Interaction among grapevine cultivars (Sangiovese, Cabernet Sauvignon and Merlot) and site of cultivation in Bolgheri (Tuscany)

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ABSTRACT

Different "landscape unit" have been identified in Bolgheri area (a viticultural appellation in the Tirrenian coast of Tuscany) by the aid of pedological, landscape and agronomic observations in the 1992-1993 period. In all cultivar (Sangiovese, Cabernet Sauvignon and Merlot) x landscape unit combinations, experimental plots were chosen in homogeneous vineyards, single cordon trained (about 3300-4500 vines/hectare). Grape maturation was studied by weekly samples of berries from veraison to vintage in the 1992-1995 period. At harvest yield and must composition traits were measured and, from the most representative plots, sixty kilograms of grapes were harvested each year and vinified according to a standardised scheme. Wines were evaluated by standard chemical and sensory analyses.

Nutritional status of vines at veraison, surveyed by leaf analysis, assessed the peculiar status of Bolgheri vineyards as concern potassium and iron content in leaves. The influence of site of cultivation (or landscape unit) on crop level, vine vegetative growth, grape composition and wine quality was the result of the combination of mesoclimatic conditions, soil characteristics, water and mineral nutrients availability. The technique of descriptive analyses assessed the peculiarities of the sensory profiles of wines obtained in some landscape units in Bolgheri appellation. In these cases landscape units might be considered as "terroirs".

INTRODUCTION

Bolgheri is a viticultural area (about 400 ha) which extends along the Tirrenian coast of Tuscany. It received official viticultural appellation status (D.O.C.) in 1983, for the production of *white (Bolgheri bianco)* and light-red wines (*Bolgheri rosato*) from *Sangiovese* and *Canaiolo*. At the same time Sassicaia, a table red wine produced in Bolgheri area, mostly from Cabernet Sauvignon grapes, became more and more famous all over the world. Later, in 1994, the appellation status was extended to red wines from *Sangiovese*, *Cabernet Sauvignon* and *Merlot*. Sassicaia is nowadays a specific zone ("sottozona", according to Italian legislation) within Bolgheri territory. Local climate may be classified as sub-umid, semi-arid and dry. Average year rainfall is about 500 mm (less than 200 mm between April and August), average year temperature is 14.4 °C. Winkler index is about

1800 degrees. Variation in mesoclimatic characteristics of different landscape unit was very strict and mostly due to altitude and wind effects.

Since 1992 the local administration financially supported the zoning of the territory of Bolgheri appellation of origin. The study aimed to detect and describe the different areas of the territory according to their quality potentials using a "genotype x environment" approach (Scienza et al., 1992). Bolgheri vineyards of Sangiovese, Cabernet Sauvignon and Merlot are generally grown according to "Cordon de Royat", plant density is about 3300-4500 vines/hectare, yield/vine id about 2.5-3 kilograms, yield /hectare is generally less than 8-9 tons of grapes. Different presumed *terroirs* have been identified in Bolgheri area (by the aid of pedological, landscape and agronomic observations carried on in 1993-1994) as homogeneous zones (landscape units) as concern soil type, plant available water, land morphology and mesoclimate characteristics (Bogoni et al., 1996). Soils ranged from silty-clay *Pliocene* soils, deep and rich in carbonates, to very deep sandy soils of *Pleistocene* origin, to silty clay Pleistocene soils, with bad drainage, to soils of *Alluvial* and *Alloctono ligure* origin. 11 landscape units were identified (tabl. 1).

Preliminary results are presented hereafter in this paper.

Table 1. Summary of geomorphologic, agronomic and chemical properties of 10 landscape units (i.e. pedoclimatic environments or areas with homogeneous environmental conditions as concern soil, mesoclimate and landscape morphology) within Castagneto Carducci territory.

Landscape Unit (provisional name)	Soil codes	Altitude (m a.s.l.)	Geological origin	Landscape morphology	Slope %	Outer/ Inner Drainage	U.S.D.A. Classification	pH	Sand %	Clay %	Silt %	exch. K_2O (µg/g)	avail. P_2O_5 (µg/g)	Read. Sol. Carb. %	Cation Exchange Capacity (me/100g)	org. matt. %
Greppi cupi	G	20-30	Pleistocene	Dunes and undulating sides	2-8	Obstructed/ excessive	Tipic Xeropsammen ts	7.32	85	10	5	145	34	0.71	6.44	0.80
Sassicaia	As-Asa-Ap	65	Pleistocene	Terraces and straight sides	6-10	slow/ not good	Acquic Xerochrepts	8.12	40	38	22	342	47	6.06	16.55	1.34.
Grascete	As-Ap	65	Pleistocene	Terraces and straight sides	6-10	slow/ not good	Acquic Xerochrepts	8.12	40	38	22	342	47	6.06	16.55	1.34.
Accattapane	F-Fs	30	Pleistocene	Undulating and straight sides	0-10	very slow/ good	Tipic Haploxeralfs	7.70	63	27	10	124	6	1.50	28.20	1.34
Colle Rosi	R-Re	190	Alberese	Convex sides	6-15	slow/moder ately good	Litic or Acquic Xerorthents	8.50	50	29	21	-	-	-	14.0	-
Cerreta	Ga	30-50	Pleistocene	Terraces and undulating sides	0-8	obstructed/ obstructed	Psammentic Haploxeralfs	7.00	77	17	6	124	14	1.00	7.60	1.19
Porcarecce	B-Bs	30-40	Ancient alluvial deposits (Holocene)	Alluvial terraces	2-10	slow/moder ately good	Fluventic Xerochrepts	8.53	68	16	16	48	10	2.16	7.68	0.90
Castagneto	Cf-Cs-Cg-A		Pleistocene	Terraces	6-15	slow/moder ately good	Acquic Palexeralfs	6.93	67	22	11	180	6	1.20	15.38	0.66
Segalari	S-Se	100	Cretaceous	Straight sides	6-15	slow/not good	Litic or Acquic Xerorthents	8.55	50	31	19	96	12	0.00	13.90	1.14
Contessine	L-Ls	30	Pleistocene	Terraces and undulating sides	0-8	slow/good	Petrocalcic Palexeralfs	7.66	63	27	10	168	20	0.81	16.81	0.99
Ornellaia	I	95	Pliocene	Straight sides	2	good/ not good	Acquic Xerochrepts	8.29	24	48	28	132	2	14.73	10.60	0.52

Exch. K_2O : exchangeable potassium in K_2O, ammonium acetate method. Aval. P_2O_5 : available phosphorus in P_2O_5, Olsen method. Read.sol.carb. : Readily soluble calcium carbonates.

MATERIAL AND METHODS

Experimental design. In all "cultivar (*Sangiovese, Cabernet Sauvignon* and *Merlot*) x landscape unit" combinations, experimental plots (replicated groups of vines) were chosen in homogeneous vineyards, single cordon trained (about 3300-4500 vines/hectare). Grape maturation was studied by weekly samples of berries from veraison to vintage in a three years period (1993-1995). Grape maturation was studied by weekly samples of berries from veraison to vintage in the three years period. At harvest yield and must composition traits were measured and, from the plots representative of landscape unit variation, sixty kilograms of grapes were vinified in Istituto Agrario di San Michele (S.Michele all'Adige, Trento) experimental cellar according to a standardised scheme. Replications of the same landscape units were made to estimate variation in vine performances due to vineyard characteristics and management systems (a total of 66 plots was surveyed). Nutritional status of vines at veraison was surveyed at veraison with leaf analysis, according to Bogoni et al. (1995). At winter pruning, pruning wood/vine was measured in all experimental plots to estimate vegetative growth and indices of balance between vine yield and vigour (Maccarrone et al., 1996). In 1995 also potentially available water in soils of different units was estimated (Falcetti *et al.*, 1996).

Estimate of soil effects. Due to its location *Tenuta dell'Ornellaia* farm had vines of *Cabernet Sauvignon* and *Merlot* of similar age, vine density and training system, clones and rootstocks, on most of the different terroirs of Bolgheri area, but located close to each other, i.e. under the same mesoclimatic conditions. By this way it was possible, according to the experimental design previously described in the 1992-1995 period, to estimate soil effects by itself on vine performance and wine quality.

Chemical and sensory analyses of wines. Methods and results concerning wine chemical and sensory evaluation are in Bogoni and Mela (1997).

Data analysis. All statistical analyses were performed using Statistical Analysis System (SAS) (1988) according to ANOVA, correlation and principal component analysis (PCA).

RESULTS

Soil effects on vine performances and wine quality. Wines obtained in *Tenuta dell'Ornellaia* vineyards from soils Ap and Asa (the sensory profile of the latter is not reported) had the highest alcohol degree, acidity and phenols. In particular Ap wines had the highest balance in taste profile, good structure and sensory complexity (fig. 1). Wines from I soil had a good aroma complexity but a low organoleptic balance. Wines obtained from sandy soils Cf and G had lower alcohol degree, acidity and anthocyanins, but high pH. They had a high fruity note, but low structure and astringency (Maccarrone, 1995).

Table 2. Effect of soil type on yield, vigour and must composition of Cabernet Sauvignon (from Maccarrone, 1995). Soil type descriptions are reported in Table 1.

Soil type	Yield (kg/vine)	Pruning wood (kg/vine)	Shoot weight (g)	PL[1]	Soluble solids (°Brix)	pH	Titratable acidity (g/l)	Total antocyanins (mg/l)
Ap	3.2 c[2]	1.56 a	131 a	2.0 c	22.02 a	3.48 a	5.48 a	405.4 a
Asa	4.4 a	1.43 a	132 a	3.3 b	22.10 a	3.49 a	5.07 b	593.1 c
I	3.5 bc	0.69 c	62 c	5.1 a	21.46 bc	3.48 a	4.50 c	562.5 c
Cf	3.3 c	1.02 b	91 b	3.7 b	20.38 c	3.43 a	5.79 a	488.8 b
G	3.9 b	0.89 b	89 b	4.8 a	20.15 a	3.48 a	5.73 a	452.4 ab
Sign. F[3]	***	***	***	***	***	n.s.	***	***

[1] : Yield/pruning wood ratio (Ravaz's index).

[2] : Values within columns with the same letter are not significantly different ($p<0.05$, Duncan's test)

[3] : n.s. = not significant ; *** = $p<0.05$.

Differences in wine quality were related to soil-induced variation of vegetative growth and crop load of vines (TABLE 2). Silty-clay soils (Ap and Asa) induced the highest vegetative growth and sugar content. Vines in I soils had an unbalanced state : vines had a low vegetative growth and a good vine yield and sugar content but their acidity was extremely low. The Ravaz index had the maximum values in both years. Vines in G and F sandy soils had high Ravaz index values : their productivity was similar to Ap soils, but their vigour was significantly lower, their sugar content was the lowest and their acidity was the highest. The reduced canopy development in soils G and Cf did not allow a sufficient sugar accumulation and an optimal ripening process.

In general, the evaluation of the ratio between vine productivity and its vegetative growth provided a valuable key for the interpretation of differences in wine quality (Scienza et al., 1996). Soil effects determined in each soil type a peculiar balance between photosynthetic apparatus and grapes and different canopy microclimates, which sometimes limited sugar accumulation in berries, modified the ripening process and, finally, determined the quality of wines.

Since 1993 experimental measures were extended over the overall territory of Bolgheri D.O.C., to estimate the influences of site of cultivation on the three main cultivars.The influence of site of cultivation, that is landscape unit, resulted a combination of mesoclimatic conditions, soil characteristics, water and mineral nutrients plant availability.

Vines nutritional status in Bolgheri landscape units. Relationships found in other researches among pedoclimatic conditions and vine nutrition (Bogoni *et al.*, 1995) indicated the importance of the diagnosis of leaf nutritional status in the study of "cultivar x environment" interactions.

As concern vine nutritional status, a high variation due to the effects of this interaction was found, but mostly a large variation for K, Fe, Mn and P content in leaves of Bolgheri vineyards if compared to Tuscany vineyards situation (Failla *et al.*, 1995). In particular leaf K resulted, in most vineyards, below its minimal threshold. These data confirmed similar results obtained on peach by Failla et al. (1993) : environmental conditions limited K absorption in vines.

Landscape unit effect resulted statistically significant in Anova on variation in N, P, K, Ca and Mg levels ; year effect affected significantly N, K and Fe content in leaves ; unit x year interaction resulted significant only on P and K variation. In general it was not observed a direct relationship between soil texture and vine nutritional status (tabl. 3). *Sassicaia* and *Segalari* soils (with similar clay content) showed a very similar situation for leaf N, Ca and Fe. K content in leaves resulted particularly low in *Greppi cupi*, *Sassicaia*, *Cerreta* and mostly *Segalari* and *Porcarecce* units. *Castagneto* and *Contessine* units, with similar soil types and mesoclimatic conditions had similar leaf nutritional status, too. A particular situation was observed for *Colle Rosi* unit, related to its unique site conditions : vines showed the highest values for N, K and Mn, the lowest for Ca and P.

Table 3. Landscape units effects on nutritional status at veraison. Means of the three cultivars in the 1992-1994 period. Values within columns with the same letter are not significantly different ($p<0.05$)

Landscape Unit	n.	N %	P %	K %	Ca %	Mg %	Fe µg/g	Mn µg/g	B µg/g
Greppi cupi	19	2.18 bcd	0.13 ab	0.54 cd	3.03 bc	0.50 ab	295 a	318 bc	37 b
Sassicaia	12	1.96 e	0.14 a	0.57 cd	3.53 a	0.46 abcd	191 b	168 ef	51 ab
Accattapane	10	2.07 de	0.14 a	0.60 bc	3.41 ab	0.39 cd	298 a	292 bcd	49 ab
Colle Rosi	4	2.39 a	0.12 c	0.78 a	2.80 c	0.48 abc	294 a	768 a	53 ab
Cerreta	9	2.37 ab	0.14 a	0.52 cd	3.28 ab	0.49 ab	298 a	362 b	47 ab
Porcarecce	4	2.31 b	0.12 c	0.32 e	3.22 ab	0.51 ab	258 ab	249 cde	61 a
Castagneto	26	2.15 cde	0.13 ab	0.65 abc	3.24 ab	0.41 bcd	302 a	206 efd	53 ab
Segalari	8	2.04 de	0.13 ab	0.40 de	3.46 a	0.54 a	186 b	131 f	62 a
Contessine	9	2.10 de	0.13 ab	0.76 ab	3.34 ab	0.37 a	282 a	240 cde	43 b
Mean		2.16	0.13	0.59	3.30	0.46	265	248	50

n : number of cases.

Grape ripening, vine yield and must composition. Interactions among grapevine cultivar, landscape unit and seasonal conditions was studied by the aid of measures of the ripening process, vine performances and must composition.

Sangiovese showed a high variation as concern crop load/hectare (from 9 to 14 tons), vine yield, cluster and berry weight, must acidity and pH among the different lanscape units (tabl. 4).

Vine productivity and must composition could be interpreted only partially on the basis of soil characteristics, yield to pruning weight ratio (no relationships were found between this index and soluble sugars in musts) or soil available water. This results could be partially due to the large heterogeneity in genetic materials and vineyard age in the different plots used for measures.

Principal component analysis (not reported data) of the basic yield and must composition data showed a good separation of landscape units along the first two principal components (PCs, 41 and 34% of the variance, respectively), on the basis of their productivity and cluster weight (PC1) and must acidity and pH (PC2). In the plane formed by the fist two PCs, units on sandy or sandy-loamy soils were grouped (Greppi cupi, Castagneto, Accattapane and Contessine) : they had different productivity, but average acidity. Cerreta and Porcarecce units were grouped for their high acidity and productivity. Segalari, Colle Rosi and Grascete units had peculiar performances.

Cabernet Sauvignon plots over the whole Bolgheri territory confirmed results obtained in the previously cited study carried out in *Tenuta dell'Ornellaia*. Sassicaia unit confirmed its peculiar balance between a high vegetative growth and an average yield per vine (tabl. 5). Pedoclimatic conditions directly or indirectly affected *Cabernet S.* yield to pruning weight ratio. This ratio was negatively statistically correlated with must soluble sugars.

Merlot performances, in this dry area, as concern vine productivity, cluster weight and must composition were strictly related to clay content of soils, which allowed a higher water availability. In clayey soils *Merlot* increased its productivity more than its vegetative growth. Principal component analysis of yield and must data allowed a separation of landscape units along the first two PCs (40 and 32 % of the variance, respectively) on the basis of crop load/hectare, cluster weight and soluble sugars (PC1) and must acidity and pH (PC2). In the plane formed by PC1 and PC2, units with clayey or sandy-loamy soils were grouped (Segalari-Sassicaia and Contessine-Castagneto, respectively). Ornellaia and Cerreta units, were grouped for their high acidity and soluble sugars.

Wine chemical and sensory analyses.The technique of descriptive analysis was successfully applied to define the sensory properties of experimental wines. Sensory tests assessed the significant variability induced on *Sangiovese, Cabernet Sauvignon* and *Merlot* wines by landscape units. Wines obtained in some units had high typicality, i.e. they were easily distinguished by tasters, and maintained their sensory characteristics over different years and locations (Bogoni and Mela, 1997). Furthermore, distinction among different units was also achieved by standard chemical data.

CONCLUSIONS

A multi-disciplinary approach was adopted for the zoning of Bolgheri D.O.C. territory. The influence of landscape unit (homogeneous zones as concern soil type, plant available water, land morphology and local climate) on crop level, vine vegetative growth, grape composition and wine quality was the result of the combination of mesoclimatic conditions, soil characteristics, soil water and mineral nutrient availability. In most cases these units showed strongly different "cultivar x environment" interactions as concern vine yield and vigour, must composition and quality of wines (Bogoni and Mela, 1997).

Since 1996 up to 1998 a phase of validation and confirmation of these preliminary results will be carried on. These first results have been immediately used by growers for the choice of sites for new vineyards.

Table 4. Average yield, pruning wood and must composition traits of Sangiovese in the different units in the 1993-1995 period. Values within columns with the same letter are not significantly different ($p<0.05$).

Landscape Unit	Yield (kg/vine)	soluble sugars (°Brix)	titratable acidity (g/l)	pH	cluster weight (g)	berry weight (g)	pruning wood/vine (kg)	Yield/prun. wood ratio
Greppi cupi	3.4 bcd	18.5 bc	7.49 ab	3.32 cd	231 c	2.16 ab	0.68 bc	5.0 bc
Sassicaia	4.2 ab	19.2 ab	5.92 e	3.35 bc	277 b	2.13 abc	0.47 cd	7.4 a
Accattapane	4.1 ab	19.1 ab	7.06 bcd	3.36 bc	251 bc	2.11 abc	1.05 a	3.6 c
Colle Rosi	2.6 d	19.8 a	6.83 cd	3.51 a	250 bc	2.01 bcd	-	-
Cerreta	4.6 a	19.4 ab	7.86 a	3.26 de	244 bc	1.91 cd	0.74 b	6.8 ab
Porcarecce	4.8 a	19.4 ab	7.12 bc	3.24 e	234 c	1.85 d	-	-
Castagneto	3.6 bc	19.1 ab	6.49 d	3.41 b	262 bc	2.14 abc	0.67 bc	5.0 bc
Segalari	2.8 cd	19.6 a	8.00 a	3.25 e	248 bc	1.61 e	0.40 d	6.7 ab
Contessine	4.8 a	18.0 c	6.98 bcd	3.30 cde	328 a	2.32 a	-	-
Mean	3.9	19.1	7.05	3.34	254	2.06	0.64	5.8

Table 5. Average yield, pruning wood and must composition traits of Cabernet S. in the different units in the 1993-1995 period. Values within columns with the same letter are not significantly different ($p<0.05$).

Landscape Unit	Yield (kg/vine)	soluble sugars (°Brix)	titratable acidity (g/l)	pH	cluster weight (g)	berry weight (g)	pruning wood/ vine (kg)	Yield/prun. wood ratio
Greppi cupi	3.3 a	20.0 cd	6.76 b	3.49 a	175 ab	1.37 a	0.87 bc	4.6 ab
Sassicaia	3.4 a	21.6 ab	5.47 de	3.43 a	177 ab	1.20 abc	1.34 a	3.0 c
Cerreta	2.9 ab	20.6 bc	6.14 bcd	3.50 a	148 ab	1.16 ab	0.56 d	5.2 a
Castagneto	3.2 a	20.5 bc	5.89 cde	3.48 a	181 a	1.29 a	0.98 b	3.8 bc
Segalari	2.2 b	22.0 a	7.73 a	3.26 b	143 b	0.97 b	0.78 bc	3.5 c
Contessine	3.2 a	19.0 d	6.52 bc	3.52 a	165 ab	1.35 a	-	-
Ornellaia	3.4 a	21.7 ab	4.60 e	3.47 a	182 a	1.16 ab	0.71 cd	4.9 a
Mean	3.2	20.9	6.05	3.45	172	1.22	0.99	3.9

Table 6. Average yield, pruning wood and must composition traits of Merlot in the different units in the 1993-1995 period. Values within columns with the same letter are not significantly different ($p<0.05$).

Landscape Unit	Yield (kg/vine)	soluble sugars (°Brix)	titratable acidity (g/l).	pH	cluster weight (g)	berry weight (g)	pruning wood/ vine (kg)	Yield/prun. wood ratio
Greppi cupi	4.3 a	20.3 bc	5.50 bc	3.33 b	219 a	1.63 a	0.91 b	5.6 a
Cerreta	2.3 b	21.5 a	4.50 c	3.46 a	220 a	1.38 bc	0.62 c	3.9 b
Castagneto	2.4 b	20.4 bc	7.03 a	3.35 b	143 c	1.56 ab	1.20 a	2.3 c
Segalari	2.6 b	21.7 a	5.43 bc	3.33 b	175 b	1.75 b	0.59 c	4.7 ab
Contessine	2.7 b	20.2 c	6.17 ab	3.43 ab	141 c	1.38 bc	1.05 ab	2.2 c
Ornellaia	2.5 b	21.3 ab	4.81 c	3.43 ab	179 b	1.24 c	0.45 c	5.7 a
	2.7	21.1	5.65	3.36	175	1.36	0.76	4.1

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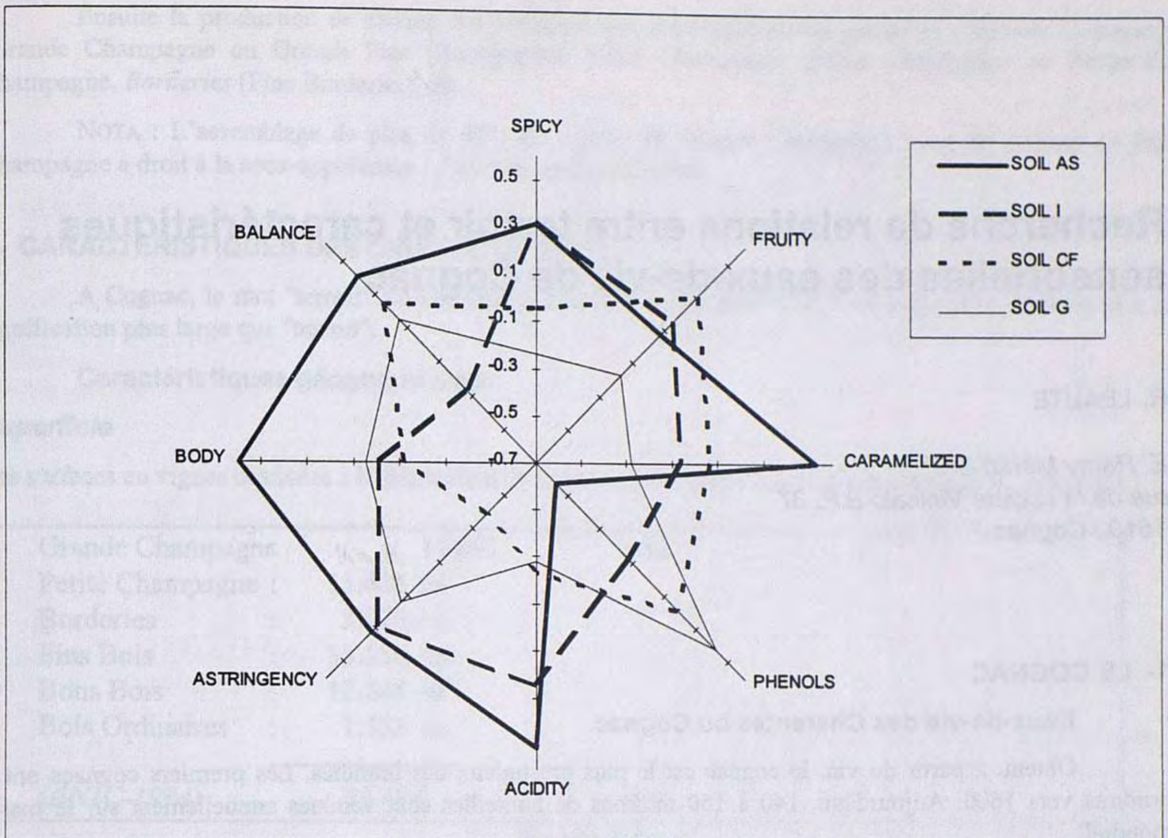

Figure 1. Sensory profiles of Cabernet Sauvignon wines obtained in different soils in 1993 in Tenuta dell'Ornellaia (modified from Maccarrone, 1995).