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THE GAS EXCHANCHE AND YIELDING OF STRAWBERRY PLANTS CULTIVATED IN BLACK SOIL AND SANDY SOIL WITH THE ADDITION OF HYDROGEL

Małgorzata Makowska, Edward Borowski*, Anna Ziemba*
University College of Arts and Natural Science in Sandomierz
*University of Agriculture in Lublin

Abstract. The influence of the addition of Potassium Ekosorb to black soil and sandy soil on water content in soils, gas exchange in leaves and yielding of strawberry plants cultivar Senga Sengana, Dukat, Kent and Elsanta was estimated in a field experiment. The obtained results show that the addition of hydrogel increased content of water in both types of soil; however, the effect was on average twice higher in black soil than in sandy soil. The highest stomatal conductance of leaves, photosynthesis and transpiration were observed in plants cultivated in both black and sandy soil with the addition of 3 g dm^{-3} of hydrogel. The addition of higher dose influenced in an ambiguous way on the values of analyzed features of leaves. Yet, regardless of the applied dose of Ekosorb, the stomatal conductance, transpiration and photosynthesis of plants cultivated in black soil were 1.8–2.9 times higher than in sandy soil. The highest yields of fruit on both types of soil were obtained from plants which took advantage of presence of 3 g dm^{-3} of hydrogel. The application of 6 g dm^{-3} influenced on decreasing of plant yields. The weakest reaction on both types of soil occurred in strawberry cultivar Elsanta.

Keywords: strawberry, hydrogel, water content, gas exchange, yielding

INTRODUCTION

The cultivation of strawberry in Poland has got long-term tradition and our country belongs to the greatest producers of fruit of this species in the world. The average long-term yield runs at the level of 204 thousand tones, which places Poland in the first five world producers of those fruit. The plantations of strawberry in Poland in 2003 occu-

Corresponding author – Adres do korespondencji: Małgorzata Makowska, University College of Arts and Natural Science in Sandomierz, 26 Krakowska Street, 27-600 Sandomierz, Poland, e-mail: wshp@wshp.sandomierz.pl; Edward Borowski, Anna Ziemba, University of Agriculture in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland

pied as much as 43931 hectares, yet the average yield amounted only 3 t ha^{-1}. The causes should be looked for in cultivation of strawberry on small farms without the possibility of irrigation of plantation in the periods of drought, which is of a vital importance as this plant is very sensitive to periodical deficiency of water. This can influence both on yield and its quality [Hołubowicz and Rebandel 1997]. Water makes up one of the basic factors of photosynthesis determining yielding of plants through the influence on the activity of Calvin reaction [Muller et al. 1986, Grzesiak et al. 1989, Gej et al. 1994, Leport et al. 1998, Michałek and Borowski 1998, Nunez-Barrios et al. 1998, Shang and Li 1998, Mwanamwenge et al. 1999, Pankovic et al. 1999, Xing et al. 1999]. The delivery of water to plants can be improved by the addition of hydrogels to soil. Those components are characterized by great ability of storing of water [Hetman and Martyn 1996, Słowińska-Jurkiewicz and Jaroszuk 1996], which is absorbed during rainfall and then can be donated to plants. The addition of hydrogels to soil increases the yield of plants through the beneficial influence on stomatal conductance of leaves, transpiration and photosynthesis [Świetlik 1989, Borowski and Michałek 1998, Borowski and Makowska 2000]. The influence of hydrogels on discussed processes is ambiguous as there are some works, in which the addition of hydrogel either did not influence on plant growth [Keever et al. 1989, Awad et al. 1995] or influenced negatively [Austin and Bondari 1992].

The aim of these studies was to estimate the influence of the addition of diverse doses of Potassium Ekosorb to black soil and sandy soil on gas exchange in strawberry leaves and yielding.

MATERIAL AND METHODS

An investigation was carried out under field conditions on a farm in Beszyce place near Sandomierz during the period of 1999–2001. "Fresh" strawberry root cuttings of the Senga Sengana, Dukat, Kent, and Elsanta cultivars, whose shoots were 12 cm high, were planted in two soil types: black soil with clay skimmed layer and sandy soil, in three replications on each type of soil on plots of the dimension of 1.0 × 2.0 m each. Plants were planted in the distance of 0.5 × 0.25 m. Each replication consisted of 16 plants. After the rows of soil 25 cm wide and 20 cm deep had been marked out, the soil was scooped and mixed up with hydrogel in the amount of either 3 or 6 g per dm^3 of soil. The plots without the addition of hydrogel were the control. The rows were filled with the mixture and the soil was lightly crumpled. There were approximately 9.5 dm^3 of soil with hydrogel per one plant. Before the plants were planted, the soil had been heavily watered three times in one-day intervals. The further cultivation and protection of plants through the whole experimental period were conducted due to agricultural science recommendations. In the years 2000 and 2001 the content of water in the layer 0–40 cm of soil was evaluated with a drying-weight method on the base of samples obtained in the middle of each month from April to September. Observations concerned the determination of the course of gas exchange in leaves of strawberry plants at the beginning of blooming period, as well as the yield of fruit. The measurements of gas exchange (stomatal conductance, transpiration and photosynthesis) were conducted in

the field conditions with the usage of mobile gas analyser LCA-4 [ADC,Great Britain] cooperating with universal camera PLC-4 [the same firm]. Analysis were conducted at midday at light intensity of PAR range of 1400-1800 µmol m^{-2} s^{-1} and the temperature inside the camera of 28–30ºC. The measurements were done on 10 random chosen plants, choosing one young, yet fully grown-up leaf. The yield was determined as a result of successive harvests of the ripe fruit from 10 random chosen plant from each experimental plot. The values of stomatal conductance, transpiration, photosynthesis and yielding obtained in the experiment were statistically analysed using the method of triple cross classification and Tukey's confidence intervals. Means statistically different were labelled in the tables with different letters.

RESULTS AND DISCUSSION

The results presented in figure 1 show that Potassium Ekosorb added to both types of soils visibly increased the percentage content of water. During the vegetative period the average (from years 2000 and 2001) hydration of black soil without hydrogel

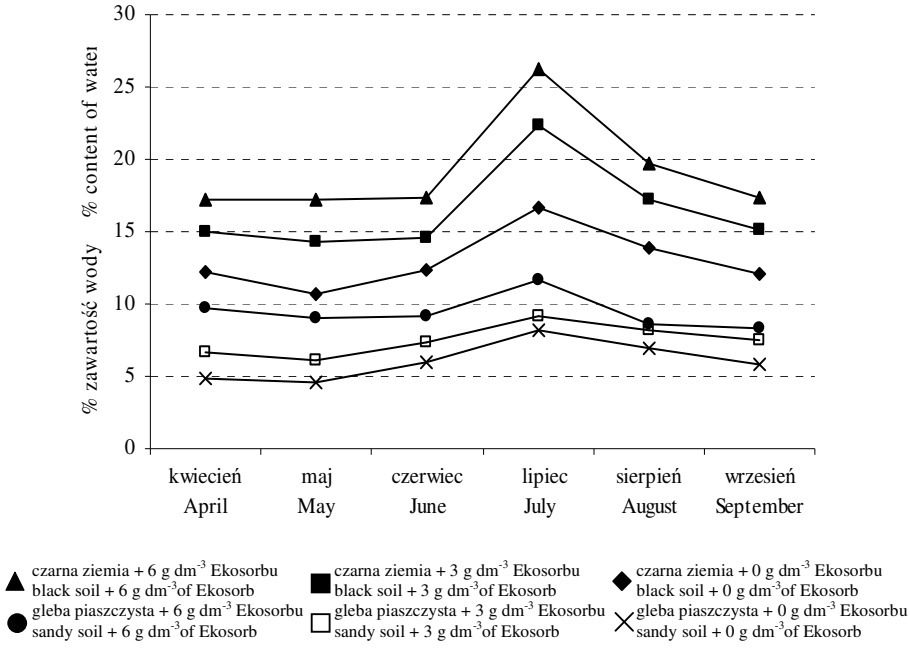

Fig. 1. Percentage content of water in black soil and sandy soil with addition of Ekosorb in layer 0–40 cm (mean for years 2000–2001)

Rys. 1. Zawartość procentowa wody w czarnej ziemi i glebie piaszczystej z dodatkiem Ekosorbu w warstwie 0–40 cm (średnia z lat 2000–2001)

amounted 13,0%, while of soil with the addition of 3 and 6 g dm^{-3} of Ekosorb adequately 16.3% and 18.9%. The similar influence of hydrogel addition was observed in sandy soil. In that case the content of water in soil without hydrogel amounted 6.0%, while it was 1.5% higher in soil with the addition of 3 g dm^{-3} of Ekosorb (7.5%), and 3.2% higher with 6 g dm^{-3} of Ekosorb (9.2%). Both soils contained the highest amount of water in the middle of the vegetative period (June-August), less at the beginning and the end of plant growth period. The high ability of water storing by horticultural grounds and soils with the addition of hydrogel was also estimated by Hetman and Martyn [1996], Słowińska-Jurkiewicz and Jaroszuk [1996], Borowski and Michałek [1998] as well as Borowski and Makowska [2000]. The increased content of water in both types of soil containing hydrogel in relation to control (without hydrogel) was undoubtedly the source of increased stomatal conductance of leaves, transpiration and photosynthesis in plants growing in those conditions. Since the obtained results has shown that, in the relation to control conditions, plants growing in black soil with the addition of 3 g dm^{-3} of hydrogel showed 42.8% higher stomatal conductance in leaves in 2000, and 40.0% higher in 2001 (tab. 1). Plants growing in sandy soil showed the similar reaction. In that case the increase of analyzed feature amounted 166.7% in 2000 and 175% in 2001. The influence of higher dose of hydrogel (6 g dm^{-3}) on stomatal conductance was visibly less because the value of that feature increased significantly in plants grown in black soil only in 2000. In other cases the influence appeared insignificant. Plants of Dukat cultivar showed the highest stomatal conductance, while 'Elsanta' the lowest one.

Table 1. The effect of Ekosorb addition to black soil and sandy soil on stomatal conductance of strawberry leaves (mol H_2O m^{-2} s^{-1})

Tabela 1. Wpływ dodatku Ekosorbu do czarnej ziemi i gleby piaszczystej na przewodność szparkową liści truskawki (mol H_2O m^{-2} s^{-1})

Soil Gleba (A)	Ekosorb dose Dawka Ekosorbu (g dm^{-3}) (B)	Cutlivar Odmiany (C)				Mean for A×B Średnia dla A×B	Mean for A Średnia dla A
		Senga Sengana	Dukat	Kent	Elsanta		
				2000 r.			
Black soil Czarna ziemia	0	0.12	0.18	0.15	0.11	0,14a	
	3	0.18	0.24	0.20	0.19	0,20b	0.17b
	6	0.17	0.23	0.18	0.16	0,18b	
Sandy soil Gleba piaszczysta	0	0.04	0.02	0.03	0.03	0,03a	
	3	0.08	0.12	0.07	0.06	0,08b	0.05a
	6	0.05	0.07	0.06	0.04	0,05a	
Mean for C Średnia dla C		0.11a	0.14b	0.11a	0.10a		
				2001 r.			
Black soil Czarna ziemia	0	0.14	0.17	0.16	0.13	0,15a	
	3	0.22	0.23	0.21	0.20	0,21b	0.17b
	6	0.16	0.15	0.15	0.16	0,15a	
Sandy soil Gleba piaszczysta	0	0.04	0.05	0.05	0.04	0,04a	
	3	0.12	0.11	0.10	0.10	0,11b	0.07a
	6	0.04	0.05	0.5	0.05	0,05a	
Mean for C Średnia dla C		0.12ab	0.13b	0.12ab	0.11a		

The transpiration of plants remained in close relation to the percentage content of water in analyzed soils. The intensity of water loss from plants grown in black soil was almost twice higher than in sandy soil (tab. 2). However, plants growing in both soils with the addition of 3 g dm-3 of hydrogel showed the most intensive transpiration. In 2000 the rate of discussed process was at 39.7% in black soil and 60.1% in sandy soil higher than in control conditions. Respectively, in 2001 the data for black soil amounted 50.6% and for sandy soil 43.6%. The addition of higher hydrogel dose influenced on the significant increase of transpiration only in 2000. Then the intensity of that process increased at 21.8% in black soil and 31.5% in sandy soil. In 2000 Kent cultivar lost water the most intensively and in 2001 'Dukat' did. 'Elsanta' lost water the least intensively.

Table 2. The effect of Ekosorb addition to black soil and sandy soil on transpiration of strawberry plants (mmol H_2O m^{-2} s^{-1})

Tabela 2. Wpływ dodatku Ekosorbu do czarnej ziemi i gleby piaszczystej na transpirację roślin truskawki (mmol H_2O m^{-2} s^{-1})

Soil Gleba (A)	Ekosorb dose Dawka Ekosorbu (g dm^{-3}) (B)	Cutlivar Odmiany (C)				Mean for A×B Średnia dla A×B	Mean for A Średnia dla A
		Senga Sengana	Dukat	Kent	Elsanta		
				2000 r.			
Black soil Czarna ziemia	0	2.96	3.81	3.79	3.05	3.40a	4.10b
	3	4.64	5.28	5.18	3.92	4.75c	
	6	4.48	3.89	4.61	3.57	4.14b	
Sandy soil Gleba piaszczysta	0	2.11	1.52	1.97	1.51	1.78a	2.32a
	3	2.86	3.35	3.41	1.78	2.85c	
	6	2.76	2.66	2.35	1.58	2.34b	
Mean for C Średnia dla C		3.30b	3.42c	3.55d	2.57a		
				2001 r.			
Black soil Czarna ziemia	0	3.21	3.68	3.49	3.32	3.42a	4.03b
	3	5.12	5.44	5.10	4.93	5.15a	
	6	3.35	3.48	3.58	3.64	3.51a	
Sandy soil Gleba piaszczysta	0	1.87	1.96	1.92	1.78	1.88a	2.16a
	3	2.92	2.86	2.54	2.47	2.70b	
	6	1.95	2.02	1.98	1.72	1.92a	
Mean for C Średnia dla C		3.07a	3.24b	3.10a	2.98a		

The process of CO_2 assimilation was closely determined by stomatal conductance of leaves. Hence the average rate of photosynthesis of plants grown in black soil was almost three times more intensive than in sandy soil (tab. 3). However, the addition of Ekosorb to both soils changed the intensity of CO_2 bonding significantly. In both experimental years hydrogel in dose of 3 g dm^{-3} increased the photosynthesis of strawberry in a significant way. In 2000 that increase for black soil and sandy soil amounted respectively 6.9% and 132.8% and in 2001 – 32.1% and 119.8% in relation to the control. The addition of higher dose of hydrogel (6 g dm^{-3}) decreased the value of analyzed feature for plants grown in black soil significantly, while increased for plants in sandy soil (on average by 40.4%). Strawberry plants of 'Senga Sengana' and 'Dukat' assimilated CO_2 the most efficiently, while 'Elsanta' significantly worse.

Table 3. The effect of Ekosorb addition to black soil and sandy soil on photosynthesis of strawberry plants (µmol CO_2 m^{-2} s^{-1})

Tabela 3. Wpływ dodatku Ekosorbu do czarnej ziemi i gleby piaszczystej na fotosyntezę roślin truskawki (µmol CO_2 m^{-2} s^{-1})

Soil Gleba (A)	Ekosorb dose Dawka Ekosorbu (g dm^{-3}) (B)	Cutlivar Odmiany (C)				Mean for A×B Średnia dla A×B	Mean for A Średnia dla A
		Senga Sengana	Dukat	Kent	Elsanta		
				2000 r.			
Black soil Czarna ziemia	0	12.63	11.21	10.68	9.20	10.93b	
	3	12.88	11.31	11.68	10.88	11.69c	11.05b
	6	10.95	10.78	10.94	9.43	10.52a	
Sandy soil Gleba piaszczysta	0	2.59	2.12	3.19	1.52	2.35a	
	3	5.98	7.34	6.15	2.42	5.47c	3.92a
	6	5.02	5.36	3.29	2.05	3.93b	
Mean for C Średnia dla C		8,34d	8.02c	7.65b	5.92a		
				2001 r.			
Black soil Czarna ziemia	0	10.56	11.38	11.06	10.39	10.85b	
	3	13.94	13.62	13.06	12.83	13.36c	11.52b
	6	10.44	10.37	10.42	10.22	10.36a	
Sandy soil Gleba piaszczysta	0	2.66	2.91	2.88	2.45	2.72a	
	3	6.71	6.22	5.94	5.05	5.98c	3.93a
	6	3.14	3.26	3.07	2.89	3.09b	
Mean for C Średnia dla C		7.91b	7.96b	7.74b	7.30a		

The obtained data concerning the course of gas exchange in the condition of diverse percentage content of water in black soil and sandy soil have confirmation in some studies of other authors. Muller et al. [1986], Grzesiak et al. [1989], Gej et al. [1994], Mwanamwenge et al. [1999] in studies on broad bean; Nunez-Barris et al. [1998], Shang and Li [1998], Xing et al. [1999] on common bean; Pankovic et al. [1999] on sunflower, Michałek and Borowski [1998] on soya bean; Leport et al. [1998] on several leguminous plant species; affirmed the decrease of stomatal conductance in leaves as well as photosynthesis during water deficiency in soil. Interestingly, that regularity occurred only at the addition of hydrogel to soil in a dose of 3 g dm^{-3}. Although the addition of Ekosorb in a dose of 6 g dm^{-3} increased the content of water in both soils by further over 2.0%, yet caused the opposite effect. However, it is worth to remember that the evaluation of water content with the drying-weight method shows its whole content. But in soil except of accessible water, there is some inaccessible for plants. While hydrogels, as it follows from the studies of Hetman and Martyn [1996] as well as Słowińska-Jurkiewicz and Jaroszuk [2001], absorb only a part of water in a way that it can be used by plants. According to Słowińska-Jurkiewicz and Jaroszuk [2001] the retention of inaccessible water in hydrogel called 'Hidroplus' at its full hydration is even a little higher than the retention of accessible for plants. However, at partial hydration of hydrogel, which obviously occurs the most frequently in field conditions, the amount of inaccessible water increases while the amount of accessible one decreases. Therefore, it can be assumed that the higher dose of these substances is added to soil there is less accessible water for plants in it.

Table 4. The effect of Ekosorb addition to black soil and sandy soil on yielding of strawberry plants (g plant^{-1})

Tabela 4. Wpływ dodatku Ekosorbu do czarnej ziemi i gleby piaszczystej na plon owoców truskawki (g roślina^{-1})

Soil Gleba (A)	Ekosorb dose Dawka Ekosorbu (g dm^{-3}) (B)	Cutlivar Odmiany (C)				Mean for A×B Średnia dla A×B	Mean for A Średnia dla A
		Senga Sengana	Dukat	Kent	Elsanta		
				2000 r.			
Black soil Czarna ziemia	0	274.1	331.7	273.5	275.5	288.7b	314.2b
	3	563.1	377.0	422.4	430.1	448.1c	
	6	266.6	278.1	280.0	278.8	205.9a	
Sandy soil Gleba piaszczysta	0	18.6	20.2	12.8	3.2	13.7a	10.1a
	3	27.6	13.7	7.1	2.1	12.6a	
	6	5.7	4.2	5.8	0.0	3.9a	
Średnia dla C Mean for C		192,6a	170.8a	166.9a	166.5a		
				2001 r.			
Black soil Czarna ziemia	0	524.0	600.9	482.7	406.5	503.5a	547.1b
	3	641.5	804.1	729.1	487.4	665.5b	
	6	368.5	561.1	524.3	434.8	472.2a	
Sandy soil Gleba piaszczysta	0	236.6	213.2	196.2	215.1	215.3a	230.9a
	3	306.7	266.0	233.7	239.9	261.6b	
	6	225.7	240.1	195.6	201.4	215.7a	
Mean for C Średnia dla C		383,8b	447.6c	393.6	330.9a		

As the addition of Ekosorb influenced on the course of gas exchange in plants, especially the photosynthesis, it also determined the yield of plants significantly. The fruit yield obtained in 2001 from plants grown in black soil with the addition of 3 g dm^{-3} was at 32.3% and in sandy soil at 21.5% higher than in soils without hydrogel (tab. 4). However, the application of higher dose of Ekosorb did not influence on the yielding of plants significantly. The yield in 2000, especially in sandy soil, was several times lower than in 2001, which was caused by spring ground frost during the period of blooming. Especially serious injuries (80%) occurred in experiment with sandy soil which was situated in the hollow of the ground where the frost marginal lake could be formed [Makowska and Borowski 2004]. However, also in 2001 the highest yield was obtained in experiment with black soil with the addition of 3 g dm^{-3} and the lowest yield – with the addition of 6 g dm^{-3} of hydrogel (tab. 4). The beneficial influence of the addition of hydrogel to horticultural grounds and soils on yielding of plants was estimated by Świetlik [1989], Borowski and Michałek [1998] as well as Borowski and Makowska [2000]. In the light of carried out studies, the lack of influence of the addition of hydrogels on growth and yielding of plants [Keever et al. 1992, Awad et al. 1995] or even the negative one [Austin and Bondari 1992] could be a result either of application of too high doses of hydrogel or too little rainfall in field conditions. In 2000, the influence of cultivar on the amount of yield was not significant, but in the following year 'Dukat' gave the highest yield and 'Elsanta' the lowest one.

CONCLUSIONS

1. The addition of Potassium Ekosorb to soils increases their content of water in a level dependent on natural water capacity of soils.

2. As only a part of water bonded by hydrogel is accessible for plants, Potassium Ekosorb influences on the course of gas exchange and yielding of strawberry beneficially in dose of 3 g dm^{-3}. The influence of the dose of 6 g dm^{-3} is ambiguous (gas exchange) or even negative (yield of fruit).

3. The strawberry plants of Elsanta cultivar react on the addition of Potassium Ekosorb in the weakest way.

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WYMIANA GAZOWA I PLONOWANIE ROŚLIN TRUSKAWKI UPRAWIANYCH W CZARNEJ ZIEMI I GLEBIE PIASZCZYSTEJ Z DODATKIEM HYDROŻELU

Streszczenie. W doświadczeniu polowym badano wpływ dodatku Ekosorbu potasowego do czarnej ziemi i gleby piaszczystej na zawartość wody w glebach, przebieg wymiany gazowej w liściach i plonowanie roślin truskawki odmian Senga Sengana, Dukat, Kent i Elsanta. Uzyskane wyniki wykazały, że dodatek hydrożelu zwiększył w okresie wegetacyjnym zawartość wody w obu glebach, jednakże ten wpływ był średnio dwukrotnie większy w czarnej ziemi niż glebie piaszczystej. Najwyższą przewodność szparkową liści, transpirację i fotosyntezę wykazywały rośliny uprawiane w czarnej ziemi i glebie piaszczystej z dodatkiem 3 g dm^{-3} hydrożelu. Dodatek do obu gleb wyższej dawki hydrożelu wywierał niejednoznaczny wpływ na wartość analizowanych cech liści. Niezależnie jednak od dawki zastosowanego Ekosorbu średnia przewodność szparkowa liści, transpiracja i fotosynteza roślin wyrosłych w czarnej ziemi była od 1,8 do 2,9-krotnie wyższa niż w glebie piaszczystej. Najwyższy plon owoców na obu typach gleb wydały rośliny korzystające z dodatku 3 g dm^{-3} hydrożelu. Zastosowanie dawki 6 g dm^{-3} spowodowało obniżenie plonowania roślin. Najsłabiej na obu glebach zareagowała truskawka odmiany Elsanta.

Słowa kluczowe: truskawka, hydrożel, zawartość wody, wymiana gazowa, plonowanie

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