ISSN 2081–2787

Institute of Soil Science and Plant Cultivation
National Research Institute

No. 4
March 2011

Polish Journal of Agronomy

formerly

PAMIĘTNIK PUŁAWSKI

Puławy, POLAND

Polish Journal of Agronomy
(formerly Pamiętnik Puławski)

Polish Journal of Agronomy is a new nationwide English-language scientific journal. It is launched by the Institute of Soil Science and Plant Cultivation – National Research Institute. The new journal is a continuation of the former Pamiętnik Puławski. Its scope will cover topics connected to broad-sense crop production and agriculture-related environmental issues. The peer-reviewed journal will publish original research papers and invited review articles.

Published by Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy, Poland
Director: *Wiesław Oleszek*

Printed in Department of Extension and Information
Institute of Soil Science and Plant Cultivation – National Research Institute
Puławy, Poland

No. 4 **March 2011**

CONTENTS

http://www.iung.pulawy.pl/PJA/

Polish Journal of Agronomy
2011, 4, 3–6

The effect of foliar application of copper on content of this element in winter wheat grain

Jolanta Korzeniowska, Ewa Stanisławska-Glubiak

Department of Weed Science and Soil Tillage in Wrocław
Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy
ul. Orzechowa 61, 50-540 Wrocław, Poland

Abstract: Copper is an essential element for plants, animals and people in small, but absolutely necessary quantities. Deficiency of this element in the diet causes many health problems at animals and people. The content of Cu in wheat grain in Poland has decreased by about 20% over the past 30 years, which adversely affects its nutritional value. The aim of the study was to examine the possibility of increasing the copper content in winter wheat grain by foliar application of this element. In 2003–2006, six one-year field trials were conducted with copper foliar fertilization of 10 varieties of winter wheat. Spraying with copper sulfate at a dose of 305 g ha^{-1} was performed in spring in full tillering stage. The average density of copper in the grain was at a very low level of 2,4–2,6 mg kg^{-1}. Such a content is not enough in terms of nutritional needs of livestock. Single copper spray did not cause a statistically significant increase in the content of this element in the grain of any of the tested varieties. At the same time, varieties that reacted with the highest, approximately a 20% increase in yield to the application of copper, showed a 11–12% decrease in Cu content of grain. This decline was most likely the dilution effect.

key words: wheat, copper content, foliar application, dilution effect

INTRODUCTION

Over 40% of people worldwide suffer from micronutrient deficits (so-called “hidden hunger”), which causes various health problems (Progress Report, 2000; Murphy et al., 2008). The large increase in the number of people suffering from the deficiency of micronutrients in the last 40 years coincides with the expansion of new highly yielding varieties of cereals, which are often characterized by a lower tolerance of their deficiency. While worldwide deficiencies concern primarily iron and zinc (White and Zasoski, 1999), the problem in Poland is primarily an insufficient quantity of copper in food and feed.

Copper is an essential element for plants, animals and people in small, but absolutely necessary quantities. An insufficient content of this element in the soil reduces the yield of crops, particularly cereals. Too low amount of Cu in the diet, relative to the demand, leads to various health problems in animals and humans. One of the most dangerous is the increased risk of cardiovascular failure, one of the most common causes of death in our time. Pietruszka et al. (1998) and Rutkowska et al. (1992) report that a very unfavourable phenomenon is that Poles consume in their diet by 30–40% less copper than stated by the required daily dose. In the light of the facts above, a disturbing trend is the decrease in Cu content in wheat grain in Poland over the past 30 years by at least 20%. The results of the research conducted on the basis of large collections of samples from the whole country show a clear decrease in the content of this element in the grain of 4,2–4,4 in the seventies (Kamińska et al., 1976; Czuba and Andruszczak, 1981) to 3,1–3,4 mg kg^{-1} in the years 2000–2001 (Report of the Ministry in 2002; Wróbel, 2000). This is largely connected with the introduction of new intensive varieties with higher nutritional requirements. In addition, Cu content in wheat grain in Poland is lower than in other countries, the latter being as follows: England – 3,9–5,4 (Fan et al., 2008), Iran – 5.5 (Karami et al., 2009), Canada – 4.1 (Gawelko et al., 2002), Sweden – 3.5–5.0 (Kirchmann et al., 2009), and the USA – 4.1 mg kg^{-1} (Murphy et al., 2008). Low copper content of Polish wheat grain raises concerns about its significant deterioration as a feedstuff, which may have a direct impact on the health of farm animals. Deficiencies of copper leads to anemia, reduce the growth and fertility, and disorders the nervous system.

It seems that the fertilization of wheat with copper, essential for good yields given the existing deficiencies in the soil, should also cause an increase in Cu content in grain.

Corresponding author:
Jolanta Korzeniowska
e-mail: j.korzeniowska@iung.wroclaw.pl
tel. +48 71 363 8707 ext. 112

Received 7 June 2010

The aim of this study was to examine the possibility of increasing the copper content in winter wheat grain due to foliar fertilization with this element.

MATERIAL AND METHODS

In the period between 2003 and 2006 one-year field experiments, three at each experimental stations of IUNG in Jelcz-Laskowice and Osiny were carried out with copper foliar fertilization of 10 varieties of winter wheat. In Jelcz-Laskowice experiments were performed in the years 2003, 2004 and 2006, and in Osiny in 2004, 2005 and 2006. All the six experiments were performed as a 2-factorial (I – Cu fertilization, II – wheat varieties) split-plot design in 4 replications.

The experiments in Jelcz-Laskowice were located on podzolic soils rated as class IVa and IVb, in Osiny on the soils belonging to quality class IIIa and IIIb. Those soils were characterized by a slightly acidic pH, organic matter content of 11–12 g kg^{-1}, and a good supply of P, K, and Mg. Soils for the experiments were deliberately chosen having an average content of Cu as the researchers expected both positive and possibly negative reaction of some cultivars to fertilization with this element. Since the experimental soil in successive years of the study showed similar characteristics, their features are presented as an average of 3 years (Table 1).

Table 1. Physical and chemical properties of soil before the foundation of experience (average of 3 years).

Site	pH KCl	F_1 [%]	So [g·kg^{-1}]	P	K	Mg	Cu
				mg·kg^{-1}			
Jelcz-Laskowice	5.7	17	12	48 s	127 w	52 w	2.4 s
Osiny	5.6	17	11	51 s	120 s	62 w	3.2 s

So – organic substance, F_1 – fraction <0.02 mm, s – average content, w – high content

Spraying with copper sulphate at a dose of 305 g ha^{-1} were performed in spring in full tillering stage using a knapsack sprayer. The same NPK fertilization was used in all treatments in accordance with agrotechnical recommendations for winter wheat. The surface of the plot at harvest was 24 m^2 in Jelcz-Laskowice and 30 m^2 in Osiny.

Granulometric assays of soil were made using Casagrande's method as modified by Prószyński, pH in 1 mol KCl dm^{-3}, C_{org} by Tiurin's method, available forms of P and K by Egner-Riehm's method, Mg – by Schachtschabel's method, and Cu – in the extract 1 mol HCl dm^{-3}. Copper in the grain was determined by the ASA method after dry mineralization.

Program AWAR was used for the analysis of variance (Filipiak and Wilkos, 1995). Differences between means were evaluated using the Tukey test. Simple correlation calculations were made using Statgraphics.

RESULTS AND DISCUSSION

The copper content in grain of tested unfertilized wheat varieties ranged between 2,18–2,87 mg kg^{-1} and the average for all the varieties in Jelcz-Laskiowice was 2.59, and in Osiny 2,42 mg kg^{-1} (Table 2 and 3). The content is much lower than the average for Poland and it is insufficient in terms of nutritional needs of animals. Standard copper content in feed for farm animals according to Polish authors is 10 (Falkowski et al., 2000; Kruczyńska, 1985), and according to the American National Research Council it is 3–6 for pigs (U.S. NRC 1998), 6–8 for turkeys and chickens for fattening (U.S. NRC 1994), 10 for horses and cattle for slaughter (U.S. NRC 1989, 2000) and 12–16 mg kg^{-1} for dairy cows (U.S. NRC 2001).

Copper content in the experimental soils in Osiny while slightly higher than that in Jelcz-Laskowice had no beneficial effect on the content of Cu in wheat grain from the control treatments. On the contrary, the grain from Osiny was characterized by a slightly lower content of that element than the grain from Jelcz-Laskowice. Perhaps the reason behind that was twice as high yield in Osiny associated with the so-called dilution effect. However, it can be assumed that the higher Cu content in soil in Osiny was the cause of the smaller wheat response to fertilization with this element. In Jelcz-Laskowice as many as five wheat varieties responded by approximately 11–23% increases in yields, while only 2 varieties in Osiny responded with the increase at a level of 7,5–8,7% (Table 2 and 3).

Foliar application of copper in the experiments carried out in Jelcz-Laskowice did not cause any statistically significant increase in the content of this element in the grain in any of the tested cultivars (Table 2). For two cultivars:

Table 2. Yield and copper content in wheat grain grown in Jelcz-Laskowice (average of 3 years).

Cultivar	Cu content [mg kg^{-1}]			Grain yield [t ha^{1}]	
	0	+Cu	increase [%]	0	increase [%]
Jawa	2.64	2.51	-4.9	4.40	7.3
Kobra	2.75	2.44	-11.3*	3.73	22.8*
Korweta	2.55	2.42	-5.1	4.10	7.8
Kris	2.59	2.49	-3.9	4.77	-11.1*
Mewa	2.46	2.17	-11.8*	4.08	19.6*
Pegasoss	2.41	2.31	-4.1	4.03	12.2*
Sakwa	2.87	2.73	-4.9	4.77	11.7*
Soraja	2.48	2.68	8.1	4.31	3.2
Symfonia	2.57	2.74	6.6	4.83	-8.8*
Zyta	2.60	2.50	-3.8	4.08	11.3*
Mean	2.59	2.50	-3.5	4.31	7.6

* Statistically significant according to the Tukey test (α <0.05)

Kobra and Mewa a significant decrease (by 11–12%) was found whereas a downward trend, though statistically insignificant, was recorded for the six other varieties. At the same time, Mewa and Kobra reacted to Cu application with the biggest, almost 20–23% increase in yield.

In experiments in Osiny, fertilization with copper did not cause any significant changes to the content of this component in the grain (Table 3). It should be noted, however, that the increases in yields obtained as a result of application of Cu were significantly less frequent and smaller here than in Jelcz-Laskowice. This suggests that the decrease in Cu content in grain in Jelcz-Laskowice was also associated with the dilution effect.

Table 3. Yield and copper content in wheat grain grown in Osiny (average of 3 years).

Cultivar	Cu content [mg kg^{-1}]			Grain yield [t ha^{1}]	
	0	+Cu	increase [%]	0	increase [%]
Jawa	2.65	2.56	-3.4	8.00	1.1
Kobra	2.27	2.20	-3.1	7.62	8.7*
Korweta	2.58	2.70	4.7	7.62	-1.2
Kris	2.28	2.28	0.0	8.82	4.2
Mewa	2.25	2.31	2.7	7.83	3.3
Pegasoss	2.34	2.29	-2.1	8.21	3.3
Sakwa	2.58	2.74	6.2	8.66	4.7
Soraja	2.61	2.84	8.8	7.94	7.5*
Symfonia	2.50	2.60	4.0	7.91	3.5
Zyta	2.18	2.10	-3.7	7.65	5.1
Mean	2.42	2.46	1.6	8.03	4.0

* Statistically significant according to the Tukey test ($\alpha < 0.05$)

In the literature, both from the previous years and the latest, there is little data on changes in copper content in the grain under the influence of fertilization with this component to make up for its deficit. Most of the currently published work on copper is about contamination of plants with this element. A few authors who engaged in the research on copper fertilization of wheat, mostly provide its contents in the aerial parts at the early stages of development, or do not study the contents of Cu in plant tissues at all (Bobrzecka at al., 1992; Domska et al., 1994; Brennan and Bolland, 2003, 2004, 2006; Faber, 1992; Gałczyńska, 1972; Gupta and Kalra, 2006; Karamanos and Goh, 2004; Karamanos et al., 2004, Potarzycki, 2004 a; Potarzycki, 2004 b). Only Bobrzecka and Domska (1996) and Warechowska (2009) reported that foliar application of Cu resulted in an increase of Cu content in grain by respectively 8–30% and 14% compared to the control. The authors do not discuss in their work, however, yields of wheat, and therefore it is not known whether in the experiments conducted by them there were positive reactions to copper, reflected in increased yields.

Supposition, that the fall in Cu content in the grain due to its foliar application observed in our study was the result of the dilution effect is confirmed by (calculated for both sites together), the simple correlation coefficient between the increase in Cu content and the increase in grain yield due to application of copper, which was -0.595 ($n = 20$, $\alpha < 0{,}01$). This means that the increases in yields were accompanied by declines in Cu content in grain. Similar results were obtained by Owuoche et al. (1995) in studies on the effects of copper fertilization on the content of Cu in the grain of the Canadian wheat varieties.

On the basis of the obtained results it can be concluded that the increase in copper content in wheat grain using a single spray is very difficult. More often, there may be a decline in the Cu content associated with an increase in yields due to applications of copper causes the dilution effect.

CONCLUSIONS

1. In experiments conducted, the average density of copper in the grain was 2,4–2,6 mg kg^{-1}. It is not a sufficient content in terms of nutritional needs of livestock.
2. Single copper spraying of winter wheat at a dose of 305 g ha^{-1} did not cause a statistically significant increase in the content of this element in the grain in any of the 10 cultivars studied.
3. A significant 11–12% decrease in Cu content in grain was observed in varieties that responded to the application of copper with the highest, about a 20%, increase in yields. This decline was most likely the dilution effect.

LITERATURE

Bobrzecka D., Domska D., 1996. Ocena zależności między zawartością miedzi w pszenicy ozimej nawożonej dolistnie azotem i miedzią a jakością ziarna i wartością wypiekową mąki. Zesz. Probl. Post. Nauk Rol., 434: 83-89.

Bobrzecka D., Domska D., Krauze A., 1992. Plony ziarna oraz jakość białka pszenicy w warunkach dolistnego dokarmiania azotem i miedzią. Mat. VII Sympozjum „Mikroelementy w rolnictwie", Wrocław, 16-17 września 1992, pp. 202-205.

Brennan R.F., Bolland M.D.A., 2003. Comparing copper requirements of faba bean, chickpea, and lentil with spring wheat. J. Plant Nutr., 26(4): 883-899.

Brennan R.F., Bolland M.D.A., 2004. Comparing copper requirements of field pea and wheat grown on alkaline soils. Aust. J. Exp. Agric., 44: 913-920.

Brennan R.F., Bolland M.D.A., 2006. Comparing soil and tissue testing of copper for early growth of wheat. Comm. Soil Sci. Plant Anal., 37: 1451-1470.

Czuba R., Andruszczak E., 1981. Wyniki badań prowadzonych w gospodarstwach przykładowych w latach 1976-1978. Wyd. IUNG Puławy, 42 pp.

Domska D., Anchim W., Bobrzecka D., Procyk Z., 1994. The effect of nitrogen and copper fertilization on yield protein content and amino acids composition of wheat protein. Fragm. Agron., 1994, 3(43): 46-53. (in Polish)

Faber A., 1992. Initial and residual effects of boron, copper, molybdenum and zinc in crop rotation. Wyd. IUNG Puławy, H(2), 81 pp. (in Polish)

Fan M.S., Zhao F.J., Fairweather-Tait S.J., Poulton P.R., Dunham S.J., McGrath S.P., 2008. Evidence of decreasing mineral density in wheat grain over the last 160 years. J. Trace Elem. Med. Biol., 22: 315-324.

Falkowski M., Kukułka I., Kozłowski S., 2000. Właściwości chemiczne roślin łąkowych. Wyd. AR Poznań, 132 pp.

Filipiak K., Wilkos S., 1995. Obliczenia statystyczne. Opis systemu AWAR. Wyd. IUNG Pulawy, R(324), 52 pp.

Gałczyńska B., 1972. Wpływ nawożenia miedzią i cynkiem na zawartość tych składników w glebach i roślinach uprawnych. Pam. Puł., 55: 179-197.

Gawalko E.J., Garrett R.G., Nowicki T.W., 2002. Cadmium, copper, iron, manganese, selenium, and zinc in Canadian spring wheat. Comm. Soil Sci. Plant Anal., 33(15): 3121-3133.

Gupta U.C., Kalra Y.P., 2006. Residual effect of copper and zinc from fertilizers on plant concentration, phytotoxicity, and crop yield response. Comm. Soil Sci. Plant Anal., 37: 2505-2511.

Kamińska W., Kardasz T., Strahl A., Szymborska H., 1976. Skład chemiczny roślin uprawnych i niektórych pasz pochodzenia roślinnego. Wyd. IUNG Puławy, pp. 1-76.

Karamanos R.E., Goh T.B. 2004. Effect of rate of copper application on yield of hard red spring wheat. Comm. Soil Sci. Plant Anal., 35(13-14): 2037-2047.

Karamanos R.E., Pomarenski Q., Goh T.B., Flore N.A. 2004. The effect of foliar copper application on grain yield and quality of wheat. Can. J. Plant Sci., 84(1): 47-56.

Karami M., Afyuni M., Khoshgoftarmanesh A.H., Papritz A., Schulin R., 2009. Grain zinc, iron, and copper concentrations of wheat grown in central Iran and their relationships with soil and climate variables. J. Agric. Food Chem., 57(22): 10876-10882.

Kirchmann H., Mattsson A.L., Eriksson A.J., 2009. Trace element concentration in wheat grain: results from the Swedish long-term soil fertility experiments and national monitoring program. Environ. Geochem. Health, 31: 561-571.

Kruczyńska H., 1985. Liczby graniczne zawartości mikroelementów w roślinach dla oceny ich wartości paszowej. Nowe Rol., 9: 45-47.

Murphy K.M., Reeves P.G., Jones S.S., 2008. Relationship between yield and mineral nutrient concentrations in historical and modern spring wheat cultivars. Euphytica, 163: 381-390.

Owuoche J.O., Briggs K.G., Taylor G.J., Penney D.C., 1995. Response of eight Canadian spring wheat cultivars to copper II. Copper content in the leaves and grains. Can. J. Plant Sci., 75: 405-411.

Pietruszka B., Brzozowska A., Puzio-Dębska A., 1998. Dietary assessment of adults in three villages in Warsaw, Radom and Biala Podlaska. Rocz. Państw. Zakł. Hig., 49: 219-229.

Potarzycki J., 2004a. The role of copper in winter wheat fertilization. Part I. Yield and grain quality. Zesz. Probl. Post. Nauk Rol., 502: 953-959. (in Polish)

Potarzycki J., 2004b. The role of copper in winter wheat fertilization. Part II. Nitrogen management. Zesz. Probl. Post. Nauk Rol., 502: 961-966. (in Polish)

Progress report, 2000. Nutrition for Health and Development. A global agenda for combating malnutrition. World Health Organization, Nutrition for Health and Development, Sustainable development and Healthy Environments, http://www.who.int/mip2001/index.pl%3Fiid=1735.html.

Raport, 2002. Raport z badań monitoringowych jakości gleb, roślin, produktów rolniczych i spożywczych w 2001 roku. Collective elaboration, ed.: W. Michna and B. Szteke, Ministerstwo Rolnictwa i Rozwoju Wsi, Warszawa, 71 pp.

Rutkowska U., Iwanow K., Kunachowicz H., 1992. Zawartość mikroelementów w krajowych racjach pokarmowych w latach 1973-1989. Mat. VII Sympozjum „Mikroelementy w Rolnictwie”, Wrocław, 16-17 września 1992, pp. 432-435.

USA NRC, 1989. Nutrient requirements of horses: 5th Revised Edition. The National Academies Press, Washington DC, USA, 101 pp.

USA NRC, 1994. Nutrient requirements of poultry: 9th Revised Edition. The National Academies Press, Washington DC, USA, 157 pp.

USA NRC, 1998. Nutrient requirements of swine: 10th Revised Edition. The National Academies Press, Washington DC, USA, 210 pp.

USA NRC, 2000. Nutrient requirements of beef cattle: 7th Revised Edition. The National Academies Press, Washington, DC, USA, 234 pp.

USA NRC, 2001. Nutrient requirements of dairy cattle: 7th Revised Edition. National Academy Press, Washington DC, USA, 381 pp.

Warechowska M., 2009. Wpływ zróżnicowanego nawożenia miedzią na zawartość miedzi i białka w ziarnie pszenicy jarej. Zesz. Probl. Post. Nauk Rol., 541: 449-455.

White J.G., Zasoski R.H., 1999. Mapping soil micronutrients Field Crops Res., 1999, 60: 11-26.

Wróbel S., 2000. Wpływ wieloletniego produkcyjnego użytkowania pól uprawnych na zaopatrzenie gleb i pszenicy jarej w mikroelementy. Zesz. Probl. Post. Nauk Rol., 471: 619-626.

Task performed within program 2.4 IUNG-PIB

Polish Journal of Agronomy
2011, 4, 7–11

The content of some micronutrients in rendzina soil cultivated using different tillage systems and catch crops

Piotr Kraska

Department of the Agricultural Ecology, University of Life Sciences in Lublin
ul. Akademicka 13, 20-950 Lublin, Poland

Abstract. The research was carried out in 2006/2007–2008/2009, using the experiment started in 2005 on Bezek experimental farm, the property of University of Life Sciences in Lublin. The experimental field was set on a medium-heavy mixed rendzina. The aim of the research was to estimate the impact of different tillage systems and different catch crops in spring wheat monoculture on the levels of Zn, Cu, Mn, Fe on topsoil.

Two-factor field experiment was established with split-plot method in four replitcations. The first factor included plough tillage (A) and two variants of conservation tillage with autumn (B) and spring disking (C) of catch crops. The second factor covered four methods of field reclamation in spring wheat monoculture in the form of undersown crops (red clover, westerwold ryegrass) and stubble catch crops (lacy phacelia, white mustard). Fields without catch crops were the control treatments.

Plough soil tillage system increased the level of Cu, Mn, and Fe in arable soil in comparison with both methods of conservation tillage. The content of zinc was significantly lower on conservation tillage treatments with autumn catch crop incorporation than on the treatments with plough soil tillage, and with conservation tillage involving spring catch crops disking. The highest level of zinc was found on the treatments with red clover seeding, a copper and iron – on the treatments with red clover and lacy phacelia, and manganese – in the control plots.

In spring, the levels of copper, manganese and iron in the soil were significantly higher than in autumn. As for zinc, its level in spring was significantly lower than in autumn. The levels of copper and iron in soil were significantly increasing, and the content of zinc – decreasing with every consecutive year. The content of micronutrients in the soils of 0–20 cm deep did not exceed their natural level, characteristic of this type of soils.

key words: tillage systems, catch crops, micronutrients

Corresponding author:
Piotr Kraska
e-mail: piotr.kraska@up.lublin.pl
tel. +48 81 4456778

Received 20 October 2010

INTRODUCTION

The level of elements in the soil is highly shaped by the richness of mother rock, soil-forming processes, eolian processes, granulometric composition, and the method of soil utilization (Dudka, 1992; Kabata-Pendias, 1993, 2004). Yields of cultivated crops are determined by nutrient richness of soil (Gembarzewski, 2000). Another important feature of crops for feed and consumption use is the content of microelements (Czuba, 2000).

Conservation methods of soil tillage increase the content of soil organic matter, which positively influences physical, chemical and biological properties of the soil (Håkansson, 1994; Rasmussen, 1999; Zimny, 1999; Holland, 2004; Wróbel and Nowak-Winiarska, 2007; Weber 2010). Catch crops can have a conditioning effect in specialized cereal rotations. They can also improve the soil balance of organic matter and nutrients, including microelements (Łoginow, 1985; Parylak, 1998; Parylak at al., 2002; Pałys at al., 2009).

Czekała and Jakubus (2000), as well as Strączyńska and Strączyński (2000) stated that the level of copper, zinc and manganese were higher in the soils with the highest level of organic carbon. The research by Strączyński and Wróbel (2000) showed that the content of soluble forms of Cu, Mn, Mo, Zn increased with the increase of soil silt and clay fraction. Kucharzewski and Dębowski (2000) stated that soils in Poland contain a medium content of copper, zinc, manganese and iron. They also attribute negative microelements balance in soils to the decrease in organic fertilization.

The aim of the research was an evaluation of the impact of plough tillage and two conservation tillage methods and different catch crops in spring wheat monoculture on the content of selected microelements in the topsoil.

MATERIALS AND METHODS

The research was carried out in 2006/2007–2008/2009, using the experiment started in 2005 on Bezek experimental farm (N: 51°19', E: 23°25'), the property of the University of Life Sciences in Lublin. The experimental field was set on medium-heavy mixed rendzina, developed from chalk bedrock that had granulometric composition of a medium silty loam. That soil had an alkaline reaction (pH 7.35), high content of P (117.8 mg kg^{-1}) and K (242.4 mg kg^{-1}) and very low of magnesium (19 mg kg^{-1}), the content of organic carbon was 24.7 g kg^{-1}. The soil belonged to IIIb valuation class and to defective wheat complex.

The layout of a static, two-factor field experiment, established with split-plot method in four replications. The first factor included plough tillage (A) and two variants of conservation tillage with autumn (B) and spring disking (C) of catch crops. The second factor covered four methods of field reclamation in spring wheat monoculture in the form of catch crops: undersown crops (red clover, westerwold ryegrass) and stubble catch crops (lacy phacelia, white mustard). Fields without catch crops were the control treatments. Harvested field area was 30 m^2 . Winter wheat, produced on this field for three years, was a preceding crop for the spring wheat. In 2005, treating as a pre-initial year, all crops were sown, and tillage systems were used in accordance with the methodology.

Plough tillage, as a part of seedbed preparation for spring wheat, was started with skimming and harrowing after preceding crop harvest. Medium-deep ploughing was performed before winter. Harrowing was done in spring, cultivating with harrowing – before sowing. At that time phosphorus and potassium fertilizers were delivered, as well as the first dosage of nitrogen fertilizers 60 kg N ha^{-1} in ammonium nitrate form. Phosphorus fertilizers at a rate of 30.5 kg ha^{-1} P in triple superphosphate form, and potassium at a rate of 74.7 kg ha^{-1} K in the 60% potash salt form, were applied in spring. Second nitrogen dose, at a rate of 40 kg ha^{-1} was applied at shooting (30-33 development phases BBCH). Spring wheat cv. 'Zebra' was sown at the number of 5 millions of seeds per ha in rows 10 cm apart. The seed was treated with Panoctine 350 SL (350 g l^{-1} of guazatine in an acetate form) seed dressing. The red clover of 'Dajana' variety – 20 kg ha^{-1} and westerwold lolium multiflorum of 'Mowester' variety – 20 kg ha^{-1} were sown on the same date as spring wheat. Lacy phacelia of 'Stala' variety – 20 kg ha^{-1} and white mustard of 'Borowska' variety 20 kg ha^{-1} were sown after spring wheat harvest and post-harvest tillage.

On the treatments with conservation tillage (B and C) after preceding crop harvest on the plots without red clover and westerwold ryegrass grubbing and harrowing were performed (18–20 cm deep). Next, lacy phacelia and white mustard were sown, analogous with plough tillage variants. Catch crops were disked before winter (B) or they were left as mulch for winter, and disk harrowed in spring (C). On the treatments with autumn catch crops disked (B), spring soil tillage was the same as in ploughed ones. On the plots with another variants of conservation tillage (C), the field was harrowed after being disked, and then harrowed again before spring wheat sowing.

The programme for spring wheat field protection included: Chwastox Extra 300 SL 3.5 l ha^{-1} (300 g l^{-1} MCPA) – 23-29 BBCH, Alert 375 SC 1 l ha^{-1} (125 g l^{-1} of flusilazole and 250 g l^{-1} of carbendazim) – 26-29 BBCH.

The soil samples for analysis were first taken in the autumn of 2006 and the spring of 2007 (the subsequent dates of taking samples are autumn 2007 and spring 2008 as well as autumn 2008 and spring 2009). Samples were taken in spring from a depth of 0–20 cm, before field works, and in late autumn before ploughing on plough tillage plots, and disking in conservation tillage variant with autumn catch crop incorporation. At the same time were soil samples taken on treatment where catch crops spring disking.

From each plot, soil samples were taken with the use of Egner's sampling stick in five randomly chosen places. Next, the samples collected in that way from four plots, constituting replications in the experimental model, were combined into one collective sample. In a cumulative samples from combinations of three repetitions Cu (PN-92R-04017), Zn (PN-92/R-04016), Mn (PN-93/R-04019), Fe (PN-R-04021:1994) were determined with ASA method. The results were statistically processed using the analysis of variance. Mean values were tested for the least significant differences based on Tukey's test (P = 0.05).

RESULTS

In the soil with conservation tillage with autumn catch crop disking, the level of zinc and manganese was significantly lower than in the soils with plough tillage and the soil with conservation method combined with spring catch crop disking (Tables 1 and 2). The level of manganese in an arable layer of plough tillage treatments was significantly higher than on conservation tillage treatments with catch crops preserved for winter (Table 2). The level of copper and iron were the highest in the soil taken from plough tillage treatments, significantly lower on mulch-free conservation tillage treatments, and the lowest on the conservation tillage variant with spring catch crop incorporation (Tables 2 and 4).

The level of Zn in soil was the highest on the treatments with red clover seeding, significantly lower on the plots with catch crop of lacy phacelia and white mustard, and the lowest – on the treatments with westerwold ryegrass and on the control treatment (Table 1). The level of copper was the highest in the soil under lacy phacelia, significantly lower on red clover, control, and undersown with westerwold ryegrass treatments, and the lowest on white mustard treatments (Table 3). The level of manganese was the highest in the soil taken from the control plots, significantly lower on the plots with stubble catch crops of white mustard and lacy phacelia, lower from the westerwold ryegrass treatments, and the lowest on red clover treatments (Fig.

Table 1. Content of Zn [mg·kg-1] in topsoil (mean in the years of study).

Experimental factors	Tillage systems# A	B	C	Mean
Catch crops				
Control	20.09	20.53	22.92	21.18
Red clover	28.51	20.90	22.32	23.91
Westerwold ryegrass	20.24	20.24	23.27	21.25
Lacy phacelia	22.80	21.16	24.68	22.88
White mustard	23.83	21.15	22.42	22.46
Sampling date				
Autumn 2006–2008	26.30	22.29	23.58	24.06
Spring 2007–2009	19.89	19.30	22.66	20.61
Years				
2006/2007	23.44	25.67	28.02	25.71
2007/2008	26.74	20.09	22.15	22.99
2008/2009	19.11	16.62	19.20	18.31
Mean	23.09	20.79	23.12	–
LSD(0.05)	tillage systems 0.041 catch crops 0.061 sampling date 0.028 years 0.041 tillage systems x catch crops 0.132 tillage systems x sampling date 0.070 tillage systems x years 0.093			

\# A – Plough tillage
B – Conservation tillage with autumn catch crops disking
C – Conservation tillage with spring catch crops disking

3). The level of Fe was the highest on the treatments with lacy phacelia, significantly lower on plots undersown with red clover, on control treatments, on stubble catch crop treatments with white mustard, and the lowest in variant with westerwold ryegrass (Table 4).

In spring, the levels of copper, manganese and iron were significantly higher than in autumn. But the level of zinc was significantly lower than in autumn (Tables 1, 2, 3, 4).

In plough tillage system on red clover treatments the levels of Zn, Cu and Fe in the soil were significantly higher than on other catch crop treatments and the control treatment (Tables 1, 3, 4). At the same time, the level of copper and iron on plough tillage fields on all catch crop treatments were higher than on all variants of conservation tillage (Tables 3, 4). Similar dependence for zinc and manganese was recorded on the red clover and white mustard treatments, and for manganese – additionally on lacy phacelia plots (Tables 1, 2).

In the soil of conservation tillage treatments with autumn disk harrowing of catch crops, the highest level of zinc was recorded on the lacy phacelia and white mustard plots. On conservation tillage treatments with spring catch crop incorporation, the highest level of zinc was recorded on lacy phacelia plots (Table 1). On catch crop treatments, the highest levels of copper and iron in a conservation variant with autumn disking were found in the soil under red clover, whereas in another conservation variant, in the treatments with lacy phacelia (Tables 3, 4). In both conser-

Table 2. Content of Mn [mg kg-1] in topsoil (mean in the years of study).

Experimental factors	Tillage systems# A	B	C	Mean
Catch crops				
Control	197.15	202.66	200.33	200.05
Red clover	200.62	187.41	192.24	193.42
Westerwold ryegrass	197.51	188.34	196.75	194.20
Lacy phacelia	199.54	190.82	196.62	195.66
White mustard	200.58	189.51	197.33	195.81
Sampling date				
Autumn 2006–2008	194.31	186.45	188.05	189.61
Spring 2007–2009	203.85	197.04	205.26	202.05
Years				
2006/2007	203.70	194.35	197.49	198.51
2007/2008	195.16	192.66	193.88	193.90
2008/2009	198.38	188.23	198.60	195.07
Mean	199.08	191.75	196.66	–
LSD(0.05)	tillage systems 0.265 catch crops 0.399 sampling date 0.181 years 0.265 tillage systems x catch crops 0.859 tillage systems x sampling date 0.456 tillage systems x years 0.609			

\# for explanations see Table 1

Table 3. Content of Cu [mg kg-1] in topsoil (mean in the years of study).

Experimental factors	Tillage systems# A	B	C	Mean
Catch crops				
Control	3.49	2.80	1.43	2.57
Red clover	4.11	2.46	1.45	2.67
Westerwold ryegrass	3.64	2.12	1.55	2.44
Lacy phacelia	3.58	2.41	2.07	2.68
White mustard	3.58	1.91	1.68	2.39
Sampling date				
Autumn 2006–2008	3.54	2.22	1.51	2.43
Spring 2007–2009	3.82	2.46	1.76	2.68
Years				
2006/2007	3.51	2.05	1.29	2.28
2007/2008	3.61	2.28	1.61	2.50
2008/2009	3.93	2.69	2.01	2.88
Mean	3.68	2.34	1.64	–
LSD(0.05)	tillage systems 0.007 catch crops 0.010 sampling date 0.005 years 0.007 tillage systems x catch crops 0.022 tillage systems x sampling date 0.012 tillage systems x years 0.015			

\# for explanations see Table 1

Table 4. Content of Fe [mg·kg⁻¹] in topsoil (mean in the years of study).

Experimental factors	Tillage systems[#]			Średnio Mean
	A	B	C	
Catch crops				
Control	218.00	210.06	86.72	171.59
Red clover	271.56	208.72	96.22	192.17
Westerwold ryegrass	235.28	153.72	85.67	158.22
Lacy phacelia	241.28	204.56	137.06	194.30
White mustard	229.50	155.78	117.28	167.52
Sampling date				
Autumn 2006–2008	244.37	179.67	89.53	171.19
Spring 2007–2009	233.89	193.47	119.64	182.33
Years				
2006/2007	227.60	162.83	73.03	154.49
2007/2008	237.77	184.10	105.97	175.94
2008/2009	252.00	212.77	134.77	199.84
Mean	239.12	186.57	104.59	–
LSD(0.05)	tillage systems 0.422 catch crops 0.635 sampling date of study 0.288 years 0.422 tillage systems x catch crops 1.367 tillage systems x sampling date 0.726 tillage systems x years 0.968			

[#] for explanations see Table 1

vation variants, the highest level of manganese was found in the control treatments (Table 2).

The levels of Cu and Mn in the soils with all tillage systems in autumn season were lower than in spring. Similar dependence for Fe was found in both conservation tillage variants (Tables 2, 3, 4). The level of Zn in the soil of all estimated tillage systems was higher in autumn than in spring season (Table 1).

The levels of copper and iron were significantly increasing with every consecutive year (Tables 3, 4), while for Zn – decreasing (Table 1). The highest level of manganese was recorded in the first period of evaluation, significantly lower in the last, and the lowest in the second season of analysis (Table 2). In all evaluated tillage variants, the level of Zn in soils in the last period of research was lower than in the first two periods (Table 1). In all tillage systems, the levels of Cu and Fe were subsequently increasing in consecutive seasons of observation (Tables 3, 4). The level of Mn on plough and conservation tillage treatments with autumn catch crop disking was significantly higher in the first season of research than in the consecutive ones. Its highest level on conservation tillage treatments with spring disking was recorded in the last season of research (Table 2).

DISCUSSION

In conservation tillage variant with spring disking of catch crops, the level of zinc in the soil 0–20 cm deep was slightly higher than on plough tillage treatments, and by 11.2% higher than on conservation tillage treatments with autumn catch crop incorporation. Blecharczyk at al. (2007) observed the increase in Zn level in the soil 0–5 cm deep on ploughless cultivation treatments and direct sowing in comparison with plough tillage. In the layer 10–20 cm deep, this dependency was reversed. The introduction of red clover undersowing into the monoculture of spring wheat resulted in the increase of zinc by 4.5% in comparison with lacy phacelia treatments, by 6.5% with white mustard, by 12.5% with westerwold ryegrass, and by 12.9% with the control plots without catch crop but with voluntary spring wheat seedling.

In plough tillage treatments, the level of manganese in the soil was by 1.2% to 3.8% higher than in conservation tillage treatments. Similarly, Blecharczyk at al. (2007) recorded the decrease in Mn level in the soil layer of 10–20 cm deep of ploughless tillage treatments with direct sowing in comparison with plough tillage treatments, whilst in the layer of 0–5 cm, only in direct sowing treatments. In non-catch crop control treatment, the level of Mn in the soil was higher by 2.2% to 3.4% than in spring wheat monocultures with undersown catch crops or stubble catch crops.

On plough tillage treatments, the level of copper was by 57.3% to 124%, and iron – by 28.2% to 128% as high as in non-plough tillage soil. Also Blecharczyk at al. (2007) observed that the level of copper in upper layer of soil was by 19.4% higher in plough tillage in comparison with a ploughless one, whilst the level of iron did not change significantly in different tillage systems. Wróbel and Nowak-Winiarska (2007) recorded a higher level of copper, manganese, iron and zinc in 0–10 cm layer of non-plough cultivated soil in comparison with plough cultivation, whilst in the layer of 10–20 cm deep, the level of these elements was lower in reduced tillage and no-tillage in comparison to conventional one. In other studies, Wróbel at al. (2007) confirmed this dependency for 0–5 cm soil layer in comparison to 20–25 cm layer.

In plough tillage treatments, the levels of copper and iron in all plots with catch crop, of zinc in red clover and white mustard plots, and of manganese additionally in lacy phacelia, were higher than in both conservation tillage variants. It can indicate a faster organic matter mineralization in plough tillage system and elements release into the soil. Kuś and Jończyk (1999) point to the slowed organic matter mineralization in the mulch conditions and lack of pre-winter soil cultivation.

In spring, the levels of Cu, Mn, and Fe were higher by respectively 10.3%, 6.6%, 6.5% than the concentration of these elements in autumn. It can be a result of the incorporation of these elements into the biomass of catch crops, and their slow release due to mineralization in the early spring season. Such a dependency was not recorded for zinc.

The levels of copper and iron in the topsoil were increasing in consecutive years of studies. It could be a result of positive influence of catch crop biomass – the source of micronutrients. Andrzejewska (1999), as well as Kuś and Jończyk (2000) emphasize the special role of catch crops due to their multilateral impact on biological and physico-chemical soil properties.

CONCLUSIONS

1. In the cultivation of spring wheat grown in monoculture, plough tillage system fostered the occurrence of higher level of copper, manganese and iron in surface layer of soil (0–20 cm) in comparison with conservation tillage.
2. The levels of iron and copper in soil surface layer were higher when catch crops were disk harrowed in autumn, whereas zinc and manganese – when this procedure was done in spring.
3. All the catch crops decreased the level of manganese in the soil, but increased the level of zinc. The level of copper in the soil decreased in the treatments where white mustard was grown as a catch crop, and the level of iron – on the treatments with westerwold ryegrass.
4. The highest level of zinc was recorded in the soils where red clover was grown, and copper and iron – where lacy phacelia and red clover were used as catch crops. The highest level of manganese was observed in non catch crop treatments.
5. The level of copper, manganese and iron in the soil was higher in spring, and zinc – in autumn.

LITERATURE

Andrzejewska J., 1999. Intercrops in cereal crop rotations. Post. Nauk Rol., 1: 19-31. (in Polish)

Blecharczyk A., Małecka I., Sierpowski J., 2007. Long-term effects of tillage systems on physico-chemical soil properties. Fragm. Agron., 1: 7-13. (in Polish)

Czekała J., Jakubus M., 2000. Occurrence of copper, zinc and manganese in arable soils. Zesz. Probl. Post. Nauk Rol., 471: 219-228. (in Polish)

Czuba R., 2000. The micronutrients in recent fertilization systems. Zesz. Probl. Post. Nauk Rol., 471: 161-169. (in Polish)

Dudka S., 1992. Ocena całkowitych zawartości pierwiastków głównych i śladowych w powierzchniowej warstwie gleb Polski. IUNG, Puławy, R(293): 5-48.

Gembarzewski H., 2000. Microelement contents and tendencies of their changes in soils and plants from arable fields in Poland. Zesz. Probl. Post. Nauk Rol., 471: 171-179. (in Polish)

Håkansson I., 1994. Soil tillage for crop production and for protection of soil and environmental quality: a Scandinavian viewpoint. Soil Till. Res., 53: 109-124.

Holland J.M., 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric. Ecosys. Environ., 103: 1-25.

Kabata-Pendias A., 1993. Behavioural properties of trace metals in soils. Appl. Geochem., vol. 8, Suppl. Issue 2: 3-9.

Kabata-Pendias A., 2004. Soil-plant transfer of trace elements – an environmental issue. Geoderma, 122: 143-149.

Kucharzewski A., Dębowski M., 2000. Reaction and content of microelements in soils of Poland. Zesz. Probl. Post. Nauk Rol., 471: 627-635. (in Polish)

Kuś J., Jończyk K., 1999. The effect of intercrops and the method of its cultivation on crop yielding and content of mineral nitrogen in soil. Rocz. Nauk Rol., ser. A, 114(3-4): 83-95. (in Polish)

Kuś J., Jończyk K., 2000. Regenerating role of intercrops in cereal crop rotation links. Zesz. Probl. Post. Nauk Rol., 470: 59-65. (in Polish)

Łoginow W., 1985. Nowoczesne podstawy nawożenia organicznego. Post. Nauk Rol., 6: 25-37.

Pałys E., Kuraszkiewicz R., Kraska P., 2009. The residual effect of undersown crops and nurse crops on chemical properties of light soil. Ann. UMCS, Sec. E, 4: 81-92. (in Polish)

Parylak D., 1998. Stubble catch crops as regenerative factor in winter triticale monoculture grown on light soil. Zesz. Probl. Post. Nauk Rol., 460: 709-718. (in Polish)

Parylak D., Wojciechowski W., Tendziagolska E., 2002. Changes in physical and chemical properties of soil in winter triticale monoculture as a result of varying pre-sowing tillage. Pam. Puł., 130: 541-548. (in Polish)

Rasmussen K. J., 1999. Impact of ploughless soil tillage on yield and soil quality: A Scandinavian reviev. Soil Till. Res., 53: 3-14.

Strączyńska S., Strączyński S., 2000. Some chemical properties of fallowed and cultivated soils. Zesz. Probl. Post. Nauk Rol., 471: 543-547. (in Polish)

Strączyński S., Wróbel S., 2000. Micronutrient concentration in soils of diverse agronomic categories. Zesz. Probl. Post. Nauk Rol., 471: 549-554. (in Polish)

Weber R., 2010. Soil properties as affected by duration of using no-tillage systems. Post. Nauk Rol., 1: 63-75. (in Polish)

Wróbel S., Nowak-Winiarska K., 2007. Dostępność składników pokarmowych dla roślin w warunkach uproszczeń w uprawie roli. Stud. Rap. IUNG-PIB, 8: 177-192.

Wróbel S., Pabin J., Mickiewicz A., 2007. The effect of reduced soil tillage on nutrient availability in the maize monoculture. Zesz. Probl. Post. Nauk Rol., 520: 791-797. (in Polish)

Zimny L., 1999. Conservation tillage. Post. Nauk Rol., 5: 41-52. (in Polish)

Polish Journal of Agronomy
2011, 4, 12–15

Phosphatases activity and plant available phosphorus in soil under winter wheat (*Triticum aestivum* L.) fertilized minerally

Joanna Lemanowicz

Department of Biochemistry, Faculty of Agriculture and Biotechnology, University of Technology and Life Sciences in Bydgoszcz, ul. Bernardyńska 6, 85-129 Bydgoszcz, Poland

Abstract. The aim of this study was to determine the effect of mineral fertilization on the activity of alkaline and acid phosphatase and content of available phosphorus in soil under winter wheat cultivation. The first factor of experiment was the fertilization with P, K, Mg, Ca and S in six levels: 1 (P, K, Mg, Ca and S), 2 (K, Mg, Ca and S), 3 (P, Mg, Ca and S), 4 (P, K, Ca and S), 5 (P, K, Mg, Ca), 6 (P, K, Mg, S). Second factor was the nitrogen fertilization in the form of ammonium nitrate (34% N) at doses: 0, 40, 80, 120, 160, 200 kg N ha^{-1}. Soil samples were assayed for the activity of alkaline and acid phosphatase and for the content of available phosphorus by Egner-Riehm method (DL). The lowest content of available phosphorus was found in soil without P fertilization (K, Mg, Ca, and S). In the soil from those treatments, the activity of phosphomonoesterases was the biggest. A low content of available phosphorus in the soil was also obtained in treatments without Mg and Ca application. A significant effect of nitrogen fertilization on the activity of alkaline and acid phosphatase was found. Increasing doses of nitrogen resulted in the increased acid phosphatase activity while contributing to the reduction of alkaline phosphatase activity.

key words: soil, mineral fertilization, available phosphorus, alkaline and acid phosphatases, nitrogen

INTRODUCTION

The ruling by the Minister of Environment (Regulation..., 2002) introduced to the national legislation to bring it in line with the Nitrates Directive (91/676/ EEC), was the first step to reduce the negative impact of agriculture on the environment. Farming practice points to the preference for nitrogen as a primary yielding factor, but an excess of that nutrient causes water pollution by nitrates. In addition to nitrogen, phosphorus is an essential element that causes disturbances in the environment by contributing to eutrophication of water. Therefore, in order to protect surface and groundwater the EU is currently preparing a Phosphates Directive.

An excess of one mineral can cause or exacerbate a shortage of others, even at their optimal content in the soil. This phenomenon is called an ion antagonism. The imbalance between high doses of nitrogen, which is the main yielding element, and an insufficient level of fertilization with other nutrients can lead to soil degradation, and thus to lower yields. The aim of this study was to determine the effect of mineral fertilization with P, K, Mg, Ca and S, and increasing doses of nitrogen on the activity of alkaline and acid phosphatase and on the content of available phosphorus in soil under winter wheat cultivation.

MATERIAL AND METHODS

Samples of soil for the study were taken from a long-term experiment, established by the Department of Plant Nutrition and Fertilization of the Institute of Soil Science and Plant Cultivation in Puławy. The experiment is conducted in the Agricultural Experimental Station in Grabów upon Vistula. Soils on which RZD in Grabów is located are typical luvisols (PN-R-04033, 1998), classified as a very good rye complex. The experiment was conducted in a four-year rotation: winter wheat + intercrop, grain maize, spring barley, winter oilseed rape. The experiment was conducted as a two-factorial one, arranged in a randomized block design in two replications. The first factor was the fertilization with P, K, Mg, Ca and S in six levels: 1 (P, K, Mg, Ca and S), 2 (K, Mg, Ca and S), 3 (P, Mg, Ca and S), 4 (P, K, Ca and S), 5 (P, K, Mg, Ca), 6 (P, K, Mg, S). Second factor was the nitrogen fertilization in the form of ammonium nitrate (34% N) at doses: 0, 40, 80, 120, 160, 200 kg N·ha^{-1}.

Forms of fertilizers were the following: in the treatments with sulfur, phosphorus and potassium fertilizers were applied – single superphosphate and potassium sulphate, in the treatments without sulfur, phosphorus and potassium fertilizers were used, such as triple superphosphate

Corresponding author:
Joanna Lemanowicz
e-mail: jl09@interia.pl
tel. +48 52 3749555

Received 21 October 2010

and high percent potassium salt, in the treatments with Ca and Mg, a dolomite containing 30% CaO and 10% Mg was used, on the plots without Mg – calcium oxide at the amount of 200 kg CaO ha^{-1}, whereas in the cases of Ca absence a magnesium sulphate at 70 kg MgO ha^{-1} was used. The doses of minerals used in the experiment were the following: 80 kg P_2O_5 ha^{-1}, 140 K_2O ha^{-1}, 70 MgO ha^{-1}, and 200 CaO ha^{-1}. The dose of sulfur results from the amount of this component introduced with appropriate doses of P, K, and Mg. Soil samples from under the cultivation of winter wheat were collected twice: in June and October 2008.

In the soil material, the activity of alkaline phosphatase (AlP) and acid phosphatase (AcP) were determined by Tabatabai and Bremner method (1969), bioavailable phosphorus (P_{E-R}) by Egner-Riehm method (DL) (Lityński and Jurkowska, 1976), and pH in 1 M KCl by potentiometry.

The obtained results were subjected to analysis of variance, and the significance of differences between means was verified using Tukey's test at a confidence level of P = 0.05. For the calculation FR-ANALWAR program was used, based on Microsoft Excel.

RESULTS

Mineral fertilization, which was used in the experiment resulted in a slight change in soil exchangeable acidity. PH_{KCl} values ranged between 4.9 and 6.0, depending on fertilization (Table 1). On the basis of the value of pH_{KCl}, the tested soil can be classified as an acidic and slightly acidic.

The content of available phosphorus in the soil in June was an average of 41.3 mg P_{E-R} kg^{-1}, whereas in the soil collected in October it was higher by 33% amounting to 62.3 mg of P_{E-R} kg^{-1} (Fig. 1). Lower content of available phosphorus in the soil in June can be explained by the increased absorbing of this component by winter wheat. In October, when the test crop had already been harvested, there were crop residues remaining in the soil, enriching the soil in this component. According to the criteria contained in the PN-R-04023 (1996), the studied soil belongs to the class III with a medium-high content of P_{E-R}.

The highest content of available phosphorus in the soils from both periods was found in sites with full mineral fertilization (P, K, Mg, Ca, S): 53.1 mg of P_{E-R} kg^{-1} in June and 75.7 mg P_{E-R} kg^{-1} in October (Fig. 1).

In the soil collected from plots without potassium fertilization (P, Mg, Ca, S), the content of available phosphorus was significantly higher (44.7 mg P_{E-R} kg^{-1} in the soil in June, 62.7 mg P_{E-R} kg^{-1} in October) than in soils not fertilized with Mg or Ca. A significant reduction in the P_{E-R} in samples of soil without Ca and Mg fertilization compared to full fertilized treatments was determined. In strongly acidic soil (fertilized with nitrogen at 200 kg N ha^{-1}) the use of liming and fertilization with Mg had a positive effect on the content of available phosphorus (Fig. 1).

A significant decrease was found in the content of available phosphorus in the treatments without sulfur fertilization (treatments P, K, Mg, Ca), collected in June (41.8 mg P_{E-R} kg^{-1}), and in October (72.4 mg P_{E-R} kg^{-1}), in comparison with full mineral fertilized treatments (P, K, Mg, Ca, S) (Fig. 1).

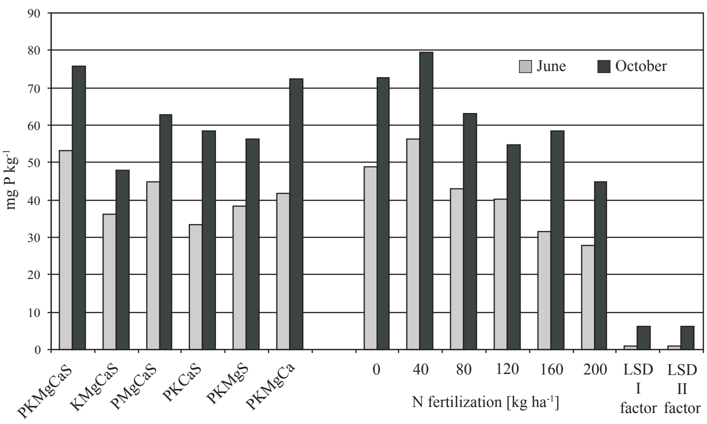


Fig. 1. The content of available phosphorus in the soil depending on fertilization.

Table 1. Exchangeable acidity of investigated lessive soil as depended on differentiated mineral fertilization (P, K, Mg, Ca, and S) and increasing nitrogen doses.

Nitrogen [kg ha^{-1}]	Mineral fertilization					
	P K Mg Ca S	K Mg Ca S	P Mg Ca S	P K Ca S	P K Mg S	P K Mg Ca
0	5.8	5.9	5.9	5.7	5.6	6.0
40	5.8	5.9	5.9	5.7	5.5	5.9
80	5.7	5.8	5.8	5.6	5.5	5.9
120	5.8	5.8	5.8	5.5	5.3	5.9
160	5.4	5.9	5.8	5.5	5.2	5.8
200	5.2	5.7	5.7	5.4	4.9	5.7

Table 2. The activity of alkaline and acid phosphatases and the ratio of alkaline to acid phosphatase AlP: ACP of investigated lessive soil as affected by differentiated mineral fertilization (P, K, Mg, Ca, and S) and increasing nitrogen doses.

Description		Alkaline phosphatase [mM pNP kg^{-1} h^{-1}]		Acid phosphatase [mM pNP kg^{-1} h^{-1}]		AlP:AcP	
		June	October	June	October	June	October
Mineral fertilization I factor	P K Mg Ca S	0.811	0.790	1.312	1.512	0.62	0.52
	K Mg Ca S	0.936	0.933	1.742	1.874	0.54	0.50
	P Mg Ca S	0.874	0.856	1.489	1.494	0.59	0.57
	P K Ca S	0.803	0.891	1.478	1.821	0.54	0.49
	P K Mg S	0.784	0.869	1.262	1.845	0.62	0.47
	P K Mg Ca	0.695	0.786	1.229	1.337	0.57	0.59
Nitrogen [kg ha^{-1}] II factor	0	0.927	0.962	1.102	1.377	0.84	0.70
	40	0.868	0.909	1.176	1.488	0.74	0.61
	80	0.832	0.881	1.364	1.583	0.61	0.56
	120	0.801	0.843	1.482	1.662	0.54	0.51
	160	0.759	0.793	1.597	1.780	0.48	0.45
	200	0.715	0.739	1.790	2.031	0.40	0.36
Mean		0.817	0.854	1.419	1.654	0.58	0.52
LSD (0.05)	I factor	0.016	0.014	0.148	0.025		
	II factor	0.016	0.014	0.148	0.025		
Interaction	I/II	0.039	0.034	0.363	0.061		
	II/I	0.039	0.034	0.363	0.061		

Acid phosphatase activity was significantly the greatest in the soil sampled in June (1.742 mM pNP kg^{-1} h^{-1}) and in October (1.874 mM pNP kg^{-1} h^{-1}) from the treatments not fertilized with P (K, Mg, Ca, S) (Table 2). In the soil without Ca fertilization, a lower alkaline phosphatase activity (0.784 mM pNP kg^{-1} h^{-1} in June) was found. The greatest activity of alkaline phosphatase was obtained in the soil not fertilized with nitrogen (0.927 mM pNP kg^{-1} h^{-1} in June and 0.962 mM pNP kg^{-1} h^{-1} in October).

The use of the highest dose of nitrogen (200 kg N ha^{-1}) resulted in a significant increase in acid phosphatase activity by 35% compared to soil not fertilized with N.

On the basis of alkaline phosphatase and acid phosphatase activity, a value of AlP:AcP ratio was calculated, known as an enzyme pH indicator (Dick et al., 2000). The value of AlP:AcP ratio was 0.36–0.84 during the study period. As optimum for plant growth and development, a soil pH can be regarded at which the correct ratio of AlP:AcP activities occurs (Dick et al., 2000). Ratio of AlP:AcP lower than 0.50 indicates an acidic soil where liming is recommended. The smallest ratio of the AlP:AcP was obtained in the soil taken from the treatments not fertilized with Ca (AlP:AcP = 0.47) and Mg (AlP:AcP = 0.49) as well as from those fertilized with the highest dose of nitrogen (200 kg N ha^{-1} – AlP:AcP = 0.36). An enzyme pH indicator can be used as an alternative method to determine pH of soil and changes occurring in it.

DISCUSSION

The research made it possible to assess the impact of fertilization on the mineral content of available phosphorus for plants and the activity of alkaline and acid phosphatase and in the soil under winter wheat.

According to Felczyński (2005) sulphate ions from the potassium fertilization cause precipitation of larger amounts of aluminium, and ultimately, the released Al binds phosphorus in aluminium phosphates unavailable for plants. Therefore, in soils where no fertilizer was applied, there was an increase of phosphorus available to plants. Potassium fertilization, through the influence on the increase of concentration of H^+ (the disclosure of exchangeable and physiological acidity) may indirectly affect changes in the bioavailability of nutrients (Skowrońska, Filipek, 2009).

Changes in the physicochemical and biological properties of soils occur under the influence of liming. Sorption capacity increases, as well as buffering and resistance to degradation, mineralization of organic matter is accelerated, thereby increasing absorption of phosphorus by plants (Skowrońska, Filipek, 2009). According to Bednarek and Reszka (2007), lack of liming increases the concentration of soluble and exchangeable Fe and Al, which may react with phosphorus, which leads consequently to the formation of poorly soluble phosphates of aluminium and iron in the soil. Filipek and Skowrońska (2009) state that oxidation of sulfur in the soil causes an increase in the concentration of H + ions, thereby reducing the supply of available phosphorus. Skwierawska and Zawartka (2009a) reported that in the 0–40 cm soil layer a sulfur dose of S-SO_4 and S-S^0 of 120 kg S ha^{-1} reduced the soil pH. Skwierawska and Zawartka (2009b) also said that only a dose of 120 kg ha^{-1} S-SO_4 affect the mobilization and migration of phosphorus in the soil. Sulfur deficiency in the soil can limit the uptake of basic nutrients, including phosphorus, by plants.

Smaller supply of sulfur reduces the uptake of phosphorus by plants, and as a result the soil not fertilized with sulfur shows a high supply of available forms of phosphorus.

The answer to the shortage of available phosphorus in soil is the phosphatase biosynthesis by both plant roots and micro-organisms. Therefore, the activity of those enzymes is largely related to the concentration of soil phosphorus (Heflik et al., 2007, Żebrowska et al., 2008). Typically, soil phosphatase activity is inversely proportional to the amount of mineral phosphorus in the soil, because low levels of inorganic phosphorus in the soil increased activity of phosphatases (Kieliszewska-Rokicka, 2001). A significant effect of nitrogen fertilization on the activity of both alkaline and acid phosphatase in the soil was found. Increasing the nitrogen dose resulted in decreased activity of AlP, while the activity of acid phosphatase increased. Higher acid phosphatase activity can be explained by the fact that phosphomonoesterases are the enzymes most sensitive to changes in soil pH. Optimum soil pH for alkaline phosphatase activity is 9.0–11.0, and 4.0–6.5 for the acid phosphatase (Dick, Tabatabai, 1984; Wittmann et al., 2004). Kucharski (1997) points out that increasing doses of nitrogen to 240 kg N ha^{-1} consistently heightened the activity of acid phosphatase in the soil while reducing the activity of AlP. According to Fukuda et al. (2001) plants usually secrete acid phosphatase in the soil when the supply of available phosphorus is low.

CONCLUSIONS

1. Nitrogen at a dose higher than 40 kg $N \cdot kg^{-1}$ caused a reduction in available phosphorus content in the tested soils, particularly in objects not fertilized with phosphorus. Lack of mineral fertilization with phosphorus and the use of high doses of nitrogen can lead to depletion of the soil in this nutrient.
2. Lack of phosphorus fertilizer increased the activity of both alkaline and acid phosphatase in the studied soil.
3. No liming and Mg fertilization resulted in a significant reduction in available phosphorus in the soil, as well as in alkaline phosphatase activity, while increasing the activity of acid phosphatase.
4. No sulfur fertilization affected the increase in the content of available phosphorus in the soil. The decrease in the activity of both studied enzymes was determined at these objects.

REFERENCES

Bednarek W., Reszka R., 2007. The effect of liming and fertilization with various nitrogen forms on the content of available forms and mineral fractions of phosphorus in the soil. Ann. UMCS, 62(2): 234-242. (in Polish)

Dick W.A., Cheng L., Wang P., 2000. Soil acid alkaline phosphatase activity as pH adjustment indicators. Soil Biol. Biochem., 32: 1915-1919.

Dick W.A., Tabatabai M.A., 1984. Kinetic parameters of phosphatases in soils and organic waste materials. Soil Sci., 137: 7-15.

Felczyński K., 2005. The effect of long-term organic and mineral fertilization on yielding of snab bean and sweet corn and NPK content in soil. Fragm. Agron., 1(85): 37-48.

Filipek T., Skowrońska M., 2009. Optimization of soil reaction and nutrient management in Polish agriculture. Post. Nauk Rol., 1: 25-37. (in Polish)

Fukuda T., Osaki M., Shinano T., Wasaki J., 2001. Cloning and characterization of two secreted acid phosphatases from rice call, Plant nutrition: Food security and sustainability of agro-ecosystems through basic and applied research. Kluwer Academic, pp. 34-35.

Heflik M., Kandziora M., Nadgórska-Socha A., Ciepał R., 2007. Aktywność kwaśnych fosfataz u roślin występujących na terenach o podwyższonej zawartości metali ciężkich. Ochr. Środ. Zas. Nat., 32: 151-154.

Kieliszewska-Rokicka B., 2001. Enzymy glebowe i ich znaczenie w badaniach aktywności mikrobiologicznej gleby. In: Drobnoustroje środowiska glebowego; ed.: H. Dahm, A. Pokojska-Burdziej, Toruń, pp. 37-47.

Kucharski J., 1997. Relacje między aktywnością enzymów a żyznością gleby. In: Drobnoustroje w środowisku, występowanie, aktywność i znaczenie, AR Kraków, pp. 327-347.

Lityński T., Jurkowska H. Gorlach E., 1976. Analiza chemiczno-rolnicza. PWN, Warszawa, 149 pp.

PN-R-04023. 1996. Analiza chemiczno-rolnicza gleby – Oznaczanie zawartości przyswajalnego fosforu w glebach mineralnych. Warszawa, Polski Komitet Normalizacji.

PN-R-04033. 1998. Gleby i utwory mineralne. Podział na frakcje i grupy granulometryczne. Polski Komitet Normalizacji.

Rozporządzenie Ministra Środowiska z dnia 23.12.2002 r. w sprawie szczegółowych wymagań jakim powinny odpowiadać programy działań mających na celu ograniczenie odpływu azotu ze źródeł rolniczych. Dz.U. 2003 nr 4 poz. 44.

Skowrońska M., Filipek T., 2009. Akumulacja azotu i fosforu przez kukurydzę pod wpływem organicznego nawożenia potasem. Proc. ECopole, 3(1): 109-112.

Skwierawska M., Zawartka L., 2009a. Soil acidity and crop yield changes under the influence of sulphur fertilization. Zesz. Probl. Post. Nauk Rol., 538: 221-229.

Skwierawska M., Zawartka L., 2009b. Effect of different rates and forms of sulphur on content of available phosphorus in soil. J. Elementol., 14(4): 795-803.

Tabatabai M.A., Bremner J.M., 1969. Use of p-nitrophenol phosphate for assay of soil phosphatase activity. Soil Biol. Biochem., 1: 301-307.

Wittmann Ch., Kähkönen M.A., Ilvesniemi H., Kurola J., Salkinoja-Salonen M.S., 2004. Areal activities and stratification of hydrolytic enzymes involved in the biochemical cycles of carbon, nitrogen, sulphur and phosphorus in podsolized boreal forest soils. Soil. Biol. Biochem., 36: 425-433.

Żebrowska E., Antkowiak A., Ciereszko I., 2008. Acid phosphatases activity and growth of two triticale cultivars underphosphate deficiency. Zesz. Probl. Post. Nauk Rol., 524: 273-279.

Polish Journal of Agronomy
2011, 4, 16–22

Effect of rainfall amount and distribution on growth, development and yields of determinate and indeterminate cultivars of blue lupin

[1]*Janusz Podleśny*, [2]*Anna Podleśna*

[1]Department of Forage Crop Production, [2]Department of Plant Nutrition and Fertilization
Institute of Soil Science and Plant Cultivation – National Research Institute
ul. Czartoryskich 8, 24-100 Puławy, Poland

Abstract. The experiment was run at the Agricultural Experiment Farm, Grabów, operated by the Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy in the years 2005–2007. The study comprised blue lupin varieties: cv. Graf, cv. Zeus (indeterminate type), cv. Sonet, cv. Boruta (determinate type). The experiment was arranged as a split-plot-split-block design with four replications and set up on a good wheat complex soil rated as crop production class IIIa. Amount and distribution of rainfall in each year had a large impact on morphological characters of blue lupin. Shortage of rain in the period of spring and summer negatively affected plant height and restricted leaf area. Yields were to the largest extent dependent on the amount of rainfall in June, i.e. in the blooming period of the plant. Decrease in yield observed in years in which the weather was unfavourable to the production of blue lupin was due to reduced values of yield components, including, first of all, number of pods per plant and number of seeds per plant since the 1000-seed weight was not altered significantly. The indeterminate cultivars, Graf and Zeus, turned out to be less sensitive to periodical shortages of water in soil in comparison to the determinate cultivars Sonet and Boruta.

key words: blue lupin, determinate cultivar, indeterminate cultivar, rainfall requirements, weather pattern, growth and development, yields

INTRODUCTION

Shortage of rainfall is one of the major factors that restrict the yields of legumes, especially in the so-called critical period i.e. at blooming and pod setting (Jasińska, Kotecki, 1993). If occurring in that period the drought causes substantial reduction of yield and yield components (Costa-Franca et al., 2000; Podleśny and Kocoń, 2006; Barrios et al., 2005; Baigorri et al., 1999; Xia, 1997). It is a common opinion that large year-to-year variation (COBORU 2008) is one of the reasons behind little interest that farmers show in the production of that crop. Given the situation, it seems to be advisable to look for genotypes that resist drought stress. The problem has been gaining in importance recently as climatic changes are bringing about more and more frequently long drought spells in the months of spring and summer (Łabędzki and Leśny, 2008). Owing to advances in crop improvement determinate cultivars of blue lupin with altered morphology and with growth and development pattern different from that in conventional varieties have been developed (Prusiński, 2007; Martyniak, 1997). Preliminary studies have shown that determinate varieties of some legumes are poorer yielders and are more sensitive to water deficit (Podleśny, 2001; Podleśny and Kocoń, 2006; Grzesiak et al., 1997; Podleśny, 2001; Podleśny and Podleśna, 2003) as well as to high temperatures at blooming (Jansen, 2008; Podleśny and Podleśna, 2010a) than indeterminate varieties. At the same time, they give a smaller biomass yield which may be linked to a lower requirement for water during growth (Podleśny and Podleśna, 2010b) related to lower transpiration.

The objective of this study was to determine the effect of shortage and uneven distribution of rainfall on yield and yield variability in different genotypes of blue lupin.

METHODS

The results for this study were derived from field experiments conducted in the years 2005–2007 at the Agricultural Experiment Farm, Grabów, operated by the Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy. Each year the experiment plots were seeded to the same blue lupin cultivars: Graf and Zeus (indeterminate type) and Sonet and Boruta (determinate type). Plot area at harvest was 32 m^2. Lupin seeds were dressed with Sarfun T 450 FS (carbendazim, thiuram) and drilled using the Amazone drill to a depth of 2–3 cm at a density of 100 plants/m^2. The experiment was arranged

Corresponding author:
Janusz Podleśny
e-mail: jp@iung.pulawy.pl
tel. +48 81 8863421 ext. 355

Received 17 June 2010

as a split-plot-split-block design with four replications and set up on a good wheat complex soil rated as crop production class IIIa. After seeding the plots were harrowed to cover the seeds and to level the surface of the field. The weeds were controlled by applying Afalon Dyspersyjny 450 SC (linuron) to the soil at a rate of 1.5 kg·ha^{-1}. In the period of blooming and pod setting the crop was protected against fungal diseases, mainly anthracnose, by spraying twice with Rovral Flo 255 SC (iprodione) at a rate of 1.5 l·ha^{-1}. Pre-plant fertilizers were applied at following rates: P – 30 and K – 50. During growth detailed observations were made of plant growth and development, plants were scored for incidence and severity of pests and diseases, and records were taken of the dates of major phenological stages: emergence, 2–3-leaf stage, 5–6-leaf stage, blooming, seed setting, seed filling, ripeness. Plant losses during growth were assessed by counting the number of plants after emergence and at harvest on an area of 1 m^2. In addition, on 10 plants picked at random measurements were made of stalk length, leaf area and dry weight of the aerial parts. Prior to harvest plant height was measured and after harvest the crop was analysed for yields and yield components: number of pods and number of seeds per plant, weight of seeds per plant and moisture content of seeds. Lupine seeds were harvested with plot combine "Seedmaster". In order to assess the effect of weather conditions on seed yield Selianinov's index, also called the water supply coefficient or the arbitrary moisture balance, was used (Radomski, 1977). The index is defined as the ratio of the total precipitation to the sum of daily air temperatures in a given period $K=10P/\Sigma t$, where P is total precipitation and Σt is a sum of mean daily air temperatures. The hydrothermal Selianinov's index is used to asses the duration and intensity of drought in its agro-climatic sense. Dry period is defined as a period in which K is lower than 1.0 and extreme dry period (drought) in which K is lower than 0.5.

The results were analyzed by ANOVA and Tukey's confidence half-interval was used to separate the means. If there were no significant differences for the analysed trait among the varieties of a given type, means for a given group of varieties were compared.

RESULTS AND DISCUSSION

The pattern of weather conditions in the study years modified the emergence, growth and development as well as the yields of blue lupin. From literature data it follows that the factor that influences crop yields is more water-related than thermal (Bombik et al., 1997; Michalska, 1998). Therefore, considerations on how weather conditions influenced those characteristics were based primarily on the analysis of the amount and distribution of precipitation over decades and on the value of Selianinov's hydrothermal index (Radomski, 1977). In the years 2005 and 2007 there was little rainfall in March and April which made it possible to start working the soil early and to sow the seeds at the beginning of April. Contrastingly, in the analogous period of 2006 rainfall was abundant and sowing was possible only in the second half of April. Seeds sown in 2006 germinated quickly since a large amount of rainfall was recorded in April (Table 1) resulting in even emergence that occurred as early as 8–10 days after sowing. In the years 2005 and 2007, though, the precipitation in April was almost three times lower than in 2006 and, consequently, emergence came about 16 days after sowing. Abundant rainfall in the sowing-emergence period of 2006 as contrasted with substantial shortages in 2005 and 2007 is also reflected by Selianinov's index values: 0.40 and 0.53, respectively (Table 2).

In each study year, plant density obtained was similar to that projected. Population density before harvest was much lower than that found after emergence as the stand progressively thinned due to competition for water, light and nutrients. Plant losses varied considerably from year to year.

The years 2005 and 2006 were characterized by substantial rainfall shortages, especially in the periods from emergence to the 2-leaf stage and from full blooming to onset of ripening, with Selianinov's index below 0.5. Under those conditions plant losses in the stands of indeterminate lupin varieties were larger by 7.5 and 10.5 percentage points and those of determinate varieties by 7.0 and 4.4 percentage points than those recorded in 2007, respectively. Due to

Table 1. Decade sums of rainfalls through the growth period of blue lupin (mm).

Month	Years												Rainfall demands[#]
	2005				2006				2007				
	decades of month												
	I	II	III	Σ	I	II	III	Σ	I	II	III	Σ	
April	3.2	0.1	6.9	10.2	19.7	7.8	2.6	30.1	8.9	2.0	2.4	13.3	32.6
May	56.5	27.2	0.3	84.0	10.3	27.9	15.2	53.4	20.9	28.9	24.8	74.6	62.9
June	16.4	10.6	1.3	28.3	22.2	0.1	15.9	38.2	76.6	11.7	11.6	99.9	80.6
July	42.0	29.5	61.3	132.8	0.0	7.6	2.4	10.0	45.8	25.7	4.0	75.5	46.9
Total				273.3				131.7				263.3	223.0

[#] according to Dzieżyc (1989)

Table 2. Value of Sielianinov's hydrothermal index at different periods of growth and development of lupin.

Developmental stage of lupin	Years		
	2005	2006	2007
Sowing (BBCH-00) – emergence (BBCH-10)	0.40	0.89	0.53
Emergence (BBCH-10) – 2 leaves unfolded (BBCH-12)	0.32	0.10	1.08
2 leaves unfolded (BBCH-12) – 5 leaves unfolded (BBCH-15)	1.34	0.37	0.68
5 leaves unfolded (BBCH-15) – Flower buds present, still enclosed by leaves (BBCH-50)	0.71	1.60	1.41
Flower buds present, still enclosed by leaves (BBCH-50) – Full flowering (BBCH-65)	0.65	0.60	2.34
Full flowering (BBCH-65) – Beginning of ripening (BBCH-80)	0.20	0.14	1.14
Beginning of ripening (BBCH-80) – Fully ripe (BBCH-89)	1.61	0.53	0.39

a stouter morphology resulting in more mutual shading by plants, indeterminate cultivars Graf i Zeus showed more plant losses than their determinate counterparts Sonet and Boruta (Table 3).

When compared with the data on the demand for water by lupin obtained by Dzieżyc (1989) results from this study indicate that in none of the months of 2006 was there enough rainfall to obtain an optimum yield of seeds. By contrast, in 2007 the amount of rainfall was sufficient to meet the requirement of lupin for rainfall water almost throughout the growing season. It is only in April that a substantial shortage was recorded. Along with the amount, also the even distribution of rainfall is essential for plant growth. The year 2005 stood out in this respect as long-lasting periods of soil water deficit alternated with two periods of very abundant rainfall.

The pattern of weather conditions also affected the development of the morphological features of lupin plants. To name a few, clear differences were found for plant height and for leaf area (Table 4). In 2005 and 2006, due to rainfall shortage in June the plants of indeterminate varieties were shorter at blooming by 27.9 and 31.2%, respectively, than in 2007, the latter year being characterized by fairly abundant rainfall in that period; for the determinate varieties the respective values were 38.0 and 32.0%. In all study years the plants of indeterminate lupin varieties, Zeus and

Table 3. Plant density and plant losses during growth.

Years	Varieties					
	indeterminate			determinate		
	number of plants per 1 m^2		losses [%]	number of plants per 1 m^2		losses [%]
	after emergence	before harvest		after emergence	before harvest	
2005	78.6 a#	58.4 a	25.7 b	94.2 b	79.1 b	16.0 c
2006	84.3 b	60.1 b	28.7 b	88.1 a	76.3 a	13.4 b
2007	88.4 b	72.3 b	18.2 a	86.7 a	78.9 b	9.0 a
Mean	83.8	63.6	24.2	89.7	78.1	12.8

Values marked with the same letters do not differ significantly.

Table 4. Values of some morphological features of blue lupin in flowering period.

Years	Varieties					
	indeterminate			determinate		
	height of plants [m]		leaf area in flowering period [(m^2 plant^{-1})·10^{-2}]	height of plants [m]		leaf area in flowering period [(m^2 plant^{-1})·10^{-2}]
	flowering	before harvest		flowering	before harvest	
2005	0.44 a#	0.49 a	0.36 a	0.31 a	0.35 a	0.25 a
2006	0.42 a	0.47 a	0.35 a	0.34 a	0.34 a	0.27 a
2007	0.61 b	0.67 b	0.50 b	0.50 b	0.54 b	0.46 b
Mean	0.49	0.54	0.40	0.38	0.41	0.33

Values marked with the same letters do not differ significantly.

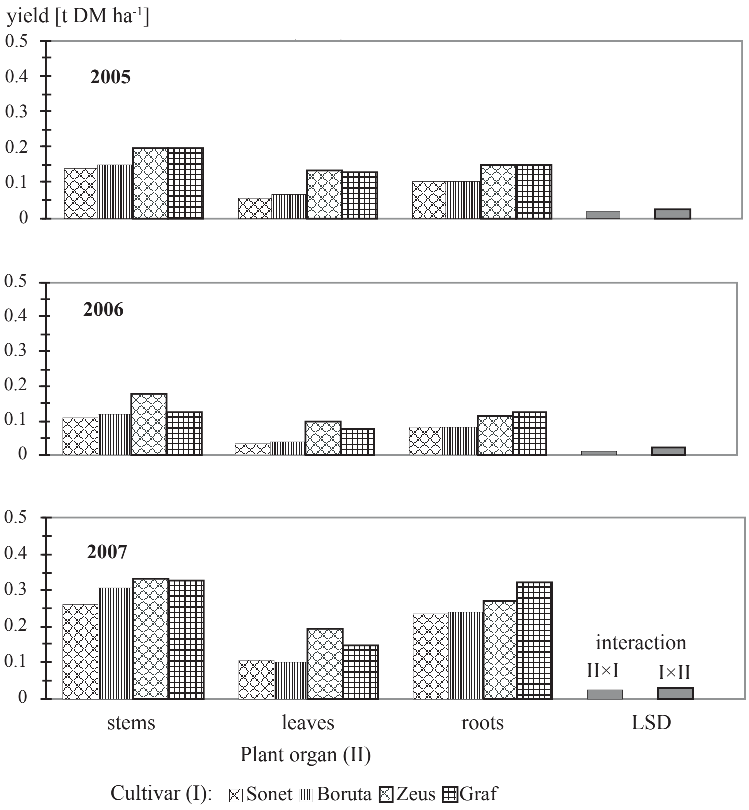


Fig. 1. Yield of dry matter of vegetative organs of lupin in flowering period.

Graf, were decisively taller than those of the determinate Sonet and Boruta. The height of the determinate varieties was more severely depressed by rainfall shortage than was that of indeterminate varieties. Likewise, weather conditions modified leaf area in lupin plants. In the year 2007, advantageous for the production of that crop, the leaf area of the indeterminate lupin varieties was larger than it was in 2005 and 2006 by 38.9 and 42.9, respectively. For the determinate varieties the respective values were 84.0 and 70.4%. Throughout the study, the indeterminate lupin varieties developed a larger leaf area than did the determinate varieties. In the ripening period, leaf area diminished due to withering and shedding of leaves, the process proceeding most rapidly in 2006. In that year a substantial shortage of rain occurred in July coinciding with plant ripening. According to Herz et al. (1992) shortage of water in the soil causes a decline in the leaf area of horse bean through restriction of the leaf number and size and through accelerated leaf ageing. Decrease in leaf area caused by deficit of water in the soil was also found by Barrios et al. (2005) for another legume – bean. In addition, those authors demonstrated that soil water deficit while bringing down the area of leaves on the lateral shoots by 60.1% reduces the leaf area of the main stalk by only 10.4%.

Weather conditions had a substantial impact on the rate at which yield was produced by individual organs of blue lupin (Fig. 1). In the initial period of growth and development no clear difference was found among the studied varieties for dry matter yield. Throughout the study, in the period from blooming to full ripeness the indeterminate varieties of blue lupin gave higher dry matter yield than did the varieties of determinate growth type. It was due to differences in plant morphology. Likewise, the effect of weather conditions on matter accumulation became manifest only in the later stages of plant development as the plants reached a fairly large size and started to compete mainly for water, light and nutrients. The plants of all lupin varieties produced the highest mass of vegetative organs in 2007, the year in which weather conditions favoured the crop, the lowest mass was produced in 2006 when water was in short supply throughout the growing season. It is noteworthy that the highest yield of vegetative organs was obtained in the years in which the yield of generative organs was also the highest (Table 5). This fails to confirm the generally known notion that excessively abundant growth of the vegetative mass restricts the yield of seeds (Jasińska and Kotecki, 1993). In all probability, such a relationship is valid for old-line lupin varieties which used to develop a much greater vegetative mass than do new cultivars. In all study years, in the blooming period the indeterminate varieties were found to have a greater weight of stalks, leaves and roots than the determinate varieties.

Over the study period, weather conditions affected substantially the length of the growth period in lupin. From among the three years, the longest growth period, 127 days, was recorded in 2007, the year in which rainfall was more abundant and, first of all, more evenly distributed than in the remaining two years. In the years 2005 and 2006 the growth period for lupin was 116 and 94 days, respectively. In 2005, the considerable rainfall shortage in the months of spring and summer notwithstanding, there were abundant rains in the first decade of July which lengthened the growth period of lupin markedly, the respective figures for cvs. Sonet, Boruta, Zeus and Graf being 110, 115, 117 and 118 days. For comparison, in 2006 the duration of growth for those varieties was 88, 90, 97 and 93 days, respectively. Rainfall shortages occurring in 2005 and 2006 caused the differences between the indeterminate vs. determinate varieties to diminish. In 2007 the difference was 12 days whereas in 2005 and 2006 they were 5 and 6 days, respectively.

Amount and distribution of rainfall produced a large impact on the seed yield of lupin (Table 5). The highest seed yields were obtained in 2007 in which the value of Selianinov's index at the most important growth and development stages was above 1 and the amount and distribution of rainfall approximated the values considered by Dzieżyc (1989) as optimal for that species. Even distribution of rainfall as essential for lupin seed yields is testified by the comparison of yields in 2005 against those in 2007. The total rainfall in lupin's growth period was similar for both years and was much in excess of the requirements for that species. This notwithstanding, the seed yields in 2005 were nearly 25% of those in 2007.

Table 5. Seed yield of blue lupin (t ha^{-1}).

Years	Varieties			
	indeterminate		determinate	
	Zeus	Graf	Sonet	Boruta
2005	2.86 a	2.83 a	2.12 a	2.28 a
2006	2.77 a	2.75 a	2.00 a	2.24 a
2007	3.45 b	3.58 b	3.17 b	3.24 b
Mean	3.03	3.05	2.43	2.59

Values marked with the same letters do not differ significantly.

On the other hand, weather conditions in the years 2005–2006 did not favour the production of that crop as there was a shortage of rainfall in April and June as well as in July of 2006 which negatively affected growth, development and yields of lupin. By having analyzed the effect of weather conditions on seed yields of lupin it can be stated that they were to the largest extent dependent on the amount of rainfall in June and July or in the period of blooming and pod setting. In spite of a substantial rainfall shortage in June of 2005, abundant rains occurred in July which allowed the seed yields to be higher than those in 2006 which was characterized by rainfall shortage throughout the growth season of lupin. Those findings are borne out by the study of Podleśny and Kocoń (2006) in which was shown that faba bean has a very high sensitivity to insufficient water in the period of blooming and pod setting. An earlier study by Demidowicz (1990) shows that faba bean has the greatest requirement for water also in June that is when the plants are in bloom and when they set pods. Critical periods of availability of water for lupin and faba bean are similar to those for other crops. It follows from the studies of Radzka et al. (2008) and Siuta (1999) that the amounts of rainfall in May and June are also essential for the yield of cereal crops.

Throughout the study years, in terms of yields, the indeterminate cultivars Graf and Zeus outperformed the determinate cultivars Sonet and Boruta by 33.3% (Table 5). In the year 2007 recognized as beneficial for lupin, the seed yield of the indeterminate varieties was higher by 25.4% and that of determinate varieties by 48.2% than the respective yields in 2005–2006, when the conditions were not propitious for lupin. It may testify to a lower sensitivity to drought shown by indeterminate varieties compared to those with determinate growth type. Similar observations were made in earlier studies with white lupin (Podleśny and Podleśna, 2003) and with faba bean (Podleśny, 2001; Podleśny and Kocoń, 2006) performed in a wire-net protected plant growth facility. However, that finding does not apply to all lupin species as it appears from the study of Pszczółkowska (2003) in which different yellow lupin varieties responded with a similar yield decrease to water shortages in the soil. By contrast, Bieniaszewski et al. (2003) demonstrated that some determinate varieties of yellow lupin are more drought-resistant than indeterminate varieties.

Yield reduction observed in the years in which weather conditions were not propitious for lupin was caused by reduced values of yield components, primarily of number of pods per plant and number of seeds per plant since 1000-seed weight was not altered significantly (Table 6). It is corroborated by the study of Pszczółkowska et al. (2003) concerned with the response of yellow lupin to drought in which was shown that water deficit in soil significantly restricts number of seeds per plant but does not change weight of 1000 seeds.

Table 6. Values of some features of lupin yield structure.

Years	Variety					
	indeterminate			determinate		
	number of pods per plant	number of seeds per plant	weight of 1000 seeds (g)	number of pods per plant	number of seeds per plant	weight of 1000 seeds (g)
2005	10.0 a	38.9 a	150 b	7.7 b	30.2 a	150 a
2006	8.0 b	30.0 b	146 a	6.6 a	27.6 b	156 a
2007	15.1 c	58.1 c	146 a	13.5 c	52.8 c	158 a
Mean	11.03	42.3	147.3	9.27	36.9	154.7

Values marked with the same letters do not differ significantly.

Indeterminate lupin varieties, regardless of whether they grew in favourable or non-favourable conditions in terms of rainfall amount, set more pods and yielded more seeds from a plant than did determinate varieties. The reduction in the number of seeds per plant brought about by unfavourable weather conditions in 2006 as opposed to those in 2007 in which the highest seed yields were obtained, was 33.0 and 42.9% for indeterminate and determinate varieties, respectively. The number of pods produced by a single plant of an indeterminate variety in 2007 was higher by 51.0% than that in 2005 and higher by 88.7% than that in 2006. For the determinate varieties, the respective figures were 75.3 i 104.5%.

The studies of Sammler et al. (1982) and of Grzesiak et al. (1989) give evidence that in the periods of drought the legumes may shed flowers or even pods the effect of which is a reduced seed yield. From other studies, it appears that drought occurring during the growth of legumes may result in a reduction of the number of pods per plant by 65% (Mwanamwenge et al., 1999) an in a decrease of seed yield of as much as 70% (Lopez et al., 1996).

CONCLUSIONS

1. Amount and distribution of rainfall have a strong impact on the development of morphological characteristics in lupin. Shortage or uneven distribution of rainfall events in the period of spring and summer depress plant height and decrease leaf area.
2. Both lupin genotypes develop the greatest mass of vegetative organs under weather conditions which favour the production of lupin; the smallest mass is produced in years characterized by rainfall shortage throughout the growing season.
3. Seed yields of lupin were dependent to the largest extent on the amount of rainfall in June and July i.e. in the periods of blooming and pod setting
4. Reduction of seed yield in the years with weather conditions that did not promote lupin production was caused by the reduction in the values of yield components, primarily of the number of pods per plant and the number of seeds per plant as the weight of 1000 seeds was not altered significantly.
5. The lupin varieties in the study varied for their sensitivity, in terms of seed yield, to the pattern of weather conditions. The indeterminate lupin varieties Graf and Zeus responded with a smaller yield decrease to periodical soil water deficits than did the determinate varieties Sonet and Boruta

LITERATURE

Baigorri H., Antolini M.C., Sanchez-Diaz M., 1999. Reproductive response of two morphological different pea cultivars to drought. Eur. J. Agron., 10: 119-128.

Barrios A.N., Gerrit Hoogenboom G., Nesmith D.S. 2005. Drought stress and the distribution of vegetative and reproductive traits of a bean cultivar. Sci. Agric., 62(1): 18-22.

Bieniaszewski T., Fordoński G., Kurowski T., Szwejkowski Z., 2003. Influence of soil moisture on the growth and development of traditional and epigonal cultivars of yellow lupin. I. Influence of soil moisture on the growth, development, yield and health of plants. Zesz. Probl. Post. Nauk Rol., 495: 95-106. (in Polish)

Bombik A., Jankowska J., Starczewski J., 1997. Effect of meteorological factors on yielding of cereals under the production conditions. Zesz. Nauk. AR Wrocław, 313: 27-36. (in Polish)

COBORU. 2008. Polish National List of Agricultural Plant Varieties. Słupia Wielka, pp. 99-110. (in Polish)

Costa-Franca, M.G., Thi, A.T., Pimentel C., Pereyra R.O., Zuily-Fodil Y., Laffray D., 2000. Differences in growth and water relations among *Phaseolus vulgaris* cultivars in response to induced drought stress. Environ. Experiment Bot., 43: 227-237.

Demidowicz G., 1990. The effect of weather conditions on the yields of faba bean cv. Nadwiślański Pam. Puł., 97: 159-170. (in Polish).

Dzieżyc J., 1989. Potrzeby wodne roślin uprawnych. PWN Warszawa, 419 pp.

Grzesiak S., Filek W., Kościelniak F., Augustyniak G. 1989. The effect of soil drought at different stages of faba bean development (*Vicia faba* L. *minor*) on hydration and photosynthesis of leaves and production of dry matter and seed yield. In: Natural and agronomic conditions of legume seed production. IUNG Puławy, Part II: 92-98. (in Polish)

Herz P., Struzel H., Aufhamer W., 1992. Adaptation of faba beans (*Vicia faba* L.) to water stress. Proc. 2nd ESA Congress, Warwick Univ., Great Britain, 86-87.

Jasińska Z., Kotecki A., 1993. Rośliny strączkowe. PWN Warszawa, pp. 97-99.

Jansen G., 2008. Effects of temperature on yield and protein content of *Lupinus angustifolius* cultivars. In: Lupins for Health and Wealth. International Lupin Association, New Zealand, 153-158.

Lopez, F.B., Johansen, C., Chauhan, Y.S., 1996. Effect of timing of drought stress on phenology, yield and yield components of a short-duration pigeon pea. J. Agron. Crop Sci., 177: 311-320.

Łabędzki L., Leśny J., 2008. Results of droughts in agriculture – present and predicted owing to global climatic changes. Wiad. Melior. Łąk., 1: 7-9. (in Polish)

Martyniak J., 1997. Biological progress in leguminous crops during economic transformation in Poland. Zesz. Probl. Post. Nauk Rol., 446: 33-41. (in Polish)

Michalska B., 1998. Yields of faba bean as affected by weather conditions at the Przelewice Experiment Station. Pam. Puł., 92, 147-161. (in Polish).

Mwanamwenge J., Loss S.P., Siddique K.H.M., Cocks P.S., 1999. Effect of water stress during floral initiation, flowering and podding on the growth and yield of faba bean (*Vicia faba* L.). Eur. J. Agron., 11: 1-11.

Podleśny J., 2001. The effect of drought on the development and yielding of two different varieties of the fodder broad bean (*Vicia faba minor*). J. Appl. Gen., 42(3): 283-287.

Podleśny J., Kocoń A., 2006. The effect of soil drought on the development and yielding of two different genotypes of faba bean. Zesz. Probl. Post. Nauk Rol., 509: 125-131. (in Polish)

Podleśny J., Podleśna A., 2003. The effect of different levels of soil moisture on development and yielding of two different genotypes of white lupine (*Lupinus albus* L.). Biul. IHAR, 228: 315-322. (in Polish)

Podleśny J., Podleśna A., 2010a. The effect of high temperature in the period of flowering on growth, development and yielding of faba bean. Ecol. Chem. Engin. (in press)

Podleśny J. Podleśna A. 2010b. Estimation of water demands of self-determinated and indeterminated varieties of faba bean. Polish J. Agron. (in press)

Prusiński J., 2007. Biological progress in lupin (*Lupinus* sp.) – present state and historical background. Zesz. Probl. Post. Nauk Rol., 522: 23-37. (in Polish)

Pszczółkowska A., Olszewski J., Płodzień K., Kulik T., Fordoński G., Żuk-Gołaszewska K., 2003. Effect of the water stress on the productivity of selected genotypes of pea (*Pisum sativum* L.) and yellow lupin (*Lupinus luteus* L.). Electronic J. Pol. Agric. Univ., 6(1): 1-9.

Radomski C., 1977. Agrometeorologia. PWN Warszawa. (in Polish)

Radzka E., Koc G., Rak J., 2008. Precipitation- and temperature-related conditions of winter triticale production for feed purposes. Fragm. Agron., 3(99): 135-143. (in Polish)

Sammler P., Egel G., Schmidt A., Bergmann H., 1982. Der Einfluss von Wasserstress auf die generative Entwicklung und die Abscission reproductiver Organe von *Vicia faba* L. Arch. Acker Pfl. Boden., 26: 227-236.

Siuta A., 1999. The effect of crop rotation and precipitation on winter wheat yielding. Pam. Puł., 118: 369-374. (in Polish)

Xia, M.Z., 1997. Effect of soil drought during the generative development phase on seed yield and nutrient uptake of faba bean (*Vicia faba* L.). Australian J. Agric. Res., 48: 447-451.

Polish Journal of Agronomy
2011, 4, 23–28

Growth rate and yields of a sorghum-sudangrass hybrid variety grown on a light and a medium-heavy soil as affected by cutting management and seeding rate

Józef Sowiński and Ewelina Szydełko

Department of Crop Production
Wrocław University of Environmental and Life Sciences
Pl. Grunwaldzki 24a, 50-363 Wrocław, Poland

Abstract. Light vs. medium-heavy soil, number of cuts and seeding rate were studied for their effect on growth rate and yields of cv. Nutri Honey, a sorghum-sudangrass hybrid grown in a field trial at Pawłowice (51º09´ N; 17º06´ E) in the years 2007–2009. The experiment site is part of the Department of Crop Production, Wrocław University of Life Sciences, Poland. The experiment was set up on two soils, light and medium-heavy, in mid-May. No interaction among the factors under study was found for the number of plants after emergence, number of shoots prior to harvest, or for the dry matter yield. Number of plants after emergence was significantly higher on the light soil. Conversely, number of tillers at the end of growth was higher on the medium-heavy soil. Increasing the number of cuts promoted tillering and increased the number of shoots as counted at the end of growth. Weather pattern was found to have the greatest impact on yields. In the favourable year of 2009 the yield of DM was 14.8 t ha^{-1}. Number of cuts significantly affected the yields of DM, the highest yields being obtained with a single harvest (16,0 t DM ha^{-1}). The hybrid Nutri Honey gave significantly higher yields on the medium-heavy soil (12,8 t DM ha^{-1}) than on the light one (10,5 t DM ha^{-1}). Increasing seeding rate by 100% had no appreciable effect on DM yields.

key words: sorghum-sudangrass hybrid, soil heaviness category, cutting frequency, growth rate, dry matter yield

INTRODUCTION

Over the recent years in Poland, the recurring drought spells combined with high incidence of corn smut, European corn borer, and western corn rootworm have prompted a search for alternative crops as a supplement to, or a partial replacement of, maize (Pyś et al., 2008). The genus *Sorghum* comprises numerous diversified annual spring-sown species which resemble maize in habit but which develop only tassels in which seeds are set. Under Poland's conditions, some varieties do not produce seeds altogether or the grains fail to reach full ripeness (Sitarski, 2008). Sorghum, being a C_4 species, is an efficient utilizer of solar heat and radiation. It is resistant to drought, tolerant of short periods of waterlogging, tolerates both salinization and alkaline soils (Śliwiński and Brzóska, 2008). During drought, the leaves of maize wither whereas those of sorghum fold up only to resume vegetation after rainfall (Sitarski, 2008).

Hybrids originate from matings performed between some types of fodder sorghum and sudangrass and are unknown from natural habitats (Tew et al., 2008). Hybrids may contain more fermenting sugars and give higher biomass yields than cultivars of fodder sorghum. Compared to maize or sorghum, the hybrids have a smaller leaf area with waxy bloom owing to which they are more resistant to drought. An advantageous trait of the hybrids is an increased number of adventitious roots which, under water stress, allow the uptake of water from deeper soil depths, continuation of growth and increase of biomass. Another beneficial trait of the hybrids is that they grow faster than sorghum and thereby are more competitive and suppress the growth of weeds (Clark, 2007). The most important feature of the hybrid varieties is their ability to regrowth when cut, a trait inherited from sudangrass. As opposed to maize or sorghum, the hybrids can be harvested several times a year and thereby supplement the shortages of roughage during the growing season.

On light soils and during drought the yields of dry matter and energy from sorghum-sudangrass hybrid varieties are higher than those from maize (Cole et al., 1996). In temperate climate zone fresh yield from hybrids released to farmers is 30–53 t ha^{-1}. High yielders in the periods of water deficit, sorghum-sudangrass hybrids give good yields also when moisture supply is abundant (Habyarimana et al., 2004).

The objective of the study conducted in the years 2007–2009 was to assess the yields of the hybrid Nutri-Honey

Corresponding author:
Józef Sowiński
e-mail: jozef.sowinski@up.wroc.pl
tel. +48 71 3201642

Received 14 May 2010

(sorghum-sudangrass hybrid) under the climatic conditions of Lower Silesia. It was assumed that the soil conditions and crop management would influence growth rate and dry matter yields.

MATERIAL AND METHODS

The study comprises results obtained from an experiment laid out as a split-plot design on fields operated by the Department of Crop Production, Wrocław University of Environmental and Life Sciences, located at Wrocław-Pawłowice. The growth rate and dry matter yield of sorghum-sudangrass hybrid cv. Nutri-Honey was investigated as influenced by three factors:

I – soil heaviness cathegory: light soil – loamy sand; medium heavy soil – light loam (Table 1),

II – utilization management (1-, 2- and 3-cut schemes),

III – seeding rate (20 and 40 grains m^{-2}).

The light soil experiment was set up on an haplic arenosol rated as class V in terms of crop production potential. The medium-heavy soil was classified as stagnic luvisol and rated as class III (Table 1).

The plot size was 13.5 m^2 (9 m in length and 1.5 m in width). Each treatment was replicated four times.

Prior to seeding fertilizers were applied at rates: 100 kg N ha^{-1} as urea, 70 kg P_2O_5 ha^{-1} as triple superphosphate and 100 kg K_2O ha^{-1} as potassium chloride. The seeds of sorghum-sudangrass hybrid cv. Nutri-Honey developed by the Desert Sun Marketing Company were drilled using a plot drill "Wintersteiger" in mid-May. After emergence the number of plants per 1 m^2 was counted. During growth, 10 plants were measured for height at two-week intervals starting from the 5–6 leaf stage to the end of tasselling. Prior to harvest, number of tillers per 1 m^2 and tillering coefficient were determined, and plant samples were taken to be analyzed for yield components and dry matter content. Once the plants were cut their dry matter yield was determined. Under the 3-cut management, the first and the second cut were done at the end of shooting-beginning of tasselling. In the 2-cut scheme, the harvest was done at tasselling – beginning of anthesis. When cut only once, the plants were harvested in the milk-waxy ripe stage.

The results were subjected to ANOVA using the Statistica 9 package. Intervals of confidence were examined using Duncan's test at α = 0.05 level of significance. Within a cutting management, the mean, standard error and standard deviation were determined for dry matter content and the results were presented as frame graphs.

Table 1. Content of sand, silt and clay fractions (%) and particle size subgroup of the soils used in the study of the agronomic performance of sorghum-sudangrass hybrid.

Soil	Fraction sums			Particle size subgroup
	2.0–0.05 mm	0.05–0,002 mm	<0.002 mm	
light	83	14	3	loamy sand
medium-heavy	62	27	11	light loam

RESULTS

In the period of 2007–2009 weather conditions varied from year to year. Higher than the analogous long-term averages, the temperatures prevailing in April, May, July, August and September as well as the total rainfall in the period from April to July and in October made the year 2009 the most favourable to the growth and yields of the hybrid (Table 2). Very abundant rainfall at the period of the highest demand of sorghum for water (from mid-July through August) was also of advantage to that crop. In the growing season of 2007 the average air temperature was the highest whereas, at the same time, slightly lower than average rainfall sums were recorded. In 2008 the distribution of temperature was beneficial but the rainfall sums for May, June and September were lower than the long-term averages for those months.

No effect of factor-by-factor interaction on the number of plants after emergence or on the number of tillers before harvest was found (Table 3). The highest population density was recorded on the light soil at the higher seeding rate – an average of 28 plants plants m^{-2} (70% of the planned stand). Prior-to-harvest number of tillers was the highest on the medium-heavy soil when the hybrid was harvested under the 3-cut regime and at the seeding rate of 40 grains m^{-2} – resulting in 81.2 tillers m^{-2}. On an average, the post-emergence number of plants on the light soil was significantly higher (by 75%) than that on the medium-heavy soil reaching 20,8 plants m^{-2}. On the end of growth, the number of tillers was higher, though insignificantly, on the medium-heavy soil (by 12%). The tillering coefficient was 2.8 and 5.5 on the light and on the medium-heavy soil, respectively. Number of tillers at harvest increased with the number of cuts and in the 3-cut regime was higher by 68% and 5% than in the 1-cut and 2-cut regimes, respectively. The tillering coefficient increased with the number of cuts from 2.7 (one cut) to 5.1 (3 cuts) (Table 3). The field emergence capacity was higher at the seeding rate of 20 grains per 1 m^2 (56.5%). Increased seeding rate resulted in a decrease of field emergence capacity to 49%. Seeding rate had a significant effect on the number of tillers at the end of the growing period.

In the initial period, Nutri-Honey showed superior growth rate when grown on the light soil. Starting from the third measurement, an insignificantly higher growth rate was recorded on the medium-heavy soil (Fig. 1). There were no cutting regime-dependent differences in plant height in the initial period of growth. The first cut in the 2- and 3-cut regimes had a significant impact on the further growth rate of the hybrid. Towards the end of the growing

Table 2. Monthly averages of air temperature and sums of rainfall in the growing period of sorghum-sudangrass hybrid.

Years	Months							Average/ Sum
	IV	V	VI	VII	VIII	IX	X	
Mean monthly temperature								
2007	10.9	16.2	19.2	19.2	18.9	12.9	8.3	15.1
2008	8.9	14.3	18.8	19.8	18.8	13.2	9.6	14.8
2009	12.0	14.2	15.8	19.5	19.3	15.4	7.9	14.9
1976–2005	8.3	14.1	16.9	18.7	17.9	13.3	9.2	14.1
Sum of rainfall								
2007	2.7	50.3	69.2	92.4	52.8	46.1	21.7	335.2
2008	87.1	37.3	36.5	65.6	74.8	27.9	41.1	370.3
2009	30.9	67.6	141.7	134.2	53.5	12.0	76.0	515.9
1976–2005	30.5	51.3	59.5	78.9	61.7	45.3	32.3	359.5

Table 3. Number of plants after emergence, number of tillers prior to harvest and tillering coefficient of sorghum-sudangrass hybrid.

Soil heaviness category	Cutting management	Number of grains per 1 m^2	Number of plants after emergence	Number of tillers prior to harvest	Tillering coefficient
light	1 cut	20	13.9	34.6	2.5
		40	28.1	43.3	1.5
	2 cuts	20	14.3	56.4	4.0
		40	26.3	74.9	2.8
	3 cuts	20	17.5	64.1	3.7
		40	25.0	76.9	3.1
medium-heavy	1 cut	20	9.8	40.5	4.1
		40	17.0	54.6	3.2
	2 cuts	20	9.2	66.6	7.3
		40	15.7	79.3	5.1
	3 cuts	20	7.0	71.2	10.2
		40	12.5	81.2	6.5
LSD(0.05)			ns	ns	-
Averaged across years					
light	-	-	20.8	58.4	2.8
medium heavy	-	-	11.9	65.6	5.5
LSD(0.05)			2.9	ns	-
-	1 cut	-	16.4	43.9	2.7
-	2 cuts	-	15.6	69.9	4.5
-	3 cuts	-	14.4	73.8	5.1
LSD(0.05)			ns	11.1	-
-	-	20	11.3	56.2	5.0
-	-	40	19.6	68.9	3.5
LSD(0.05)			2.5	10.0	-
Averaged across factors					
	2007		13.9	68.8	4.9
	2008		19.2	46.3	2.4
	2009		11.0	84.0	7.6
LSD(0.05)			3.5	11.1	-

ns – non significant

season, the tallest plants were recorded under the single harvest management, averaging 232.4 cm. Under the 2-cut management the hybrid reached the maximum of 166.7 cm in height whereas under 3 cuts the plants were 118.3 cm tall (Fig. 2). Seeding rate had no significant effect on plant height (Fig. 3).

The stalks accounted for the largest percentage of total yield components of the hybrid (from 60.5% under the

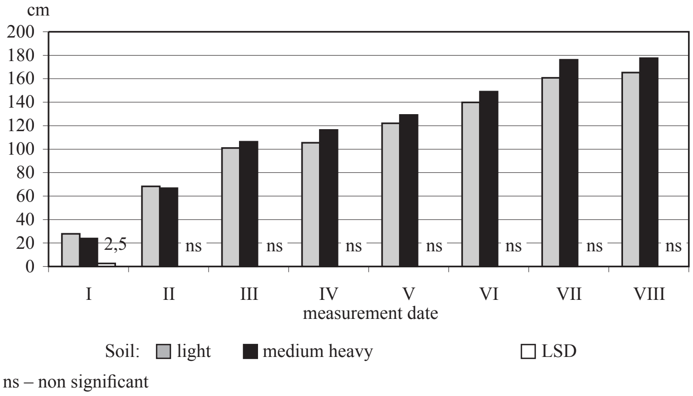


Fig. 1. Effect of soil heaviness category on plant height in sorghum-sudangrass hybrid.

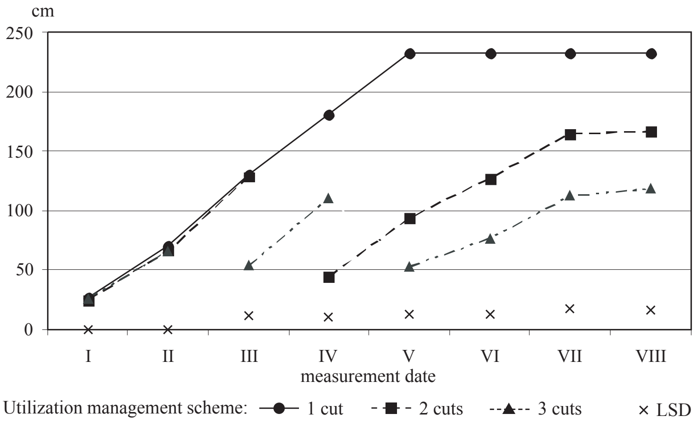


Fig. 2. Effect of cutting management on plant height in sorghum-sudangrass hybrid.

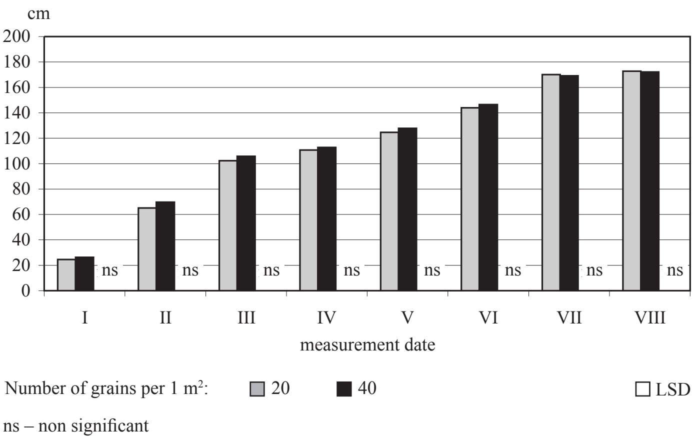


Fig. 3. Effect of seeding rate on plant height in sorghum-sudangrass hybrid.

1-cut regime on the medium heavy soil to 72.4% from plants harvested twice on the medium-heavy soil) (Table 4). The tassels accounted for the smallest percentage (from 7.1% under three cuts on the light soil to 19.9% in the single harvest scheme, medium heavy soil). The percentage of tassels was the highest (14.8–19.9%) when the hybrid was managed under the single cut scheme which was related to the hybrid's reaching the waxy-ripe stage. The percentage of leaves in the total yield was the highest under the 3-cut management (from 21.0 to 31.5%). Higher number of grains per area unit on the light soil increased percentage of stalks on total yield. In medium-heavy soil. Higher stalks percentage accounted on lower sowing rate.

The different management schemes caused the plants of Nutri-Honey to be harvested at different development stages. Under a single harvest scheme, dry matter content was significantly higher, an average of 32%, than under 3 cuts – average of 18% (Fig. 4). The parameter was not found to be significantly affected by either the seeding rate or the soil heaviness category.

No factor-by-factor interaction was found to affect DM yield (Table 5). In the year 2009, the most favourable in terms of sorghum-sudangrass hybrid production, the significantly highest DM yield was obtained – 14.8 t ha^{-1}. When cropped to the medium heavy soil, Nutri-Honey gave a DM yield higher by 22% (12.8 t ha^{-1}) than when grown on the light soil (10.5 t per 1 ha). DM yield varied significantly depending on cutting management. The highest yield

Table 4. Yield components (% green matter) of sorghum-sudangrass hybrid.

Soil heaviness category	Cutting management	Number of grains per 1 m^2	Percentage of fresh yield		
			stalks	leaves	tassels
light	1 cut	20	62.3	21.0	16.8
		40	66.3	19.0	14.8
	2 cuts	20	69.3	21.6	10.9
		40	69.3	21.6	9.2
	3 cuts	20	61.3	31.5	7.3
		40	62.9	30.1	7.1
medium heavy	1 cut	20	62.5	20.2	17.4
		40	60.5	19.6	19.9
	2 cuts	20	72.4	18.4	9.3
		40	70.2	20.6	9.3
	3 cuts	20	68.4	21.0	10.6
		40	61.3	29.0	9.7

Table 5. Dry matter yield (t ha^{-1}) of sorghum-sudangrass hybrid.

Cutting management	Soil heaviness category			
	light		medium-heavy	
	Number of grains per 1 m^2			
	20	40	20	40
1 cut	14.3	16.9	15.1	17.4
2 cuts	9.2	10.9	11.8	13.7
3 cuts	5.6	5.9	9.2	9.7
LSD(0.05)	ns			

Average							
years		soil heaviness category		cutting management		number of grains per 1 m^2	
2007	9.3	light	10.5	1 cut	16.0	20	11.1
2008	12.5	medium heavy	12.8	2 cuts	11.6	40	12.6
2009	14.8	-	-	3 cuts	7.9	-	-
LSD (0.05)	2.0		1.7		1.5		ns

ns – non significant

was obtained from a single cut scheme (16.0 t ha^{-1}). As the number of cuts increased there was a decrease in the DM yield: by 27.5% in the 2-cut scheme and by 50.6% in the 3-cut scheme. There was no effect of seeding rate on DM yield in the sorghum-sudangrass hybrid (Table 5).

DISCUSSION

The yields of the sorghum-sudangrass hybrid obtained over the years of the study were related to weather conditions prevailing in the growing season. Temperature and rainfall pattern in the critical stage of development affected plant yield significantly. During the growing season, sorghum requires ca. 250–300 mm of evenly distributed rainfall (Stichler et al., 1997). Moisture requirements decline rapidly once the grains have reached the waxy-ripe stage. In the study years the total rainfall in the growing season was higher than the requirement by that species but in the first year the rainfall was not evenly distributed which might have affected the yield.

The field emergence capacity (69.3% on the light soil and 39.7% on medium-heavy soil) was lower than that obtained in the study by Sowiński and Liszka-Podkowa (2008) for the tassel-less sugar sorghum G 1990, 75.5%, and for tasselled sugar sorghum (506) – 92%. Number of tillers at the end of growth was higher, 34.6 tillers m^{-2}, than in tassel-less sorghum, 17.8, or in tasselled sorghum 18.3 tassels m^{-2}. Hybrid varieties show a greater tendency to tiller than does sugar sorghum.

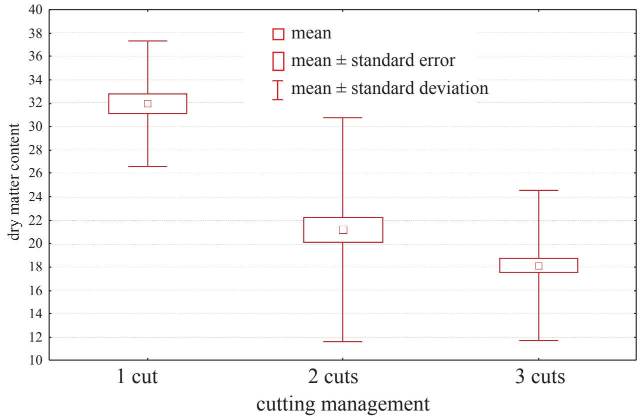


Fig. 4. Effect of cutting management on dry matter content of sorghum-sudangrass hybrid.

In this study, the highest dry matter yield was obtained under the single cut management (16.0 t DM ha^{-1}). In Uher's study (2005) the best results were recorded when the plants were cut after tasselling (27.4 t DM ha^{-1}). High yields were also obtained for a sorgum-sudangrass hybrid (24.2 t DM ha^{-1}) harvested at earing and at waxy-ripe stage (Lee, 2005).

In this study, insignificantly higher yields of dry matter were obtained when sorghum-sudangrass hybrid was seeded at 40 grains m^{-2}. Response of sorghum to seeding rate shows extensive variation and divergent results are reported in literature. Habyarimana et al. (2004) found dry matter yield to be dependent on seeding rate, genotype and availability of water. Under high moisture, at a plant density of 20 plants m^{-2} yields were higher than at a seeding rate of 10 seeds per 1 m^2. Under water stress, though, the results were comparable. According to the European Energy Crops Interwork (Habyarimana et al., 2004) the differences in yield at high (29 plants m^{-2}) vs. low (7 plants m^{-2}) plant densities were not valid statistically. Berenguer and Faci (2001) established that a density of 30 plants m^{-2} is more productive than that of 15 plants m^{-2}.

CONCLUSIONS

1. Temperature and moisture conditions of the Lower Silesia region ensured good growth and high yields of the sorghum-sudangrass hybrid Nutri-Honey originally cultivated in the US and Canada.
2. On a light soil, better temperature and moisture conditions ensured significantly higher number of plants after emergence. Superior soil fertility and more vigorous tillering shown by the hybrid contributed to its higher dry matter yields on a medium-heavy soil.
3. Increasing the number of cuts promoted tillering and decreased plant height of the hybrid.

4. Under a single cut regime, the sorghum-sudangrass hybrid showed a dry matter content that was optimum for ensiling. Increasing the number of cuts caused the DM content to fall below the optimum level. When grown under such management the hybrid must be ensiled with other crops that have a higher DM content or ensilage additives should be added. Alternatively, the crop can be used in a different manner e.g. fed directly to animals.

5. Defoliation and recovery of the assimilation area after cutting caused the yield of dry matter to decrease in proportion to the number of cuts. Compared to that under the 1-cut regime, the yields from cutting regimes involving 2 and three harvests were lower by 27.5 and 50.6%, respectively.

LITERATURE

Berenguer M.J., Faci J.M., 2001. Sorghum (*Sorghum Bicolor* L. Moench) yield compensation processes under different plant densities and variable water supply. Eur. J. of Agron., 15(1): 43-55

Clark A., 2007. Managing cover crops profitably. SARE Outreach ss. 244 http://www.sare.org/publications/covercrops/covercrops.pdf, 06.05.2010

Cole C.A., Kaiser A.G., Piltz J.W., Harden S., 1996. An evaluation of sorghums for silage production in northern New South Wales. Proceedings of the 3rd Australian Sorghum Conference, Tamworth, NSW, No. 93: 127-139.

Habyarimana E., Bonardi P., Laureti D., di Bari V., Cosentino S., Lorenzoni C., 2004. Multilocational evaluation of biomass sorghum hybrids under two stand densities and variable water supply in Italy. Ind. Crops Prod., 20: 3-9.

Lee S. M., 2005. Effect of the cultivation metod and cutting time on the growth characteristics, dry matter yield and voluntary intake in sorghum·sudangrass hybrid. J. Kor. Soc. Grass. Sci., 25(1): 7-16.

Pyś J.B., Borowiec F., Karpowicz A., 2008. Wpływ dodatku bakteryjno-chemicznego oraz absorbentów soku na skład chemiczny i stabilność tlenową kiszonek z sorgo cukrowego. 239-241. In: T. Michalski „Problemy agrotechniki oraz wykorzystania kukurydzy i sorgo", UP Poznań.

Sitarski A., 2008. Wykorzystanie sorga do celów paszowych. 245-247. In: T. Michalski „Problemy agrotechniki oraz wykorzystania kukurydzy i sorgo", UP Poznań.

Sowiński J., Liszka-Podkowa A., 2008. Fresh and dry matter yield quantity and quality of maize (*Zea mays* L.) and sweet sorghum (*Sorghum bicolor* (L.) Moench.) on sandy soil depending on nitrogen fertilization. Acta Sci. Pol., Agricultura., 7(4): 105-115. (in Polish)

Stichler C., McFarland M., Coffman C., 1997. Irrigated and dryland grain sorghum production south and southwest Texas. http://lubbock.tamu.edu/sorghum/pdf/b6048.pdf, 07.05.2010.

Śliwiński B., Brzóska F., 2008. Wykorzystanie kiszonek z sorgo w żywieniu krów mlecznych. 263-266. In: T. Michalski „Problemy agrotechniki oraz wykorzystania kukurydzy i sorgo", UP Poznań.

Tew T. L., Cobill R. M., Richard E. P., 2008. Evaluation of sweet sorghum and sorghum·sudangrass hybrids as feedstocks for ethanol production. BioEnergy Res., 1: 147-152

Uher D., Štafa Z., Maćešić D., Kaučić D., Vukašinović Z., 2005. The effect of cutting regime on yield of sorghum in different climatic (vegetation) seasons. Mljekarstvo, 55(1): 15-30. (in Croatian)

Polish Journal of Agronomy
2011, 4, 29–32

Impact of zero tillage system on the nutrient content of grain and vegetative parts of cereals

Ewa Stanisławska-Glubiak, Jolanta Korzeniowska

Department of Weed Science and Soil Tillage Systems in Wrocław
Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy
ul. Orzechowa 61, 50-540 Wrocław, Poland

Abstract. Evaluating differences in mineral composition of cereal crops grown in zero and conventional tillage systems have been performed with the use of the results of the experiments carried out in experimental stations of IUNG-PIB in Jelcz-Laskowice, near Wrocław (years 2002–2009) and Baborówko near Poznań (2007–2009). The study covered results of various one-year experiments with: winter wheat (9 experiments), maize (4 exp.), spring barley (3 exp.), oats (3 exp.). Conventional tillage consisted of a group of post-harvest tillage operations to a depth of 10–15 cm, and then pre-plant plowing to a depth of 25 cm and sowing cultivation with an active harrow. Zero tillage was performed without using any mechanical tillage, with mulching of the soil surface with shredded straw. The plant samples were analyzed for contents of N and P by flow absorption spectrophotometry, K – by flame emission spectrometry and Ca, Mg, Cu, Mn and Zn by AAS. Also the mineral content of the so-called indicator parts collected during the growing season were evaluated acc. to Bergmann values, to determine if there were any shortages of elements in the earlier phases of development, which could affect the mineral composition of grain. In soil samples the content of available P and K were determined by Egner-Riehm method, Mg by Schachtschabel method and organic carbon by Tiurin method. The evaluation of the significance of differences between the studied farming systems in the mineral contents in grain and cereal biomass was based on the analysis of variance for two independent samples using the Tukey test ($P<0.05$).

Growing of cereals and maize in zero tillage systems, in the conditions of light soils, did not cause differences in the concentration of macro-and micronutrients in plants at the beginning of the vegetation, nor did it bring about any deterioration of grain quality in terms of content of the primary minerals, which is important in assessing its value as a feed or foodstuff.

key words: zero-tillage system, cereals, maize, nutrient content

Corresponding author:
Ewa Stanisławska-Glubiak
e-mail: e.glubiak@iung.wroclaw.pl
tel. +48 71 363 87 07 ext. 114

Received 25 June 2010

INTRODUCTION

The use of zero-tillage methods, consisting of direct sowing in a non plowed soil using a specialized drill, has many advantages, which may include prevention of soil erosion, reducing water losses and lower costs of production compared to traditional methods of using the plow. In the literature, it is reported that no-tillage methods affects yield differently. There are many factors that determine the effects of direct sowing, the most important are: the climate, the time elapsed since the beginning of a method of zero tillage in a given field, as well as soil type (Martinez et al., 2008). The benefits of zero tillage are typically achieved in a dry climate or in years with less rainfall (Arshad et al., 1999; Bonfil et al., 1999; De Vita et al., 2007). The impact of soil type on the effects of zero tillage is associated with the fact that changes in physical properties of soil in relation to conventional tillage, especially density and air-water relations, as well as chemical and biological properties occur faster and can reach deeper into the heavier soils rather than the lighter ones. In the climatic conditions of western and south-western Poland, zero tillage of light soil often produces worse results than traditional tillage (Korzeniowska and Stanisławska-Glubiak, 2009). Many authors have reported differences in the content and distribution of macronutrients in the soil, depending on farming practices (Franzluebbers et al., 1996; Martin-Rueda et al., 2007; Tarkalson et al., 2006). These differences could certainly have an impact not only on the rate of biomass production and crop yields, but also on the nutrient intake and content in a plant. At present, there is not too much information on the impact of zero tillage on the chemical composition of plants (Lavado et al., 2001; Stanisławska-Glubiak and Korzeniowska, 2009). This is particularly true of those parts which are intended for consumption by humans and animals. The aim of this study was to assess the content of basic minerals in the grain and vegetative parts of cereals from the fields cultivated by a zero tillage method in relation to the traditional tillage system.

MATERIALS AND METHODS

Evaluating differences in mineral composition of cereal crops grown in zero and conventional tillage systems have been performed with the use of the results of all the experiments which concerned the comparison effects of yielding of the zero tillage method to the traditional tillage cultivation of the soil. The experiments were carried out in experimental stations of IUNG-PIB in Jelcz-Laskowice, near Wrocław (years 2002–2009) and Baborówko near Poznań (2007–2009). Conventional tillage (CT) consisted of a group of post-harvest tillage operations to a depth of 10–15 cm, and then pre-sowing plowing to a depth of 25 cm and pre-sowing cultivation with an active harrow. Zero tillage (ZT) was performed without using any mechanical tillage, with mulching of the soil surface with shredded straw. Sowing seeds on ZT, after the eradication of weeds with herbicides, was carried out using the drill for direct sowing with disk coulters: Great Plain (Jelcz-Laskowice) or Kongskilde Demeter Classic 3000 (Baborówko).

For the comparison of the mineral composition of cereal at the ZT and CT, the results of various one-year experiments were used in a total number of: winter wheat – 9, maize – 4, spring barley – 3, oats – 3. These plants were grown in cereal crop rotations and the varieties were not identical in every year. The results for the concentration of macro-and micronutrients in the grain were selected from all the experiments for both tillage methods, with the exception of barley and oats, for which only the analyzes of the content of macroelements were performed. In addition to that, the content of analysed elements in the so-called indicator parts collected during the growing season were evaluated (Bergmann, 1992), to determine if there were any shortages of elements in the earlier phases of development, which could affect the mineral composition of grain. For cereals, the indicator part was the whole above-ground part of plant, and for maize – fully developed leaves, at the plant height of 40–60 cm.

Due to the fact that the patterns of individual experiments were varied, the number of samples where the mineral composition was assessed was not the same in each experiment. Only the objects with full mineral fertilization were chosen. Total number of samples of grain, and accordingly, the same number of trials of vegetative parts of plants, for each tillage system was: for winter wheat from Jelcz-Laskowice (winter wheat I): n = 12, for winter wheat from Baborówko (winter wheat II): n = 8, for maize: n = 12, for spring barley: n = 3, and for oats: n = 3. Winter wheat was divided into two sets, according to the location of the experiments, due to the relatively large difference in soil pH between the experimental points, and therefore to the difference in the nutrient availability to plants and their intake. In the ES in Jelcz-Laskowice there were acid soils, and in ES Baborówko – soils with a pH close to neutral (Table 1).

Table 1. Selected physicochemical properties of topsoil (0–20 cm) in soils of field trials.

Experimental station/field	Soil textural group	pH (KCl)	C org. [%]	Content [mg kg^{-1}]		
				P	K	Mg
ES Jelcz-Laskowice						
Winter wheat I	pg	4.7–5.5	0.69–0.75	64–93	83–234	43–70
Maize	pg	4.2–5.2		48–87	162–232	31–76
Barley, Oats	pg	4.7–4.8	0.69–0.76	64–66	83–100	43–44
ES Baborówko						
Winter wheat II	pg, gp	6.2–6.4	0.60–0.80	67–92	84–116	66–97

pg – loamy sand, gp – sandy loam

Other soil conditions in both places were similar. All the experiments were conducted on sandy soils with low organic carbon content, high phosphorus content and the average content of potassium and magnesium.

Fertilization of plants in each year of the study was adapted to the requirements of plants growing conditions that year which, to some extent, differentiated the doses of fertilizer between particular years (Table 2). In ES in Baborówko, a slightly higher level of nitrogen was used under the wheat than in ES Jelcz-Laskowice. Doses of P and K in both places were the result of the nutritional requirements of cultivated plants and fertility of soil found in a given year.

Table 2. The ranges of doses of fertilizer used in the study years.

Experimental Station/field	N	P	K
	kg ha^{-1}		
ES Jelcz-Laskowice			
Winter wheat I	100–110	25–30	70–85
Maize	100–120	30–50	50–80
Barley, oats	50–70	25	70
ES Baborówko			
Winter wheat II	120–160	15–20	50

The plant samples were analyzed for contents of N and P by flow absorption spectrophotometry, K – by flame emission spectrometry and Ca, Mg, Cu, Mn and Zn by AAS. Analyses of soil samples were carried out with the methods used in chemical and agricultural stations. The contents of available P and K were determined by Egner – Riehm method, Mg by Schachtschabel method and organic carbon by Tiurin method.

The evaluation of the significance of differences between the studied farming systems in the mineral contents in grain and cereal biomass was based on the analysis of variance for two independent samples using the Tukey test ($P < 0.05$).

RESULTS AND DISCUSSION

An analysis of the indicator parts of the tested plants, taken during the growing season, showed the same macronutrient content in the biomass, irrespective of tillage system (Table 3). According to the criteria of Bergmann (1992), this content was optimal. Only in the tissues of barley a nitrogen content in the zero tillage was higher than in the traditional one, but this was not reflected in the increased concentration of this constituent in grains. Macroelements content in grain was not in fact considerably varied depending on the tillage system (Table 3).

Zero tillage did not generally cause changes in the concentration of macroelements in grain in relation to the plants from the plots where the traditional method of cultivation was used. The exception was the grain of wheat grown in Baborówko (winter wheat II) in zero-tillage system, which had a significantly lower nitrogen content than in traditional cultivation. This could be due to the improved habitat conditions for wheat in ES Baborówko compared to ES Jelcz-Laskowice. Soil pH was here close to neutral, and therefore compliant with the requirements of this species, and the level of nitrogen fertilization was higher than in experiments in Jelcz-Laskowice. The positive effects of zero tillage are revealed generally in poorer growing conditions, especially under insufficient rainfall. In the studies of De Vita et al. (2007) differences in the concentration of nitrogen in wheat grain between zero and traditional cultivation occurred at the site with a lower amount of precipitation during the growing season, while at the site with the higher amount of precipitation, such differences were not found. In good moisture conditions, Lavado et al. (2001) also did not observe differences between crops in the content of macroelements neither in grain, nor in wheat leaves. Only the roots contained more phosphorus in the zero tillage system. Małecka and Blecharczyk (2008) in the studies with spring barley found that at the zero tillage, nitrogen intake of grain was significantly lower than in conventional tillage, with tillage system having a much lower effect on this difference than mulching and the dose of nitrogen fertilization.

Of all the microelements analyzed in this study, only copper in the grain of wheat grown on acid soils showed a higher content at zero tillage than at the conventional one (Table 4). In the indicator parts, though, there was a higher concentration of manganese. The probable cause of these differences was the higher content of Cu and Mn in the soil of the zero cultivation than on those with the traditional cultivation, as reported in some papers (Rahman et al., 2008; De Santiago et al., 2008).

Table 3. Content of basic macroelements in grain and vegetative parts of cereal in the traditional system (CT) and zero tillage (ZT).

Plant and tillage system	Grain					Indicator parts				
	Content [g kg^{-1}]									
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Winter wheat I (mean from 2002–2004 i 2007–2009; n=12)										
CT	20.6 a	3.2 a	3.8 a	0.43 a	1.22 a	30.7 a	4.0 a	35.2 a	3.3 a	1.1 a
ZT	19.5 a	3.3 a	4.0 a	0.51 a	1.28 a	29.7 a	4.1 a	32.3 a	2.9 a	1.1 a
Winter wheat II (mean from 2007–2009; n=8)										
CT	21.1 a	3.2 a	3.9 a	0.53 a	1.25 a	32.8 a	3.8 a	27.9 a	3.6 a	1.3 a
ZT	18.5 b	3.1 a	4.0 a	0.48 a	1.22 a	32.9 a	3.8 a	28.9 a	3.2 a	1.2 a
Spring barley (mean from 2002–2004; n=3)										
CT	21.4 a	3.3 a	4.7 a	0.51 a	1.17 a	25.4 b	3.7 a	35.0 a	3.8 a	0.9 a
ZT	22.7 a	3.3 a	4.9 a	0.49 a	1.13 a	35.0 a	4.1 a	38.5 a	5.2 a	1.3 a
Owies (mean from 2002–2004; n=3)										
CT	20.7 a	3.2 a	4.4 a	0.69 a	1.16 a	24.5 a	4.3 a	34.7 a	4.1 a	1.0 a
ZT	20.1 a	3.3 a	4.6 a	0.65 a	1.17 a	29.0 a	4.9 a	41.9 a	4.1 a	1.2 a
Maize (mean from 2004–2009; n=12)										
CT	14.3 a	3.1 a	3.5 a	0.19 a	1.21 a	37.6 a	3.8 a	47.9 a	6.4 a	2.4 a
ZT	14.7 a	3.4 a	3.9 a	0.17 a	1.27 a	36.5 a	3.9 a	43.3 a	6.0 a	2.5 a

Identical letters (a comparison between the CT and ZT separately in each column) show no significant difference by Tukey test (P <0.05).

Table 4. Contents of selected microelements in vegetative parts and grain of cereal in the traditional system (CT) and zero tillage (ZT).

Plant and tillage system	Grain			Indicator parts		
	Content [mg kg^{-1}]					
	Cu	Mn	Zn	Cu	Mn	Zn
Winter wheat – Jelcz-Laskowice (mean from 2002–2004 i 2007–2009; n=12)						
CT	2.34 b	32.6 a	30.7 a	4.09 a	36.5 b	24.8 a
ZT	2.82 a	36.6 a	32.9 a	4.04a	50.8 a	26.9 a
Winter wheat – Baborówko (mean from 2007–2009; n=8)						
CT	2.09 a	21.9 a	19.8 a	3.43 a	28.0 a	23.4 a
ZT	2.25 a	24.3 a	19.1 a	3.50 a	29.5 a	23.3 a
Maize (mean from 2004–2009; n=12)						
CT	1.51 a	6.17 a	19.0 a	6.47 a	58.4 a	35.3 a
ZT	1.23 a	5.83a	19.2 a	6.65 a	72.4 a	42.8 a

Identical letters (a comparison between the CT and ZT separately in each column) show no significant difference by Tukey test (P <0.05).

In the present study conducted in the conditions of light sandy soils, it was found that tillage system did not significantly affect the nutrient content of cereal grains and corn. Similar results of no difference between zero and traditional cultivation in terms of the concentration of nitrogen in the grain of corn grown on loamy sand were obtained by Mehdi et al. (1999). Other authors, in experiments on heavy clay soils (Iqbal et al., 2005) and on loam (Campbell et al., 1998), also found the same nitrogen content in wheat grain straw and roots in conditions of traditional and zero-tillage systems.

CONCLUSION

Growing of cereals and maize in zero tillage systems, in the conditions of light soils, did not cause differences in the concentration of macro- and micronutrients in plants at the beginning of the vegetation, nor did it bring about any deterioration of grain quality in terms of content of the primary minerals, which is important in assessing its value as a feed or foodstuff.

REFERENCES

Arshad M.A., Franzluebbers A.J., Azooz R.H., 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil Till. Res., 53(1): 41-47.

Bergmann W., 1992. Nutritional disorders of plants - development, visual and analytical diagnosis. Gustav Fischer Verlag Jena, Stuttgart, New York.

Bonfil D.J., Mufradi I., Klitman S., Asido S., 1999. Wheat grain yield and soil profile water distribution in a no-till arid environment. Agron. J., 91: 368-373.

Campbell C.A., Thomas A.G., Biederbeck V.O., McConkey B.G., Selles F., Spurr D., Zentner R.P., 1998. Converting from no-tillage to pre-seeding tillage: Influence on weeds, spring wheat grain yields and N, and soil quality. Soil Till. Res., 46: 175-185.

De Santiago A., Quintero J.M., Delgado A., 2008. Long-term effects of tillage on the availability of iron, copper, manganese and zinc in Spanish Vertisol. Soil Till. Res., 98: 200-207.

De Vita P., Di Paolo E., Fecondo G., Di Fonzo N., Pisante M., 2007. No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. Soil Till. Res., 92: 69-78.

Franzluebbers, A.J., Hons F.M., 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. Soil Till. Res., 39: 229-239.

Iqbal M.M., Akhter J., Mohammad W., Shah S.M., Nawaz H., Mahmood K., 2005. Effect of tillage and fertilizer levels on wheat yield, nitrogen uptake and their correlation with carbon isotope discrimination under rainfed conditions in north-west Pakistan. Soil Till. Res., 80: 47-57.

Korzeniowska J., Stanisławska-Glubiak E., 2009. Comparison of production effects of zero and conventional tillage on sandy soil of south-west Poland. Fragm. Agron., 26(4): 65-73. (in Polish)

Lavado R.S., Porcelli C.A., Alvarez R., 2001. Nutrient and heavy metal concentration and distribution in corn, soybean and wheat as affected by different tillage systems in the Argentine Pampas. Soil Till. Res., 62: 55-60.

Małecka I,. Blecharczyk A., 2008. Effect of tillage systems, mulches and nitrogen fertilization on spring barley (*Hordeum vulgare*). Agron. Res., 6(2): 517-529.

Martinez E., Fuentes J.P., Silva P., Valle S., Acevedo E., 2008. Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile. Soil Till. Res., 99: 232-244.

Martin-Rueda I., Munoz-Guerra L.M., Yunta F., Esteban E., Tenorio J.L., Lucena J.J., 2007. Tillage and crop rotation effects on barley yield and soil nutrients on a Calciortidic Haploxeralf. Soil Till. Res., 92: 1-9.

Mehdi B.B., Madramootoo C.A, Mehuys G.R., 1999. Yield and nitrogen content of corn under different tillage practices. Agron. J., 91: 631-636.

Rahman M.H., Okubo A., Sugiyama S., Mayland H.F., 2008. Physical, chemical and microbiological properties of an Andisol as related to land use and tillage practice. Soil Till. Res., 101: 10-19.

Stanisławska-Glubiak E., Korzeniowska J., 2009. Concentration of micronutrients in pea and lupin plants depending on the soil tillage system. J. Element., 14(2): 357-364.

Tarkalson D.D, Hergert G.W., Cassman K.G., 2006. Long-term effects of tillage on soil chemical properties and grain yields of a dryland winter wheat-sorgum/corn fallow rotation in the Great Plains. Agron. J., 98: 26-33.

Polish Journal of Agronomy
2011, 4, 33–37

Dissolvable organic carbon in groundwater as an indicator of its contamination as a result of many years of on-ground storage of manure

Marek Urbaniak, Stefan Pietrzak

Department of Water Quality Protection
Institute of Technology and Life Sciences in Falenty
Al. Hrabska 3, Falenty, 05-090 Raszyn

Abstract. The paper presents results of studies on the effects of long-term storage of cattle manure directly on the ground on the contamination of shallow groundwater with dissolved organic carbon (DOC). The research was carried out from January 2008 to December 2009. It was conducted at the site where cattle manure had been stored for about 20 years. Water samples were collected from three wells located at the site of manure storage and next to it. Moreover, at the same time water from two nearby ditches was sampled. Water samples were analyzed calorimetrically for the concentration of DOC using segmented flow analysis (S.F.A.S.).

The research indicated that long-term manure storage on the ground resulted in significant pollution of groundwater with dissolved organic carbon. Annual average DOC content in groundwater from the monitored units was approximately from 51.0 to approximately 189.0 mg C dm^{-3}. Its concentration in water samples collected on a monthly basis was as high as 597.0 mg C dm^{-3}. The concentration of DOC in the surrounding ditches in the study period ranged from 3.5 mg C dm^{-3} to 12.5 mg C dm^{-3}. Concentration of that element was higher in water from a ditch located in close proximity to manure storage (11.1 mg C dm^{-3}) than in a ditch located further away from that area (6 mg C dm^{-3}).

The research indicates that it is necessary to intensify research towards a better identification of the role of DOC in the movement and accumulation of minerals in the water, and that DOC can be a good indicator of water pollution from agricultural sources.

key words: DOC, groundwater, storage manure

INTRODUCTION

Manure stored directly on the ground poses a great threat to the environment, especially for waters. This threat is usually considered in terms of loss of nitrogen from the fertilizer. However, in the process of mineralization of organic matter during manure storage, in addition to nitrogen, other mineral elements and carbon leak into the environment. They can be once more put into biological circulation or get washed deeper in the soil profile and thus get into the groundwater and surface water. Organic carbon in soil solution and surface water has a form of humic substances of complex chemical structure which include basic components of fertilizer, such as nitrogen and phosphorus. The most labile fraction of organic carbon is dissolved organic carbon (DOC). This is a fraction of carbon defined as all organic substances present in the solution less than 0.45 μm (Aiken, 2002; Silveira, 2005). DOC is a very important component in biogeochemical cycling of elements characterized by high susceptibility to leaching. It is recommended to be used as an indicator of ground water pollution (Gooddy, Hinsby, 2007). It is believed that DOC may be a particularly useful indicator of water pollution from landfills and similar sites which release high loads of organic carbon (Gooddy, Hinsby, 2007). In a typical uncontaminated groundwater DOC concentration is on the level of 1 mg C dm^{-3} (Chomycia et al., 2008). This value can serve as a benchmark in assessing the quality of the water analyzed for that component. The aim of this study is to assess the effects of long term “on-ground” storage of cattle manure on the pollution of shallow ground waters with dissolved organic carbon (DOC).

MATERIAL AND METHODS

The study covered the period from January 2008 to December 2009. It was carried out near Warsaw at the site where manure had been stored on the soil developed from sand over the period of 20 years. By 2007, the use of the storage site consisted of repeated annual cycles of stockpiling and removal of the manure to be used to fertilize crops. In 2008 only a small batch of manure was delivered to the site, and from 2009 its exploitation was stopped. In 2008 and 2009 rainfall amounted to respectively over 840 and

Corresponding author:
Marek Urbaniak
e-mail: m.urbaniak@wp.pl
tel. 22 720 05 31 ext. 226

Received 2 November 2010

Table 1. Average monthly rainfall and temperature distribution in the studied period (Szymczak, Klasicka, 2008, 2009).

Years	Rainfall [mm]												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	annual sum
2008	113.8	50.5	77.7	58.3	60.6	29.1	127.0	108.5	79.9	22.6	48.6	63.8	840.4
2009	39.4	62.7	82.5	10.4	108.5	184.0	88.0	74.0	26.6	114.3	90.1	65.7	946.2
Years	Temperature [°C]												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	annual average
2008	1.2	3.1	3.8	9.4	14.0	18.8	19.5	18.9	12.7	10.2	5.2	1.5	9.8
2009	-3.1	-1.1	2.4	10.7	13.4	16.2	19.9	18.3	14.6	6.4	b.d.	b.d.	9.8

b.d. – no data

946 mm, and average annual air temperature was in each year 9.8 °C (Table 1).

During the study period the samples of ground water were collected for analysis from the site of manure storage, three groundwater sampling wells installed in its vicinity, and two sampling points from nearby ditches (Fig. 1).

Samples of groundwater were collected from sampling wells bored along the direction of the movement of ground water (Fig. 1) at monthly intervals during the whole time of the research. Before the collection of the samples, the level of ground water was measured, and then water was pumped out from the well, and after about ten minutes a sample of newly seeped water was taken for the analysis. The bottom of the wells was at a depth of 2 m below ground level.

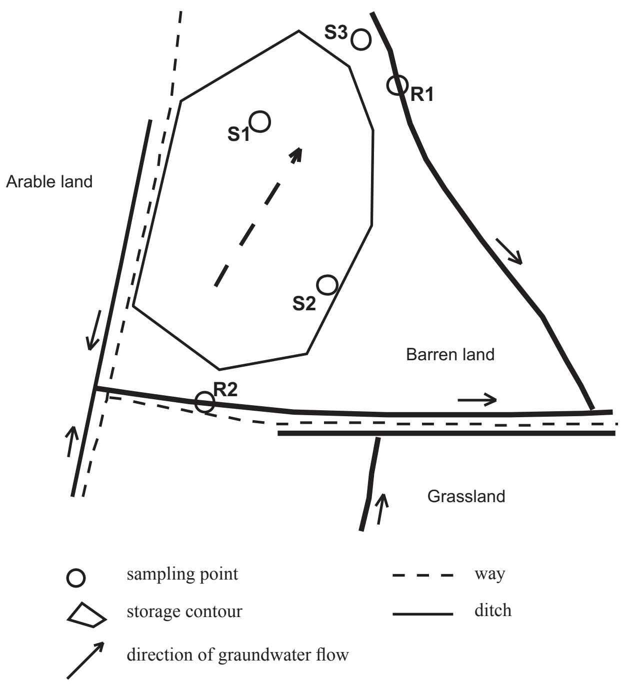


Figure 1. Outline location of FYM storage on the ground together with the sampling points of waters.

DOC concentration in the samples was determined colorimetrically, using a segmented flow of the stream (S.F.A.S.) using the autoanalyser manufactured by "Skalar". The process of determining the DOC, after filtration through a 0.45 µm filter was performed in the following stages (Skalar Methods, catnr. 311-411):

1) Acidification of the samples with sulfuric acid and removing non-organic carbon by the stream of dry nitrogen;
2) Subjecting the samples to UV radiation in the presence of buffered potassium persulfate resulting in the release of carbon dioxide from dissolvable compounds of organic carbon;
3) The dialysis of the sample at the presence of hydroxylamine hydrochloride, during which carbon dioxide passes through a gas-permeable silicone membrane, reducing the pH of phenolphthalein indicator solution which due to the acidification solution gets discoloured in proportion to the concentration of dissolved organic carbon in the sample;
4) The measurement of the intensity of discoloration of the phenolphthalein solution in 30 mm flow cuvette at the wave length of λ = 550 nm.

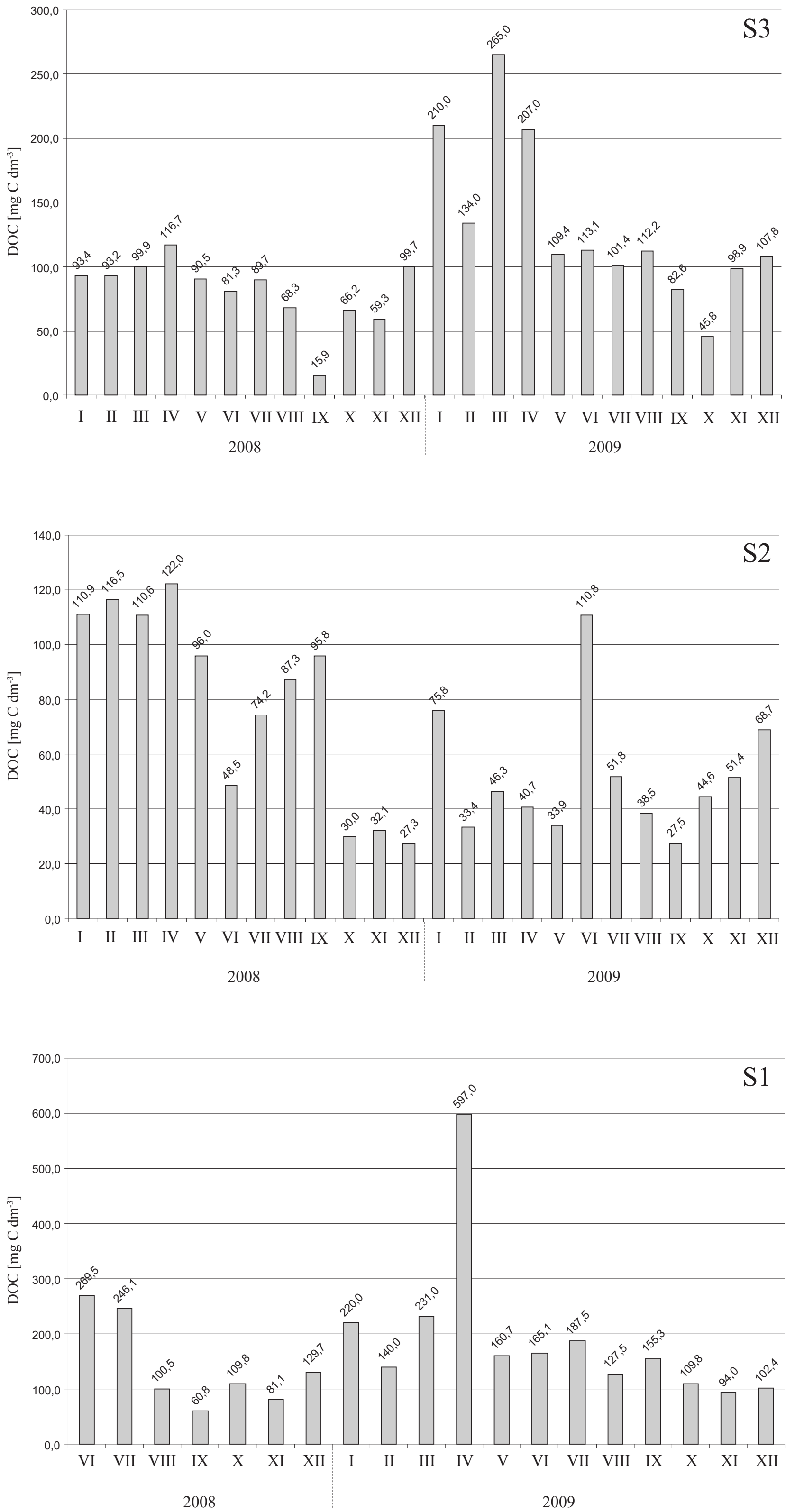
RESULTS AND DISCUSSION

In the result of manure storage directly on the sandy soil there was also a significant enrichment of ground water in DOC in the zone of its impact. This impact varied depending on the year of the research and the localization of a monitoring point. The highest average level of DOC (134.8 mg C dm^{-3} in 2008 and 189.0 mg C dm^{-3} in 2009) was found in ground water from S1 well, located in the main part of the stockpiling site. The lowest average level of DOC was found in sampling well S2, located on the edge of the landfill (Fig. 1). It was 79.3 mg C dm^{-3} in 2008, and 50.7 mg C dm^{-3} in 2009, which was the lowest average level of this component during the whole study period (Table 2). In 2009 a significant increase of groundwater content of DOC (135.1 mg C dm^{-3}) was recorded in the well situated outside the S3 landfill in comparison with 2008 (81.2 mg C dm^{-3}). It can be explained by significant changes in the amount and distribution of precipitation in the years of study, and therefore by a different rate and direction of the spread of this element with groundwater.

In other studies located in the vicinity of the study site (in the distance of approximately 1200 m), carried out in 2008/2010 on a meadow experiment – with no natural but only mineral fertilizers being used, it was determined that in the samples of shallow groundwater (n=60), the concentration of DOC was 8.58 mg C dm^{-3} (Burzyńska, 2010). So, by comparison, the concentrations of DOC at and close to the manure stockpiling site were much higher. When considered on a monthly basis the largest concentration of DOC was determined in water taken from well S1 for the spring months of 2009 – April (597.0 mg C dm^{-3}), with PWG (level of groundwater table) -26 cm being also one of the highest (Fig. 3), and March (231.0 mg C dm^{-3}), PWG -11 cm. A similar tendency was observed for well S3 – March (265.0 mg C dm^{-3}), PWG -45 cm. In the case of point S2, situated on the periphery of the site, the largest concentrations of DOC occurred in the first four months of 2008 and June 2009 (Fig. 2). A high variation, both month-to-month and year-to-year, can be explained by a significant variability in the amount and distribution of precipitation in the period of the research (Table 1), which contributed to considerable changes in groundwater level (Fig. 3).

Generally, we can observe (Fig. 2) higher concentration of DOC in winter – spring season, but it was dependent on the location of the monitoring point.

It must be noted that the results of previously conducted studies at the same study site showed that the groundwater occurring within its area was also substantially contaminated with fertilizer components. On average, in the water samples taken from the period of 7 months up to 13 months, depending on the localization of monitoring point were: 2.7–25.9 mg $P\text{-}PO_4$ dm^{-3}, 3.0–73.4 mg $N\text{-}NO_3$ dm^{-3}, 6.7–11.0 mg $N\text{-}NH_4$ dm^{-3}, 175.0–1085.1 mg K dm^{-3}



S1, S2, S3 – see Fig. 1

Figure 2. DOC concentration in water samples from various points at a former FYM on-ground storage site from January 2008 to December 2009.

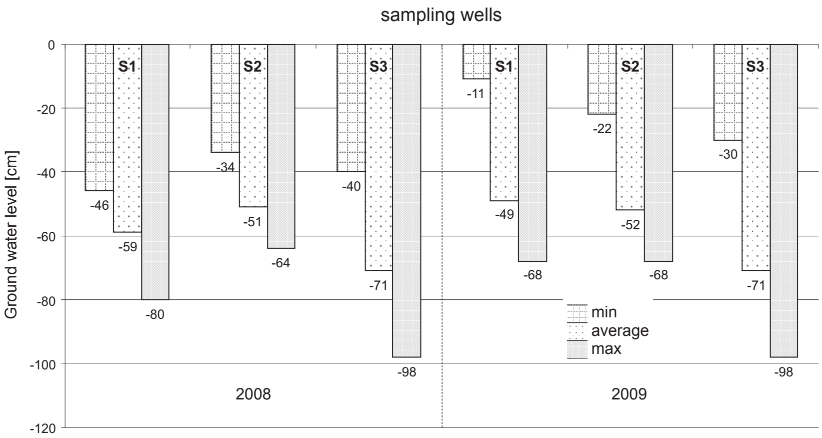


Figure 3. Average level of groundwater table in the sampling wells as measured in 2008 and 2009.

(Pietrzak, Nawalany, 2009). The most polluted was water from the well situated in the centre of the stockpile. The content of nitrate nitrogen, ammonium nitrogen, phosphate phosphorus and potassium exceeded the limits accepted in the ruling by the Minister for the Environment of July 23, 2008 (Rozporządzenie Ministra..., 2008) for groundwater of class V.

In watercourses situated in the vicinity of the research area (Fig. 1), average annual concentrations of DOC from the ditches were respectively 6.6 mg C dm^{-3} and 10.5 mg C dm^{3} in different years. The content of DOC in surface water from the nearest ditches was much smaller than in water from sampling wells (Fig. 2). Those contents were close to the amounts of dissolvable organic carbon measured in soil solutions by other researchers (Kalbitz et al., 2001; Łabętowicz, 1995). In nearby watercourses, the highest level of DOC was determined in the initial months of the year (February – 18.3 mg C dm^{-3}, March – 20.3 mg C dm^{-3}), while the smallest in September 1.2 mg C dm^{-3} (Table 2).

Table 2. The average content of DOC in groundwater and surface water in 2008 and 2009 in monitoring points.

Monitoring point	Year	Number of samples	DOC content [mg C dm^{-3}] in ground and surface water			
			mean	SD	max	min
S1	2008	7	134.8	92.8	269.5	6.8
	2009	12	189.0	129.5	597.0	94.0
S2	2008	12	79.3	35.8	122.0	27.3
	2009	13	50.7	22.8	110.8	27.5
S3	2008	12	81.2	26.2	116.7	15.9
	2009	13	135.1	60.8	265.0	45.8
R1	2008	9	9.7	4.2	18.3	5.6
	2009	8	12.5	5.7	20.3	5.1
R2	2008	8	3.5	1.5	5.6	2.0
	2009	12	8.5	7.5	20.2	1.2

S – wells
R – ditches
SD – standard deviation

Intensity of the transformation of organic matter from organic fertilizers, and thus dispersion processes of carbon compounds, can be to a large extent conditioned by basic conditions of soil-water and meteorological factors. One of the factors which can contribute to an increased carbon transformation in the soil, and thus to the presence of larger amounts of soluble organic compounds in soil is water outflow from the soil profile and fluctuations in groundwater table (Kalbitz et al., 2001; Wolt, 1994; Trojanowski, 1973). Groundwater level is presented on the chart (Fig. 3). Despite significant seasonal fluctuations in groundwater and DOC content (Fig. 2), no statistically significant correlation coefficients were obtained between the level of ground water and the concentration of DOC in the water. It could be caused by the time lag of the impact of PWG on the mobilization of dissolvable organic carbon from the soil. A similar view is expressed by Zsolnay (2001), who points also to the fact that soluble form of organic matter, despite constituting a relatively small part (<1%) of the total amount of carbon in the soil, is extremely mobile and can be an excellent indicator of changes of organic carbon in soils.

Our results indicate that the impact of agricultural practices and of livestock production, in particular, on pollution of groundwater with dissolved organic carbon may be very large. It is also confirmed by the results of other, more comprehensive studies carried out on dairy farms in the US. It was shown there that the average concentrations of DOC in ground water were (Chomycia et al., 2008):

- next to ponds for storage of liquid manure – 27.5 (13.0–55.0) mg C dm^{-3},
- in paddocks for animals – 16.9 (8.0–30.0) mg C dm^{-3},
- on fields fertilized with manure – 7.6 (4.0–15.0) mg C dm^{-3},
- at drainage pipe outlets to the drainage channel 10.0 (5.0–12.0) mg C dm^{-3}.

The lack of unequivocal results defining the role of dissolved organic carbon in the movement and accumulation of minerals in the water prompted this study aimed at a better identification of this phenomenon

CONCLUSIONS

1. Long-term storage of manure directly on the ground causes significant pollution of soil and groundwater with soluble organic carbon.
2. Fluctuations in the groundwater level are not unequivocally related to the seasonal variations of dissolvable organic carbon.
3. Although dissolved organic carbon is not yet an official indicator of water quality, its large quantities observed in groundwater appear not to be without impact on its quality.
4. The principles of long-term storage of manure on the ground must be re-examined in the light of environmental protection requirements.

REFERENCES

Aiken G., 2002. Organic Matter in Ground Water. In: U.S. Geological Survey Artificial Recharge Workshop Proceedings, April 2-4, 2002, Sacramento, California. George R. Aiken and Eve L. Kuniansky, editors, pp. 21-24, http://water.usgs.gov/ogw/pubs/ofr0289/ofr0289.pdf

Burzyńska I., 2010. Wpływ użytkowania i nie użytkowania łąkowego na wartość odczynu i zawartość RWO w glebie łąkowej w aspekcie przenikania składników mineralnych do płytkich wód gruntowych. Sprawozdanie z realizacji zadania badawczego nr 2.8 za rok 2010. Falenty: ITP, Zakład Ochrony Jakości Wody, grudzień 2010. (typescript)

Chomycia J.C., Hernes P.J., Harter T., Bergamaschi B.A., 2008. Land management impacts on dairy-derived dissolved organic carbon in ground water. J. Environ. Qual., 2008 Feb. 11; 37(2): 333-43.

Gooddy D., Hinsby K., 2007. Dissolved organic carbon in European groundwaters. In: EGU General Assembly, Vienna, Austria, 16-20 April 2007. Geophysical Research Abstracts, Volume 9, European Geosciences Union. http://nora.nerc.ac.uk/4890/. (lecture)

Kalbitz K., Rupp H., Meissner R., 2001. N-, P-, and DOC – dynamics in soil and groundwater after restoration of intensively cultivated fens. In: Wetlands in Central Europe, Soil organisms, soil ecological processes and trace gas emissions. Eds.: Broll G., Merbach W., Pfeiffer, E.-M., 99-116, Springer, Berlin, Heidelberg, New York.

Łabętowicz J., 1995. Skład chemiczny roztworu glebowego w zróżnicowanych warunkach nawożenia. Zesz. Nauk. AR Kraków, 421a: 245-253.

Pietrzak S., Nawalany P., 2009. Ocena stanu jakości wód będących pod wpływem oddziaływania długoletniego składowania obornika bezpośrednio na gruncie. Zesz. Eduk., Wyd. IMUZ, 12/2009: 143-150.

Rozporządzenie Ministra Środowiska z dnia 23 lipca 2008 r. w sprawie kryteriów i sposobu oceny stanu wód podziemnych. Dz.U. z 2004 r. Nr 143, poz. 896.

Silveira M.L.A., 2005. Dissolved organic carbon and bioavailability of N and P as indicators of soil quality. Sci. Agric. (Piracicaba, Braz.), 62(5): 502-508.

Skalar Methods, catnr. 311-411 issue 110600/MH/9921477.

Szymczak T., Klasicka E., 2008. Raport: Charakterystyka klimatyczna Falent na podstawie obserwacji na stacji meteorologicznej IMUZ w roku hydrologicznym i kalendarzowym 2008. Zakład Zasobów Wodnych – IMUZ.

Szymczak T., Klasicka E., 2009. Raport: Charakterystyka klimatyczna Falent na podstawie obserwacji na stacji meteorologicznej IMUZ z uwzględnieniem pomiarów automatycznych w roku hydrologicznym 2009. Zakład Zasobów Wodnych – IMUZ.

Trojanowski J., 1973. Przemiany substancji organicznej w glebie. Warszawa, PWRiL.

Wolt J., 1994. Soil solution chemistry. Applications to Environmental Science and Agriculture. John Wiley & Sons, INC. New York, pp. 275-293.

Zsolnay A., 2001. The prediction of the environmental function of the dissolved organic matter (DOM) in ecosystems. ESF Exploratory Workshop, Beilngries, Germany, Sei, Report, pp. 1-18.

Skład i druk:
Dział Upowszechniania i Wydawnictw IUNG-PIB
ul. Czartoryskich 8, 24-100 Puławy
tel. (81) 8863421 w. 301, faks (81) 8863421 w. 302, e-mail: duw@iung.pulawy.pl

IUNG-PIB – zam. 74/B/11
format A4, 280 egz.