Discriminant value of soil properties for terroir zoning

Valeur discriminante des variables du sol dans les études de zonage de terroirs

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Abstract: Environmental analysis (climate, vegetation, geomorfoloy-lanscape, lithology and soil) and its integration in a quality index taking the Appellation of Origin as the sole universe are used as general methodology for terroir zoning in Spain (Sotés and Gómez-Miguel, 1986-2005). This methodology is also applied to specific aspects of different Spanish Appellations of Origin (size, distribution and landscape peculiarities and vine occupation index).
In this work, the whole set of results of all Appellations of Origin is taken as the universe (2.323.094 ha of surface and 144.248 ha of vineyard) and the two higher taxonomic units (soil series), where more than 75 % of the vineyard is located, are taken as comparative elements.
Unit characterization is made with ninety soil variables and a multicriterion method, which explains behavior differences in these variables and in the vineyard quality index, is used for comparison.
This analysis shows how every compared unit has a more similar behaviour to different units of the same Appellation than to other units with the same soil taxonomy but from different Appellations, except for more closed Appellations with similar environmental characteristics.
The value of soil variables as discriminant elements for terroir classification in zoning studies can, then, be known. In the studied cases of this work, the overall statistic behavior of the variables set is related to the wine production specific characteristics of every Appellation.

Key words: terroir, soil, zoning, geomorphology, Spain

Introduction

Environmental analysis (climate, vegetation, geomorfoloy-lanscape, lithology and soil) and its integration in a quality index taking the Appellation of Origin as the sole universe are used as the general methodology for terroir zoning in Spain (Sotés and Gómez-Miguel, 1986-2005). This methodology is also applied to the specific problems and other aspects of the different Spanish Appellations of Origin (size, distribution and landscape peculiarities and vine occupation index). In such studies, soil properties along with other environmental variables are the main criteria for zonal discrimination.
In this work, the whole set of results of all Appellations of Origin is taken as the universe (2.323.094 ha of surface and 144.248 ha of vineyard) and the two higher taxonomic units (soil series), where more than 75 % of the vineyard is located, are taken as comparative elements.
Main characteristics of the ten Appellations of Origin included in this work are shown in table 1.

Material and Methods

Available Environmental Homogeneous Units (the Spanish Unidades Homogéneas del Medio, UHM) are used as the starting point of this work, which appears as an additional application of zoning studies: Discriminant value analysis of environmental factors, soil, in this case, in classification of viticultural zones.
UHM have already been defined in previous zoning works in three steps (Gómez-Miguel *et al*.; Sotés *et al*.,): **selection of variables or parameters** (information treatment is carried out with regard to cartographic units from properties of the different factors that characterize the environment: climate, vegetation, lithology, geomorphology, soil. Analysis of different layers by a GIS results in contents quantification and the chance of its statistical use for validation aims); **parameters integration** (General methodology arise from the convergence of two specific and independent approaches, one of them defines a quality index from different parameters (see i.e. Riquier, 1972) and the second, by comparison by multicriteria analysis of units with interest and known viticultural performance; **validation** (Comparison of both methods gives the final result:

Zone classification in five different levels: -*optimum, suitable, unfavourable, unfit and excluded*- is based on steady statististical intervals with enough distance between them and on acquired experience in viticultural areas).
In this work, selected UHM are all zones classified as optimum and suitable in each Appellation of Origin, including, as said before, more than 75 % of total vineyard surface. Analysis uses a database of parameters describing different soil series of UHM. Ninety soil variables are compared by a multicriterion method similar to the one used for climate comparison (i.e.Tonietto and Carbonneau, 2004). Differences in vineyard performance and in the quality index are explained with those variables (tables 2 and 3).

Results and Discussion

Five soil orders (Soil Taxonomy, 2003) are present in the set of Appellations of Origin studied (alfisol, inceptisol, entisol, ultisol, vertisol). However, inceptisols (calcixerept, 18; haploxerept, 4) and alfisols (haploxeralf, 14; palexeralf, 4; rhodoxeralf, 1) should be clearly emphasized over the rest (xerorthent, 3; haploxerert, 1; haploxerult, 1).
A parametric system for soil series evaluation has been used. This system is based on defined factors for each variable expressed as percentage and allows grouping them in a single index. The resulting Quality Index obtained by multiplying method for each soil taxon, can be weighed by giving 100 to the greatest index value. Quality Index classification in five different categories -optimum, suitable, unfavourable, unfit and excluded- is based on steady statististical intervals with enough distance between them and on acquired experience in viticultural areas.
Soil series (46) Quality Index of the UHM of the studied Appellations of Origin is shown in table 3. The obtained values in different Appellations give a first comparison between them. QI ranges from relatively low values, 26.7 %, to the greatest 100 %, while the whole set of soils are included in the optimum and suitable classes of the UHM. These obvious important differences are modified and reduced in cartographic units when the rest of climate, lithology, and geomorfology-landscape variables are taken into account.

Table 1 - Cultivated area and environmental characteristics of the studied Appellations of Origin (Sotés and Gómez-Miguel)

APPELLATION OF ORIGIN	TOTAL AREA (ha) (VINEYARD)	CLIMATE			ORIGINAL MATERIALS	Altitude (m) Slope (%)	SOILS	
		Annual average T (ºC)	Annual average P (mm)	ITEWink ºC day			Perfil	Clasification (Soil Taxonomy, v.a)
BIERZO	142.055 (6.903)	12.2/13.6	214/217	1378/1485	Serie conglomerática silícea (Terciario) Glacis y rañas (Pliocuaternario) Terrazas medias (Cuaternario	525-1100 (0-60)	A/C A/Bw/C A/Bt/C A/Bt/C	Xerorthent dystrico Xerochrept dystrico/Típico Haploxeralf típico Haploxerult típico
JEREZ	195.703 (10.507)	16.7/18.3	479/876	2705	Albarizas y margas (Terciario)	(0-10)	A/Bw/C A/Bk/Ck A/Bss/Ck	Xerochrept típico Xerochrept calcixeróllico Haploxerert/ Calcixerert
GUADIANA (Tierra de Barros)	407.809	14-16	350-450	-		500-650 (0-15)	A/Bw/C A/Bk/C A/Bt/C	Haploxerept típico Calcixerept típico Haploxerert/Calcixerert Haploxeralf típico
GUADIANA (Montánchez)	243.913	14-16	500-690	2000/2300	Pizarras y grauwacas (Precámbrico) Rocas graníticas Materiales con matriz roja (Pliocuaternario)	600-650 (0-25	A/C; A/R A/Bw/C A/Bt/C	Xerorthent típico Haploxerept típico/dystrico Haploxeralf/ult
RIBERA DE DUERO	285.212 (18.451)	10.1/11.7	425/600	1003/1447	Arcillas arenosas, ocres y rojizas (Terciario) Terrazas medias y bajas (Cuaternario)	680-1200 (0-30)	A/C/Ab A/Bw/C A/Bk/Ck A/Bt/Bk	Xerofluvent típico Xerochrept típico Xerochrept calcixeróllico Haploxeralf cálcico
RIOJA	342.526 (62147)	9.5/13.8	375/700	1130/1304	Areniscas ocres. Arcillas (Mioceno) Areniscas finas y arcillas rojas (Mioceno) Glacis y Terrazas medias (Cuaternario)	475-1450 (0-40)	A/C A/Bk/Ck A/Bt/Bk	Xerorthent típico Xerochrept calcixeróllico Haploxeralf cálcico
RUEDA	280.274 (7.600)	11-0/13.3	350/425	1188/1683	Arenas y lutitas (Terciario) Terrazas medias y bajas (Cuaternario) Arenas eólicas	675-900 (0-25)	A/Bt/Bk A/Bk/Ck A/Bt/C	Haploxeralf cálcico Xerochrept calcixeróllico Haploxeralf psamméntico
SOMONTANO	200.809 (4.297)	9.5/14.8	263/1120	824/2155	Conglomerados y arcillas(Oligomiocenas) Glacis (Pliocuaternarios) Terrazas media y bajas (Cuaternario)	285-1150 (0-75)	A/C A/Bw/C A/Bk/C A/Bt/C	Xerorthent típico Xerochrept típico Xerochrept calcixeróllico Haploxeralf típico
TORO	76.374 (5.945)	11.2/12.9	375/450	1243/1675	Conglomerados y areniscas (Oligoceno) Series rojas (Terciario inferior) Terrazas medias y bajas (Cuaternario)	650-825 (0-20)	A/Bw/Ck A/Bk/Ck A/Bt/Bk	Xerochrept típico Xerochrept calcixeróllico Xeralf cálcico
VALDEPEÑAS	148.419 (29.108)	14/15.5	400/500	-	Terraza, aluviales y detríticos marginales (Cuaternario) Costras caliza y limos yarcillas rojas (Pliocuaternario) Caliza, margas y limos calcáreso (Mioceno)	600-850 (0-25)	A/Bk/Ck A/Bkm/Ck A/Bt/Bc	Xerochrept calcixeróllico Xerochrept petrocálcico Haploxeralf cálcico

Table 2 - Dependent variables of the Soil Taxonomic Unit

PROPERTIES	SÍMBOL			
	Horizon 1	**Horizon 2**	**Horizon 3**	**Horizon 4**
Difficult to change by management				
Effective depth (cm)	PF1	PF2	PF3	PF4
Width (cm)	ES1	ES2	ES3	ES4
Coarse elements (cm)	EG1	EG2	EG3	EG4
Sand (%)	AT1	AT2	AT3	
Silt (%)	LI1			
Clay (%)	AC1	AC2	AC3	AC4
Total CaCO3 (%)	CT1	CT2	CT3	CT4
Active CaCO3 (%)	CAC1		CAC3	
Organic matter (%)	MO1	MO2		
Nitrogen (%0)	N1	N2		
C/N Rate	CN1			
Electric conductivity (dS/m)	CE1	CE2	CE3	CE4
Cation exchange capacity (cmolc/kg)	CIC1	CIC2	CIC3	
Apparent density (g/cm^3)	DA1	DA2	DA3	
More easily changeble by management				
pH	PH1	PH2	PH3	PH4
Phosphorus (Olsen) ppm	PO1	PO2	PO3	
Calcium (cmolc/kg)	CA1	CA2	CA3	
Magnesium (cmolc/kg)	MG1	MG2	MG3	
Sodium (cmolc/kg)	NA1	NA2	NA3	
Potasium (cmolc/kg)	K1	K2	K3	
Exchangeable acidity (cmolc/kg)	H1	H2	H3	
Exchangeable aluminium (cmolc/kg)	AL1	AL2	AL3	
Ca/Mg Rate	KM1	KM2	KM3	
K/Mg Rate	CM1	CM2	CM3	
Base Saturation (%)	V1	V2	V3	
Exchangable calcium (%)	PC1	PC2	PC3	
Exchangeable magnesium (%)	PM1	PM2	PM3	
Exchangeable potasium (%)	PK1	PK2	PK3	
Exchangeable sodium (%)	PN1	PN2	PN3	
Clay exchange capacity (cmolc/kg)	CIA1	CIA2		
Quality Index (%)	IC			

Furthermore, Quality Index low values in soils with proved good viticultural performance is related to the use of soil variables easily modified by management. Exchange complex of ultisols is regularly equilibrated before planting. In other soils (psamentic), irrigation solves the problem of their low water holding capacity. This raises the question about the use of such soil variables in the Quality Index.
Comparison between observations and variables is done by conventional statistical analysis, including multicriterion analysis.
Many studied variables are correlated between them. Analysis of the forty six observations allows their grouping in classes with homogeneous characteristics using twenty four independent variables (AC1, AC2, AT1, AT2, CA1, CA2, CAC, CE1, CIC1, CIC2, CT1, CT2, H1, H2, IC, K1, K2, MG1, MG2, MO1, NA1, NA2, PF2, PF3). With different classification methods as centroids, Ward, etc and with different metric distances, eleven initial classes are obtained. These classes may be reasonably well explained: Appellations with similar lithology are grouped in the higher levels, and, acidic soils and calcareous soils or shallow and deeper soils are included in different groups. In this manner, some soil series of Ribera del Duero are grouped with those of Toro and Rueda because they share the same lithology and derived properties due to their proximity. Finally, because of their peculiar properties (vertisolization), some soil series form a completely separated group from the rest.
Twenty two explanatory variables are initially included in the analysis (AT1, AC1, CT1, CAC, MO1, CE1, CIC1, CA1, MG1, NA1, K1, H1, PF2, AT2, CT2, CIC2, CA2, MG2, NA2, K2, PF3, IC). Nine discriminant functions explain 100 % of the variance and the first five explain 93.85 %. Classification of observations by discriminant functions allows a correct allocation of 45 from 46 soil series in the appropriate Appellation of Origin. Just T03 soil series from Toro Appellation of Origin is allocated in Rueda, but with a minimum differential probability.

Table 3 - Environmental Homogeneous Units Soil Series of the studied Appellations of Origin and their Quality Index (IC, %) (Sotés and Gómez-Miguel)

Clase	Símbolo	REGION	CLASIFICACION (Soil Taxonomy, 1992-2003)	IC	Rfª
1	B01	DOBierzo	Xerochrept dystrico, franca fina, mésica, mixta	83.0	1
1	B02	DOBierzo	Xerochrept típico, franca fina, mésica, mixta	75.7	2
1	B03	DOBierzo	Haploxerult típico, franca fina, mésica, mixta	53.9	3
2	T01	DOToro	Haploxeralf típico, franca fina, mésica, mixta	89.6	4
2	T02	DOToro	Haploxeralf típico, franca fina, mésica, mixta	54.7	5
2	T03	DOToro	Palexeralf cálcico, franca muy fina, mésica, mixta	100.0	6
2	T04	DOToro	Palexeralf cálcico, franca muy fina, mésica, mixta	61.8	7
2	T05	DOToro	Rhodoxeralf cálcico, franca muy fina esquelética, mésica, mixta	44.1	8
3	M01	DORueda	Haploxeralf cálcico, arcillosa fina, mésica,mixta	63.5	9
3	M02	DORueda	Haploxeralf cálcico, esquelética franca, mésica, mixta	76.2	10
3	M03	DORueda	Haploxeralf cálcico, franca, mésica, mixta	85.7	11
3	M04	DORueda	Palexeralf cálcico, franca muy fina, mésica, mixta	90.0	12
3	M05	DORueda	Xerochrept calcixerólloico, franca, mésica, mixta	65.0	13
4	R01	DOCRioja	Xerochrept calcixeróllico, franca fina, mésica, mixta	38.5	14
4	R02	DOCRioja	Xerochrept calcixeróllico, esquelética, mésica, mixta	40.9	15
4	R03	DOCRioja	Xerochrept calcixeróllico, franca, mésica, mixta	46.2	16
4	R04	DOCRioja	Xerochrept calcixeróllico, esquelética, mésica, mixta	82.4	17
4	R05	DOCRioja	Xerochrept calcixeróllico, franca fina, mésica, mixta	57.5	18
4	R06	DOCRioja	Xerochrept calcixeróllico, franca, mésica, mixta	45.9	19
4	R07	DOCRioja	Xerochrept calcixeróllico, franca, mésica, mixta	38.9	20
5	D01	DORDuero	Xerorthent típico, arenosa sobre franca gruesa ligera, calcárea, mésica, mixta	36.6	21
5	D02	DORDuero	Xerochrept típico, franca fina ligera sobre pesada, mésica, mixta	64.9	22
5	D03	DORDuero	Xerochrept calcixeróllico, franca fina sobre arcillosa pesada, mésica, mixta	62.2	23
5	D04	DORDuero	Haploxeralf típico, franca fina pesada, mésica, mixta	58.4	24
5	D05	DORDuero	Haploxeralf cálcico, arcillosa pesada, mésica, mixta	73.4	25
5	D06	DORDuero	Haploxeralf psamméntico, arenosa sobre franca fina ligera, mésica	36.5	26
5	D07	DORDuero	Palexeralf cálcico, arcillosa pesada, mixta, mésica	57.3	27
6	J01	DOJerez	Haploxerert típico, arcillosa, térmica, mixta	37.2	28
6	J02	DOJerez	Calcixerept típico, arcillosa fina, térmica, mixta	32.9	29
6	J03	DOJerez	Calcixerept tipico, arcillosa, térmica, mixta	41.0	30
6	J04	DOJerez	Xerorthent típico, arcillosa, calcárea, térmica, mixta	26.9	31
7	S01	DOSomontano	Calcixerept típico, arenosa, mésica, mixta	50.6	32
7	S02	DOSomontano	Haploxeralf cálcico, franca fina, mésica, mixta	32.8	33
7	S03	DOSomontano	Calcixerept típico, franca gruesa, mésica, mixta	57.8	34
7	S04	DOSomontano	Calcixerept típico, franca fina, mésica, mixta	26.7	35
7	S05	DOSomontano	Calcixerept típico, franca fina pesada, mésica, mixta	63.7	36
8	Z01	DOG (Montanchez)	Xerorthent típico, franca gruesa, térmica, mixta	39.5	37
8	Z02	DOG (Montanchez)	Haploxeralf típico, francoarcillosa, térmica, mixta	47.7	38
8	Z03	DOG (Montanchez)	Haploxerept típico, francoarenosa, térmica, mixta	64.9	39
8	Z04	DOG (Montanchez)	Haploxeralf típico, franca, térmica mixta	48.1	40
9	E01	DOG (T Barros)	Haploxeralf cálcico, franca fina ligera, mésica, mixta	96.3	41
9	E02	DOG (T Barros)	Haploxeralf cálcico, franca gruesa, mésica, mixta	53.9	42
9	E03	DOG (T Barros)	Calcixerept típico, arcillosa, mésica, mixta	56.0	43
10	V01	DOValdepeñas	Calcixerept petrocálcico, franca gruesa, térmica, mixta	63.9	44
10	V02	DOValdepeñas	Calcixerept cálcico, franca gruesa ligera, térmica, mixta	65.2	45
10	V03	DOValdepeñas	Haploxeralf cálcico, franca fina, mésica, mixta	77.3	46

The first two discriminant functions (73 %) are represented in figure 1 and the coefficients of the variables of each Appellation of Origin in table 4. First function explains 40 % of the variance and corresponds to negative values of potential and actual fertility, and, active and total lime of the surface horizon and to positive values of sand and Quality Index. The second function (33 %) represents subsurface horizon fertility and soil effective depth (positive values) and exchangeable acidity (negative values).

Each Appellation of Origin forms a steady, clearly separated group. The most continuous relation is established between Ribera de Duero, Rueda and Toro where the soils of river Duero terraces are more alike.

A stepwise selection algorithm concludes that eight variables (AC1, AT1, CAC, CIC2, MO1, NA2, MG1, PF2) are significative predictors in the Appellation of Origin. Six discriminant functions (P values less than 0.05) are statistically significant at 95 % confidence level. The use of these discriminant functions allocates in the right Appellation of Origin 44 of 46 soil series (95.65 %) and just the Toro soil series T03 is allocated in Rueda and the Ribera del Duero soil series D06 in Toro, but, in both cases, with a very low probability.

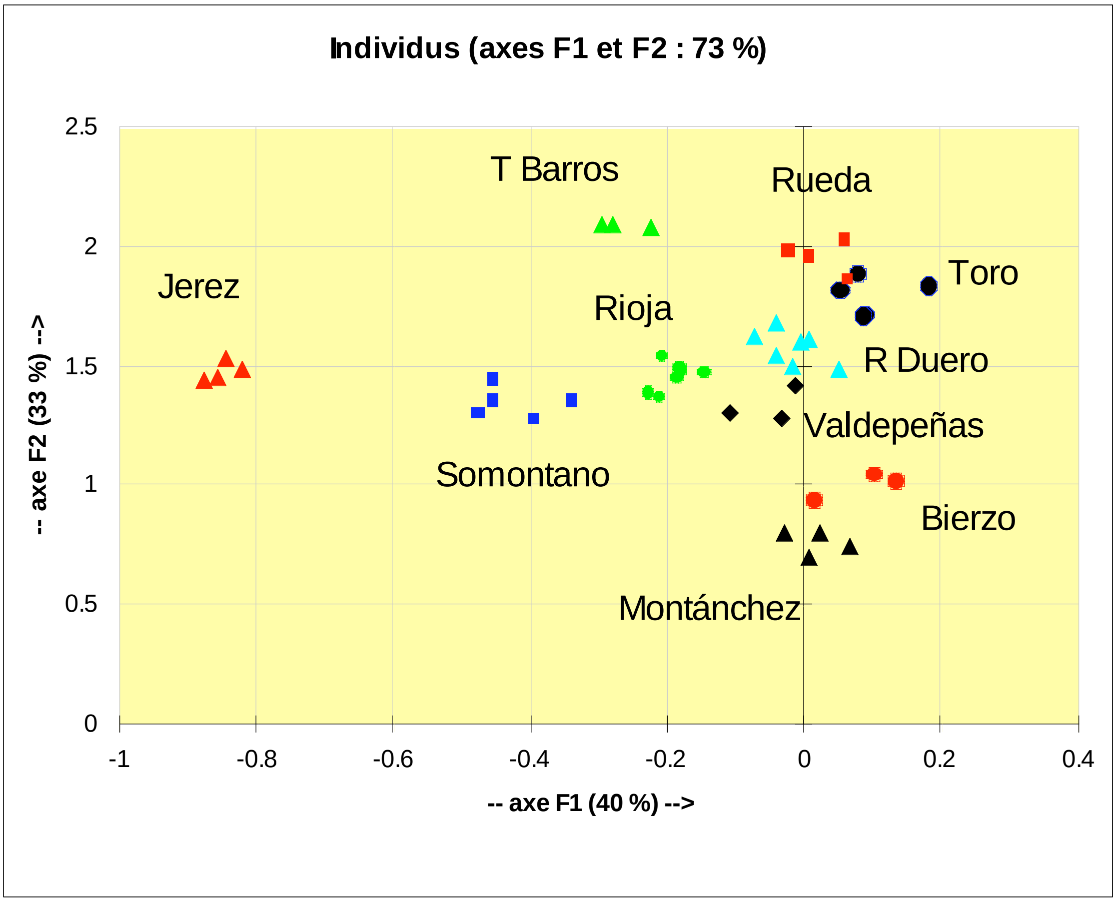

Figure 1 - Synthesis of forty six-soil series classification and their allocation in Appellations of Origin. The first two discriminant functions (73 %) are represented.

Conclusions

The following conclusions can be drawn from results:

- Multicriterion analysis is an indispensable tool that can be applied to soil properties in terroir zoning studies not only within an Appellation of Origin but also among Appellations where the soils are very different
- Soil variables as potential and actual fertility, lime, sand, effective soil depth and exchangeable acidity are those with the greatest value to discriminate specific situations among the studied Spanish Appellations of Origin. The Quality Index defined for zoning within an Appellation may be used as another additional variable for this aim.
- Classification of observations by discriminant functions allows the correct allocation of almost the total soil series in the right Appellation.
- Each Appellation of Origin forms a steady, clearly separated group. Geographic and lithologic relations explain the distance or proximity between classes.
- A model based in a few variables (AC1, AT1, CAC, CIC2, MO1, NA2, MG1, PF2) may be selected as significative predictor in each Appellation of Origin.

	Bierzo	Toro	Rueda	Rioja	R.de Duero	Jerez	Somontano	Montánchez	T.de Barros	Valdepeñas
Constant	-388.61	-629.97	-685.03	-553.59	-541.96	-687.05	-488.90	-291.22	-905.61	-473.76
AT1	6.02	8.43	8.33	7.15	8.10	8.60	7.36	4.90	10.05	6.84
AC1	3.85	4.73	5.54	5.30	5.74	12.50	7.69	2.84	7.25	3.53
CT1	2.19	5.02	5.95	3.42	4.75	5.78	4.70	1.48	6.24	3.29
CAC	6.97	7.53	4.21	15.19	6.60	12.96	11.02	7.88	16.76	13.43
MO1	107.64	71.49	49.97	115.18	86.67	128.16	123.75	107.17	125.50	95.88
CE1	56.90	4.41	-11.91	137.25	-5.39	84.09	78.83	90.41	19.54	107.41
CIC1	-13.46	-0.99	2.52	-6.04	-7.33	-8.01	-8.57	-10.85	-3.75	-5.11
CA1	11.26	3.42	2.19	5.85	9.48	9.73	8.94	9.12	6.49	4.68
MG1	95.46	85.27	79.61	86.02	107.84	85.39	95.76	85.05	130.01	68.99
NA1	12.57	205.13	235.24	66.34	118.59	-64.98	-30.34	11.58	139.85	32.88
K1	-12.06	-86.96	-114.66	-72.17	-91.28	-159.56	-107.27	-35.14	-154.46	-14.12
H1	3.27	-8.24	-14.18	-8.04	-4.60	-14.36	-9.14	2.70	-14.37	-6.93
PF2	2.27	3.30	3.61	3.09	2.86	2.02	2.27	1.62	3.66	2.61
AT2	0.05	0.41	0.86	0.39	0.31	0.33	0.54	0.39	0.76	0.29
CT2	-1.62	-3.09	-2.97	-2.24	-2.96	-2.90	-2.50	-1.19	-3.72	-1.64
CIC2	12.48	7.22	9.78	10.24	9.29	12.28	12.46	12.70	14.16	10.11
CA2	-11.38	-1.32	-1.89	-5.54	-4.61	-5.17	-6.83	-11.03	-5.26	-6.82
MG2	7.19	5.87	-0.13	-3.09	2.95	-23.99	-14.10	4.41	-11.64	0.41
NA2	-31.71	-65.39	-79.97	-3.82	-52.07	119.06	43.71	-13.42	-22.45	0.30
K2	-18.01	28.13	45.20	-16.94	-13.25	-109.32	-58.80	-51.61	-43.82	34.79
PF3	0.17	-0.10	-0.29	-0.08	-0.17	-0.57	-0.42	0.17	-0.40	-0.21
IC1	1.06	2.16	2.41	1.09	1.28	-0.12	0.59	0.53	1.52	2.00

Table 4 - Classification functions coefficients in each Appellation of Origin.

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