Journal of Elementology ISSN 1644-2296

Kozera W., Majcherczak E., Barczak B., Knapowski T., Wszelaczyńska E., Pobereżny J. 2015. *Response of the yield and mineral composition of garden thyme (Thymus vulgaris* L.*) herbage to various NPK proportions*. J. Elem., 20(4): 921-931. DOI: 10.5601/jelem.2015.20.1.802

RESPONSE OF THE YIELD AND MINERAL COMPOSITION OF GARDEN THYME (*THYMUS VULGARIS* L.) HERBAGE TO VARIOUS NPK PROPORTIONS

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Abstract

Garden thyme is a very important essential herbal plant grown in Poland. As well as being able to regulate digestion processes, thyme herbage possesses disinfecting, expectorant, antioxidant, spasmolytic properties. Research has been launched to define the effect of NPK fertilisation on yielding, the content of essential oil as well as the mineral composition of garden thyme (*Thymus vulgaris* L.) herbage. The experimental factor consisted of NPK mineral fertilisation applied into soil at the following doses per hectare and proportions: A_0 – without mineral fertilisation, A_1 – 30 kg N + 22 kg P + 100 kg K (N:P:K was: 1:0.75:3.33), A_2 – 60 kg N (30 kg N + 30 kg N) + 22 kg P + 100 kg K (1:0.37:1.67), A_3 – 90 kg N (45 kg N + 45 kg N) + 22 kg P + 100 kg K (1:0.24:1.11). The experiment comprised 4 fertilisation objects with 4 replications, and the sowing area and the harvest area of 3 m^2 $plot^{-1}$. Nitrogen was applied in the form of ammonium nitrate twice: pre-sowing as well as after plant emergence. Phosphorus and potassium were used pre-sowing, in the form of triple superphosphate 40% and 60% of potassium salt, respectively. The doses of 152 kg NPK ha^{-1} (1:0.75:3.33) – A_1 and 182 kg NPK ha^{-1} (1:0.37:1.67) - A_2 showed the most favourable effect on the yield of fresh weight, air-dried weight and essential oil of herbage as well as the quality characteristics of the yields. The dose of 152 kg NPK ha^{-1} (A_1), including 30 kg less nitrogen, was as favourable as that of 182 kg NPK ha^{-1} in terms of the content of air-dry weight of herbage, essential oil as well as mineral nutrients. Its application also resulted in a similar yield of essential oil. The application of 212 kg NPK ha^{-1} (1:0.24:1.11) was economically unjustified since, in general, it decreased the size of the yield of fresh weight of herbage and the values of its parameters studied.

Keywords: thyme, NPK fertilization, macronutrients, chemical composition.

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INTRODUCTION

Garden thyme is one of the most important essential herbal plants grown in Poland. As well as being able to regulate digestion processes, thyme (*Herba thymi*) herbage collected at full flowering demonstrates disinfecting, expectorant, antioxidant, spasmolytic properties (ŚLIWIŃSKA et al. 2001). Apart from essential oils, herbage contains tannins as well as other compounds, such as phenols, considered to be one of the strongest antioxidants. Herbage and the essential oil distilled from it are often used in the food, pharmaceutical and cosmetic industries. Yields of herbal plants, including garden thyme, depend on genetic traits, climate, soil as well as agrotechnical conditions. In production of herbal plants, it is important to achieve high quality herbage yield, which is defined by its microbiological purity, the content of active substances as well as minerals. Presumably, a high potential for increasing the yield quantity and quality lies in the enhancement of the plant cultivation agrotechnical practice, especially by designing appropriate shares between fertiliser components. With this in mind, research has been launched to define the effect of NPK fertilisation on yielding, the content of essential oil as well as the mineral composition of the herbage of garden thyme (*Thymus vulgaris* L.).

Keywords: nutrition, nitrogen doses, garden thyme, chemical composition, essential oil.

MATERIAL AND METHODS

A three-year field experiment, on which the present research, was conducted in 2009-2011 at the Experiment Station of the Faculty of Agriculture and Biotechnology of the University of Technology and Life Sciences in Wierzchucinek (the Kujawy and Pomorze Province). A controlled, one-factor field experiment was set up with the method of random blocks in four replications. It was established on Haplic Luvisol, developed from glacial till and classified as good rye complex soil. The soil sampled from the arable layer (0-20 cm) had neutral reaction (pH_{KCl} – 6.8) and the following content of organic carbon – 8.12 g kg^{-1} (the Tiurin method) and total nitrogen – 0.95 g kg^{-1} (the Kjeldahl method), as well as moderate concentrations of the available forms of phosphorus – 55.2 mg kg^{-1}, potassium – 107.2 mg kg^{-1} (the Egner -Riehm method) and magnesium – 48.8 mg kg^{-1} (the Schachtschabel method). The experimental factor consisted of NPK mineral fertilisation applied into soil at the following doses per hectare and proportions: A_0 – without mineral fertilisation, A_1 – 30 kg N + 22 kg P + 100 kg K (N:P:K was: 1:0.75:3.33), A_2 – 60 kg N (30 kg N + 30 kg N) + 22 kg P + 100 kg K (1:0.37:1.67), A_3 – 90 kg N (45 kg N + 45 kg N) + 22 kg P + 100 kg K (1:0.24:1.11). The experiment covered 4 fertilisation objects run in 4 replications, which corresponded to 16 experimental plots with the sowing area and the harvest area of 3 m^2 $plot^{-1}$. Nitrogen was applied in the form of ammonium nitrate twice: pre-sowing as well as after plant emergence in the first year, and in the following years – in spring, after the onset of plant growing and after the first harvest. Phosphorus and potassium were supplied pre-sowing in the first year, and in the following years – in spring, after the onset of plant growing. The elements were applied in the form of triple superphosphate 40% as well as 60% of potassium salt, respectively.

Garden thyme cv. Słoneczko was sown in April, directly into soil, into rows spaced at 30 cm. The seeds were supplied by the herbal medicine company *Firma Zielarska Lewandowski* of Kruszynek. No herbicides or pesticides were applied, and the plant protection treatments involved hoeing of the inter-rows as well as manual weed control. The plant material was also collected by hand, once in the first year (the first decade of August), and twice in the consecutive years (the third decade of May and the first decade of August). The fresh weight was determined and then the herbage was dried in a laboratory dryer at the temperature of 35°C, so that the dry weight yield was determined immediately after harvest. The content of essential oil in the plant material samples was determined with the Deryng method. The dried samples were homogenized and the following were assayed: total nitrogen with the Kjeldahl method (Kjeltec 1026), total phosphorus – colorimetrically (Xion 500), potassium, magnesium and calcium – with the method of Atomic Absorption Spectrometry AAS (Varian AA 240 FS). All chemical analyses of thyme herbage were performed at the Sub-Department of Agricultural Chemistry, the University of Technology and Life Sciences in Bydgoszcz, in the Laboratory of Supporting Safe Food Production Technology, which had been opened as part of the Regional Centre of Innovation.

The research results were statistically verified with the analysis of variance, defining the significance of differences with the Tukey's test at the level of significance of $\alpha = 0.05$.

The mean air temperature during the thyme growing period (April-August) in each year (2009-2011) was higher than the multi-year mean (14.4°C), namely: 14.7°C in 2009, 15.2°C in 2010 and 15.4°C in 2011 (Figure 1).

Particularly unfavourable hydrological conditions for the growing of thyme were reported in 2009, when the water deficit in April inhibited plant emergence. In the 2010 plant-growing period, rainfall was 107.6 mm higher than the multi-year mean (254.2), but in June, when the development of thyme is considerably conditioned by the water content in soil, precipitation was low. In the 2011 season, the total precipitation exceeded the multi-year total by almost 39%. The rainfall deficit in April made the plant emergence more difficult, and the total rainfall in June and July being nearly twice as high as the multi-annual mean did not help the plants to grow, either. The analysis of climographs (Figure 1) in the research years revealed droughts in April 2009 and 2011 as well as in June 2010.

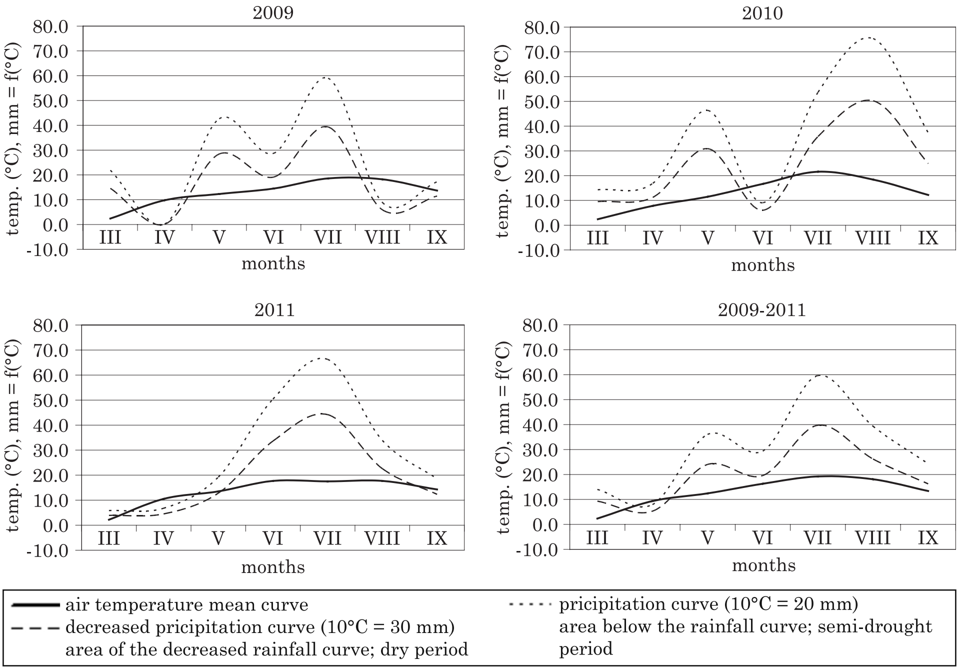

Fig. 1. Climographs for research years

RESULTS AND DISCUSSION

The mineral fertilisation in all the fertilisation objects (A_1, A_2, A_3) caused a significant increase, as compared with object $A_{0,}$ of the fresh thyme herbage yield (Table 1). In A_2, the three-year mean yield was 109.6 kg 100 m^{-2}, being 36.5% higher than the control. For A_1, the analogous difference was 31.9%. The lowest increase in the fresh weight yield of thyme herbage was recorded in A_3 (1:0.24:1.11), characterized by the biggest N:P:K ratio; the difference, as compared with the control, was 18.1%. Similar dependencies were recorded by Dzida (2007), who tested the narrowing of N:K proportions in thyme growing. The results coincide with other reports (Golcz, Bosiacki 2008, Khalid 2012), which emphasize that the right nitrogen dose as well as the correct proportions of nutrients are essential for obtaining an adequately high yield.

A decrease in the crop yield can be caused by an application of excessively low or excessively high doses of mineral fertilisers, but another reason could be the supply of an excessively low amount of one nutrient, which may limit the uptake of the other nutrients (Biczak et al. 2011, Bielski et al. 2011). According to Baranauskienne et al. (2003), nitrogen fertilisation is the key factor affecting not only the volume of herb yields but also their quality.

Table 1

Yielding, dry weight and essential oil content in thyme herbage

Specification	Year	Fertilisation treatments				Mean	LSD
		A_0	A_1	A_2	A_3		
Fresh herbage yield (kg 100 m^{-2})	2009	31.7	37.3	38.7	33.7	35.4	2.00
	2010	116.0	158.0	160.3	139.3	143.4	7.80
	2011	93.3	122.3	129.7	111.7	114.3	3.47
	mean	80.3	105.9	109.6	94.9	97.7	8.87
Dry weight content (g kg^{-1})	2009	308.7	292.7	291.5	273.8	291.7	18.58
	2010	304.9	286.7	275.6	269.9	284.3	10.52
	2011	300.3	288.4	285.4	274.6	287.2	11.49
	mean	304.6	289.3	284.1	272.8	287.7	10.68
Dry herbage yield (kg 100 m^{-2})	2009	9.67	11.00	11.33	9.33	10.33	0.767
	2010	35.33	45.33	44.33	37.67	40.67	2.367
	2011	28.00	35.33	37.00	30.67	32.75	1.633
	mean	24.33	30.56	30.89	25.89	27.92	2.233
Essential oil content (g kg^{-1})	2009	17.63	16.88	16.50	15.50	16.63	n. s.
	2010	19.08	18.15	18.05	17.81	18.27	n. s.
	2011	17.85	17.35	17.00	15.77	16.99	0.849
	mean	18.19	17.46	17.18	16.36	17.30	0.828
Essential oil yield (g 100 m^{-2})	2009	173.0	185.0	185.7	142.3	171.5	7.53
	2010	675.7	822.0	797.7	668.7	741.0	50.63
	2011	500.7	612.3	629.0	483.3	556.3	40.73
	mean	449.8	539.8	537.4	431.4	489.6	38.40

A_0 – without mineral fertilisation, A_1 – 30 kg N + 22 kg P + 100 kg K (N:P:K was: 1:0.75:3.33), A_2 – 60 kg N (30 kg N + 30 kg N) + 22 kg P + 100 kg K (1:0.37:1.67), A_3 – 90 kg N (45 kg N + 45 kg N) + 22 kg P + 100 kg K (1:0.24:1.11), n.s. – non-significant differences

Nitrogen is a macroelement that mostly stimulates the increase of the vegetative mass of plants. The element is an essential building block of proteins and nucleic acids. It is also incorporated in vitamins, nucleotides, alkaloids and chlorophyll. By extending the plant growing period, nitrogen also regulates the uptake of other nutrients, such as potassium and phosphorus. According to the second degree regression model, developed for the thyme herbage and based on means for the three research years, the maximum herbage yield in the whole experiment was achieved for the nitrogen rate equal 52 kg ha^{-1} (Figure 2*a*).

The highest mean yield of fresh thyme herbage was harvested in 2010 (143.4 kg 100 m^{-2}). Compared to its value of 2011 (114.3 kg 100 m^{-2}), the difference reached 25.5%. Such a considerable difference in thyme yielding in

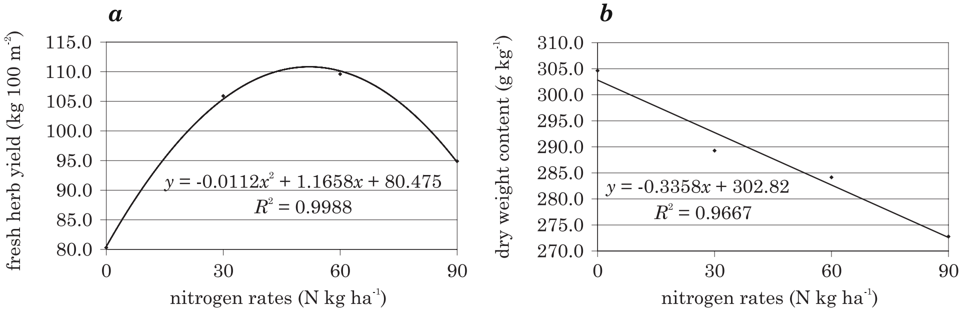

Fig. 2. Dependence of the fresh herbage yield (*a*) and the content of dry weight (*b*) on the nitrogen dose

the two successive years was due to the uneven distribution of rainfall during the plant growing seasons. In 2009 (single harvest), an average 35.4 kg 100 m^{-2} of fresh herbage was collected.

The three-year mean content of air-dried dry weight of thyme herbage for all the fertilisation objects was significantly lower than the one recorded for the control (Table 1). Narrowing the ratio of the fertilisation components by increasing the nitrogen shares significantly decreased the value of that yield characteristic (Figure 2*b*). The mean content of air-dried herbage weight was lower than in the control by 5.0% in object A_1, by 6.7% in A_2 and by 10.4% in A_3. A similar variation in the content of dry weight occurred in the herbage collected in the subsequent years.

An adequate supply of nutrients to crops, including herbs, is one of the conditions that can ensure adequately high and favourable yield quality criteria. Results of studies on various species of herbs show a strong dependence of yield (Eich et al. 2005, Hassan et al. 2012, Kozera et al. 2013) as well as the dry weight yield (Khalid 2012) on the fertilisation with nitrogen, phosphorus and potassium. The research performed on thyme also confirmed an increase in the yield of dry weight affected by the NPK doses used. In addition to that, the yield considerably depended on the doses and proportions of nutrients (Table 1). A significant effect of fertilisation on the mean total yield of air-dried weight of garden thyme herbage was found in objects A_1 and A_2, as compared with the control, the increase accounted, on average, for 26.3%. Compared with the doses in A_1 and A_2, the narrowing of the proportions of the fertilisation components to 1:0.24:1.11 (A_3) resulted in a decrease in the above parameter by an average of 15.7%. Interestingly, the increase in the dry weight yield of thyme herbage noted in the present research was a product of the plant's higher yield owing to the application of mineral fertilisation, and not a result of an increase in the content of dry weight.

The mean content of essential oil in the air-dried herbage was: 18.19 g kg^{-1} (A_0), 17.46 g kg^{-1} (A_1), 17.18 g kg^{-1} (A_2) and 16.36 g kg^{-1} (A_3). In objects A_2 and A_3, it was significantly lower than the one recorded for the control, the decrease being 5.6 and 10.1%, respectively. Generally, in the consecutive research years, no significant effect of the fertiliser doses applied on the mean content of oil in thyme herbage was found, although it was lower than the one determined for the control. In 2011, significantly less oil than in the control was noted in objects A_2 and A_3 (by 4.8 and 11.7%, respectively), which points to the tendency of decreasing the content of oil in thyme herbage as the yield of its fresh weight increased. The above dependence is confirmed by the reports of BERBEĆ et al. (2003). Contrary research results were reported by SHAHRAM (2011) who recorded a higher content of essential oil in thyme herbage in treatments fertilised with nitrogen and phosphorus than in the control.

Essential oil is one of the key biologically active substances found in plant material produced by the family *Lamiaceae*, which includes thyme (PAVEL et al. 2009, MORADKHANI et al. 2010). It is the most common secondary metabolite. The main components of thyme oil are thymol and carvacrol, both compounds of high anti-oxidant activity (KALT et al. 1999). According to various sources, the content of essential oil in thyme material ranges from 13 to 28 g kg^{-1} (CARLEN et al. 2010, KAYA et al. 2013) and is highly changeable, depending, *inter alia*, on environmental conditions in the area where it is grown, e.g. temperature and light availability (SEIDLER-ŁOŻYKOWSKA 2007, PORTE, GODOY 2008, KOŁODZIEJ 2009).

The NPK fertilisation, especially the varied nitrogen doses applied in our study, decreased the content of essential oil in thyme herbage compared to the control (Figure 3*a*). However, the theoretical yield of essential oil, being the product of the herbage yield and the content of oil in the material was higher on all the fertilised plots, except for object A_3.

The optimal nitrogen dose, calculated from the regression equation, for which the oil yield was the highest equalled 43.3 kg N ha^{-1} (Figure 3*b*). The mean oil yield recorded in the present research was 489.6 g 100 m^{-2} (Table 1). The fertilisation treatments applied in the nutrient proportions tested significantly increased the value of this parameter (three-year means) in objects A_1 (539.8 g 100 m^{-2}) and A_2 (537.4 g 100 m^{-2}); the difference relative to the control (449.8 g 100 m^{-2}) approximated 20%. Thyme herbage harvested from

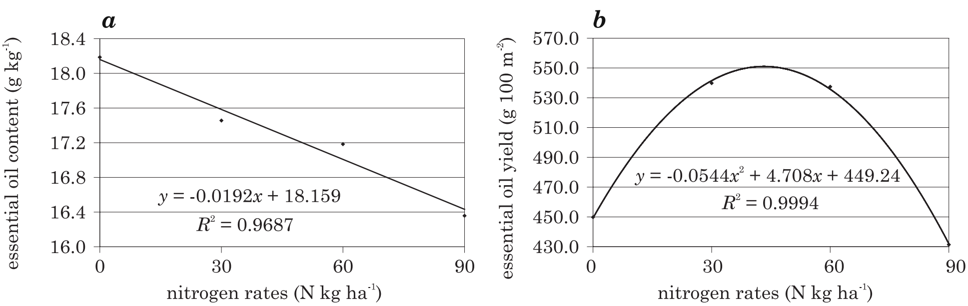

Fig. 3. Dependence of the content (*a*) and yield (*b*) of essential oil on the nitrogen dose

object A_3 had the significantly lowest mean oil yield (431.4 g 100 m^{-2}), which was lower by 20.1 and 19.7% than in objects A_1 an A_2, respectively. In the research years, the oil yield was significantly higher in objects A_1 and A_2 than the in the control, although a significant decrease in the oil yield per plot appeared due to the further narrowing of the nutrient proportions (1:0.24:1.11) tested in object A_3.

The above relationships arise from a strong dependence between the content of dry weight in thyme herbage and the content and yield of essential oil. According to the second degree regression model evaluated for thyme, the maximum oil yield appeared when the content of dry weight in herbage was 289.3 g kg^{-1} (Figure 4*a*). The dependence of the oil content in herbage on the dry weight was negatively correlated and linear in nature (Figure 4*b*).

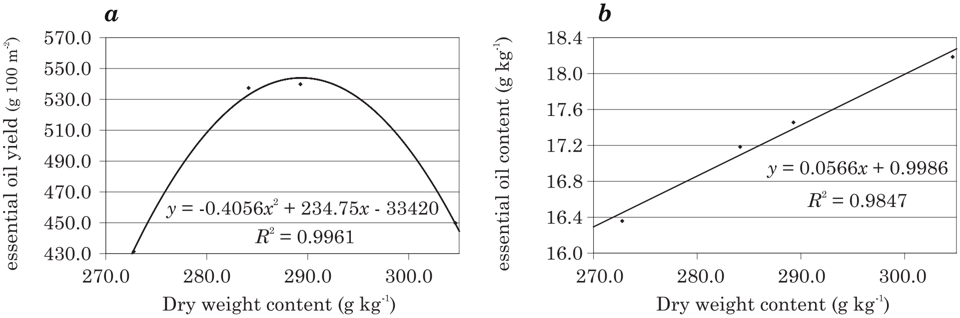

Fig. 4. Dependence of the yield (*a*) and the content (*b*) of essential oil on the content of dry weight in herbage

Beside essential oil, mineral compounds, such as flavonoids, tannins, phenolic acids, carbohydrates, vitamins and saponins, are important components of thyme herbage (JABBARI et al. 2011). The cultivar Słoneczko contains the highest share of these desirable compounds in herbage among all European cultivars of thyme. In the thyme herbage harvested during our experiment, as thre-year means, a significant increase in the content of total nitrogen was found in all the fertilised objects compared with the non-fertilised control (Table 2). The highest total nitrogen content was recorded for object A_3 (21.08 g kg^{-1}), which was 14.7% more than in the non-fertilised object. The nitrogen content in the herbage from objects A_2 and A_1 was 20.42 and 19.66 g kg^{-1}, respectively, which corresponded to 11.10 and 7.0% more than in the control. A significant increase in the total nitrogen content in thyme herbage was reported in 2010 and 2011. The above relationships coincide with the reports by GOLCZ and BOSIACKI (2008), where increasing nitrogen fertilisation led to the increasing total nitrogen content in thyme leaves.

The fertiliser doses tested in three variants of nutrient proportions did not cause, in any of the fertilisation object, a significant increase in the mean content of phosphorus, potassium, calcium and magnesium in thyme herbage, although the content of those elements was generally higher than in the non

Table 2

Content of macronutrients in thyme herbage (g kg^{-1})

Nutrient	Year	Fertilisation treatments				Mean	LSD
		A_0	A_1	A_2	A_3		
Total nitrogen	2009	18.46	18.80	19.11	19.69	19.01	0.772
	2010	20.85	23.20	24.49	25.34	23.47	0.883
	2011	15.84	16.97	17.67	18.21	17.17	0.769
	mean	18.38	19.66	20.42	21.08	19.89	0.795
Total phosphorus	2009	2.99	3.04	3.07	3.10	3.05	n. s.
	2010	2.06	2.26	2.39	2.44	2.29	0.172
	2011	2.50	2.66	2.60	2.58	2.59	n. s.
	mean	2.52	2.65	2.69	2.71	2.64	n. s.
Potassium	2009	20.99	20.47	20.07	19.57	20.27	0.998
	2010	22.70	23.07	24.66	23.91	23.59	1.394
	2011	19.60	19.83	20.23	20.23	19.97	n. s.
	mean	21.09	21.12	21.65	21.24	21.28	n. s.
Magnesium	2009	3.55	3.38	3.17	3.13	3.31	0.244
	2010	3.20	3.52	3.48	3.40	3.40	0.156
	2011	4.10	4.15	4.15	4.05	4.11	n. s.
	mean	3.62	3.69	3.60	3.52	3.61	n. s.
Calcium	2009	4.91	4.70	4.61	4.54	4.69	n. s.
	2010	6.24	6.83	6.81	6.67	6.63	n. s.
	2011	5.45	5.41	5.33	5.18	5.34	n. s.
	mean	5.53	5.64	5.58	5.46	5.55	n. s.

Explanations under Table 1

-fertilised object. DZIDA (2007) reports on increasing doses of nitrogen applied with the potassium chloride and sulphate forms being unaccompanied by significant changes in the content of this element in herbage. However, an increased accumulation of calcium and magnesium in the dry weight of herbage was detected. GOLCZ and BOSIACKI (2008) observed thyme leaves had an increasing content of nitrogen, phosphorus, calcium, magnesium and, except for the highest fertilisation, potassium. In the present research, the highest nitrogen doses tended to result in a decreased mean content of mineral nutrients in thyme herbage. Fertilisation with nitrogen, phosphorus and microelements reported by KHALID (1996) increased the content of nitrogen, phosphorus and potassium in medicinal plants representing the family *Apiaceae*.

The NPK applied at the doses and proportions chosen in our experiment differentiated the yields of herbage, dry weight and thyme oil as well as, albeit to lesser extent, its biological value expressed by the content of mineral nutrients and essential oil. The dose of 182 kg NPK ha^{-1} (1:0.37:1.67) – A_2

showed the most favourable effect on the yield of fresh weight and air-dried weight of herbage as well as on the quality parameters of the yields. The dose of 152 kg NPK ha^{-1} (A_1), including 30 kg less nitrogen, was as favourable as 182 kg NPK ha^{-1} in terms of its influence on the content of air-dry weight of herbage, essential oil and mineral nutrients. After its application, a similar yield of essential oil was also recorded. The application of 212 kg NPK ha^{-1} (1:0.24:1.11) was economically unjustified since, in general, it decreased the volume of the yield of fresh weight of herbage and the values of the yield quality parameters studied.

The higher the doses of fertilisers, the lower the level of their utilization by plants and the higher the amount of nutrients leached from soil to groundwater. Therefore, it is necessary to undertake action in agricultural production, and especially in herbal production, to improve facilitating the effective use of fertilisers by plants and to ensure adequately high, good-quality yields without increasing the fertilisation level, which will be beneficial for both ecological and economical reasons. When this objective is achieved, less environmental pollution will be caused.

The results reported in this paper suggest that research on extensifying thyme fertilisation can help to enhance selected herbage quality parameters.

CONCLUSIONS

1. The NPK fertilisation at the proportions of 1:0.75:3.33 (A_1) and 1:0.37:1.67 (A_2) significantly increased the volume of the yield of fresh, dry weight and essential oil of thyme herbage, as compared with the control.

2. The narrowing of the ratio of the fertiliser components decreased the content of air-dry weight and oil in herbage.

3. A significant decrease in the dry weight yield and the oil yield in thyme herbage was found in object A_3 (1:0.24:1.11), as compared with the other NPK fertilised objects.

4. The doses and proportions of NPK in the fertilisation variants studied did not change the mineral composition of thyme herbage significantly, except for nitrogen, although the content of phosphorus, potassium and magnesium in herbage was generally higher than in the non-fertilised object.

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