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IMPROVING THE PRODUCTIVITY AND QUALITY OF RYE PRODUCTION, BY APPLYING FOLIAR FERTILIZERS WITH A HIGH CONTENT OF MICROELEMENTS, IN SANDY SOIL CONDITIONS

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Abstract

*The research was carried out in the period 2019-2021 on the autumn rye crop, located in the conditions of sandy soils in southern Oltenia, Romania and aimed at involving foliar fertilizers with a high content of microelements on plant productivity and quality of grain production. The obtained results showed that the highest production of rye grains, of 3566.25 kg / ha, was achieved by foliar fertilization with the product Basfoliar 36 Extra, applied in a dose of 8 l / ha, on an agrofund of $N_{150}P_{80}K_{80}$, in the phase forming the first internode of the plant. Grain production was significantly positively correlated with the number of grains in the ear (r = 0.859**) and with the weight of one thousand grains (r = 9.914**). From the point of view of grain quality, foliar fertilization with Polyactiv Mn product, applied in a dose of 2.5 l/ha, on the $N_{150}P_{80}K_{80}$ agrofound (Crude Protein = 13.23%; Gluten = 28.48%; Zeleny index = 48.67 ml), foliar fertilizer that increased rye production by 524.35 kg/ha, significant difference from non-fertilized foliar.*

Key words*: fertilization, rye, productivity, quality.*

INTRODUCTION

Due to the low organic matter content of sandy soils, the success of most crops requires large amounts of chemical fertilizers, which can often lead to pollution of groundwater with nitrates, due to poor hydrophysical properties in terms of chemical retention (Gheorghe et al., 2003). Under the conditions of a sustainable agriculture, obtaining high and stable yields for most plants cannot be conceived without the controlled application of fertilizers with macro and microelements, as a means of restitution in soil of mineral elements extracted at harvest (Rosculete & Rosculete, 2018; Jansone & Gaile, 2015). Rye (*Secale cereale* L.) is a cereal, whose grains are used mainly for human consumption, but also in animal and bird feed. Therefore, the content of micronutrients and macronutrients in cereals is as important as production (Kowieska et al., 2011). In the agronomic practices of cereals, the main factors that allow to obtain a high production with favorable qualitative properties, include both the habitat conditions and the genetic determinants of the varieties (Beáta et al., 2008; Ruzgas & Plycevaitiene, 2005; Smatas & Gaurilcikiene, 2005; Cioromele & Contoman, 2015). The literature mentions that the production and nutritional value of cereals are largely determined by the satisfaction of nutritional needs through fertilization (Stępień & Wojtkowiak, 2015; Kipling et al., 2018). In intensive agriculture, which requires high yields, in order to maintain the health of the soil, the importance of using inputs (pesticides, fertilizers) is undeniable (Matei et al., 2021; Paraschivu & Cotuna, 2021). The choice of a market economy production technology should be preceded by economic calculations of technology inputs (Jankowskik et al., 2003). Thus, in Poland the increase in rye production resulting from more intensive production methods did not fully cover the increase in direct costs. Oltenia is an important agricultural region where drought occurs frequently, only two out of ten years being favorable to agricultural crops (Bonea, 2020a; Bonea, 2020b; Nicolescu et al., 2008). From the point of view of ensuring the nutrients necessary for the nutrition of rye plants, sands and sandy soils are characterized by low natural fertility, determined by the low content of organic matter and fertilizers (Matei et al., 2009;

Gheorghe et al., 2009; Bonea & Urechean, 2020). In order to preserve and increase soil fertility, and to prevent soil and groundwater contamination with nitrates, it is necessary for fertilization to be carried out in a controlled manner so as to ensure the optimal use of nutrients by cultivated plants (Bonea, 2016; Hera, 2002; Paraschivu et al., 2015; López et al., 2019). In this regard, in the agricultural years 2019/2020 and 2020/2021 research was initiated on rye culture, which aimed at foliar fertilization with some environmentally friendly products to promote sustainable agriculture in the area of sandy soils.

MATERIALS AND METHODS

The researches were carried out in the period 2019-2021 for the Suceveana rye variety, by sowing it in autumn, between October 10-20 at RDSPCS Dabuleni, located in southwestern Oltenia, Romania. The experiment was organized in field conditions, according to the method of plots subdivided with 2 factors, on a sandy soil, which on the soil profile 0-50 cm was poorly supplied with total nitrogen (0.045-0.05%) and organic carbon (0.44-0.46%), had a good supply of extractable phosphorus (63.8-67.5 ppm), medium in exchangeable potassium (69.4-78 ppm), and showed a reaction of neutral soil with a pH = 7.1-7.2. The factors studied were:

Factor A: Root fertilization:

a_1 - $N_{75}P_{40}K_{40}$ (1/2 of the technological dose NPK);

a_2 - $N_{150}P_{80}K_{80}$ (technological dose NPK).

Factor B: Foliar fertilization:

b_1 - Unfertilized foliar;

b_2 - Basfoliar 36 Extra, at a dose of 8 l/ha;

b_3 - Maturevo 3.35.35 + ME, at a dose of 3.5 kg/ha;

b_4 - Biohumussol Liquid, in concentration of 1%;

b_5 – Polyactiv Mn, at a dose of 2.5 l/ha.

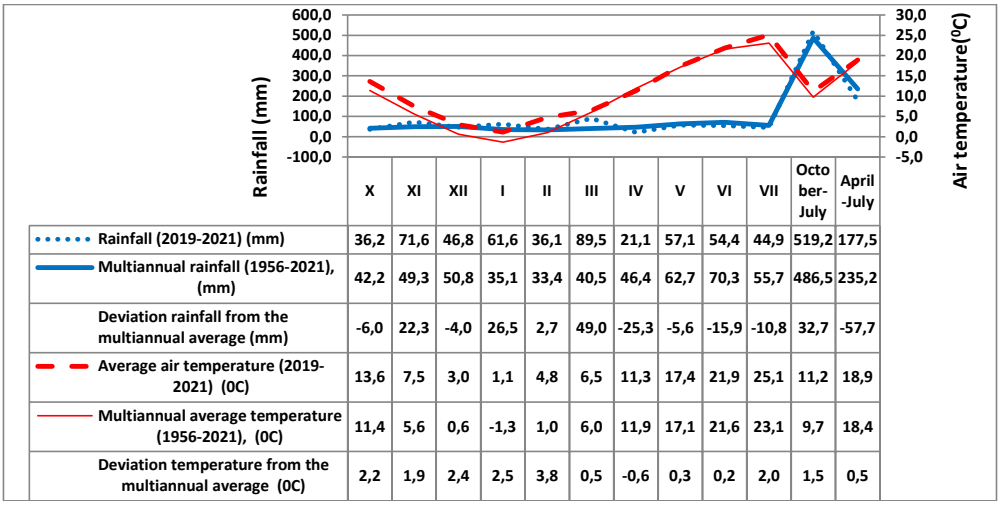
Root fertilization with $N_{40}P_{40}K_{40}$ (a_1) and $N_{80}P_{80}K_{80}$ (a_2) was applied in autumn to prepare the germination bed, and the difference in nitrogen dose, respectively N_{35} (a_1) and N_{70} (a_2), was applied in early spring, at the beginning of March, which coincides with the end of the twinning phase of rye twinning, the BBCH 29 vegetation stage (according to the BBCH scale for coding vegetation for straw cereals). Foliar fertilization was applied to the formation of the first internode in rye culture (BBCH 31). In the flowering phase of the plant, vegetation stage BBCH 65-69, leaf samples were collected to assess the supply status of plants in macroelements, respectively the total nitrogen content, determined by the Kjeldahl method, the total phosphorus content, determined by the colorimetric method and the total potassium content, determined by the method of dosing by flame emission photometry. During the vegetation period (BBCH 87-89), determinations were made of biometrics (plant height, spike length) and plant productivity (number of spikes / m^2, number of grains in spike). At harvest, it was determined: grain production, weight of one thousand grains (WTG), hectolitre weight (HW) and grain quality (Crude Protein, Wet Gluten, Zeleny Sedimentation Index), by spectrophotometric method, with NIR analyzer, INFRAMATIC model 9200 - Perten. The results were calculated and analyzed by the method of analysis of variance (ANOVA) and using mathematical functions.

RESULTS AND DISCUSSIONS

Analyzing the climatic conditions recorded in the period 2019-2021 at the weather station of RDSPCS Dabuleni (Figure 1), they were favorable for the growth and development of rye plants, within the limits of the biological requirements of the plant (minimum seed germination temperature of 1- 2^0C, the sum of temperatures during the vegetation of 1800-2000 ^{0}C, resistance in winter to minimum temperatures of minus 20^0C, without being covered by snow).

During the vegetation period of the rye crop (October-July), an average air temperature of 11.2^0C was registered, with 1.5^0C higher, compared to the multiannual average, thus noticing the accentuation of the arid climate in the area of sandy soils. Although the rainfall recorded exceeded the multiannual average by about 32.7 mm, they were unevenly distributed over the vegetation period of the rye, being necessary to supplement the water deficit in the soil during the critical periods for water (at sunrise and the phase of sprouting the plant).

Between April and July, compared to the multiannual average, there was a moisture deficit of 57.7 mm, which combined with the increase in air temperature accentuated the drought, which required water supply by irrigating the crop. Adverse weather conditions (especially droughts) in recent years, which often last a long part of the growing season, have a negative effect on plant yield, but not only on susceptible species, but also on resistant ones, such as rye (Czyczyło & Myśków, 2017).



	X	XI	XII	I	II	III	IV	V	VI	VII	October-July	April-July
Rainfall (2019-2021) (mm)	36,2	71,6	46,8	61,6	36,1	89,5	21,1	57,1	54,4	44,9	519,2	177,5
Multiannual rainfall (1956-2021), (mm)	42,2	49,3	50,8	35,1	33,4	40,5	46,4	62,7	70,3	55,7	486,5	235,2
Deviation rainfall from the multiannual average (mm)	-6,0	22,3	-4,0	26,5	2,7	49,0	-25,3	-5,6	-15,9	-10,8	32,7	-57,7
Average air temperature (2019-2021) (0C)	13,6	7,5	3,0	1,1	4,8	6,5	11,3	17,4	21,9	25,1	11,2	18,9
Multiannual average temperature (1956-2021), (0C)	11,4	5,6	0,6	-1,3	1,0	6,0	11,9	17,1	21,6	23,1	9,7	18,4
Deviation temperature from the multiannual average (0C)	2,2	1,9	2,4	2,5	3,8	0,5	-0,6	0,3	0,2	2,0	1,5	0,5

Figure 1. Evolution of climatic conditions recorded at the weather station of RDSPCS Dăbuleni

The results regarding the biometry of the rye plant showed higher values at the fertilization of the crop with the technological dose of $N_{150}P_{80}K_{80}$, compared to the fertilization with ½ from the technological dose (Table 1).

Table 1. Influence of root and foliar fertilization on rye plant biometrics and productivity in sandy soil conditions

Root fertilization	Foliar fertilization	Plant height (cm)	No. of spikes/ m^2	Spike length (cm)	No grains / spike	WTG (g)	HW (kg/hl)
$N_{75}P_{40}K_{40}$ (½ from the technological dose of NPK)	Unfertilized foliar	147.0	472	10.4	46	29.8	68.8
	Basfoliar 36 Extra (8 l/ha)	148.9	499	11.4	53	36.0	70.8
	Maturevo 3.35.35 + ME (3.5 kg /ha)	153.2	502	11.0	51	36.3	71.5
	Biohumussol Lichid (1 %)	154.9	495	11.1	51	30.5	71.2
	Polyactiv Mn (2.5 l/ha)	151.8	490	10.3	54	31.7	70.7
Average		151.1	491	10.8	51	32.9	70.6
$N_{150}P_{80}K_{80}$ (the technological dose of NPK)	Unfertilized foliar	163.3	494	10.7	53	30.0	70.8
	Basfoliar 36 Extra (8 l /ha)	170.3	550	11.9	60	37.7	75.0
	Maturevo 3.35.35 + ME (3.5 kg /ha)	168.0	540	11.6	57	37.2	75.4
	Biohumussol Lichid (1 %)	168.0	544	12.0	60	36.5	74.7
	Polyactiv Mn (2.5 l / ha)	165.0	516	11.2	56	36.5	72.7
Average		166.9	528.7	11.4	57.4	35.6	73.7

Thus, compared to fertilization with $N_{75}P_{40}K_{40}$, fertilization of rye crop with $N_{150}P_{80}K_{80}$ led to an increase of 15.8 cm in plant height, by 37.7 spikes/square meter of plant density, by 0.6 cm

of spike length, by 6.4 grains in spike, with 2.7 g of WTG and with 3.1 kg/hl of HW. Nitrogen fertilization is one of the most important factors in the growth and development of cereal crops. The availability of nitrogen for the plant is indispensable because it is a basic component of the organic molecules involved in plant growth and development (Salas, 2003). Analyzing the effect of foliar fertilization, it was noticed the increase of the values of the productivity traits of the plant, compared to foliar non-fertilizer, on both agro-funds of root fertilization. The best results were obtained in foliar fertilization with the product Basfoliar 36 Extra, applied at a dose of 8 l/ha in the formation phase of the first internode, which, compared to non-fertilized foliar, caused increases of 11.3-25.6% on the productivity elements, respectively the number of spikes/m^2, the length of the spike, the number of grains in the spike, the WTG and the HW. The growth is due to the high content of microelements in foliar fertilizers, which are very quickly absorbed by the leaves and do not turn into compounds inaccessible to plants.

The results obtained on the state of supply of plants in macroelements (N, P, K) are shown in Figure 2.

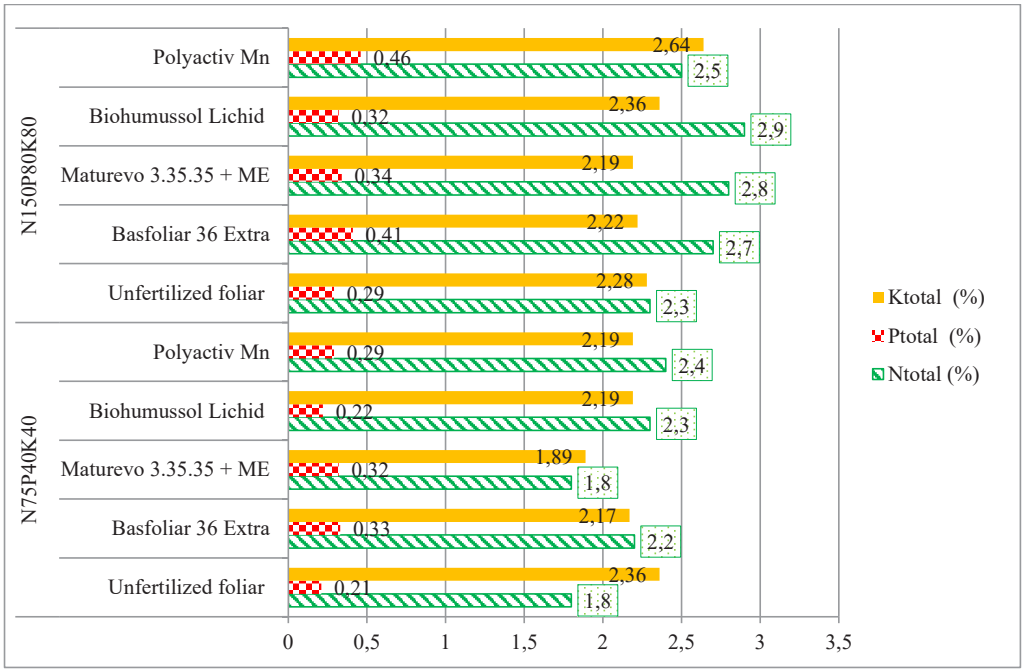


Figure 2. State of supply of rye plants in nitrogen, phosphorus and potassium according to the fertilization system

The content of rye plants in nitrogen was between 1.8% in the fertilized version with ½ of the technological dose and non-fertilized foliar and 2.9% in the version fertilized with the technological dose and foliar fertilized with the liquid Biohumussol product, in a dose of 1%. The values obtained indicate a reduced state of supply of plants in total nitrogen, with a tendency to increase the nitrogen content with increasing doses of fertilizers. The supply status of rye plants in total phosphorus indicates optimal values between 0.21%, in the fertilized version with ½ of the technological dose and non-fertilized foliar and 0.46%, in the version fertilized with the technological dose and foliar fertilized with the product Polyactiv Mn (2.5 l/ha). Also, the state of supply of plants in potassium has highlighted values in the optimal field of supply of plants.

Analyzing the interaction of the two factors studied on the production results obtained in rye, it was highlighted the foliar fertilization with Basfoliar 36 Extra, in a dose of 8 l/ha, on an agrofund of $N_{150}P_{80}K_{80}$, with a maximum production of 3566.25 kg/ha, ensuring a production difference of 1172.65 kg / ha, very

statistically significant compared to non-fertilized foliar (Table 2). Statistically assured production differences, compared to foliar non-fertilizer, at the same level of root fertilization were registered for the other foliar products applied, respectively: Maturevo 3.35.35 + ME, Biohumussol Lichid and Polyactiv Mn. Similar results were obtained in Poland for rye grown on clay loam soil with an organic carbon content of 0.79%, where production increases due to foliar fertilization with microelements Cu, Zn, Mn, applied alone or in combination on an agrofund of mineral fertilization with NPK, were 980-1480 kg/ha, compared to non-fertilized (Stępień et al., 2016). Research conducted in Romania (Brăila), in the conditions of a chernozem soil with an alkaline pH, showed that the production results obtained from rye were differentiated by variety and fertilization regime (Cioromele & Contoman, 2015). Under these conditions, the Suceveana variety achieved the maximum production (4147 kg/ha) when applying the dose of N_{50}, and the Ducato variety achieved the maximum production (4013 kg/ha) at fertilization with N_{100}, the differences compared to non-fertilized being very significant for both varieties.

Table 2. Significance of rye crop yields under the influence of root and foliar fertilization

Fertilization variant		Grain Yield		Difference from the unfertilized (kg/ha)	The significance
Root fertilization	Foliar fertilization	(kg/ha)	(%)		
$N_{75}P_{40}K_{40}$ (½ from the technological dose of NPK)	Unfertilized foliar	1744.20	100.00	Unfertilized	Unfertilized
	Basfoliar 36 Extra (8 l/ha)	2547.20	146.04	803.00	***
	Maturevo 3.35.35 + ME (3.5 kg/ha)	2509.95	143.90	765.75	**
	Biohumussol Lichid (1%)	2216.75	127.09	472.55	*
	Polyactiv Mn (2.5 l/ha)	2032.55	116.53	288.35	-
$N_{150}P_{80}K_{80}$ (the technological dose of NPK)	Unfertilized foliar	2393.60	100.00	Unfertilized	Unfertilized
	Basfoliar 36 Extra (8 l/ha)	3566.25	148.99	1172.65	***
	Maturevo 3.35.35 + ME (3.5 kg/ha)	3344.00	139.71	950.40	***
	Biohumussol Lichid (1%)	3305.75	138.11	912.15	***
	Polyactiv Mn (2,5 l/ha)	2917.95	121.91	524.35	*
			LSD 5%	404.55	
			LSD 1%	557.2	
			LSD 0.1%	767.05	

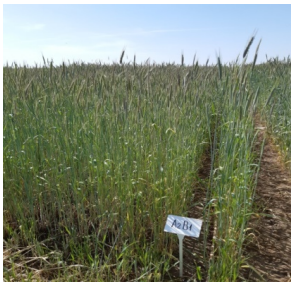


Photo 1. Foliar unfertilized rye crop
Source: Original

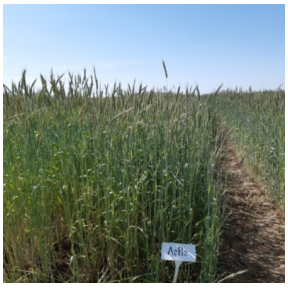


Photo 2. Foliar fertilized rye culture with *Basfoliar® 36 Extra SL*
Source: Original

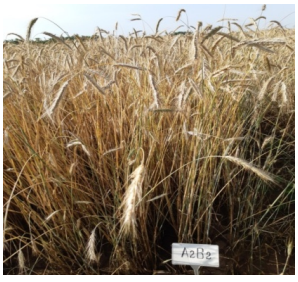


Photo 3. Foliar fertilized rye culture with *Basfoliar® 36 Extra SL*
Source: Original

Analyzing the functional link between grain production and the productivity elements of the plant (number of grains in spike and weight of one thousand grains) showed distinctly significant positive correlations (r = 0.859 **, r = 0.914 **), which emphasized the increase in production as the productivity of the plant increased (Figure 3).

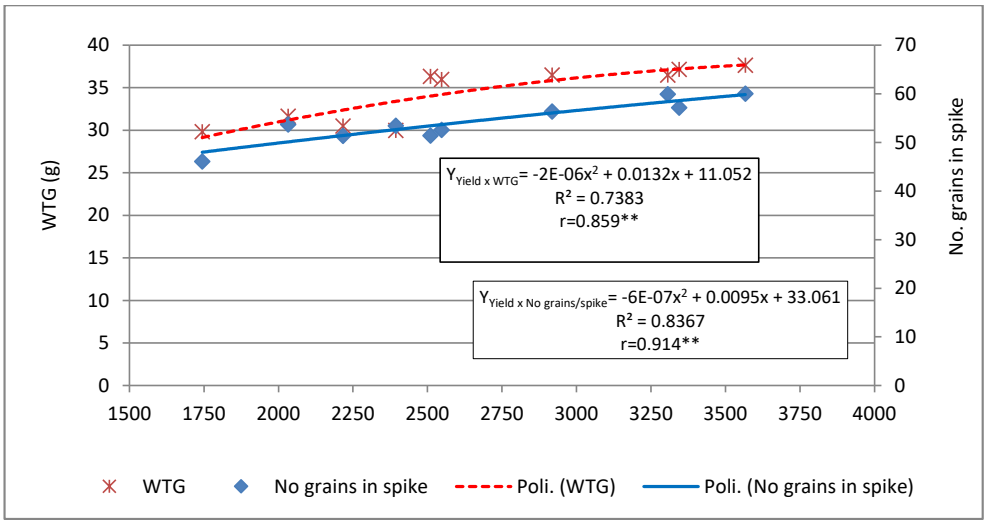


Figure 3. Correlations between the productivity elements of the plant and the production obtained from rye in different fertilization variants

The quality of rye grains was influenced by both root fertilization and foliar fertilization (Table 3). The protein content of rye grains was between 8.25% in the fertilized version at ½ of the technological dose and non-fertilized foliar and 13.23% in the version fertilized with the technological dose of NPK and foliar fertilized with the product Polyactiv Mn (2.5 l/ha). In all variants fertilized with the technological dose of NPK and with different foliar products, the amount of protein in the grains showed higher values compared to the variants fertilized at ½ in the technological dose. Similar results were obtained for rye grown in north-western Mexico, which showed that the yield and quality of production increased significantly by fertilization by 150 kg/ha N, compared to unfertilized with nitrogen (López et al., 2019). The results obtained by Stępień et al. (2016), also highlighted the role of mineral fertilization with NPK in increasing by 5% the protein content of the grain, compared to unfertilized. Gluten in rye grains was between 14.05% in the fertilized version at ½ of the technological dose and non-fertilized foliar and 28.48% in the variant fertilized with the technological dose of NPK and foliar fertilized with the product Polyactiv Mn, in a dose of 2.5 l/ha. However, the protein and gluten content is not sufficient for a complete characterization of the quality of cereal flour, so it is very useful to determine the value of the sedimentation index. The value of the Zeleny Sedimentary Index depends on the composition of the proteins, but it is also correlated with the protein content (Marinciu & Şerban, 2018). The content of wet gluten grains and the Zeleny Sedimentary Index are very important quality indicators for the technological process, contributing to the characterization of the dough, especially its processing capacity and its baking potential (Banu, 2003). The results obtained in our experiment also showed that the high values of protein and gluten content, recorded in the fertilized variants with the technological dose of NPK and foliar products, were also reflected in the high values of the Zeleny Index in the same variants (28.67-48.67 ml).

Table 3. Nutritional quality of rye grains according to fertilization system

Foliar fertilization	Root fertilization					
	$N_{75}P_{40}K_{40}$			$N_{150}P_{80}K_{80}$		
	Crude protein (%)	Gluten (%)	Zeleny index (ml)	Proteina (%)	Gluten (%)	Zeleny index (ml)
Unfertilized foliar	8.25	14.05	15.00	10.44	20.17	22.33
Basfoliar 36 Extra (8 l/ha)	9.04	16.03	13.97	11.77	24.45	30.00
Maturevo 3.35.35 + ME (3.5 kg /ha)	9.42	14.12	17.00	11.12	21.94	28.67
Biohumussol Lichid (1%)	9.04	16.39	23.67	11.94	24.74	32.67
Polyactiv Mn (2.5 l/ha)	8.87	18.65	22.33	13.23	28.48	48.67

CONCLUSIONS

Fertilization with Basfoliar 36 Extra, carried out in the formation phase of the first internode of the plant, with a dose of 8 l/ha, on an agrofund of $N_{150}P_{80}K_{80}$, determined the obtaining of the maximum production for rye cultivation (3566.25 kg/ha).

Grain production was significantly positively correlated with the number of grains in the spike (r = 0.859**) and with the weight of one thousand grains (r = 9.914**).

From the point of view of the quality of the grains, the best results showed the foliar fertilization with the Polyactiv Mn product, applied in a dose of 2.5 l/ha, on the agrofund of $N_{150}P_{80}K_{80}$ (Crude Protein = 13.23%; Gluten = 28.48%; Zeleny index = 48.67 ml), foliar fertilizer that increased rye production by 524.35 kg/ha, a significant difference from non-fertilized foliar.

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