Cluster and discriminant analysis of agricultural soils from Manica province in Mozambique

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Introduction

Abstract

The quality of agricultural soils is a critical factor for the environmental and socio-economic sustainability of a rural region [1]. Few studies about the quality of agricultural soils of Mozambique could be found in literature [2-4]. Five samples soils from agricultural farms of Manica province, two of Manica and three of Sussundenga district, were collected by random sampling (Figure 1). The random sampling was done in a zigzag manner collecting for each soil by three times during four years from 2021 to 2024. Five soils in each sampling time with a total of fifteen samples were collected [5].

Twenty-seven physical-chemical parameters were analyzed for all the fifteen samples: extractable ions (K, Mg, Ca, Fe, Mg, Zn, Cu and B), exchangeable ions (Na, K, Ca, Mg and Al), cation exchange capacity (CEC), fertility properties of soils (total limestone, active limestone, pH2O, pHKCl, extractable P, organic carbon, organic matter, N total, N nitrate, conductivity) and texture (sand, clay and slit) [5].

A multivariate analysis design was used to classify the soil samples under research. Cluster analysis (supervised hierarchical and non-supervised K means) was performed in order to evaluate the similitude of the soil samples and the statistically significant variables that contribute to the variability of the model. Also, a non-supervised two-step cluster and discriminant analysis were performed in order to further explore the results of the initial cluster analysis [6,8]. In this multivariate analysis the variables extractable B, exchangeable Al and active and total limestone were not considered for the analysis, and not presented in Table 1, due to the fact that the values found for all the soils were unchanged and are below the limit of detection of the analytical methodology used.

The non-standardized supervised hierarchical cluster analysis for the five samples along the same sampling time resulted in a two-cluster model and for the all the fifteen soil samples along the time a three-cluster model. By a non-hierarchical K means cluster analysis the more stable model, for the five samples at each sampling time, was found with the two clusters model and, for all the fifteen samples along the time, was found for the three-cluster model. The two-step cluster analysis confirmed these previous results. The more and the less important predictor found for each of the five samples for the three sampling times is not the same. For all the fifteen samples the more important predictor found with is the extractable K and the less important predictor is the N nitrate. The discriminant analysis confirms the previous cluster models for the five samples at each sampling time and for all the fifteen samples along the time.

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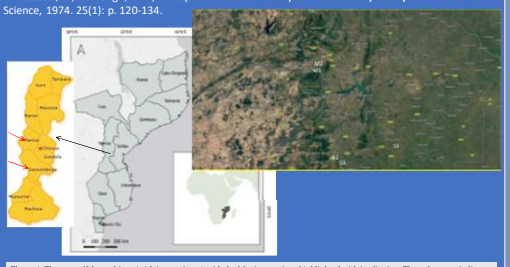

Figure 1. The map of Mozambique (with its provinces) with the Manica province highlighted with its districts. The red arrows indicate the areas where soil samples were collected. Adapted from reference [2].

Table 1. Characteristics of the soil samples in campaigns 2021/2022 (first row – Y1). 2022/2023 (second row – Y2) and 2023/2024 (third row – Y3).

	Manica		Sussundenga	
Property	M1	M2	S1	S2	S3
Extractable K (K2O), mg/kg	157	211	157	40.1	49.2
	149	124	110	45.0	37.9
	213	189	203	104	77.0
Extractable Mg, mg/kg	268	386	128	46.4	75.8
	622	102	121	47	40.1
	680	125	112	49.2	54.2
Extractable Ca, mg/kg	916	1191	512	448	424
	1474	458	516	516	270
	1634	555	645	459	308
Micronutrient Fe, mg/kg	183	230	117	49.3	107
	88.9	170	81	50.9	74.3
	104	243	78.9	44.1	66.3
Micronutrient Mn, mg/kg	263	307	180	45.6	22.6
	101	163	153	51.8	14.2
	414	157	179	40.0	13.6
Micronutrient Zn, mg/kg	1.9	1.9	0.95	2.0	3.0
	1.4	1.6	0.86	1.3	2.7
	1.8	2.4	1.1	1.9	2.4
Micronutrient Cu, mg/kg	3.5	3.6	2.0	0.45	0.68
	2.2	3.2	1.4	0.42	0.38
	2.9	4.2	1.7	0.44	0.44
Exchangeable Na, cmol(+)/kg	0.10	0.15	0.11	0.04	0.05
	0.17	0.04	0.07	0.05	0.04
	0.22	0.07	0.09	<0.010	0.05
Exchangeable K, cmol(+)/kg	0.33	0.44	0.39	0.14	0.16
	0.39	0.31	0.33	0.15	0.12
	0.39	0.33	0.39	0.17	0.13
Exchangeable Ca, cmol(+)/kg	4.6	5.9	2.6	2.2	2.1
	7.4	2.3	3.2	2.6	1.3
	8.2	2.8	3.2	2.3	1.5
Exchangeable Mg, cmol(+)/kg	2.2	3.2	1.0	0.38	0.62
	5.1	0.84	0.99	0.39	0.33
	5.6	1.0	0.92	0.40	0.45
CEC, cmol(+)/kg	7.30	9.74	4.22	2.83	3.08
	13.11	3.59	4.67	3.26	1.91
	14.44	4.24	4.64	2.94	2.18
pH(H2O) 1:5	6.0	6.1	5.7	5.8	5.4
	6.2	5.4	6.0	5.9	5.2
	6.4	5.7	6.2	5.8	5.5
pH(KCl) 1:5	5.2	5.4	4.8	5.2	4.6
	5.2	4.5	5.3	4.5	4.5
	5.2	4.8	5.1	5.0	4.6
Extractable P (P_O_) mg/kg	132	186	36.0	37.1	37.9
	44.8	174	<20	38.5	37.3
	79.2	198	27.8	55.8	41.2
Organic Carbon (%)	0.43	0.77	0.79	0.60	0.78
	1.0	0.52	0.76	0.64	0.66
	0.78	0.50	0.81	0.76	0.63
Organic Matter (%)	1.09	1.33	1.81	1.04	1.34
	1.77	0.90	1.31	1.10	1.14
	1.29	0.86	1.40	1.31	1.09
Nitrogen Kjeldahl, g/kg	0.94	1.23	1.10	0.59	0.80
	1.24	0.78	0.68	0.66	0.68
	1.2	0.6	0.7	0.1	2.2
Nitrate (N-NO_), mg/kg	18.5	23.2	7.0	12.0	16.9
	19.8	14.5	4.7	14.3	20.1
	2.6	4.9	3.2	5.2	3.4
Conductivity, mS/m	10.1	11.8	7.8	6.6	6.9
	6.3	5.7	4.2	4.9	5.3
	5.0	8.0	4.4	5.3	5.0
Sand, %	10.1	11.8	7.8	6.6	6.9
	6.3	5.7	4.2	4.9	5.3
	5.0	8.0	4.4	5.3	5.0
Clay, %	21.7	26.3	20.3	10.2	13
	32.3	17	19.2	9.7	10.5
	34	14.8	17.5	10.7	10.8
Silt, %	15.6	18.5	11.8	12.4	7.6
	33.7	12	14.4	4.4	11
	26.3	15.02	16.1	11.5	15.7

Cluster analysis

Hierarchical unsupervised cluster analysis

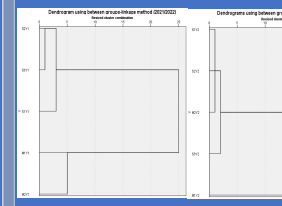

Figure 2 – Dendograms obtained in the cluster analysis of the 5 samples of each sampling time (2021/2022, 2022/2023, 2023/2024) using non standardized between-group linkage method.

Table 2 – Clusters and respectively composition found in the supervised hierarchical cluster analysis of the 5 samples of each sampling time (2021/2022, 2022/2023, 2023/2024) using non standardized between-group linkage method.

Clusters (2021/2022)	Samples in the cluster	Sub-Clusters	Samples in the sub-clusters	Origin of the soils
Cluster 1	S1Y1, S2Y1, S3Y1	Cluster 1A	S3Y1	Sussundenga
		Cluster 1B	S2Y1, S3Y1	
Cluster 2	M1Y1, M2Y1	---	---	Manica

Clusters (2022/2023)	Samples in the cluster	Sub-Clusters	Samples in the sub-clusters	Origin of the soils
Cluster 1	S1Y2, S2Y2, S3Y2 M2Y2	Cluster 1A	S1Y2, S2Y2, M2Y2	Sussundenga / Manica
		Cluster 1B	S3Y2	Sussundenga
Cluster 2	M1Y2	---	---	Manica

Clusters (2023/2024)	Samples in the cluster	Origin of the soils
Cluster 1	S2Y3, S3Y3	Sussundenga
Cluster 2	S1Y3, M2Y3	Sussundenga / Manica
Cluster 3	M1Y3	Manica

- ✓ A 2 to 3 clusters model seems to be the right model in order to evaluate the 5 samples for each sampling time.
- ✓ Through the time, an initially two cluster model for the first time sampling (2021/2022), evolves for a 3 cluster model for the last sampling time (2023/2024).
- ✓ Only for the first sampling time (2021/2022) the two soils of Manica district are found in a same cluster and the three soils of Sussundenga district are found in a same different cluster.

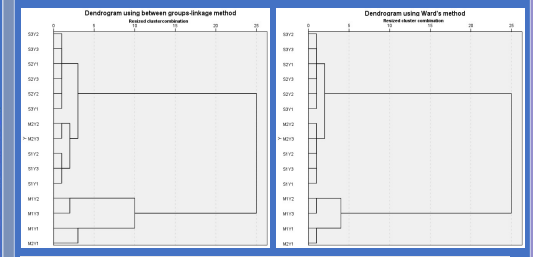

Figure 3 – Dendograms obtained in the supervised hierarchical cluster analysis of the 15 samples with the 3 sampling times using between group-linkage and Ward's methods.

Table 3 – Clusters and respectively composition found in the supervised hierarchical cluster analysis of the 15 samples with the three sampling times.

Cluster	Samples in the cluster	Sub-Clusters	Samples in the sub-clusters	Origin of the soils
Cluster 1	S2Y1, S2Y2,S2Y3 S3Y1, S3Y2,S3Y3	---	---	Sussundenga
Cluster 2	M2Y2, M2Y3	Cluster 2A	M2Y2, M2Y3	Manica
	S1Y1, S1Y2,S1Y3	Cluster 2B	S1Y1, S1Y2,S1Y3	Sussundenga
Cluster 3	M1Y2, M1Y3	---	---	Manica
Cluster 4	M1Y1, M2Y1	---	---	Manica

- ✓ A different number of clusters of 5, obtained by non standardized between groups-linkage method, and of 4, obtained by non standardized Ward's method, were found by each of the methods.
- ✓ A 4 cluster model seems to be the right model in order to evaluate the 15 samples with the 3 sampling times.
- ✓ The same clusters were found for the 3 soils of Sussundenga district for the 3 sampling times and different clusters were found for the 2 soils of Manica district for the 3 sampling times .
- ✓ The soils of Manica that are found in a different cluster are the soils obtained in the first sampling time (MYY1, M2Y1) and both are found in the same cluster.

K means supervised cluster analysis

Table 4 – ANOVA table obtained with 4 clusters by supervised K means cluster analysis of the 15 samples with the three sampling times.

Property	Between Cluster Mean Square	df	Error Mean Square	df	F	Significance p < (0.05)
Extractable K (K2O), mg/kg	15040.0	3	1921.3	11	7.828	**0.004**
Extractable Mg, mg/kg	195898.1	3	2314.8	11	84.5	**<0.001**
Extractable Ca, mg/kg	769256.1	3	12987.3	11	59.2	**<0.001**
Micronutrient Fe, mg/kg	8349.8	3	2993.2	11	2.790	0.090
Micronutrient Mn, mg/kg	57438.6	3	4117.0	11	14.0	**<0.001**
Micronutrient Zn, mg/kg	0.190	3	0.456	11	0.418	0.744
Micronutrient Cu, mg/kg	4.275	3	1.225	11	3.490	0.054
Exchangeable Na, cmol(+)/kg	0.013	3	0.001	11	22.2	**<0.001**
Exchangeable K, cmol(+)/kg	0.041	3	0.005	11	6.4	**0.009**
Exchangeable Ca, cmol(+)/kg	19.4	3	0.344	11	56.4	**<0.001**
Exchangeable Mg, cmol(+)/kg	13.4	3	0.154	11	87.4	**<0.001**
CEC, cmol(+)/kg	68.4	3	0.965	11	71.0	**<0.001**
pH(H2O) 1:5	0.356	3	0.052	11	6.8	**0.007**
pH(KCl) 1:5	0.172	3	0.073	11	2.4	0.127
Extractable P (P2O5), mg/kg	1697.9	3	3505.9	11	0.484	0.700
Organic Carbon (%)	0.021	3	0.022	11	0.944	0.453
Organic Matter (%)	0.067	3	0.076	11	0.885	0.479
Nitrogen Kjeldahl, g/kg	0.147	3	0.241	11	0.608	0.623
Nitrate (N-NO3), mg/kg	63.7	3	49.7	11	1.280	0.329
Conductivity, mS/m	10.7	3	3.026	11	3.545	0.052
Sand, %	850.0	3	23.3	11	38.2	**<0.001**
Clay, %	248.8	3	11.9	11	20.9	**<0.001**
Silt, %	201.3	3	9.972	11	20.2	**<0.001**

Two step supervised cluster analysis

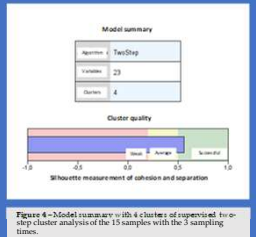

Figure 4 – Model summary with 4 clusters of supervised two-step cluster analysis of the 15 samples with the 3 sampling times.

- ✓ By supervised two step cluster analysis were obtained already a successful analysis with a 2 cluster model for the 5 samples for each of the 3 sampling times.
- ✓ By supervised two step cluster analysis was obtained a successful analysis with a 4 cluster model for all the 15 samples at the 3 sampling times.
- ✓ By supervised K means and two step cluster analysis the variables that contribute more for the 4 cluster model are are the Percentage of sand, clay and silt; Exchangeable Ca and Mg; Micronutrient Mn; Exchangeable Na, Ca, Mg and K and CEC.

Discriminant analysis

Discriminant analysis with 3 clusters

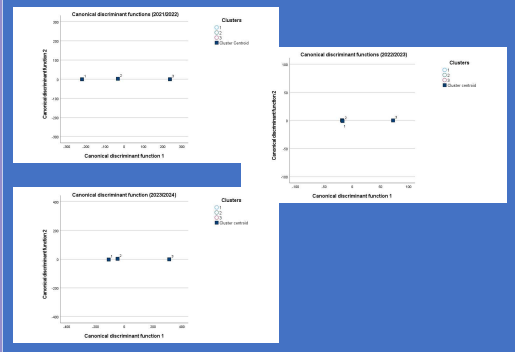

Figure 4 – Discriminant plot found by discriminant analysis with 3 clusters of the 5 samples with the first (2021/2022), second (2022/2023) and third (2023/2024) sampling time.

Table 5 – Statistical tests about the discriminating capacity of the discriminant analysis with 2 clusters of 5 soils for each the 3 sampling times.

2021/2022						2022/2023						2023/2024					
Property	Wilk's lambda	F	df1	df2	Significance p < (0.05)	Wilk's lambda	F	df1	df2	Significance p < (0.05)		Wilk's lambda	F	df1	df2	Significance p < (0.05)	
Extractable K (K2O), mg/kg	0.419	4.2	1	3	0.134							0.749	1.0	1	3	0.390	
Extractable Mg, mg/kg	0.127	20.6	1	3	0.020							0.020	145.9	1	3	0.001	
Extractable Ca, mg/kg	0.091	30.1	1	3	0.012							0.082	33.8	1	3	0.010	
Micronutrient Fe, mg/kg	0.391	12.7	1	3	0.038							0.997	0.01	1	3	0.935	
Micronutrient Mn, mg/kg	0.239	9.6	1	3	0.054							0.327	6.2	1	3	0.089	
Micronutrient Zn, mg/kg	0.996	0.01	1	3	0.920							0.980	0.06	1	3	0.822	
Micronutrient Cu, mg/kg	0.360	15.8	1	3	0.029							0.900	0.3	1	3	0.605	
Exchangeable Na, cmol(+)/kg	0.502	3.0	1	3	0.183							0.050	57.6	1	3	0.005	
Exchangeable K, cmol(+)/kg	0.606	1.9	1	3	0.258							0.623	1.4	1	3	0.270	
Exchangeable Ca, cmol(+)/kg	0.086	31.8	1	3	0.011							0.057	49.1	1	3	0.006	
Exchangeable Mg, cmol(+)/kg	0.135	19.2	1	3	0.022							0.020	148.9	1	3	<0.001	
CEC, cmol(+)/kg	0.114	23.4	1	3	0.017							0.049	58.8	1	3	0.005	
pH(H2O) 1:5	0.306	6.8	1	3	0.080							0.629	1.7	1	3	0.275	
pH(KCl) 1:5	0.476	3.3	1	3	0.168							0.839	0.6	1	3	0.503	
Extractable P (P2O5) mg/kg	0.040	71.2	1	3	0.003							0.974	0.08	1	3	0.795	
Organic Carbon (%)	0.886	0.35	1	3	0.597							0.224	10.4	1	3	0.048	
Organic Matter (%)	0.888	0.38	1	3	0.581							0.197	12.2	1	3	0.040	
Nitrogen Kjeldahl, g/kg	0.690	1.4	1	3	0.329							0.036	80.0	1	3	0.003	
Nitrate (N-NO3), mg/kg	0.388	4.7	1	3	0.118							0.789	0.80	1	3	0.437	
Conductivity, mS/m	0.111	24.0	1	3	0.016							0.486	3.2	1	3	0.173	
Sand, %	0.253	8.8	1	3	0.059							0.138	18.7	1	3	0.023	
Clay, %	0.375	5.0	1	3	0.111							0.201	11.9	1	3	0.041	
Silt, %	0.264	8.4	1	3	0.063							0.113	23.6	1	3	0.017	

- ✓ By the analysis of the discriminant plots found by discriminant analysis with 3 clusters, and attending to the centroids of the clusters, was obtained for the first sampling time (2021/2022) 3 well separate agglomerates and for the second (2022/2023) and third sampling times (2023/2024) 2 agglomerates respectively are overlapping and in the otherare very close (clusters 1 and 2).
- ✓ By the analysis of statistical texts found by discriminant analysis with 2 clusters the 5 discriminant variables, with a lower Wilk's lambda, higher F and lowest significance value, are common to the 3 sampling times: Extractable Mg, Extractable Ca, Exchangeable Mg and CEC. Beside this 4 discriminant variables are common to the last 2 sampling times (2022/2023, 2023/2024): Exchangeable Na, Percentage of clay, sand and silt.

Discriminant analysis with 4 clusters

Table 6 – Statistical tests about the discriminating capacity of the discriminant analysis with 4 clusters of 15 soils with 3 sampling times.

Property	Wilk's Lambda	F	df1	df2	Significance p < (0.05)
Extractable K (K2O), mg/kg	0.247	11.2	3	11	**<0.001**
Extractable Mg, mg/kg	0.016	224.6	3	11	**<0.001**
Extractable Ca, mg/kg	0.050	70.0	3	11	**<0.001**
Micronutrient Fe, mg/kg	0.400	5.5	3	11	**0.015**
Micronutrient Mn, mg/kg	0.043	82.0	3	11	**<0.001**
Micronutrient Zn, mg/kg	0.640	2.1	3	11	0.163
Micronutrient Cu, mg/kg	0.219	13.1	3	11	**<0.001**
Exchangeable Na, cmol(+)/kg	0.127	25.2	3	11	**<0.001**
Exchangeable K, cmol(+)/kg	0.069	49.3	3	11	**<0.001**
Exchangeable Ca, cmol(+)/kg	0.049	71.7	3	11	**<0.001**
Exchangeable Mg, cmol(+)/kg	0.020	183.3	3	11	**<0.001**
CEC, cmol(+)/kg	0.020	127.1	3	11	**<0.001**
pH(H2O) 1:5	0.477	4.0	3	11	**0.037**
pH(KCl) 1:5	0.659	1.10	3	11	0.188
Extractable P (P2O5), mg/kg	0.723	1.4	3	11	0.293
Organic Carbon (%)	0.805	0.9	3	11	0.479
Organic Matter (%)	0.808	0.9	3	11	0.485
Nitrogen Kjeldahl, g/kg	0.878	0.5	3	11	0.683
Nitrate (N-NO3), mg/kg	0.616	2.3	3	11	0.135
Conductivity, mS/m	0.292	8.9	3	11	**0.003**
Sand, %	0.049	71.6	3	11	**<0.001**
Clay, %	0.042	84.5	3	11	**<0.001**
Silt, %	0.175	17.3	3	11	**<0.001**

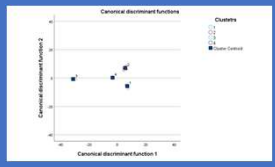

Figure 4 – Discriminant plot for 4 clusters of the 15 samples with the 3 sampling times.

Table 6 – Average and standard deviation of the 15 soils with the 3 sampling times in the four clusters of soil samples observed by discriminant analysis.

Property	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
Extractable K (K2O), mg/kg	58.9 (26.2)	156.8 (40.1)	181.0 (45.3)	204.0 (66.5)	127.1 (68.8)
Extractable Mg, mg/kg	52.1 (12.5)	117.8 (10.2)	653.0 (41.0)	327.0 (81.4)	190.5 (209.2)
Extractable Ca, mg/kg	**404.1 (95.0)**	**562.2 (81.4)**	**1554.0 (111.1)**	**1053.5 (194.5)**	**696.7 (418.4)**
Micronutrient Fe, mg/kg	65.3 (21.4)	138.0 (69.3)	96.5 (10.7)	206.5 (33.2)	112.5 (64.4)
Micronutrient Mn, mg/kg	31.3 (16.6)	166.4 (12.5)	357.5 (80.0)	285.0 (31.1)	153.7 (124.7)
Micronutrient Zn, mg/kg	2.2 (0.6)	1.4 (0.6)	1.6 (0.3)	1.9 (0.0)	1.8 (0.6)
Micronutrient Cu, mg/kg	0.5 (0.1)	0.5 (0.1)	3.5 (0.2)	3.5 (0.07)	1.8 (1.6)
Exchangeable Na, cmol(+)/kg	**0.04 (0.01)**	**0.08 (0.03)**	**0.20 (0.04)**	**0.13 (0.04)**	**0.09 (0.06)**
Exchangeable K, cmol(+)/kg	0.2 (0.02)	0.35 (0.04)	0.4 (0.0)	0.39 (0.08)	0.3 (0.1)
Exchangeable Ca, cmol(+)/kg	2.0 (0.5)	2.8 (0.4)	7.8 (0.6)	5.3 (0.9)	3.5 (2.1)
Exchangeable Mg, cmol(+)/kg	0.4 (0.1)	0.95 (0.07)	5.4 (0.4)	2.6 (0.8)	1.5 (1.7)
CEC, cmol(+)/kg	2.7 (0.5)	4.3 (0.4)	13.8 (0.9)	8.5 (1.7)	5.5 (3.9)
pH(H2O) 1:5	5.6 (0.3)	5.8 (0.3)	6.3 (0.1)	6.10 (0.07)	5.8 (0.3)
pH(KCl) 1:5	4.9 (0.3)	4.9 (0.3)	5.2 (0.0)	5.3 (0.1)	5.0 (0.3)
Extractable P (P_O_) mg/kg	41.3 (7.3)	91.2 (87.1)	62.0 (24.1)	119.0 (18.4)	71.1 (55.8)
Organic Carbon (%)	0.7 (0.07	0.7 (0.2)	0.9 (0.2)	0.7 (0.1)	0.7 (0.1)
Organic Matter (%)	1.2 (0.1)	1.3 (0.4)	1.5 (0.3)	1.2 (0.2)	1.2 (0.3)
Nitrogen Kjeldahl, g/kg	0.8 (0.7)	0.8 (0.2)	1.22 (0.03)	1.1 (0.2)	0.9 (0.5)
Nitrate (N-NO_), mg/kg	12.0 (6.6)	6.9 (4.5)	11.2 (12.2)	20.1 (3.0)	13.4 (7.1)
Conductivity, mS/m	5.7 (0.9)	6.0 (1.8)	5.7 (0.9)	11.0 (1.2)	6.5 (2.1)
Sand (%)	78.8 (4.1)	68.2 (2.0)	36.9 (4.0)	59.0 (5.3)	67.0 (14.5)
Clay (%)	10.8 (1.1)	17.8 (2.1)	33.2 (1.2)	24.0 (3.3)	17.9 (7.9)
Silt(%)	10.4 (3.9)	14.0 (2.0)	30.0 (5.2)	17.1 (2.1)	15.1 (7.1)

- ✓ By the discriminant plot obtained by discriminant analysis with 4 clusters, and attending to the cluster centroid, the clusters 1, 2 and 4 are close to each other and the cluster 3 (M1Y1, M1Y3) is isolated and far from the other three soils. The greatest dispersion of the centroid of the soils is found for the cluster 2 with 2 sub-clusters.
- ✓ By the analysis of statistical texts the first 10 discriminant variables, with a lower Wilk's lambda, higher F and lowest significance value, are by order the Extractable Mg, Exchangeable Mg, CEC, Percentage of clay, Micronutrient Mn, Percentage of sand, Exchangeable Ca, Extractable Ca, Exchangeable K and Exchangeable Na beside some 4 more discriminant variables.
- ✓ Attending to the average and standard deviation of each variables in the 4 clusters the Extractable Ca have the highest average with also a higher standard deviation and the Exchangeable Na have the lowest average with a low standard deviation.

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Conclusions

- ✓ For the soils of Manica district the multivariate analysis along the time of their physical-chemical characteristics allows to conclude that the 2 soils of the first sampling time (2021/2022), both (M1Y1, M2Y1) in the same evaluate cluster, have physical-chemical characteristics different of the soils of the last 2 sampling times. For both soils, and for the last 2 sampling times, the soils M1Y2 and M1Y3; M2Y1 and M2Y3 have the same physical-chemical characteristics. Both soils with a similar behaviour along the time are in the same geographical area.
- ✓ For the soils of Sussundenga district the multivariate analysis along the time of their physical-chemical characteristics allows to conclude that the each of the 3 soils keep the same physical-chemical characteristics. The second and third soils in the same geographical area have the same physical-chemical characteristics and the first soil in a different geographic area have different physical-chemical characteristics.
- ✓ The second soil of Manica in the last 2 sampling times have similar physical-chemical characteristics to the first soil of Sussedunga.
- ✓ Generally at the same sampling time and along the time the main physical-chemical characteristics that define the kind of soils are the Extractable and Exchangeable Mg and Ca and the Cation Exchange Capacity (CEC).

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