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EFFECT OF FOLIAR FERTILISATION WITH MICROELEMENTS ON COMMON BEAN (*Phaseolus vulgaris* L.) DEVELOPMENT AND SEED YIELDING

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ABSTRACT

A field 2-factor split-plot experiment was carried out over 1998-2000 at the Pawłowice Agricultural Experiment Station. The aim of the experiment was to define the reaction of three bean cultivars ‘Longina’, ‘Małopolanka’ and ‘Mela’ cultivated for dry seeds on foliar fertilisation with boron and molybdenum and their mixture. The length of bean vegetation period depended on the cultivar and weather conditions. Over the three-year research the longest vegetation period was recorded for ‘Longina’ (121 days), and shorter – ‘Małopolanka’ (118 days) and ‘Mela’ (115 days). Morphological features, seed yield, content of organic components and crude ash in seeds were differentiated mostly by genetic factor and much less considerably by fertilisation with microelements. Fertilising bean with molybdenum or molybdenum with boron applied at the beginning of flower buds forming resulted also in an increase, compared to the control, in the number of pods with seeds by 5% and seed weight per plant and the seed yield by 3%. The highest seed yields (2.50 $t \cdot ha^{-1}$) and straw yields (2.33 $t \cdot ha^{-1}$) were obtained from ‘Małopolanka’.

Key words: common bean, foliar fertilisation, boron, molybdenum, seed yield, chemical composition.

INTRODUCTION

As for the cultivation area, bean represents the third most important leguminous crop in the world, right after soybean and ground nut, and the first in Poland. The use of its yielding potential in our country does not exceed 68%, and the mean seed yield is low and amounts to 1.77 $t \cdot ha^{-1}$, while the highest seed yields in the world - 4.59 $t \cdot ha^{-1}$, are obtained in Ireland [7,14].

Bean yield and its quality, similarly to other crops, depend on fertilisation. Duczmal [13] observed in the initial growth stage 0.25 – 0.30% of dry matter $N\text{-}NO_3$, 0.20 – 0.25% of $P\text{-}PO_4$, 4.5 – 5% of K and 0.12 – 0.14% of Mg in leaves conditions high seed yields. The application of concentrated mineral fertilisers with a decreasing share of organic fertilisers in crop rotation leads to soil deterioration, especially fewer available microelements forms [11,18,19,20,46]. It is estimated that currently in the country there are about 76% of soils of low contents of B and 30% of a low content of Mo [11].

The research results available show that a low level of molybdenum in the seeds bean sown (< 1.41 $mg \cdot kg^{-1}$) results in plants of a lower weight of root nodules, yielding lower, accumulating less nitrogen, and producing seeds with 50% lower germination [6]. Numerous experiments involved foliar fertilisation of bean with molybdenum in various plant development stages: 18-25 days after emergence, at the beginning of flowering and in mid-flowering. Molybdenum was taken up by leaves, and then migrated into the roots and nodules. All of the microelement applied was found in plants already after 10 days [5,27,31]. Foliar fertilisation with molybdenum rates from 14 to 100 $g \cdot ha^{-1}$ increased the seed yield even by 40% and was the result of a favourable effect of molybdenum on structural seed yield components [2,4,8,10,12,16,34,42,43,44,45]. Similarly other characteristics were enhanced; plant fresh and dry matter increased, reductases and nitrate nitrogenase activities grew, so did the number of root nodules [1,44,45].

Bean ontogenesis depends greatly on boron. A physiological role of this element is not known completely, however, it is known that it has a positive effect on the development and generative growth of plants, transformations of carbohydrates and nitrogen compounds as well as oxidation-reducing processes [25,28,35]. The reports of Majewski [29] show that the greatest demand for boron is reported in papilionaceous plants (> 0.5 mg $B \cdot kg^{-1}$ of soil). In bean, boron deficiency results in the formation of a weak root system, bud abortion on the top, leaf hardening and a lack of proper leaves forming. Li et al. [26], investigating the reaction of pea, faba bean, bean and cucumbers to boron deficiency observed that bean as the first one reacts to apex necrosis when other species were still growing regularly. When the cultivated bean plants are exposed to a deficiency of this microelement, they do not grow beyond the seedling stage or are affected by necrosis after 55 days after emergence [3,9,26,30]. Soil-applied boron at the optimal dose to 1 $kg \cdot ha^{-1}$ increases the length of pods, their number per plant, and at the same time, the seed yield [9,23,36]. An accelerated flowering and a higher green pods yield due to an increasing phosphorus and boron fertilisation were also observed [36,37]. Investigating the effect of various nutrients on the bean yield, Gavras [17] showed that increasing doses of N, P and K results in a high yield. Its high quality is, however, determined by moderate amounts of molybdenum, as well as a combination of high doses of N and medium of P. The authors of numerous publications stress that exceeding the dose of 1 kg $B \cdot ha^{-1}$ results in toxicity of this microelement for plants and considerably reduces the plant weight, the number of plants per area unit and seed yield [15,22,23,37,38].

Padma et al. [32, 33] notice that a combined application of molybdenum and boron over 20 or 40 days after bean sowing increases the plant height, number of leaves, flowers and pods, root length and assimilation area, which increases the green pods yield on average up to 4.7 $t \cdot ha^{-1}$, compared to 3 $t \cdot ha^{-1}$ obtained for control objects.

As all the reports presented that concern bean fertilisation with microelements come from other climate zones, mainly from South America, and cover different growing conditions, thus, one shall be careful when referring to them. The lack of applicable experiments in Polish literature served as an inspiration to undertake this research. The working hypothesis assumed a different reaction of bean cultivars to plant fertilisation with boron, molybdenum and/or their mixture; special changes were expected in the effect of these microelements on structural bean cultivars yield components and the chemical composition of plants and seeds.

MATERIAL AND METHODS

Over 1998-2000 field and lab experiments were carried out on the reaction of common bean, cultivated for dry seeds, to foliar fertilisation with boron and molybdenum. The 2-factors split-plot field experiments in four replications were carried out at the Agricultural Experiment Station at Pawłowice near Wrocław. The factors investigated were:

- I – common bean cultivars whose seeds were: large (‘Longina’), medium (‘Małopolanka’) and small (‘Mela’),
- II – foliar fertilisation of plants with microelements at the flower bud formation phase: control – with no fertilisation, boron (169 $g \cdot ha^{-1}$), molybdenum (48 $g \cdot ha^{-1}$), boron (169 $g \cdot ha^{-1}$) + molybdenum (48 $g \cdot ha^{-1}$). Molybdenum was applied in the form of 0.02% solution of sodium molybdate ($Na_2MoO_4 \cdot 2\ H_2O$), and boron in 0.3% solution of borax ($Na_2B_4O_7 \cdot 10\ H_2O$).

The experiment was set up every year on brown-earth soil, lessive type, typical subtype, from light loam on medium loam, representing the good wheat complex, of IIIb quality evaluation class. Prior to setting up the experiment, every year soil samples were taken for chemical analysis and the contents of phosphorus, potassium, magnesium, molybdenum, boron and soil pH reaction were determined. The soil richness in mineral components and soil pH reaction over respective research years was as follows:

- 1998: P_2O_5 – very high, K_2O – mean, Mg – mean, B – mean, Mo – mean, soil pH reaction – slightly acidic reaction,
- 1999: P_2O_5 – high, K_2O – mean, Mg – high, B – low, Mo – mean, soil pH reaction – acidic,
- 2000: P_2O_5 – very high, K_2O - high, Mg - high, B - low, Mo - low, soil pH reaction – slightly acidic.

Bean was grown annually after winter wheat. Due to a high content of P_2O_5 and K_2O in soil no phosphorus and potassium fertilisation was used. Directly before sowing 30 kg $N \cdot ha^{-1}$ was applied in a form of ammonium nitrate (34% N). Seeds were sown on 14.05.1998, 11.05.1999 and 9.05.2000. The number of seeds sown per 1 m^2 depended on the cultivar and amounted to: ‘Longina’ – 25, ‘Małopolanka’ – 30, ‘Mela’ – 50, while the row spacing was 15 cm, and the sowing depth for all the cultivars investigated was 4 cm. The plots were 19.5 m^2 each. Weeds were controlled with herbicides (Stomp 330EC and Dual 960EC) with the doses of 2 $dm^3 \cdot ha^{-1}$ directly after sowing. In the first research year, anthracnose (*Colletotrichum lindemuthianum* Sacc. et Magn.) was controlled with Miedzian 50WP over pod formation, while in the second year Pirimor 50 DP was used to control a migrating generation of bean aphid (*Aphis fabae* Scop.). In the last research year neither fungicides nor insecticides were applied.

After emergence and prior to harvest plant density per 1 m^2 was defined. Directly prior to harvest 10 plants per plot were used to define the following morphological features: plant height, setting height of the first pod, number of pods per plant, including the number of unfertile pods, number and weight of seeds per pod and per plant, fresh and dry matter of seeds, threshed pods, stems and roots to the depth of 20 cm.

After the bean seed harvest the seed yield and 1000 seed weight were defined. Seed water content was equilibrated to 13%. Chemical seed analyses were made with the following methods:

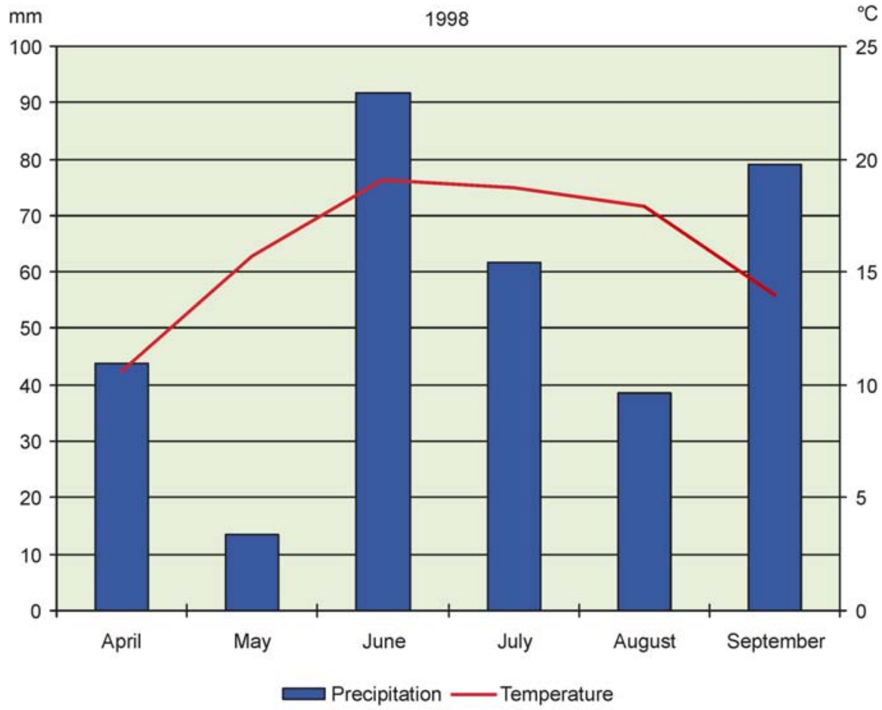
- dry matter – with the oven-drying method,
- total nitrogen – modified with the Kjeldahl method; in seeds total nitrogen was determined and converted into total protein applying the coefficient of 6.25,
- crude ash – by burning the plant material (seeds) in electric oven at 600°C,
- crude ash (ether extract) – with the method of defatted residue using the Soxhlet apparatus,
- crude fibre – with the Hanneberg-Stohmann method.

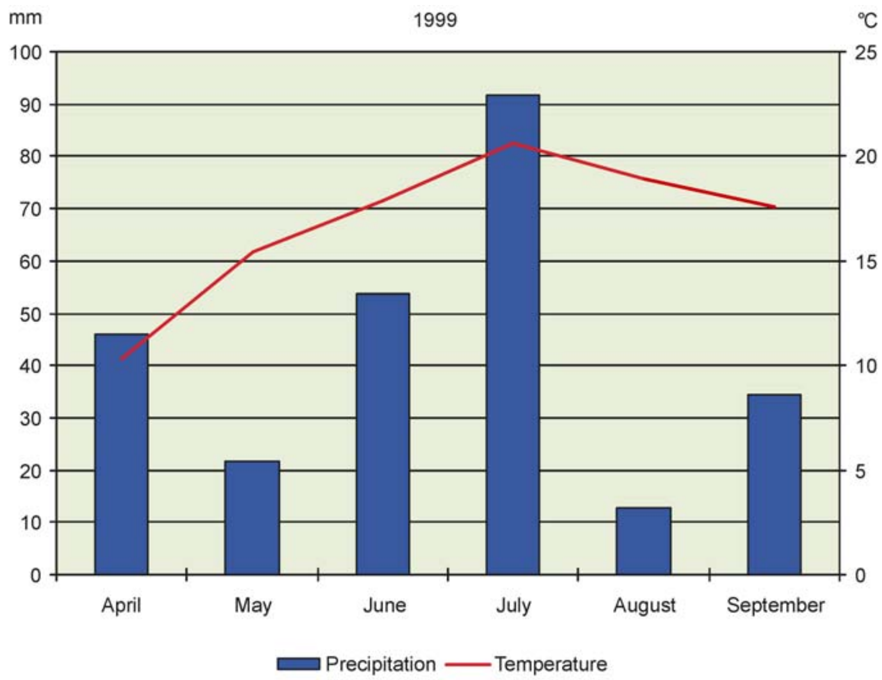
The content of nitrogen-free extract in seeds was calculated by deducting from 100 the total content of protein, fat, fibre and crude ash. Based on the results of chemical analysis total protein yield per 1 ha was calculated. All the parameters researched were verified statistically with variance analysis at $\alpha = 0.05$.

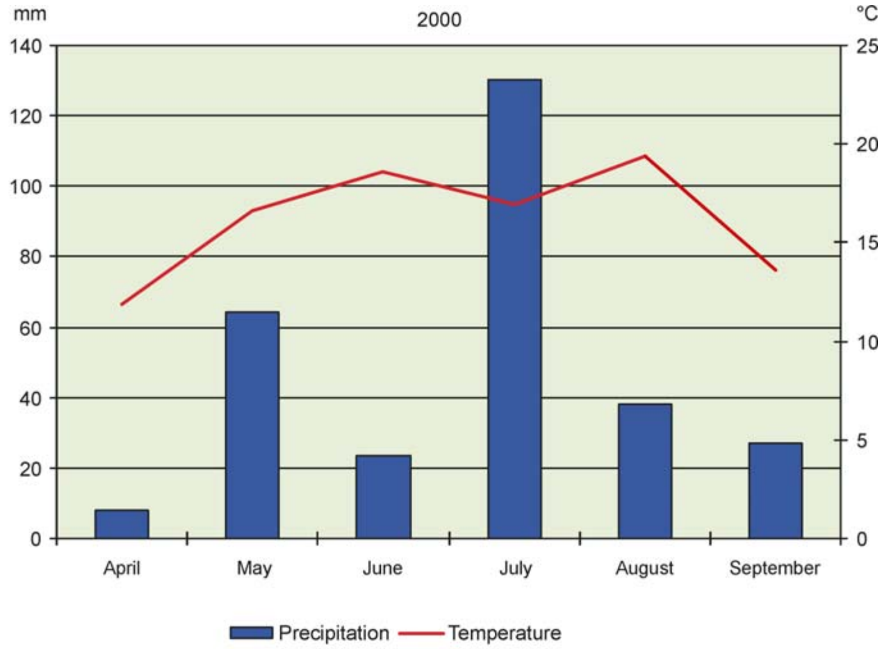
RESULTS

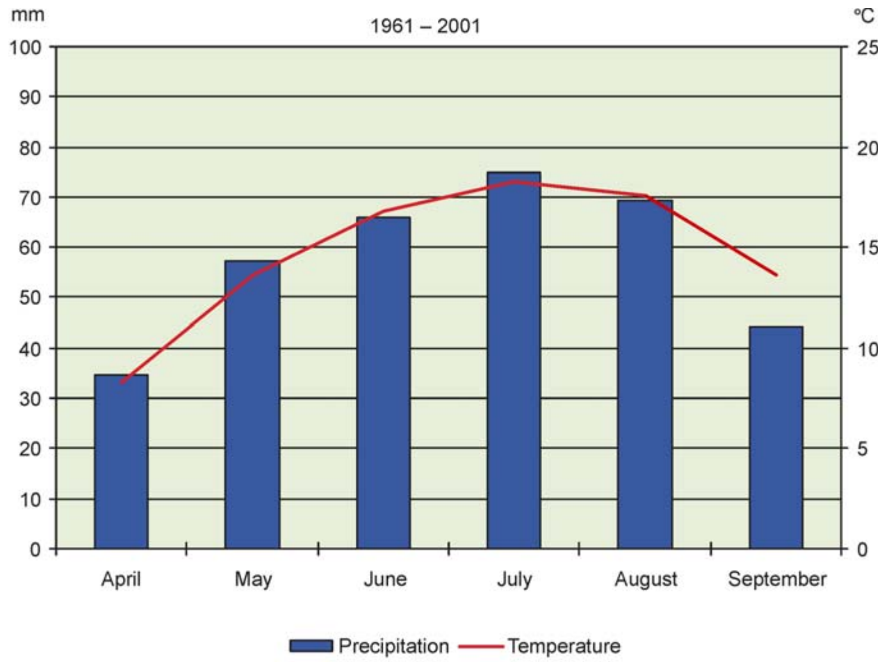
In 1998 from the first decade of April to the second decade of May very low precipitation was recorded, compared to the multi-year (Fig. 1). The high air temperature over that period which coincided with total low precipitations was the reason of drought. Precipitations at the end of May and in June substantially enhanced the moisture conditions and bean pod setting. For the second time the shortage of moisture was recorded in the second decade of July and the first decade of August. A considerable increase in the total precipitations in August and September, at temperature similar to multi-year mean prolonged the vegetation period and caused difficulties in bean harvest. In the spring of 1999 the weather conditions were similar to those of 1998. Moisture shortages were recorded from the second decade of April to the end of May. Precipitations in June and in the first half of July enhanced moisture conditions for a short time. High mean air temperature and low total precipitations resulted in drought which lasted from the third decade of July to the end of September. The course of weather conditions in July and August was not favourable for pod setting and development of seeds, which was unfavourable for bean yielding. The last year of the field experiment showed extreme weather conditions. The turn of May and June 2000 recorded moisture shortages inflicting drought. June, compared to the multi-year, showed higher mean air temperature and lower total precipitations. In July the precipitations were record-breaking (130 mm, compared to the multi-year mean of 74.8 mm), however already at the end of this month a 2-month drought started.

Fig. 1. Air temperature and total precipitation at Pawłowice









In the first and second year, the bean plant densities after emergence and prior to harvest were similar to the theoretical assumptions and plant losses during the vegetation ranged from 2 to 7%. A heavy soil crusting in the last research year made emergence much more difficult, which was the reason for a low plant density. Then there were also recorded the highest plant losses, which were, on average, 9% (Table 1). The length of respective bean development periods were mainly differentiated by moisture and thermal conditions, and less considerably by cultivar properties (Table 2). The period from sowing to plant emergence at a favourable weather course in 1998 and 1999 ranged from 14 to 15 days, and in 2000, due to a powerful soil crusting, was 21-24 days longer. Moisture conditions showed an especially significant effect on the period from emergence to the beginning of flowering which lasted from 29 to 47 days and got prolonged with increasing total precipitations. The flowering period and from the end of flowering to full maturity and all the vegetation period were determined by the weather conditions course and the cultivar factor. ‘Mela’, compared to ‘Longina’ and ‘Małopolanka’ in 1999 and 2000 flowered 3-6 days longer. In all the research years ‘Longina’ showed the longest, while ‘Mela’ - the shortest period from the end of flowering to full maturity and the shortest vegetation period.

Table 1. Common bean (*Phaseolus vulgaris* L.) plant density and losses over the vegetation period

Cultivar	Number of plants per 1 m^2						Plant losses over the vegetation period, %		
	after emergence			prior to harvest					
	1998	1999	2000	1998	1999	2000	1998	1999	2000
Longina	24	24	11	23	24	10	4.2	0.0	9.1
Małopolanka	29	30	22	28	28	21	3.5	6.7	4.6
Mela	49	50	33	48	48	30	2.0	4.0	9.1

Table 2. Length of common bean (*Phaseolus vulgaris* L.) growth stages in view of weather conditions over the research years

Specification	Number of days				
	from sowing to emergence	from emergence to the beginning of flowering	flowering	from the end of flowering to full maturity	vegetation period
1998					
Longina	14	45	9	66	134
Małopolanka	14	47	8	61	130
Mela	14	47	8	59	128
Precipitation, mm	10.2	107.2	17.0	153.0	287.4
Mean daily air temperature, °C	15.3	18.4	16.8	16.2	17.1
1999					
Longina	15	37	3	45	100
Małopolanka	15	37	3	45	100
Mela	15	37	6	39	97
Precipitation, mm	16.0	57.8	0.0	68.5	142.3
Mean daily air temperature, °C	15.9	18.4	22.3	19.7	18.4
2000					
Longina	24	29	23	53	129
Małopolanka	24	29	21	50	124
Mela	21	29	27	33	110
Precipitation, mm	67.3	26.0	102.8	171.1	367.2
Mean daily air temperature, °C	17.9	18.6	15.8	18.3	17.4

It was noted that a considerable variation in morphological bean features is caused by weather conditions, fertilisation and the interaction between the factors investigated (Table 3). As for the total number of pods per plant and pods with seeds per plant, the interaction between the cultivar and microelements fertilisation was observed. Fertilising 'Longina' with boron, molybdenum or boron + molybdenum, compared to the control, increased the number of pods with seeds on average by 13%. 'Małopolanka' did not react significantly to microelements fertilisation, while in 'Mela' the number of pods with seeds after fertilisation with boron + molybdenum was 10% higher.

Table 3. Effect of the interaction between cultivars and microelements fertilisation on generative features of common bean (*Phaseolus vulgaris* L.) prior to harvest (means for 1998-2000)

Specification		Number of pods per plant		
Cultivar	Fertilisation	total	with seeds	unfertile
Longina	0	11.3	9.7	1.6
	B	12.4	10.9	1.5
	Mo	12.4	11.1	1.3
	B + Mo	12.3	10.9	1.4
Małopolanka	0	13.0	12.3	0.7
	B	13.6	12.9	0.7
	Mo	12.5	11.8	0.7
	B + Mo	13.7	12.9	0.8
Mela	0	16.1	15.0	1.1
	B	16.4	15.2	1.2
	Mo	16.8	15.5	1.3
	B + Mo	17.8	16.5	1.3
$LSD_{0.05}$		0.69	0.71	ns

ns – non-significant differences

The 1998 weather conditions favourable for bean growth and development resulted in the highest values of the generative features in the 3-year research cycle. The precipitations shortage in 1999 decreased the total number of pods and number of pods with seeds per plant (Table 4) and the number of seeds per pod (Table 5) by 60%, 59% and 56%, respectively, compared to 1998. In the warm and moist year of 2000, bean showed the highest seed weight per pod and 1000 seed weight. The most favourable generative features (total number of pods and the number of pods with seeds per pod, the number of seeds per plant) were observed in 'Mela'. Compared to the other cultivars, 'Mela' developed on average 36% of pods with seeds and 39% of seeds per plant more. 'Małopolanka' and 'Mela' showed the greatest number of seeds per pod. The seed weight per pod, at the lowest number of seeds per plant was most favourable in 'Longina', which was due to the highest 1000 seed weight of this cultivar. Fertilising with all the microelements significantly affected most of the morphological features of bean. Foliar fertilisation with boron combined with molybdenum most considerably determined the plant height and generative features, increasing the number of pods with seeds, compared to the control, by 9%, and the number of seeds per plant by over 10%. Fertilising with molybdenum increased the seed weight per pod and 1000 seed weight.

Table 4. Effect of cultivars and microelements fertilisation on morphological features of common bean (*Phaseolus vulgaris* L.) prior to harvest (means for 1998-2000)

Specification	Plant height cm	Height to the first pod, cm	Number of pods per plant		
			total	with seeds	unfertile
Cultivar					
Longina	33	15	12.0	10.6	1.4
Małopolanka	32	14	13.2	12.5	0.7
Mela	25	9	16.8	15.6	1.2
$LSD_{0.05}$	1.0	0.7	0.32	0.35	0.12
Fertilisation					
0	29	12	13.4	12.3	1.1
B	30	13	14.1	13.0	1.1
Mo	30	12	13.9	12.8	1.1
B + Mo	31	13	14.6	13.4	1.2
$LSD_{0.05}$	0.8	ns	0.41	0.41	ns
Year					
1998	34	12	18.8	17.2	1.6
1999	28	15	7.6	7.0	0.6
2000	27	10	15.7	14.5	1.2
$LSD_{0.05}$	1.0	0.7	0.32	0.35	0.12

ns – non-significant difference

Table 5. Effect of cultivars and microelements fertilisation on structural common bean (*Phaseolus vulgaris* L.) yield components prior to harvest (means for 1998-2000)

Specification	Number of seeds per pod	Number of seeds per plant	Seed weight per pod, g	1000 seed weight, g
Cultivar				
Longina	2.4	24.9	1.2	508
Małopolanka	2.8	35.2	1.0	351
Mela	2.7	41.8	0.5	172
$LSD_{0.05}$	0.06	1.29	0.02	3.5
Fertilisation				
0	2.6	32.2	0.8	342
B	2.6	33.9	0.9	343
Mo	2.7	34.2	1.0	349
B + Mo	2.6	35.5	0.9	342
$LSD_{0.05}$	ns	1.50	0.03	4.6
Year				
1998	2.5	42.3	0.8	343
1999	2.6	18.7	0.7	304
2000	2.8	40.9	1.0	384
$LSD_{0.05}$	0.06	1.29	0.02	3.5

ns – non-significant difference

The interaction between the factors investigated was shown for the weight of stems, overground part and the whole plant (overground part + roots) (Table 6). Out of all the cultivars researched only 'Longina' reacted significantly to the fertilisation with boron, molybdenum and boron combined with molybdenum. The most favourable effect on these parameters was attributed to foliar fertilisation with molybdenum. The highest percentage share of seeds in the overground plant parts (harvest index) was recorded for 'Longina' and 'Mela' fertilised with molybdenum and 'Małopolanka' – following the application of boron with molybdenum (Table 7).

Table 6. Effect of the interaction between cultivars and microelements fertilisation on structural features of 1 common bean plant (*Phaseolus vulgaris* L.) prior to harvest (g) (means for 1998-2000)

Specification		Weight of					
Cultivar	Fertilisation	seeds	stems	threshed pods	overground parts	roots	plant
Longina	0	11.5	6.5	5.2	23.2	1.1	24.3
	B	12.5	7.1	5.4	25.0	1.2	26.2
	Mo	13.5	7.5	5.2	26.2	1.2	27.4
	B + Mo	12.8	7.2	5.3	25.3	1.3	26.6
Małopolanka	0	11.9	4.9	5.1	21.9	1.3	23.2
	B	12.7	5.0	5.3	23.0	1.4	24.4
	Mo	11.9	5.1	5.0	22.0	1.4	23.4
	B + Mo	12.6	4.9	5.0	22.5	1.4	23.9
Mela	0	6.8	2.6	2.6	12.0	0.8	12.8
	B	7.0	2.7	2.5	12.2	0.8	13.0
	Mo	7.5	2.4	2.4	12.3	0.9	13.2
	B + Mo	7.7	2.7	2.4	12.8	0.8	13.6
$LSD_{0.05}$		ns	0.39	ns	1.32	ns	1.38

ns – non-significant difference

Table 7. Effect of the interaction between cultivars and microelements fertilisation on the percentage share of overground part per 1 common bean (*Phaseolus vulgaris* L.) plant prior to harvest (means for 1998-2000)

Specification		% share in the overground plant part		
Cultivar	Fertilisation	seeds	threshed pods	stems
Longina	0	47.9	22.4	29.7
	B	48.8	21.4	29.8
	Mo	50.4	19.9	29.7
	B + Mo	49.2	20.8	30.0
Małopolanka	0	53.8	23.4	22.8
	B	54.8	23.1	22.1
	Mo	54.0	22.5	23.5
	B + Mo	55.3	22.3	22.4
Mela	0	55.9	21.6	22.5
	B	56.7	20.3	23.0
	Mo	60.2	19.6	20.2
	B + Mo	59.0	19.2	21.8
$LSD_{0.05}$		2.03	ns	1.63

ns – non-significant difference

The structural yield components in the bean cultivars researched were modified by the course of weather conditions and fertilisation. The highest weight of seeds, stems, threshed pods, overground parts and the whole plant was reached by ‘Longina’. The highest percentage share of seeds in overground plant part was recorded in ‘Mela’, threshed pods in ‘Małopolanka’, and stems in ‘Longina’. The greatest bean seed weight was recorded following the fertilisation of plants with molybdenum or boron combined with molybdenum, and the stem weight following the application of boron or molybdenum. The weight of the overground part, the whole plant and the percentage share of seeds in overground part were enhanced by fertilising with molybdenum. The course of weather conditions in 1998 was favourable for the weight of seeds and their percentage share in overground plant parts, and in 2000 it facilitated the development of vegetative parts of bean (Tables 8 and 9).

Table 8. Effect of cultivars and microelements fertilisation on the structural features of 1 common bean (*Phaseolus vulgaris* L.) plant prior to harvest (g) (means for 1998-2000)

Specification	Weight					
	seeds	stems	threshed pods	overground part	roots	plants
Cultivar						
Longina	12.5	7.1	5.3	24.9	1.2	26.1
Małopolanka	12.3	5.0	5.1	22.4	1.4	23.8
Mela	7.3	2.6	2.5	12.4	0.8	13.2
$LSD_{0.05}$	0.49	0.16	0.16	0.64	0.06	0.67
Fertilisation						
0	10.1	4.7	4.3	19.1	1.1	20.2
B	10.7	5.0	4.4	20.1	1.1	21.2
Mo	11.0	5.0	4.2	20.2	1.1	21.3
B + Mo	11.0	4.9	4.2	20.1	1.1	21.2
$LSD_{0.05}$	0.55	0.24	ns	0.77	ns	0.80
Year						
1998	14.0	5.2	5.3	24.5	1.3	25.8
1999	5.0	2.8	2.1	9.9	1.0	10.9
2000	13.1	6.7	5.4	25.2	1.1	26.3
$LSD_{0.05}$	0.49	0.16	0.16	0.64	0.06	0.67

ns – non-significant difference

Table 9. Effect of cultivars and microelements fertilisation on the percentage share of overground part in 1 common bean (*Phaseolus vulgaris* L.) plant prior to harvest (means for 1998-2000)

Specification	% share in the overground part plant		
	seeds	pods	stems
Cultivar			
Longina	49.1	21.1	29.8
Małopolanka	54.5	22.8	22.7
Mela	57.9	20.2	21.9
$LSD_{0.05}$	1.09	0.54	0.95
Fertilisation			
0	52.5	22.5	25.0
B	53.4	21.6	25.0
Mo	54.9	20.7	24.4
B + Mo	54.5	20.7	24.8
$LSD_{0.05}$	1.14	0.69	ns
Year			
1998	57.1	21.3	21.6
1999	51.3	21.2	27.5
2000	53.1	21.7	25.2
$LSD_{0.05}$	1.09	ns	0.95

ns – non-significant difference

The main factors which differentiated the chemical composition of seeds were the weather course and genetic properties of bean cultivars, and inconsiderably fertilisation with microelements. ‘Longina’ accumulated in seeds 0.6% more total protein than ‘Małopolanka’ and 0.8% than ‘Mela’. The highest content of crude ash was recorded in ‘Małopolanka’ and ‘Longina’ seeds, and of crude fibre in ‘Mela’ and ‘Małopolanka’ seeds. Foliar fertilisation did not affect the content of crude ash and organic components in seeds. However, a high variability in the chemical composition of seeds over successive research years was recorded. The year 1998, chilly and moderately moist, facilitated the accumulation of total protein and crude ash in seeds, while the year 1999, which was dry and warm, increased the content of fat and crude fibre as well as N-free extract (Table 10).

Table 10. Effect of fertilisation with microelements on the chemical composition ($g \cdot kg^{-1}$) of common bean seed cultivars (*Phaseolus vulgaris* L.) (means for 1998-2000)

Specification	Total protein	Crude fat	Crude fibre	Crude ash	N-free-extract
Cultivar					
Longina	243	14	51	45	647
Małopolanka	237	13	54	45	651
Mela	235	14	55	43	653
$LSD_{0.05}$	4.4	ns	2.8	1.0	ns
Fertilisation					
0	237	14	54	44	651
B	238	14	53	45	650
Mo	240	14	53	44	649
B + Mo	239	14	53	45	649
$LSD_{0.05}$	ns	ns	ns	ns	ns
Year					
1998	258	12	50	46	634
1999	214	18	57	43	668
2000	245	12	54	44	645
$LSD_{0.05}$	4.4	1.1	2.8	1.0	5.0

ns – non-significant difference

Fig. 2. Effect of microelements on seed yield of common bean cultivars (*Phaseolus vulgaris* L.) (means for 1998-2000)

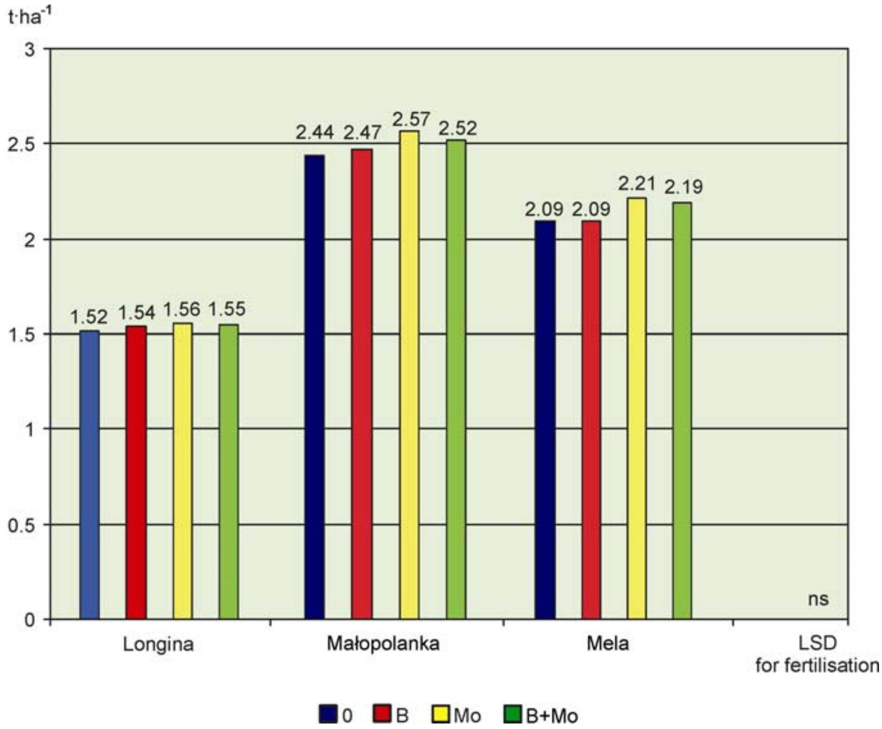


Fig. 3. Effect of microelements on straw yield of common bean cultivars (*Phaseolus vulgaris* L.) (means for 1998-2000)

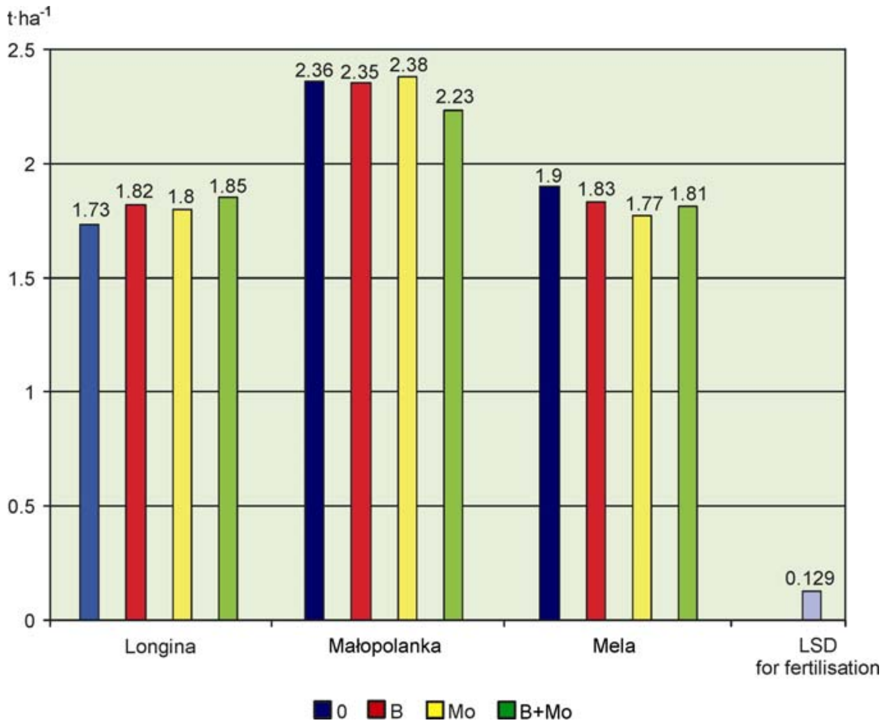


Fig. 4. Effect of microelements on total protein yield of common bean cultivars (*Phaseolus vulgaris* L.) (means for 1998-2000)

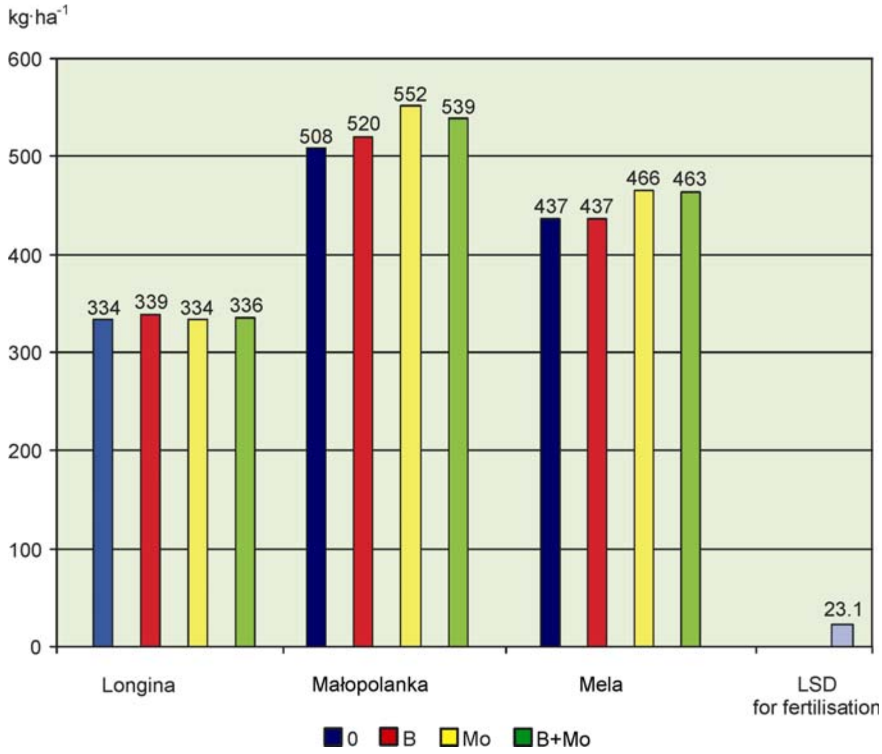


Fig. 5. Effect of microelements on seed yield of common bean cultivars (*Phaseolus vulgaris* L.) (means for factors and years)

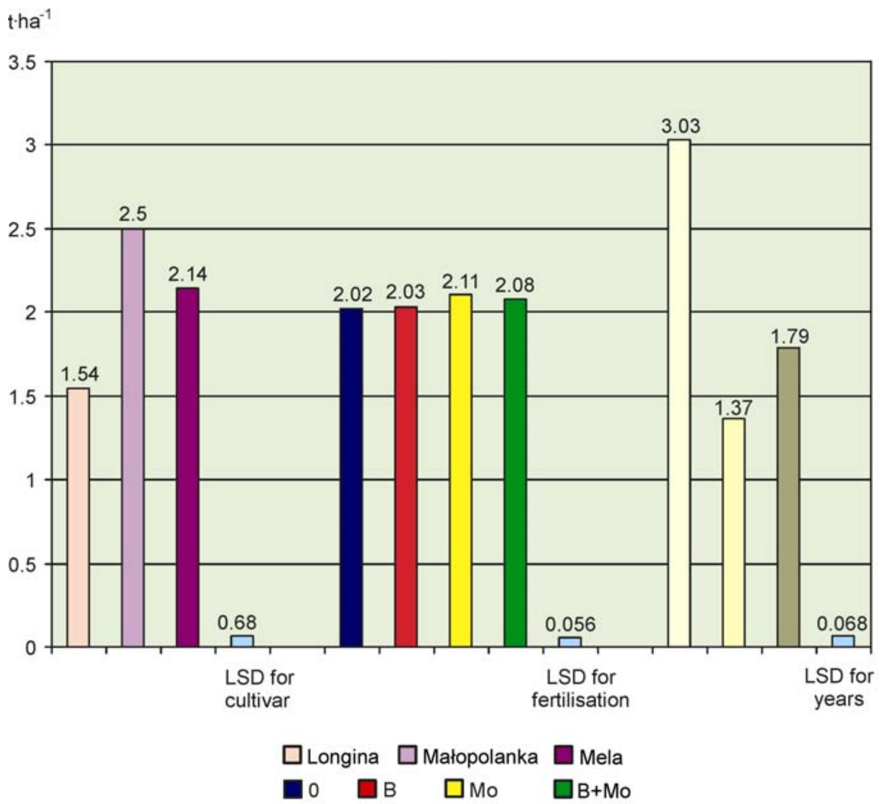


Fig. 6. Effect of microelements on straw yield of common bean cultivars (*Phaseolus vulgaris* L.) (means for factors and years)

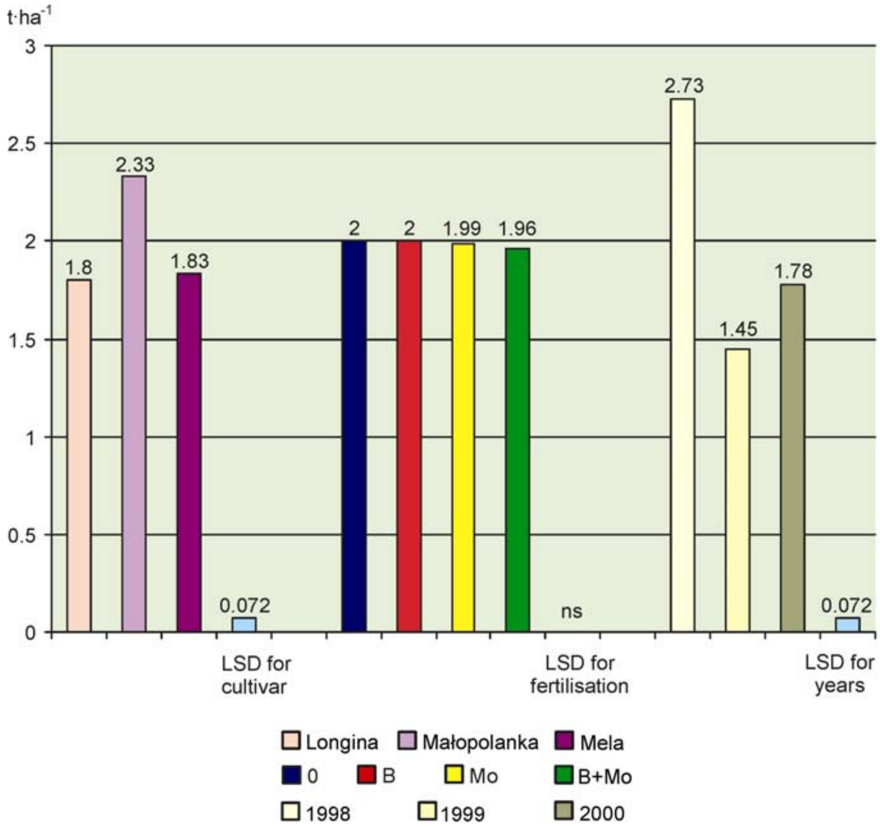
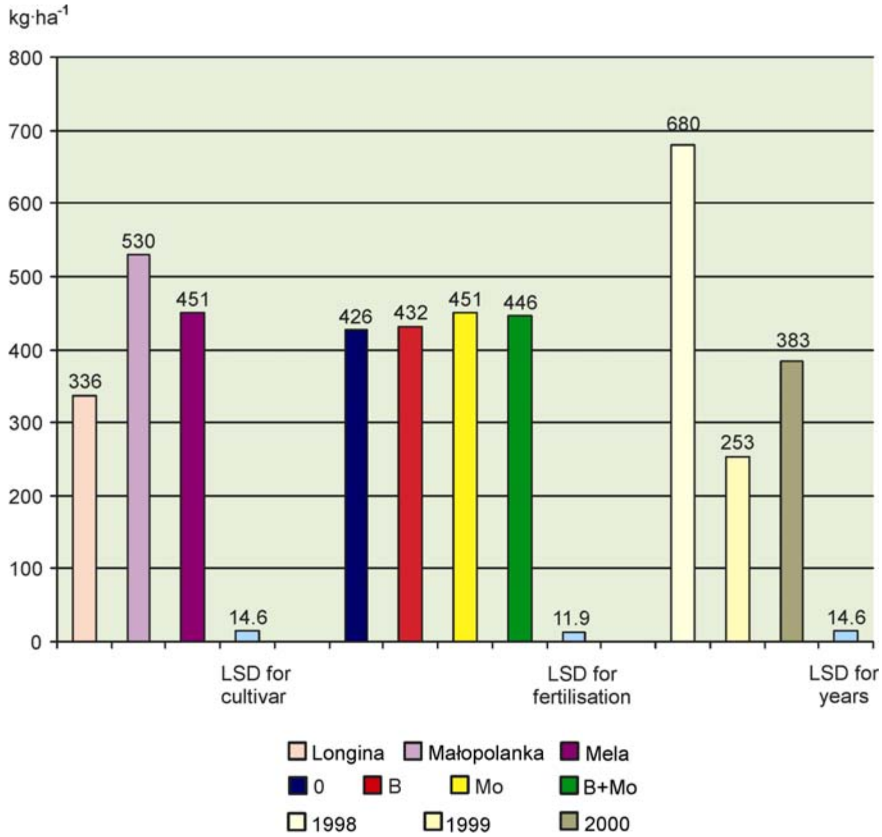


Fig. 7. Effect of fertilisation on total protein yield of common bean cultivars (*Phaseolus vulgaris* L.) (means for factors and years)



Genetic properties of the cultivars and varied weather course over the years significantly modified the seed yield; 'Małopolanka' yielded highest, and then, respectively lower, 'Mela' and 'Longina'. The variability in seed yielding over the respective research years exceeded 50% (Figs. 2-7). Total protein seed yield was affected by all the researched factors and their interaction and was a function of the seed yield and the percentage content of this component. In 'Małopolanka' and 'Mela' seeds it increased considerably, compared to the control, when fertilised with molybdenum or boron combined with molybdenum. The highest total protein yield was obtained from 'Małopolanka' seeds, 15% lower from 'Mela' and 37% lower from 'Longina'. Foliar fertilisation with molybdenum increased the protein yield by 5.5% compared to the control. In the 3-year research cycle, the highest total protein yield was obtained in 1998, which was due to the highest seed yields of the highest protein content that year.

DISCUSSION

According to Hołubowicz [21], the optimal temperature over bean vegetation is 23°C, while lower or higher temperature significantly decreases pod and seed yield. High air temperature results in a poor pod setting, and less considerably also in flower abortion. Similar observations were made in the present research, when in 1999 high air temperature combined with low total precipitations over flowering and pod setting resulted in the most unfavourable generative features in the 3-year research cycle. According to Lipiński and Kowalczuk [24], the highest demand of bean for water coincides with flowering and pod setting. Precipitations shortage over that period limits pod setting and makes them shed before forming, while excessive amounts of precipitations prolongs flowering and vegetation period. In the present research the length of flowering and vegetation period depended mainly on the total precipitations. In 1998 which coincided with favourable moisture and temperature conditions, bean developed the highest total numbers of pods with seeds and of seeds per plant. Szyrmer and Boros [41] reported on the weather course modifying considerably the seed yield. In the present research, the course of weather conditions in 1999, which was unfavourable for bean, decreased the seed yield by 55% compared to 1998 and by 41%, compared to the year 2000. Sypniewski [40] claims that protein yield per ha is a product of the seed yield and the percentage content of this component. In the present research the highest content of seeds was recorded for 'Longina', while protein yield per 1 ha was similar to the seed yields and was highest in 'Małopolanka', and lowest in 'Longina'.

The results reported by numerous authors show a favourable effect of foliar fertilisation with molybdenum on the seed yield and structural yield components in bean [2,4,10,34,38,45], while the highest increases in the seed yield were recorded following the application of 76-90 g $Mo \cdot ha^{-1}$. Compared to the control, Vieira et al. [43] recorded a 40% seed yield increase. Reports by Correa et al. [10] showed that molybdenum itself increases the number of pods and seeds per plant, number of seeds per pod, while molybdenum combined with cobalt facilitates obtaining the highest seed yields. Padma et al. [32,33] and Deka and Shadeque [12] recorded an increase in plant height, leafy area, number of flowers and pods per plant. In the present research foliar application of 48 g $Mo \cdot ha^{-1}$ over flower bud formation was most favourable for the seed weight per pod, 1000 seed weight, weight of overground part and of the whole plant and the percentage share of seeds in the overground part. A combined application of boron and molybdenum coincided with the highest bean plants, and the number of pods with seeds and of seeds per plant increased by 9 and 10%, respectively, compared to the control. Out of all the three fertilisation variants (boron, molybdenum, boron with molybdenum), the application of molybdenum resulted in the highest seed and protein yields. The increase in yields compared with the control was 5% on average. The present research showed, however, no effect of the microelements application on the percentage content of organic compounds or mineral components in bean seeds. Boron, molybdenum as well as molybdenum combined with boron did not enhance the increase in N content in bean seeds, which was reported by Stoyanowa et al. [39] and Vieira et al. [44].

CONCLUSIONS

1. The bean vegetation period length depended on the cultivar properties and the course of weather conditions. In the three-year research cycle the longest vegetation period was reported for 'Longina', and then, respectively shorter, 'Małopolanka' and 'Mela'.
2. Morphological features of plants, seed yield, content of organic components and crude ash in seeds depended mainly on genetic features of the cultivars researched, and much less considerably on fertilisation with microelements.
3. The highest seed and straw yields were recorded for 'Małopolanka'.

4. Foliar fertilisation of bean with molybdenum or molybdenum combined with boron at the beginning of flower bud formation resulted in a 5% increase in, compared to the control, the number of pods with seeds and a 3% increase in the seed weight per plant and seed yield.
5. Under the natural conditions of the Lower Silesia, the highest bean seed yields can be obtained by cultivating 'Małopolanka' which over flower bud formation should be fertilised with microelements: molybdenum or boron combined with molybdenum.

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