	0.88	0.83	0.83	0.94	0.94	1.00	1.00
3	1.00	1.00	0.94	0.94	0.88	0.88	0.94	0.94	0.88	0.88
4	1.00	1.00	0.88	0.88	0.94	0.94	1.00	1.00	1.00	1.00
5	1.00	1.00	0.94	0.94	0.94	0.94	1.00	1.00	0.88	0.88

Soil used in the experiment had acidic reaction (pH_{KCl} = 4.6). Spring barley belongs to plants that are sensitive to acidic reaction and associated high concentration of exchangeable aluminium [6]. We used calcium sulphate for fertilizing (variant IV and V), which did not change pH of soil, despite it contains calcium. Thus, using calcium sulphate for de-acidification of acidic soils will not bring the expected effect. However, calcium sulphate would be good fertilizer in soils of alkaline reaction but with a deficit of calcium. Application of the calcium sulphate can give good effects where soil contains calcium in a form temporarily inaccessible for plants [5]. Low content of aluminium at the level of 0.6 mg/100 g of soil, was obtained by applying fertilizing by

NPK only (variant II) and in the control variant (0.5 mg/100 g of soil). Other authors [6] obtained similar results for the control sample, with the content at the level of 0.4 mmol(+) · kg^{-1}. The largest content of aluminium was found in the combination of fertilizing with NPK and ammonium nitrate (variant III), where pH was also the lowest among all analysed samples (pH_{KCl} = 3.9). The content of aluminium in this variant of fertilizing varied from 1.6 to 2.0 mg/100 g, which was caused by acidification effect of ammonium nitrate [7], which increases amount of exchangeable aluminium [8].

Production of biomass in plants is a function of their assimilation surface, efficiency of photosynthesis from a unit of this surface, and the duration of photosynthesis. The amount of biological crop of different plant species is varied and depends on their productive capacity expressed as the amount of produced dry mass, which is associated with the size of their organs. According to Pecio [9], the larger the assimilation surface grows before barley flowers the greater is the chance it produces shapely grain. We used some simplification in our two years of studies using vases. We did not measure the assimilation surface. Instead we assessed the biomass of plants before they started flowering, assuming that assimilation surface that affects the crop increases proportionally to the mass of individuals. We are aware that individual plants of the same biomass may differ in assimilation surface.

Statistical analyses showed large variation of individuals in biomass, height, length of stems and in the mass and number of grains. Biometric analysis of the root length of the spring barley showed that the longest roots occurred in these vases where we applied calcium sulphate (variants IV and V). In both these variants the length of the root was about 24 cm (Fig. 1). Thus the double dose of calcium sulphate in variant V did not cause increase of the root length proportional to fertilizing. The weakest root systems occurred in variant III, where NPK and ammonium nitrate were applied. In this variant the mean length of a root was 16 cm, the longest root had 27 cm and the shortest had 4 cm. The coefficient of variation for the length of roots was between 27% (variant I) and 54% (variant V) (Table 2).

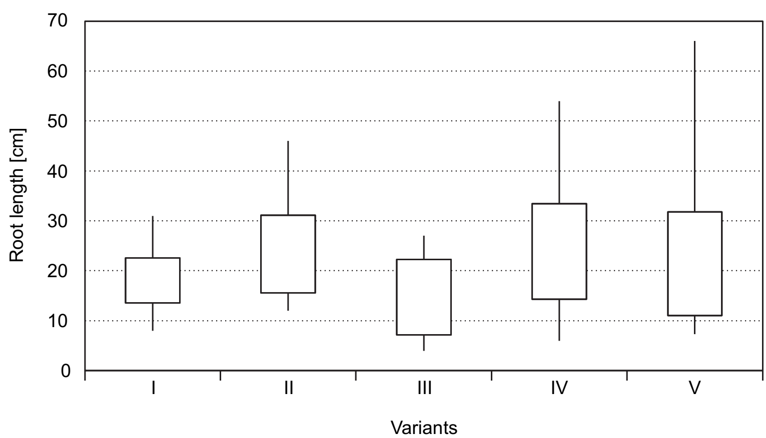

Fig. 1. Root length of spring barley depending on the dose applied fertilization variants

Table 2

Biometric parameters of spring barley of the variety Propino in relation to applied doses of mineral fertilizers, divided into overground and underground parts (harvested before flowering)

Measures of central tendency and dispersion	Biometric parameters of spring barely in the variants of the experiment									
	I		II		III		IV		V	
	Overground parts	Root	Overground parts	Root	Overground parts	Root	Overground parts	Root	Overground parts	Root
	[cm]									
Mean	65.1	18.8	57.2	23.4	58.6	15.6	61.1	23.9	51.0	23.9
SD	9.9	5.1	18.7	7.7	21.2	7.6	16.9	9.5	16.2	12.5
Min	40.0	8.0	22.0	12.0	12.0	4.0	24.0	6.0	15.0	10.0
Max	83.0	31.0	94.0	46.0	84.0	27.0	90.0	54.0	76.0	66.0
Mo	70.0	20.0	70.0	20.0	73.0	21.0	77.0	25.0	61.0	25.0
Me	67.0	20.0	63.0	22.0	72.0	16.0	64.0	23.0	55.0	21.0
v [%]	15.2	27.3	32.7	32.9	38.8	51.7	28.1	40.4	32.5	53.7

Symbols: I – control without fertilizing; II – multi-component fertilizer NPK (4%N; 12%P_2O_5, 12%K_2O); III – NPK + NH_4NO_3; IV – NPK + NH_4NO_3 + + $CaSO_4 \cdot 2\,H_2O$ – at a dose of 250 kg/ha; V – NPK + NH_4NO_3 + $CaSO_4 \cdot 2\,H_2O$ – at a dose of 500 kg/ha; Mean – arithmetic mean, SD – standard deviation, Min – minimum value, Max – maximum value, Mo – modal value, Me – median, v – coefficient of variation [%].

Similar relationships occurred in the height of individuals. Application of calcium sulphate at a dose of 250 kg/ha increased the height of plants 16% in relation to the applied dose of this fertiliser in the variant V (500 kg/ha). Thus, using high dose of calcium sulphate did not improve the height of barley. A half of studied individuals of the variant IV reached the height over 64 cm (Table 2, Fig. 2). According to the producer, the mean height of the barley of the variety Propino is 65 cm. Variation of the overground parts of plants was smaller than that of the root system, and was between 15% (variant I) and 39% (variant III).

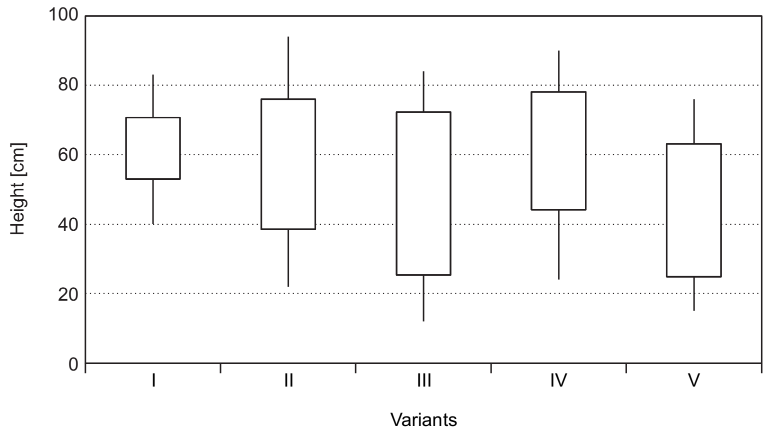

Fig. 2. The height of spring barley depending on the dose of fertilization

Fertilising had positive effect on the biomass of the underground parts and of the roots of spring barley. Individuals in vases that were fertilised with calcium sulphate at a dose of 250 kg/ha reached the largest mean biomass. Dry mass in this variant increased on average for 56% in relation to the control variant. A half of examined individuals had greater mass than 2.430 g [dry mass] (Table 4, Fig. 3). Application of the double dose of calcium sulphate caused 44% increase of biomass in relation to the control. Introducing NPK fertilizer only into the soil caused 27% increase of the biomass (variant II). Fertilizing with combination of NPK and ammonium nitrate (variant III) caused decrease in the mass of roots. General biomass of spring barley increased for 34% in relation to the control (Table 4), but the root system with this combination of fertilizers was the smallest of all four variants of fertilizing (Table 3). This situation may be associated with the content of exchangeable aluminium. According to Marschner [10] the toxic effect of aluminium affects mostly roots of plants. Badora [11] also stated that the first symptom of aluminium stress in spring barley is a significant decrease of the mass of the root system. According to this author the first symptoms of shortage of phosphorus, magnesium and calcium occur with about 70 mg of exchangeable Al per one kg of soil, which gives 7 mg/100 g. In our laboratory experiment we observed decrease of the root system already with 2 mg Al/100 g of soil [5].

Table 3

Biomass of spring barley of the variety Propino in relation to applied doses of mineral fertilizers (harvested before flowering) split into the overground parts and roots

Measures of central tendency and dispersion	Biomass spring barley depending on the fertilization									
	I		II		III		IV		V	
	Overground parts	Root	Overground parts	Root	Overground parts	Root	Overground parts	Root	Overground parts	Root
	[g d.m.]									
Mean	1.123	0.066	1.393	0.235	1.628	0.171	2.270	0.462	1.759	0.348
SD	0.421	0.036	0.732	0.166	0.844	0.122	0.930	0.338	1.104	0.266
Min	0.248	0.020	0.353	0.062	0.162	0.039	0.885	0.124	0.262	0.015
Max	1.948	0.173	3.114	0.927	3.004	0.404	5.242	1.379	4.837	1.015
Me	1.108	0.082	1.332	0.218	1.457	0.132	2.054	0.352	1.332	0.316
v [%]	37.47	54.72	52.53	70.69	51.85	71.36	41.50	74.11	62.78	76.43

Explanations see Table 2.

Table 4

Biomass of spring barley of the variety Propino in relation to applied doses of mineral fertilizers (harvested before flowering)

Measures of central tendency and dispersion	Biomass of spring barley [g d.m.]				
	I	II	III	IV	V
Mean	1.189	1.628	1.798	2.732	2.107
SD	0.430	0.854	0.881	1.160	1.293
Min	0.315	0.511	0.206	1.108	0.298
Max	2.014	3.704	3.408	6.621	5.495
Me	1.197	1.595	1.775	2.430	1.626
v [%]	36.11	52.45	48.98	43.02	61.39

Explanations see Table 2.

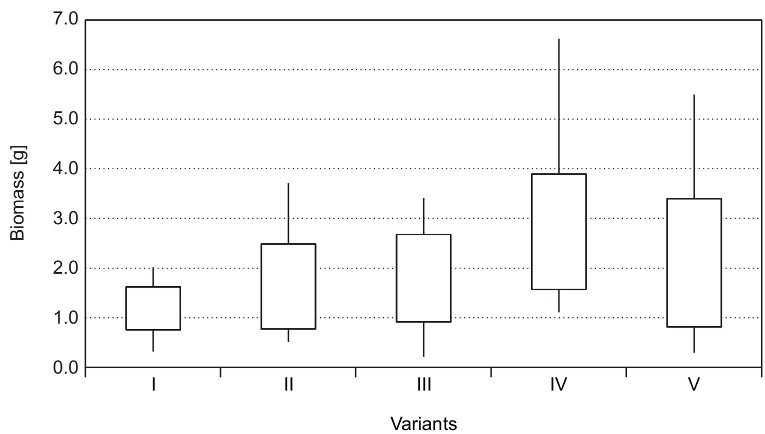

Fig. 3. The average biomass of a single individual (*Hordeum vulgare* L.) in relation to the fertilizer dose

The differences in chlorophyll content, depending on the applied fertilizer, were determined by Chlorophyll Content Index (CCI) – proportional to chlorophyll content in the sample. The lowest relative content of chlorophyll was observed in the control variant. Fertilizing with NPK (variant II), as well as adding ammonium nitrate (variant III) caused small increase in the content of chlorophyll in leaves of barley. But treating the soil with calcium sulphate doubled the content of chlorophyll in relation to the control variant.

In our experiment we determined the effect of fertilizing on features of crop structure. Statistical analysis showed that all factors in the experiment (fertilizing with NPK, ammonium nitrate and calcium sulphate) had significant effect on layerage (Table 4) and on the increase of crop (Table 5). The largest improvement of crop was obtained by fertilizing with a combination of NPK, ammonium nitrate and calcium sulphate (variant IV). Crop of grain from this variant was 5200 kg/ha, which was 36%

Table 5

The structure of yield depend on fertilization – mean values

Variants experience	Length of ear [cm]	Number of productive ears per m^2	Number of grains per ear	Weight of grains per ear [g]
I	8.2	377	17.5	0.82
II	8.6	476	19.0	0.88
III	8.5	400	18.8	0.85
IV	9.0	528	19.8	0.97
V	8.8	489	18.9	0.90

increase of harvest of grain in relation to the control (Table 5). It is known from literature [3] that nitrogen improves layering of plants and increases the number of grains in an ear, which is an additional important factor that improves crop. In all combinations of fertilizing the number of grains in a head was greater than in a control (Table 4). However, too high doses of fertilizing with nitrogen may cause decrease in the number of grains in an ear, because greater productive layering requires the plant to feed more grains. The accuracy of grain deteriorates at the same time, which means that the proportion of shapely grains in crop decreases. With a similar length of the head (variant II and III) we obtained different number and mass of grain in an ear (Table 5). Moreover, variant III caused production of low number of ears in comparison to the remaining variants of fertilizing. The recorded biomass of the overground part of barley in the variant III (mean = 1.628 g of dry mass) was greater than in the control variant and the variant with NPK fertilizing (Table 3). This indicates sufficient layering of the plants. However, a part of plants did not enter the generative phase, which could be caused by the increased content of aluminium in soil [5, 11].

Conclusions

Based on the study the we drew the following conclusions:

1. Combination of fertilising with NPK, ammonium nitrate and calcium sulphate had the greatest effect on the crop of spring barley.
2. Calcium sulphate did not change pH of soil, but had a positive effect on the biomass of the overground parts and roots and crop of grain.
3. Application of double dose of calcium sulphate did not cause measurable improvement in layering of plants and thus in crop of grain from barley.
4. In conditions of low content of exchangeable aluminium in soil, larger biomass produced by barley plants before they flower had a positive effect on production of shapely grain.

References

[1] Machado S, Petrie S, Rhinhart K, Qu A. Long-term continuous cropping in the Pacific Northwest: Tillage and fertilizer effects on winter wheat, spring wheat, and spring barley production. Soil Till Res. 2007;94:473-481. DOI: 10,1016/j.still.2006.09.007.

[2] Dubis B, Hłasko-Nasalska A, Hulanicki P. Yield and malting quality of spring barley cultivar prestige depending on nitrogen fertilization. Acta Sci Pol Agricultura. 2012;11(3):45-56. http://www.agricultura.acta.utp.edu.pl/uploads/pliki/Artykul%204.pdf.
[3] Valkama E, Salo T, Esala M, Turtola E. Nitrogen balances and yields of spring cereals as affected by nitrogen fertilization in northern conditions: A meta-analysis. Agr Ecosyst Environ. 2013;164:1-13. http://dx.doi.org/10.1016/j.agee.2012.09.010.
[4] Muhammad Z, Ahmad G, Iqbal B, Subhanullah, Khan RM, Bari A, et al. Effect of fertilizer dose on the performance of spring cereals. Pure Appl Biol. 2016;5(3):458-463. http://dx.doi.org/10.19045/bspab.2016.50059.
[5] Sporek M, Jurasz A, Ciesielczuk T. Effect of fertilisation on the changes of soil pH and exchangeable aluminium content in soil. Proc ECOpole. 2015;9(2):499-504. DOI: 10.2429/proc.2015.9(2)058.
[6] Rutkowska B, Szulc W, Twardowska A. Wpływ niezrównoważonego nawożenia na zmiany odczynu oraz zawartości glinu wymiennego w glebie lekkiej. [Effect of unbalanced fertilization on the changes of soil pH and exchangeable aluminium content in sandy soil]. Zesz Probl Post Nauk Roln. 2010;556:923-928. http://omega.sggw.waw.pl/sk/media/ PUBLIKACJE_3/rutk_szulc_tward_2010.pdf.
[7] Malhi SS, Harpiak JT, Nyborg M, Wiśniowska-Kielian B. Effect of long-term application of different nitrogen forms on soil reaction and some microelements contents in soil land bromegrass hay. Zesz Probl Post Nauk Roln. 1999;465:547-558.
[8] Filipek T, Skowrońska M. Aktualne dominujące przyczyny oraz skutki zakwaszenia gleb użytkowanych rolniczo w Polsce. [Current dominant causes and effects of acidification of soils under agricultural use in Poland]. Acta Agrophys. 2013;20(2):283-294. http://produkcja.ipan.lublin.pl/uploads/publishing/files/Filipek-283-294.pdf.
[9] Pecio A. Środowiskowe i agrotechniczne uwarunkowania wielkości i jakości plonu ziarna jęczmienia jarego browarnego. [Environmental and agronomic conditions of the size and quality of the crop of spring barley] Fragm Agronom. 2002;19(4):6-111. http://www.up.poznan.pl/pta/pdf/Fragm.%20Agron.%20vol.%2019%20(2002)/19(4)%202002.pdf.
[10] Marschner H. Mechanism of Manganese Acquisition by Roots from Soils. In: Graham RD, Hannam RJ, Uren EC, editors. Manganese in Soils and Plants. Dordrecht: Kluver Academic Publishers; 1988;191-204.
[11] Badora A, Kozłowska-Strawska J. Wybrane wskaźniki roślin uprawnych. [Some quality indicators of arable plants]. Ochr Środ Zasob Natur. 2011;48:439-452. http://www.ios.edu.pl/pol/pliki/nr48/nr_48_441.pdf.

BIOMASA JĘCZMIENIA JAREGO (*Hordeum vulgare* L.) JAKO FUNKCJA NAWOŻENIA

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Abstrakt: Dwuletnie doświadczenie wazonowe z jęczmieniem jarym odmiany browarniczej Propino rozpoczęto w 2014 roku. Celem pracy była ocena wpływu rodzaju i dawki nawozu na biomasę jęczmienia. W nawożeniu wykorzystano m.in. siarczan wapnia będący odpadem odsiarczania spalin w elektrociepłowniach. Założono hipotetycznie, że dwuwodny siarczan wapnia wejdzie w reakcję z glinem, tworząc nierozpuszczalną formę $AlSO_4^+$. Zakres badań obejmował pomiary biometryczne części nadziemnej wraz z kłosem i ziarniakami oraz system korzeniowy. Określono zawartość chlorofilu w liściach roślin, a także wykonano badania glebowe w zakresie zmiany odczynu i glinu wymiennego pod wpływem zastosowanych dawek nawozów.

Największy wpływ na wielkość plonu jęczmienia jarego miało zastosowanie kombinacji nawozowej: NPK, saletry amonowej i siarczanu wapnia. Siarczan wapnia nie wpływa na zmianę pH gleby, ale ma korzystny wpływ na biomasę części nadziemnej i systemu korzeniowego oraz plon ziarna. Zastosowanie podwójnej dawki siarczanu wapnia nie przyniosło wymiernych korzyści w plonie ziarna jęczmienia.

Słowa kluczowe: biomasa, nawożenie, plon ziarna, jęczmień jary