# Effects of Soil Parent Material and Climate on the Performance of *Vitis vinifera* L. cvs. Sauvignon blanc and Cabernet Sauvignon - Part I. Soil Analysis, Soil Water Status, Root System Characteristics, Leaf Water Potential, Cane Mass and Yield

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**In the Helderberg area of the Western Cape, South Africa, soil parent material may vary between granite and shale over relatively short distances. However, little information is available concerning the possible effects of different soil parent materials on grapevine performance. A five-year investigation (2004/05 to 2008/09) was therefore carried out. Two Sauvignon blanc and two Cabernet Sauvignon vineyard blocks were selected at four localities. Soils derived mainly from granite and shale were identified in each vineyard block. Climate and soil parameters, root distribution, grapevine water status, cane mass and yield were evaluated at all localities. Shale-derived soils contained significantly greater amounts of fine sand, but less coarse sand, than granite-derived soils. These differences resulted in water-holding capacities that were generally higher in the shale-derived soils. Shale-derived soils contained higher concentrations of total potassium (K), but the levels of water-soluble K were generally greater in the granitic soils. Root system development could not be related directly to soil parent material. However, in most cases fine root density in the granite-derived soils tended to be higher, while the cane mass and yield of grapevines in the same soils also tended to be higher, at least at two of the four localities. The effect of soil parent material on grapevine water constraints seemed more prominent during the drier seasons, namely 2004/05 and 2005/06, compared to the wet and coolest seasons, 2007/08 and 2008/09.**

## INTRODUCTION

Geological processes have shaped every viticulture environment seen today. However, the role of geology as a component in the formation of grapevine terroirs is often dealt with superficially (Wilson, 1998; Wooldridge, 2000, Bargmann, 2005; Maltman, 2008), rather than based on scientific research. Even though there is no single geological formation that results in wine of a high quality (Seguin, 1983), geology was used in France as a key to identifying certain terroirs (Morlat, 1996). Geology is recognised as being of importance in highlighting the uniqueness of specific vineyards in Australia and America (Bargmann, 2003). South Africa (SA) has a rich geological heritage, with its Coastal Region (specifically the Stellenbosch and Paarl districts) being regarded as one of the two most important geological zones (Bargmann, 2005). The Coastal Region forms the heartland of the South African wine industry and produces about 45% of the country's wine. Geologically, the soils in the Coastal Region are derived mainly from (i) Precambrian sedimentary formations of the Malmesbury Group, including shales, schists, phyllite and greywacke (Theron *et al*., 1992); (ii) granitic intrusions of the Cape Granite Suite (granites); and (iii) Ordovician-Devonian quartzitic sandstones of the Table Mountain Group.

In a study by Conradie *et al*. (2002) in the Stellenbosch district in South Africa (SA), soils originating from phyllitic shales contained the lowest K levels, compared to those from granite and sandstone origin. Wooldridge (1988) indicated that the granite soils were relatively rich in total K, but possess little capacity to retain it, resulting in luxury consumption of K by Italian rye grass. Different practices (e.g. Ca and Mg fertilisation and various canopy management practices) have been used in attempts to decrease K uptake in granite-rich vineyards under the Mediterranean climatic conditions of

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the Western Cape (Engelbrecht, 2005; Agenbach, 2006). In terms of particle size distribution, granite-derived soils were found to contain larger amounts of coarse sand, while the shale-derived soils contained greater amounts of fine sand (Van Schoor, 2001; Conradie *et al*., 2002).

Little research of importance has been done regarding the role of soil parent material on grapevine performance. No direct relationship has been found between soil parent materials and soil K (Carey *et al*., 2009) and grapevine growth (Van Schoor, 2001). A study focusing on the impact of the geological origin of soils on grapevine performance under similar climatic, topographic and vineyard management conditions was considered to be of great importance for specific wine-growing areas, where soil parent material may change from granite to shale within the same vineyard block. The issue addressed in this research is whether root distribution, grapevine water status and grapevine performance differ between granite-derived and shale-derived soils, when weather conditions, topography and vineyard management practices are similar. This was done through a field study in the Helderberg area, which is a part of the Stellenbosch Wine of Origin District.

## MATERIALS AND METHODS

### Experiment vineyards and layout

The study was conducted over five seasons (2004/05 to 2008/09) in four commercial vineyards (two x Sauvignon blanc and two x Cabernet Sauvignon) in the Helderberg area. The Sauvignon blanc vineyards were designated as higher altitude (SH) and lower altitude (SL), and the Cabernet Sauvignon vineyards were designated as CH and CL respectively (Table 1). Within each vineyard, two soil parent materials were identified through identification of the underlying rock. The first soil parent material was granite of the Stellenbosch pluton, and the other was greywacke/phyllitic shale of the Namibian Malmesbury Group, Tygerberg Formation (Theron *et al*., 1992). In the South African wine industry, soils that result through weathering of the latter formations are generally regarded as shale derived, in spite of not being derived from pure Malmesbury sediments. The same approach was followed in the current investigation. The two soil parent materials identified within each vineyard were taken as experimental plots. Coordinates for each granite-derived and shale-derived soil site are shown in Table 1.

Experimental plots were in the same vine rows at SH, CH and CL, but the rows differed at SL. Each experimental plot comprised two adjacent vine rows with at least 15 vines in each row, resulting in 30 vines per plot. Within individual vineyards the distance between the two experimental plots varied from 40 m (SH) to 250 m (CL). All the grapevines were at least eight years old at the start of the study. Locality CH was rain fed, whilst the others received supplementary drip irrigation (one or two irrigations per season). Planting widths were 2.75 m x 1.0 m for SH, 2.70 m x 1.20 m for SL and 2.50 m x 1.25 m for CL and CH.

Vines were trained onto vertical trellis systems made up of one wire for the cordon arms and two to four wires for the foliage. Aspects and gradients are shown in Table 1.

The study was conducted in commercial vineyards, therefore plant material was not necessarily from the same commercial nursery. Consequently, scion and rootstock clones may have differed between localities, but not within a specific vineyard. Similarly, canopy management practices, irrigation scheduling and managerial decisions differed from one farm to the next, but not within the same vineyard. Normal viticulture practices such as suckering, topping and thinning of leaves and grapes were done as needed. General cultivation practices done before the grapevines were planted included delve ploughing to a depth of approximately 800 mm, and the addition of lime with the aim of increasing soil pH (KCl) to approximately 5.5 (Conradie *et al*., 2002). After planting, N, P and K were applied according to soil analysis and production.

### Climate

In order to measure certain weather parameters, automatic weather stations (Campbell Systems) were erected at each locality, except for SL, which is situated close to CL (≈ 200 m). The difference in elevation between SL and CL was only 5 m (Table 1). Climatic conditions were assumed to be reasonably similar at these two localities.

### Soil studies

At the start of the investigation (2004), a soil profile with dimensions of approximately 2 m x 3 m surface area was used to classify the soils at each site according to the South African soil classification system (Soil Classification Working Group, 1991). Soil forms and families are shown in Table 1. Soils were sampled according to the different diagnostic horizons. During the winter season (month of July 2006), more samples, 144 in total (four vineyards x two soil types x three depths (0 to 300 mm, 300 to 600 mm and 600 to 900 mm) x six vines) were taken using an auger. All soil samples were air dried and passed through a 2 mm sieve. The fine soil was analysed for pH (1:2.5 in 1 M KCl), K, Ca, Mg and Na (extracted with 1 M $NH_4OAc$ and determined by inductively coupled plasma optical emission spectrometry (ICP-OES)). Phosphorus and K (Bray No. 2 extract: 0.03 M $NH_4F$ in 0.01 M HCl), soluble K (1:5 water) and total K (5 g soil extracted with 30 mL aqua regia on a hot plate) were determined by ICP-OES. Total N was analysed by means of a Kjeldahl digestion (Bremner & Mulvaney, 1982), while $NO_3$-N (1:5 water) was determined by a colorimetric method as described by The Non-affiliated Soil Analysis Work Committee (1990). Organic C was analysed according to the Walkley Black procedure (Soil Classification Working Group, 1991). Cation exchange capacity (CEC) was determined by utilising 1 M of $NH_4Cl$ at the pH of the soil. A hydrometer method was used to determine soil particle size distribution (Day, 1956; Van der Watt, 1966). Clay mineralogical composition of soil samples taken from the diagnostic horizons was investigated by X-ray diffractometry, after the preparation of KCl/$MgCl_2$-saturated soil paste slides according to Whittig and Allardice (1986).

Changes in soil water content were measured weekly during the growing season and once every two weeks during winter by means of a neutron probe at depths of 300 mm up to 1 500 mm. One access tube was inserted at each experimental plot. Field calibrations were carried out to convert neutron counts to volumetric soil water content. Soil water retention was determined using the pressure pot technique (Klute, 1986). For this purpose, undisturbed soil samples were collected from the different horizons. Thereafter the water-holding capacity of the soils was calculated as the difference between the soil water content at field capacity (-0.01 MPa) and permanent wilting point (-1.5 MPa).

**Grapevine studies**

***Root systems***

New profile pits that exposed the vine roots of six vines at each experimental plot were dug in June 2007, after which root distribution was determined using the profile wall method of Böhm (1979). A 1 $m^2$ (1 m deep and 1 m wide) frame with a 25 cm x 25 cm inner grid was placed against the profile wall with the grapevine centrally positioned. The total number of thin (diameter ≤ 2 mm) and thick (diameter > 2 mm) roots per grid was recorded.

***Grapevine water status***

Leaf water potentials (LWP) were measured weekly from November to March, using the pressure chamber technique of Scholander *et al*. (1965). Uncovered, fully mature sunlit leaves were used. Measurements were taken on four leaves per experimental site between 12:00 and 14:00.

***Grapevine parameters***

During winter (month of July), grapevines were hand pruned to two-node spurs and the pruned cane mass was determined. Canopy density measurements were carried out using the point quadrat method (Smart & Robinson, 1991). After véraison, a thin metal rod was inserted perpendicularly into the canopy (fruit zone) of each vine. Ten insertions were made in each grapevine and contacts with leaves and clusters were noted. This data was used to calculate canopy density parameters such as the number of leaf layers per grapevine. Yield and number of bunches per grapevine, bunch mass, number of berries per bunch and berry mass were recorded during harvest.

**Statistical analysis**

Analysis of variance was performed on soil and grapevine data by means of the general linear model (GLM) procedure of SAS statistical software version 9.1 (SAS, 2000). Grapevine data from the five seasons were used as replicates. The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t least for significant difference was calculated at the 5% and 10% levels to compare treatment means (Snedecor & Cochran, 1980).

RESULTS AND DISCUSSION

**Climate**

Climatic conditions, as experienced during the five experimental seasons, will be described in the subsequent article (Shange & Conradie, 2012). For the purpose of this paper, climatic conditions are summarised as follows:

- The 2004/05 and 2005/06 seasons could be classified as dry, while spring temperatures were also high in 2004/05.
- Rainfall was normal during 2006/07, but spring temperatures were high.
- Rainfall was high during 2007/08 and 2008/09, with 2008/09 being the coolest season as indicated by spring temperatures.
- Mean summer temperatures varied by less than 1°C between the warmest (2007/08) and the coolest (2006/07) seasons.

**Soil studies**

***Soil forms and families***

Tukulu soil forms, from the same family (2120), were identified for both granite-derived and shale-derived soils at SH and CH (Table 1). This meant that all these soils exhibited non-red, neocutanic B horizons with luvic characteristics (increase in clay content from A to B horizon), while signs of wetness could be observed in the subsoil. However, as will be discussed in the next section, the abovementioned four soils did show differences, especially in terms of sand grade distribution. The granite-derived soil at SL also belonged to the same Tukulu family (2120), but the shale-derived soil at this locality belonged to a different (2220) family, due to a reddish B horizon. At CL the granite-derived soil was classified as a Pinedene and the shale-derived soil as an Oakleaf (Table 1).

***Particle size distribution***

The granite-derived soils (300 mm to 600 mm and 600 mm to 900 mm soil depths) contained more coarse sand than the shale-derived soils (Table 2). The gravel fraction (> 2 mm) showed a similar pattern (data not shown). However, shale-derived soils had more fine sand than granite-derived soils for all soil depths (Table 2). Similar results were reported by Van Schoor (2001) and Conradie *et al*. (2002). The differences in fine and coarse sand fractions, especially in the 300 mm to 600 mm and 600 mm to 900 mm soil depths, support the likelihood that the soil parent materials were mainly of granite and shale origin. The differences in particle size in the upper soil depths (0 to 300 mm) were not as large as in the deeper soil depths (300 mm to 900 mm). This confirmed that the topsoils were not derived by *in situ* weathering of the underlying rock formations (Conradie *et al*., 2002), but that the material in the upper soil depth may have been mixed due to colluvial action during the accumulation of the parent material (White, 2003), thus not reflecting differences due to soil parent materials as clearly as the soil in the deeper soil depths. Differences in soil parent materials did not affect the amounts of medium sand, silt and clay (Table 2).

***Clay mineralogy***

Intensity peaks from the X-ray diffraction analyses of the soils showed that kaolinite was the dominant mineral, whereas quartz and feldspar were subdominant in both the shale-derived and granite-derived soils. A relative abundance of kaolinite in the Western Cape soils has been reported by Wooldridge (1988), Van Schoor (2001), Bühmann *et al*. (2004) and Agenbach (2006). Kaolinite and quartz are weathering products that are usually found in soils that have reached an advanced stage of weathering (Nortcliff, 1988), such as the ones investigated in this study. Furthermore,

TABLE 1
Characteristics of the four experimental localities planted to Sauvignon blanc and Cabernet Sauvignon in the Helderberg area, Western Cape, South Africa.

| Locality[1] | Scion/ Rootstock | Coordinates | Altitude (m) | Aspect | Slope (%) | Soil form and family | Soil profile description |
|---|---|---|---|---|---|---|---|
| SH | Sauvignon blanc/ 110 Richter | 34.0254°S, 18.8588°E | 417 | NE | 1 | Tukulu 2120 | Yellow brown, luvic, medium texture[2], favourable structure[3], with signs of wetness in the **granite** subsoil. |
| | | 34.0258°S, 18.8584°E | 411 | SW | 15 | Tukulu 2120 | Yellow brown, luvic, medium texture[2], favourable structure[3], with signs of wetness in the **shale** subsoil. |
| SL | Sauvignon blanc/ 99 Richter | 34.0216°S, 18.8399°E | 227 | NE | 9 | Tukulu 2120 | Yellow brown, luvic, medium texture[2], favourable structure[3], with signs of wetness in highly weathered **granite** subsoil. |
| | | 34.0220°S, 18.8417°E | 230 | NE | 6 | Tukulu 2220 | Reddish brown, luvic, medium texture[2], favourable structure[3], with signs of wetness in highly weathered **shale** subsoil. |
| CL | Cabernet Sauvignon/ 110 Richter | 34.0188°S, 18.8409°E | 224 | W/NW | 1 | Pinedene 1200 | Lightly textured[4], luvic, yellow-brown B horizon, favourable structure (apedal), with signs of wetness in heavier textured **granit**e subsoil. |
| | | 34.0193°S, 18.8435°E | 238 | W/NW | 7 | Oakleaf 2210 | Reddish-brown, non-luvic, favourable structure[3], well drained, with no signs of wetness in the **shale** subsoil. |
| CH | Cabernet Sauvignon/ 110 Richter | 34.0303°S, 18.8450°E | 270 | W/NW | 8 | Tukulu 2120 | Yellow-brown, luvic, medium texture[2], favourable structure[3], with signs of wetness in highly weathered **granite** subsoil. |
| | | 34.0302°S, 18.8443°E | 280 | W/NW | 15 | Tukulu 2120 | Yellow-brown, luvic, medium texture[2], favourable structure[3], with signs of wetness in highly weathered **shale** subsoil. |

[1]Sauvignon blanc (SH & SL) and Cabernet Sauvignon (CH & CL) experimental vineyards in the Helderberg area (S = Sauvignon blanc, C = Cabernet Sauvignon, H = High altitude, L = Low altitude), [2]15% to 25% clay content, [3]neocutanic, [4]< 15% clay content.

TABLE 2
Particle size distributions at different soil depths of granite-derived and shale-derived soils at four localities in the Helderberg area.

| Particle size (%) | 0-300 mm | | 300-600 mm | | 600-900 mm | |
|---|---|---|---|---|---|---|
| | Granite | Shale | Granite | Shale | Granite | Shale |
| Coarse sand (2.0-0.50 mm ) | 20.1 a* | 13.9 a | 20.2 a | 10.1 b | 16.9 a | 6.4 b |
| Medium sand (0.50-0.25 mm) | 24.4 a | 23.1 a | 22.4 a | 19.7 a | 11.8 a | 8.6 a |
| Fine sand (0.25-0.05 mm) | 26.5 a | 38.8 b | 24.0 a | 38.3 b | 24.5 a | 42.3 b |
| Silt (0.002-0.05 mm) | 25.1 a | 21.7 a | 18.2 a | 20.3 a | 13.2 a | 9.7 a |
| Clay (< 0.002 mm) | 18.3 a | 14.4 a | 18.1 a | 18.4 a | 17.1 a | 14.6 a |

*Different letters within the same row for the same soil depth indicate significant differences ($p \leq 0.1$).

kaolinite may have been neoformed from chlorite following the loss of K (Bühmann *et al.*, 2004). The presence of feldspar, which is a major component of granite, in the shale-derived soil implies mixing of soil parent materials. The presence of quartz was attributed to its ability to resist decomposition in soils during weathering (McBride, 1994; Wilson, 1998). Small quantities of mica were found in certain soils, but few, if any, weathered micaceous structures (e.g. vermiculite, chlorite or interstratified 2:1 silicates) were present. Intensity peaks for feldspar and kaolinite were stronger in granite-derived (upper and 300 mm to 800 mm soil depths) (Fig. 1A) than in shale-derived soils (0 to 400 mm and 400 mm to 900 mm soil depths) at SH (Fig. 1B). Peaks for quartz and mica were poorly represented. A similar pattern was shown at SL, except that mica was absent (data not shown). Quartz was only detected in the upper soil depth at CL, and its intensity peaks were stronger in the granite-derived than in the shale-derived soils (data not shown). Peaks for kaolinite and feldspar were minimally defined in the upper soil depths, but were better defined in the deeper soil depths, particularly in the granite-derived soils. Peaks for only two minerals, kaolinite and feldspar, were observed in the granite-derived

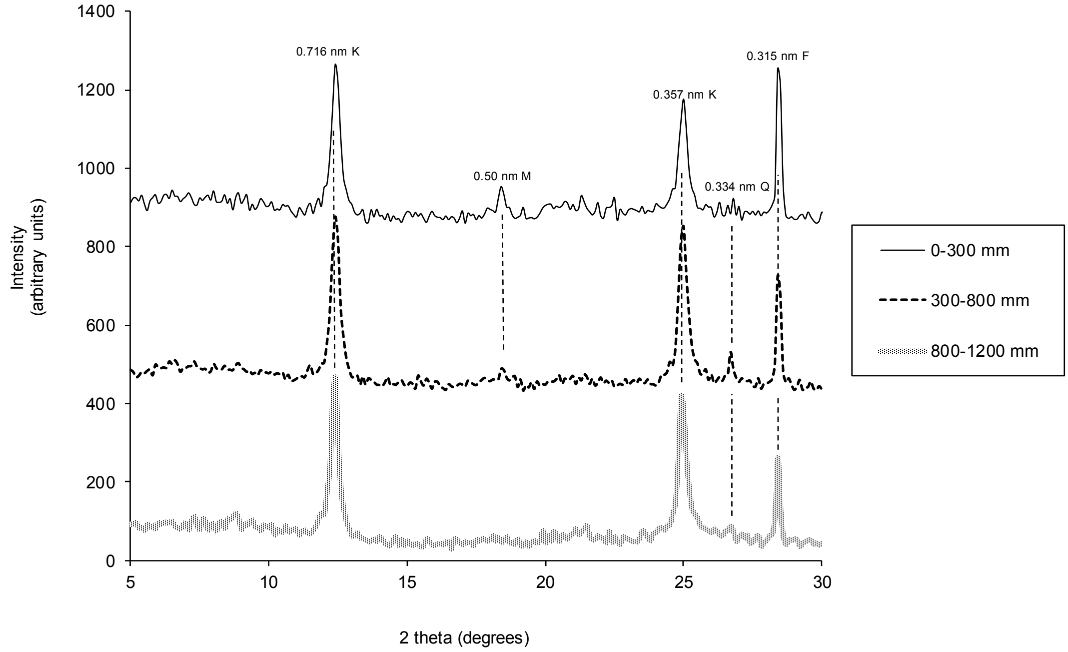


FIGURE 1A
Clay diffraction pattern of a granite-derived soil profile from a Sauvignon blanc locality (SH) in the Helderberg area (F = feldspar, Q = quartz, K = kaolinite and M = mica).

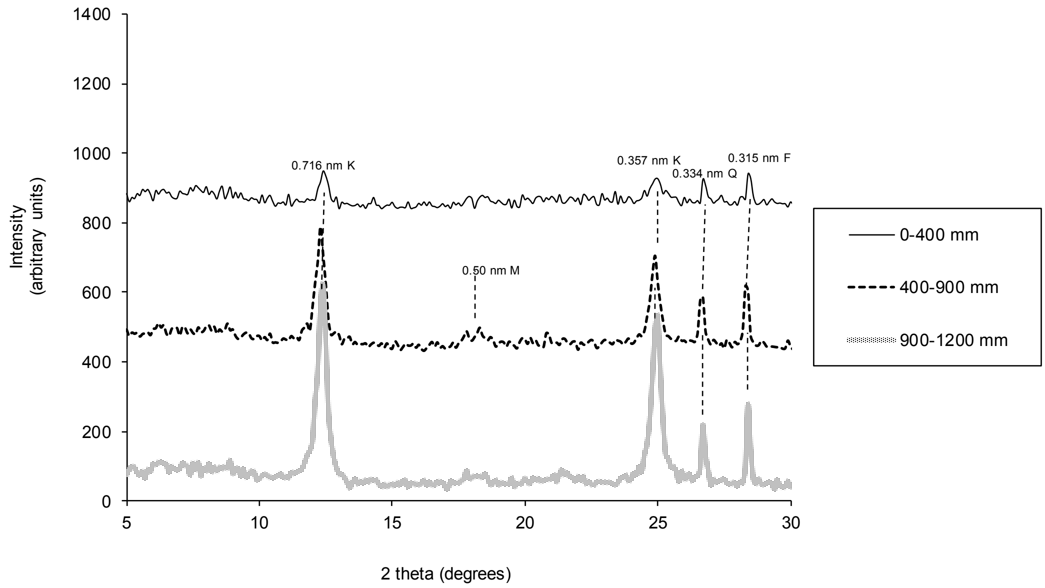


FIGURE 1B
Clay diffraction pattern of a shale-derived soil profile from a Sauvignon blanc locality (SH) in the Helderberg area (F = feldspar, Q = quartz, K = kaolinite and M = mica).

soils at CH (data not shown). Peaks were subdued, notably in the upper soil depth of the shale-derived soils, where only kaolinite and feldspar were present; nevertheless, peaks representing kaolinite, feldspar and quartz were apparent at the deeper soil depths.

Collectively, the mineralogical compositions indicated that these soils were highly weathered, probably due to high temperature and rainfall during a previous geological period, which would have caused leaching of cations, notably K. Since differences in the mineral composition of the clay fraction were small, evidently reflecting the convergent effects of weathering on soil mineralogy, these soils were expected to show very similar chemical characteristics per unit clay content.

***Soil chemical properties***

Shale-derived soils tended to have higher pH values than the granite-derived soils, notably in the upper soil depths (Table 3). This was largely on account of the values at SH, where pH was much higher for the upper soil depths of the shale-derived soil (5.5) than for the granite-derived soil (4.5). During soil preparation, lime is generally applied at an equal rate over the whole block, irrespective of lime requirement not being equal over the whole of the block. This suggests that granite-derived soils may have been under-limed in comparison to the shale-derived soils. Furthermore, low pH values (3.98 to 4.25) in the 300 mm to 900 mm soil depths suggest that all soils were inadequately limed during soil preparation. According to Conradie (1983), grapevine performance may be seriously impeded at such low pH values. As expected, P content was highest in the upper soil depths (Table 3), and this can be attributed to the use of fertilisers. Low P levels in the 300 mm to 900 mm depths (1.3 mg/kg to 3.3 mg/kg) confirmed that the P content of soil parent materials of the Western Cape soils tends to be low (Visser, 1964). However, on account of adequate P levels in the upper soil depths, which were similar to those observed by Conradie and Saayman (1989), grapevine performance should not have been seriously hampered by P deficiency.

The relatively high concentration of exchangeable K in the upper soil depths, for both the granite-derived and shale-derived soils (Table 3), could be ascribed partly to exceptionally high values at SL (217 mg/kg and 207 mg/kg respectively). In this case (SL), the annual K application rate must have been higher than the generally recommended rate of 30 kg K/ha (Conradie, 1994). At the other three localities (SH, CL and CH), K levels were marginally higher than the "adequate" norm (70 mg/kg to 80 mg/kg) for the Stellenbosch area (Conradie, 1994). Exchangeable K levels (600 mm to 900 mm soil depth) were not affected significantly by parent material (Table 3), suggesting that these soils had experienced a high degree of weathering, which is known to diminish differences in soil K due to soil parent materials (McBride, 1994). This agrees with the conclusion of Conradie *et al.* (2002), that K levels in the deeper soil depths can generally not be related to underlying geological formations. On the other hand, total K, being largely insoluble, was significantly higher in the upper and deeper (300 mm to 600 mm) soil depths of shale-derived than granite-derived soils (Table 3), while soluble K tended to be higher in the 300 mm to 600

TABLE 3
Chemical parameters in different soil depths of granite-derived and shale-derived soils at four localities in the Helderberg area[1].

| Soil chemical parameters | 0-300 mm | | 300-600 mm | | 600-900 mm | |
|---|---|---|---|---|---|---|
| | Granite | Shale | Granite | Shale | Granite | Shale |
| pH (KCl)[2] | 4.78 ± 0.53 | 5.15 ± 0.32 | 4.15 ± 0.11 | 4.25 ± 0.21 | 3.98 ± .13 | 4.18 ± 0.29 |
| Resistance (Ohm)[2] | 2393 ± 650 | 1823 ± 342 | 3715 ± 629 | 3928 ± 681 | 2893 ± 397 | 3025 ± 582 |
| P (mg/kg)[2] | 20 ± 9.0 | 29.3 ± 5.7 | 3.3 ± 1.0 | 2.3 ± 0.5 | 2.4 ± 0.41 | 2.0 ± 0.99 |
| Exchangeable K (mg/kg)[2] | 117 ± 30 | 132 ± 25 | 49.5 ± 15 | 50.0 ± 18 | 38.3 ± 30.2 | 42.5 ± 31.3 |
| Total K (mg/kg)[3] | 550 ± 190 | 752 ± 325 | 466 ± 226 | 644 ± 259 | 368 ± 211 | 484 ± 323 |
| Soluble K (mg/kg)[3] | 29.7 ± 11.8 | 30.4 ± 12.1 | 18.9 ± 8.5 | 13.7 ± 7.6 | 11.3 ± 6.8 | 9.5 ± 5.7 |
| Exchangeable Ca (cmol(+)/kg)[2] | 2.53 ± 0.90 | 4.14 ± 1.17 | 0.70 ± 0.24 | 0.91 ± 0.30 | 0.69 ± 0.41 | 0.94 ± 0.53 |
| Exchangeable Mg (cmol(+)/kg)[2] | 0.68 ± 0.22 | 0.81 ± 0.19 | 0.27 ± 0.08 | 0.25 ± 0.02 | 0.26 ± 0.10 | 0.25 ± 0.14 |
| Exchangeable Na (cmol(+)/kg)[2] | 0.047 ± 0.008 | 0.052 ± 0.014 | 0.037 ± 0.012 | 0.045 ± 0.013 | 0.035 ± 0.009 | 0.042 ± 0.012 |
| CEC (cmol(+)/kg)[3] | 6.10 ± 0.44 | 6.76 ± 1.49 | 5.37 ± 0.83 | 5.74 ± 1.25 | 4.80 ± 0.79 | 5.01 ± 1.12 |
| C (%)[3] | 2.03 ± 0.38 | 2.59 ± 0.60 | 0.59 ± 0.15 | 0.71 ± 0.20 | 0.35 ± 0.15 | 0.44 ± 0.18 |
| N (%)[3] | 0.119 ± 0.030 | 0.124 ± 0.031 | 0.090 ± 0.024 | 0.090 ± 0.021 | 0.07 ± 0.019 | 0.08 ± 0.032 |
| $NO_3$-N (mg/kg)[3] | 4.2 ± 2.0 | 6.0 ± 4.9 | 2.3 ± 1.4 | 2.5 ± 1.8 | 3.3 ± 4.8 | 1.6 ± 2.4 |

[1]Values indicate means ± standard deviation, [2]n = 4, [3]n = 24

mm soil depths of granite-derived soils. These results were in agreement with the findings of Wooldridge (1988), namely that the granite-derived soils of the Western Cape had a greater ability to release K than the shale-derived soils. This supports the suggestion that K is taken up or lost through leaching at a faster rate from granite-derived than shale-derived soils. Calcium levels tended to be higher in shale-derived than granite-derived soils, and the pH values followed the same trend (Table 3). Magnesium levels appeared to have been unaffected by soil parent material, apart from a marginally higher value in the upper soil depths of the shale-derived soils. All soils were characterised by low CEC values (Table 3), which is typical of highly weathered soils in the Coastal Regions of South Africa (Conradie, 1981).

The organic carbon (C) content of shale-derived soils in all depths tended to be higher than that of granite-derived soils (Table 3). However, according to Stevenson (1986), soil C content is normally related to prevailing climatic conditions during the process of soil formation. No major differences could be detected in terms of total N and $NO_3$-N between the granite-derived and the shale-derived soils (Table 3). Low concentrations of $NO_3$-N were found in all the soils, probably due to leaching or to low mineralisation rates during the winter when the samples were taken. Fertilisation, as well as the mixing of soil parent materials in the upper soils as a result of colluvial action, appeared to have lessened differences in the chemical properties that may have been due to soil parent materials.

### *Soil water status*

Water-holding capacity (WHC) calculated for the 300 mm, 600 mm and 900 mm soil depths tended to be higher in the shale-derived than in the granite-derived soils at all localities (Table 4). Examples of soil water content curves for the 2008/09 season at SH are shown in Figures 2A to 2C. A similar tendency was observed at the other localities, albeit to a smaller (CL) or a greater (SL and CH) extent (data not shown). Even though there was no effect of soil parent material on clay content, shale-derived soils contained more fine sand than granite-derived soils. These differences in sand grade may have affected the WHC of the soils. This is in agreement with previous results (Conradie *et al*., 2002), where the WHC of a soil of granitic origin (20% clay and 22% fine sand) was 111 mm/m, while WHC was higher (143 mm/m) for a shale-derived soil with a similar clay content (19%) but a higher fraction of fine sand (36%). According to Maltman (2008), such results emphasise the differences in hydrological properties of a particular soil, rather than the effects of geology-related factors. In the current study it was clear that soil parent material may have a large effect on the hydrological properties of a particular soil, as it directly affects the soil's particle size distribution pattern, which in turn affects the WHC. The implications for grapevine cultivation in the Helderberg area may be that grapevines on shale-derived soils could have less problems with regard to water availability than vines on granite-derived soils, especially during dry seasons. Granite-derived soils with their higher coarse sand content may possess larger pores, resulting in fairly rapid drainage after irrigation or rain. Furthermore, water-soluble nutrients, viz. $NO_3^-$ and K, may be more rapidly leached below the vine root zone by percolating waters in granite-derived soils.

## Grapevine studies

### *Root systems*

The same rootstock (110 Richter) was used in the Cabernet Sauvignon vineyards. However, rootstocks varied between the two localities (110 Richter and 99 Richter) in the Sauvignon blanc vineyards, but both rootstocks were of the same parentage (*Vitis berlandieri* x *Vitis rupestris*) (Kodur, 2011). This discussion therefore focuses on comparing root distribution within individual vineyards, where the same rootstock was used in both granite-derived and shale-derived soil sites. Fine and thick roots were distributed similarly in the granite-derived and shale-derived soils at SH, i.e. approximately 55% of the fine roots in the upper soil depths, compared to 30% and 15% in the 300 mm to 600 mm and 600 mm to 900 mm soil depths respectively (Table 5). Fine root density (roots/$m^2$) tended to be higher in the granite-derived soil than in the shale-derived soil. In contrast, the density of thick roots was highest in the shale-derived soils. Fine roots are considered more important than thick roots for the qualitative performance of grapevines during warm, dry summers (Archer & Hunter, 2005). Fine root density also tended to be higher in the granite-derived soils at SL, but the fine root fraction in the 600 mm to 900 mm soil depths was higher in the shale-derived than in the granite-derived soils

TABLE 4
Water-holding capacities (mm)(1) in different soil depths of granite-derived and shale-derived soils in Sauvignon blanc (SH and SL) and Cabernet Sauvignon (CL and CH) vineyards in the Helderberg area.

| Locality(2) | Soil parent material | 0-300 mm | 300-600 mm | 600-900 mm | Total (mm) |
|---|---|---|---|---|---|
| SH | Granite | 41.8 | 43.7 | 50.9 | 136 |
| | Shale | 38.0 | 63.3 | 64.3 | 166 |
| SL | Granite | 42.3 | 58.5 | 48.9 | 150 |
| | Shale | 38.1 | 62.5 | 66.2 | 167 |
| CL | Granite | 54.6 | 44.8 | 47.2 | 147 |
| | Shale | 54.7 | 52.5 | 56.2 | 163 |
| CH | Granite | 45.8 | 54.6 | 59.0 | 159 |
| | Shale | 55.2 | 63.3 | 69 | 188 |

(1)Water retained between -0.01 MPa and -1.50 MPa, (2)See Table 1 for a detailed description

(Table 5). The latter may have been due to a generally higher soil moisture, which may have favoured the development of fine roots. In a study at Helshoogte, also in the Stellenbosch district, fine root density was higher in a wetter Tukulu soil than in a well-drained Hutton soil (Conradie *et al*., 2002).

The granite-derived soil (upper soil depths) contained a higher fraction of fine and thick roots at CL, whereas the reverse was true for thick roots in the 300 mm to 600 mm soil depths, with the shale-derived soils containing a higher fraction (Table 5). Furthermore, fine root density was higher in the shale-derived than in the granite-derived soils. At this locality, the generally higher soil water content of the Oakleaf

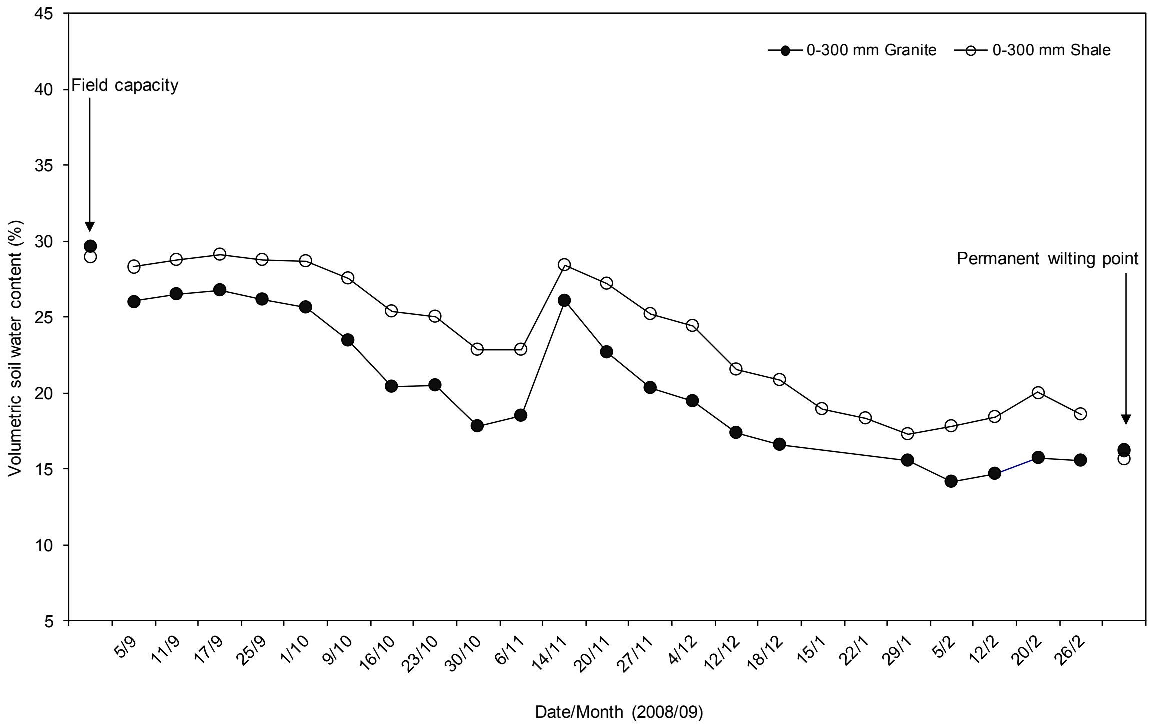


FIGURE 2A
Soil water content curves (300 mm soil depth) of a granite-derived and shale-derived soil at a Sauvignon blanc locality (SH) in the Helderberg area (2008/09 season).

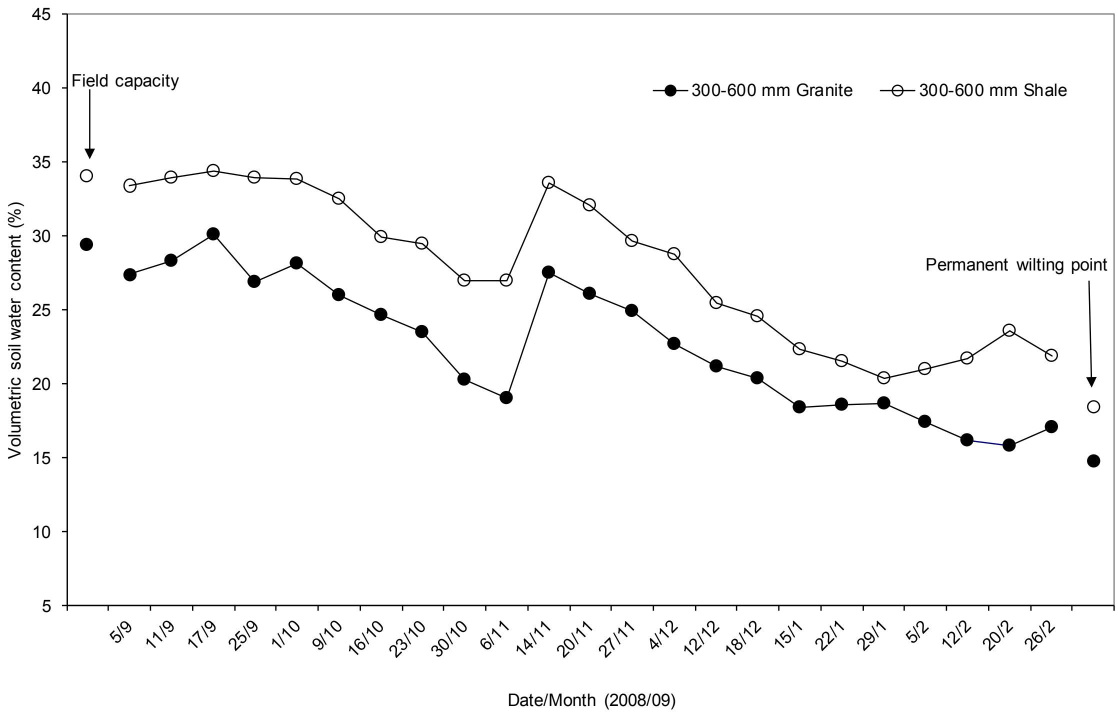


FIGURE 2B
Soil water content curves (600 mm soil depth) of a granite-derived and shale-derived soil at a Sauvignon blanc locality (SH) in the Helderberg area (2008/09 season).

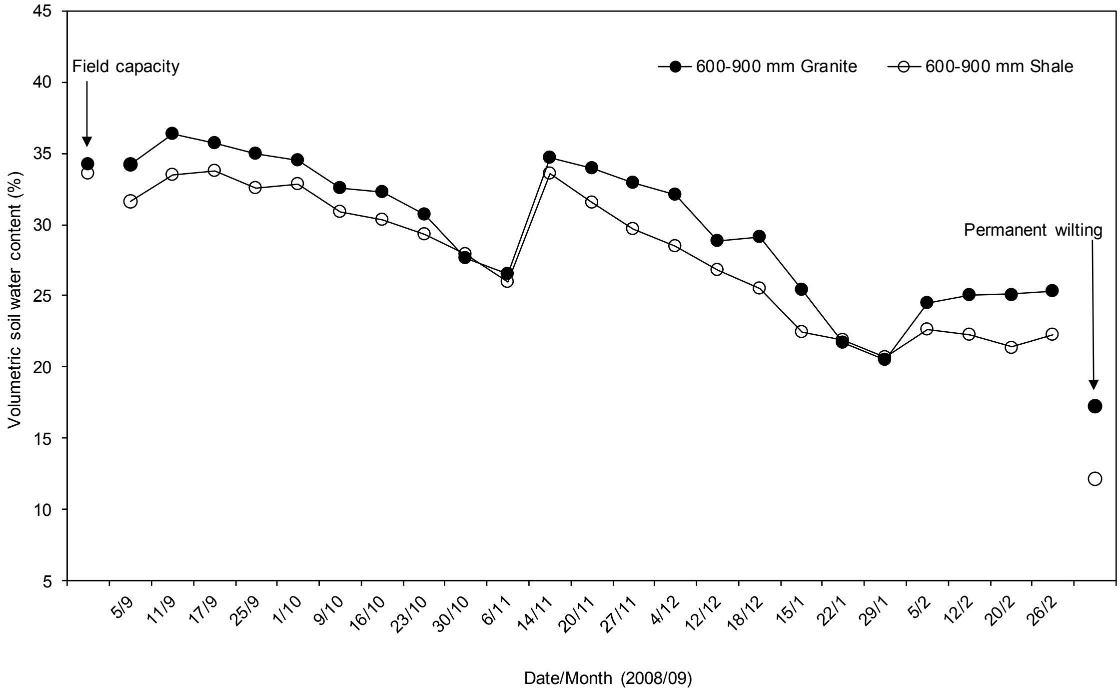


FIGURE 2C
Soil water content curves (900 mm soil depth) of a granite-derived and shale-derived soil at a Sauvignon blanc locality (SH) in the Helderberg area (2008/09 season).

soil (shale-derived), as indicated in Table 4, may have been beneficial for fine root development. The density of fine roots was greater in the granite-derived than the shale-derived soils at CH. If fine root density is accepted as an indicator of the quality of the root system, as suggested by Archer and Schloms (2001), the root systems in the granite-derived soils at SH, SL and CH may therefore be of better quality than those in the shale-derived soils. In general, the less moist, coarse sandy granite-derived soils seemed to have favoured the development of fine roots more that the wetter, fine sand textured shale-derived soils. However, these results do not suggest that root system development is directly related to soil parent material. It is possible that the fine roots in deeper soil depths may be more important than those in the upper soil depths, especially from véraison onwards, thus implying that a slightly higher fraction of fine roots in the deeper soil depths, e.g. 600 mm to 900 mm shale-derived soils at SL, may play a critical role in improving root system efficiency. Furthermore, the quality of a root system is known to be affected significantly by the method and efficiency of the chemical and physical preparation of soil before planting (Archer & Hunter, 2005). Due to the absence of a consistent root distribution pattern in the soils of different origins, it is likely that soil preparation before planting affected root distribution and development more than soil parent material.

***Leaf water potentials***

As described previously, growing seasons 2004/05 and 2005/06 were relatively dry, while conditions during 2006/07 were close to the long-term average. This highlighted the effect of soil parent material and soil type on grapevine water constraints. In contrast, growing seasons 2007/08 and 2008/09 were relatively wet, resulting in soil parent material differences being less discernible. At SH, grapevines on the granite-derived soils were generally more water stressed throughout the investigation period than those on the shale-derived soils. This may have been due to a higher WHC in the shale-derived soils, despite the fine root density being higher in the granite-derived soils. However, as indicated above, this difference was more pronounced during the first three seasons. This is illustrated in Figures 3A and 3B for the 2006/07 and 2008/09 seasons respectively. Apart from the difference being more pronounced in 2006/07, the grapevines were already subjected to high water constraints from the 25$^{th}$ of January. In 2008/09, grapevines were subjected to high water constraints only once, viz. at the time of harvest (27$^{th}$ of February). No specific trends could be observed in any of the seasons at SL (data not shown), suggesting that the effect of soil parent material on leaf water potentials was not as pronounced as at SH. Different rootstocks were used at SH and SL (Table 5), and this may have contributed to the leaf water potentials of Sauvignon blanc not being affected in a similar manner by soil parent materials at these localities.

For Cabernet Sauvignon at the lower altitude (CL), there was also no clear soil parent material effect on leaf water potentials, in spite of higher WHC and a possibly superior root system in the shale-derived soils. At CH, the only locality without irrigation, water constraints tended to be higher for the grapevines on shale-derived soils than for vines on granite-derived soils in three consecutive seasons (2004/05 to 2006/07). This is in agreement with a superior rooting system in the granite-derived soils (greater fine root density). A superior root system (granite) was apparently more beneficial than a higher water-holding capacity (shale). During the wet and relatively cool seasons (2007/08 and 2008/09), there were no observable soil parent material effects on leaf water potentials, implying that specific weather conditions may minimise or enhance the effects of

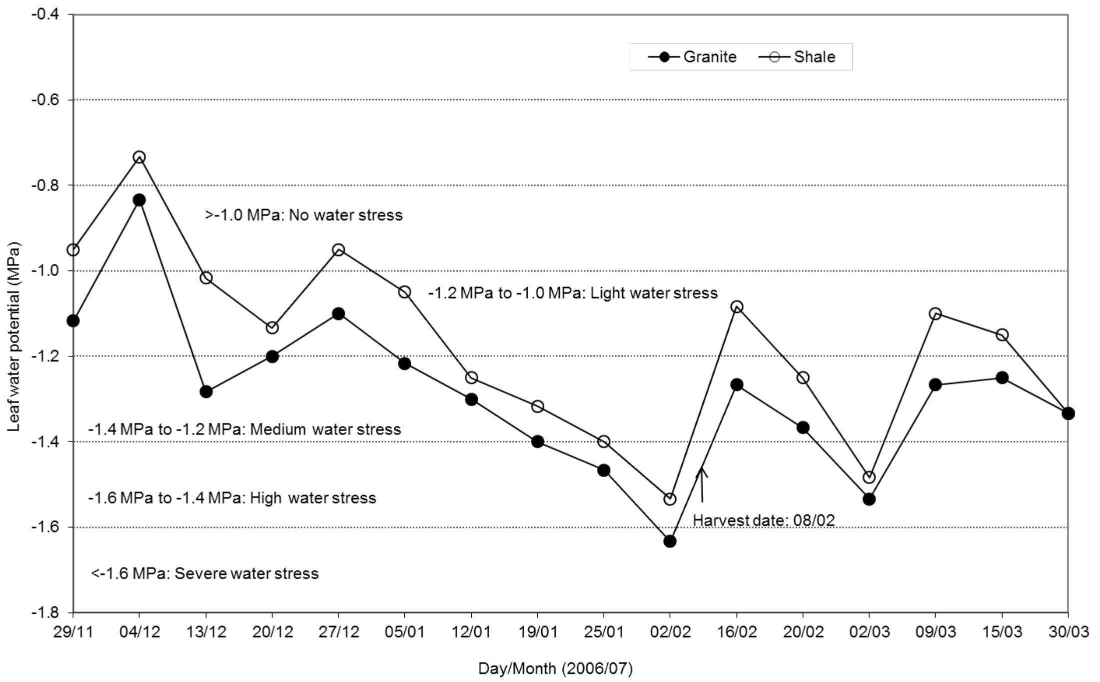


FIGURE 3A
Leaf water potential (LWP) curves for grapevines on granite-derived and shale-derived soils at a Sauvignon blanc locality (SH) in the Helderberg area (2006/07 season).

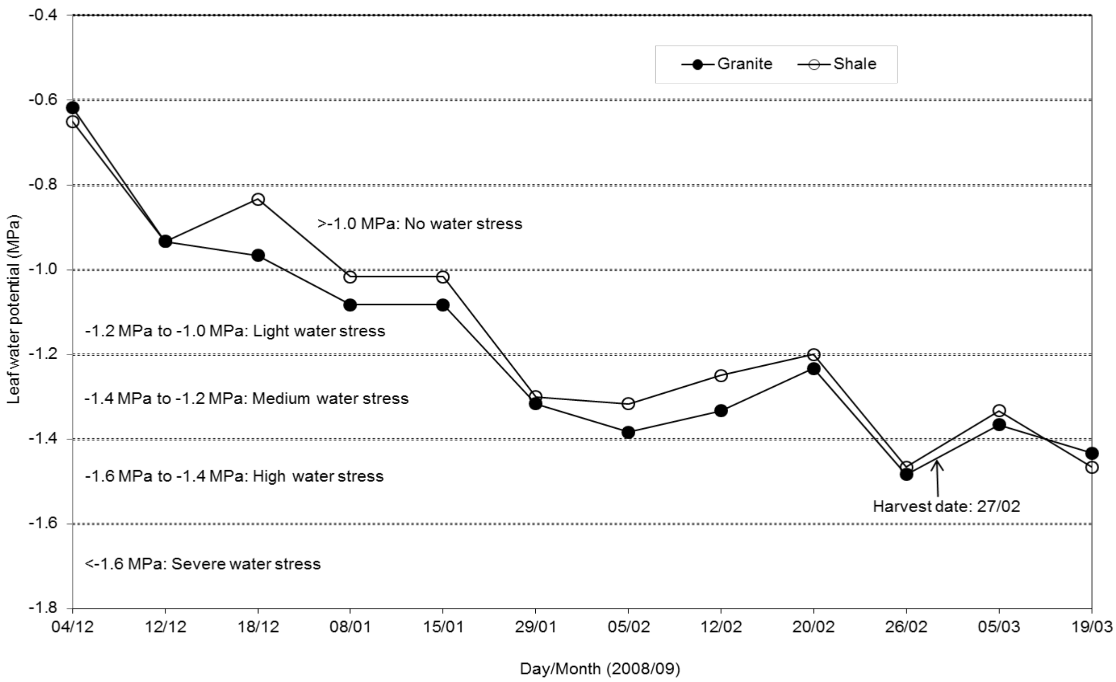


FIGURE 3B
Leaf water potential (LWP) curves for grapevines on granite-derived and shale-derived soils at a Sauvignon blanc locality (SH) in the Helderberg area (2008/09 season).

soil parent material and root performance on the grapevine's water status.

***Cane mass, yield, leaf layers and bunch parameters***
*Sauvignon blanc*
Cane mass, yield and number of leaf layers were not significantly affected by soil parent material at the site at the higher altitude (SH), but the yield of grapevines on granite-derived soil tended to be higher than that of vines on shale-derived soil. The latter could be ascribed to a higher number of bunches per grapevine for vines on the granite-derived soil. Slightly higher water constraints during the early part of the season for grapevines on the granite-derived soil may have been conducive to higher fertility. Furthermore, a steeper slope and a different aspect for grapevines on the shale-derived soil, in relation to those on the granite-

TABLE 5
Root distribution and density at different depths of granite-derived and shale-derived soils in Sauvignon blanc and Cabernet Sauvignon vineyards in the Helderberg area.

| Locality[1] | Scion/ Rootstock | Soil parent material | Root distribution (%) Fine roots (≤ 2.0 mm diameter) 0-300 mm | 300-600 mm | 600-900 mm | Thick roots (> 2.0 mm diameter) 0-300 mm | 300-600 mm | 600-900 mm | Root density per m$^2$ profile Fine roots (≤ 2.0 mm diameter) | Thick roots (> 2.0 mm diameter) |
|---|---|---|---|---|---|---|---|---|---|---|
| SH | Sauvignon blanc/ | Granite | 57 ± 11[2] | 29 ± 7 | 14 ± 8 | 42 ± 4 | 36 ± 7 | 23 ± 6 | 264 ± 112 | 56 ± 29 |
| | 110 Richter | Shale | 50 ± 14 | 33 ± 9 | 18 ± 7 | 45 ± 10 | 34 ± 8 | 22 ± 7 | 191 ± 92 | 102 ± 26 |
| SL | Sauvignon blanc/ | Granite | 28 ± 8 | 41 ± 9 | 30 ± 7 | 32 ± 13 | 41 ± 12 | 27 ± 11 | 171 ± 56 | 68 ± 20 |
| | 99 Richter | Shale | 22 ± 9 | 34 ± 9 | 44 ± 8 | 21 ± 7 | 49 ± 6 | 30 ± 6 | 103 ± 14 | 50 ± 11 |
| CL | Cabernet Sauvignon/ | Granite | 62 ± 15 | 25 ± 10 | 14 ± 16 | 65 ± 10 | 28 ± 11 | 8 ± 8 | 136 ± 36 | 36 ± 18 |
| | 110 Richter | Shale | 48 ± 15 | 32 ± 6 | 20 ± 16 | 40 ± 21 | 45 ± 17 | 15 ± 14 | 239 ± 122 | 57 ± 39 |
| CH | Cabernet Sauvignon/ | Granite | 46 ± 11 | 36 ± 9 | 18 ± 5 | 30 ± 12 | 45 ± 12 | 25 ± 8 | 325 ± 72 | 40 ± 7 |
| | 110 Richter | Shale | 46 ± 4 | 43 ± 4 | 11 ± 2 | 28 ± 17 | 53 ± 18 | 19 ± 13 | 218 ± 79 | 24 ± 10 |

[1]See Table 1 for a detailed description, [2]Values indicate means ± standard deviation (n = 6)

derived soil (Table 1), may also have affected some of the phenological growth stages. Grapevines on the granite-derived site were the first to receive morning sun and to bud. Cane mass, yield and the number of leaf layers were also unaffected by soil parent material at the lower altitude site, SL (Table 6). However, while cane masses were comparable for SH and SL, yield was significantly higher at SL, with the number of leaf layers indicating a denser canopy. The higher yield could be ascribed to larger berries, resulting in heavier bunches. Different rootstocks (99 Richter vs. 110 Richter) and slightly different management practices may have contributed to the latter and to the higher canopy density. Berry mass was highest for the granite-derived soil at SL (Table 6), but the reason for this phenomenon is not clear, although it is known that berry size may be affected by soil type (Conradie *et al*., 2002).

*Cabernet Sauvignon*

Cane mass, yield and number of leaf layers tended to be higher for the grapevines on the granite-derived than on the shale-derived soils at CL (Table 6). The slightly higher yield was due to more berries per bunch, resulting in a higher bunch mass. According to the number of leaf layers, the canopy at CH tended to be less dense than the one at CL, but cane mass and yield were slightly higher at CH. The latter was also due to more berries per bunch, resulting in a higher bunch mass. At CH, no soil parent material effects on grapevine characteristics could be detected.

Different grapevine characteristics, such as yield, cane mass, number of berries per bunch, etc., were affected to a greater extent by different localities and/or different rootstocks than by soil parent materials. However, at two of the localities (SH and CL), the yield of grapevines on granite-derived soils tended to be higher than that of vines on shale-derived soils.

## CONCLUSIONS

Particle size distribution, and especially a dominant sand grade, showed that shale-derived soils contained a higher percentage of fine sand than granite-derived soils, while granite-derived soils contained more coarse sand. On account of this, shale-derived soils can retain more water than granite-derived soils. Consequently, different irrigation regimes may be required for granite-derived and shale-derived soils. Hydrological properties of granite-derived and shale-derived soils should be researched further. Although total K (largely insoluble) was found to be higher in shale-derived soils, water-soluble K tends to be higher in granite-derived soils, suggesting that granite-derived soils may have a higher ability to release K. Due to this, it may be necessary to adjust K fertilisation guidelines depending on soil parent material. Root studies showed that soil preparation before planting negated the effects of soil parent material on root distribution. However, fine root density tended to be higher in the granite-derived soils. Grapevine water status may be affected to a greater extent by changes in environmental conditions than by soil parent material. However, the latter should still be considered during irrigation scheduling. Cane mass and yield generally tended to be higher for grapevines on granite-derived soils.

TABLE 6
Viticultural parameters for Sauvignon blanc and Cabernet Sauvignon grapevines on granite-derived and shale-derived soils at four different localities in the Helderberg area (means for five seasons, 2004/05 to 2008/09).

| Grapevine parameters | Sauvignon blanc | | | | Cabernet Sauvignon | | | |
|---|---|---|---|---|---|---|---|---|
| | SH | | SL | | CL | | CH | |
| | Granite | Shale | Granite | Shale | Granite | Shale | Granite | Shale |
| Cane mass (t/ha) | 3.58 a | 3.93 a | 3.60 a | 4.00 a | 4.54 b | 3.86 b | 5.87 a | 6.33 a |
| Yield (t/ha) | 6.54 b | 5.66 b | 9.03 a | 8.97 a | 6.51 ab | 5.54 b | 7.43 a | 7.61 a |
| Number of leaf layers | 3.28 b | 3.08 b | 4.58 a | 4.00 ab | 3.28 a | 3.08 ab | 2.83 b | 2.68 b |
| Bunch mass (g) | 135 b | 134 b | 183 a | 171 a | 143 ab | 128 b | 163 a | 158 a |
| Berry mass (g) | 1.65 c | 1.68 c | 2.01 a | 1.86 b | 1.35 a | 1.35 a | 1.40 a | 1.33 a |
| Number of berries per bunch | 95 a | 84 a | 86 a | 94 a | 115 a | 101 b | 122 a | 123 a |
| Number of bunches per vine | 19 a | 14 c | 17 b | 16 b | 18 a | 18 a | 19 a | 20 a |

*Different letters within the same row for each cultivar denote significant differences ($p \leq 0.1$)

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