Relation between chemical composition of soil and biomass for poplar short rotation coppice in Portugal and Belgium

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Lochristi, Belgium : 51^0 06’ N; 03^0 51’ E
POPFULL project
Planted area 14.5 ha;
Management: no fertilization, no irrigation
Plant density 8000 trees/ha;
12 poplar clones; 3 willow clones;

First harvesting Lochristi 2012 : harvesting and chipping
First harvesting of about 8 tons/ha;

Poplar SRC Site

Santarém, Portugal 39^{0}93’ N; 8^{0}68 ’ W
Management: drip irrigation , fertilization 200 kg/ha (N:14:14)
2 Italian clones
Planted area: 3,5 ha;
6700 plants/ha;

First harvesting 2014: about 8 tons/ha;
Santarém : hand-sawing;

Methodology- soil and biomass:

Lochristi: previous agricultural and pasture land. Sandy soil texture, with a deeper clay enriched layer;

Santarém: former fallow and agricultural lands with medium or low use capacity. Sandy texture;

Chemical elements common to soils (0-20cm depth) and biomass- P_2O_5(ppm); K_2O(ppm), Mg(ppm), Ca(ppm), Na(ppm), C(ppm);

Lochristi poplar clones: Grimminge (Dx(TxD)), Bakan (TxM), Skado(TxM), Wolterson(N);

Santarém poplar clones :
AF_2(DxN); AF_8(TxG); AF_8 was planted in two plots being denominated as AF_8b and AF_8m in our analysis;

(Populus deltoides-D, Populus maximowczii- M, Populus nigra- N, Populus trichocarpa-T, Populus generosa-G);

Methodology (soil analysis):

Chemical components common to soils (0-20cm depth) and biomass- P_2O_5(ppm); K_2O(ppm), Mg(ppm), Ca(ppm), Na(ppm), C(ppm);

Soil P_2O_5 and K_2O with calcium lactate and acid acetic extraction (Egner-Riehm method) followed by analysis with Inductively coupled plasma-optical emission spectrometry (ICP-OES) and Flame Atomic Emission Spectroscopy (AES) , respectively;

Soil extractable Mg and Ca with amonium acetate (1 M) followed by analysis with atomic absorption spectroscopy (AAS);

Soil exchangable Na with amonium acetate (1M) followed by analysis with Flame Atomic Emission Spectroscopy (AES) ;

Organic C by wet oxidation with sodium dichromate followed by analysis with molecular ultraviolet–visible spectroscopy (EAM UV/Vis);

Methodology(biomass) :

Moisture and ashes in biomass by gravimetry at 105ºC and 905ºC , respectively;

The proximate and ultimate analysis of the biomass fuels used were carried out following the procedures specified in the standards ASTM-E-870, EN 14918 and EN 14775;

P_2O_5, Mg, Ca,Na, K_2O in biomass ashes by X-ray fluorescence (spectroscopy XRF);

Analytical results- biomass: average and standart deviations of chemical composition of biomass in both sites (#)

	P_2O_5 (ppm)	K_2O (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	C (%)
Biomass Lochristi	1166.75 ± 171.56 (0.15)	512.25 ± 182.02 (0.36)	540.33 ± 52.72 (0,1)	4158.8 ± 708.43 (0,17)	44.08 ± 10.07 (0,23)	48.82 ± 0.64 (0,01)
Biomass Santarém	2220.33 ± 637.32 (0.28)	1430.66 ± 529.78 (0.37)	1496.6 ± 948.9 (0,63)	3316.87 ± 1637.23 (0,49)	66.23 ± 12.64 (0,19)	48.27 ± 1.36 (0,03)

Biomass in Santarém with higher average amounts of P_2O_5, K_2O, Mg and Na;
Biomass in Lochristi with higher average amounts of calcium;
Average amounts of carbon of the same order of magnitude on biomass of both sites;
Concentrations in chemical elements higher in biomass than in soils;

 # in parenthesis relative standart deviation

Analytical results- soil: average and standart deviations of chemical composition of soil in both sites(#)

	P_2O_5 (ppm)	K_2O (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	C (%)
Pre-agricultural Lochristi soils	266.3 ± 60.36 (0.23)	153.8 ± 33.00 (0.21)	123.1 ± 8,26 (0,06)	976.6 ± 123.37 (0,13)	15,1 ± 9.96 (0,66)	1,2 ± 0.13 (0,10)
Pre-pasture Lochristi soils	208,8 ± 37.73 (0,18)	92,5 ± 27.38 (0,40)	131,6 ±18.29 (0,14)	966,9 ± 271.63 (0,28)	12,2 ± 2.19 (0,18)	1,4 ± 0.14 (0,10)
Santarém soils	113,67 ± 75.37 (0.66)	150,33 ± 46.04 (0,31)	81±24.54 (0,30)	432.2 ± 83.27 (0,19)	6,13 ± 3.51 (0,57)	0,66 ± 0.30 (0,30)

Amounts of P_2O_5, Mg ,Ca, Na and C much higher in Lochristi soils; K_2O levels of the same order of magnitude in both sites;
Former agricultural soils in Lochristi with higher average amounts of P_2O_5 and K_2O comparatively to former pasture soils;
Concentrations in chemical elements higher in biomass than in soils;

in parenthesis relative standart deviation

Analytical results : average composition of soil and biomass in Lochristi and Santarém
The matrix sample data to apply multivariate analysis below consisting of six chemical component variables and eighteen biomass and soil cases was the following:

	P_2O_5(ppm)	K_2O(ppm)	Mg(ppm)	Ca(ppm)	Na(ppm)	C(%)
AF_8b (bio)	1496	944	810.4	2080.8	68	46.7
AF_8m (bio)	2695	1353	1101.1	2696.1	52.8	49
AF_2 (Bio)	2470	1995	2578.3	5173.7	77.9	49.1
Gri(Bio)	952	328	496.8	3840	41.6	49.7
Bak(Bio)	1136	408	501.6	3600	56	48.9
Ska(Bio)	1215	576	553.5	4003.2	46.8	48.4
Wolt(Bio)	1364	737	609.4	5192	31.9	48.3
AF2 (soil)	200	164	87	436.872	6.897	0.957
AF8b(soil)	61	188	102	513.024	9.196	0.667
AF8m(soil)	80	99	54	346.692	2.299	0.348
GriAgr(soil)	285	160	115	892.5	10	117.125
SkaAgr(soil)	290	190	117.5	853.75	10.5	11.425
WolAgri(soil)	177.5	110	132.5	1112.5	9.75	1.185
BakAgri(soil)	312.5	155	127.5	1047.5	30	14.375
GriPast(soil)	256.25	122.5	131.25	1051.25	9.625	131.875
SkaPast(soil)	213.75	107.5	120	838.75	11.375	1.24
WolPast(soil)	165	77.5	117.5	675	14.75	15.725
BakPast(soil)	200	62.5	157.5	1302.5	13	1.32

Exploratory statistical methodology and results (STATISTICA and NTSYS packages):

Correlation matrix:

Correlations (soilbiomassPtBe) Marked correlations are significant at p < ,05000 N=18						
	P_2O_5(ppm)	K_2O(ppm)	Mg(ppm)	Ca(ppm)	Na(ppm)	C(%)
P_2O_5(ppm)	1,00	0,94	0,87	0,78	0,88	0,87
K_2O(ppm)	0,94	1,00	0,97	0,71	0,84	0,74
Mg(ppm)	0,87	0,97	1,00	0,73	0,83	0,69
Ca(ppm)	0,78	0,71	0,73	1,00	0,78	0,90
Na(ppm)	0,88	0,84	0,83	0,78	1,00	0,89
C(%)	0,87	0,74	0,69	0,90	0,89	1,00

Higher significant correlations were 0.90, 0.94 and 0.97, respectively between C and Ca, P_2O_5 and K_2O and Mg and K_2O. P_2O_5 showed higher average of 0.87 with the other five chemical elements;

Exploratory multivariate analysis methodology and results:

Principal component (PCA) analysis:

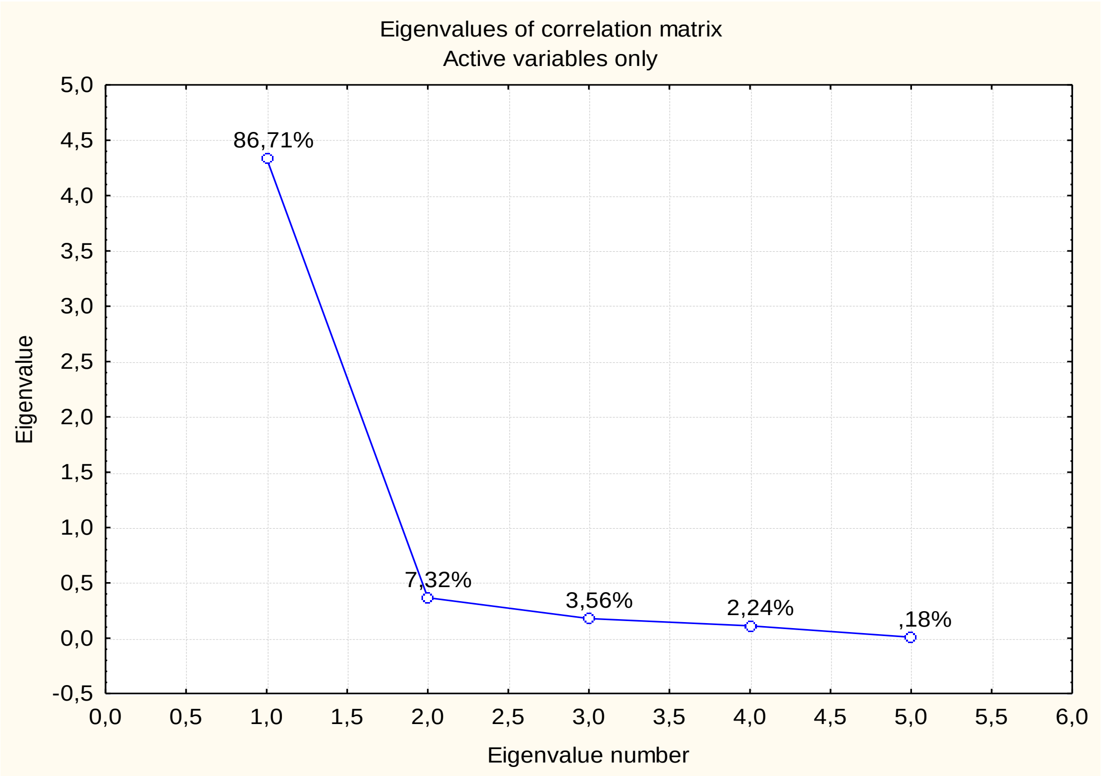
Based on the principle that although p random variables are required to reproduce the total system variability, often much of this variability can be accounted for a small number *k* of orthogonal principal components. Algebraically PCs are particular linear combinations of the p random variables (Johnson and Wichern, 2002);

Also Sum(σ_{ii}) (trace of diagonal elements in variance-covariance matrix) = Sum (λ_i) (trace of diagonal elements in the diagonal matrix of λ_i), λ_i being the variance of the i_{th} PC, and so the proportion of total variance explained by the i_{th} PC is ($\lambda_i/(\lambda_1+ \lambda_2+....+ \lambda_p)$; $_{(1<i<p)}$

So we can calculate the acumulated variance due to the first higher eingenvalues and express them in a scree plot;

Exploratory multivariate analysis methodology and results(PCA) :

Principal components: the scree plot showed that two eingenvalues corresponding to two principal components are responsible for accumulated 94% of the sample variance;



Exploratory multivariate analysis methodology and results :
Factorial analysis(FA) :

Factorial analysis aims to find common factors F which are a few unobservable random variables allowing to describe the covariance relationships among many variables;

The data matrix X can be factored as a matrix linear orthogonal factor model:

$$\underset{(p\times1)}{X} = \underset{(p\times1)}{\mu} + \underset{(p\times m)}{L}\,\underset{(m\times1)}{F} + \underset{(p\times1)}{\varepsilon}$$

where μ is the mean vector, F is the common factor vector, L is the matrix loading or correlation between the data variables and the common factors and ε is the vector of errors (or specific factors);

This model correpond to a variance-covariance matrix $\sum^* = LL' + \psi$ where the second and third terms on the right side are communalities (variance due to the individual loadings) and the specific variance due to specific factors;

Exploratory multivariate analysis methodology and results :
Factor rotation, residual matrix and variance contribution in (FA) :

i) It can be shown that a rotation of the loading matrix is possible without changing the total variances (Johnson and Wichern, 2002) and thereby when the original loadings are not readibly interpretable, it is possible to rotate them till a simple structure L*is possible. One possibility is the varimax criterium aiming to spread the squares of the loadings as much as possible, hoping to find groups of large and negligible coefficients in any column of L*;

ii) The residual correlation matrix Re is a measure of correlation not extracted from the factorial analysis:

$Re = \sum - (LL' + \psi)$ so that low residual correlations are a measure of the approximation of the real $\sum$ by $\sum^*$;

iii)Also the contribution of the common factor F_j ($PropF_j$) to the total sample variance can be estimated as the ratio of the communality due to F_j and sum of total variances:

$PropF_j = (h_j^2\ (=\mathrm{Sum}\ (l^2_{ij}))/\ \mathrm{Sum}(\sigma_{ii})_{\ 1<i<p,\ 1<j<m}$ where l_{ij} is the generic element of the column j $(l_{1j}, l_{2j}, \ldots\ldots, l_{pj})$ of matrix L $_{(1<j<m)}$;

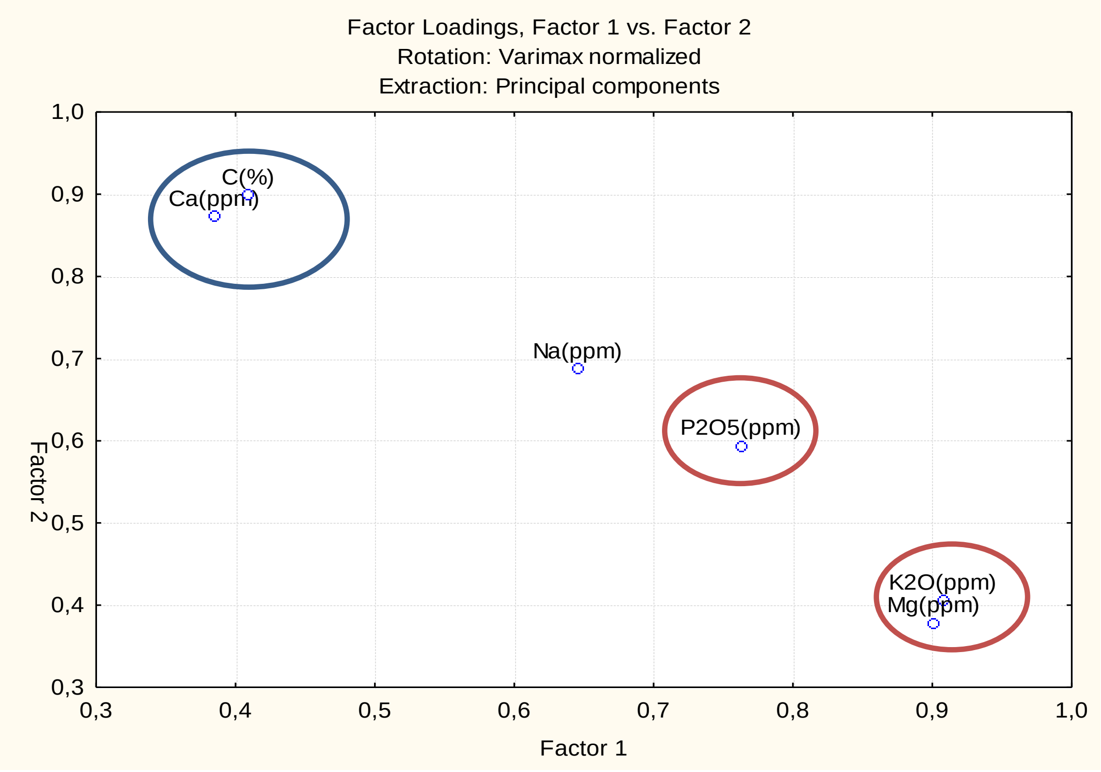
Exploratory multivariate analysis methodology and results :
Factorial analysis with varimax rotation (FA) :

The two main factors explaining 94% of the variability (sum of the two lower cells)(#)).
On the other hand, for the first factor the higher loadings concerned P_2O_5(0.77) , K_2O(0.91) and Mg(0.9) and for the second factor the higher loadings concerned Ca(0.87) and C(0.9). These results reflected the higher correlations mentioned above between these elements and also a prominent role of P_2O_5, K_2O and Mg in the dynamics of chemical properties of soil and biomass in both sites;

Factor Loadings (Varimax raw) (soilbiomassPtBe) Extraction: Principal components (Marked loadings are >,700000)		
	Factor 1	**Factor 2**
P_2O_5(ppm)	0.767434	0.588042
K_2O(ppm)	0.910871	0.398798
Mg(ppm)	0.904000	0.371327
Ca(ppm)	0.391739	0.869415
Na(ppm)	0.651040	0.682166
C(%)	0.416363	0.895829
Expl.Var	2.986527	2.666459
Prp.Totl (#)	0.497755	0.444410

Exploratory multivariate analysis methodology and results :
Factorial analysis with varimax rotation (FA) :

For the first factor the higher loadings concerned P_2O_5(0.77) , K_2O(0.91) and Mg(0.9) and for the second factor the higher loadings concerned Ca(0.87) and C(0.9).



Exploratory multivariate analysis methodology and results :
Factorial analysis(FA) : The residual correlation matrix with very low values showing that factorial analysis extracted most of the correlation;

Residual Correlations (soilbiomassPtBe) Extraction: Principal components (Marked residuals are > ,100000)						
	P_2O_5(ppm)	**K_2O(ppm)**	**Mg(ppm)**	**Ca(ppm)**	**Na(ppm)**	**C(%)**
P_2O_5(ppm)	0,07	0,01	-0,04	-0,04	-0,02	0,02
K_2O(ppm)	0,01	0,01	-0,01	0,01	-0,02	0,00
Mg(ppm)	-0,04	-0,01	0,04	0,05	-0,02	-0,02
Ca(ppm)	-0,04	0,01	0,05	0,09	-0,07	-0,04
Na(ppm)	-0,02	-0,02	-0,02	-0,07	0,11	0,01
C(%)	0,02	0,00	-0,02	-0,04	0,01	0,02

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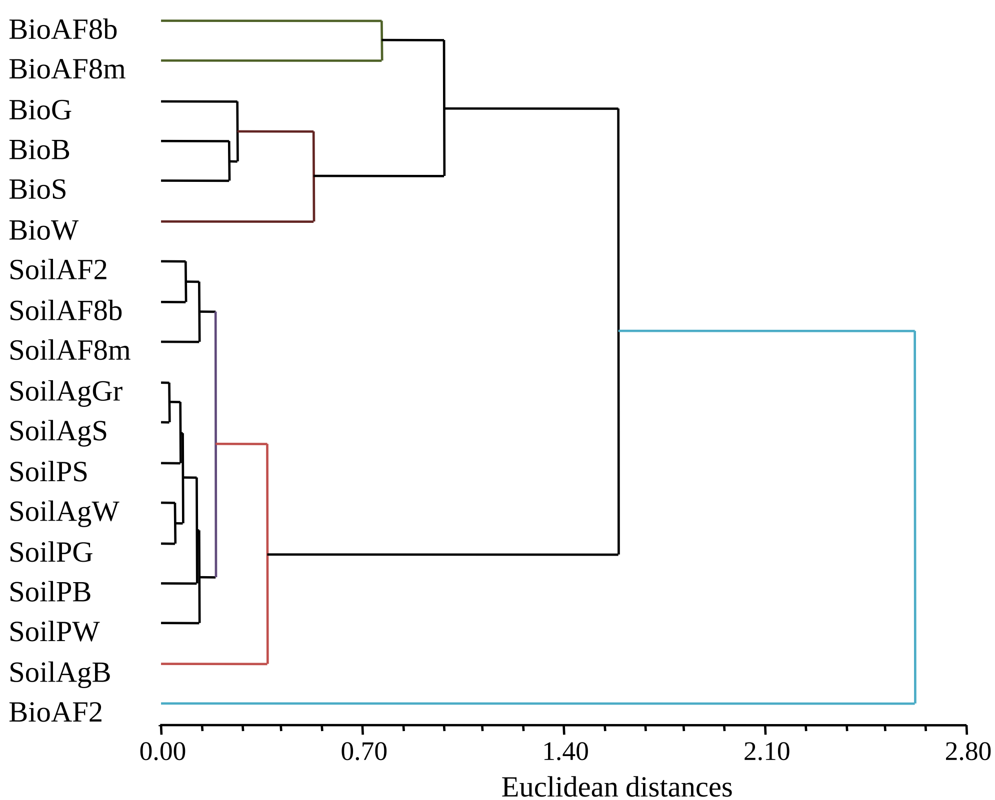
Exploratory multivariate analysis methodology and results :

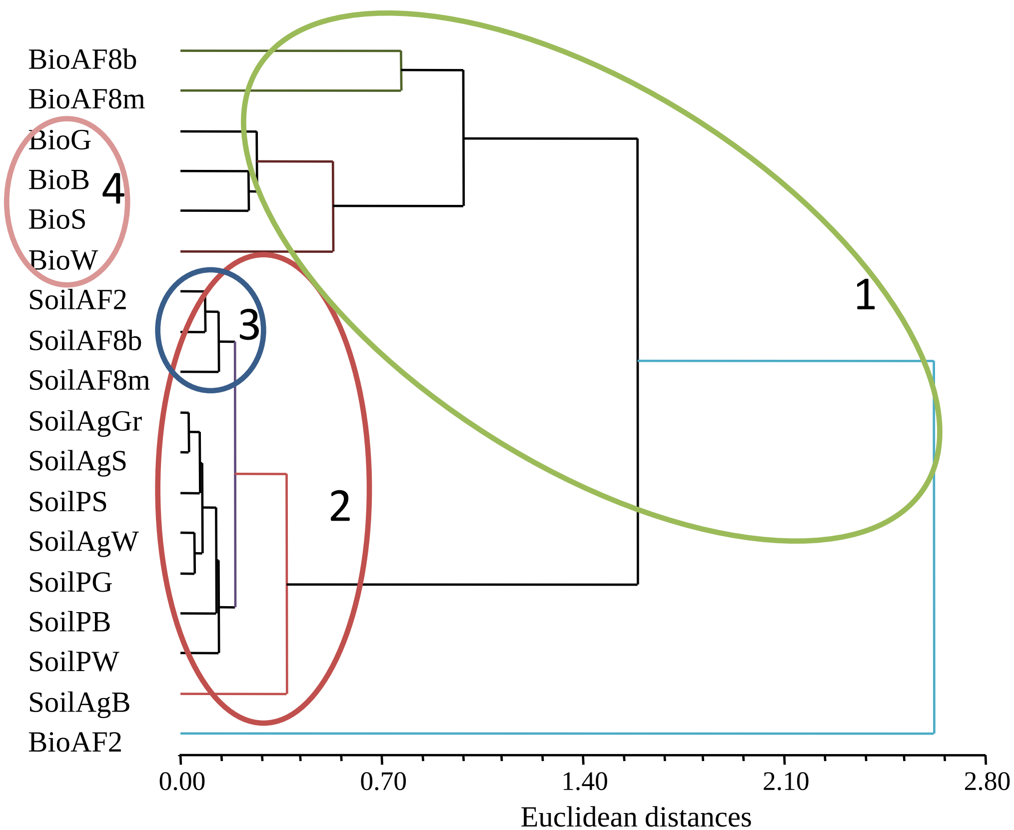
Hierarchical clustering was performed by UPGMA (Unweighted Pair Group Method with Arithmetic Mean) agglomerative (bottom-up) method to obtain the grouping of clusters of soil and biomass (dendrogram or phenogram) , based on euclidean distances.



The cophenetic correlation coefficient (CCC) is a matrix correlation indicating the distortion produced by clustering the original data Euclidean distances. The term cophenetic is due to a new symmetric distance matrix derived directly from the UPGMA dendrogram. In our study CCC was 0.95 a value close to the maximum 1, showing that the dendrogram preserves the pairwise euclidian distances between the original unclustered data points.

Exploratory multivariate analysis methodology and results :
Soils

UPGMA phenogram reflected global soil homogeneity with a <u>maximum</u> 0.5 distance (on a scale 0-2.8) between Bakan pre-agricultural soil (SoilAgB) and a cluster of all other soils. The soils of Santarém plots clustered with the remnant Lochristi soils at a <u>maximum</u> distance of 0.15. The Lochristi soils, excepting SoilAgB, clustered among themselves with distances lesser than 0.1, and without distinction of whether the soil had a previous agricultural or pasture use;



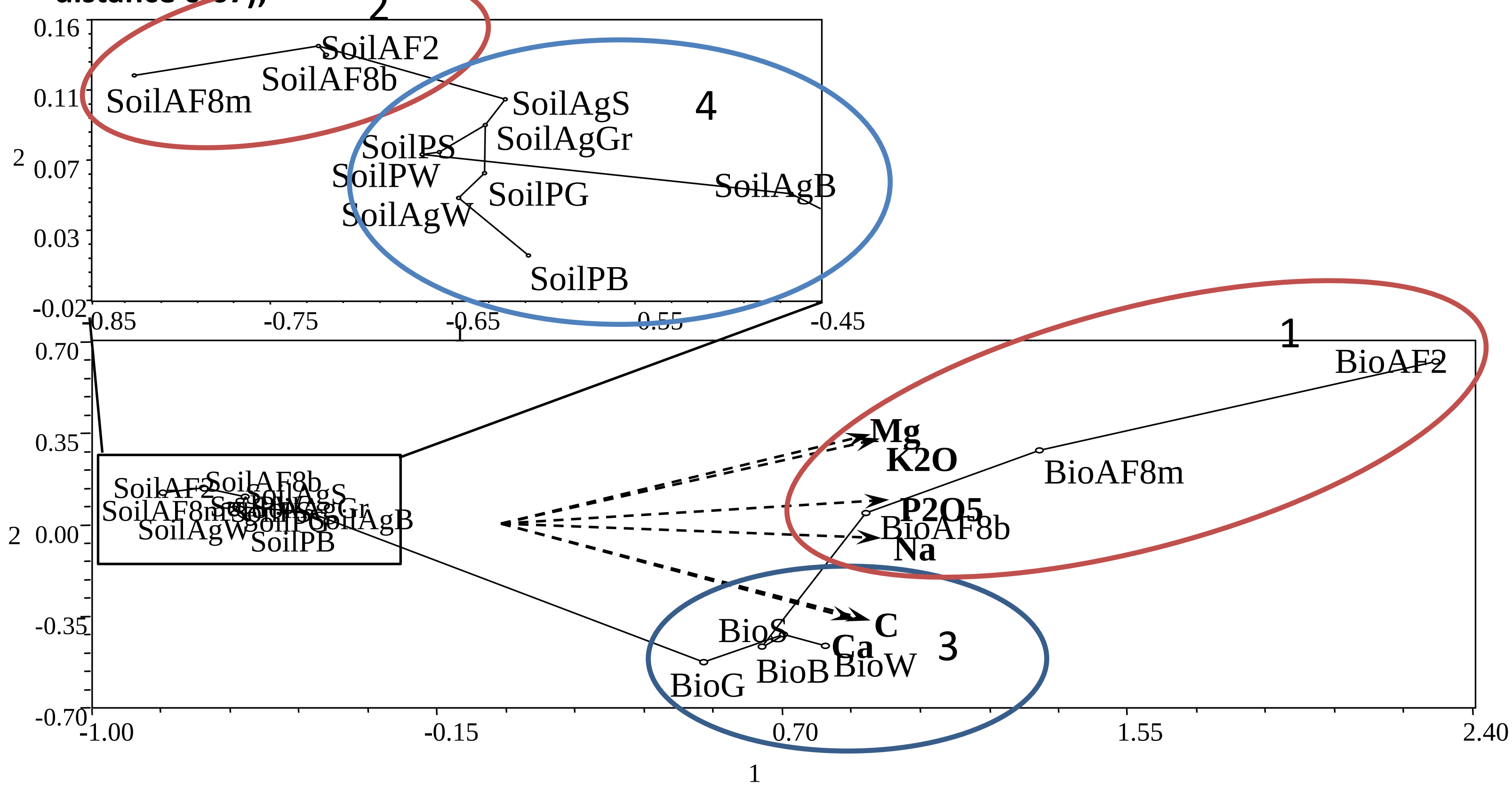
Biomass

The biomass clusters were much more heterogeneous with a <u>maximum</u> 2.7 distance from biomass of AF2 to a cluster formed by the other 17 cases;

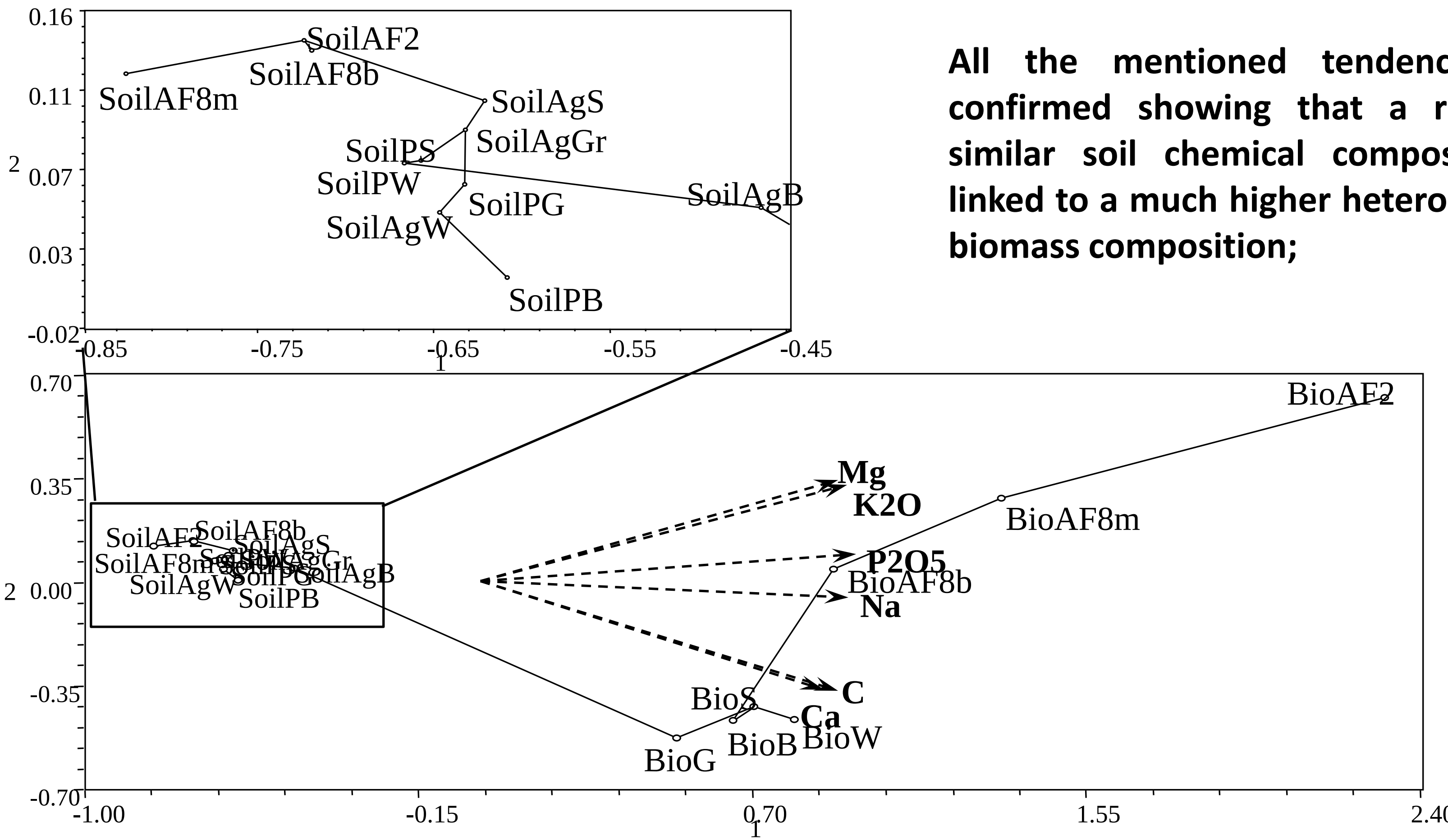
The remaining two Santarém biomass clones formed a cluster distanced by 0.9 from the Locristi clones. BioW formed a cluster distanced by 0.7, from two clusters separated by an average distance of 0.3;

Exploratory multivariate analysis methodology and results :

The cophonetic matrix of clusters allowed to build a minimum spanning tree (MST) (by Prim algorithm) which was overlaid with the variable coordinates of the six principal components in the plane of first two main principal components. The MST of Euclidian distances confirmed a much clear homogeneity of chemical composition of soil cases(average distance 0.1) than of biomass cases (average distance 0.67);



Exploratory multivariate analysis methodology and results :



All the mentioned tendencies are confirmed showing that a relatively similar soil chemical composition is linked to a much higher heterogeneous biomass composition;

Conclusions

A relatively similar soil chemical composition is linked to a much higher heterogeneous biomass chemical composition;

Phosphurus, potassium and magnesium were the main chemical elements fundamental to the soil and biomass dynamics in both sites;

As following work, a multivariate comparision will be made between soils, biomasses, and joint dynamics of soil and biomass relationships considering an enlarged set of different cases and variables;

Thank you