SOILS, ROOTSTOCKS AND GRAPEVINE VARIETIES IN PRESTIGIOUS BORDEAUX VINEYARDS AND THEIR IMPACT ON YIELD AND QUALITY

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Abstract

Aims: To study the impact of soil-type, grapevine variety and rootstock on grape yield and wine quality in prestigious estates located in the Bordeaux area (France).

Methods and results: High-resolution soil maps (scale: 1/3000th) were created for seven prestigious red wine-producing estates in Bordeaux, covering a total area of approximately 400 ha. Soil-type, rootstocks and grapevine varieties were recorded for each vineyard block. A Quality Index was created by considering the destination of the grapes produced in each block, whether they were integrated in the first, the second or the third quality wine produced by the estate. Quality Index was averaged over five vintages. Yield was also measured for each vineyard block and averaged over five vintages. PEYROSOL (gravelly soil) was the most frequent soil-type in these estates (45% of the total mapped area). Soils with temporary waterlogging (REDOXISOL), heavy clay soils (PLANOSOL) and sandy-gravelly soils (BRUNISOL) covered around 10% of the mapped area each. Highest quality was obtained on PLANOSOLS, ARENOSOLS (sandy soils), BRUNISOLS and PEYROSOLS. Quality was low on COLLUVIOSOLS (deep soils on colluvium), LUVISOLS (leached acidic soils) and REDUCTISOLS (soils with permanent waterlogging). Cabernet-Sauvignon was the dominant grapevine variety (59% of the mapped area), followed by Merlot (32%), Cabernet franc (8%) and Petit Verdot (1%). On average, the Quality Index was higher for Cabernet-Sauvignon and Merlot compared with Cabernet franc and Petit Verdot. Riparia Gloire de Montpellier (RGM) was by far the most used rootstock. It covered 45% of the mapped area. Including 3309C and 420A, these three rootstocks covered 75% of the total acreage planted in these estates. Highest quality wine was produced with 420A, RGM, 3309C and Gravesac. Highest yields were obtained with 161-49C, 101-14 MG, RGM, SO4 and 420A.

Conclusions: Soil, grapevine variety and rootstock have a major impact on yield and wine quality in prestigious Bordeaux wine producing estates.

Significance and impact of the study: Assessment of a Quality Index by soil-type, cultivar and rootstock can indicate which combinations of soil-type, cultivar and rootstock would best optimise quality performance in Bordeaux vineyards.

Key words: Soil-type, Bordeaux wine-growing area, vine variety, rootstock, wine quality, yield

Résumé

Objectifs : Étudier l'effet du sol, du cépage et du porte-greffe sur le rendement et la qualité du vin produit dans des domaines prestigieux du vignoble de Bordeaux.

Méthodes et résultats : Des cartes de sol à haute résolution (échelle : 1/ 3000^{e}) ont été réalisées pour sept domaines produisant des vins rouges réputés à Bordeaux sur une superficie totale d'environ 400 ha. Le type de sol, le cépage et le porte-greffe ont été identifiés pour chaque parcelle de vigne. Un indice de qualité a été créé en tenant compte de la destination des raisins produits sur chaque parcelle. Une note différente a été attribuée suivant qu'ils furent intégrés dans la première, la deuxième ou la troisième qualité du vin produit sur chaque domaine. L'indice de qualité a été pondéré sur cinq millésimes. Le rendement a également été évalué pour chaque parcelle de vigne sur cinq millésimes. Le PEYROSOL (sol graveleux) est le sol dominant dans ces domaines (45 % de la superficie totale cartographiée). Les sols présentant une hydromorphie temporaire (REDOXISOLS), les sols argileux (PLANOSOLS) et les sols sablo-graveleux (BRUNISOLS) couvrent chacun environ 10 % de la superficie cartographiée. La plus haute qualité a été obtenue sur les PLANOSOLS, les ARENOSOLS (sols sableux), les BRUNISOLS (sols sablo-graveleux) et les PEYROSOLS. La qualité a été faible sur les COLLUVIOSOLS (sols profonds de colluvions), les LUVISOLS (sols lessivés acides) et les REDUCTISOLS (sols à hydromorphie permanente). Le Cabernet-Sauvignon est le cépage dominant (59 % de la superficie cartographiée), suivi par le Merlot (32 %), le Cabernet franc (8 %) et le Petit Verdot (1 %). En moyenne, l'indice de qualité était plus élevé pour le Cabernet-Sauvignon et le Merlot, comparativement au Cabernet franc et au Petit Verdot. Le Riparia Gloire de Montpellier (RGM) est de loin le porte-greffe le plus utilisé. Il couvre 45 % de la surface cartographiée. Les trois porte-greffe les plus plantés (RGM, 3309C et 420A) couvrent 75 % de la superficie totale. La meilleure qualité de vin a été produite avec 420A, RGM, 3309C et Gravesac (indice de qualité > 2,5). Les rendements les plus élevés ont été obtenus avec 161-49C, 101-14 mg, RGM, SO4 et 420A.

Conclusion : Le sol, le cépage et le porte-greffe ont un effet majeur sur le rendement et la qualité du vin produit dans des domaines prestigieux du vignoble de Bordeaux.

Signification et l'impact de l'étude : Ces données quantitatives et qualitatives permettent d'évaluer les performances de différents types de sol et du matériel végétal associé dans le vignoble de Bordeaux. Elles permettent de formuler des recommandations concernant les associations entre le type de sol, le porte-greffe et le cépage qui permettent de valoriser le mieux quelques-uns des principaux types de sol du vignoble de Bordeaux.

Mots clés : Type de sol, cépage, porte-greffe, qualité du vin, rendement, vignoble bordelais

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INTRODUCTION

A viticultural terroir is an ecosystem, in which the vine is in interaction with factors of the natural environment, such as climate and soil (van Leeuwen and Seguin, 2006). Soil is considered as an important factor in terroir expression (van Leeuwen *et al.*, 2004). Bordeaux vineyard soils and their impact on grape ripening, have been extensively studied (Duteau *et al.*, 1981; van Leeuwen et Seguin, 1994; Choné *et al.*, 2001; Trégoat *et al.*, 2002). However, little data has been published about their spatial distribution and their relative frequency in high quality wine-producing estates. In most studies on the impact of soil, cultivar or rootstock on wine quality, grapes are analysed to assess their quality potential. Another approach is to consider selling prices of wine as an accurate tool to characterise their quality (Markham, 1997).

A wine-producing estate in Bordeaux (château viticole) is variable in size (from a few hectares to over 100 hectares) and generally comprises several grapevine varieties, several rootstocks and a complexity of soil-types. Grapes from different vineyard blocks are fermented separately. Quality potential varies from block to block, depending on soil-type, topography, grapevine variety, vine age, rootstock and viticultural practices. Brands marketed by the estate are a blend of wines produced from various blocks. In prestigious estates, only the best wines are blended to be sold under the name of the estate for the highest possible price. Second quality wine is blended and sold under a second label, generally for about one third of the price of the first wine. Third quality wine is in most cases sold anonymously for even lower prices. Destination of the crop (first, second or third quality wine) and their related selling prices can thus be considered as an integrative indicator of the quality of grapes produced in a given block.

In this study, soils of seven among the most prestigious red wine-producing estates in Bordeaux were mapped at very high spatial resolution (scale: 1/3000th), covering an area of approximately 400 ha. Soil-type, grapevine variety and rootstock were recorded for each vineyard block of these estates. A Quality Index was created and applied to each block. Yield was measured on each block and weighted over 5 vintages. Quality and yield were related to soil-type but also to grapevine variety and rootstock. This study gives an insight into soil-types in prestigious Bordeaux wine estates. It allows classification of their potential for obtaining high quality wines in relation to the grapevine variety and the rootstock chosen.

MATERIALS AND METHODS

1. Estates of the studies

The seven estates studied during this work are located in appellations Pauillac (3 estates), Margaux (1), Pessac-Léognan (1), Saint-Émilion (1) and Pomerol (1) and cover approximately 400 ha of vines, divided into 500 individual vineyard blocks.

2. Soil mapping and plant material

Soil maps were established at 1/3000th spatial resolution (Trégoat, 2003). Soil mapping techniques are described by van Leeuwen and Chéry (2001). Soils are classified according to the French « Référentiel Pédologique » (Baize and Girard, 1995). According to soil maps, the main soil-type was determined for each block. Grapevine variety, rootstock and vine age were recorded for each block. The relative percentages of each grapevine variety are Cabernet-Sauvignon 59%, Merlot 32%, Cabernet franc 8% and Petit-Verdot 1%. The percentages of each rootstock are presented in table 1.

3. Characterisation of the production

In Bordeaux estates, first quality wine is sold approximately three times more expensive than second quality wine. Third wine is sold for a price that just covers

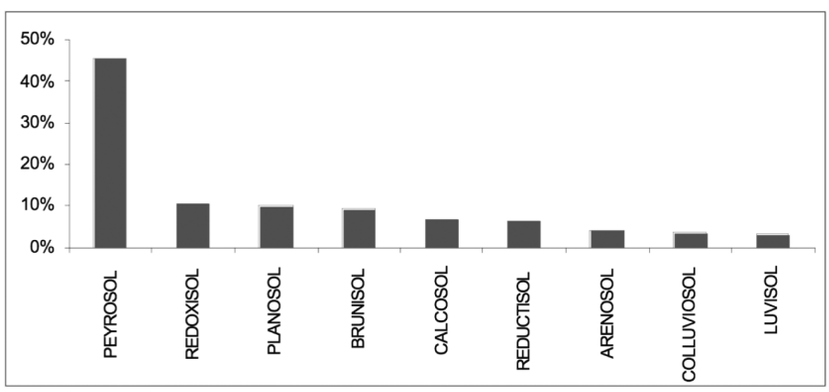

Figure 1 - Frequency of soil-types in seven prestigious Bordeaux wine-producing estates.

the production costs. Based on these assumptions, a Quality Index is attributed to each block by the following scale: 4 points are given if the wine produced in the block is blended into first quality wine; 1.5 point is given if the wine produced is blended into second quality wine; 0 point is attributed if the wine is blended into the third quality wine. This Quality Index is established for each vintage from 2002 to 2006 and averaged over these years. Yields were recorded for each individual block and averaged for the same series of vintages. Yield was controlled by grape thinning. In these estates, the crop reduction is generally a proportion of the natural yield, so that relative differences in yield among blocks remain after grape thinning. Hence, a database of approximately 2,500 references (500 blocks over 5 years) was established, from which it is possible to trace how soil-type, grapevine variety and rootstock, as well as their interactions, affect grape quality potential and yield in these estates.

The effect of soil, grapevine variety and rootstock on the mean yield and on the mean Quality Index were statistically analysed by using Sigmastat® software (Two way ANOVA test). When the probability was less than 0.05 it was accepted that the variable under consideration had a significant effect on the parameter studied.

RESULTS

1. Soil distribution

Soil-type is highly variable in these estates, depending on the geological substrate (Tertiary or Quaternary), quantity of stones, level of weathering of the soil profile and possible temporary or permanent waterlogging. An inventory of main soil-types recorded in the seven estates shows that gravelly soils (PEYROSOL) are the dominant soil type (45%, figure 1). Soils with temporary waterlogging (REDOXISOL) cover 11% of the mapped area. In these soils, a temporary water table is present in the root zone during winter, but disappears during summer. PLANOSOL is a soil type made up of a sandy or gravelly topsoil and a heavy clay sub-soil. It covers 10% of the mapped area, while BRUNISOL (sandy-gravelly soil, slightly acidic or neutral) covers 9%. Other soil-types cover small areas. CALCOSOL (7%) is a lime-holding, generally clayey textured soil. REDUCTISOL (7%) is a soil with a permanent water table that is always accessible by the roots. ARENOSOL (4%) is a sandy soil. COLLUVIOSOL (4%) is a deep soil developed on colluvium in a downhill position. LUVISOL (3%) is an acidic, leached soil, often affected by some degree of waterlogging.

2. Quality index and yield for each type of soil

Quality Index is soil-type related (figure 2). Three different groups of soils provide statistically different values for the Quality Index. Mean quality is high on PLANOSOL, ARENOSOL, BRUNISOL and PEYROSOL. Mean quality is low on REDOXISOL, LUVISOL and REDUCTISOL. Quality is intermediate on CALCOSOL and COLLUVIOSOL.

Yield is also an important point for plot characterisation in relation to soil-type (figure 3). Two groups are statistically distinguished. COLLUVIOSOL, PLANOSOL, LUVISOL and REDOXISOL have the highest mean yield. Yield is lower on REDUCTISOL, CALCOSOL, PEYROSOL, BRUNISOL and ARENOSOL.

3. Plant material: grape variety and rootstock

In the seven estates selected for this survey, Cabernet-Sauvignon is the most widely planted variety (59%), followed by Merlot (32%). Cabernet franc (8%) and Petit Verdot (1%) are complementary varieties. The high percentage of Cabernet-Sauvignon in this study (59%) is related to the high proportion of Médoc estates in this

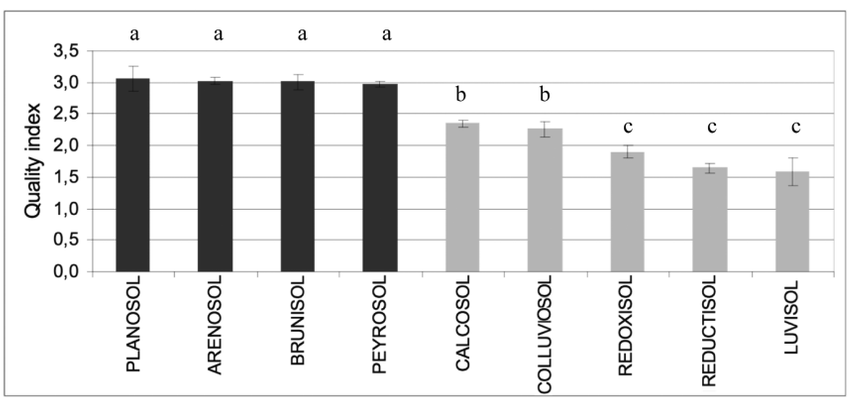

Figure 2 - Mean Quality Index (for vintages 2002-2006) for main soil types in seven prestigious Bordeaux wine producing estates.
Letters indicate statistically significant differences at the 5% level.

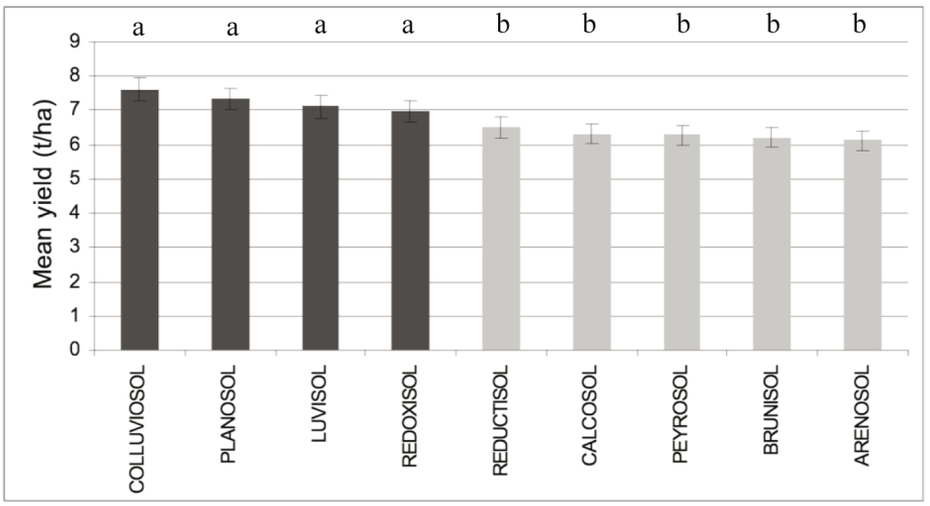

Figure 3 - Mean yield (for vintages 2002-2006) for main soil-types in seven prestigious Bordeaux wine-producing estates.
Letters indicate statistically significant differences at the 5% level.

Table 1 - Percentage of different rootstocks used in the seven estates studied. Impact on wine quality and yield.

Rootstocks	Acreage (%)	Mean Quality Index	Mean Yield (t/ha)
RGM	45	2.69	6.74
3309C	17	2.72	5.83
420A	13	3.30	6.50
101-14 MG	9	2.00	7.02
SO4	8	2.15	6.63
GRAVESAC	3	2.79	4.99
5BB	3	2.19	6.37
Others	2	1.94	7.77

survey (4 out of a total of 7 estates), a region in Bordeaux where Cabernet-Sauvignon is widely planted. Moreover, Médoc estates are big in size compared to estates located in other appellations. Global quality changes according to the grapevine variety. Mean Quality Index is high for Cabernet-Sauvignon (2.82) and Merlot (2.78), average for Cabernet franc (2.23) and low for Petit Verdot (1.81). Yield is also variety-dependant. Yield is highest for Merlot (7.08 t/ha), followed by Cabernet-Sauvignon (6.36 t/ha), Cabernet franc (5.72 t/ha) and Petit Verdot (4.12 t/ha).

Among rootstocks, RGM is largely predominant. It covers 45% of the mapped area, followed by 3309C, 420A, 101-14 MG and SO4. These five rootstocks represent 92% of the acreage studied (table 1). Differences in Quality Index and yield appear among rootstocks. 420A seems to be best performing for quality. Gravesac, 3309C and RGM also favour quality. They are significantly better than 5BB and SO4, which appear to perform less well with regard to quality. Surprisingly so, Quality Index is also low for 101-14 MG, although it is generally considered as a high quality rootstock. As far as yield is considered, it is interesting to note that vines grafted on Gravesac and 3309C produce less in these estates. Their mean yield is significantly lower than that obtained on other rootstocks.

Quality results and yield change with the age of the plantation. This evolution is rootstock dependant. Quality and yield performances of RGM, 3309C and SO4 were considered over time (figure 4). On RGM and 3309C quality increases with time. Conversely, quality of grapes produced by vines grafted on SO4 decreases over the years. Globally, mean yield decreases with vine age. This decrease is regular for RGM and asymptotic for the SO4. Yield tends to increase on 3309C until 40 years old and then decreases quite rapidly.

4. Performances of soil - cultivar - rootstock associations

It is possible to show whether a variety performs better on a given soil-type than its average performance and hence to assess optimum soil – cultivar combinations. Cabernet-Sauvignon and Cabernet franc are largely cultivated on PEYROSOL. Merlot is more evenly distributed over the various soil-types (table 2). Over 50% of the Cabernet-Sauvignon is grafted on RGM whereas for Merlot both RGM and 420A are widely used (table 3). RGM, 3309C and 420A are common rootstocks in association with Cabernet franc. Cabernet-Sauvignon on RGM on PEYROSOL is by far the most common combination in the studied estates.

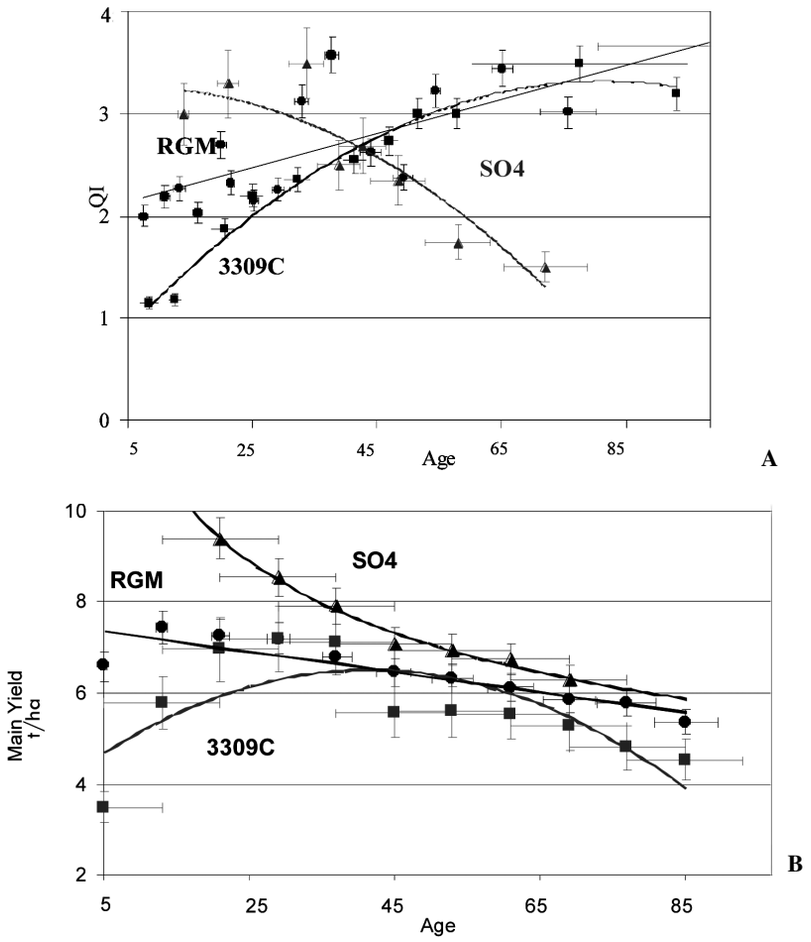

Figure 4 - Quality Index (A) and yield evolutions (B) over time for RGM (●), 3309C (■) and SO4 (▲).

Table 2 - Distribution of grapevine varieties according to the soil-type.

	Cabernet-Sauvignon (%)	Cabernet franc (%)	Merlot (%)
PEYROSOL	58	42	21
BRUNISOL	11	3	8
REDOXISOL	8	22	12
REDUCTISOL	6	13	
PLANOSOL	5	9	19
CALCOSOL	4		15
ARENOSOL	3	8	7
COLLUVIOSOL	2		7
LUVISOL	3	3	5

Table 3 - Distribution of grapevine varieties according to the rootstock.

	Cabernet-Sauvignon (%)	Cabernet franc (%)	Merlot (%)
RGM	52	39	37
3309C	15	20	11
101/14 MG	14	8	3
SO4	9	8	4
420A	6	16	25
Others	3		11
Gravesac	1	9	2
5BB	-	2	7

Table 4 - Associations most used with Merlot by comparison with global results obtained for all Merlot plots.

Associations	Surface (%)	Mean Quality Index	Mean Yield (t/ha)
Merlot on RGM on PLANOSOL	10	3.45	8.4
Merlot on RGM on PEYROSOL	9	2.90	6.2
Merlot on 420A on PEYROSOL	8	3.70	6.9
Total / average	100	2.78	7.1

The mean yield of the association Cabernet-Sauvignon on RGM on PEYROSOL (35% of planted area with Cabernet-Sauvignon) is equal to 6.72 t/ha and its mean Quality Index is equal to 2.94. These results are very close to those obtained for all Cabernet-Sauvignon plots (mean yield = 6.36 t/ha and mean QI = 2.82).

For Merlot (table 4), the three major associations are Merlot on RGM on PLANOSOL (10% of the Merlot plots), Merlot on RGM on PEYROSOL (9%) and Merlot on 420A on PEYROSOL (8%). Interesting differences appear on the Quality Index. The best result is obtained with Merlot associated with 420A on PEYROSOL (QI = 3.70). With respect to yield, Merlot on RGM produces more on PLANOSOL (8.4 t/ha) than on the PEYROSOL (6.2 t/ha). This difference is statistically significant at $p < 0.05$. These results show the importance of choosing plant material according to the soil-type. While Cabernet Sauvignon gives very good results with RGM on PEYROSOL, Merlot grafted on RGM is better performing on PLANOSOL.

For Cabernet franc, the most frequent association is, similar to that for Cabernet-Sauvignon, RGM on PEYROSOL (23% of the Cabernet franc plots). Mean yield (5.8 t/ha) and mean QI (2.58) for this association is similar to those obtained for all the Cabernet franc plots studied (mean yield = 5.72 t/ha and mean QI = 2.23). The small qualitative gain is statistically not significant. Some not very frequent associations perform well, such as Cabernet franc on 420A on ARENOSOL (mean QI = 3.0) and even more remarkably Cabernet franc on 101-14 MG on PEYROSOL (mean QI = 3.5). It is also worth emphasizing that Cabernet franc planted on low quality soils (LUVISOL and REDUCTISOL) provides very low Quality Indexes, sometimes even below 1 (Cabernet franc on 101-14 MG on LUVISOL QI = 0.7; Cabernet franc on 5BB on REDUCTISOL QI = 0.8; Cabernet franc on SO4 on REDUCTISOL QI = 0.8).

DISCUSSION

Viticultural estates generally produce a range of wines that are sold for different prices, according to their quality. Selling prices are an accurate tool to characterise quality in wine production (Markham, 1997). In this study, we introduce a Quality Index based on the frequency that wine produced from a given block is used in the blend for the first wine (the most expensive), for the second wine or for the third wine (the least expensive) of an estate. Together with the yield compiled from five successive vintages, this provides information on the quality and the quantity of grapes produced in relation to soil and plant material (grapevine variety and rootstock).

High Quality Index is obtained on PLANOSOL, ARENOSOL, BRUNISOL and PEYROSOL. These soils are weakly weathered. Morlat and Bodin (2006) also found that grape quality potential for red wine production was highest on weakly weathered soils in the Loire Valley.

The prestigious estates presented in this study also have plots with lower quality potential soils (REDUCTISOL, LUVISOL, COLLUVIOSOL) but they cover only 14% of the total area. Wine produced on these soil-types is rarely used in the blend of the first wine as it is shown by the low Quality Index they obtain in this study.

Quality potential in these estates is related to soil type in interaction with grape variety and rootstock. The high percentage of Cabernet-Sauvignon in this study (59%) can be explained by the high proportion of Médoc estates used for this survey (4 out of a total of 7 estates) and the fact that the Médoc estates are larger in size. On average, Merlot and Cabernet-Sauvignon obtain a similar Quality Index. It seems to be more difficult in Bordeaux to produce regularly first quality wine with Cabernet franc and Petit Verdot. Merlot and Cabernet franc perform well on BRUNISOL and ARENOSOL; the performance of Cabernet-Sauvignon is average on these soil types. All grapevine varieties show poor results on REDOXISOL, REDUCTISOL, LUVISOL and COLLUVIOSOL, supporting the idea that these soils have lower quality potential for red wine production in Bordeaux. However, REDOXISOL and LUVISOL appear to contribute more to quality for Merlot, and COLLUVIOSOL for Cabernet-Sauvignon. Surprisingly, better quality results are obtained with Cabernet-Sauvignon than with Merlot on CALCOSOL but this result might not be significant due to the small acreage of CALCOSOL studied.

The great majority of Cabernet-Sauvignon is planted on PEYROSOL and this combination provides very good quality performances. On PLANOSOL, excellent results are obtained with the three main varieties. It is acknowledged in Bordeaux that this soil-type is suitable for Merlot (particularly so in Pomerol), but this study shows that it also associates very well with Cabernet-Sauvignon and Cabernet franc. On ARENOSOL, high quality wine is produced with Merlot and Cabernet franc, but Cabernet-Sauvignon also performs reasonably well. Merlot performs better than Cabernet-Sauvignon and Cabernet franc on REDOXISOL and LUVISOL. Grape ripening is delayed on these soil types, which explains that better ripeness is obtained with an early-ripening variety. Quality results can also be enhanced on these soils by the use of a rootstock that induces precocity (RGM). Poor results are obtained on REDUCTISOL with all varieties because of permanent waterlogging.

A great diversity of rootstocks is used in the studied estates. Those that are known for inducing low vigour generally give the best quality results with the exception of 101-14MG. However, SO4, often regarded as too vigorous and inducing late ripening (Delas *et al.*, 1991), can sometimes give good results in terms of quality and quantity of grapes produced. These results change over time. Overall quality increases with age and yield decreases with age, more or less quickly, depending on the rootstock. The results of this study show that young plantations (< 25 years) can produce grapes of very good quality. More than a quarter of these young blocks (26%) have obtained a quality index > 3.

The most frequent association of soil, grapevine variety and rootstock is, unsurprisingly, the most common soil (PEYROSOL), planted with the most widely grown grape variety (Cabernet-Sauvignon) grafted on the most widely planted rootstock (RGM). Our study shows that quality potential of a soil can be enhanced by the choice of the grapevine variety and the rootstocks. However, in less quality potential soils, rootstocks cannot compensate wine quality, and, whatever the plant material used, results on LUVISOL or REDUCTISOL are always lower than those found on PEYROSOL or PLANOSOL, for example.

CONCLUSION

PEYROSOL (gravelly soil) is the major soil type in prestigious estates in Bordeaux, but in these estates, significant acreages of the equally high quality wine-producing PLANOSOL (heavy clay soil) can be found. Wine quality is more irregular on deep soils with high water-holding capacity (LUVISOL, COLLUVIOSOL) and on soils with permanent waterlogging (REDUCTISOL). Cabernet-Sauvignon is the dominant grapevine variety, followed by Merlot, Cabernet franc and Petit Verdot. On average, Quality Index is higher for Cabernet-Sauvignon and Merlot compared with Cabernet franc and Petit Verdot. Highest yields are obtained with Merlot, but this does not seem to alter quality performances of this variety.

To characterise associations between soil and grapevine variety, we have shown that Cabernet-Sauvignon performs well on PEYROSOL, Merlot provides high performance on PLANOSOL and the best Cabernet franc is obtained on ARENOSOL. On low quality soils, Merlot appears to be less prejudicial. RGM is, by far, the most widely planted rootstock in the surveyed estates, followed by 3309C, 420A and 101-14MG. However, a total of over a dozen rootstocks are cultivated, leading to a great number of possible associations of soil-cultivar-rootstock. Quality index is highest with RGM, 3309C, 420A and Gravesac. Quality index increases over the years on blocks planted on RGM and 3309C. The choice of rootstock is crucial because it commits the plantation over a period of many years. It must be chosen according to soil-type and production goals.

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