Grapevine Root System and Soil Characteristics in a Vineyard Maintained Long-term with or without Interrow Sward

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Grapevine root system and soil chemical and physical properties were studied in the Loire Valley, France. The vineyard was planted in 1977 with Cabernet Sauvignon grafted onto SO4 and maintained for 17 years with or without interrow sward. Three treatments were compared: complete weed control by herbicide, permanent grass (*Festuca Arundinacea* cv. Manade) covering over 50% of the soil surface, and permanent grass covering over 25% of the soil surface achieved by a grass interrow alternating with a herbicide-treated interrow. At the end of the experiment in 1994, observations showed that the permanent grass cover caused a considerable decrease in the number of vine roots in the interrow, mainly in the upper soil layers, but an increase close to the row. The amount of organic matter, nitrogen, exchangeable K_2O, pH, and soil moisture at field capacity increased under permanent grass cover, while bulk density and the mechanical resistance of the soil decreased.

Key words: Soil management practices, chemical weed control, permanent grass cover, vine root system, physical and chemical properties of soil, competition

In France, permanent grass cover is increasingly used by grapegrowers because of its beneficial effects, including improvement in soil characteristics [18,19], limitation of runoff and erosion, decrease in vine vigor and grape production, reduction in *Botrytis* bunch rot, and improved vine microclimate, thus improving wine quality [15]. Permanent grass cover influences the vine root system, although its long-term effects are not well known. Competition between grass rooting and the vine root system influences capacity and conditions of water absorption [3,9], photosynthates allocation to roots, root penetration and distribution, and quality of root colonization [1]. Consequently, the permanent grass cover of soil can greatly affect the water supply of grapevines [17], particularly in the topsoil.

Soil physical properties can affect the development and activity of the grapevine root system. Soil type influences the depth of roots [23,25]. Increase in bulk density, poor water infiltration, and soil acidity decrease the number of roots [5,16,25]. Many authors have noted that soil water content has a strong effect on rooting. Morlat and Jacquet [16] reported a positive effect of soil available water content on the grapevine root system. In young citrus trees, Bevington and Castle [2] suggested that both the number of growing roots and the rate of root elongation were influenced by shoot growth, soil temperature, and soil water content. Several authors [6,8] showed that part of the grape root system in dry soil can survive because water is transferred from regions of high water availability to those of low availability.

In 1977, a long-term experiment was installed in an Anjou vineyard (France) to compare different soil cultivation practices (several herbicide control and permanent grass cover conditions). In 1994, at the end of the experiment, the grapevine root system and soil characteristics were studied in different soil cultivation treatments. The present paper describes and discusses the main results obtained.

Materials and Methods

Experimental layout. The experimental vineyard was planted in 1977 in the Loire Valley, France, on the Anjou plateau (47°21' N, 0°28' W, 57 m above sea level). The climate is relatively dry, with a mean annual rainfall of 550 mm. The soil has a loamy-clayey A-horizon (60% silt, 19% clay) resting over a clayey B-horizon enriched in clay (32% clay, 48% silt) and resulting from the weathering of green schists (Ordovician to Silurian geological complex). In some places, quartz veins are responsible for an increase in the amount of pebbles. The soil depth varies from 0.8 to 1.0 m, according to the weathering level of schists. The soil has large water reserves (185 mm in the first meter of soil).

Three treatments were compared (Figure 1): (1) herbicide control over the total soil surface (herbicide treatment, HT); (2) permanent sward (*Festuca Arundinacea* cv. Manade) over 50% of the total soil surface (sward treatment, ST); and (3) an interrow with herbicide control over the total soil surface (HTI treatment), alternating with an adjacent interrow with sward

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(*Festuca Arundinacea* cv. Manade) over 50% of the total soil surface (STI treatment).

In HT and HTI plots, as under the vine row of all treatments, weed control was achieved through the application of a preemergence herbicide (1 kg diuron/Ha + 0.5 kg simazine/Ha) in March and a systemic herbicide (2.2 kg herbicide glyphosate/Ha) during summer. The vines (*Vitis vinifera* L. cv. Cabernet Sauvignon, grafted onto SO4 rootstock) were spaced 3.2 x 1.2 m, resulting in 2604 vines/Ha. N, P, and K fertilization was similar in all treatments. A block design with six replicates per treatment was used and border effects were eliminated by guard rows and four guard vines at the edge of each block. Each treatment replicate was a cluster of 84 plants with 12 vines measured along two vine rows (Figure 1).

Study of the grapevine root system. In March 1994, the last year of the experiment, the grapevine root system was studied according to the method described by Morlat and Jacquet [16]. After measuring the circumference of scions along two measurement rows, one vine with near average trunk diameter was selected per replicate in each treatment (Figure 1), that is, six vines per treatment. One half of a vine root system was studied by digging a pit parallel to the row, in front of each selected vine. In each treatment, three pits were dug on the right side (east position) of the row and three others on the left (west position) (Figure 1), to account for the asymmetry of lateral rooting [18]. As described by Morlat [18], the root asymmetry index (RAI) was calculated as follows:

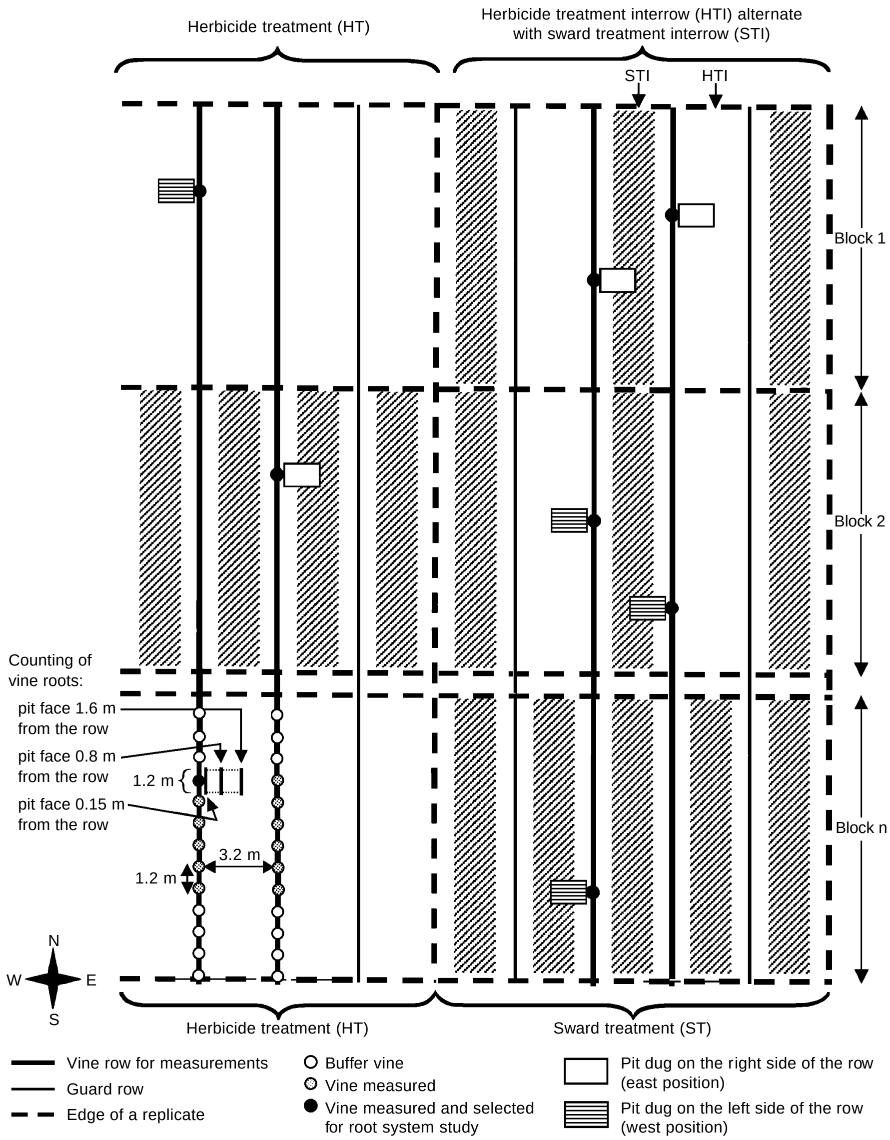

Figure 1 Diagram of experimental plot showing different soil cultivation treatments and pit sites for the root system study of grapevine (ST = sward treatment; HT = herbicide treatment; HTI = herbicide treatment interrow alternating with STI = sward treatment interrow).

$$RAI = \left[\sum_{n=1}^{Ni} (xn,i) / Ni\right] / \left[\sum_{n=1}^{Nj} (xn,j) / Nj\right]$$

where xn, i = root number counted for the pits N that are on the row side i

xn, j = root number counted for the pits N that are on the opposite row side j

and Ni = Nj.

If $\left[\sum_{n=1}^{Ni} (xn,i) / Ni\right] = A$ and $\left[\sum_{n=1}^{Nj} (xn,j) / Nj\right] = B$, and $RAI \geq 1$,

we can write:

$RAI = A / B$ if $A \geq B$, or $RAI = B / A$ if $B \geq A$

For each pit, three vertical profiles 1.6, 0.8, and 0.15 m from the vine row were progressively dug and immediately counted from the furthest face (1.6 m) inward to the 0.15 m face. Living roots only were counted in four soil layers of variable thickness corresponding to pedological horizons, that is, 0 to 0.2 m for the first, 0.2 to 0.45 m for the second, 0.45 to 0.65 m for the third, and 0.65 to 0.90 m for the fourth, according to the following diameter classes: <1 mm, 1 to 2 mm, and >2 mm, and also summarized on each vertical plane. The depth of vertical profiles was 0.9 m and the length was equal to the inrow spacing (1.2 m).

Additional information on deep rooting was obtained by counting roots penetrating two horizontal planes (1.2 m long, 0.15 m wide) situated at the bottom of the pit (0.9 m deep) and 0.15 m (0.15 m to 0.3 m) and 1.6 m (1.45 m to 1.6 m) from the vine row. All results are expressed as number of root interceptions/m^2.

For each sward treatment (ST and STI), one sample of 250 cm^3 of soil was taken in each replicate in levels 0 to 0.2 m and

0.2 to 0.45 m, in the middle of the interrow (1.6 m from the vine row). After washing, white, living grass roots were separated visually and the mass of the oven-dried (105°C during 72 hr) roots was determined.

Soil characteristics. Soil bulk density, which quantifies soil compaction, was measured using a gamma ray attenuation method (Campbell 501 gamma probe, CPN® Corp., Martinez, CA) in three soil layers, 0 to 0.2 m, 0.2 to 0.45 m, and 0.45 to 0.65 m in the interrow (1.6 m from the vine row), with six replicates per treatment. A similar protocol was applied for chemical determination. Soil strength was measured with a field cone penetrometer (Labotest® Instruments, Paris, France) in the same soil layers, with 10 replicates per layer for each of three root-counting vertical profiles. The moisture of soil in March 1994 was considered representative of the field capacity. In each soil layer from every treatment, six soil samples (one per replicate) were taken in the middle of the interrow (1.6 m from the vine row). To determine the amount of water stored by soil at field capacity, the soil weight was measured before and after drying in forced-air ovens at 105°C during 168 hr.

Soil organic matter content was determined by oxidizing organic compounds with potassium dichromate in sulfuric acid solution. Soil total nitrogen was analyzed after H_2SO_4 mineralization and distillation (Kjeldahl method). Soil pH was measured using an electronic pH meter with a 1:2.5 soil/water ratio. Available P_2O_5 was extracted by shaking soil with 2% citric acid solution at pH 2.0 (Dyer method). Extractable K_2O and MgO were measured by exchange with neutral N ammonium acetate, with the potassium and magnesium concentrations in the filtrate being determined by flame atomic absorption.

Data analysis. Results were subjected to analysis of variance (ANOVA) with the Newman and Keuls test method.

Results

Grapevine rooting in different soil management systems. Data collected from vine roots were first treated by analysis of variance (Table 1), and the block effect was never significant for any diameter class of roots. Concerning the total number of roots counted in vertical profiles, all other sources of variation—soil management practices (A), distance from the counting profile to the vine row (B), and soil layer (C)—as well as most of their interactions had a highly significant effect. It was the same for the <1 mm diameter classes (fine roots, according to Richards [21]) and 1 to 2 mm; whereas for the >2 mm class (permanent woody roots, according to the same author), the effect of soil management practices was less significant than that of other sources of variation. Because there were many significant statistical interactions between A, B, and C (Table 1), root numbers for the A treatment were analyzed by single ANOVA for each distance from the counting profile to the vine row (B) and each soil layer (C) and also for the whole surface of each vertical counting profile. Means were compared by the Newman and Keuls test method.

Fine roots (<1 mm diameter) were the most abundant and represented 73 to 98% of the total grapevine roots counted in vertical profiles and 61 to 98% in horizontal profiles (Table 2). In the vertical counting profile situated 0.15 m from the vine row, root numbers of <1 mm diameter class were significantly higher in sward treatments ST (194 roots/m²) and STI (178 roots/m²) and lower in the herbicide treatment HT (112 roots/m²). In the profile situated 0.8 m from the vine row, the root number of <1 mm diameter class was greatest in the HTI treatment (167 roots/m²), but the lowest in the herbicide treatment HT (101 roots/m²); 1.6 m from the vine row there were far more roots in the HTI (175 roots/m²) and HT (141 roots/m²) treatments than in the ST (64 roots/m²) and STI (56 roots/m²) treatments. For roots counted in horizontal profiles 0.9 m deep (deep roots), means were rarely different between treatments (Table 2). However, 0.15 m from the vine row, the number of roots was slightly greater in the sward treatments, and the mean of total roots counted in the STI treatment was significantly greater than in the HT treatment.

With permanent woody roots (>2 mm diameter class), no significant differences were observed between treatments, except in the vertical profile situated 0.8 m from the vine row where the number of roots was greater in the herbicide treatments. A decrease in the number of roots was observed (Table 2) between the counting profiles situated 0.15 and 1.6 m from the vine row.

Table 1 F values from variance analysis for total root number and numbers of roots of varying diameter of grapevine grown under four treatments of soil cultivation.

	Root numbers[a]							
	Total		<1 mm diam		1-2 mm diam		>2 mm diam	
Sources of variation	F	CV (%)	F	CV (%)	F	CV (%)	F	CV (%)
Soil management (A)	12.49***[b]	38.8	9.33***	41.9	12.32***	76.3	1.63*	76.1
Distance from vine row (B)	48.85***		20.05***		38.21***		114.05***	
Soil layer (C)	27.07***		13.54***		22.72***		37.44***	
Block effect	2.14 ns		1.68 ns		2.10 ns		0.44 ns	
A x B interaction	20.50***		17.72***		8.40***		5.46***	
A x C interaction	1.61*		0.92*		3.69***		1.46*	
B x C interaction	3.30**		1.46*		2.32**		12.99***	
A x B x C interaction	3.17***		2.55***		2.97***		1.46*	

[a]Roots were counted on the vertical profiles of pits dug at three distances from the vine row and at four soil depths.
[b]*, **, ***, and ns indicate significance at $p \leq 0.05$, 0.01, 0.001, and not significant, respectively.

Table 2 Vine root number counted in different diameter classes at three distances from the vine row, under different systems of soil management.

Distance from vine row	Soil management[b]	Roots/m² on vertical faces[a]				Roots/m² on horizontal faces[b]			
		Total	Ø <1 mm	Ø 1–2 mm	Ø >2 mm	Total	Ø <1 mm	Ø 1–2 mm	Ø >2 mm
0.15 m	ST	266 a[c]	194 a	42 a	30 a	93 ab	73 a	10 a	10 a
	STI	237 ab	178 ab	29 ab	30 a	131 a	117 a	6 a	8 a
	HTI	200 abc	146 abc	30 ab	24 a	72 ab	57 a	10 a	5 a
	HT	152 c	112 c	18 b	22 a	63 b	50 a	6 a	7 a
0.8 m	ST	199 hi	158 hi	32 h	9 hi	—	—	—	—
	STI	140 hi	123 hi	13 i	4 i	—	—	—	—
	HTI	211 h	167 h	28 hi	16 h	—	—	—	—
	HT	131 i	101 i	14 hi	16 h	—	—	—	—
1.6 m	ST	64 y	62 y	1 y	1 x	86 x	84 x	0.5 x	0.5 x
	STI	56 y	55 y	0.5 y	0.5 x	55 x	54 x	0.5 x	0.5 x
	HTI	203 x	175 x	22 x	6 x	89 x	77 x	7 x	5 x
	HT	159 x	141 x	14 xy	4 x	69 x	42 x	4 x	3 x

[a]Roots counted on the whole surface of vertical pit faces (1.2 x 0.9 m) and counting horizontal faces were at 0.9 m depth.
[b]ST = sward treatment; HT = herbicide treatment; STI = interrow with sward treatment alternating with HTI = interrow with herbicide treatment.
[c]Means followed by the same letter do not differ significantly at $p \leq 0.05$ by Newman and Keuls test.

Total numbers of vine roots calculated in different treatments at three different distances from the vine row (0.15, 0.8, and 1.6 m) in four soil layers were compared and are shown as grapevine vertical root profiles (Figure 2). Generally, root density was higher in the upper soil layers (0 to 0.2 m and 0.2 to 0.45 m) than in the deeper soil layers, except at 1.6 m from the vine row (center of the interrow).

Under herbicide treatment (HT) in many soil layers (particularly in the top soil), there were fewer roots in pit profiles 0.15 m and 0.8 m from the vine row; but in the profile at 1.6 m, there were more roots than under the sward treatments (ST and STI).

In the sward treatments (STI and especially ST), upper soil layers gave the highest root numbers in the 0.15 m pit profile, but the lowest in the pit profile 1.6 m from the vine row. In the 1.6 m profile, root numbers increased slightly in depth, but decreased considerably in the 0.15 m and 0.8 m pit profiles, especially under the sward treatment (ST). In contrast, the STI treatment showed remarkable stability in root numbers in all pit profiles and considerable colonization.

In deeper horizons (0.45 to 0.65 m and 0.65 to 0.9 m), there were more roots in the 0.15 m and 0.8 m pit profiles than in the pit profile 1.6 m from the vine row (Figure 2). In the first three soil horizons of the 1.6 m pit profile, the root number was greater ($p < 0.001$) under the herbicide treatments (HT and HTI).

A negative exponential regression of vine root numbers in the 0 to 0.2 m and 0.2 to 0.45 m soil layers on grass root dry weight of grass and vine root numbers could be calculated (Figure 3), indicating a negative effect of grass roots on the number of vine roots in these layers.

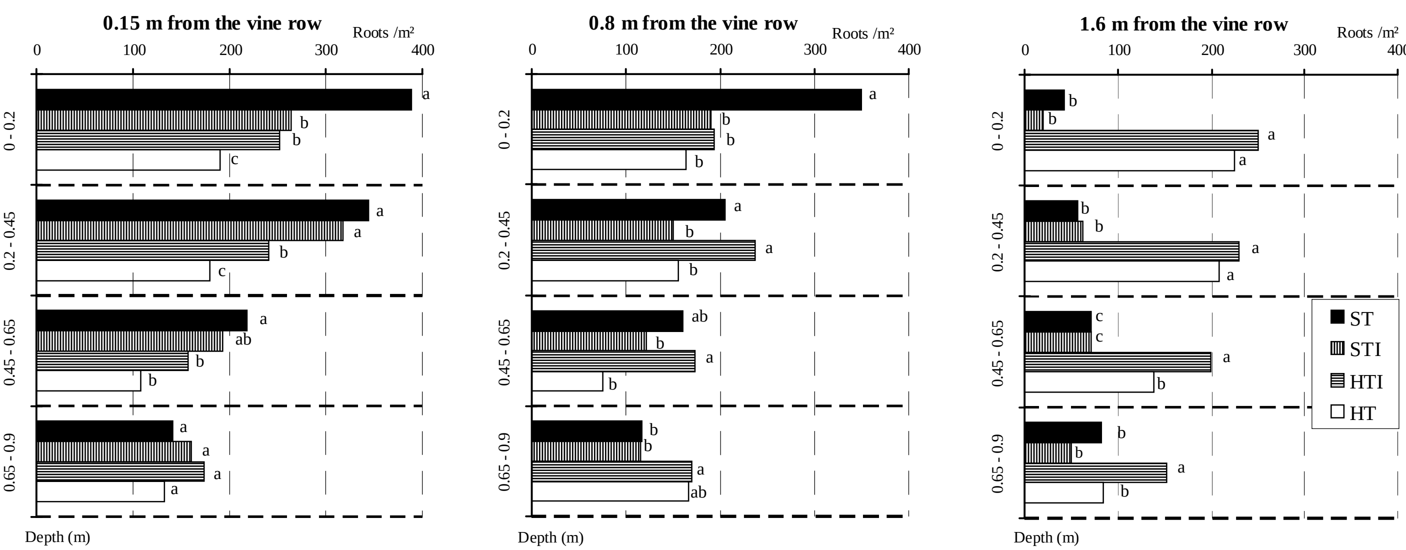

Figure 2 Mean total number of grapevine roots grown under four systems of soil management and counted into four different soil layers on three vertical pit faces up to a depth of 0.9 m. (In each of the soil layers, data were treated by single ANOVA; means followed by the same letter do not differ significantly at $p = 0.05$ by the Newman and Keuls test.) Systems of soil management: ST = sward treatment; HT = herbicide treatment; STI = interrow with sward treatment alternating with HTI = interrow with herbicide treatment.

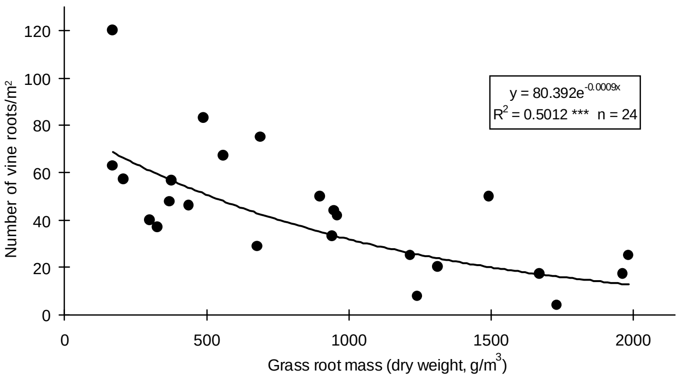

Figure 3 Regression of number of total vine roots/m² on grass root dry matter/m³, both measured in levels 0 to 0.2 m and 0.2 to 0.45 m.

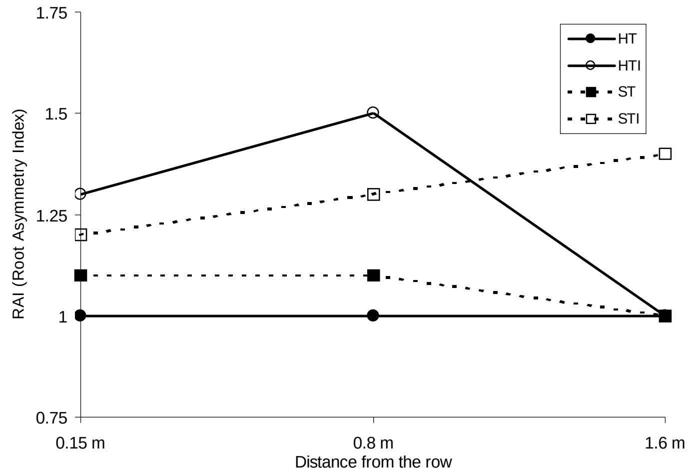

Figure 4 Root asymmetry index (RAI) calculated for total root numbers in the vertical faces of pits dug in interrows in east and west positions for grapevines grown under four systems of soil management: ST = sward treatment; HT = herbicide treatment; STI = interrow with sward treatment alternating with HTI = interrow with herbicide treatment).

The root asymmetry index (RAI) was calculated for total root numbers. In the vertical pit profiles, RAI values were equal to 1 (Figure 4) under herbicide treatment HT, and slightly greater (1.1) in sward treatment ST, mainly in the profiles situated 0.15 and 0.8 m from the vine row. In the HTI treatment, RAI greatly increased (1.3 and 1.5, respectively in the pit profiles 0.15 and 0.8 m from the vine row), whereas it reached the HT and ST values in the profile 1.6 m from the vine row. Under the STI treatment, RAI was also higher and increased between the vertical profile 0.15 m from the vine row and the profile 1.6 m away from 1.2 to 1.4. In the horizontal pit profiles (0.15 and 1.6 m from the vine row), the RAI was generally above 1.4, without any significant differences due to soil treatments.

Influence of soil management practices on soil physical and chemical properties. Because treatment effects were observed predominantly in the topsoil, only results for samples taken from the 0 to 0.2 m and 0.2 to 0.45 m soil layers at the center of the interrow (1.6 m from the vine row) are presented here. The organic matter content of the upper soil layer (0 to 0.2 m) was significantly higher in the sward treatments (13.2 to 14.3 g/kg) than under chemical weeding (9.6 to 9.8 g/kg), but there was no difference in the lower zone (0.2 to 0.45 m) (Table 3). Only in the 0 to 0.2 m layer was the amount of nitrogen significantly greater (0.77 to 0.89 g/kg) in grass soils than in weed-free soils (0.62 to 0.64 g/kg). The C/N ratio of the topsoil (0 to 0.45 m) was the highest in the ST treatment. Soil pH values were significantly greater in the sward treatments than in the herbicide treatments, in both upper soil layers (Table 3). Available phosphorus content was low and similar in all treatments. Amount of exchangeable potassium was significantly greater in soil with grass cover than in weed-free soil, in both soil layers (Table 3). Treatments did not affect the quantity of exchangeable magnesium, which was high in both soil layers (0.26 to 0.36 g/kg).

In upper soil layers, clay and silt contents were similar in all treatments (Table 3). Soil moisture at field capacity was sig-

Table 3 Effect of soil management on chemical and physical characteristics of soil measured at varying depths in the interrow, 1.6 m from the vine row.

	Soil layer depth 0–0.2 m				Soil layer depth 0.2–0.45 m			
	ST[a]	STI	HTI	HT	ST	STI	HTI	HT
Organic matter (g/kg)	13.2±0.12 a[b]	14.3±0.27 a	9.8±0.12 b	9.6±0.11 b	10.1±0.07 a	10.2±0.09 a	9.3±0.10 a	8.7±0.13 a
Kjeldahl nitrogen (g/kg)	0.77±0.11 b	0.89±0.11 a	0.64±0.06 c	0.62±0.06 c	0.61±0.06 a	0.65±0.06 a	0.62±0.07 a	0.58±0.04 a
C/N ratio	10.0±0.75 a	9.3±0.56 b	8.9±0.37 b	9.0±0.30 b	9.7±0.99 a	9.1±0.24 b	8.8±0.53 b	8.6±0.65 b
pH (soil/water ratio = 1:2.5)	6.78±0.13 a	6.77±0.10 a	6.48±0.13 b	6.43±0.21 b	6.87±0.10 a	6.77±0.10 a	6.33±0.08 b	6.47±0.26 b
Available P_2O_5 (g/kg)	0.09±0.02 a	0.08±0.03 a	0.08±0.04 a	0.07±0.03 a	0.07±0.02 a	0.08±0.05 a	0.06±0.02 a	0.05±0.04 a
Exchangeable K_2O (g/kg)	0.30±0.08 a	0.36±0.12 a	0.20±0.04 b	0.22±0.06 b	0.20±0.04 a	0.24±0.06 a	0.14±0.02 b	0.15±0.02 b
Exchangeable MgO (g/kg)	0.31±0.03 a	0.36±0.07 a	0.30±0.04 a	0.31±0.05 a	0.26±0.04 a	0.29±0.06 a	0.27±0.06 a	0.31±0.08 a
Clay (g/kg)	170±26 a	193±29 a	178±36 a	186±21 a	176±26 a	195±31 a	195±51 a	218±41 a
Silt (g/kg)	603±10 a	586±20 a	600±11 a	603±12 a	601±13 a	596±15 a	586±20 a	576±21 a
Soil moisture at field capacity (g/kg)	199±8.1 a	203±11 a	179±16.1 b	156±17.7 c	188±10.3 a	197±16 a	180±15 b	168±13 c
Bulk density (g/cm³)	1.41±0.04 a	1.44±0.13 a	1.75±0.08 b	1.76±0.05 b	1.52±0.10 a	1.53±0.10 a	1.58±0.13 a	1.61±0.09 a
Soil strength (kPa x 10²)	16.2±4.7 a	17.3±2.9 a	20.0±2.9 b	26.6±2.7 c	16.4±2.8 a	18.1±3.8 a	19.9±3.2 b	26.1±2.0 c

[a]Systems of soil management compared: ST = sward treatment; HT = herbicide treatment; STI = interrow with sward treatment alternating with HTI = interrow with herbicide treatment.
[b]Means followed by the same letter do not differ significantly at p =0.05, by the Newman and Keuls test.

nificantly greater under the sward treatments than under the herbicide treatments, in both soil layers (Table 3). Only in the 0 to 0.2 m soil layer was the bulk density significantly less under the sward treatments (1.41 to 1.44 g/cm^3) than under the herbicide treatments (1.75 to 1.76 g/cm^3). In both upper soil layers, soil strength decreased significantly under the sward treatments, and values measured in the HT treatment were the highest (26.1 to 26.6 kPa x 10^2).

Discussion

These results show that soil management practices greatly influence the grapevine root system. Rooting is better distributed, vertically and horizontally, in treatments with herbicide application (HT and HTI), where all the subterranean space seems to be colonized. Generally, permanent grass cover (ST and STI treatments) induces considerable decrease in total root numbers in most soil layers at the center of the interrow (Figure 2), as shown by Van Huyssteen [24] in grapevine and Parker and Meyer [20] in peach trees. Vine roots are also much more abundant in the weed-free soil under the row (in the 0.15 m pit profile), especially with the sward treatments. The alternation of a sward interrow (STI) with a weed-free one (HTI) leads to an increase in HTI root numbers, in upper soil layers under the vine row (in the 0.15 m pit profile) and also in deeper layers at the center of the interrow (in the 1.6 m pit profile), relative to the HT treatment (Figure 2). The subterranean competition between grass and vine determines a deeper vine-rooting pattern under the row (pit profile 0.15 m from the row), particularly for the STI treatment (Table 2), but drastically reduces the lateral expansion of the vine root system at the center of the interrow. Therefore, sward treatments are responsible for uneven root colonization in the soil that is the highest for grapevine rooting grown under treatments with alternating STI and HTI interrows.

Regarding the subterranean competition between grass and vine, soil water availability is probably the most important factor in explaining vine root colonization of different soil layers at several distances from the row. The climate in Anjou, as in most Loire Valley vineyards, results in a water deficit during vegetative and ripening periods. At the site, rainfall from budbreak to the harvest period (April to September) averaged 278 mm and evapotranspiration 553 mm, with a climatic water deficit of 275 mm. Thus, soil volume availability and colonization by roots greatly influence vine water supply. Because the growth of grass begins early in the spring, soil moisture content quickly decreases in the topsoil and becomes unfavorable to vine root development as shown for grapevines [12] and for peaches [8]. Part of the vine water supply is made available by deep roots [21] that are more abundant under the row in grass treatments. Morlat [17] also showed that during the summer period water extraction by vine is greater in the sward treatments under the row.

Root proliferation in the topsoil is dependent on available nitrogen [22] and phosphorus levels. Moreover, P uptake can be severely limited when the soil moisture content approaches the wilting point [11]. These conditions usually occurred at the experimental site in August, before veraison stage, under sward treatments in upper soil layers where the phosphorus level is low and soil moisture can reach the wilting point [17].

In conditions of our trial, from 1980 to 1994, sward treatment ST compared to herbicide control HT had significant effects on vine performance: vigor, yield, and grape composition [15]. In ST treatment, the pruning weight was 25%. The leaf area of lateral shoots was highly reduced on ST vines (45%), but the primary leaf area of vines was less affected by ST treatment (22% reduction). ST vines yielded 15% less grapes than HT vines. Sugar, anthocyanin, and tannin contents of berries were higher in ST treatment than in grapes of HT treatment. In years with a rainy ripening period (1987 for example), ST treatment induced a considerable decrease in number of grapes infected by *Botrytis cinerea.* Previously mentioned effects of the ST treatment were due to the competition between grass rooting and vine root system, which had a strong influence on water supply and nutrient uptake (particularly on nitrogen) of vine. Diurnal leaf water potential measured in different climatic years during the veraison period did not exhibit differences between ST and HT vines. In addition, leaf photosynthetic rate during veraison was the same in different treatments. The limitation of aboveground biomass of plant (particularly leaf area of lateral shoots) can be an adaptation mechanism of the vine to a reduced water supply. Consequently, the total water loss by vine was lower in ST treatment while the leaf photosynthetic rate was not reduced. As well, the microclimate (temperature and sun exposure) was improved in ST vines. Thus, the berry composition was better in ST treatment; another reason could be that more photosynthates were transferred to the berry due to reduction of vegetative growth [26].

The practice of permanent grass cover significantly modifies several properties of upper soil layers. The organic matter content is increased [18,27] by the decomposition of decaying grass parts every year. Consequently, the nitrogen content increases, as well as the pH and exchangeable K_2O. Nitrogen uptake of grapevine in the top soil is reduced by grass root competition [7,13], and, in sward vineyards, several studies reported low N levels in the musts that are sometimes insufficient to ensure good yeast activity, thereby affecting alcoholic fermentation [4,10]. Grass roots may also contribute to the recycling of deep horizon cations, through aboveground grass decay. The improvement in physical properties of sward soils could be partly explained by the beneficial effects of organic matter and pH on soil structure [14]. Lastly, soil porosity might be improved by grass roots.

One issue may be the way in which mineral fertilization, especially nitrogen, is applied in sward vineyards. While sward increases organic N content in upper soil layers of the interrow, nitrogen uptake by vine is reduced by fewer roots and less water. It would be interesting to experiment with fertilizer placement under the row, where the vine roots are the most abundant, without grass root competition. Nitrogenous foliar application could also be envisaged.

Conclusions

Soil management practices influence the grapevine root system and soil characteristics. Comparison of grass and herbicide treatments shows that, under permanent grass cover, there is a considerable decrease in the number of vine roots in the interrow, mainly in the upper soil layers, but an increase close to the row. Rooting is better distributed, vertically and horizontally, in treatments with herbicide. In the row, the number of roots counted in horizontal profiles 0.9 m deep (deep roots) is slightly greater in the sward treatments. The amount of organic matter, nitrogen, exchangeable K_2O, pH, and soil moisture at field capacity increase under permanent grass cover, while bulk density and mechanical resistance of the soil decrease. In the interrow, the improvement in the physical and chemical properties of soil through permanent grass cover does not directly benefit the grapevine root system, which is greatly reduced in the topsoil by the competition phenomenon.

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