J. Elementol. 2008, 13(4): 615-623

EFFECT OF FOLIAR AND SOIL APPLICATION OF COPPER ON THE LEVEL AND QUALITY OF WINTER RAPESEED YIELDS

Urszula Sienkiewicz-Cholewa

**Institute of Soils Science and Plant Cultivation,
Departament of Weed Science and Tillage Systems in Wroclaw**

Abstract

In Poland nearly 40% of land under agricultural use is characterised by a progressing deficit of copper available to plants. Inventory studies revealed that 25% of rapeseed plantations are undernourished with this component.

The objective of the study was to estimate the yield-forming effects of foliar and soil fertilisation of rapeseed with copper, to identify the optimum dose of Cu for the crop species, and to compare the effects of the two methods of application on the quality of the seeds. The study comprised two three-year strict field experiments, in which pre-sowing fertilisation of rapeseed with copper was applied at rates of 4, 8 and 12 kg $Cu \cdot ha^{-1}$, as well as foliar spraying at the optimum dose of 250 Cu $g \cdot ha^{-1}$ in the phase of closed bud. The experiments were set up on light soils of acid and light acid reaction and with a low or medium content of available copper.

Significant increases in rapeseed yields, compared to the control treatment (without Cu), were obtained in treatments fertilised to the soil with doses of 8 and 12 kg $Cu \cdot ha^{-1}$ and in the treatment with foliar spraying. In plants from treatments without copper fertilisation, insufficient levels of the content of this component were found. Sufficient copper nutrition of plants caused a significant increase in yields of rape seeds. In some of the treatments, there was a tendency for the copper content in seeds to increase favourably, especially in the case of foliar application and of the higher copper doses applied to the soil. Also, some cases of increased oil content in seeds were recorded, even by several percent compared to seeds from treatments without Cu fertilisation.

With the existing copper deficit in soils in Poland, fertilisation of rapeseed with this component appears to be crucial.

Key words: rape, copper, fertilization, yield of seeds, oil content.

Urszula Sienkiewicz-Cholewal, Institute of Soils Science and Plant Cultivation, Departament of Weed Science and Tillage Systems in Wroclaw, phone: (071) 363 87 07, e-mail: u.sienkiewicz@iung.wroclaw.pl

WPŁYW DOLISTNEGO I DOGLEBOWEGO NAWOŻENIA MIEDZIĄ NA WIELKOŚĆ I JAKOŚĆ PLONÓW RZEPAKU OZIMEGO

Abstrakt

W kraju blisko 40% użytków rolnych cechuje pogłębiający się niedobór miedzi przyswajalnej dla roślin. Badania inwentaryzacyjne wykazały 25% plantacji rzepaku niedożywionych w ten składnik.

Celem badań była ocena efektów plonotwórczych dolistnego i doglebowego nawożenia rzepaku ozimego miedzią, wskazanie optymalnej dawki Cu dla tego gatunku oraz porównanie wpływu obu sposobów aplikacji na cechy jakościowe nasion. Przeprowadzono 2 trzyletnie ścisłe doświadczenia polowe, w których zastosowano przedsiewnie nawożenie rzepaku miedzią dawką 4, 8 i 12 kg $Cu \cdot ha^{-1}$ oraz oprysk dolistny o optymalnej dawce 250 Cu $g \cdot ha^{-1}$ w fazie zwartego pąka Doświadczenia prowadzono na glebach lekkich o odczynie kwaśnym i lekko kwaśnym oraz niskiej bądź średniej zawartości przyswajalnej miedzi.

Istotne zwyżki plonów nasion rzepaku w stosunku do obiektu kontrolnego (bez Cu) uzyskano na obiektach nawożonych doglebowo dawką 8 i 12 kg $Cu \cdot ha^{-1}$ oraz pod wpływem dolistnej aplikacji. W roślinach z obiektów nie nawożonych miedzią stwierdzono niedostateczne dla rzepaku zawartości tego składnika. Optymalne odżywienie roślin miedzią spowodowało istotny wzrost plonów nasion rzepaku. W poszczególnych doświadczeniach pojawiła się tendencja do korzystnego zwiększania się zawartości miedzi w nasionach szczególnie po zastosowaniu dolistnego nawożenia oraz wyższych dawek doglebowych.

Odnotowano również przypadki zwiększenia zawartości tłuszczu w nasionach nawet o kilka procent w stosunku do obiektów bez nawożenia Cu.

Wobec niedoborów miedzi w glebach kraju, nawożenie rzepaku tym składnikiem staje się niezbędne.

Słowa kluczowe: rzepak, miedź, nawożenie, plon nasion, zawartość tłuszczu.

INTRODUCTION

In the nearest years, rapeseed may gain strategic importance for the Polish agriculture and economy in general. Until now, the cultivation of the crop species has been limited primarily by the demand of the national oil-producing industry. Recently, a new major customer for rapeseed, i.e. the industry producing ecological diesel fuel, bio-fuel, has appeared. In accordance with the EU requirements, in the future Poland will be required to systematically increase rapeseed production (Kuś 2002). Rapeseed oil production may be increased through reliable and high yields of rapeseed with the required level of oil content.

Production of high crop yields, stimulated by basic fertilisation, causes gradual depletion of nutrients from soil, mainly microelements which are not added to soil by fertilisation. Microelemental deficiency grows, resulting in limited plant growth and development. Copper is among the most deficient components of soils in Poland (Czuba 2000, Gembarzewski 2000). Studies on the fertility of Polish soils of Poland in 1994-1999 showed that low cop-

per content occurs in 36% of arable soils (DĘBOWSKI, KUCHARZEWSKI 2000). Insufficient copper content for rapeseed plants was observed in 28% of fields (SIENKIEWICZ-CHOLEWA 2001).

Rapeseed belongs to plants which are sensitive to excessive levels of copper, yet – like cereals – it takes up approx. 40 g of Cu per 1 ha (10 g per 1 ton of seed yield). This indicates a high requirement of rapeseed for this element. As copper performs important physiological functions in the plant, rapeseed fertilisation with this component appears to be crucial in view of the existing deficit of copper in soils (KATYAL, RANDHAWA 1983, SHORROCKS 1990).

MATERIAL AND METHODS

In 2003-2006, two three-year strict experiments were carried out at the Experimental Stations Baborówko and Osiny, which included varied copper fertilisation of rapeseed. Against the background of the optimum basic NPK fertilisation as established in the IUNG Fertilisation Recommendations, the experiments included soil fertilisation with increasing doses of copper and foliar fertilisation at a dose accepted as optimum for plants (SZUKALSKI 1987). The experiments were set up in a random block system, with 4 replications, and included the following experimental treatments:

1) control (without Cu) – K;
2) Cu to soil, at a dose of 4 $kg \cdot ha^{-1}$ – Cu1;
3) Cu to soil, at a dose of 8 $kg \cdot ha^{-1}$ – Cu2;
4) Cu to soil, at a dose of 12 $kg \cdot ha^{-1}$ – Cu3;
5) Cu in foliar application, at a dose of 250 $g \cdot ha^{-1}$ – Cu4 (BBCH 50-59).

In the experiments two population cultivars of rapeseed were tested – cv. Lisek at ES Baborówko and cv. Californium at ES Osiny. The area of the experimental plots was 24 m^2.

The plots were fertilised to soil with copper in the form of technical salt – copper sulphate $CuSO_4 \cdot 5H_2O$. Foliar fertilisation in the form of spraying was performed at the budding phase of rapeseed (BBCH 50-59), using 0.2% water solution of copper sulphate.

Content of macro- and micronutrients in the experimental soils and in rape seeds was determined using the methods commonly applied at agrochemical stations (Metody Badań Laboratoryjnych w Stacjach Chemiczno-Rolniczych 1980). The content of copper was determined with the AAS method. Crude fat in seeds was determined with the Soxlet method after extraction with ethyl ether.

The yields obtained have been worked out statistically using variance analysis. The significance of cross-object differences in variance analysis were evaluated with the Tukey's test (α = 0.05).

The experiments were conducted on light soils, slightly acidic in reaction and with low or medium content of available copper (Table 1). Determinations made for the soils revealed high and medium levels of content of available forms of P, K and Mg and high content of zinc and manganese, fully covering the nutritional requirements of rapeseed. Estimation of the content of the nutrients was performed on the basis of the valid limit values in accordance with the IUNG Fertilisation Recommendations (1985).

Table 1

Chemical characteristics of soils under trials

Experimental station (soil)		pH in KCl	P	K	Mg	Cu	Mn	Zn
			($mg \cdot kg^{-1}$)					
Baborówko (light loamy sand)	I*	5.6	68 ^{h}	124 ^{m}	90 ^{h}	2.3 ^{m}	132 ^{m}	9.8 ^{h}
	II	5.8	76 ^{h}	100 $_{m}$	100 ^{h}	1.5 ^{l}	96 ^{m}	10.4 ^{h}
	III	6.4	65 ^{m}	104 ^{m}	98 ^{h}	4.5 ^{m}	112 ^{m}	13.0 ^{h}
Osiny (heavy loamy sand)	I	6.0	65 ^{m}	108 ^{m}	105 ^{h}	1.6 ^{l}	168 ^{m}	6.3 ^{m}
	II	6.0	64 ^{m}	124 ^{m}	93 ^{h}	2.5 ^{m}	201 ^{m}	12.0 ^{h}
	III	6.0	76 ^{h}	83 ^{m}	110 ^{h}	1.8 ^{m}	156 ^{m}	14.3 ^{h}

*I,II,III – consecutive years of the experiment;
Concentration in soil: l – low, m – medium, h – high

RESULTS

One of the approved indicators of rapeseed requirement for copper was the effect of fertilisation with this component on the level of seed yields. Rapeseed yields obtained in the particular experiments were varied, from 3.0 to 7.3 $t \cdot ha^{-1}$, and depended largely on the weather conditions. The lowest yield at the level of 3.0-7.3 $t \cdot ha^{-1}$ was obtained at Baborówko II. Plant emergence and growth was limited by drought conditions. Plant density in autumn was low (50 per m^2). Some of the population was destroyed by frost. Relatively high yields within the range of 4.0-4.5 $t \cdot ha^{-1}$ were achieved at Baborówko I, III and Osiny II, III. The highest yield of seed – 7.3 $t \cdot ha^{-1}$ was noted in a trial at Osiny Station after favourable winter survival. Weather conditions during the vegetation period were conducive to plant development.

In the first two years of the experiments, a statistically proven increase in rapeseed yields was obtained in treatments with soil fertilisation at the highest dose of copper – 12 kg Cu·ha^{-1} (Cu3) and under the effect of foliar fertilisation with copper at the dose of 0.250 kg Cu·ha^{-1} (Cu4). The increase in seed yields was in the range of 2-6% (Table 2). Pre-sowing fertilisation with the lowest doses, 4 and 8 kg Cu·ha^{-1} (Cu1), did not result in any increase in rapeseed yields. In the 3rd year of the experiments no yield response was recorded at either of the two experimental locations.

Table 2

Rape seed yields in separate trials in t·ha^{-1}

Cultivar		Fertilization					
		0	Cu1	Cu2	Cu3	Cu4	$LSD_{0.05}$
Lisek	I	4.09 ^{a}	4.13 ^{ab}	4.17 ^{ab}	4.22 ^{b}	4.22 ^{b}	0.111
	II	2.96 ^{a}	2.93 ^{a}	3.00 ^{ab}	3.00 ^{ab}	3.17 ^{b}	0.205
	III	4.00	4.08	4.07	4.10	4.18	n.s.
Californium	I	7.31 ^{a}	7.57 ^{ab}	7.71 ^{ab}	7.72 ^{b}	7.93 ^{b}	0.392
	II	4.52 ^{a}	4.56 ^{ab}	4.60 ^{ab}	4.83 ^{ab}	4.94 ^{b}	0.425
	III	5.30	5.34	5.44	5.39	5.44	n.s.

Yields marked with the same letter are not significantly different acc. to Tukey's test;
n.s. – differences not significant

In the control treatments (without Cu) copper levels were insufficient for plants – on average they reached 4.7 mg·kg^{-1} whereas the optimum copper content for rapeseed given by Bergmann is 5-12 mg·kg^{-1} (Bergmann 1986). Under the effect of the fertilisation applied in our experiments, the concentration of copper in the plants increased reaching 4.9, 4.9, 5.4, 9.3 mg·kg^{-1} in treatments Cu1, Cu2 , Cu3 and Cu4, respectively. Optimum nutrition of rapeseed with copper was ensured by the soil fertilisation at the dose of 12 kg Cu·ha^{-1} and the foliar fertilisation.

Oil content in rapeseed without copper fertilisation was notably lower than the mean values given by COBOR (Centre for Studies on Crop Plant Cultivars): 44.6 and 45.2 % d.m in cv. Lisek and Californium, respectively. Copper application, both to the soil and in the form of foliar fertilisation, resulted in an increase in the oil content of seeds of both rapeseed cultivars. Pre-sowing application of the higher doses of copper – 8 and 12 kg (Cu2 and Cu3) and foliar application at the dose of 0.250 kg Cu·ha^{-1} caused a significant increase in oil concentration with relation to the control treatments. Fertilisation to the soil with the lowest dose of 4 kg Cu·ha^{-1} (Cu1) did not result in any improvement in the oil content of seeds of the two rapeseed cultivars. The highest increase in seed oil content, by 2.5-2.7%, was recorded after the foliar application of copper on soils with low levels of copper (Baborówko II, Osiny I).

Table 3

Oil content in rapeseed (%)

Cultivar		Fertilization					
		0	Cu1	Cu2	Cu3	Cu4	$LSD_{0.05}$
Lisek	I	43.8	42.8	44.5	44.4	45.7	0.56
	II	43.0	43.2	43.4	44.5	45.7	0.84
	III	42.3	41.7	42.7	42.7	43.5	0.82
Californium	I	44.0	44.8	45.7	45.2	45.9	0.99
	II	43.3	43.3	43.7	43.0	43.5	0.95
	III	43.0	43.0	43.8	44.0	44.6	0.93

Copper concentration in seeds of the two rapeseed cultivars was considerably lower than the average of 3.1 $mg \cdot kg^{-1}$ d.m., recorded in Poland in the 1970's (KAMIŃSKA i in. 1976). Seeds harvested from the treatments without copper fertilisation (K) contained on average 2.2 mg $Cu \cdot kg^{-1}$ for both cultivars. Under the effect of the dose of 12 $kg \cdot ha^{-1}$ applied to the soil, and of the foliar fertilisation, the level of copper concentration increased to 2.8--3.0 $mg \cdot kg^{-1}$ d.m.

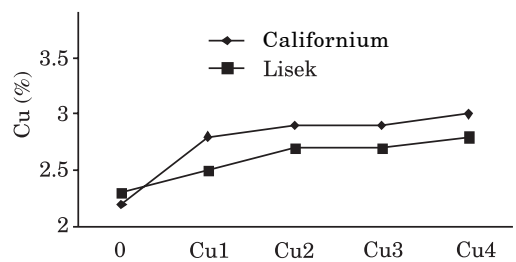

Fig. 1. Mean copper content in the seeds of the rapeseed cultivars

DISCUSSIONS

The need of fertilising rapeseed with copper, at a high level of basic fertilisation, on light soils with a low content of copper was indicated by the results of a pot experiment conducted by RUSZKOWSKA, ŁYSZCZ (1975) with traditional rapeseed cultivars "0". With a high level of NPK fertilisation, the increase in rapeseed yields was as much as 40%. The yield-forming effect of copper in the cultivation of "00" rapeseed cultivars is also indicated by the results of a strict field experiment conducted by BOBRZECKA, SALAMONIK (1997).

These authors found a significant increase in rapeseed yields on grey-brown podzolic soil and alluvial soil with low and medium content of available copper after the application of copper at 10 kg $Cu \cdot ha^{-1}$. In a study conducted by SIENKIEWICZ-CHOLEWA (2001), on soils with a medium content of Cu, synthesis of yields obtained in the experiments indicated a 6% increase in rapeseed yields.

In this study, the best results were achieved with the foliar fertilisation at the dose of 250 g $Cu \cdot ha^{-1}$. Increase in the dose of copper applied to the soil resulted, in most of the experiments, in a slight increase of the seed yield. This shows that on soils with pH in the range of 5.4-6.4 adsorption of copper is high, which limits its availability to plants. Copper could have also partly accumulated in plant roots, which happens when high doses of the component are introduced in soil. Many authors argue that analysis of the index parts of plants – leaves – is not an indicator that would reliably reflect the actual status of copper supply for plants (KORZENIOWSKA, STANISŁAWSKA-GLUBIAK 2003, STANISŁAWSKA-GLUBIAK, KORZENIOWSKA, IGRAS 2007).

Oil is the most important parameter of rapeseed quality. Apart from the genetic factor, the content of oil in rape seeds is largely determined by mineral fertilisation of the plants. Decrease in rapeseed oil content may result from deficit of nutrients, among others of such microelements as zinc and copper that control the metabolic transformations in the plants.

The pre-sowing fertilisation with copper applied in this study at the rates of 8 and 12 kg $Cu \cdot ha^{-1}$ and the foliar fertilisation at the dose of 0.250 kg $Cu \cdot ha^{-1}$ resulted, in most of the experiments, in a significant increase of oil concentration in the final yield of rapeseed as compared to the control treatments. A favourable increase in rapeseed oil content was also obtained by BOBRZECKA, SALAMONIK (1997) on a light soil with low copper content. Under the effect of foliar fertilisation with 0.200 kg $Cu \cdot ha^{-1}$, the level of oil content increased by 3.5% d.m.

Natural supplementation of the required amount of copper in fodders and feeds is expected to maintain a suitable level of this component in plant products. Analysis of rape seeds from the experiments showed that seeds from treatments without copper fertilisation had a low copper content compared to the national mean value used for comparison. This indicates a notable deterioration of rapeseed quality over the years, which is due to an increasing deficit of copper in soils. The chemical composition of seeds is determined genetically but can be modified, to a certain extent, by the environmental factors. Under the effect of the copper fertilisation applied in our trials, a tendency towards increased copper concentration in rape seeds was observed in the two test rapeseed cultivars. This is favourable in terms of the consumption value of oil as well as of the fodder value of rapeseed oil cake and meal. Studies indicate that the content of copper in plant products and its consumption have decreased notably, resulting in increased incidence of several human and animal diseases (ŻECHAŁKO-CZAJKOWSKA 1992, KUBIŃSKI 1996).

The favourable effect of copper fertilization on the level of yields, content of oil and concentration of copper in seeds provides evidence supporting the necessity of including copper in rapeseed fertilisation.

CONCLUSIONS

1. The application of rapeseed fertilisation with copper under conditions of low and medium level of this component in soil resulted in 2-6% increase in rapeseed yields. A statistically significant increase in rapeseed yields was obtained under the effect of foliar fertilisation with copper at 250 $g \cdot ha^{-1}$ and of the soil fertilisation with copper at 12 $kg \cdot ha^{-1}$.

2. The foliar fertilisation and pre-sowing fertilisation with copper at 8 and 12 $kg \cdot ha^{-1}$ led to a significant increase in the concentration of oil in seeds of the test rapeseed cultivars. Under the effect of copper fertilisation, a favourable tendency towards increased copper concentration in seeds of the test rapeseed cultivars was observed.

3. Foliar copper application produced a stronger effect on the concentration of this element and fat level in rape seed was more pronounced than soil Cu fertilization

REFERENCES

Bergmann W. 1986. *Bemerkungen und Tabellen zur analytischen Pflanzendiagnose der Pflanzen oder Blattanalyse.* VEB Fischer Verlag, Jena.

Bobrzecka D., Salamonik S. 1997. *Zależność między technologią nawożenia miedzią a plonem i zawartością tłuszczu w nasionach podwójnie ulepszonych odmian rzepaku ozimego.* IHAR Poznań, Rośliny Oleiste. 18 (1): 219–225.

Czuba R. 2000. *Mikroelementy we współczesnych systemach nawożenia*. Cz.I. Zesz. Probl. Post. Nauk Rol., 471, 161-170.

Dębowski M., Kucharzewski A. 2000. *Odczyn i zawartość mikroelementów w glebach Polski.* Zesz. Probl. Post. Nauk. Rol., 471 (1): 627-636.

Gembarzewski H. 2000. *Stan i tendencje zmian zawartości mikroelementów w glebach i roślinach z pól produkcyjnych w Polsce*. Zesz. Probl. Post. Nauk. Rol., 471(1): 171-177.

Kamińska W. i in. 1976. *Skład chemiczny roślin uprawnych i niektórych pasz pochodzenia roślinnego.* Wyd. IUNG, Puławy.

Katyal J.C., Randhawa N.S. 1983. *Micronutrients.* FAO Fert. & Plant. Nutr. Bull., 7.

Korzeniowska J., Stanisławska-Glubiak E. 2003. *Copper concentration in the top plant tissue as an indicator of Cu toxicity*. EJPAU, Ser. Environ. Develop., 6 (1).

Kubiński T. 1996. *Rola miedzi i molibdenu w żywieniu zwierząt*. Zesz. Nauk. PAN, Człowiek i Środowisko, 14: 210-215.

Kuś J. 2002. *Możliwości wykorzystania surowców roślinnych na cele energetyczne.* Biul. Inform. IUNG, 18: 1-10.

Metody Badań Laboratoryjnych w Stacjach Chemiczno-Rolniczych. 1980. Cz. I-IV. IUNG, Puławy.

Ruszkowska M., Łyszcz S. 1975. *Wpływ dawek NPK i Cu na plony oraz pobieranie miedzi i azotu w warunkach doświadczeń wazonowych.* Pam. Puł., 62: 229-250.

Shorrocks V.M. 1990. *Micronutrient assessment at country level an international study*. FAO Soils Bull., 63: 20.

Sienkiewicz-Cholewa U. 2001. *Ocena stanu odżywienia plantacji produkcyjnych rzepaku ozimego.* Pam. Puł., 126: 126-137.

Sienkiewicz-Cholewa U. 2001. *Wpływ nawożenia mikroelementami na plony rzepaku ozimego.* Pam. Puł., 126: 140-154.

Stanisławska-Glubiak E., Korzeniowska J., Igras J. 2007. *Przydatność części nadziemnych i korzeni do oceny fitotoksyczności miedzi i niklu na przykładzie gorczycy białej.* Ochrona Środowiska i Zasobów Naturalnych, 32: 76-80,.

Szukalski H. 1979. *Mikroelementy w produkcji roślinnej*. PWRiL, Warszawa.

Zalecenia Nawozowe. 1985. Pr. zbiorowa. *Liczby graniczne do wyceny zawartości w glebach makro- i mikroelementów*. Wyd. IUNG, Puławy.

Żechałko-Czajkowska A. 1992. *Mikroelementy w pożywieniu człowieka*. Mat. VII Symp. *Mikroelementy w rolnictwie.* AR Wrocław, 20-25 ss.