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EFFECT OF MULTI-MICRONUTRIENT FERTILIZERS APPLIED TO FOLIAGE ON NUTRITIONAL STATUS OF WINTER OILSEED RAPE AND DEVELOPMENT OF YIELD FORMING ELEMENTS

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Abstract

Yields of oilseed rape harvested by farmers in Poland are usually much below the attainable potential of currently cultivated varieties, mainly because of the insufficient supply of nutrients during the yield foundation period, which determines the final number of secondary branches. This situation is typical of whole Poland, but may take place even on farms where high yields are harvested, for example in 2007. In 2006, 2007 and 2008, the year effect of multi-micronutrient fertilizers on yield of seeds, elements of yield structure and macronutrient content was studied. Multi-micronutrient fertilizers were applied twice over oilseed rape foliage during its pre-anthesis growth (BBCH45 and 53). In 2007, due to a drought in April, the harvested yields of seeds were below the country's average. However, in each year of the study, a significant increase in the seed yield owing to the foliar application of multi-micronutrient fertilizers was found. The increase in the yield of seeds, averaged for the three years, reached 0.486 t ha^{-1} for the NPK+MiMo treatment (full set of micronutrients) and 0.36 t ha^{-1} for the NPK + Mi treatment (without molybdenum). The increments of the oilseed rape yield resulted from an increased number of developed secondary branches. This yield-forming element was an indirect result of the application of multi-micronutrient fertilizers, which affected the nitrogen economy by oilseed rape plants during the foundation period of their growth. At the same time, the increase in seed yield was significantly modified by the total number of developed pods, which is shaped during the yield-forming period of oilseed rape crop growth. Under conditions of the study, the magnesium content in secondary branches was found to be an element significantly correcting their number, thus increasing the yield of seeds.

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Key words: oilseed rape, multi-micronutrient fertilizer, macronutrient content, yield structure elements.

WPŁYW DOLISTNEGO STOSOWANIA WIELOSKŁADNIKOWYCH NAWOZÓW MIKROLEMENTOWYCH NA STAN ODŻYWIENIA RZEPAKU OZIMEGO I WYKSZTAŁCENIE ELEMENTÓW STRUKTURY PLONU

Abstrakt

Plony rzepaku zbierane przez rolników w Polsce kształtują si,e na poziomie dużo niższym od potencjału aktualnie uprawianych odmian. Główną przyczyną jest niedostateczne odżywienie roślin w okresie budowy podstaw struktury plonu, gdy ustala się ostateczna liczba pędów bocznych. Jest to przypadek typowy w Polsce, lecz może pojawić się także w gospodarstwach zbierających, z zasady, duże plony, jaki wystąpił w trakcie badań w roku 2007. W latach 2006, 2007, 2008 badano wpływ dolistnego stosowania nawozów mikroelementowych na plon nasion, elementy struktury plonu i zawartość makroskładników. Nawozy mikroelementowe stosowano 2-krotnie w okresie przed kwitnieniem rzepaku ozimego (BBCH54 i 53). W 2007 r. z powodu suszy w okresie formowania się podstaw struktury plonu (kwiecień) plony były mniejsze od średniej krajowej. Jednakże, we wszystkich trzech latach badań, wzrost plonów w następstwie dolistnej aplikacji nawozów mikroelementowych był istotny. Wzrost plonów, średnia z lat, wyniósł 0.486 t ha^{-1} dla wariantu NPK+MiMo (pełen zestaw mikroelementów) i 0.36 dla wariantu NPK+Mi (bez molibdenu). Uzyskany wzrost plonów wynikał bezpośrednio z wytworzenia przez roślinę większej liczby pędów bocznych. Ten element struktury plonu był pośrednio następstwem działania nawozu mikroelementowego, który istotnie kształtował gospodarkę azotową rośliny w okresie budowy podstaw struktury plonu. Jednocześnie wzrost plonu nasion podlegał istotnej modyfikacji wynikającej z całkowitej liczby łuszczyn na roślinie, cechy plonu kształtowanej w okresie formowania się plonu nasion. W warunkach badań zawartość magnezu w pędach bocznych okazała się czynnikiem istotnie korygującym ich liczbę, a tym samym zwiększającym plon nasion.

Słowa kluczowe: rzepak, wieloskładnikowy nawóz mikroelementowy, zawartość makroskładników, elementy struktury plonu, zbiór.

INTRODUCTION

Oilseed rape varieties currently cultivated in Poland, with respect to a standard variety (indexing the level of attainable yield), yield at a level of 4.0 to 5.0 t ha^{-1} (COBORU 2009). However, yields harvested by farmers are much lower, ranging from 2.6 to 3.1 (GUS 2007, 2009). These two data sets clearly demonstrate that even in good years farmers in Poland are able to exploit *ca* 60% of attainable yield of oilseed rape.

The final yield of oilseed rape seeds is a result of many natural and agronomic factors affecting the plant growth during the growing season. Spring is particularly important for the growth of this crop. It is frequently assumed the final yield of seeds is a function of four main elements such as: i) number of plant per unit area; ii) number of capsules per plant,

iii) number of seeds per capsule, and iv) individual mass of a seed (expressed as 1000 seeds weight, TSW) (RATHKE 2006). It is only the first element that is established early in spring. All the other elements of yield structure are formed during anthesis and the seed filling period. Any internal or external factor disturbing carbon, nitrogen or water plant economy negatively affects plant yield structure, causing decay and drop of the youngest pods or even secondary branches (HABEKOTTE 1993).

The main cause of the shedding of the newest branches and pods is shortage of carbon due to competition between main oilseed rape plant organs, such as leaves and main branches with new developing branches as well as simultaneous in-organ competition among older and the newest developing pods. All these new, fast growing plant parts tend to have a high demand for assimilates to cover both the cost of respiration and new seed-oriented tissue ingrowths (LAWOR 2002). All these processes depend on nitrogen and carbon balance, which cannot be achieved without a sufficient supply of micronutrients (GRUSAK et al. 1999). Hence, it was assumed that application of multi-micronutrient fertilizer, containing mostly iron, manganese as well as a smaller amount of molybdenum, to oilseed rape foliage during plant growth stages preceding anthesis will be a simple agronomic measure taken to reduce loss of potentially fruit-bearing pods.

The main objective of this study has been to assess sensitivity of oilseed rape yield structure elements to the nutritional status of plant canopy at harvest and in turn the yield of seeds to an external supply of multi-micronutrient fertilizers.

MATERIAL AND METHODS

Field experiments were conducted in three consecutive growing seasons, 2006, 2007 and 2008, in Bierzglinek, a village 50 km east of Poznań (Poland; 52.40°N, 16.90°E). The field trials were established on soil classified according to the FAO as albic luvisol, originating from loamy sand lying on sandy loam or sand postglacial materials, and classified according to the Polish agronomical taxonomy to class IVb, good rye complex. The soil was agrochemically assayed in the topmost soil layer (0-30 cm) throughout the three years of the experiment, providing the following data: pH_{KCl} – 5.0 (in 2006); 5.1 (2007); 5.7 (2008); P and K (lactate buffor, pH 3.55) – 79 and 128; 77 and 101; 91 and 167 mg kg^{-1}, respectively; Mg (0.0125 M $CaCl_2$) – 101; 92 and 68 mg kg^{-1}, respectively. Each year, cereals (winter wheat or spring barley) were a preceding crop. Oilseed rape was sown at the end of August (VIII/3). Autumn dressing of P, K and Mg fertilizers was performed each year in doses based on the actual soil fertility level for each nutrient and the expected yield of seeds of 4.0 t ha^{-1}. Nitrogen dressing was conducted in accordance to soil N_{min} test (the beginning of plant spring regrowth) and fertilizers were applied in two split rates, i.e. at the beginning of spring regrowth and three weeks later. Herbicides and all other agrotechniques were applied according to standard practices.

The single-factor experiment consisted of three treatments:

1. Basic N, P, K fertilization – acronym NPK;
2. NPK + multi-micronutrient fertilizer, containing cations plus molybdenum (NPK+MiMo);
3. NPK + multi-micronutrient fertilizer without molybdenum, Mi, (NPK+Mi).

All treatments were replicated 6 times in a simple block design. Each replication was 18 m wide and 50 m long. The experiment was located on a large field characterized by uniform distribution of plants of 50(± 2) per m^2. The tested multi-microelement fertilizers were prepared at concentrations of 70 Cu, 400 Fe, 170 Mn, 150 Zn mg dm^{-3} chelated by EDTA for the Mi formulation and plus 40 g dm^{-3} of Mo as ammonium molybdate for the MiMo formulation. Both fertilizers were applied to oilseed rape foliage during two consecutive stages in the pre-anthesis growth of its canopy, accordingly to the BBCH scale, at 45 (five internodes visible) and 53 (flowers buds raised above the youngest leaves).

The average annual precipitation and average temperatures during five months of oilseed rape growth in spring were 202 mm and 13.5°C in 2006, 282 mm and 11.5°C in 2007 and 178.2 mm and 12.6°C in 2008. It should be emphasized that in two years (2006 and 2008) the weather conditions for oilseed rape growth were much more suitable in comparison to 2007, characterized by a severe drought, which took place in April, i.e. during stem elongation and inflorescence emergence.

At maturity (the third decade of July), crops were harvested from an area of 80 m^2 using a combine-harvester. Total yields of seeds were adjusted to 8% moisture content. Plant samples, each containing 8 plants per replication, were taken at the stage of the physiological maturity of seeds. In the second step of our analysis, each plant was partitioned into subsamples (plant parts = elements of yield structure) and than dried (65°C). The following elements of yield structure were determined: i) number of secondary branches, acronym SB, ii) number of pods per main branch, PMB, iii) number of pods per each secondary branch, PSB, iv) number of seeds per pod of the main branch, SMB, v) number of seeds per pod of the secondary branch, SSB, vi) weight of 1000 seeds (TSW). The content of nitrogen and other elements (as listed in Table 1) of respective plant tissues was determined by using the Kjeldahl method (Kjeltec Auto Distillation) and the flame atomic absorption spectrometry (FASS) method, respectively. Concentrations of all the investigated elements in all the tested organs are expressed on a dry matter basis.

The empirical data underwent conventional analysis of variance. The least significant difference values (LSD at $P = 0.05$) were calculated to establish the significance of mean differences. Path analysis and stepwise regression were applied to assess interrelationships between oilseed yield and its yielding components (Konys, Wiśniewski 1984). Linear regression fit was determined for all the replications from 2006 and 2008, representing high yielding populations, by using statistical software Statistica 7. The goodness of fit was evaluated by R^2 values.

Table 1

Effect of multi-micronutrient fertilizers on macronutrient content of the main branch at harvest

Factor	Level of factor	Nutrients (g kg^{-1})				
		N	P	K	Mg	Ca
Fertilizers	NPK	8.972	2.078	16.99	1.222	7.189
	NPK+MiMo	9.333	2.172	17.24	1.344	7.550
	NPK+Mi	9.383	2.217	17.21	1.244	7.494
LSD, $P \leq 0.05$		0.027	0.010	0.013	0.007	0.021
Years	2006	9.107	2.139	17.13	1.272	7.483
	2007	9.350	2.183	1.718	1.283	7.500
	2008	9.233	2.144	17.13	1.256	7.250
LSD, $P \leq 0.05$		-	-	-	-	0.021

RESULTS AND DISCUSSION

Yield of seeds and its relationship to yield forming elements

Harvested yields of oilseed rape were variable due to the effect of year-to-year variability and the applied multi-micronutrient fertilizers (Figure 1). With respect to the first factor, yields decreased in the order: 2006 > 2008 > 2007. Yields harvested in the NPK treatment tended to be lower, corresponding to *ca* 78%, 68%, 55%, of the "standard variety yield" in the subsequent years. These results clearly indicate the size of a yield gap caused by the weather in each growing season. However, as compared to the country's average, the harvested yields were 47% and 6% higher in 2006 and 2008, being 12% lower in 2007 (Heimann, Broniarz 2009, GUS 2008, 2009). The multi-micronutrient fertilizers significantly increased the yield of oilseed rape seeds in comparison to the NPK treatment, considered as an experimental control. The highest increase, averaged for the three years to 0.486 t ha^{-1}, was attributed to the NPK+MiMo treatment. A slightly smaller increase, namely 0.362, was noted for the NPK+Mi treatment. However, irrespectively of the weather in a given growing season, both fertilizers affected the yield of seeds in the same manner. The existing yield gap was therefore

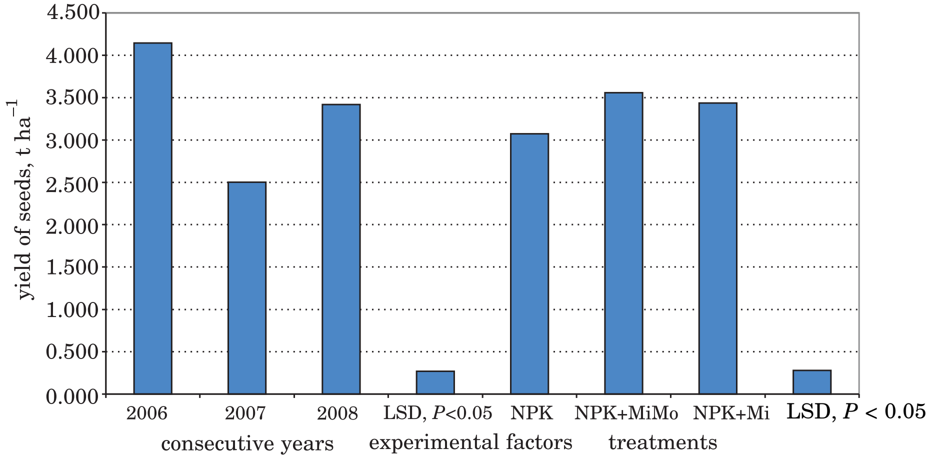

Fig. 1. Yields of oilseed rape in consecutive growing seasons and in response to the multi-micronutrient fertilizers

significantly covered owing to the application of both fertilizers, especially the MiMo variant. In 2006, the above gap diminished to 9%; but in 2008 it reached 21% and in 2007 it was the worst, namely 38%. Considering the effect of the MiMo fertilizer, in relative terms, the highest yield gap cover was noticed in 2007 (+17%), which indirectly suggests the stabilization effect of the applied multi-micronutrient fertilizers on oilseed rape growth and yielding.

The yield increase determined in our experiment was validated by an evaluation of the sensitivity of yield structure elements to the applied multi-micronutrient fertilizers (Table 2). The first yield structure component was the number of secondary branches (SB), which depends on plant density and water and nitrogen supply from the stage of rosette up to full flowering (Habekotte 1993, Rathke et al. 2006). The influence of initial characteristics of the plant canopy, i.e. number of plants per unit area, was eliminated by locating the experiments on part of a field with a constant number of plants, i.e. *ca* 50±2 averaged for the three years. Both factors, independently of each other, affected however the number of secondary branches (SB). The effect of year-to-year variability was significant in the two following years compared to 2006. The fFertilizers applied to oilseed rape foliage increased significantly the number of branches compared to the NPK object. The number of pods developed on the main branch (PMB) was significantly affected only by the applied fertilizers, where the effect was much stronger than in the case of secondary branches. The number of pods per secondary branch (PSB) was much lower than on the main branch and the response to micronutrient fertilizers was small and insignificant. The total number of pods per plant (TPP) showed a strong response to both tested fertilizers. However, a significant response was attributed only to the NPK+MiMo ferti-

Table 2

Effect of multi-micronutrient fertilizers on yield-forming elements of oilseed rape

Factor	Level of factor	Elements of yield structure						
		SB*	PMB	PSB	TPP	SMB	SSB	TSW
Fertilizers	NPK	5.806	38.89	28.17	166.7	14.36	12.12	4.122
	NPK+MiMo	6.706	46.61	33.72	226.9	16.39	12.57	4.422
	NPK+Mi	6.578	45.39	31.17	207.5	15.01	12.32	4.367
LSD, $P \leq 0.05$		0.383	3.807	-	51.19	0.818	-	0.195
Years	2006	7.039	44.56	34.61	247.3	16.12	13.13	4.739
	2007	6.033	43.50	27.00	164.33	14.97	12.02	4.133
	2008	6.017	42.83	31.44	189.5	14.67	11.87	4.039
LSD, $P \leq 0.05$		0.370	-	-	-	0.791	0.698	0.188

*Acronyms: SB – number of secondary branches; PMB – number of pods per main branch; PSB – number of pods per secondary branch; TPP – total number of pods per plant SMB – number of seeds per pod of the main branch; SSB – number of seeds per pod of the secondary branch; TSW – thousand weight of seeds, g

lizer as compared to the NPK control. Plants fertilized with NPK+MiMo developed 36% more pods than in the NPK treatment.

The response of both vegetative oilseed rape organs and finally the yield of seeds to the applied multi-micronutrient fertilizers indirectly indicates improved nitrogen economy in the whole plant during its consecutive stages of growth, i.e. i) yield foundation and ii) yield formation (HABEKOTTE 1993, MALAGOLI et al. 2005).

The number of seeds per pod is considered as one of the most important indices of oilseed rape growth conditions during the flowering and seed filling phases (RATHKE et al. 2006). With respect of the main branch, a significant effect of both factors was noted. The effect of the applied multi-micronutrient fertilizers followed the same pattern as determined for the total number of pods. The number of seeds in a pod on a secondary branch was much lower than on the main branch. However, similarly to the main branch, the seasonal effect was significant, demonstrating much worse conditions in 2007 and 2008 in comparison to 2006. The weight of seeds is the last yield-forming element, generally highly sensitive to internal factors, i.e. plant nutritional status, and external factors, i.e. weather conditions (RATHKE et al. 2006). The effect of the applied fertilizers showed the same pattern as for all the previously described yield structure elements, but its percentage increase in comparison to the NPK treatment was much lower. At the same time, the seasonal effect was much stronger, again indicating much worse growth conditions during the seed filling period in 2007 and 2008.

Taking into account all the elements of yield structure, one can find much similarity of the harvested yields to the total number of pods per plant (TPP). However, the conducted regression analyses showed slightly more complicated patterns due to different sets of data affecting yield of seeds depending on the applied multi-micronutrient fertilizer type. In the NPK treatment, as evidenced by the conducted stepwise regression, the yield of harvested seeds was significantly correlated to two elements, as seen in the equation:

$$Y = -1.773 + 0.120\ PMB + 0.826\ TSW, \text{ for } R^2 = 74.12\% \qquad (1)$$

where:

Y – yield of seeds, t ha^{-1};

PMB – number of pods per main branch;

TSW – weight of a thousand seeds, g.

This equation is however only partly supported by the simultaneously conducted path analysis, which showed a decisive role of TSW evidenced by the path coefficients for the total number of pods per plant (TPP) – Figure 2a. In the NPK+MiMo treatment, the relationship showed a much more complicated pattern. The final yield of seeds (Y) was correlated to three yield elements such as i) number of secondary branches (SB), ii) number of pods per secondary branch (PSB) and iii) number of seeds per pod on a secondary branch (SSB). All of these elements, as presented below, affected significantly and positively the final yield of seeds:

$$Y = -1.382 + 0.435\ SB + 0.018\ PSB + 0.140\ SSB \qquad \text{for } R^2 = 87.07\% \qquad (2)$$

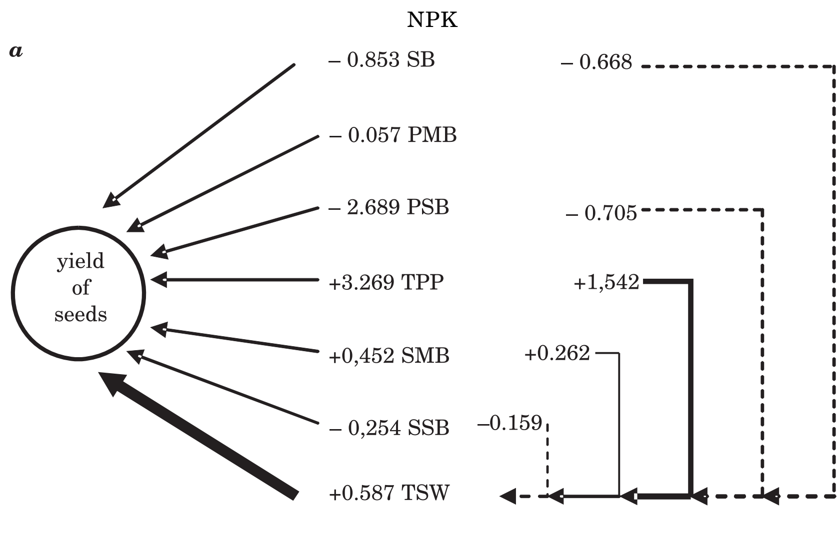

Fig. 2. Path diagram: relationships between yield-forming elements and yield of oilseeds rape

The path analysis, conducted simultaneously, indicated the number of secondary branches (SB) as the main single yield structure element directly affecting the yield of seeds and only slightly balanced via indirect effects of the other elements (Figure 2b). The most negative, but moderate effect has been attributed to the total number of pods per plant (TPP).

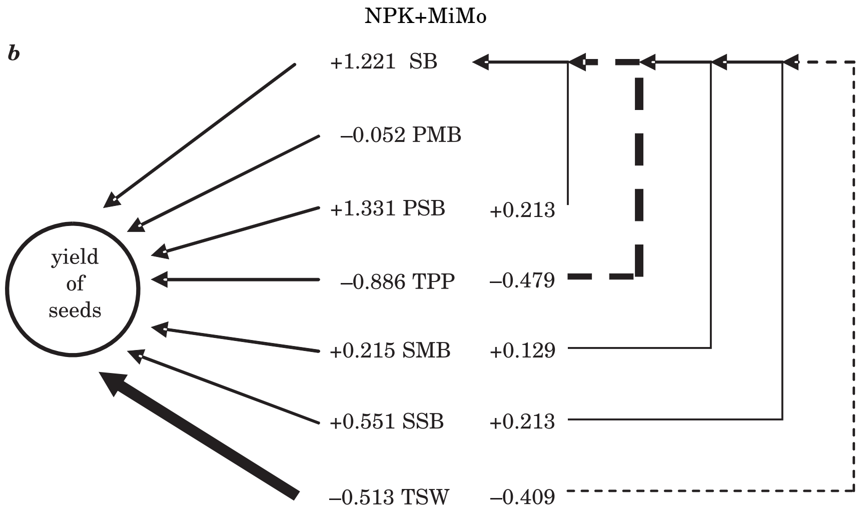

Fig. 2. Path diagram: relationships between yield forming elements and yield of oilseeds rape

The relationship analyzed for the NPK+Mi treatment confirmed the data obtained for the NPK+MiMo treatment. Generally, as implied by the stepwise regression analysis, the number of secondary branches (SB) affected the final yield of seeds with sufficient accuracy, as presented by the following equation:

$$Y = -0.499 + 0.645\ SB \qquad \text{for } R^2 = 84.43\% \qquad (3)$$

This finding has been corroborated by the path analysis (Figure 2c). The results underline the dominating role of the number of secondary branches in yield formation, although the yield is also significantly shaped by the total number of pods per plant.

As demonstrated by the analysis of all the above equations, the yield forming effects of the applied multi-micronutrient fertilizers are related to an increasing number of secondary branches and subsequently occurring events, i.e. a higher number of pods and seeds per pod. Such yield-oriented end-results of the fertilizers sprayed over leaves indirectly suggest significant changes in plant nitrogen economy (MALAGOLI et al. 2005). It can be concluded that any increase in the number of secondary branches on each oilseed rape plant needs to be balanced by an adequately developed number of total pods per plant (TPP). Both yield forming characteristics significantly limited the yield increment on the NPK plot due to some excess of secondary branches and shortage of well-developed pods (see Figure 2a). Therefore, any production measure should be oriented towards increasing the number of pods per plant as a prerequisite of an increase in the final yield of seeds, but should also maintain some balance according to the following rule: the higher number of secondary branches, the lower number of total but well-developed pods (see Figures 2b,c).

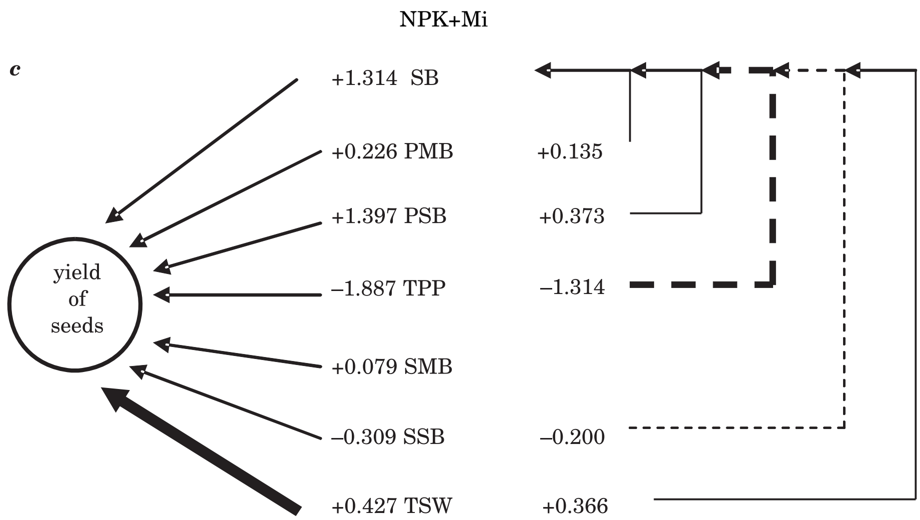

Fig. 2. Path diagram: relationships between yield forming elements and yield of oilseeds rape

Nutritional composition of plants at harvest

The second part of the present paper describes oilseed rape plant nutritional composition at physiological maturity shaped under the influence of the applied multi-micronutrient fertilizers against the background of year-to-year variability. In order to find some interesting rules, the nutrient composition of plant parts is described as shown in Table 2.

In the previous chapter it was explained that the applied multi-micronutrient fertilizers can be mainly affected the number of secondary branches (SB). The content of nutrients in secondary branches (Table 3) tended to be much higher than in a physiologically older main branch (Table 1). The highest differences between both plant parts were observed for calcium and magnesium, second to phosphorus and nitrogen, but excluding potassium. Plants exposed to an external supply of micronutrients significantly increased the content of all macronutrients of the main branch (raceme) and

Table 3

Effect of multi-micronutrient fertilizers on macronutrient content of secondary branches at harvest

Factor	Level of factor	Nutrients (g kg^{-1})				
		N	P	K	Mg	Ca
Fertilizers	NPK	9.283	3.139	17.61	2.222	12.68
	NPK+MiMo	10.05	3.489	17.88	2.383	13.37
	NPK+Mi	10.75	3.389	17.95	2.356	13.45
LSD, $P \leq 0.05$		0.051	0.020	0.021	0.009	0.030
Years	2006	10.04	3.389	17.76	2.283	13.16
	2007	10.03	3.333	17.82	2.300	13.15
	2008	10.01	3.294	17.87	2.379	13.19
LSD, $P \leq 0.05$		-	-	-	0.008	-

secondary branches. However, it was only the magnesium content in secondary branches that responded to both the applied fertilizers and seasons. At the same time, this element showed the highest difference in the concentration between the main and secondary branches, exceeding 80% in the NPK treatment. The MiMo fertilizer resulted in a significant Mg content increase, but caused a slight decrease of the gap between the main and secondary branches (down to 77%), significantly affecting the final yield of seeds:

$$Y_{NPKMiMo} = -2.453 \text{ Mg} + 9.841 \text{ for } n = 12 \text{ , } R^2 = 0.472 \text{ and } P = 0.01 \qquad (4)$$

where:

$Y_{NPKMiMo}$ – yield of seeds, t ha^{-1};
Mg – Mg content in secondary branches, g kg^{-1} DM.

The negative sign of the direction index of the developed linear equation informs us about excess of magnesium in secondary branches. In order to explain this unspecific result, the levels of macronutrients in secondary branches were regressed against the indicative attribute of yield structure, i.e. number of secondary branches. The analysis corroborated the specific yield-forming effect of magnesium (Mg), which significantly affected the number of secondary branches (Y) in two of the three treatments:

1. NPK $Y = -3.457 \text{ Mg} + 13.88 \; R^2 = 0.607$ for $n = 12$ and $P < 0.001$ (5)

2. NPK+MiMo $Y = -18.03 \text{ Mg}^2 + 80.42 \text{ Mg} - 82.22 \; R^2 = 0.513$ for $n = 12$ (6)

The first equation clearly shows that oilseed rape canopy fertilized with NPK alone had excess magnesium in secondary branches, causing their number to decrease alongside the increasing content of magnesium, up to 2.100 g kg DM. Foliar application of the MiMo fertilizer changed this relationship, indicating a positive effect of magnesium up to its critical content amounting to 2.230 g kg DM. It is well known that magnesium and molybdenum are an effective controller of nitrates taken up by plants (Kaiser et al. 2005). Differences between the main and secondary branches were as follows: NPK – 103%, NPK+MiMo – 108% and NPK+Mi + 115%. The last figure is too high, showing some disturbance of the gentle balance between the number of secondary branches and the total number of pods (see and compare Figures 2b and 2c).

The number of pods developed by the main or secondary branches was taken into account as an index of the final yield in the NPK treatment (the main branch, see equation No. 1; Figure 2a) in the NPK+MiMo (minor one, secondary branches, see equation No. 2; Figure 2b). Patterns of nitrogen and phosphorus content in pods followed all the rules found for vegetative branches (Tables 4 and 5). For the other elements, these differences tended

Table 4

Effect of multi-micronutrient fertilizers on macronutrient content of pods of the main branch at harvest

Factor	Level of factor	Nutrients ($g\ kg^{-1}$)				
		N	P	K	Mg	Ca
Fertilizers	NPK	6.239	2.717	21.71	1.817	22.96
	NPK+MiMo	6.778	2.922	22.06	2.000	23.13
	NPK+Mi	6.717	2.856	22.03	1.956	23.49
LSD, $P \leq 0.05$		0.035	-	0.033	0.012	0.041
Years	2006	6.544	2.939	21.97	1.900	23.40
	2007	6.583	2.983	22.03	1.917	23.27
	2008	6.606	2.572	21.19	1.956	22.91
LSD, $P \leq 0.05$		-	0.027	-	-	0.040

to be negligible. Significant effect of the applied multi-micronutrient fertilizers on macronutrient content was much stronger for the main branch that for secondary branches. In the former case, it was only phosphorus content in pods that did not show any response to the applied fertilizers. Pods of secondary branches responded to the applied fertilizers in terms of the concentrations of N and P, showing significant their increase. The effect of year-to-year variability was generally small, concerning mainly the main branch. The content of calcium was used as a nutritional index for the final seed yield forecast. Significant relationships were found only for treatments with the multi-micronutrient fertilizers, as shown below:

1. NPK+MiMo Y = 0.597 Ca - 9.796 for R^2 = 0.343 and n = 12, P = 0.05 (7)

2. NPK+Mi Y = 0.551Ca - 8.961 for R^2 = 0.334 and n = 12, P = 0.05 (8)

Seeds are the last yield component to be discussed, although thwey are the target of the oilseed rape crop production. The effect of the applied fertilizers on the macronutrient content in seeds was variable, although seeds are considered to be a conservative plant organ. Seeds developed on the main branch contained much less nitrogen in comparison to those developed on the secondary branches (Tables 6 and 7). The differences can be used to indicate the nutritional status of seeds at harvest. WOJNOWSKA et al. (1995), who demonstrated yields of seeds at a level of 5 t ha^{-1}, showed the total nitrogen content (TNC) comparable to the one obtained here for seeds from the main branch. BARŁÓG et al. (2006) found different values of TNC, showing significant dependence on the level of harvested yield of seeds. For yields above 3.5 t ha^{-1}, the data presented by these authors are within the range found in the present study for the main branch, but for lower yields, the TNC content tended to be much higher. Therefore, the differences between TNC values for seeds of the main and secondary branches can be used as an index of seed immaturity. The effect of the applied multi-micronutrient fertilizers on nitrogen content was generally positive and significant, but only for the main branch. The content of the other nutrients showed a variable response to the applied experimental factor. The most conspicuous effect was found for phosphorus. This nutrient did not show

Table 5

Effect of multi-micronutrient fertilizers on macronutrient content of pods of secondary branches at harvest

Factor	Level of factor	Nutrients (g kg^{-1})				
		N	P	K	Mg	Ca
Fertilizers	NPK	8.822	3.144	21.64	1.917	23.14
	NPK+MiMo	9.311	3.339	21.79	2.000	23.52
	NPK+Mi	9.272	3.306	21.77	1.956	23.40
LSD, $P \leq 0.05$		0.022	0.013	-	-	-
Years	2006	9.206	3.322	21.80	1.928	23.56
	2007	9.000	3.250	21.60	1.950	23.47
	2008	9.200	3.217	21.80	1.994	23.04
LSD, $P \leq 0.05$		-	-	-	-	-

any significant differences between branches but at the same time significantly responded to the applied fertilizer. In respect of secondary branches, a year-to-year variability in the P content was observed. In comparison to the data presented by Barłóg et al. (2006) and Wojnowska et al. (2000), our values for P are much higher but those for calcium and potassium are much lower. However, the nutrients did not show any significant influence on the final yield of seeds.

Table 6

Effect of multi-micronutrient fertilizers on macronutrient content of seeds of the main branch at harvest

Factor	Level of factor	Nutrients (g kg^{-1})				
		N	P	K	Mg	Ca
Fertilizers	NPK	30.89	8.122	8.194	2.433	1.833
	NPK+MiMo	32.58	8.422	8.383	2.556	1.95
	NPK+Mi	32.00	8.461	8.344	2.483	2.056
LSD, $P \leq 0.05$		0.120	0.017	0.014	-	0.017
Years	2006	31.62	8.400	8.344	2.578	1.933
	2007	31.67	8.300	8.267	2.517	1.900
	2008	32.18	8.306	8.311	2.378	2.006
LSD, $P \leq 0.05$		-	-	-	0.013	-

Table 7

Effect of multi-micronutrient fertilizers on macronutrient content of seeds of secondary branches at harvest

Factor	Level of factor	Nutrients (g kg^{-1})				
		N	P	K	Mg	Ca
Fertilizers	NPK	35.20	8.394	8.300	2.411	1.911
	NPK+MiMo	36.31	8.522	8.461	2.500	2.067
	NPK+Mi	36.26	8.556	8.472	2.522	2.044
LSD, $P \leq 0.05$		-	0.014	-	-	0.010
Years	2006	35.44	8.406	8.400	2.494	2.000
	2007	35.90	8.533	8.450	2.500	1.983
	2008	36.42	8.533	8.483	2.439	2.039
LSD, $P \leq 0.05$		-	0.014	-	-	-

CONCLUSIONS

1. The yield gap occurring between the actually harvested and attainable yields of oilsseed rape can be partly covered by foliar application of multi-micronutrient fertilizers.

2. Status of yield structure elements at harvest can be applied as a very sensitive measure of oilseed crop response to the applied multi-micronutrient fertilizers during its pre-anthesis growth.

3. The multi-micronutrient fertilizers, in-season applied, through gentle changes of the nutritional status of oilseed rape plants allow farmers to improve the balance between the number of secondary branches and the total number of pods.

4. In the present experiment, the magnesium content in secondary branches was the most yield-forming nutritional factor.

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