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Grapevine roots: interaction with natural factors and agronomic practices

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Abstract

Selection of a suitable rootstock lays the foundation for meeting vineyard, grape and wine objectives. Tolerance to biotic and abiotic conditions is a determining factor. Despite the significance of the grapevine root system in vegetative and reproductive growth as well as grape and wine composition and quality, root behaviour under an array of very complex and integrated environmental impacting factors is largely unknown and research in this regard is surprisingly limited. In this paper, a compilation of some of the research done over many years on root system behaviour is presented. Various aspects of the interaction between the root system and the complex natural environment in which it grows as well as commonly known viticulture practices are discussed. Results obtained under controlled and field conditions are shown. Physical and chemical properties and pre-establishment preparation of the soil have defining effects on metabolic behaviour and spatial distribution (horizontally and vertically) of roots. Alleviation of soil impediments to root penetration provides the best possible basis for above-ground growth. The health status of plant material, genetic characteristics and grafting and nursery processes have a steering impact on the ability of the root system to perform within biotic and abiotic constraints of the soil environment to such an extent that expectations in terms of growth, yield and grape quality of the scion are met. Agronomic practices exert a further tailoring impact on root system performance and support to above-ground growth. The study of only above-ground factors is clearly not sufficient to explain vineyard behaviour. Intensified inter-disciplinary research efforts are required in our quest to understand scion-root system inter-relationships and to control scion behaviour in order to facilitate greater sustainability in grape and wine production.

Keywords: root system, environment, cultivation, rootstocks, scions, sustainability

INTRODUCTION

Judicious selection of a rootstock that is suitable to the environmental conditions in which the vineyard is to be established, lays the foundation for successful grape production according to the vineyard objectives (Southey and Archer, 1988; Van Zyl, 1988; Swanepoel and Southey, 1989; Southey, 1992; Morlat and Jacquet, 1993; Goma-Fortin et al., 2001).

Although a healthy phyto-sanitary status, physical and physiological quality of plant material, a sound grafting process, satisfactory growth in the nursery, and affinity of graft material are eminently important, tolerance of rootstocks to biotic and abiotic factors is a determining aspect in prolonging grapevine life (Schaefer, 1981; Bavaresco and Lovisolo, 2000; Gambetta et al., 2009; Hunter et al., 2013). Such factors include cultivation practices and would largely impact on physiological functioning of the grapevine and the final valorisation of the terroir (Hunter et al., 2010).

Despite the profound effect of the grapevine root system on vegetative and reproductive growth as well as grape and wine composition and quality (Van Zyl, 1988; Hunter and Le Roux, 1992; Southey, 1992), surprisingly little comprehensive work has been done on the quantitative and qualitative value of the root system in grapevine performance. In this paper, a compilation of some of the research that has been done on this subject is presented. It mostly considers the interaction of the root system/rootstock with natural factors and agronomic practices. The focus is on root growth performance under field conditions, mostly studied by using classic methods, such as total root system excavation and root profile wall analyses.

RESULTS AND DISCUSSION

Growth uniformity and longevity of vineyards are primarily dependent on the judiciousness by which plant material is selected, soil variation is accommodated and basic practices (e.g., planting techniques) are managed. The use of rootstocks to reduce the impact of biotic and abiotic restrictions of the soil environment on grapevine growth is a vital and natural solution to increase sustainability.

Rootstock selection

Although all rootstocks have shortcomings, they should specifically be selected according to their properties to buffer unfavourable (biotic and abiotic) environmental conditions. Some properties of selected rootstocks that have surfaced over years of investigation are listed in Table 1 (Southey, 1992). Since the scarceness of water for agricultural use is a serious constraint for sustainability, drought tolerance is becoming an increasingly important rootstock property.

Table 1. Rootstock properties under South African conditions (scion: 'Chenin blanc') (Southey, 1992).

Rootstock	Affinity	Vigour	Phylloxera	Nematodes	Phytophthora	Lime	Salinity	Wetness	Drought
99 Richter (*V. berlandieri* × *V. rupestris*)	A	A	1	2	4	B	B	C	B
110 Richter (*V. berlandieri* × *V. rupestris*)	A	A	1	2	3	B	B	B	A
101-14 Mgt (*V. riparia* × *V. rupestris*)	C	B	2	2	2	D	A	A	C
420-A Mgt (*V. berlandieri* × *V. riparia*)	B	B	3	3	2	D	D	C	B
143-B Mgt (*V. vinifera* × *V. riparia*)	B	A	2	2	1	C	B	A	B
Jacquez (*V. aestivalis* × *V. cinerea* × *V. vinifera*)	A	B	4	4	1	B	C	B	C
775 Paulsen (*V. berlandieri* × *V. rupestris*)	C	A	1	2	1	B	B	B	A
1045 Paulsen (*V. berlandieri* × *V. rupestris*)	C	B	1	2	2	B	B	B	B
1103 Paulsen (*V. berlandieri* × *V. rupestris*)	A	A	1	2	4	B	C	B	A
3306 Couderc (*V. riparia* × *V. rupestris*)	C	B	2	3	4	B	D	B	C
3309 Couderc (*V. riparia* × *V. rupestris*)	B	B	1	2	3	B	D	C	D
140 Ruggeri (*V. berlandieri* × *V. rupestris*)	A	A	2	3	3	A	B	C	A
SO4 (*V. berlandieri* × *V. riparia*) × *V. riparia*	B	B	2	2	4	C	D	B	D
Rupestris du Lot (*V. berlandieri* × *V. rupestris*)	C	A	1	1	4	B	B	B	B

A=Excellent; B=Good; C=Fair; D=Poor; 1=Resistant; 2=Moderately resistant; 3=Moderately susceptible; 4=Susceptible.

Implications of climate change (IPCC, 2013) on winegrape growing and wine quality would undoubtedly include higher temperatures and drought conditions during the growth season. This would directly relate to rootstock selection, root distribution and efficiency of the root system, while playing a role in the predicted accelerated depletion of already scarce water supplies, changes in terroir and cultivar selection, timing of phenological events, harvest date, and wine style (Hunter et al., 2004, 2010; Jones, 2007; Nadal and Hunter, 2007; Bonnardot and Carey, 2008; Van Leeuwen et al., 2008; Hunter et al., 2010; Ladányi et al., 2010).

Soil-borne pests and diseases

Since the discovery of the vine phylloxera (*Daktulosphaera vitifoliae*) in South Africa in 1886, the wine industry was quickly transformed by the use of grafted vines. Together with different races of phylloxera (De Klerk, 1979), some other prominent and commonly occurring soil-borne pests and diseases that grapevines need to shield/tolerate include root-knot (*Meloidogyne*), lesion (*Pratylenchus*), spiral (*Criconemoides*) and dagger (*Xiphenema*) nematodes (Loubser, 1988), Phytophthora root-rot (*Phytophthora cinnamomi*) (Marais, 1983), *Margarodes* (mainly *M. vredendalensis* and *M. capensis*) (De Klerk, 1985) and crown gall (*Agrobacterium tumefaciens*) (Loubser, 1978). These pests and diseases cause decay of roots and restrict or prevent new root development, resulting in a decline of the whole vine even under optimal conditions for root growth (De Klerk and Loubser, 1988). In a study by De Klerk (1974) phylloxera was found to be present on 'Jacquez' roots to a depth of 1.2 m in a primarily sandy soil, irrespective of compacted gravel layers in the soil (Table 2). In another study on 'Jacquez', grown in a loamy sand soil, the close relationship between root distribution of the grapevine and root-knot nematode (*M. incognita*) larvae was confirmed (Table 2) (Loubser, 1985). It appeared that the condition of the roots and sap flow, and not temperature, were direct factors determining the quiescent stage of phylloxera. Root-knot nematode populations were found to fluctuate in close association with annual root growth periods, the latter being during flowering and postharvest (Figure 1; Van Zyl, 1984).

Table 2. Occurrence of phylloxera infestation at various soil depths on 'Jacquez' roots in sandy soil (De Klerk, 1974) and *Meloidogyne incognita* populations on 'Jacquez' roots in loamy sand soil (Loubser, 1985).

Depth (mm)	Phylloxera	Nematode larvae	
	Root mass (g)/ infestation	Roots (% of total)	Nematodes (% of total)
0-150	107.35/heavy	21	20
150-300	672.20/heavy	26	23
300-450	493.50/heavy	18	17
450-600	25.45/heavy	10	14
600-900	26.75/heavy	15	19
900-1200	24.30/heavy	10	7

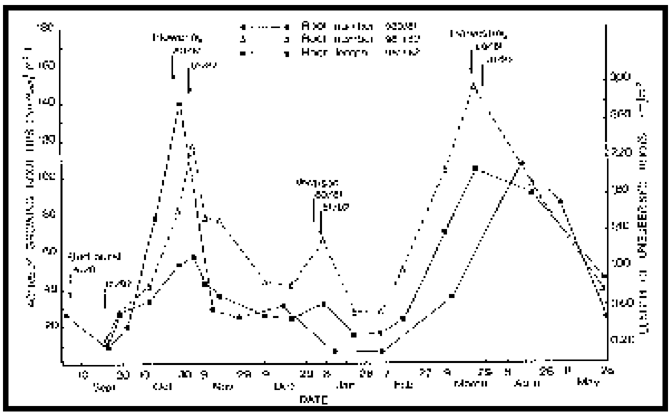


Figure 1. Fluctuation of root formation in terms of root number and root length for 'Colombar'/99 Richter during the course of two seasons (Van Zyl, 1984).

Soil conditions

Soil type affects vine water relations and balances between subterranean and aboveground growth via water percolation and holding capacity, nutrient availability, temperature, depth, proneness to compaction and presence of soil born pests (Southey and Archer, 1988; Barbagallo et al., 2004; Archer and Hunter, 2005; Costa Leme et al., 2005). Alleviating natural root restricting soil layers before planting would contribute to obtaining well-distributed root systems and homogeneous vineyards capable of buffering environmental stress. Soil compaction impedes root distribution (Figure 2) and can be mitigated by adjusting soil preparation and tillage procedures (Van Huyssteen, 1988a, b; Piccolo et al., 2010). Prior to establishment, soils should be prepared under optimum soil moisture conditions; too wet soils would result in trenches of which the compacted sides are impenetrable to roots, whereas too dry soils would lead to large, hard clods which are also impenetrable to roots – both situations would effectively decrease available soil volume for root distribution (Van Huyssteen, 1988a). Deep, vertical root distribution can be promoted by judicious soil preparation, correct basic planting techniques (incl. planting holes), a favourable water regime and proper soil drainage. Young vine root growth restriction is often directly related to compacted walls of planting holes and poor planting practice (Figure 3), resulting in heterogeneous vineyard growth and long-term detrimental effects on yields and grape/wine quality performance not favouring sustainability.

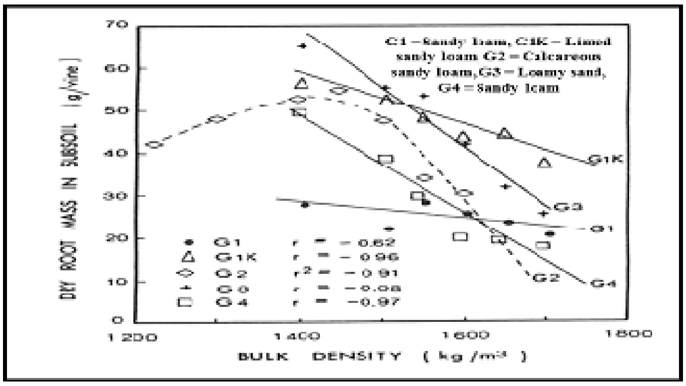


Figure 2. Relationship between dry root mass in subsoil and bulk density for different soil types (Van Huyssteen, 1988a, b).

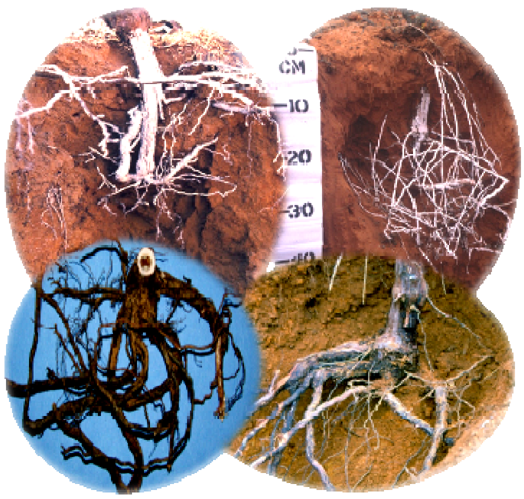


Figure 3. Planting hole and planting technique mistakes affecting root growth (Archer and Hunter, 2010).

Soil variation over short distances is a global and natural feature of grape growing regions that impacts greatly on grapevine growth. To obtain uniform growth under such conditions would require the use of multiple rootstocks per surface area/vineyard block. For this reason, the planting site should be thoroughly mapped to indicate differences in soil type and vigour potential (Saayman, 2009; Archer and Hunter, 2010). This would further dictate the soil preparation method(s), soil amelioration, cultivar/clone and rootstock selection, vine spacing and trellis size. For example, in patches where limited water supply is expected, more drought resistant rootstocks (e.g., 140 Ruggeri, 1103 Paulsen, 110 Richter) may be used, whereas in areas where higher vigour may occur, more de-vigourising rootstocks (e.g., 101-14 Mgt, 3306 Couderc, 3309 C, 1045 P, 420 A Mgt) may be used, but with thorough consideration of the other genetic characteristics of the different rootstocks (Table 1). In addition, soil mapping would also indicate where other practices, such as ridging, should be used (in shallower soil areas or where high water tables or salinity occur). If uniform soil patches are large enough, separate blocks can be made. If not, the rootstock, scion clone and vine spacing can be changed in the same block (while maintaining row spacing) in order to reduce heterogeneous growth. Correct decisions are prerequisites for establishment of uniform vineyards and would reduce differential management and thus production costs, while favouring predictability of the vineyard regarding growth, grape development and grape quality.

Although grapevine roots mainly occupy 0-80 to 100 cm soil depth, they can penetrate to very deep soil layers if soil (and above-ground) conditions are favourable (Seguin, 1972; Richards, 1983; Champagnol, 1984; Swanepoel and Southey, 1989; Hunter et al., 1995a; Hunter, 1998a; Van Schalkwyk and Hunter, 2014, unpublished). Sporadic, deep-penetrating roots seem to contribute to water supply during periods of prolonged water stress without necessarily stimulating vigour (Van Huyssteen, 1988a). Spatial distribution is predominantly a function of soil conditions, but the genetic ability of the rootstock to overcome adverse soil biotic and abiotic restrictions as displayed in Table 1 is a very important factor for sustainability. In a study on the effect of various impacting factors on root growth, it was evident that under normal water conditions generally more roots occurred in the clayey soil part of the vineyard compared to the sandy soil part, whereas under wet, anoxia-like conditions, root growth performance seemed better in sandy soils (Figure 4a) (Hunter and Volschenk, 2012). Prolonged wet conditions in soils with high water holding capacity would affect aerobic respiratory processes detrimentally and therefore restrict root growth. As commonly found, fine and small-sized roots were present in largest quantities in both clayey and sandy soils (Figure 4b).

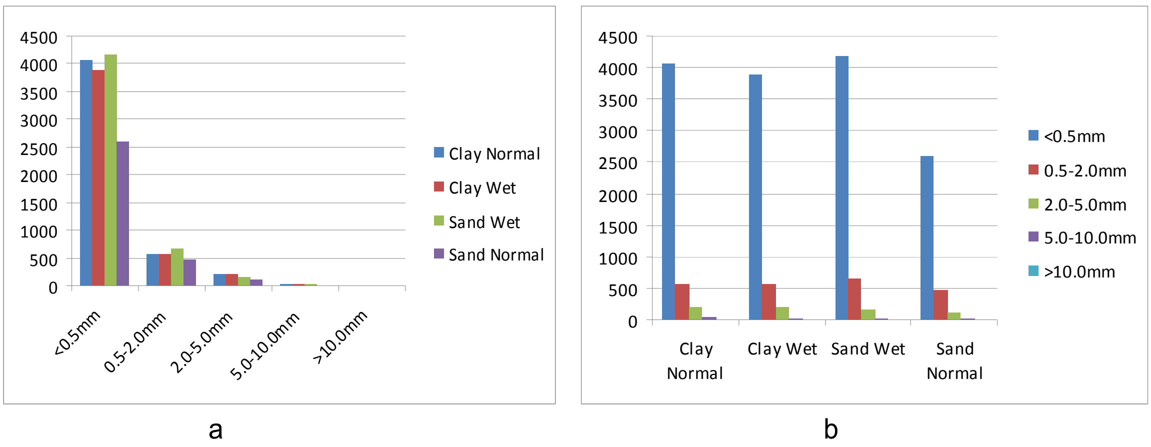


Figure 4. Presence of different root sizes in clayey and sandy parts of a Stellenbosch vineyard for either normal or wet soil conditions, expressed as total number of roots per profile (Hunter and Volschenk, 2012).

The yielding capacity of soils can be increased by, e.g., ridging, liming, irrigation, nitrogen fertilization and cover crop tillage (Van Huyssteen, 1988b; Conradie, 1991; Christensen et al., 1994; Barbeau et al., 2005; Fourie et al., 2007; Reis Júnior et al., 2013). Although irrigation and high soil water holding capacity may, within limits, compensate for soil depth (Myburgh et al., 1996), deeper soil preparation (from 40 to 120 cm) increased the uptake of minerals (N, Ca, Mg, K) by young 'Pinot noir'/99 R vines (Table 3) (Conradie et al., 1996). Rootstocks (140 Ru, 110 R, 99 R, Rupestris du Lot, SO4, 44-53 Malégue, 101-14 Mgt, Ramsey) responded positively to higher soil pH, generally increasing root mass (Figure 5) (Conradie, 1988). A positive response of mineral absorption to a higher pH was also found by Bates et al. (2002) with own-rooted 'Concord' vines, clearly differentiating between minerals with favourable and potentially detrimental effects. Fertilisation neglect and water stress during peak root activity periods (flowering and postharvest) (Van Zyl, 1984) would have a detrimental effect on root, canopy and bunch development during consecutive seasons.

Table 3. Soil preparation effects on mineral uptake of young Pinot noir/99 Richter (Conradie et al., 1996).

Year after soil preparation	Depth of soil preparation (mm)	Cane mass ($t\ ha^{-1}$)	Yield ($t\ ha^{-1}$)	Nutrient uptake ($kg\ ha^{-1}$)[1]			
				N	Ca	Mg	K
3rd	400	[2]	[3]	<10	<10	<5	<5
	800			<10	<10	<5	<5
	1200			<10	<10	<5	<10
4th	400	0.96a	[3]	12.6a	12.6a	5.8a	7.4a
	800	1.16a		15.2a	15.3a	9.4a	8.9a
	1200	1.87a		24.5a	24.5b	15.2b	14.4b
5th	400	1.62a	6.91a	31.5a	22.1a	7.4a	26.1a
	800	2.04a	6.93a	37.2a	27.4a	9.2ab	29.4ab
	1200	3.13b	7.35a	52.5b	41.6b	13.8b	38.4b

[1]Total amount of nutrients contained in leaves, canes and bunches.
[2]Not measured.
[3]Bunches were removed.

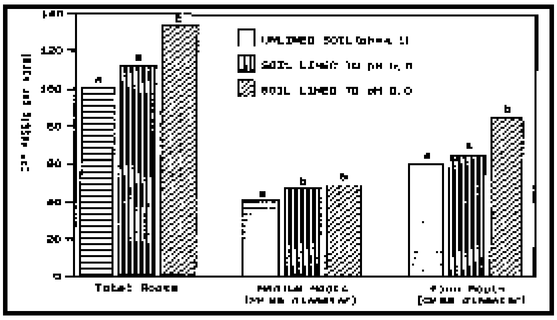


Figure 5. Response of the root system (avg root mass of 140 Ruggeri, 110 Richter, 99 Richter, Rupestris du Lot, SO4, 44-53 Malégue, 101-14 Mgt, Ramsey) to increasing soil pH (Conradie, 1988).

Viticulture practices

The graft union is a very important connection between soil/rootstock and scion, and sound grafting and callus and vascular system development are critical in nutrient and hydraulic flow, directly affecting water use efficiency, growth and below- and above-ground balances (De Herralde et al., 2005). In a study on graft union development (of combinations of 101-14 Mgt and 110 R with 'Cabernet Sauvignon' and 'Sauvignon blanc') it was found that warm callusing would likely lead to the thickest graft unions and the thinnest rootstocks, irrespective of the graft combination, while cold callusing is likely to result in the thinnest graft union and the thickest rootstock (Hunter et al., 2013). The latter in particular may be an indication that better growth and a more balanced development with less xylem and phloem translocation restrictions may be expected with cold callusing. Regressions of graft union and rootstock diameter with cane mass during the three years of the experiment indeed showed that the rootstock diameter per se is better associated with aboveground growth than the graft union diameter (Figure 6). Observations regarding growth potential of a graft combination may therefore be more accurate if focused on the diameter of the rootstock (below the graft union). Any restriction in the graft union immediately after grafting and during callusing, whether from physical damage/improper grafting technique, poor callus formation or poor fusion/integration of vascular tissue of both scion and rootstock, would limit translocation in xylem and phloem tissue and may lead to physical phenomena similar to that caused by girdling (Hunter and Ruffner, 2001). Auxin:cytokinin balances and the transport of mainly water, N-containing compounds, and minerals from roots via the xylem and sucrose, amino acids, and minerals from shoots via the phloem, would be affected (Mohr and Schopher, 1995). Such conditions would lead to source/sink physical and physiological imbalances which would further restrict the ability of the graft combination to buffer severe environmental influences.

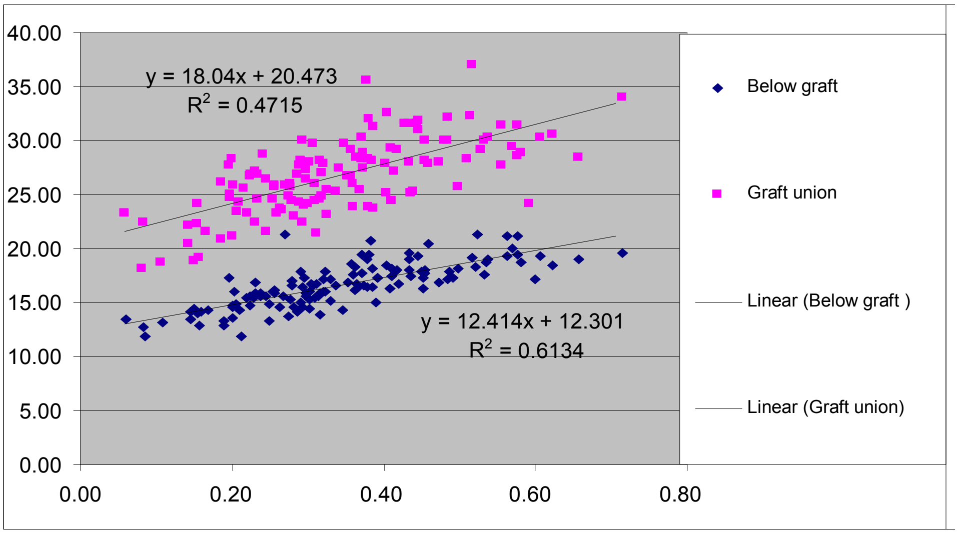


Figure 6. Regressions of graft union/rootstock diameter with cane mass (avg. 3 seasons) (Hunter et al., 2013).

It was shown that rootstocks (mother material) differ in mineral requirement/ absorption ability for growth (Figure 7; Hunter et al., 2003) (see also Tardáguila et al., 1995; Stefanini et al., 1996; Mancuso et al., 2001; Tandonnet et al., 2005; Lambert et al., 2013; Reis Júnior et al., 2013; Sato et al., 2013) and together with other biotic and abiotic impacting factors this would have direct impact on scion growth, vineyard management and production costs. In a study by Kidman et al. (2014) rootstocks were found to affect the sequestration of nutrients that affect reproduction, i.e., fertilization and pollination processes. Production performance is also affected by the scion partner (Southey, 1992; Tandonnet et al., 2005). This was demonstrated in a 9-year study involving three rootstocks and twelve scion varieties in the Stellenbosch region of South Africa (Table 4) (Carstens et al., 1981).

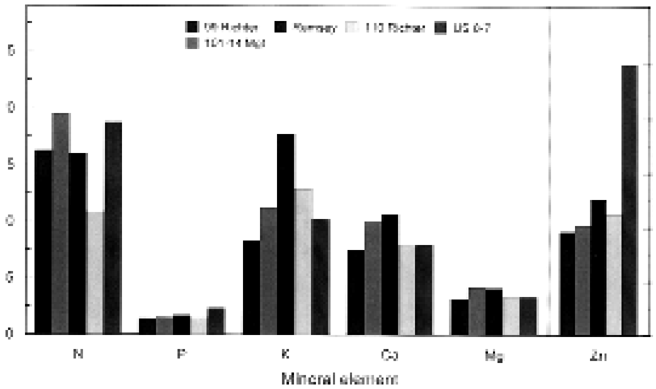


Figure 7. Aboveground mineral requirement of rootstocks for the production of one ton of graft cane material over two growth seasons (1997/98-1998/99) on a loamy clay soil under low intensity irrigation at Grondves Farm, Stellenbosch (Hunter et al., 2003).

Table 4. Yield interaction between cultivars and rootstocks in the Stellenbosch region (Carstens et al., 1981).

Cultivars	Rootstocks and yield (t ha^{-1})		
	99 Richter	101-14 Mgt	3306 Couderc
Chenin blanc	16.4	16.4	14.7
Palomino	19.1	16.4	15.3
Colombar	16.4	16.2	14.2
Cinsaut	16.6	16.0	14.2
Clairette blanche	17.8	20.0	9.5
Sémillon	14.0	12.4	13.1
Tinta Barocca	18.0	11.5	12.2
Muscat d'Alexandrie	10.4	6.2	12.2
Riesling	11.1	11.8	9.8
Cabernet Sauvignon	8.2	10.2	10.2
Bukettraube	17.3	4.4	12.0
Sauvignon blanc	16.6	13.8	10.7

In a hydroponic study under controlled conditions in the glasshouse, the root system of 'Sultanina'/143B was subjected to different water temperatures (Volschenk and Hunter, unpublished). The data clearly showed the tandem response of root and shoot growth, with concomitant starch depletion, to root temperature (Figure 8). The root system is known to be the primary starch storage organ (Hunter et al., 1995a; Hunter, 1998a). This balanced relationship (at physiological/vegetative/reproductive level) between canopy and root system was also well-illustrated under field conditions by applying different pruning methods to 'S. blanc' and 'Shiraz' grafted onto 99 R on a sandy loam soil under intensive irrigation (Figure 9; Van Schalkwyk and Hunter, 2014, unpublished) (see also Archer and Van Schalkwyk, 2007); accommodating the vigour of 'Chenin blanc'/99 R on different trellis systems on a loamy clay soil with low intensity irrigation (Figure 10; Table 5) (Archer et al., 1988; Archer and Hunter, 2005); plant spacing of 'P. noir'/99 R on a medium potential duplex soil under dryland and low intensity irrigation conditions (Figures 11 and 12; Table 6) (Archer and Strauss, 1985; Hunter, 1998a, b); and by accommodating own-rooted 'Villard blanc' vines on different trellis systems in combination with plant spacing on a sandy loam soil with intensive irrigation (Figure 13; Volschenk and Hunter, unpublished). The root system mainly responded to larger and better accommodated canopies by increasing its density/activity via changing balances between fine and thicker roots. Growth balances were improved in favour of grape production. The efficiency (with focus on the paramount significance of activity) of the root system to support grape production and composition can also be improved by, e.g., canopy management (specifically partial defoliation, affecting microclimate and source:sink relationships) (Hunter and Le Roux, 1992; Hunter et al., 1995a; Hunter, 2000) or by changing the canopy (including yield):root system balance and therefore demand on the root system (by converting the training system of vigorously growing vines confined to a VSP trellis, to that suited for a Lyre trellis) (Table 7; Hunter and Volschenk, 2001). Nevertheless, to fully valorize the land surface, large, deep penetrating root systems that occupy the total available soil volume should nevertheless be promoted by judicious practices and consideration of natural rootstock characteristics. Production cost, which embodies a critical component of sustainability, is directly affected by the choice of rootstock (Table 8). A study over many years in Bordeaux showed that the age of rootstocks affected their yield and grape quality support (Roby et al., 2008).

Table 5. Trellis effect on root development and distribution of Chenin blanc/99 Richter (Archer et al., 1988).

Trellising system	Shoot mass:crop mass ratio	Root number									
		Soil depth (cm)								Total	Fine roots (<0.5 mm)
		0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160		
2-strand hedge	0.25	180	285	223	175	224	94	27	0	1208	1010
3-strand hedge	0.25	235	398	374	124	317	184	6	0	1638	1494
4-strand hedge	0.22	266	465	780	517	464	351	28	0	2871	2606
1.5 m slanting	0.20	439	687	569	577	716	604	179	173	3944	3482

Bulk density (kg m^{-3}); 0-40 cm = 1871; 40-80 cm = 1687; 80-120 cm = 1555.

Table 6. Vine spacing effect on root density of Pinot noir/99 Richter (Hunter, 1998a).

Spacing (m)	Number of roots/ profile wall	Root density (number of roots m^{-2} profile wall)					Total
		Root size (mm)					
		<0.5	0.5-2	2–5	5-10	>10	
3×3	506.0 a	120.1 c	12.2 c	5.6 c	1.3 a	1.4 a	140.6 b
3×1.5	307.3 bc	133.0 bc	15.6 c	7.1 c	2.6 a	1.7 a	160.1 b
2×2	382.7 b	124.5 c	23.8 bc	8.5 c	1.7 a	1.1 a	159.4 b
2×1	337.3 bc	230.3 a	33.3 ab	14.2 ab	1.7 a	1.7 a	281.1 a
1×1	301.7 bc	208.9 ab	30.6 b	9.4 bc	1.1 a	1.4 a	251.4 a
1×0.5	236.3 c	265.7 a	44.9 a	15.7 a	1.4 a	0.5 a	328.2 a

Table 7. Trellis conversion effect on root growth of C. blanc/99 Richter (Hunter and Volschenk, 2001).

Trellising system	Number of roots m^{-2} profile wall	Root density (number of roots m^{-2} profile wall)					Total root density (root number m^{-2} profile wall)	Yield (t ha^{-1}) and root number: cane mass+yield
		Root size (mm)						
		<0.5 mm	0.5-2 mm	2-5 mm	5-10 mm	<10 mm		
Vertical	508 b	279 a	46 a	21 a	5 b	2 a	353 a	23.1c/56.19
Vertical (extended)	1129 a	323 a	42 a	20 a	5 b	1 a	392 a	25.6b/57.51
Lyre	595 b	319 a	50 a	30 a	13 a	3 a	413 a	38.1a/40.87

Table 8. Labour input for C. Sauvignon vineyards grafted onto two rootstocks (Hunter et al., 2010).

Description of the vineyard blocks						
Soil potential: medium; altitude: 85-95 m; aspect: west; row orientation: n-s; spacing: 3.0×1.2 m; trellis: 5-wire hedge, fixed wires; pruning: spur; bud load/m cordon:16.5; drip irrigation						
Rootstock	**Pruning**	**Shoot thinning**	**Shoot positioning**	**Tipping (hand)**	**Leaf thinning**	**Total labour input (man h ha^{-1})**
101-14 Mgt	75	86	129	1.8	54	345.8
99 Richter	94	105	197	4.2	89	489.2

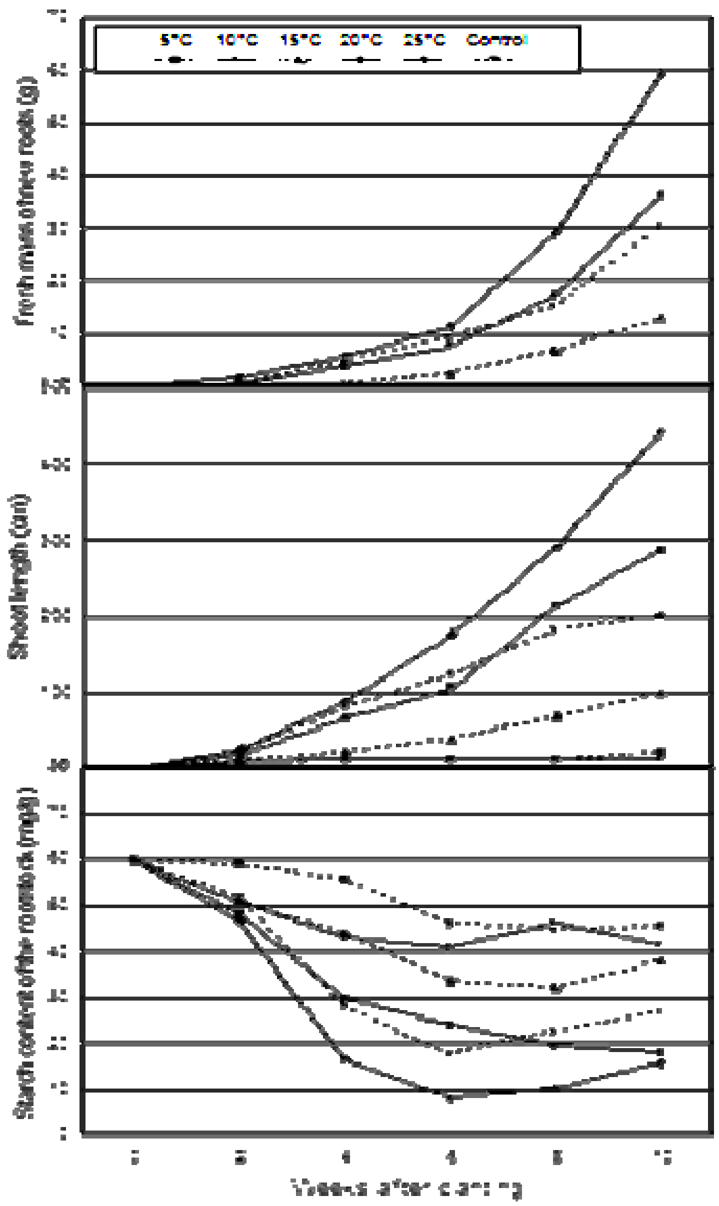


Figure 8. Response of 'Sultanina', grafted onto 143B, to root (water) temperature under hydroponic conditions in the glasshouse (Volschenk and Hunter, unpublished).

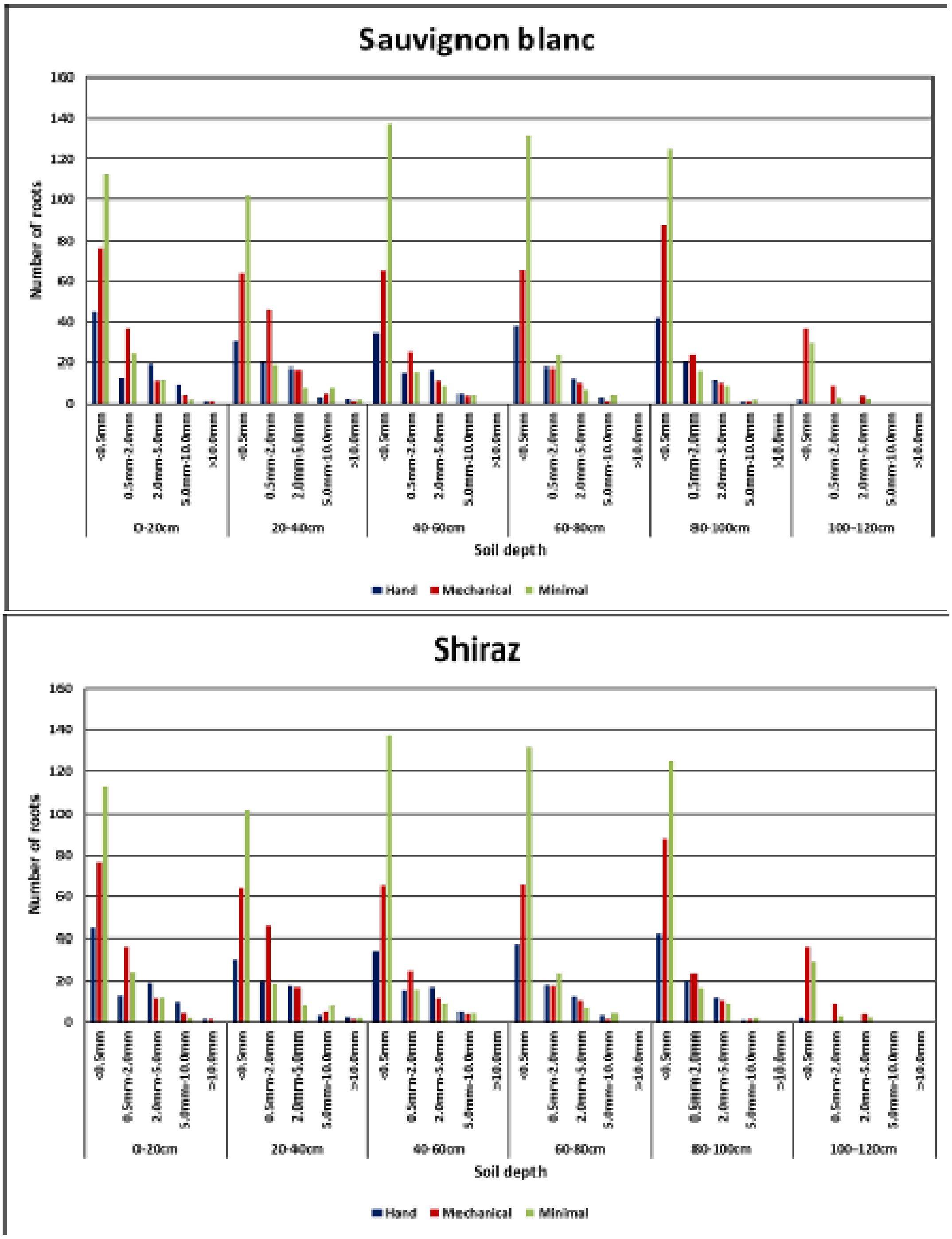


Figure 9. Response of the root system to different pruning methods, applied to ‘Sauvignon blanc’ and ‘Shiraz’ grafted onto 99 Richter, in a sandy loam soil under intensive irrigation (Van Schalkwyk and Hunter, 2014, unpublished).

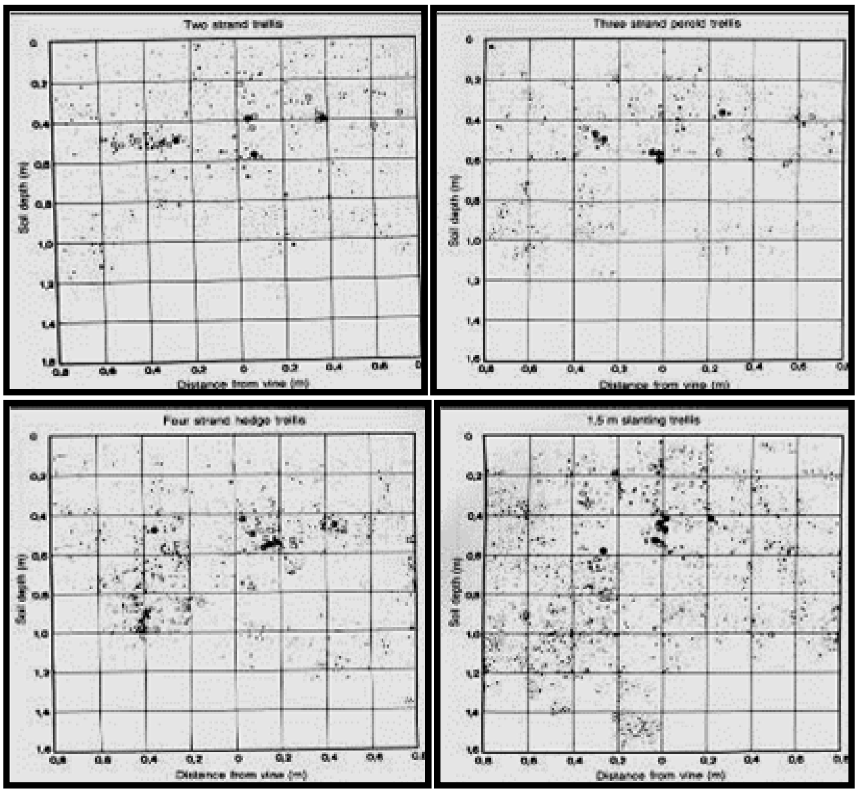


Figure 10. Response of the root system of Chenin blanc grafted onto 99 Richter to different trellis systems in a loamy clay soil under low intensity irrigation (Archer et al., 1988).

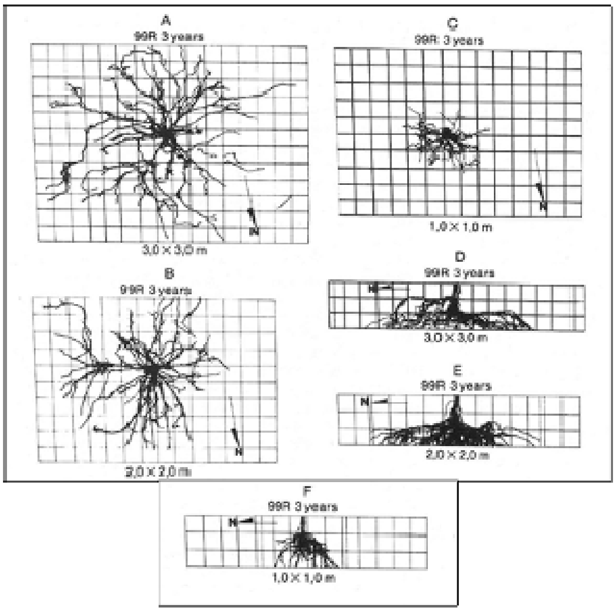


Figure 11. Effect of plant density of 'Pinot noir' grafted onto 99 Richter on vine root distribution in a medium potential duplex soil under dryland conditions (Archer and Strauss, 1985).

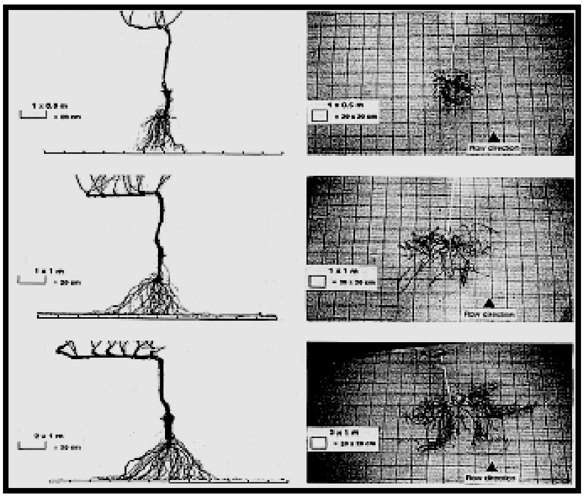
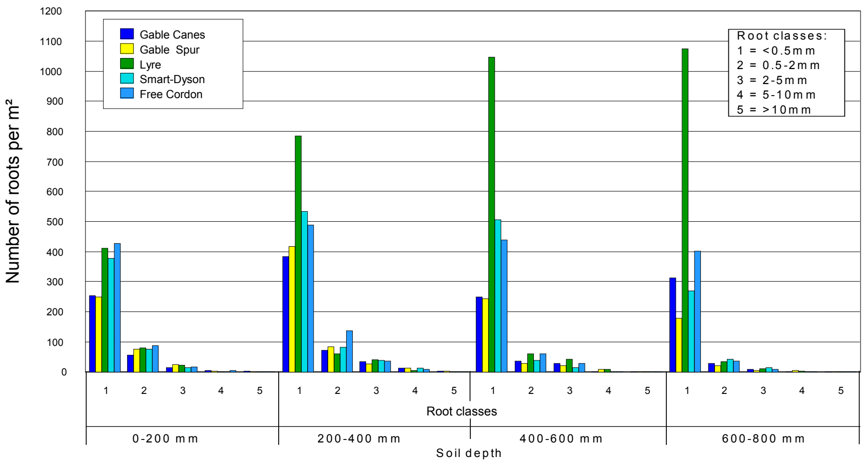


Figure 12. Effect of plant density (1×0.5, 1×1, 2×1 m) of ‘Pinot noir’ grafted onto 99 Richter on root distribution in medium potential duplex soil under supplementary irrigation (Hunter, 1998a).



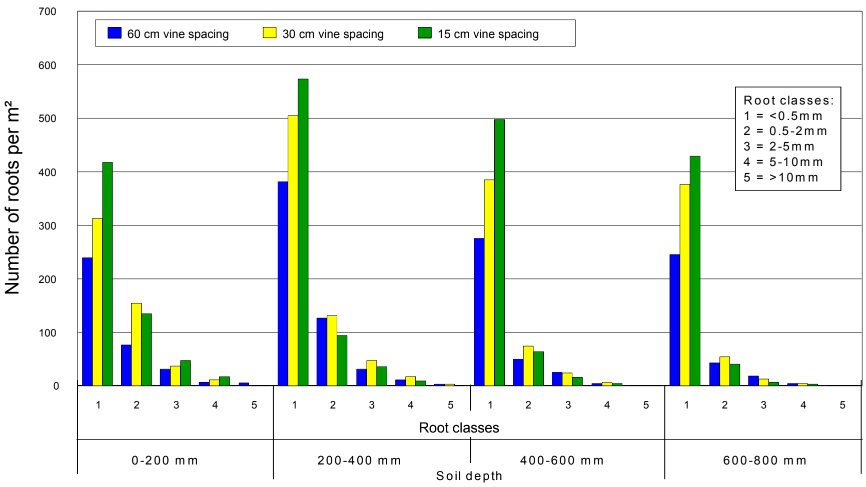


Figure 13. Response of own-rooted ‘Villard blanc’ roots to different trellises/plant spacings [Gable (3×1.5 m spacing), Lyre, Smart-Dyson and Free cordon (2×1.5 m spacing) and bush vines (avg. of 2, 1.5 and 1 m row spacing × 60, 30 and 15 cm vine spacing) (Volschenk and Hunter, 2014, unpublished).

According to the growth properties of the different rootstocks (Southey and Archer, 1988), they can be combined with a single scion cultivar (and even different clones) in the same vineyard or in different blocks to change grape composition and the flavour spectrum of wines (Southey, 1992; Stefanini et al., 1996; Ollat et al., 2001; Sampaio and Vasconcelos, 2005; Roby et al., 2008; Lafontaine et al., 2011). This may result from the well-known direct effect of grape exposure (Smart et al., 1990; Allen and Lacey, 1993; Marais et al., 1991, 1992, 1999; Spayd et al., 2002; Pereira et al., 2006; Tarara et al., 2008) or the indirect effect of vigour expression impacting on source:sink relationships, leaf exposure, photosynthetic activity and translocation to the grapes (Hunter and Visser, 1988; Hunter and Le Roux, 1992; Koblet, 1996; Stefanini et al., 1996; Hunter, 2000; Hunter et al., 2004; Agut et al., 2005; Andrade et al., 2005; Sampaio and Vasconcelos, 2005). Uniform growth is nonetheless required to not only reduce production costs, but to facilitate an even grape ripening that is critical for predicting and controlling the harvest date as well as grape and wine quality.

CONCLUSIONS

The study of only above-ground factors is not sufficient to explain vineyard behaviour. Physical and chemical properties and pre-establishment preparation of the soil have determining effects on metabolic behaviour and spatial distribution (horizontally and vertically) of roots. Impediments to root penetration should be alleviated in order to provide the best possible basis for scion growth. The health status of plant material, characteristics of the rootstock cultivar, and grafting and nursery processes have a steering impact on the ability of the root system to perform within biotic and abiotic constraints to such an extent that expectations in terms of growth, yield and grape quality of the scion are met. Vineyard practices largely exert a further tailoring impact on root system performance and support to above-ground growth. A larger, deep penetrating root system consisting of different root sizes that would increase its reserve storage capacity and functional absorptive and regenerative capabilities, would ensure continued sustenance under adverse biotic and abiotic soil- as well as environmental conditions, such as drought and high temperature. It would facilitate sustained growth and a slow and predictable grape ripening. The spatial distribution, particularly vertical penetration, of the root system is therefore of fundamental importance in achieving product objectives, from yields to wine style.

As metabolic and morphological behaviour of roots under an array of environmental impacting factors is far from completely understood, intensified inter-disciplinary research efforts are required in order to clarify scion-root system inter-relationships and to control scion behaviour to benefit greater sustainability in grape and wine production.

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