Soil type and soil preparation influence vine development and grape composition through its impact on vine water and nitrogen status

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Abstract. The influence of soil type and preparation on vine development and grape composition was investigated in a 50 ha estate located in Saint-Emilion (Bordeaux, France) and planted predominantly with Merlot. Part of the vineyard was planted down the slopes and another part of the vineyard was planted on terraces, where soils were profoundly modified through soil preparation. Grape composition (berry weight, sugar, total acidity, malic acid and pH), vigor (pruning weight), vine nitrogen status (Yeast Available Nitrogen (YAN) in grapes) and vine water status ($\delta^{13}C$) was measured at a very high density grid of 10 data points per hectare. Water deficit was globally weak over the estate because of high soil water holding capacity whereas vine nitrogen status was highly variable. Vine vigor and grape composition were predominantly driven by vine nitrogen status. On terraces, where soils were deep, due to invasive soil preparation, water deficits were particularly small or non-existent and vine nitrogen status was highly variable. Grape quality potential was medium to low, except in places with low nitrogen status, but at the expense of low yields. On parcels planted down the slopes water deficits were recorded because vine rooting was limited by compact subsoils. Vine nitrogen status was homogeneous. Grape quality and yield were medium to high and relatively homogeneous. When possible, downhill plantations are to be preferred over terraces because in the latter vine yield and quality parameters are highly variable because of massive soil movements prior to plantation.

1 Introduction

Wine quality and style are influenced by environmental factors like climate, topography and soil type [1]. These influences are mediated through the vine and may be impacted by management practices [2]. On hills, soil erosion has an impact on soil distribution [3]. To quantify soil impact on vine vigor and grape composition, it has to be broken down in measurable effects. Among these, vine water and nitrogen status are of major importance [4]. In this study, the soil effect on vine vigor and grape composition was investigated in a 50 ha estate in Saint-Emilion (Bordeaux, France), planted predominantly with Merlot. Soils were developped either on Tertiairy massive limestone bedrock (located on the plateaux) or on Tertiairy unconsolidated limestone bedrock (located on the slopes beneath the plateaux). Soils were predominantly silty-clay or clayey-silt textured. Part of the soils contained limestone, part of the soils did not. Relations between vine water status, vine nitrogen status, vine vigor, berry size and grape composition were investigated through measurements implemented on a regularly grid of 10 samples per hectare. On a subset of parcels, the effect of pre-planting soil preparation was studied. Part of these parcels were located on terraces created prior to plantation (invasive soil preparation) and part of these parcels were planted down the slopes (non-invasive soil preparation). Soil pits were excavated to measure physical and chemical soil composition and to relate soil preparation to soil depth. Around each soil pit, vine vigor was measured, as well as yield parameters, vine nitrogen status, vine water status, and grape composition, including phenolic compounds. This approach allowed to investigate the effect of soil preparation, vine water and nitrogen status and their subsequent effect on vine vigor and grape composition.

2 Methods

2.1 Investigation of relations between vine water status, vine nitrogen status, vine vigor and grape composition

A regular grid of 10 locations per hectare (500 over the whole estate) was sampled prior to harvest. Each sample was composed of 60 berries taken randomly on 20 adjacent vines. Berries were weighted, pressed, and analyzed for $\delta^{13}C$ in order to determine vine water status [5] and Yeast Available Nitrogen (YAN) to determine vine nitrogen status [6]. Reducing Sugars, Total Acitidy (TA), Malate (MAL) and pH were assessed through classical methods. Shoots were counted and pruning wood was weighed on three vines per location and pruning weights were averaged per vine and per shoot at all the locations.

2.2 Investigation of the effect of soil preparation

The effect of soil preparation on soil depth, vine nitrogen and water status, vine vigor and grape composition was investigated on a subset of seven hectares. In this area, pre-planting soil preparation had been invasive, including the creation of terraces in sector A (Figure 1). Vines were planted down the slopes with limited soil preparation in sector B.

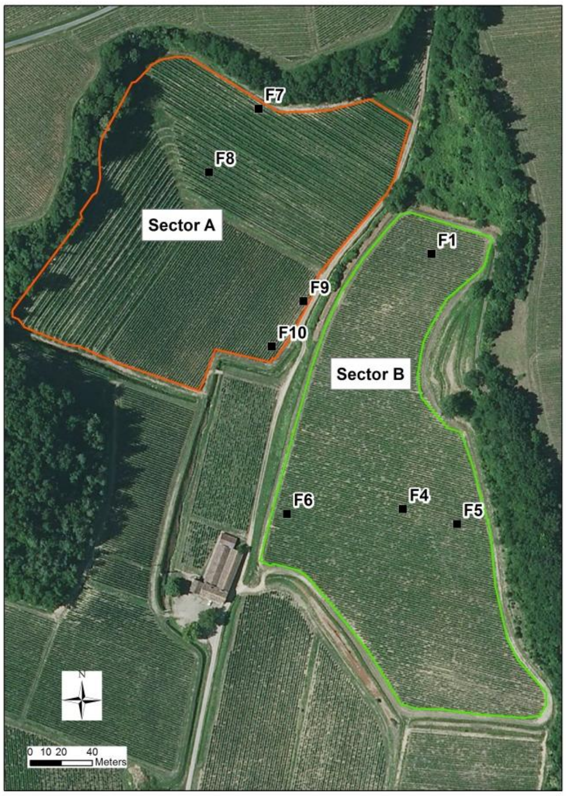

Figure 1. Location of the sector with invasive soil preparation (A) and the sector with conservative soil preparation (B).

2.2 Soil pits

Four soil pits were excavated in sectors A and B respectively (Figure 1) in order to determine soil type and soil depth (i.e. the depth at which the unaltered bedrock could be identified). In hillside context, soil depth is controlled by natural factors. It is the result of soil formation processes (duration and intensity) and of soil distribution along the slope driven by erosion processes. On cultivated areas, soil depth can be modified (generally increased, sometimes reduced) through pre-planting soil preparation operations, or the creation of terraces. Around each soil pit yield parameters were recorded at harvest (berry weight, number of bunches per vine, total yield per vine, bunch weight). Vine water status was assessed by means of stem water potential measurements (SWP, three measurements over the season) and δ^{13}C. Only the results from the last SWP measurement (9 September 2016), when water deficits were most intense, are presented. Vine nitrogen status was assessed over the whole 7 ha section through N-tester measurements over a grid of 142 locations at two dates, at bloom and at veraison [6]. Only vine nitrogen status at veraison is presented. Grape composition was measured prior to harvest on four replicate samples per soil pit: YAN, Reducing Sugars, TA, MAL, pH, total anthocyanins and total phenolics.

3 Results

3.1 Relations between vine water status, vine nitrogen status, vine vigor and grape composition

A Principal Component Analysis (PCA) was carried out to investigate the relations between vine water status, vine nitrogen status, vine vigor and grape composition, on the data collected on the 500 locations over the whole estate (Figure 2). The first two dimensions (Dim 1 and Dim 2) explained 41% of the total variance of the dataset. The first Dim (24% of the total variance) separated the individuals according to the level of ripeness of the grapes, with individuals with high sugar on the left of the map and variables with high acidity on the right of the map. The second Dim (17% of the total variance) was driven by slope, U (North-South aspect) and Y (longitude). δ^{13}C was located close to the center of the Dim 1 - Dim 2 PCA mapping. The results of the PCA show that the total variance of the data set is better explained by YAN than by δ^{13}C.

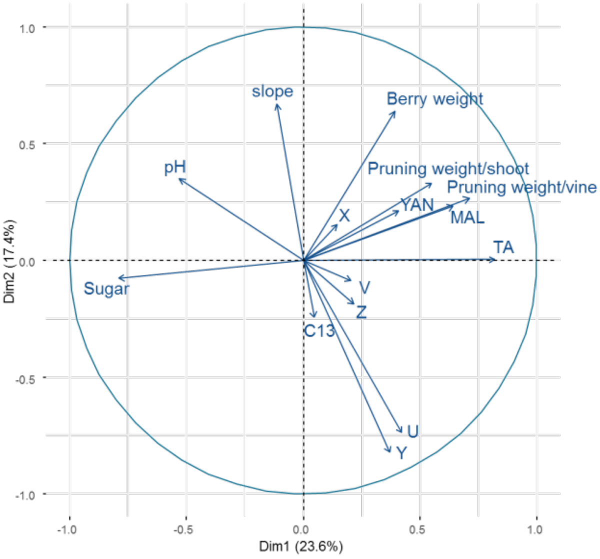

Figure 2. Projection of the first two dimensions of a PCA analysis carried out on the total data set.

Grape sugar content decreases with YAN (Figure 3a), while MAL increases with YAN (Figure 3b) and so does TA (data not shown). Hence, grapes from low nitrogen status vines produce grapes with greater ripeness at a given date. This effect is partially mediated through berry weight, which increases with YAN (linear regression significant t = 2.34; p = 0.02).

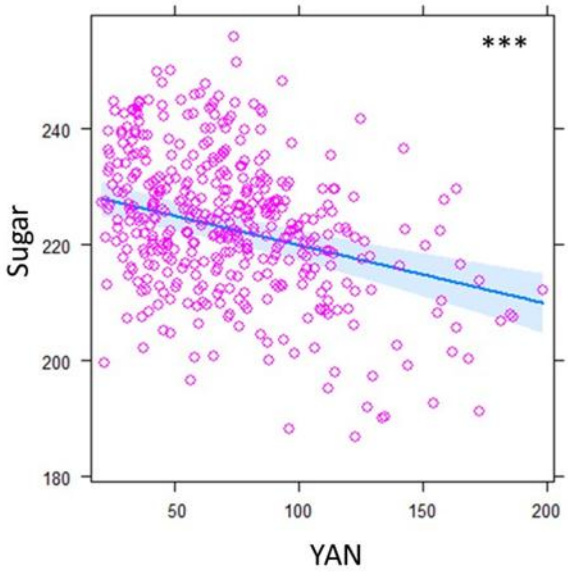

Figure 3a. Linear regression between grape sugar and YAN (t=5.66; p<0.001).

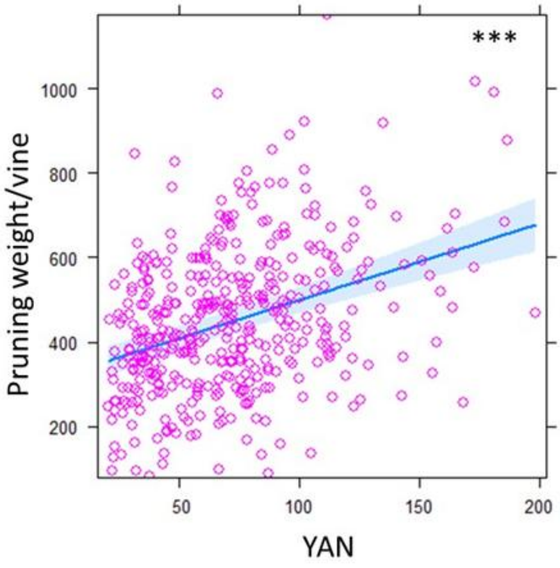

Figure 4a. Linear regression between pruning weight per vine and YAN (t=8.17; p<0.001).

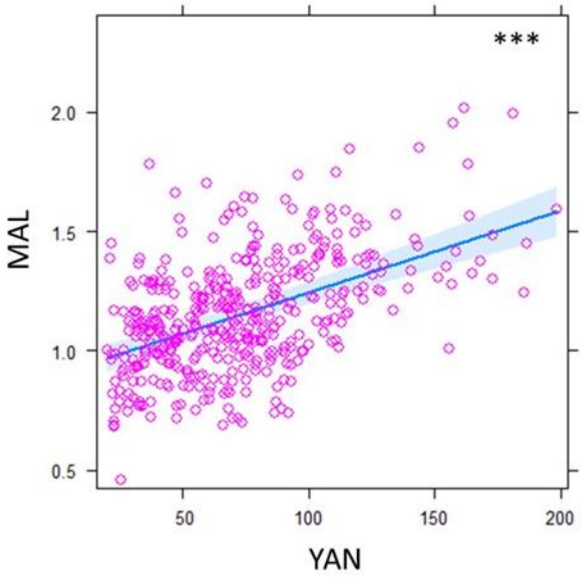

Figure 3b. Linear regression between malic acid and YAN (t=8.96; p<0.001..

Vine vigor is also driven by vine nitrogen status, as shown by the highly significant relation between YAN and pruning weight per vine (Figure 4a) and per shoot (Figure 4b).

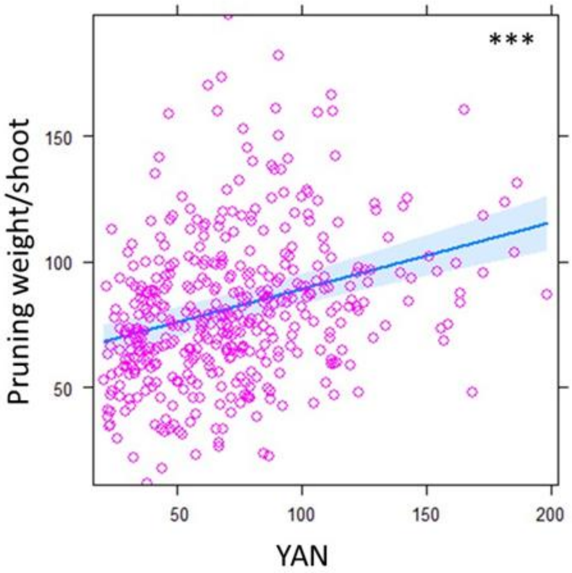

Figure 4b. Linear regression between pruning weight per shoot and YAN (t=7.65; p<0.001).

3.2 Vigor, yield and grape composition in relation to soil preparation before planting

Soils were deeper than 110 cm in all parcels with invasive soil preparation (sector A). Soils were shallow (55 to 80 cm deep before reaching the undisturbed unconsolidated limestone bedrock) in three of the four soil pits located in sector B (non-invasive soil preparation).

Stem water potential readings were taken around the location of the soil pits. At the end of the season, stem water potential readings were between 0.7 and 0.9 MPa in sector A, indicating weak water deficits. Three out of the four readings were lower than -1.0 MPa in sector B, indicating moderate water deficits.

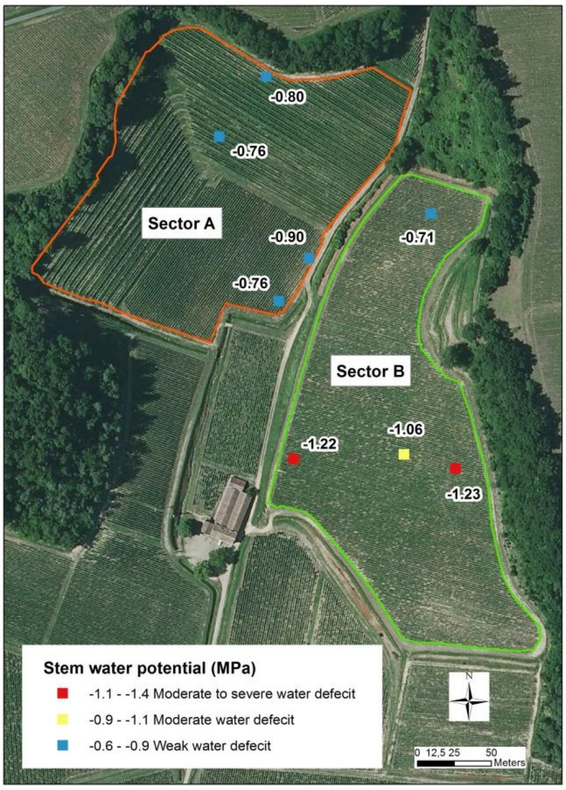

Figure 5. Stem water potential values at the location of the soil pits measured at the end of the season (21 September 2016).

Vine nitrogen status, as assessed by N-tester readings, was very heterogeneous in sector A, where soil was moved by bulldozers prior to planting. Vine nitrogen status was rather homogeneous in sector B where pre-planting soil preparation had been less invasive.

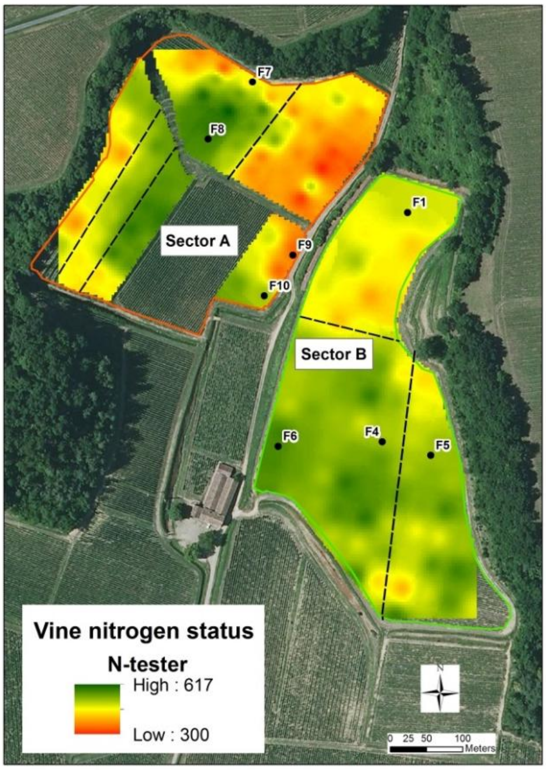

Figure 6. Vine nitrogen status map of sectors A and B, created by N-tester measurements at veraison over a regular grid of 142 data points.

Berry weight (Figure 7) and yield components (Table 1) were highly variable on the blocks with intense soil preparation (sector A). Berry weight and yield where low where vine nitrogen status was low (F7 and F9) and high where vine nitrogen status was high (F8 and F10; Figure 7). Homogeneous nitrogen status in sector B (F1, F4, F5 and F6) resulted in little variation in berry weight (Figure 7) and bunch weight (Table 1). However, bunch number and yield were high in F6, which was located down the slope and where vine N-status was slightly higher compared to other locations in sector B.

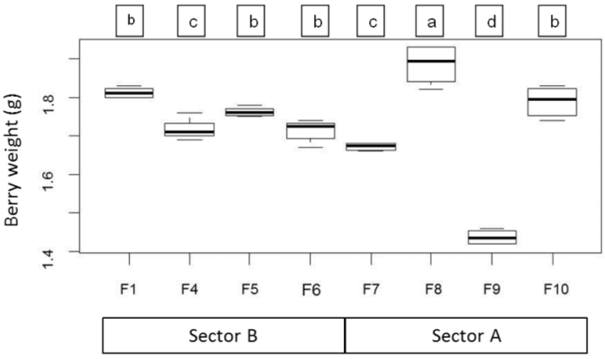

Figure 7. Berry weight at the location of the soil pits.

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Table 1. Yield parameters at the location of the soil pits.

	Sector B				Sector A			
	F1	F4	F5	F6	F7	F8	F9	F10
Bunches/vine	9	8	9	13	6	11	6	11
Yield/vine (kg)	1.93	1.51	2.28	3.45	0.50	2.88	0.73	2.38
Bunch weight (g)	223	187	243	242	93	243	126	218

Grape composition was more heterogeneous in sector A compared to sector B (Table 2). In sector A, grape quality potential was very high on the locations with low vine nitrogen status (F7, F9), showing particularly high total anthocyanin concentrations, but low on locations with high vine nitrogen status (F8, F10). In low nitrogen locations, the high quality potential was at the expense of particularly low yields (0.5 kg/vine on F7, 0.73 kg/vine on F9).

Table 2. Grape composition at ripeness at the location of the soil pits.

		N-tester veraison	Grape sugar	TA	MAL	Total anthocyanin	Total phenolics index
Sector B	F1	average	220	3,9	1,9	1195	42
	F4	average	241	3,4	1,3	1537	51
	F5	average	241	3,4	1,4	1519	48
	F6	slightly high	225	3,9	1,5	1449	44
Sector A	F7	low	237	3,0	1,2	1804	49
	F8	high	215	3,8	2,2	1308	39
	F9	very low	240	2,8	1,1	1934	59
	F10	slightly high	221	3,7	1,9	1563	43

4 Discussion and conclusion

In the geological context of this study (limestone soils on Tertiairy bedrock with moderately high soil water holding capacity), grape quality potential and vine vigor were predominantly driven by vine nitrogen status. Only weak water deficits were recorded around the soil pits where the soil was profoundly modified before plantation, probably because increased soil depth allowed vines to have access to greater soil water reserves through deeper rooting. Moderate water deficits were recorded around three of the four soil pits located in downhill planted parcels and vine nitrogen status was moderate to low in all four. Vine nitrogen status was highly variable in parcels where the soil was moved before plantation (including terraces): in locations where the topsoil was removed vine nitrogen status was very low and where topsoil was accumulated, vine nitrogen status was very high. In those parcels with highly variable vine nitrogen status, grape quality potential was high in places with low nitrogen status (small berries, high sugar and anthocyanins), but vigor and yield were particularly low. In the same parcels, at locations where vine nitrogen status was high, grape quality potential was low (large berries, low sugar, anthocyanins and total phenolics, high malate) but vigor and yield were high. This study shows that in locations where soil water is not much limiting because of medium to high soil water holding capacity, vine nitrogen status is a major driver of the soil effect on yield, vigor and grape composition. Downhill plantations with minimal soil preparation do better respect soils and provide more homogeneous performances in terms of vigor, yield and grape quality potential. When the soil is moved during soil preparation prior to plantation (which is the case when creating terraces), vine water status is less limited because soil depth is increased and vine nitrogen status is highly variable, resulting in very heterogeneous performances in terms of grape quality potential, yield and vigor. The study also emphasizes that vine nitrogen and water status are relevant parameters for the interpretation of vine behavior in response to soil type, including anthropogenic modifications.

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