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Pre-sowing bacterial treatment and chemical fertilizer application impact on yield capacity and grain quality of hulless (*Avena nuda* L.) and hulled oats (*Avena sativa* L.)

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ABSTRACT

The problems of introduction into practice of intensive oats cultivation technologies in the North-Eastern part of the Forest-Steppe of Ukraine have been considered. The oats plant yield capacity depends on mineral nutrition optimization. It was defined that hulless oat cultivars have more expressed response level of yield capacity on pre-sowing treatment with composition of Diazophyt and Microhumin bacterial fertilizers, that allows to reach closer to the level of hulled oat yield. The highest crop yield (for all cultivars) provided by combination of pre-sowing treatment with Diazophyt + Microhumin composition and application of $N_{60}P_{60}K_{60}$ with foliar nutrition in tillering and panicle forming phase by Nutrivant Plus (2 kg/ha) + Urea (46.2%) 30 kg/ha. The maximum additional yield was fixed in Salomon cultivar with pre-sowing Diazophyt + Microhumin treatment (+0.73-0.75 t/ha). Vegetative development and yield capacity of oats cultivars in the experiment revealed the group reaction dynamics on pre-sowing treatment, doses and ways of fertilizer application under conditions of the North-Eastern Forest-Steppe of Ukraine. The oat cultivar reaction specifies on optimization of zonal growing technologies for hulled and hulless cultivars. Thus, it is considered the possibility of increasing crop yield by improving of cultivation technology separately in the context of hulless and hulled groups of cultivars.

Keywords: fertilizers, hulled cultivars, hulless cultivars, oats, pre-sowing treatment, yield

INTRODUCTION

Oats is one of the principal cereals in the world and it is characterized by great potential. Oats (*Avena sativa* L.) are marked by high nutritional quality, there are lots of proteins, fats, starch and fiber in its seeds (Hartman et al., 1983; Matros et al., 2005). Its grain surpasses other crops in many qualitative indicators. Oats grains are used for making cereals, flakes, flour, lozenges, cookies, coffee drinks and diet foods (Burrows, 2005). It is applied in the pharmaceutical industry as well. (Coffman, 1964; Welch, 1995).

Recently the hulless oats has become more suitable crop due to the absence of grain hulls. Other advantages of hulless cultivars are more balanced chemical composition of grain and quantitative yield parameters compared to hulled ones. (Cuddeford, 1990; Zhao et al., 2011; Ma et al., 2012).

The oats plant yield capacity depends on mineral nutrition optimization. The efficiency of chemical fertilizer application due to its dose and form, soil conditions and content of nutrients (Ohm, 1976; Helin et al., 2006). Chemical fertilizers are important factor not only for increasing the oats yield, but for improving the grain quality as well. (Mahli et al., 1987; Marshall et al., 1987; Mohr et al., 2007).

The use of bacterial fertilizers is one of the main conditions for achieving stability of agroecosystems under environmental stress and low availability of resources (Weller, 1983). Thus, under favorable conditions, bacteria are able to provide the plant with nitrogen. The use of phosphorus mobilizable bacteria increases the amount of dissolved phosphates in the soil. The application of bacterial fertilizers with chemical ones increases the yield capacity of plants, promotes their better growth and development, provides increasing groats grain yield (Merriman et al., 1974; Izsáki, 2004; Gupta et al., 2017).

North-East Forest-Steppe region is the area of Ukraine where there are opportunities for increasing the oats yield due to the effective use of agro-climatic potential and modern intensification methods. To complete the task, it is necessary to do research on determining the optimal impact of chemical and bacterial fertilizers on the growth, development and yield capacity of hulless and hulled oats cultivars.

MATERIALS AND METHODS

The experiments were carried out for three-year vegetative seasons (2015-2017) in the North-Eastern part of the Forest-Steppe of Ukraine on the experimental fields of the Sumy National Agrarian University (SNAU), meeting generally accepted requirements and recommendations for experiments in Ukraine (Yeshchenko et al., 2005).

The soil of the experimental plot is chernozem with a typical heavy-loam medium-humus, which is characterized by the following indicators: the humus content in the arable layer – 4%, the reaction of the soil is close to neutral (pH 6.5), the content of easily hydrated nitrogen – 9 mg, mobile phosphorus and exchangeable potassium – 14 mg and 6.7 mg per 100 g of soil, respectively. This type of soil is typical for significant part of the North-Eastern Forest-Steppe area of Ukraine.

The climate of the region is continental, characterized by unevenly distributed precipitation, medium air humidity, frequent droughts. The average sum of active temperatures above +10 °C (April-August) is 2,568 °C, precipitations - 294 mm, and the hydrothermal coefficient is 1.21. Weather conditions during the years of research differed a little bit in the temperature regime, amount and distribution of atmospheric precipitation, but in general they were typical for the zone of the North-Eastern Forest-Steppe of Ukraine.

Potato was the preceding crop in rotation. Way of sowing – in rows (15 cm width), depth of sowing – 4-5 cm. The seeding rate was 550 seeds/m^2 for hulless cultivars, 500 seeds/m^2 for hulled cultivars. One plot area was 14.4 m^2.

The experimental design included the following factors and their variants (Table 1).

Placement of variants was systematic, in fourfold replicates. The factorial experiment formula was

$$N = L_A \times L_B \times L_C \times n = 5 \times 4 \times 4 \times 4 = 320.$$

Diazophyt (D) is the type of bacterial fertilizer for the pre-sowing seed treatment of cereal crops. It is based on nitrogen fixing bacterium *Agrobacterium radiobacter*. The action of microorganisms is multifaceted: supplying the plants with bounded nitrogen, increasing the energy of seeds germination, forming the better developed root system, intensifying the use of nutrients, increasing the resistance of plants to diseases, growth the content of essential amino acids.

Microhumin (M) belongs to the bacterial fertilizers as well. Its composition includes associative nitrogen-fixing bacteria *Azospirillum brasilense* 18-2 and phosphorus-metabolizing microorganisms. In addition, the fertilizer contains physiologically active substances of biological origin, trace elements in chelating form and microelements.

Both fertilizers are safe for humans and friendly to environment. Nutrivant Plus cereal (NP) is a completely water-soluble complex fertilizer, which is used for foliar spraying of crops for increasing their yield. Its chemical composition (included mg/dm^3: 6 N, 23 P, 35 K, 1 MgO, 0.1 B, 0.2 Mn, 0.2 Zn, 0.2 Cu, 0.05 Fe, 0.002 Mo) is fully

Table 1. Scheme of three-factor field experiment

Variants		
Oats cultivar (Factor A)	Chemical fertilizer application (Factor B)	Pre-sowing seed treatment with bacterial fertilizer (Factor C)
1. Zakat – hulled	1. Without fertilizers – control (c)	1. Without treatment – control (c)
2. Busol – hulled	2. $N_{60}P_{60}K_{60}$ (complex fertilizer, $N_{15}P_{15}K_{15}$, 400 kg/ha rate) before autumn deep tillage	2. “Diazophyt” (100 ml/ha seed rate) (D)
3. Skarb of Ukraine – hulless	3. $N_{60}P_{60}K_{60}$ + foliar nutrition with mixture of “Nutrivant Plus cereal” 2 kg/ha + N_{14} (Urea, N $_{46,2\%}$, 30 kg/ha rate) in phase of BBCH 30-35	3. “Microhumin” (200 g/ha seed rate) (M)
4. Salomon – hulless	4. $N_{60}P_{60}K_{60}$ + 2 foliar nutrition: “Nutrivant Plus cereal” 2 kg/ha + N_{14} in the phase of BBCH 30-35 and “Nutrivant Plus cereal” 2 kg/ha + N_{14} in the phase of BBCH 40-45	4. “Diazophyt” (100 ml/ha seeding rate) + “Microhumin” (200 g/ha seed rate) (D+M)
5. Samuel – hulless		

consistent with the physiology of mineral nutrition of cereal crops.

The observations and analyzes were conducted according to the following methods:

- leaf area was determined according to the accepted methodology in Ukraine (Yeshchenko et al., 2005);
- the content of chlorophyll in the leaves was determined by spectrophotometric method (Yeshchenko et al., 2005);
- the yield was determined on the part of direct harvesting ("VOLVO-830", reconstructed for plot harvesting). Grain yield was calculated based on a cleaned subsample with moisture adjusted to 14%. Thousand seed weight was calculated based on the mass of two subsamples consisting of 500 seeds in each;
- chemical composition of plants and grain quality were determined using the infrared spectrometry method on the infrared analyzer NIP-4500 Scanner 4250 with computer software ADIDM-3114;
- statistical analysis of collected data was done according to the analysis of variance at P≤0.05 by using Statistica 6.0 software (StatSoft, Tulsa, USA).

The test of least significant differences (LSD) was used to compare calculated averages of traits (Steel and Torrie, 1981).

RESULTS AND DISCUSSION

An important parameter characterizing the general condition of sowing and its potential yield is the development of the leaf surface and the level of chlorophyll concentration in the leaves.

In the experiments it was found the average index value of the leaf surface (in order of growth) was 5.42 m^2/m^2 in the Zakat cultivar; 6 in the Samuel cultivar; 6.07 in the cultivar of the Treasure of Ukraine; 6.15 and 6.3 m^2/m^2 in the Busol and Solomon cultivars, respectively. An increase in the dose and intensity of mineral fertilizer application (factor B) was accompanied by the growth in the values of the indicator by 7; 7.7 and 8.1% in variants 2, 3 and 4, respectively. In the context of the factor C, the increase in the index values occurred in the following order: Diazophyt, Microhumin and "D + M" and was equal 8.1; 15.6 and 21%.

Efficiency of photosynthesis is closely connected with the chlorophyll content in leaves, which affects the intensity of this process and accumulation of dry substances. The content of chlorophyll increases proportionally to chemical fertilizers rates and ways of their application. The value of the indicator varied from 3.72 mg/g in the control to 4.45 mg/g in the $N_{60}P_{60}K_{60}$ + 2×N_{14}NP variant. In variants with bacterial fertilizers treatment the chlorophyll content varied from 3.97 to 4.31 mg/g. The maximum increase (+8.6%) was determined in the variant with pre-sowing seed treatment with Diazophyt + Microhumin.

The integral indicator of these parameters is the chlorophyll content per leaf area unit (Table 2). Traditionally, the index of chlorophyll content determines the actual intensity of photosynthesis, and an increase of chlorophyll concentration is an identical increase in the area of leaf surface. In the experiment of the chemical and bacterial fertilizers impact of the indicator value varied from 4.04 to 8.23 g/m^2.

Table 2. The content of chlorophyll per leaf area unit depending on chemical and bacterial fertilizers (g/m^2); average for 2015-2017

Variants		Oats cultivar (Factor A)					Average	
Chemical fertilizers application (Factor B)	Seed treatment (Factor C)	Zakat	Busol	Skarb of Ukraine	Salomon	Samuel	Factor B	Factor C
Without fertilizers – control (C)	Without treatment (c)	4.68	4.04	4.38	4.54	4.18	5.43	5.46
	D	4.78	5.65	5.12	5.09	4.93		6.07
	M	5.8	6.29	5.46	5.6	6.26		6.59
	D+M	6.42	6.58	5.68	7.08	6.04		7.21
$N_{60}P_{60}K_{60}$	Without treatment (c)	4.84	5.68	5.62	6.89	5.42	6.31	×
	D	4.97	6.36	5.74	7.02	5.43		
	M	5.89	6.48	6.76	7.14	7.02		
	D+M	6.55	7.33	6.26	7.65	7.21		
$N_{60}P_{60}K_{60}$ + N_{14}NP	Without treatment (c)	4.94	5.89	5.9	6.89	5.43	6.61	×
	D	5.23	6.81	6.44	7.2	6.37		
	M	6.18	6.68	6.94	7.24	6.8		
	D+M	7.05	7.75	7.26	7.76	7.53		
$N_{60}P_{60}K_{60}$ + 2 × N_{14}NP	Without treatment (c)	5.03	6.15	5.98	7.01	5.71	6.98	×
	D	5.43	7.42	6.63	7.59	7.25		
	M	6.41	7.12	7.17	7.3	7.35		
	D+M	7.8	8.23	7.79	8.01	8.18		
Average, factor A		5.75	6.53	6.2	6.88	6.32	×	×
Variation (V), %		16	24.1	18.9	21.1	20.2	×	×

In variants with the application of $N_{60}P_{60}K_{60}$, the average chlorophyll content per unit area of oat leaves was increased in 0.88 g/m² (+16.2%) compared to the control. Foliar nutrition provided the additional increase of 4.8% with a single spraying in the tillering phase and +28.5% with the double spraying. The clear increase was noted with the use of bacterial fertilizers. The maximum content of chlorophyll in leaves per unit area was provided by pre-sowing seed treatment with the Diazophyt and Microhumin fertilizers – 7.21 g/m² (+32.1%).

The difference between dynamics of the indicator values depending on chemical and bacterial fertilizers was fixed at the level of cultivars. On average, the content of chlorophyll per unit of leaf area in the hulled oat cultivars of Zakat and Busol was increased in 23% and 62% respectively. The indicator value in the group of hulless cultivars varied from 42% (Skarb of Ukraine) to 51% (Salomon and Samuel). The most stable index for the content of chlorophyll was formed by Zakat cultivar.

As the results showed (Figure 1a, Figure 1b), in the variants with the application of chemical fertilizers of $N_{60}P_{60}K_{60}$ the value of the 1,000 seeds weight increased to 26.9 g (+1 g). Thus, single foliar spraying provided an additional increase by 0.5 g (27.4 g) but double foliar spraying promoted in 1 g more (27.9 g).

Significant effect on the weight of 1,000 seeds was observed in variants with pre-sowing seed treatment. The variant with the use of the bacterial fertilizer's composition ensured the better way of grains development and increasing the weight of 1,000 seeds to 28.2 g (+2.5 g to control). The results for the weight of 1,000 seeds in this experiment are far above those obtained by Volkogon (2006), Jarecki et al. (2017) reported that in spring wheat three-time foliar fertilization increased weight of 1,000 seeds and yield.

However, Jarecki and Bobrecka-Jamro (2011) concluded that the application of Urea and Micro complex fertilizers did not significantly modify the weight of 1,000

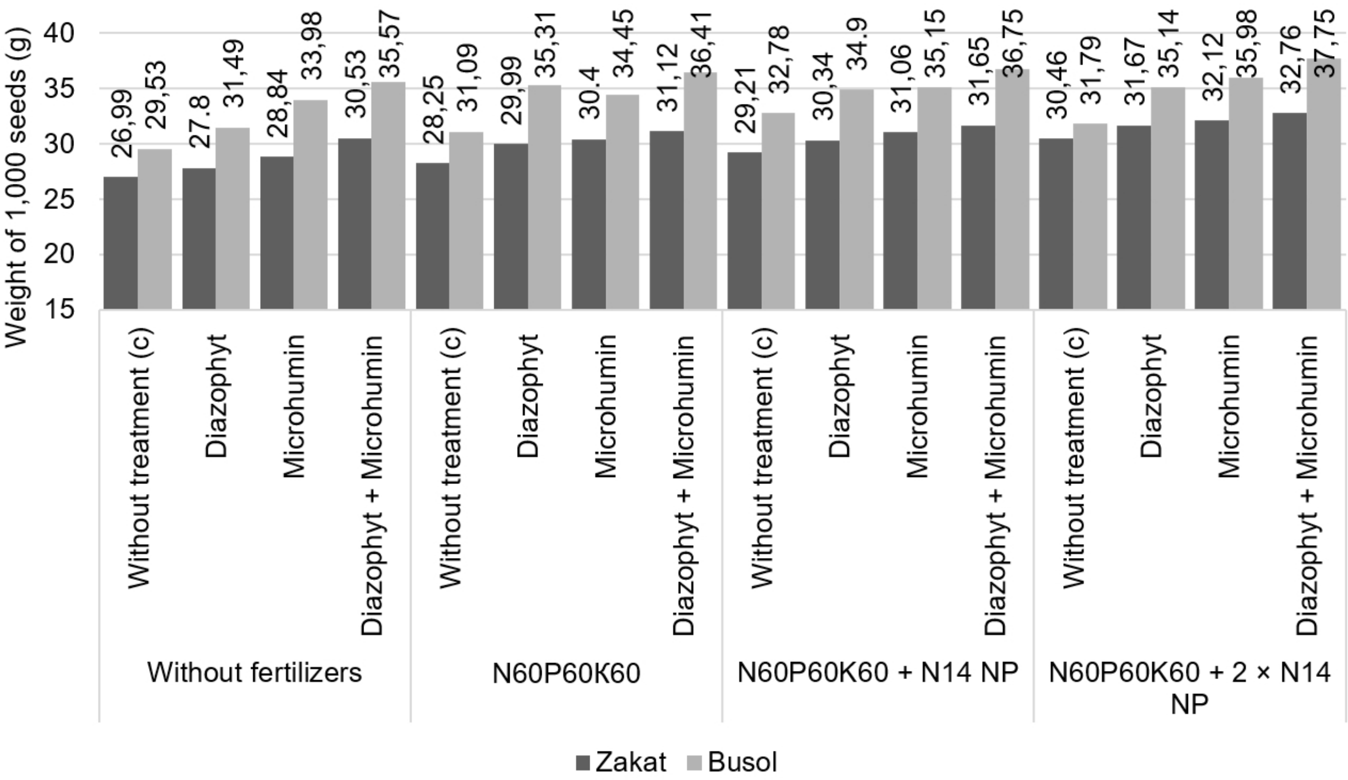

Figure 1a. Weight of 1,000 seeds of hulled oats depending on chemical and bacterial fertilizers (g); average for 2015-2017

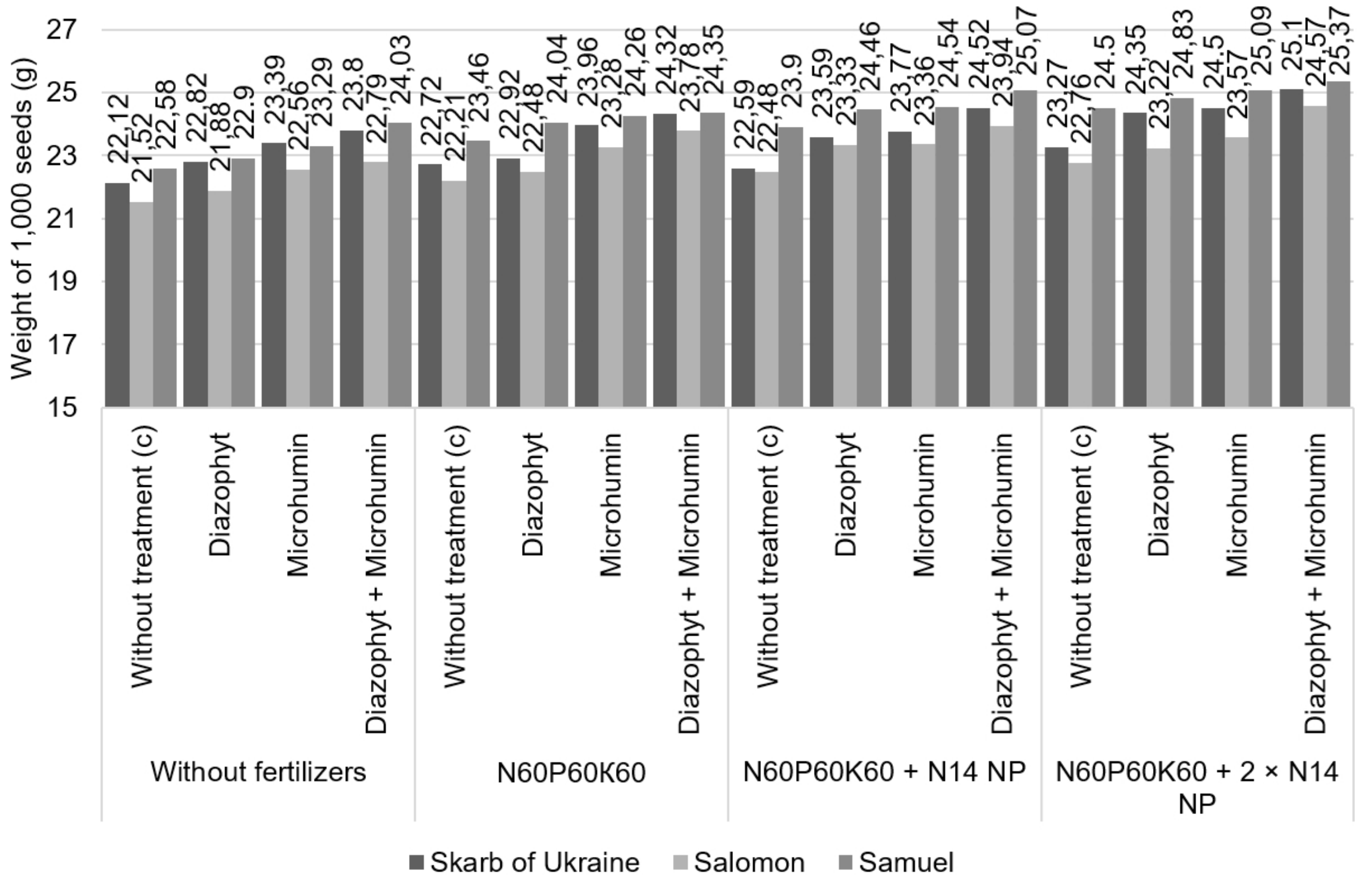

Figure 1b. Weight of 1,000 seeds of hulles oats depending on chemical and bacterial fertilizers (g); average for 2015-2017

seeds; at the same time, the yield of grains was higher from a control plot and a significant difference was found for the application of Urea and Micro complex mixture.

The average yield of hulled oat cultivars of Zakat and Busol was 2.87 and 2.91 t/ha respectively (Table 3). The yield was increased to 0.08-0.09 t/ha by the single foliar fertilizer application and to 0.19-0.26 t/ha by double foliar spraying. Mohr et al. (2007) indicated that a plant-available N supply of approximately 100 kg N ha was sufficient to achieve optimum grain yield. Applying of additional N fertilizer above this level did not result in further yield increases and may result in declines in physical grain quality and increases in lodging.

The application of chemical fertilizers of $N_{60}P_{60}K_{60}$ provided additional yield of 1.24-1.44 t/ha (+41.2-44.2%). The statistically significant increase of yield was also determined by other measures of mineral nutrition optimization.

The effect of pre-sowing seed treatment (+0.34-0.48 t/ha) was provided by the use of the D+M composition. Their separate use for seeds treatment was not so effective. The biggest increase of yield was obtained by the seed treatment with composition of Diazophyt + Microhumin and the application of chemical fertilizer scheme as $N_{60}P_{60}K_{60}$ + $2×N_{14}$NP.

The isolation of the factors influences on hulless oats yield capacity showed that the range of extra yield varies from 0.94 to 1.31 t/ha, and in the variants of bacterial fertilizers from 0.12 to 0.77 t/ha (Table 4).

Chemical fertilizers application ($N_{60}P_{60}K_{60}$) increases the hulless oats yield in 1.08 t/ha compared to the control (without fertilizers). Foliar nutrition (N_{14}NP) provided an additional yield (+0.07 t/ha) as well as variant with double spraying of $2×N_{14}$NP - (+0.18 t/ha). Maximum yield growth (1.25 t/ha) was obtained in the variant of $N_{60}P_{60}K_{60}$ + $2×N_{14}$NP. Hulless cultivars have more significant reaction

Table 3. Yield of hulled oats cultivars depending on chemical and bacterial fertilizers, t/ha (average for 2015-2017)

Variants		Oats cultivar (Factor A)							
		Zakat (c)				Busol			
Chemical fertilizers application (Factor B)	Seed treatment (Factor C)	Average	± to control			Average	± to control		
			Factor A	Factor B	Factor C		Factor A	Factor B	Factor C
Without fertilizers – control (C)	Without treatment (c)	2.87	c	c	c	2.91	0.04	c	c
	D	3.06	c	c	0.19	3.15	0.09	c	0.25
	M	3.14	c	c	0.27	3.23	0.08	c	0.31
	D+M	3.25	c	c	0.38	3.3	0.05	c	0.39
$N_{60}P_{60}K_{60}$	Without treatment (c)	4.15	c	1.28	c	4.26	0.11	1.35	c
	D	4.34	c	1.28	0.19	4.54	0.2	1.38	0.28
	M	4.38	c	1.24	0.24	4.61	0.23	1.39	0.35
	D+M	4.51	c	1.26	0.36	4.74	0.24	1.44	0.48
$N_{60}P_{60}K_{60}$ + N_{14}NP	Without treatment (c)	4.26	c	1.38	c	4.4	0.14	1.49	c
	D	4.38	c	1.32	0.12	4.65	0.28	1.5	0.25
	M	4.46	c	1.33	0.21	4.69	0.23	1.47	0.29
	D+M	4.57	c	1.36	0.35	4.74	0.17	1.43	0.34
$N_{60}P_{60}K_{60}$ + 2 × N_{14}NP	Without treatment (c)	4.43	c	1.56	c	4.50	0.07	1.59	c
	D	4.57	c	1.51	0.14	4.72	0.15	1.57	0.22
	M	4.64	c	1.49	0.21	4.79	0.15	1.56	0.28
	D+M	4.77	c	1.52	0.34	4.89	0.12	1.58	0.38

$LSD_{0.05}$ A – 0.12; B – 0.17; C – 0.17; ABC – 0.47

on pre-sowing seed treatment with the composition of Diazophyt and Microhumin (+0.24-0.77 t/ha), while its separate usage provided yield growth to +0.09-0.44 and +0.11-0.57 t/ha, respectively.

The protein content of grains of hulled oat in control variants was 12.86-12.94% (Figure 2). The higher amount of protein (15.52-16.01%) was noted in variants with hulless cultivars, due to absence of hull on grains. The highest protein content in hulled oat (13.54%) and hulless oat (16.76%) was fixed in variants with seed treatment with the composition of Diazophyt and Microhumin and application of $N_{60}P_{60}K_{60}$ + 2×N_{14}NP. Obtained data regarding to amount of protein values were similar or slightly higher compared to ones reported by Izsáki (2004), Mohr et al. (2007), Batalova (2010).

Table 4. Yield of hulless oats depending on chemical and bacterial fertilizers (t/ha); average for 2015-2017

Variants		Oats cultivar (Factor A)											
		Skarb of Ukraine (c)				Salomon				Samuel			
Chemical fertilizers application (Factor B)	Seed treatment (Factor C)	Average	± to control			Average	± to control			Average	± to control		
			Factor A	Factor B	Factor C		Factor A	Factor B	Factor C		Factor A	Factor B	Factor C
Without fertilizers – control (C)	Without treatment (c)	2.37	c	c	c	2.38	0.01	c	c	2.25	-0.12	c	c
	D	2.71	c	c	0.34	2.57	-0.14	c	0.19	2.4	-0.31	c	0.15
	M	2.84	c	c	0.47	2.65	-0.19	c	0.27	2.59	-0.25	c	0.34
	D+M	2.9	c	c	0.53	2.78	-0.12	c	0.4	2.76	-0.14	c	0.51
$N_{60}P_{60}K_{60}$	Without treatment (c)	3.48	c	1.11	c	3.48	к	1.1	c	3.19	-0.29	0.94	c
	D	3.75	c	1.04	0.27	3.6	-0.15	1.03	0.12	3.58	-0.17	1.18	0.39
	M	3.91	c	1.07	0.43	3.62	-0.29	0.97	0.14	3.74	-0.17	1.15	0.55
	D+M	4.05	c	1.15	0.57	3.75	-0.3	0.97	0.27	3.95	-0.10	1.19	0.76
$N_{60}P_{60}K_{60}$ + N_{14}NP	Without treatment (c)	3.59	c	1.22	c	3.6	0.01	1.22	c	3.23	-0.36	0.98	c
	D	3.86	c	1.15	0.27	3.69	-0.17	1.12	0.09	3.67	-0.19	1.27	0.44
	M	3.9	c	1.06	0.31	3.71	-0.19	1.06	0.11	3.80	-0.1	1.21	0.57
	D+M	4.06	c	1.16	0.47	3.83	-0.23	1.05	0.23	4.00	-0.06	1.24	0.77
$N_{60}P_{60}K_{60}$ + 2 × N_{14}NP	Without treatment (c)	3.86	c	1.49	c	3.65	-0.21	1.27	c	3.35	-0.51	1.1	c
	D	3.99	c	1.28	0.13	3.77	-0.22	1.2	0.12	3.79	-0.2	1.39	0.44
	M	4.02	c	1.18	0.16	3.78	-0.24	1.13	0.13	3.86	-0.16	1.27	0.51
	D+M	4.18	c	1.28	0.32	3.89	-0.29	1.11	0.24	4.07	-0.11	1.31	0.72
$LSD_{0.05}$ A – 0.13; B – 0.15; C – 0.15; ABC – 0.53													

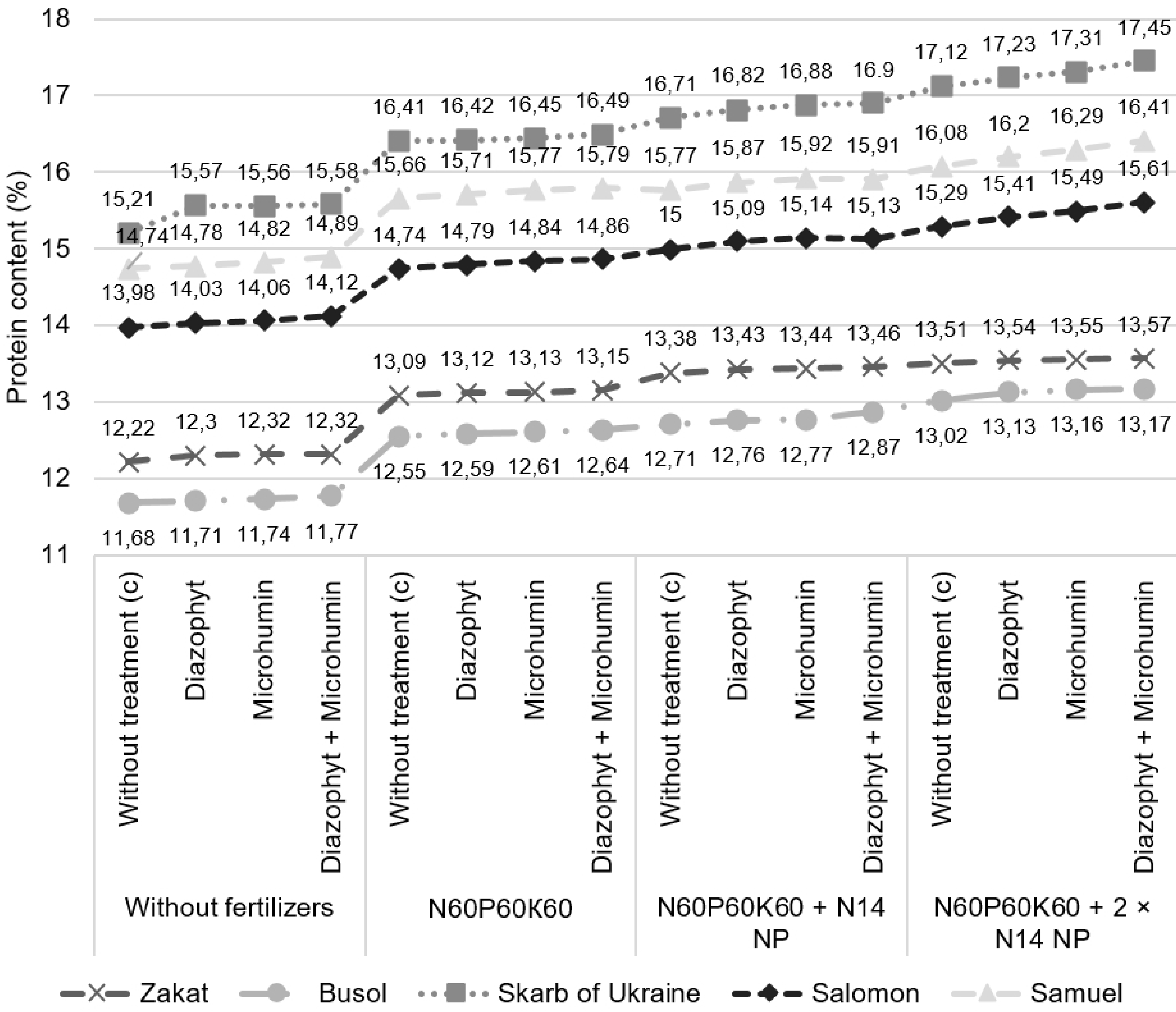

Figure 2. Protein content of hulled and hulless oats cultivars depending on chemical and bacterial fertilizers (%); average for 2015-2017

CONCLUSION

It was established that the highest values of chlorophyll content per unit area of the leaf surface of sowing, namely to 7.8 g/m² in hulled and 7.79-8.18 g/m² in hulless oats cultivars provided by pre-sowing seed treatment with bacterial fertilizers of Diazophyt and Microhumin composition in combination with chemical fertilizers application in the scheme of $N_{60}P_{60}K_{60}$ + 2×N_{14}NP.

Experimentally it was determined that due to pre-sowing seed treatment with bacterial fertilizers the yield level was increased for the hulled oat cultivars to 7% and for the hulless ones - to 15.2%. Chemical fertilizers application increased the yield of hulled oats cultivars from 2.89 to 4.47 t/ha (+54.7%) and in hulless cultivars –from 2.33 to 3.62 t/ha (+55.4%). The maximum yield growth was provided by combination of pre-sowing treatment with Diazophyt and Microhumin composition and application of chemical fertilizers of $N_{60}P_{60}K_{60}$+ 2×N_{14}NP: +1.55 t/ha (+67.1%) for hulled oats and +1.23 t/ha (+73.8%) for hulless oats cultivars.

Pre-sowing treatment with Diazophyt and Microhumin composition and application of chemical fertilizers of

$N_{60}P_{60}K_{60}$ + 2×N_{14}NP provided the maximum increase in the protein content of the seeds to 13.17-13.57 in hulled and to 15.61-17.45% in hulless oats cultivars.

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