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INTERDEPENDENCE RELATIONSHIPS BETWEEN AGROCHEMICAL INDICES FOR CHARACTERIZATION AN AGRICULTURAL LAND

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Abstract

This study evaluated the relationship of interdependence between agrochemical indices of the soil in the pedoclimatic conditions of Beregsău area, Timiș County, Romania. The agrochemical indices that characterize the agricultural soil, were taken into consideration: soil pH, nitric nitrogen (NO_3^-), ammoniacal nitrogen (NH_4^+), mineral nitrogen (Nmin), phosphorus (P_2O_5), potassium (K_2O), secondary macro-elements (Ca, Mg, S), sodium (Na), and microelements (Fe, Mn, Cu, Zn, and B). Very high positive correlation was recorded between Nmin and NO_3^- (r = 0.990), and very high negative correlation was recorded between Mn and pH (r = -0.973). High positive correlations were recorded between Cu and K (r = 0.857), between Cu and Mg (r = 0.834), and between Na and Mg, respectively (r = 0.893); high negative correlation was recorded between Mg and Ca (r = -0.855). Moderate positive correlations were recorded between B and pH (r = 0.783), between Mg and K (r = 0.700), and moderate negative correlations were recorded between Ca and K (r = -0.738), and respectively between Na and Ca (r = -0.703). Based on the values of the coefficients of variation (CV) it was appreciated that pH, and potassium had the highest degree of uniformity in the characterization of the studied soil. High degree of variation was recorded in the case of nitrogen (NO_3^-, NH_4^+, Nmin), phosphorus, followed by secondary macro-elements, and micro-elements. The interdependence relationships between certain agrochemical indices were described by different mathematical model in the form of linear equations (NO_3^- and Nmin, in condition of $R^2 = 0.981$, $p << 0.001$; Mn and pH, in condition of $R^2 = 0.947$, $p << 0.001$), and in the form of polynomial equations, respectively (Mg and Ca, in condition of $R^2 = 0.779$, $p = 0.0107$; Cu and K, in condition of $R^2 = 0.768$, $p = 0.012$; Cu and Mg, in condition of $R^2 = 0.819$, $p = 0.0059$). PCA explained 98.7808% of variance in relation to the main soil macro-elements, 99.9986% of variance in relation to the secondary soil macro-elements and 99.8228% of variance in relation to the soil micro-elements, respectively.

Key words: *agrochemical indices, correlations, mathematical model, PCA, soil.*

INTRODUCTION

Agricultural soil and land fertility is periodically evaluated on the basis of general quality indices and specific agrochemical indices that define soil reaction, soil organic matter, supply with main and secondary macroelements (N, P, K, S, Ca, Mg), microelements (Fe, Mg, Cu, Zn, B, Mo), cation exchange capacity (CEC), saturation degree in basic cations, electrical conductivity (EC) etc. (Plaster, 2003; Havlin et al., 2005; Jónsson et al., 2016).

Knowing these agrochemical indices is important for establishing soil health and improvement measures, evaluating the relationship between plants and soil, managing fertilization plans and optimizing fertilizer doses (Idowu et al., 2009; Gelaw et al., 2015; Boldea et al., 2015; Andriucă et al., 2018; Cojocaru and Cerbari, 2018; Norris and Congreves, 2018; van Es and Karlen, 2019).

Soil quality indices and soil supply level with mineral nutrients, varies in time and space in relation to the type of soil, agricultural technologies level, crops structure and rotation, yields, farm management, natural and anthropogenic factors of influence (Santillano-Cázares et al., 2012; Wang et al., 2014; Congreves et al., 2015; Apesteguía et al., 2017; Roper et al., 2017; Su et al., 2018).

Carbon fractions and changes of soil organic carbon, were evaluated according to diversity and crop rotation, soil tillage systems, pedoclimatic conditions (Weil et al., 2003; Alhameid et al., 2017; Bongiorno et al., 2019).

Soil pH has been intensively studied in relation to soil type, microbiological activity, precipitation regime, type and dose of ameliorative substances and fertilizers used, agricultural crops, watering system, soil tillage system, etc. (Bolan et al., 2003; Aciego Petri and Brookes, 2008; Goulding, 2016; Ghimire et al., 2017; Bai et al., 2018).

Soil fertility and macroelement regime were studied in relation to soil type and its characteristics, climatic conditions, land use, crops and yields, agricultural practices, fertilizer inputs, nutritional imbalances in plants (Rolando et al., 2018; Cojocaru, 2019; Datcu et al., 2019; Sala et al., 2019; Willy et al., 2019).

Soil microelements regime was studied in relation to soil type, soil pH, soil organic matter, macroelement content, especially those with antagonistic effect (eg. Ca^{2+}), cultivated plants, fertilizers application methods and techniques, production quality (Jivan and Sala, 2014; Zhao et al., 2014; Rawashdeh and Sala 2015a;2015b; 2016; Dhaliwal et al., 2019; Ma et al., 2019).

The spatio-temporal variation of soil fertility and influence on agricultural crops has been studied both by classical, analytical or quantitative method (Andrews et al., 2004; Moebius et al., 2007; Kinoshita et al., 2017; Rinot et al., 2019), and by imagistic methods which are increasingly promoted as a result of the advantages presented, especially for precision agriculture (Yasrebi et al., 2008; Li et al., 2012; Herbei and Sala, 2015; 2016; Vohland et al., 2017; Song et al., 2018).

Some agrochemical indices have greater stability in soil fertility characterizing, while others have much more dynamic variation. Soil organic matter content has a high stability (Kirkby et al., 2011; Clercq et al., 2015), while nitric and ammoniacal nitrogen have an increased dynamics (Nurulhuda et al., 2018; Pacifico et al., 2019).

Soil pH varies with soil type and agricultural practices, in particular with the type and doses of fertilizers used, with crop structure, with watering regime, etc., and in turn the pH influences the nutrients regime in soil (Jia et al., 2009; Marinca et al., 2009; Vašák et al., 2015).

Between agrochemical indices of the soil there is a close interdependence (Marschner, 1995; Havlin et al., 2005).

Present study evaluated the interdependence relationships between agrochemical indices that define the fertility of the soil, in field crops conditions.

MATERIAL AND METHODS

The study evaluated the fertility status and the relationships of interdependence between the agrochemical indices of the soil, chernozem type, in the pedoclimatic conditions of Beregsău area, Timiș County, Romania.

Specific agrochemical indices, currently used for the characterization of agricultural land, have been studied. Soil samples were taken at 0-30 cm depth from plot BF 506, and agrochemical indices were determined: soil pH, nitric nitrogen (NO_3^-), ammoniacal nitrogen (NH_4^+), mineral nitrogen (Nmin), phosphorus (P_2O_5), potassium (K_2O), secondary macro-elements (Ca, Mg, S), sodium (Na), and microelements (Fe, Mn, Cu, Zn, B). The soil sample analysis was performed by SC Vantage Balkans SRL (2018), using accredited laboratory methods and software.

The statistical analysis of the experimental data was done with the statistical calculation module from EXCEL, Office 2007 and with the PAST software (Hammer et al., 2001).

Single-factor ANOVA test, correlation analysis, regression analysis, coefficient of variation (CV), and PCA were performed. For the statistical certainty of the results, the correlation coefficients r and R^2, the parameter p, and F test were used.

RESULTS AND DISCUSSIONS

The study of soil agrochemical indices on plot BF 506, Beregsău area, Timiș County, led to the values presented in Table 1.

The pH values ranged from 7.66 to 8.04, the soil being characterized by a weak - moderately alkaline reaction. Mineral nitrogen (Nmin) recorded values between 9.87 mg kg^{-1} and 19.97 mg kg^{-1}, based on nitric nitrogen (NO_3^-) and ammoniacal nitrogen (NH_4^+) in soil.

Phosphorus content recorded values between 19.21 mg kg^{-1} P_2O_5 and 46.48 mg kg^{-1} P_2O_5. Potassium has recorded values in the range 325.82 and 439.13 mg kg^{-1} K_2O. Calcium content was between 7379.45-11288.23 mg kg^{-1} CaO, and magnesium had values between 1015.98-1721.35 mg kg^{-1} MgO. Sodium had values between 39.78-70.58 mg kg^{-1} Na. In the case of microelements, iron had values in the range of 12.04-25.22 mg kg^{-1} Fe, manganese oscillated between 3.53 and 6.33 mg kg^{-1} Mn, copper oscillated between 0.71 and 1.2 mg kg^{-1} Cu, zinc had values between 0.33 and 0.6 Zn, and boron had values within the range of 0.83-1.59 mg kg^{-1} B.

ANOVA test, single factor, highlighted the presence of variance in the experimental data set, in statistical safety conditions, p << 0.001, F > Fcrit, for Alpha = 0.001.

The correlation analysis applied to the experimental data revealed a series of positive and negative correlations, of different intensities between the agrochemical indices studied (Table 2).

Table 1. The values of soil agrochemical indices for plot BF 506

Samples	pH (H_2O)	NO_3^-	NH_4^+	Nmin	P_2O_5	K_2O	CaO	MgO	Na_2O	S	Fe	Mn	Cu	Zn	B
		(mg kg^{-1})													
BF 506-1	7.67	10.75	2.71	13.46	46.48	345.19	10689.11	1087.62	40.61	11.25	25.22	6.33	0.9	0.33	1.04
BF 506-2	7.66	9.96	1.38	11.34	25.46	357.44	9735.54	1142.32	40.76	10.36	19.86	6.16	0.8	0.38	0.83
BF 506-3	7.69	8.27	1.6	9.87	22.93	396.62	8408.73	1177.12	40.04	9.92	18.42	6.04	0.83	0.37	1.02
BF 506-4	7.97	18.34	1.63	19.97	19.21	392.33	10305.82	1090.38	44.91	11.67	16.39	3.65	0.89	0.33	1.46
BF 506-5	7.96	14.1	1.21	15.31	38.13	439.13	9293.34	1314.92	40.97	19.18	23.71	4.34	1.19	0.4	1.59
BF 506-6	7.83	10.57	1.31	11.88	38.25	418.92	7379.45	1721.35	70.58	12.31	21.68	5.3	1.2	0.59	1.47
BF 506-7	7.81	9.06	1.42	10.48	33.7	398.3	9884.45	1284.08	43.58	12.26	21.4	4.92	1.06	0.53	1.24
BF 506-8	7.85	8.77	1.44	10.21	32.96	350.51	10430.61	1109.65	41.95	13.16	16.31	4.53	0.81	0.6	1.1
BF 506-9	8.04	11.92	1.66	13.58	32.04	325.82	11288.23	1015.98	39.78	12.05	12.04	3.53	0.71	0.38	1.3

Table 2. Matrix table of correlations

	pH	NO_3^-	NH_4^+	Nmin	P_2O_5	K_2O	CaO	MgO	Na_2O	S	Fe	Mn	Cu	Zn	B
pH		0.0726	0.3551	0.1089	0.8005	0.7998	0.4462	0.8994	0.9156	0.1427	0.1526	0.0000	0.8164	0.9014	0.0126
NO_3^-	0.624		0.9749	0.0000	0.5065	0.5462	0.5634	0.7410	0.9984	0.3818	0.7531	0.0777	0.7240	0.2055	0.0637
NH_4^+	-0.350	-0.012		0.7462	0.2697	0.1512	0.2365	0.2511	0.4848	0.3246	0.5208	0.3413	0.3962	0.1883	0.3704
Nmin	0.570	0.990	0.126		0.6122	0.6825	0.4614	0.6298	0.9260	0.4681	0.8229	0.1164	0.8143	0.1425	0.0964
P_2O_5	-0.099	-0.256	0.413	-0.197		0.9529	0.9474	0.4305	0.5878	0.3145	0.0844	0.5471	0.2436	0.5159	0.7142
K_2O	0.099	0.233	-0.520	0.159	-0.023		0.0231	0.0357	0.2476	0.1479	0.1830	0.9549	0.0031	0.6157	0.0820
CaO	0.292	0.223	0.440	0.283	0.026	-0.738		0.0033	0.0346	0.9198	0.3025	0.3069	0.0688	0.3362	0.6113
MgO	-0.049	-0.129	-0.427	-0.187	0.301	0.700	-0.855		0.0012	0.5393	0.2233	0.6694	0.0052	0.0961	0.2266
Na_2O	0.042	0.001	-0.269	-0.036	0.210	0.430	-0.703	0.893		0.9642	0.6114	0.9088	0.0850	0.1152	0.2610
S	0.529	0.333	-0.372	0.278	0.379	0.524	-0.039	0.237	-0.018		0.4484	0.2504	0.0907	0.7011	0.0449
Fe	-0.519	-0.123	0.248	-0.087	0.605	0.488	-0.388	0.451	0.197	0.290		0.0801	0.0428	0.9822	0.9433
Mn	-0.973	-0.615	0.360	-0.561	0.233	-0.022	-0.385	0.166	0.045	-0.428	0.612		0.9474	0.8579	0.0410
Cu	0.091	0.138	-0.323	0.092	0.434	0.857	-0.630	0.834	0.604	0.596	0.682	0.026		0.3107	0.0590
Zn	0.048	-0.467	-0.483	-0.530	0.250	0.195	-0.364	0.588	0.562	0.149	0.009	-0.070	0.382		0.7078
B	0.783	0.639	-0.340	0.587	0.143	0.609	-0.197	0.448	0.420	0.678	0.028	-0.687	0.648	0.146	

Very high positive correlation was recorded between Nmin and NO_3^- (r = 0.990), and very high negative correlation was recorded between soil manganese content and pH (r = -0.973). High positive correlations were recorded between Cu and K (r = 0.857), between Cu and Mg (r = 0.834), respectively between Na and Mg (r = 0.893), and high negative correlations were recorded between Mg and Ca (r = -0.855).

Moderate positive correlations were recorded between B and pH (r = 0.783), between Mg and K (r = 0.700), and moderate negative correlations were recorded between Ca and K (r = -0.738) and between Na and Ca (r = -0.703). Also positive or negative correlations were recorded, lower in intensity, between other agrochemical indices studied (Table 2).

Between calcium and magnesium content of soil, respectively calcium and microelements, negative correlations were recorded, known be the antagonistic relation of calcium with the bioavailability of microelements for plants in the soils with basic reaction (Merschner, 1995).

The statistical analysis of the agrochemical indices studied showed different levels of variation, expressed by the values of coefficient of variation (CV).

The lowest variation was recorded in the case of pH (CV = 1.7802), and the largest variation was recorded in the case of nitric nitrogen NO_3^- (CV = 28.1509). In the case of ammoniacal nitrogen NH_4^+ the coefficient of variation had the value CV = 27.8444, and in the case of mineral nitrogen (Nmin), the coefficient of variation had the value CV = 24.8661. In the case of phosphorus, the value of the coefficient of variation was CV = 26.4695, and in the case of potassium CV = 9.8772. In the case of secondary macro-elements, the coefficient of variation had the values CV = 12,426 for calcium, CV = 17.4537 for Mg, CV = 21.9090 for Na and respectively CV = 21.7598 for S. In the case of microelements, the coefficient of variation recorded the values CV = 21.1678 for Fe, CV = 21.2224 for Mn, CV = 18.9461 for Cu, CV = 24.9721 for Zn and respectively CV = 20.4058 for B.

In terms of the spatial variability, compared to the analyzed surface area, based on the values of the variation coefficients, it was appreciated that the pH had the highest degree of uniformity in the characterization of the studied soil. In the case of the main macro-elements, a high degree of non-uniformity was recorded in the case of nitrogen (NO_3^-,NH_4^+, Nmin) and phosphorus, and potassium showed a higher degree of uniformity. High non-uniformity also presented the secondary macro-elements, respectively the micro-elements.

Starting from the high level of correlations, positive or negative, identified between soil agrochemical indices, the models of equations were analyzed that described the interaction of indices.

The interdependence relation between nitric nitrogen (NO_3^-) and mineral nitrogen in soil (Nmin) was most accurately described by a linear equation, relation (1), under conditions of R^2=0.981, p<<0.001, F=154.47. The graphical distribution of the Nmin values according to NO_3^-, is presented in Figure 1.

$$N\,min = 0.9983x + 1.615 \quad (1)$$

where: Nmin - mineral nitrogen in soil; x - nitric nitrogen in soil (NO_3^-).

The variation of the Mn content in the soil in relation to soil pH was described by a linear equation, relation (2), under conditions of R^2 = 0.947, p << 0.001, F = 125.52. The graphical distribution of the Mn values according to the soil pH values is presented in Figure 2.

$$Mn = -7.375x + 62.73 \quad (2)$$

where: Mn - Mn content in soil; x - soil pH

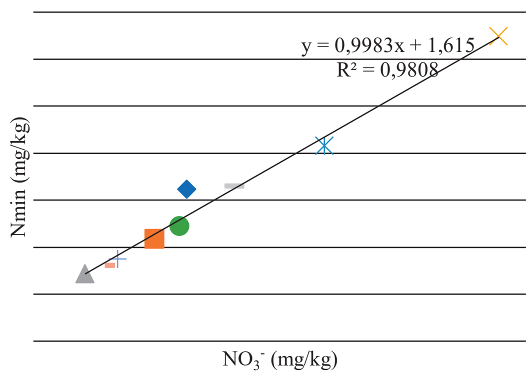

Figure 1. Graphical distribution of Nmin values in relation to NO_3^-

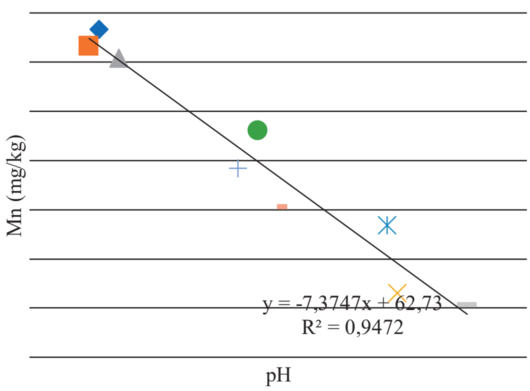

Figure 2. Graphical distribution of Mn content values according to soil pH

The variation of the Mg content in the soil with respect to the Ca content was described by a polynomial equation of degree 2, relation (3), under conditions of R^2 = 0.779, p = 0.0107, F = 10.601, and the graphical distribution is presented in the Figure 3.

$$Mg = 3.217E - 05x^2 - 0.7487x + 5412 \quad (3)$$

where: Mg - Mg content in soil; x - Ca content in soil

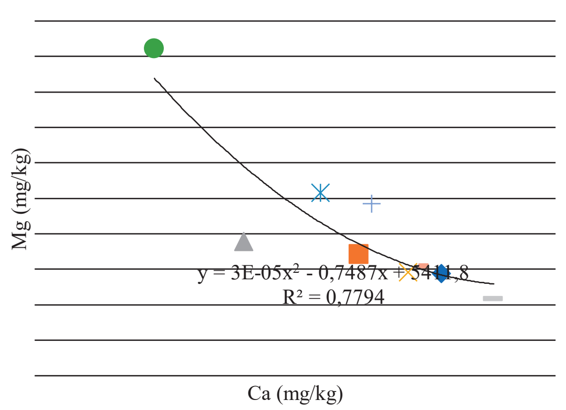

Figure 3. Graphical distribution of Mg values in relation to soil Ca content

The interrelation between Cu and K was described by a polynomial equation of degree 2, relation (4), under conditions of $R^2 = 0.768$, p = 0.012, F=9.9771. The interrelation between Cu and Mg was described by a polynomial equation of degree 2, relation (5), under conditions of $R^2 = 0.819$, p = 0.0059, F = 13.553, with graphical distribution in Figure 4.

$$Cu = 2.693E - 05x^2 - 0.01652x + 3.285 \quad (4)$$

where: Cu – Cu content in soil; x –K content in soil

$$Cu = -1.409E - 06x^2 + 0.004577x - 2.494 \quad (5)$$

where: Cu –Cu content in soil; x –Mg content in soil

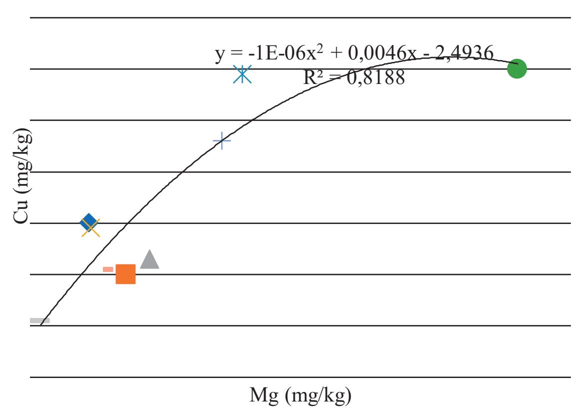

Figure 4. Graphical distribution of Cu content values according to Mg in soil

As the soil studied had a basic reaction, the interdependence relationship between Na and Ca, respectively Na and Mg, was analyzed. Were found a polynomial equation of degree 3, relation (6), which described the most faithful interdependence between Na and Ca in the soil, under conditions of $R^2 = 0.966$, p << 0.001, F = 47.957. Also was found a polynomial equation of degree 2, relation (7), that described the interdependence between Na and Mg, under conditions of $R^2 = 0.961$, p << 0.001, F = 74,151.

$$Na = -2.949E - 09x^3 + 8.648E - 05x^2 - 0.8405x + 2748 \quad (6)$$

where: Na - Na content in soil; x - Ca content in soil

$$Na = 9.034E - 05x^2 - 0.2077x + 160.1 \quad (7)$$

where: Na - Na content in soil; x -Mg content in soil

The variation of the B content according to the pH values was described by a polynomial equation of degree 2, relation (7), under conditions of $R^2 = 0.720$, p = 0.021.

$$B = -5.518x^2 + 87.9x - 348.6 \quad (8)$$

where: B - B content in soil; x - soil pH

PCA analysis explained 93.887% of variance for PC1 and 4.8938% of variance for PC2, respectively, in relation to the values of the agrochemical indices represented by the soil main macro-elements (Nmin, NO_3^-, NH_4^+, P, K). Soil samples BF 506-5, BF 506-6 and BF 506-7 were associated with P and K (P and K biplots). Soil samples BF 506-3 and BF 506-4 are more strongly associated with nitrogen (Nmin, NO_3^- and NH_4^+ biplots). The other soil samples, BF 506-1, BF 506-2, BF 506-8 and BF 506-9 showed relative independent position with respect to the soil main macro-elements (Figure 5).

In relation to the secondary macro-elements (Ca, Mg, S) and Na, PCA analysis explained 99,206% variance for PC1 and 0.79262% variance for PC2 respectively, figure 6. Soil samples BF 506-1, BF 506-7, BF 506-8 and BF 506-9 were associated with Ca (Ca biplot). Sol samples BF 506-5 and BF 506-6 were associated with Mg (Mg biplot). Soil samples BF 506-2 and BF 506-4 showed affinity for S and Na (Na and S biplots). BF 506-3 presented an independent position.

In relation to the microelements studied (Fe, Mn, Cu, Zn and B), PCA analysis explained 95,746% of variance for PC1 and 4.0768% of variance for PC2, respectively, figure 7. Soil sample BF 506-2 was strongly associated with Mn.

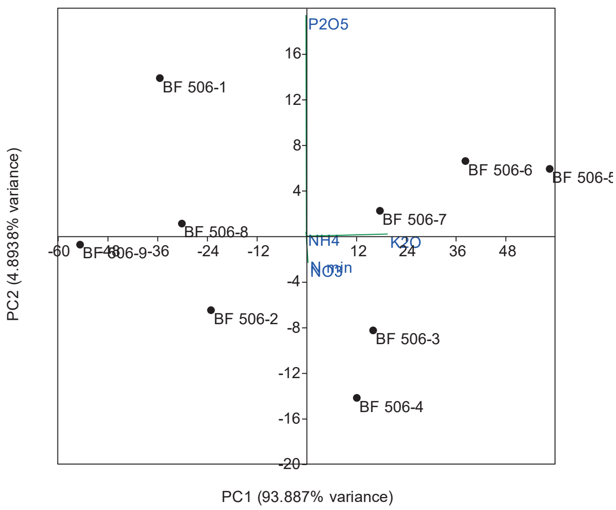

Figure 5. PCA analysis in relation to soil main macro-elements (Nmin, NO_3^-, NH_4^+, P and K)

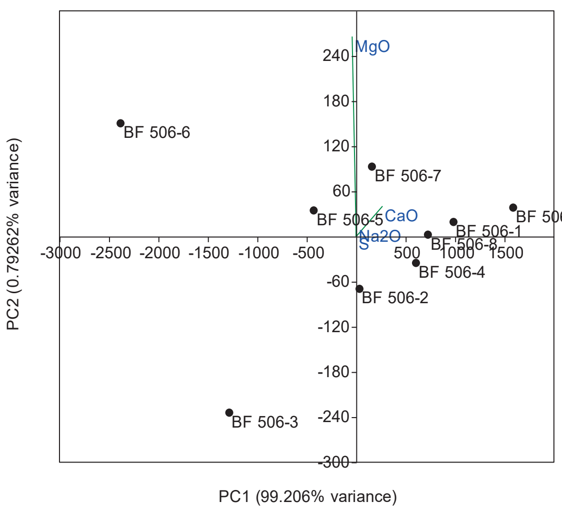

Figure 6. PCA analysis in relation to soil secondary macro-elements (Ca, Mg, S and Na)

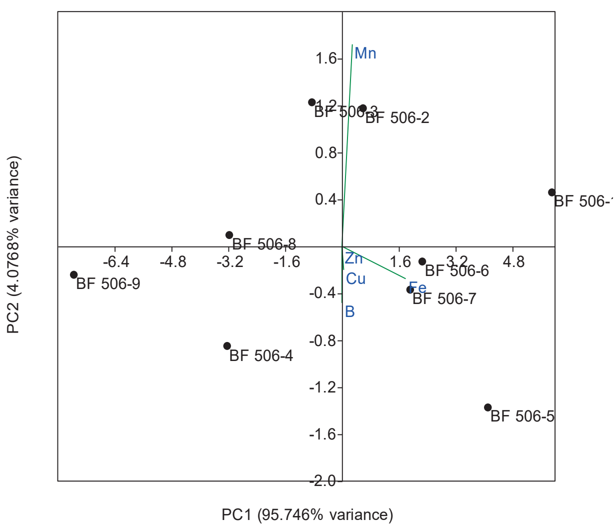

Figure 7. PCA analysis in relation to soil micro-elements (Fe, Mn, Cu, Zn and B)

Soil samples BF 506-5, BF 506-6 and BF 506-7 were strongly associated with Fe, Zn, Cu and B (Figure 7). The other soil samples, BF 506-3, BF 506-4, BF 506-8 and BF 506-9 had an independent position relative to the microelements studied (Figure 7).

Studies on soil fertility and soil-plant relationship have been conducted to establish soil health and improvement measures (Kibblewhite et al., 2007; Sigua et al., 2016; Shiau et al., 2017; Bünemann et al., 2018), for the optimization of agricultural crops fertilization (Sala and Boldea, 2011; Sala et al., 2015; 2016; Xu et al., 2015), for the improvement of agricultural technologies, the implementation and development of smart agriculture services, or for precision agriculture (Yasrebi et al., 2008; Herbei et al., 2015a; 2015b; Chen et al., 2019). The variability and high mobility of mineral nitrogen in soil has been well studied and highlighted in relation to different factors of influence, soil conditions and crop plants (Mulvaney et al., 2009; Stępień and Wojtkowiak, 2015; Nascente et al., 2017; Sharma and Bali, 2017).

Prediction models of the content or variation of mineral elements in soil have been developed for nitrogen (Bleken et al., 2009; Jégo et al., 2012; Sharifi et al., 2017; Lee et al., 2018), for phosphorus (Yang et al., 2013; Keshavarzi et al., 2015; 2016), for potassium (Phong et al., 2011; He and CHEN, 2013; Akbas et al., 2017; Laekemariam et al., 2018), for secondary macro-elements (Saggar et al., 1990; Lemos et al., 2007; Aşkın et al., 2012; Aikpokpodion et al., 2013), and for micro-elements (Grieve and Poss, 2000; Arias et al., 2005; Cheng et al., 2007; Rawashdeh and Sala, 2015a; 2015b; Huang et al., 2018).

The results obtained and communicated in the present study, are in the context of those of the specialized literature consulted, and at the same time contribute to the development of the knowledge regarding the interrelations of the nutritional elements and the agrochemical indices in the description and characterization of agricultural lands.

CONCLUSIONS

Between the agrochemical indices studied (eg soil pH, macroelements - N, P, K, secondary macroelements - S, Ca, Mg; microelements - Fe, Mn, Cu, Zn, B, Mo) interdependences were found varying levels intensity. Very high positive correlation was recorded between Nmin and NO_3^- (r = 0.990), and very high negative correlation was recorded between Mn and pH (r = -0.973).

The regression analysis facilitated the obtaining of models, in the form of linear and polynomial equations of degree 2, which described under conditions of high statistical certainty the variation Nmin in relation toNO_3^-, the variation of the content of Mn against the pH of the soil, the variation of the content of Mg with respect to Ca in soil, respectively the variation of Cu content in relation to K and Mg in soil.

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