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The soil effects on the grapevine root system in several vineyards of the Loire valley (France)

by

R. MORLAT and A. JACQUET

INRA, Unité de Recherches sur la Vigne et le Vin, Angers, Beaucouzé, France

Summary: The effects of different soil types on grapevine root distribution are presented and discussed for Loire Valley (France) conditions. Field studies with Cabernet franc/SO 4 rootstock vines showed four main rooting patterns in different soil types. A statistical analysis was used to determine the influence of several physical soil factors on root distribution. The soil water supply appears to have a beneficial effect on the root system. Conversely the penetrometer soil strength, bulk density and hydromorphic conditions are unfavourable for root development.

Key words: Root distribution, soil type, soil effect, soil water capacity, penetrometer soil strength, SO 4 rootstock, Vitis vinifera cv. Cabernet franc.

Introduction

The work we have been pursuing for several years aims at studying the effects of diverse soils on chemical and sensorial characteristics of wines rather than bringing agronomical explanations to account for the observed differences. In this context, the root system appears as the main interface between grapevine and the underground components (soil and rock). This less understood part of the plant is subjected to a number of constraints below the soil surface. Roots perform a number of physiological functions (supply of water, absorption of minerals, synthesis of organic elements for growth, carbohydrates storage), and as well, their growth requires a great amount of energy given by the shoots.

Considering its relevance, few research workers have, directly or indirectly, studied the influence of the soil on the grapevine rooting system (BRANAS and VERGNES 1957; SEGUIN 1972; WAKABAYASHI *et al.* 1974; MORLAT *et al.* 1981; GARCIA DE LUJAN and GIL MONREAL 1982; VAN HUYSSTEEN 1988; MORLAT 1989).

The object of this communication is to present results of a study carried out to investigate the influence of soil factors on the distribution of grapevine roots.

Materials and methods

Locations: 15 experimental plots (each identified by a code) in the main soils of Chinon, Bourgueil and Saumur Champigny vineyards. This region is characterized by low rainfall (600 mm/year) and an average annual temperature near 11.5 °C. 100 about 12-year-old Cabernet franc/SO 4 vines per plot were grown on trained rows according to the traditional training system (single foliar plane, Guyot pruning system with 35 000 buds per ha, spacing constant at 2 m x 1 m; height of foliage was 1 m), rows were oriented north-south and weed growth controlled by herbicides. Nitrogen, phosphorous, potassium, magnesium were spread on the soil at the end of winter. The main constraints for studies in the vineyard are a strong spatial heterogeneity of root distribution, an important volumetric root expansion, a frequent asymmetry on either side of plant rows and a great variability in root diameter.

Correspondence to: Dr. R. MORLAT, INRA Angers, Unité de Recherches sur la Vigne et le Vin, B.P. 57, F-49070 Beaucouzé, France

Profile wall method: After measuring the circumference of scions and rootstocks, we selected 6 vines in each plot. Measurements of these trunks represented as near average conditions as possible and were distributed on 4 rows. One half of a vine root system was studied by digging a trench between the rows; the walls were used as numbering planes. Three trenches were dug on the right side of the vine row and 3 others on the left to take into account the asymmetry of lateral rooting. The roots were counted on 2 vertical planes (1 m length). The first plane was situated at 20 cm from the vine trunk (row plane) and the second in the middle between rows (1 m away, inter-row plane). Living roots only were numbered in soil layers of variable thickness corresponding to pedological layers. They were distinguished from dead roots by cutting. Additional information on deep rooting was accomplished by counting roots penetrating 2 horizontal planes situated at the bottom of the trenches (about 1 m depth): one plane located 20 cm away from vine rows and the other in the row middle.

The roots were divided into three categories: (1) diameter < 1 mm roots having absorbing root hairs, little suberization and characterized by a quick cycle of renewal; used mainly in water and nutrient uptake of the vine and the synthesis of organic substances; (2) from 1 to 2 mm, more suberized and with slower renewal; (3) over 2 mm (main roots, very suberized and functioning mainly to anchor the plant and to transport and store nutrients). Similar categorization of roots was made by WAKABAYASHI *et al.* 1974; SOUTHEY and ARCHER 1988; VAN ZYL 1988.

Results are epxressed as number of root interceptions per m^2. Root development profiles are presented in 4 successive layers and deep roots. The studies were made in February—March 1984 and 1985 before the start of vegetative growth. The data were treated by variance analysis with one or more criteria after logarithmic transformations of gross values if the required conditions (homogeneity of variances, normal distribution of data) were not met.

Measurements: Separation between coarse elements (diameter > 2 mm) and fine soil (< 2 mm) - Granular composition including 8 fractions without decarbonatation - Organic matter and pH (water) - Soil bulk density by a gammametric probe (Campbell Model 501) - Penetrometer soil strength with a cone penetrometer in the field - Soil moisture characteristics determinations on samples sieved at 2 mm for 0.32 and 1 bar suction (extraction with ceramic plates) and 16 bars suction (with a membrane extractor).

Soil types: Thin chalky sandy-clayey soils on glauconeous chalk (1DAM); thick calcic clayey-sandy soils on micaceous chalk (1POY, 1BOI); colluvial sandy neutral soils resting on glauconeous sandy clays (1ING); thick colluvial calcic muddy-sandy soils covering sandy clays (1GAR); thick colluvial acid sandy soils on thick glauconeous clayey sands (2ING); neutral soils with thick upper sandy colluvial horizons on sandy clays (3EL); neutral soils with low thickness upper sandy layers on sandy clays (2EL); neutral hydromorphic soils with leaching of colloids, with thick sandy-clayey layers on clay (4EL); acid and hydromorphic soils with leaching of colloids, very stony, with silt in surface and clayey-silty in depth (1VAU); neutral soils with leaching of colloids and thick sandy clayey layers resting on clay (1PER); acid and hydromorphic soils with leaching of colloids, stony, silty-sandy on the surface and clayed and heavy in depth on clay with pudding-stones (1ROC); neutral to alkaline stony soils, with thick sandy to sandy-clayey horizons on grit and pudding stones (1CHA); neutral to medium acid and very gravelly soils, located on a sandy-gravelly alluvial terrace of the river Loire (1FON); neutral to alkaline soils with thick silty-sandy-clayey on the surface and clayey-silty in depth on wind-carried silts (1TUR).

Results and discussion

Variance analysis: The root data were subjected to variance analysis to observe the effects of the planes (row or inter-row), soil type, horizon type and their interactions. Analysis was performed on the total number of roots of different diameter (Tab. 1). In the case of roots numbered vertically, the influence of the numbering plane is significant on roots with a diameter >2 mm. They are less numerous in the middle between two rows in the soils corresponding to 2ING, 1ING, 4EL, 1ROC and 1FON (Tab. 2). This result could be explained by the diverse effects of their physical constraints (Morlat 1989). With the deep roots, a numbering plane effect was observed for the class <1 mm (Tab. 1). Their number decreased significantly in the inter-rows in 2ING, 1ING, 1PER, 3EL and 1ROC (Tab. 2).

Table 1

Results of variance analysis on roots of different diameter.

NUMBERING PLANE	VERTICAL PLANES		HORIZONTAL PLANES (Deep Roots)	
ROOT DIAMETER CLASSES	**STUDIED FACTOR**	**F SNEDECOR**	**STUDIED FACTOR**	**F SNEDECOR**
ALL DIAMETER MINGLED	Numbering Plane	0,00		
	Plot (Soil Type)	20,98***	Numbering Plane	0,12
	Horizon	35,52***	Plot (Soil Type)	6,89**
	Plane x Plot	0,89	Plane x Plot	0,92
	Horizon x Plot	3,15*		
UNDER 1 mm DIAMETER	Numbering Plane	1,33		
	Plot (Soil Type)	20,58***	Numbering Plane	129,0***
	Horizon	24,53***	Plot (Soil Type)	8,22**
	Plane x Plot	0,83	Plane x Plot	4,92
	Horizon x Plot	2,90*		
1-2 mm DIAMETER	Numbering Plane	1,74		
	Plot (Soil Type)	5,71***	Numbering Plane	0,00
	Horizon	29,00***	Plot (Soil Type)	3,93**
	Plane x Plot	1,96	Plane x Plot	1,13
	Horizon x Plot	3,08*		
OVER 2 mm DIAMETER	Numbering Plane	17,74***		
	Plot (Soil Type)	23,17***	Numbering Plane	0,91
	Horizon	49,79***	Plot (Soil Type)	5,32**
	Plane x Plot	1,71	Plane x Plot	0,58
	Horizon x Plot	3,42*		

* Significant at P level <5% ;** P <1% ;*** P <1‰

The interaction between plane and soil type is almost never significant and consequently will not be commented upon. The effect of the soil type is highly significant and shows the importance of edaphic conditions for the growth of vine roots. It will be discussed later for the most typical cases. The influence of the horizon is equally clear and shows a poor homogenous, vertical distribution of roots. Usually the 2nd or 3rd horizon contained the maximum number of roots. This result agrees with the observations of others (Branas and Vergnes 1957; Hidalgo and Candela 1969; van Zyl and Weber 1981; Garcia de Lujan and Gil Monreal 1982). The interaction of horizon and soil type, which is always highly significant, suggests that the soil layers in which roots are concentrated can vary from one soil to another. We will be able to distinguish these differences in the next section on root profiles, in four typical soil types.

Table 2

Average number of roots/m² counted on vertical and horizontal planes in different soils.

NUMBERING PLANE	VERTICAL PLANE														
EXPERIMENTAL PLOTS	1DAM	1BOI	1POY	2EL	1GAR	2ING	3EL	1ING	1TUR	1VAU	1PER	4EL	1ROC	1CHA	1FON
INTER-ROW PLANE ALL Ø	154	235	326	127	84	71	171	65	145	157	146	103	140	156	120
Variation Coefficient	0.44	0.43	0.31	0.24	0.25	0.18	0.35	0.31	0.18	0.10	0.60	0.17	0.33	0.32	0.25
ROW PLANE ALL Ø	176	198	346	122	94	126	132	76	120	181	170	84	139	140	98
Variation Coefficient	0.43	0.14	0.11	0.35	0.35	0.29	0.23	0.27	0.19	0.14	0.36	0.34	0.22	0.23	0.74
INTER-ROW PLANE Ø <1mm	126	162	261	100	67	53	121	53	113	128	114	88	129	93	102
Variation Coefficient	0.49	0.29	0.37	0.25	0.35	0.14	0.34	0.27	0.21	0.13	0.66	0.19	0.30	0.21	0.23
ROW PLANE Ø <1mm	135	155	272	92	63	90	86	50	87	144	121	60	97	79	73
Variation Coefficient	0.47	0.25	0.13	0.35	0.52	0.18	0.24	0.40	0.27	0.16	0.39	0.30	0.29	0.40	0.85
INTER-ROW PLANE Ø 1-2mm	12	54	28	15	7	10	29	7	13	15	19	9	8	47	10
Variation Coefficient	0.23	1.02	0.43	0.49	0.48	0.72	0.67	0.64	0.34	0.37	0.47	0.31	1.18	0.67	0.59
ROW PLANE Ø 1-2mm	22	26	34	15	15	25	26	15	15	22	29	15	15	25	26
Variation Coefficient	0.34	0.56	0.27	0.60	0.40	0.79	0.27	0.49	0.20	0.28	0.29	0.68	0.25	0.34	0.86
INTER-ROW PLANE Ø >2mm	16	20	37	12	11	6	20	4	19	13	13	6	3	20	7
Variation Coefficient	0.41	0.13	0.28	0.32	0.35	0.69	0.30	0.74	0.14	0.44	0.46	0.45	0.65	0.48	0.43
ROW PLANE Ø >2mm	19	17	40	15	15	12	15	11	18	15	19	13	13	29	12
Variation Coefficient	0.43	0.25	0.16	0.25	0.34	0.30	0.44	0.21	0.29	0.18	0.42	0.46	0.40	0.34	0.50
NUMBERING PLANE	HORIZONTAL PLANE (Deep Roots)														
EXPERIMENTAL PLOTS	1DAM	1BOI	1POY	2EL	1GAR	2ING	3EL	1ING	1TUR	1VAU	1PER	4EL	1ROC	1CHA	1FON
INTER-ROW PLANE ALL Ø	81	93	127	95	165	119	7	21	99	12	53	63	8	69	9
Variation Coefficient	0.54	1.09	0.45	0.60	0.59	0.67	1.62	1.39	0.61	0.35	0.46	0.41	0.58	0.58	1.38
ROW PLANE ALL Ø	84	49	126	83	88	151	16	50	58	26	82	83	20	53	10
Variation Coefficient	0.80	1.00	0.24	0.62	0.30	1.13	0.97	0.83	0.74	1.01	0.21	0.86	0.42	0.52	1.13
INTER-ROW PLANE Ø <1mm	65	73	107	55	105	93	0	14	58	8	38	31	9	34	5
Variation Coefficient	0.62	1.03	0.52	1.00	0.72	0.77	--------	1.48	0.52	0.72	0.51	1.09	0.58	0.80	2.12
ROW PLANE Ø <1mm	66	39	109	57	48	131	11	32	32	13	60	49	17	16	7
Variation Coefficient	0.81	0.89	0.16	0.52	0.56	0.77	1.30	0.91	0.75	1.45	0.33	1.20	0.49	1.12	1.40
INTER-ROW PLANE Ø 1-2mm	15	13	10	14	30	15	3	8	22	0	6	11	0	22	3
Variation Coefficient	0.33	1.30	0.31	0.95	0.98	0.78	1.39	1.20	0.82	--------	1.16	0.43	--------	0.45	0.93
ROW PLANE Ø 1-2mm	13	3	15	13	12	26	0	14	16	7	11	16	4	21	0
Variation Coefficient	0.91	1.86	0.61	1.34	0.58	1.00	--------	1.17	1.12	1.17	0.91	0.76	0.90	0.49	--------
INTER-ROW PLANE Ø >2mm	9	8	10	24	29	11	2	4	19	2	9	22	0	12	2
Variation Coefficient	1.50	1.62	1.39	0.36	0.50	0.80	1.86	1.39	0.97	1.16	0.52	0.74	--------	0.42	1.16
ROW PLANE Ø >2mm	12	8	17	19	28	19	6	4	11	7	12	18	0	17	3
Variation Coefficient	1.21	1.92	0.52	0.74	0.23	2.06	1.16	1.39	0.83	1.30	0.93	0.42	--------	0.43	0.93

Ø = Root Diameter

Characteristic root profiles: They were examined by evaluating the average number of roots per m² in the soil horizons obtained on the row and inter-row numbering planes. They illustrate the vertical root distribution. We also calculated the number of deep roots in the same way. In order to be as clear and exhaustive as possible after previous analysis we will only present the results obtained on the mingled diameter classes. The roots < 1 mm diameter constituted about 80 % of total amount of roots.

We selected four cases which enabled us to represent the main types of root profiles studied.

Case of chalky soils on glauconeous and micaceous chalk of middle Turonian (1DAM *example*): This root profile (Figure) was characterized by a large number of roots and a slow decrease with the depth. Maximum number of roots was in the first horizon. The deep roots were numerous. Our observations indicate that roots can penetrate the friable chalk through a considerable thickness at several meters. The good physical properties (Tab. 3) of different soil horizons explained this type of root profile. In these conditions, vine nutrition is favorable in the upper horizons with the lower chalk contributing much to the overall water supply.

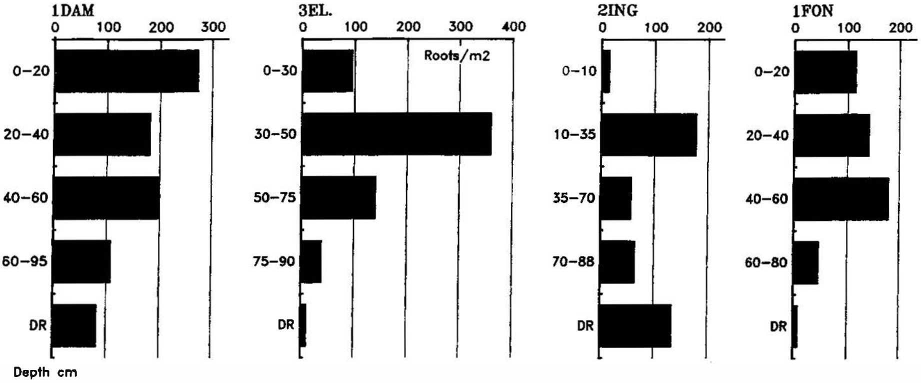

Figure: Average root profiles in main soil types (row and inter-row, every diameter). DR = deep roots.

Case of thick sandy soils, with complex profiles on clayey sands of the Senonian (3EL *example*): For this case rooting is quite different, as maximum development is observed in the second horizon (Figure). In the first horizon, root growth is minimal because of a very sandy texture and a low level of organic matter (Tab. 3) which cause too rapid drying. An important decrease of the root number is observed in the third and fourth layers, and could be explained by the same mechanism. The very numerous roots, established in the second horizon, dry up indirectly these middle layers by capillary phenomenon and cause also an increase of penetrometer soil strength. These factors are not favorable on root elongation (TAYLOR and GARDNER 1963; MAERTENS 1964; DAVIDSON and HAMMOND 1977; THOMPSON *et al.* 1987). The deep roots are very few in number and have not a major role on mineral and water supply of vine.

Case of sandy, acid, colluvial soils on clayey sands and glauconeous clays of upper Turonian (2ING *example*): Roots are fewer in number in this profile than in the previously mentioned soils (Figure). The first level had the number lowest because of early drying of a very limited water supply (Tab. 3). At first zone of root development was observed in the second horizon. But the root density was noticeably lower than in 3EL, because of strong acidity and high quantity of easily reductable manganese, which create unfavorable conditions for rooting (BLUE and DANTZMAN 1977; CONRADIE 1988). In the middle horizons (3 and 4) the root number was limited, but they did not show the sharp decline observed in 3EL. The indirect drying, mentioned for 3EL, seems to be less important, as a result of a lower quantity of roots in the second horizon. This enables a great number of deep roots, as a second zone of root development, to exploit the clayey sands which constitute a more favorable surrounding.

Case of gravelly soils on the Loire terraces (1FON *example*): The soil was moderately exploited down to 70 cm. It was one of the less developed root systems. Roots

Table 3

Main analytical results of soil profiles studied.

ANALYTICAL DETERMINATIONS	Stones and Gravels %	Fine Soil %	Clay % *	Silt % *	Sand % *	Organic Matter % *	Ca Co$_3$ % *	pH (water)	Bulk Density g / cm^3	Total Porosity %	Soil Strength kPa x 10^2	Water Capacity mm
1DAM Ap11** 0-20 cm	7,0	93,0	18,7	18,7	62,6	1,43	18,6	8,0	1,5	39,5	11,2	19,9
1DAM Ap12 20-40 cm	5,0	95,0	19,5	17,0	63,5	1,24	17,1	8,0	1,5	43,7	17,9	17,1
1DAM A/C 40-60 cm	2,8	97,2	23,8	20,0	56,2	------	40,6	8,3	1,4	48,3	17,0	17,1
1DAM Cca 60-95 cm	3,0	97,0	15,6	22,5	61,9	------	59,8	8,4	1,4	45,4	23,2	74,6
1DAM R >95 cm	2,0	98,0	15,8	20,3	63,9	------	67,0	8,5	1,4	47,1	-----	------
3EL Ap11 0-30 cm	1,0	99,0	4,0	8,6	87,4	0,77	------	7,8	1,35	46,7	0,9	13,5
3EL Ap12 30-50 cm	0,0	100,0	3,2	9,0	87,8	0,28	------	7,6	1,4	45,5	0,9	5,7
3EL A3 50-75 cm	0,5	99,5	3,6	12,1	84,3	------	------	7,5	1,5	40,9	2,0	12,4
3EL B 75-90 cm	1,0	99,0	5,0	15,8	79,2	------	------	7,7	1,65	34,5	2,0	10,7
3EL IIBt 90-145 cm	1,5	98,5	20,3	14,6	65,1	------	------	7,3	1,7	33,0	14,1	39,8
2ING Ap11 0-10 cm	0,0	100,0	2,8	6,2	91,0	0,77	------	6,3	1,4	46,0	0,6	1,6
2ING Ap12 10-35 cm	0,0	100,0	3,3	7,5	89,2	0,55	------	4,7	1,5	41,4	1,0	8,9
2ING A3/B 35-70 cm	0,0	100,0	3,4	5,7	90,9	------	------	5,6	1,6	41,1	0,9	16,9
2ING B 70-88 cm	0,0	100,0	3,4	9,9	86,7	------	------	6,6	1,7	35,8	1,1	8,5
2ING IIBg 88- 105 cm	0,0	100,0	17,8	14,5	67,7	------	------	5,3	1,7	33,0	12,3	20,5
1FON Ap11 0-20 cm	31,0	69,0	3,2	8,8	88,0	0,70	------	7,4	1,7	34,8	------	13,4
1FON Ap12 20-40 cm	31,0	69,0	3,7	9,1	87,2	0,25	------	5,9	1,7	34,5	------	13,4
1FON B 40-60 cm	36,0	64,0	4,1	11,2	84,7	------	------	6,6	1,7	35,2	------	14,5
1FON C1 60-80 cm	42,0	58,0	2,4	3,7	93,9	------	------	5,8	1,7	33,8	------	10,7
1FON C2 80-140 cm	40,0	60,0	1,7	2,8	95,5	------	------	6,3	1,8	33,4	------	37,4

* Results on fine soil dried at 105 °C. ** Horizon Type according to C.P.C.S (1967)

are not numerous (Figure) in the top horizon because of reduced water supply and a high bulk density (Tab. 3). We notice a more intense rooting in the third horizon. Lower in the gravelly parent material, the number drops considerably because of compaction and the very limited water retention. Deep roots are nearly nonexisting because of the previously mentioned physical constraints. Vine nutrition takes place exclusively in the first meter of the soil and will largely depend on the weather conditions of the year.

Influence of a few soil parameters on vine root system: In soil, a plant root system is subjected to the combined influences of several variables. Consequently, evaluating of each one by simple linear regression is difficult. We employed a method of progressive multiple regression which allows for the gradual introduction of different variables. Interpretation is difficult if the explanatory variables are strongly correlated. In this case there is some redundance between the variables. The correlation matrix was calculated with 12 variables selected in a first stage to explain fluctuations of the total numbered roots on vertical planes in each soil. Mathematical analysis showed 6 factors (Tab. 4) which give a multiple correlation coefficient with a 0.843 value and accounted for 71 % of the total variation. Among these factors, the available water supply had an important positive effect whereas the hydromorphy intensity, the penetrometer soil strength and the bulk density have a negative influence on vine rooting. Previous studies (Morlat *et al.* 1981) also show the unfavourable effect of the last two variables. To a lesser extent we also note the negative influence of textural differentiation of the profile whereas the clay percentage was favourable.

Table 4

Results of analysis by stepwise multiple regression. Analyzed variable: Total number of roots/m^2.

EXPLANATORY FACTOR	REGRESSION COEFFICIENT	F (1,8)	PROBABILITY %	r**2 partial	R**2	R multiple
Soil Water Capacity	20,258	6,914	2,94	0,464	0,711	0,843
Hydromorphy Intensity	-33,914	4,810	5,49	0,376		
Soil Strength	-3,238	2,785	13,12	0,258		
Bulk Density	-228,226	2,394	15,81	0,230		
Soil Textural Differenciation	-20,413	1,999	19,33	0,200		
Clay Percentage	2,371	1,562	24,60	0,163		

Conclusion

The results obtained strongly identify soil parameters that influence the quantity of existing vine roots (Cabernet franc/SO 4) as well as the vertical distribution of roots by horizons. We identified four main types of root profiles by contrasting soils. In several cases (Morlat 1989) they largely account for the behaviour of the vine (water supply conditions, root warming, vigour and yield). In some soils, a deep root system is important. It is interesting to notice that for the same rootstock (SO 4) the rooting pattern, often presented as the consequence of genetical characteristics, is closely tied to edaphic conditions.

The available water supply, hydromorphy intensity and penetrometer soil strength are the most explanatory variables for root density in the soil. We have also been able to show, generally, that a good correlation exists between the amount of roots on a vine-stock and the vigour of its aerial part.

Rooting is a vital part of the vine, difficult to study, but performing many physiological and biochemical functions. The yield and over all quality of grapes depend on a viable and healthy root system. It is necessary for the vine grower to use the most appropriate agronomic and viticultural techniques to obtain the most developed root system for existing soils.

References

BLUE, W. G.; DANTZMAN, C. L.; 1977: Soil chemistry and root development in acid soils. Soil and Crop Sci. Soc. Fla. Proc. **39**, 9—15.

BRANAS, J.; VERGNES, A.; 1957: Morphologie du système radiculaire. Progr. Agric. Vitic. (3—4), 92—104.

CONRADIE, W. J.; 1988: Effect of soil acidity on grapevine root growth and the role of roots as a source of nutrient reserves. Tech. Commun. Dep. Agricult. Water Supply Pretoria, Republic of South Africa (215), 16—29.

C.P.C.S.; 1967: Classification des Sols, E.N.S.A. Grignon. Pédologie. Ouvrage collectif. Document ronéoté.

DAVIDSON, J. M.; HAMMOND, L. C.; 1977: Soil physical aspects of root development. Soil Crop Sci. Soc. Fla. Proc. **36**, 1—4.

GARCIA DE LUJAN, A.; GIL MONREAL, M.; 1982: Sobre la distribución del sistema radicular de la vid. Ann. Inst. Nac. Invest Agrar., 35—67.

HIDALGO, L.; CANDELA, M. R.; 1969: Morfologia radicular de la vid. Inst. Nac. Invest. Agronom., Madrid, Spain.

MAERTENS, C.; 1964: La résistance mécanique des sols à la pénétration; ses facteurs et son influence sur l'enracinement. Ann. Agronom. **15**, 539—554.

MORLAT, R.; 1989: Le terroir viticole: contribution à l'étude de sa caractérisation et de son influence sur les vins. Application aux vignobles rouges de Moyenne Vallée de la Loire. Thèse Univ. de Bordeaux II, France.

— —; PUISSANT, A.; ASSELIN, C.; LEON, H.; REMOUE, M.; 1981: Quelques aspects de l'influence du milieu édaphique sur l'enracinement de la vigne. Conséquences sur la qualité. Sci. Sol. **2**, 125—145.

SEGUIN, G.; 1972: Répartition dans l'espace du système radiculaire de la vigne. C.R. Acad. Sci. **274**, 2178—2180.

SOUTHEY, J. M.; ARCHER, E.; 1988: The effect of rootstock cultivar on grapevine root distribution. Tech. Commun. Dep. Agricult. Water Supply Pretoria, Republic of South Africa (215), 57—73.

TAYLOR, H. M.; GARDNER, H. R.; 1963: Penetration of cotton seedlings tap-roots and influenced by bulk density, moisture content and strength of soil. Soil Sci. **96**, 153—156.

THOMPSON, P. J.; JANSEN, I. J.; HOOKS, C. L.; 1987: Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. Soil Sci. Soc. Amer. J. **51**, 1288—1292.

VAN HUYSSTEEN, L.; 1988: Soil preparation and grapevine root distribution — A qualitative and quantitative assessment. Tech. Commun. Dep. Agricult. Water Supply Pretoria, Republic of South Africa (215), 1—15.

VAN ZYL, J. L.; 1988: Response of grapevine roots to soil water regimes and irrigation system. Tech. Commun. Dep. Agricult. Water Supply Pretoria, Republic of South Africa (215), 30—43.

— —; WEBER, H. W.; 1981: The effect of various supplementary irrigation treatments on plant and soil moisture relationships in a vineyard (*Vitis vinifera* var. Chenin blanc). S. Afr. J. Enol. Viticult. **2**, 83—99.

WAKABAYASHI, S.; ANDO, Y.; KIMURA, Y.; 1974: Studies on the root system of trees growing on the volcanic ash soil in North Kanto District. 2. Vertical root distribution of grapevine planted on particularly thick humic volcanic ash soil and some properties of the soil. Bull. Coll. Agricult. Utsunomiya Univ. **9** (1), 15—20.

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