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Differentiated Contribution of Minerals through Soil and Foliar Fertilization to the Winter Wheat Yield

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Authors' contributions

This work was carried out in collaboration between all authors. Author FS designed the study, wrote the protocol and wrote the first draft of the manuscript. Author HR managed the literature searches and author MB performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Research has evaluated the contribution of minerals through soil and foliar fertilization on winter wheat yield, the purpose being to identify the interdependence relations for the optimization of the fertilization system. Two types of mineral and foliar fertilizers were tested. The complex mineral fertilizer of the type NPK (1:1:1) was used for achieving three differentiated nutrition levels: NPK_0, NPK_{30} (30 kg active substance ha^{-1}) and NPK_{60} (60 kg active substance ha^{-1}). There are five types of foliar fertilizers applied and 18 experimental variants were studied. The research was conducted in Soil Science and Plant Nutrition (SSPN) and Mathematics and Statistics (MS), Banat University of Agricultural Sciences and Veterinary Medicine„ Regele Mihai I al României„ from Timisoara, Romania (USAMVBT), between 2011 and 2012. The influence of interaction between the two types of fertilizer compared to their individual influence on wheat production was analyzed. Based on

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regression analysis were obtained mathematical model of interdependence, reliability of the results and models have been certified by LSD, p and R^2 (maximum value is better). The complex fertilizers generated yield increase between 925*** and 1425*** kg ha^{-1}. The foliar fertilizers determined yield increase between 355 and 810*** kg ha^{-1} with natural soil fertility (NPK_0), between 550** and 900*** kg ha^{-1} with NPK_{30}, and between 500** and 795*** kg ha^{-1} with NPK_{60}. The yield increase determined by the joint effect of the two types of fertilization was between 1475*** and 2220*** kg ha^{-1}. The experimental results have high statistical confidence (p<.01; Fcrit<F for Alfa = .01). The study recorded a decrease in the potentiation effect of the foliar fertilizers and at the same time in their contribution to the winter wheat yield, when the doses of complex fertilizers applied on the soil were increased.

Keywords: Fertilizers interaction; growth model; optimization; winter wheat; yield.

1. INTRODUCTION

Wheat is one of the three main cereal crops that cover large areas of land all over the world, with annual yields of over 600 million tons [1]. The major wheat production worldwide is highly concentrated in a few countries, and the European Union is by far the most important producer, accounting for 21% of total world harvest. In the next decades, an increase is expected in the global food demand, and especially in the wheat demand. At European level, 55% of wheat production is concentrated in three countries: France (41 Mio. tons), Germany (24 Mio. tons) and the UK (15 Mio. tons), Romania also having a significant production of wheat (almost 5 Mio. Tons) [2]. *The largest agricultural area in Romania* country, 747,000 ha, is found in Timis county, bounding area of research, out of which 531 373 ha is arable land. In this region, there are different systems of agriculture practiced, with different levels of productivity, winter wheat and corn crops occupying the largest share.

Together with the genetic performance of the biological material [3,4], perfecting the crop technologies is the main means of ensuring high wheat yields [5,6]. The tendency towards climatic changes, characterized by increased average values of annual temperatures and variations in the distribution of rainfall, brings new challenges regarding the safety of the wheat yield [7,8]. These conditions make it necessary to improve wheat crop technologies, where fertilization is one of the primary elements [9,10].

The basic nutrition of plants takes place through the root system, based on the nutritive elements in the soil [11] supplementing the intake of nutrients through the leaves contributes to getting the nutriment balance right in what the wheat crop is concerned, in view of high and stable yields. The overall cost of the crop technology for the cultivation of wheat has determined the orientation towards cheaper fertilization systems, frequently based on unilateral nitrogen fertilization or foliar fertilization. Fertilization system based on complex fertilizers applied on soil and foliar fertilizers in vegetation is also commonly practiced in wheat crop for economic reasons. But at the same time, they has had serious implications on crop productivity and on soil fertility [12,13]. Many studies have focused on the influence of foliar fertilization on the vegetation status and on wheat yield quality and quantity, in various soil and climatic conditions [14-16].

In the context of these general and specific aspects, the present research aims at assessing the differentiated contribution of mineral fertilization and foliar fertilization to the wheat yield, for improving the fertilization system for winter wheat.

2. MATERIALS AND METHODS

The main objective of the present research was to assess and compare the part that mineral fertilization and foliar fertilization play in the winter wheat yield.

2.1 Experimental Field Area

The reference area for the study is in the West Plain of Romania, more exactly in Timiș County, Fig. 1. Field experiments were carried out at Didactic Station of BUASVM Timișoara, plot A 363, 45º 28' N, 21º 7' E, during 2011-2012 growing seasons.

2.2 Study Area and Soil Condition

The area of the present experiment is included in the great Pannonian Depression, the eastern part to be more exact; this was formed in Pleistocene-Quaternary by gradual clogging of the lake. The natural setting of the experiment presents slightly gleized cambic chernosem with neutral reaction (pH = 6.97-7.10), good humus supply (H = 3.2%), nitrogen index IN = 2.97, high degree of base saturation (over 87%), poor supply of phosphorus (P = 23.6 ppm) and medium supply of potassium (K = 132 ppm).

2.3 Climatic Condition

The climate conditions in the trial area are typical to the continental climate with Mediterranean influences. During the trial period, mean daily temperatures were higher compared to the multi-annual means particularly between May and September (Fig. 2). As for the precipitations, there were two periods of rainfall deficit compared to the multi-annual mean: the first interval of rainfall deficit was in May-June and the first decade of July and the second interval of rainfall deficit was in the third decade of July and in August-September (Fig. 3).

2.4 Biological Material

The biological material was represented by Alex wheat cultivar, species *Triticum aestivum* (L.) ssp vulgare.

Fig. 1. Timiș county area, Romania–the reference area for study and research (pe-harta.ro)

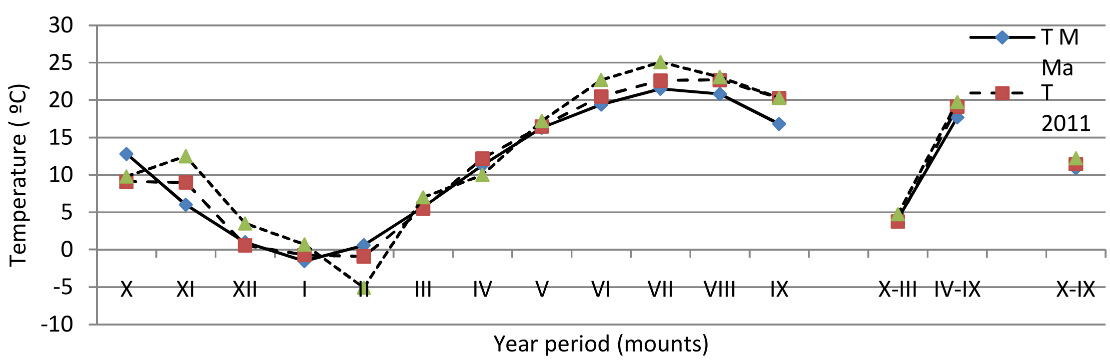

Fig. 2. Mean temperature during the trial period; T M Ma–multiannual mean temperature; T 2011–the temperature in 2011; T 2012–the temperature in 2012

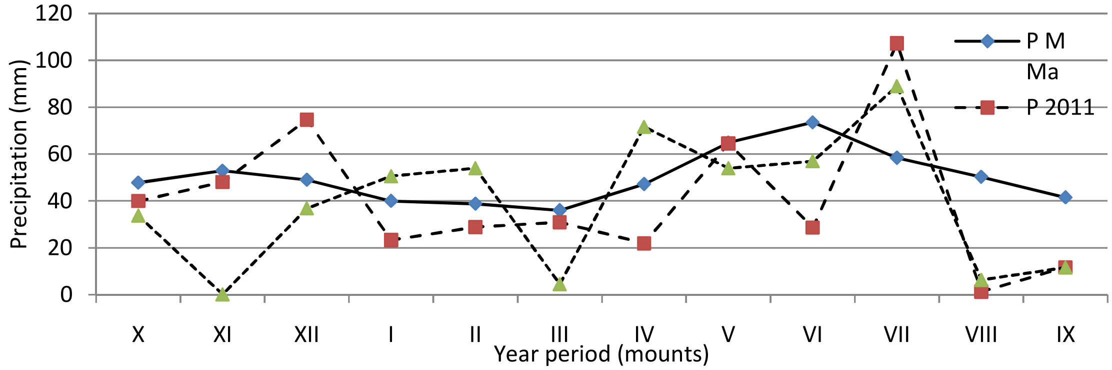

Fig. 3. Distribution of rainfalls during the trial period; PM Ma–multiannual mean rainfall; P 2011–rainfall in 2011; P 2012–rainfall in 2012

2.5 Treatments and Experimental Design

Complex fertilizers of the type NPK (1:1:1), containing 15% active substance for each element, were used in three fertilization levels: NPK_0 (0 kg active substance ha^{-1}), NPK_{30} (30 kg active substance ha^{-1} for each element) and NPK_{60} (60 kg active substance ha^{-1} for each element). In addition to the three basic levels, foliar fertilizers were also applied (300 l water ha^{-1}): Ft – Fertitel 0.5%, containing N (6.7%), P_2O_5 (6%), K_2O (4.2%), Cu (0.025%), Fe (0.1%), Mn (0.01%), Zn (0.008%), B (0.02%) and Mo (0.001%); NZn - Nutrion Zn 0.5%, containing N (8.5%), P_2O_5 (8.5%), K_2O (4.61%), MgO (0.34%), Zn, Fe, Mn, Cu, B, Mo and essential amino acids; Bc - Biocomplex 900 0.5%, brown seaweed liquid extract; Mf – Megafol 0.5%, containing aminoacids (35%), N_t (5.6%), C_{org} 18.7%), K_2O (3.8%); Nt – Nutrilene 0.5% containing N (12%), P_2O_5 (7%), K_2O (8%), B (0.1%), Fe (0.2%) and Zn (0.05%) and thus there were 6 variants for each NPK base (five foliar fertilized variants, and each control variant). Foliar fertilizers were applied in spring, in two treatments with an interval of 20 days (20 - 30 and 35 – 37 BBCH stage code). The combination of mineral soil fertilization and foliar fertilization resulted in 18 randomized experimental variants, arranged in three repetitions. The area of each plot was 30 m^2 (10 m length, 3 m width). The crop of each plot unit was harvested at maturity stage by a combine harvester (Hege, Germany).

2.6 Statistical Analysis

The experimental data of wheat production, on each variant, were processed through analysis of variance (ANOVA) using the mathematical module on EXCEL 2007. Correlations coefficient, regressions and multivariate analysis were determined using the software PAST [17]. The symbol*, ** and *** used in the paper represent statistically significance at 99.9% ($LSD_{0.01\%}$), 99% ($LSD_{0.1\%}$) and 95% ($LSD_{0.5\%}$) probability level.

3. RESULTS AND DISCUSSION

Under the experimental conditions presented above, the fertilizers applied in each fertilization variant were differently used up by the winter wheat crop, resulting in different levels of yields. The yield varied from 2925±72.17 kg ha^{-1} in variant Mt_0 and 5145±106.81 kg ha^{-1} in the variant fertilized with Megafol on a NPK_{60} base, as shown in Table 1. The overall yield increase ranged from 355 kg ha^{-1} in the variant fertilized with Biocomplex 900 with NPK0 fertilization and 2220 kg ha^{-1} in the variant fertilized with Megafol, with NPK_{60}.

ANOVA test reveals statistical assurance for the experimental results, both for complex mineral fertilizers (rows sources of variance; $p < .01$; $F > Fcrit$) and for foliar fertilizers (column sources of variance; $p < .01$; $F > Fcrit$), Table 2.

The comparative analysis of the results obtained in the experimental variants reveals the different contribution of the two types of fertilizers in the formation of the yield. The complex fertilizers – as a singular effect – generated yield increases between 925*** and 1425*** kg ha^{-1}, the comparative analysis being made between variants Mt_1 (NPK_{30}) and Mt_2 (NPK_{60}) respectively, with the control Mt_0 (NPK_0).

In the cases in which foliar fertilizers were applied together with soil fertilizers, the effect of the complex fertilizers was potentiated by 0.9 – 1.24 production units with NPK_{30} and by 0.78 – 1.14 production units with NPK_{60}. The study revealed that the potentiation effect decreased if the doses of complex fertilizers applied on the soil were increased, because in that case plant roots were supplied with higher nutriment content. Generally, plants prefer to feed through the root system if the soil, which is their main medium for nutrition, ensures enough nutrients. The large share of root nutrient absorption as compared to the foliar nutrient absorption has been revealed by other studies as well [18,19].

With foliar fertilization on the background of NPK_0, the yield obtained ranged from 3280±75.06 kg ha^{-1} in the variant fertilized with Biocomplex 900, to 3735±152.98 kg ha^{-1} in the variant fertilized with Nutrilene. The control variant (Mt_0), given by the natural fertility of the soil, resulted in a yield of 2925±72.17 kg ha^{-1}. The yield increase generated by foliar fertilization combined with the natural fertility of the soil (NPK_0) was between 355 kg ha^{-1} in the variant fertilized with Biocomplex 900 and 810*** kg ha^{-1} in the variant fertilized with Nutrilene. In the other variants with foliar fertilization, the yield increase was 550** kg ha^{-1} in the variant fertilized with Nutrion Zn, 675** kg ha^{-1} in the variant fertilized with Fertitel and 700*** kg ha^{-1} in the variant fertilized with Megafol.

Table 1. The yield of winter wheat, Alex cultivar, obtained under the influence of foliar fertilization, combined with different NPK doses of soil fertilizers (average values over the experimental period 2011 – 2012)

Fertilization variant		Variant number	Yield (mean values 2011-2012)	General yield increase as compared to the control variant	Yield increase generated by foliar fertilizers	Yield increase generated by complex fertilizers
NPK_0	Mt_0	V_1	2925±72.17	-	-	-
	Fertitel	V_2	3600±144.33	675^{**}	675^{**}	-
	Nutrion Zn	V_3	3475±129.90	550^{**}	550^{**}	-
	Biocomplex 900	V_4	3280±75.06	355	355	-
	Megafol	V_5	3625±187.64	700^{***}	700^{***}	-
	Nutrilene	V_6	3735±152.98	810^{***}	810^{***}	-
	The yield increase generated by foliar fertilizers was calculated by comparison with the control variant, Mt_0					
NPK_{30}	Mt_1	V_7	3850±86.60	925^{***}	-	-
	Fertitel	V_8	4750±144.33	1825^{***}	900^{***}	1150^{***}
	Nutrion Zn	V_9	4590±132.79	1665^{***}	740^{***}	1115^{***}
	Biocomplex 900	V_{10}	4400±173.21	1475^{***}	550^{**}	1120^{***}
	Megafol	V_{11}	4740±127.02	1815^{***}	890^{***}	1115^{***}
	Nutrilene	V_{12}	4595±101.04	1670^{***}	745^{***}	860^{***}
	The yield increase generated by foliar fertilizers was calculated by comparison with the Mt_1 The yield increase generated by complex fertilizers was calculated by comparison with the similar variants of foliar fertilizers with NPK_0 (Mt_0)					
NPK_{60}	Mt_2	V_{13}	4350±109.69	1425^{***}	-	-
	Fertitel	V_{14}	4905±152.99	1980^{***}	555^{**}	1305^{***}
	Nutrion Zn	V_{15}	5085±147.22	2160^{***}	735^{***}	1610^{***}
	Biocomplex 900	V_{16}	4900±115.47	1975^{***}	550^{**}	1620^{***}
	Megafol	V_{17}	5145±106.81	2220^{***}	795^{***}	1520^{***}
	Nutrilene	V_{18}	4850±150.11	1925^{***}	500^{*}	1115^{***}
	The yield increase generated by foliar fertilizers was calculated by comparison with the Mt_2 variant The yield increase generated by complex fertilizers was calculated by comparison with the similar variants of foliar fertilizers with NPK_0 (Mt_0)					
Limits the significance of differences		$LSD_{5\%}$ = 382.65; $LSD_{1\%}$ = 512.71; $LSD_{0.1\%}$ = 676.71				

Table 2. ANOVA: Two-factor without replication

Source of variation	SS	Df	MS	F	P-value	F crit
Rows (mineral fertilizer)	20229842	8	2528730	55.76621	2.81E-19	4.207037
Columns (foliar fertilizer)	3832050	5	766410	16.90168	5.84E-09	5.128263
Error	1813808	40	45345.21			
Total	25875700	53				

Alfa = .01

The particular influence of foliar fertilization has been assessed in other studies as well, with differentiated contribution on yield quantity and quality, depending on the type of fertilizer, the type and association of nutriments, climate and soil conditions, biological material and the time of fertilization [20,21].

Complex fertilizers administered in quantities of 30 kg a.s. ha^{-1} ensured the second medium for nutrition (NPK_{30}) for the winter wheat crop where foliar fertilizers were applied. Under these conditions, the yield level ranged from 3850±86.60 kg ha^{-1} in the control variant Mt_1, represented by the conditions created by mineral fertilization (NPK_{30}) and 4750±144.33 kg ha^{-1} in the variant fertilized with Fertitel, Table 1.

The general yield increase, as compared to the control variant Mt_0, was from 925*** kg ha^{-1} in variant Mt_1 (NPK_{30} fertilization level) and 1825*** kg ha^{-1} in the variant fertilized with Fertitel on the background of NPK_{30}. Complex fertilizers ensured yield increase between 860*** and 1150*** kg ha^{-1} in comparison with similar variants with NPK_0. The highest yield, 4750±144.33 kg ha^{-1}, was obtained by the associating complex soil fertilization with Fertitel. The foliar fertilizers potentiated differently the effect of the complex fertilizers, with values of 0.93 units (Nutrilene), 1.21 units (Biocomplex 900), 1.20 units (Nutrion Zn, Megafol) and 1.24 units, respectively (Fertitel). The yield increase given by foliar fertilizers on NPK_{30} ranged from 550** kg ha^{-1} in the case of Biocompex900 to 900*** kg ha^{-1} in the case of Fertitel, with statistical assurance.

Base fertilization with complex fertilizers at the level of 60 kg active substance ha^{-1} (NPK_{60}) constituted the third type of base fertilization that was combined with foliar fertilizers. The yield level was between 4350±109.69 kg ha^{-1} in the variant NPK_{60} (Mt_2) and 5145±106.81 kg ha^{-1} in the variant where Megafol was applied, Table 1. The general yield increase, compared to Mt_0, ranged from 1425*** kg ha^{-1} in the case of variant Mt_2 (NPK_{60}) and 2220*** kg ha^{-1} in the case of the variant fertilized with Megafol on the background of NPK_{60}, where the yield differences are statistically assured.

Complex fertilizers determined yield increases ranging from 1115*** kg ha^{-1} and 1620*** kg ha^{-1}, as compared to Mt_0, with statistically assured differences. The highest yield was obtained when complex mineral; fertilization was combined with the foliar fertilizer Megafol (5145±106.81 kg ha^{-1}). The effect of complex fertilizers applied on the soil was potentiated in a different way by foliar fertilizers on the background of this NPK base fertilization, but generally the values were lower than in the previous NPK dosage (NPK_{30}); 0.78 (Nutrilene), 0.92 (Fertitel), 1.07 (Megafol), 1.13 (Nutrion Zn) and 1.14 (Biocomplex 900). Foliar fertilization on this NPK dosage (NPK_{60}) determined yield increases ranging from 500* kg/ha in the variant fertilized with Nutrilene and 795*** kg/ha in the variant fertilized with Megafol, the yield differences being statistically assured. Although in most cases there were differences from the control variant, the yield increase generated by foliar fertilization was relatively small, of about 300 to 800 kg ha^{-1}, in the conditions of natural soil fertility (NPK_0).

Under the soil and climate conditions of the present research, application of only foliar fertilization on the wheat crop determined relatively low yields and small increases as compared to the yield given by the natural fertility of the soil. In some cases, the yield differences were not statistically assured, which means that unilateral fertilization with foliar fertilizers presents a certain degree of uncertainty. Similar results were communicated also by [22,23], according to which, foliar fertilizers had the main influence of the quality of the wheat crop. The nutrient content in foliar fertilizers and the dilutions in which they are applied, as well as other bioactive products applied on the leaves, cause them to have an influence on the metabolic and enzymatic processes in plants that stimulate photosynthesis [24], synthesis and accumulation of carbohydrates [25,26], the increase of the protein content in beans [27,28].

When associated with complex soil fertilization (NPK_{30}, NPK_{60}), foliar fertilizers had a significantly higher contribution to the wheat yield, with variations from one type of fertilizer to another. Nevertheless, soil nutrients had the major contribution to the yield; foliar fertilizers only potentiated their effect and contributed to significant yield increases with statistical assurance.

Regression analysis of the potentiation capacity of foliar fertilization on the effect of complex fertilizers generated models that describe, with high statistical certainty, the contribution of foliar fertilization on yield increase after mineral fertilization, R^2 = 0.844, equation (1) with NPK_{30} and R^2 = 0.989, equation (2) with NPK_{60}, Fig. 4.

$$PF_{NPK_{30}} = -0.0347x^2 + 0.2153x + 0.9232 \quad (1)$$

$$PF_{NPK_{60}} = -0.0767x^2 + 0.5806x + 0.0646 \quad (2)$$

where:

$PF_{NPK_{30}}$ - potentiation factor on NPK_{30};

$PF_{NPK_{60}}$ - potentiation factor on NPK_{60};

x – foliar fertilizer.

Multivariate analysis of the experimental results facilitated the orientation and grouping of variants based on similarity. The experimental variants were grouped in two major clusters, with two large subgroups each. The first cluster contains mainly the variants with foliar fertilization on the background of NPK_0 (V_1 – V_6) and variant V_7, which gave yields in the same value group, Fig. 5. The second major cluster comprises the variants with foliar fertilization, on the background of NPK_{30} (V_8 – V_{13}) and NPK_{60} (V_{14} – V_{18}), which in their turn have two subclusters according to their values. The cophenetic coefficient had the value of 0.859, which gives high degree of confidence to the grouping of the experimental results based on Euclidean distances.

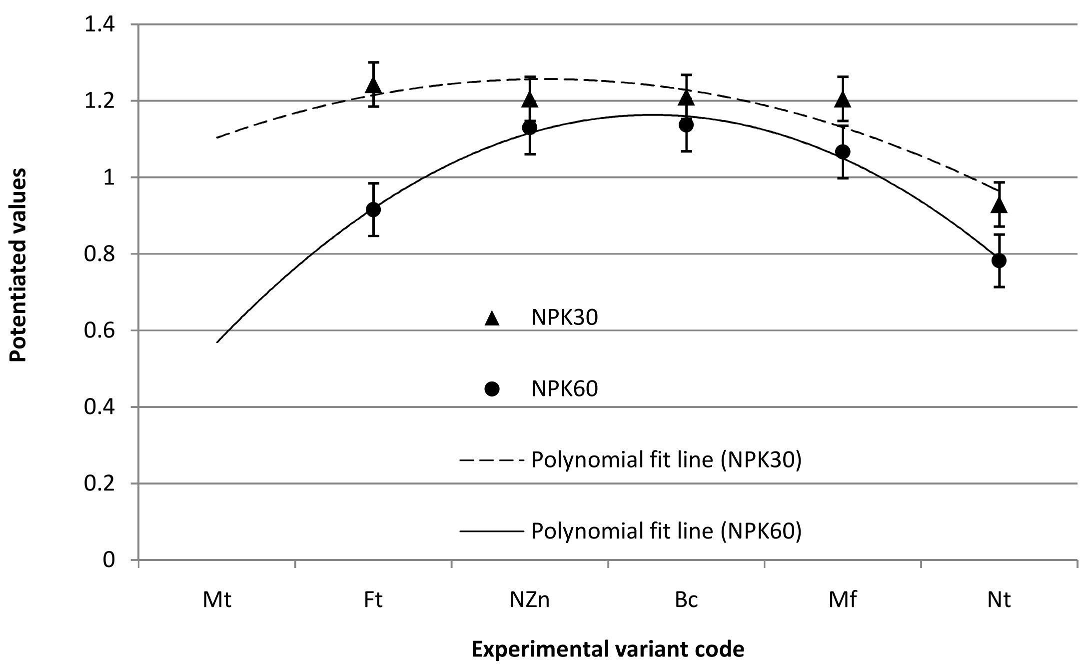

Fig. 4. The particular distribution of the potentiation values given by foliar fertilizers in relation to the experimental results obtained (Mt–control variant, Ft–fertitel, NZn– nutrion Zn, Bc–Biocomplex900, Mf–Megafol, Nt–nutrilene)

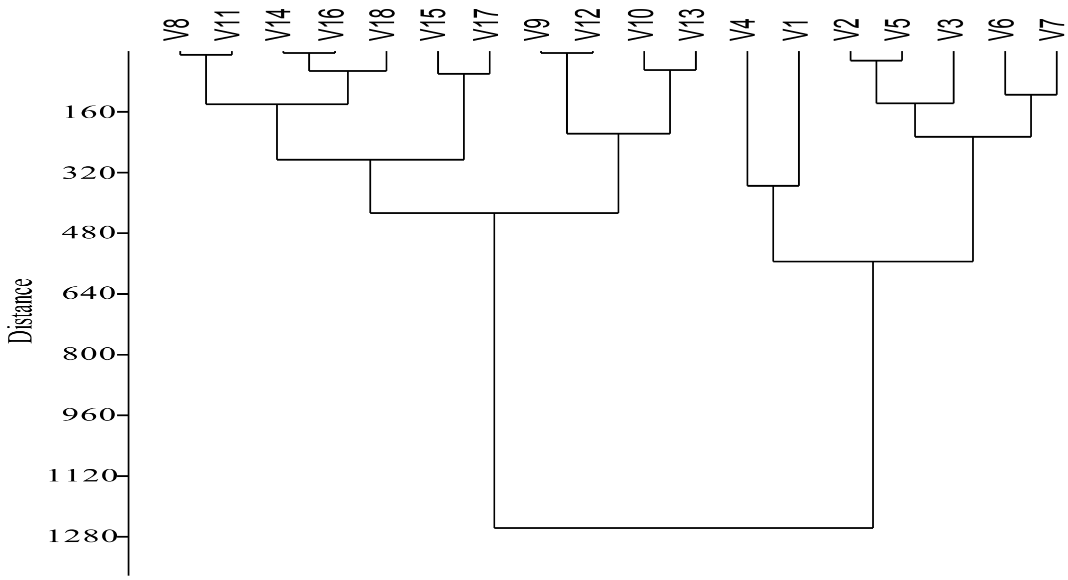

Fig. 5. Variants grouping based on similarity, according to the Euclidean distances

4. CONCLUSION

Soil mineral fertilization and foliar fertilization had different contributions to the winter wheat yield, the contribution of soil fertilization being significantly higher. Foliar fertilization potentiated the effect of mineral fertilization applied on the soil, with values ranging from 0.93 to 1.24 yield units where mineral fertilization was NPK_{30} and from 0.78 to 1.14 yield units where soil fertilization was NPK_{60}. The study revealed a reduction in the effect of foliar fertilizers on the winter wheat yield as the doses of soil fertilizers were increased. The prediction model for the potentiation factor (PF) is described by polynomial equations of the second degree that allow high certainty prediction of the contribution of foliar fertilizers to the yield increase. Multivariate analysis based on Euclidean distance facilitated the orientation and grouping of the variants depending on similarities in result generation, the value of the cophenetic coefficient 0.963 providing statistical assurance to the results. From the distribution of the data, convenient variants can be chosen based on similarity in result generation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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