ROOT DEVELOPMENT AND THE PERFORMANCE OF GRAPEVINES IN RESPONSE TO NATURAL AS WELL AS MAN-MADE SOIL IMPEDIMENTS

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Abstract:

Context and purpose of the study -The majority of soils used for wine and table grape production in South Africa are notoriously shallow, *i.e.* they are restricting root penetration. The result of such shallow soils is uneven and poor vineyard performance that eventually lead to unprofitable vineyards. The purpose of this study was to investigate soil impediments to root growth, methods to detect such impediments, and practices to alleviate obstructions before planting, as well as in existing vineyards.

Material and methods - Many investigations in South Africa have addressed the reasons for poor grapevine root development and methods to rectify this detrimental factor. This large body of knowledge is not only spread over different generations of researchers and experts, but also fragmented among many articles and journals. Starting with recommendations for "dynamite-ploughing" in 1912, all research on soil profile modification was reviewed and a synopsis made regarding soil conditions, root studies, grapevine response and corrective measures.

Results -Natural soil compaction is the main cause of root restriction in the majority of vineyard soils in the Western Cape, but man-made compaction through vehicle traffic and implement use occurs. Acid soils, *i.e.* pH_{KCl}< 5.5 are commonly found in the coastal areas of the Western Cape. Further impediments to grapevine root penetration include dense clay in the subsoil, various types of hardpan, water tables, rock and sharp transitions between soil layers of different textures. Plant holes incorrectly made can be a serious impediment to root distribution and poor growth of young vines.

Penetrometer measurement of soil resistance is the most practical, easiest and quickest method to detect the degree, position and extent of soil compaction. Grapevine root penetration is drastically impeded above 2000 kPa penetrometer readings. The EM38 apparatus that measures the bulk electrical conductivity of the soil, is also increasingly used to determine root restricting layers in the soil.

Grapevine root distribution is the most reliable, direct and accurate indicator of soil conditions. Root distribution of grapevines is generally shaped by soil conditions and cultivation practices and not by genetic traits of the rootstock. Scientific root studies in South Africa date back to the 1930's and include the profile wall method, core sampling, glass wall methods, excavation methods. A recent novel technique employed, is the scanning of roots against the walls of chambers made of perspex. In addition to deep tillage, shallow soils can be improved by ridging while loosening of the inter-row area is an option in existing vineyards that perform poorly. This should only be done when poor performance is due to soil compaction. Grapevine response to root pruning depends particularly on timing, severity of pruning and the presence or absence of roots in the inter-row area.

Keywords: soil compaction; penetrometer; root studies; re-compaction; root pruning; plant holes

1. Introduction

Good root distribution, *i.e*. deep, even and dense root systems, is needed for healthy and high yielding grapevines that are also buffered against drought and deficient nutrient applications. Soil layers that impede root growth, reduce the quantities of water and nutrients available to the plant. Furthermore, there is a balance between root size and aerial growth of grapevines. A restricted root system will consequently reduce above-ground growth.

In South Africa, soil compaction is the main impediment to vineyard roots, but soil acidity, water logging, salinity, soil stratification, hardpans, subsoil clays and rock are also limiting factors in many localities. Soil preparation aims to modify the soil in several ways before planting, namely to a) alleviate soil compaction, b) increase soil depth and improve poor soil physical structure, c) improve water storage, and d) allow deep chemical amelioration.

2. Materials and methods

Many investigations in South Africa have addressed the reasons for poor grapevine root development and methods to rectify this detrimental factor. This large body of knowledge is not only spread over different generations of researchers and experts, but also fragmented among many articles and journals. Starting with recommendations for "dynamite-ploughing" in 1912, all research on soil profile modification was reviewed and a synopsis made regarding soil conditions, root studies, grapevine response and corrective measures.

3. Results and discussion

3.1 Soil compaction

Soil compaction is well-defined by Mitchell & Berry (2001) as "the detrimental modification of the pore structure when total porosity is so reduced that aeration, root penetration and drainage are restricted, bulk density is increased and hydraulic conductivity and permeability are reduced". The visible results of such increases in soil strength, is increased difficulty in tillage and decreased root penetration.

Root penetration is affected by both soil porosity and soil strength. Compaction particularly reduces the volume and continuity of large pores (Hillel, 1980). Roots are unable to reduce in diameter in order to penetrate rigid pores narrower than the diameter of their root caps (Wiersum, 1957; Taylor & Bruce, 1968; Cannell, 1977). Therefore, if roots attempt to grow through a compacted soil they must be able to open the pores by exerting a large enough pressure to overcome the mechanical strength of the soil. Although instances of deep root penetration and even the splitting of rocks by root growth are well-known, the aim in productive vineyards is always to get maximum root distribution using minimum root pressure.

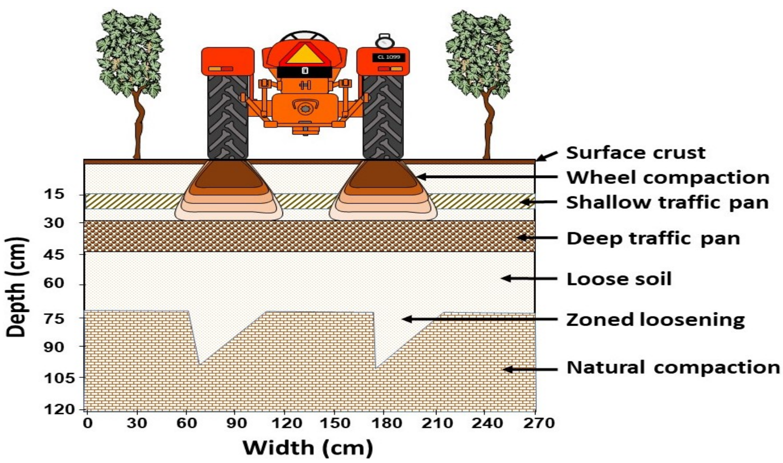

Fig. 1: Schematic illustration of the different types and positions of compaction generally found in vineyards (redrawn from Van Huyssteen, 1989).

Wine and table grapes are grown on a wide diversity of soils as well as under varying management practices, and consequently all types of compaction occur in vineyard soils (Figure1). Management of soil compaction therefore needs knowledge of how it happens, when it becomes harmful, how it affects root growth, and of course, how to rectify it. In South Africa soil compaction and other physical impediments to root growth are alleviated through deep tillage or through ridging of the soil. Various types of implements are available to achieve all kinds of loosening and mixing of the soil.

Soil compaction can occur naturally due to texture, wetness and the manner in which soils were formed *in situ.* Such naturally compact soils are the rule rather than the exception in the Western Cape of South Africa. Natural soil compaction – indeed any kind of compaction – prohibits, or seriously limits, root penetration (Figure 2).

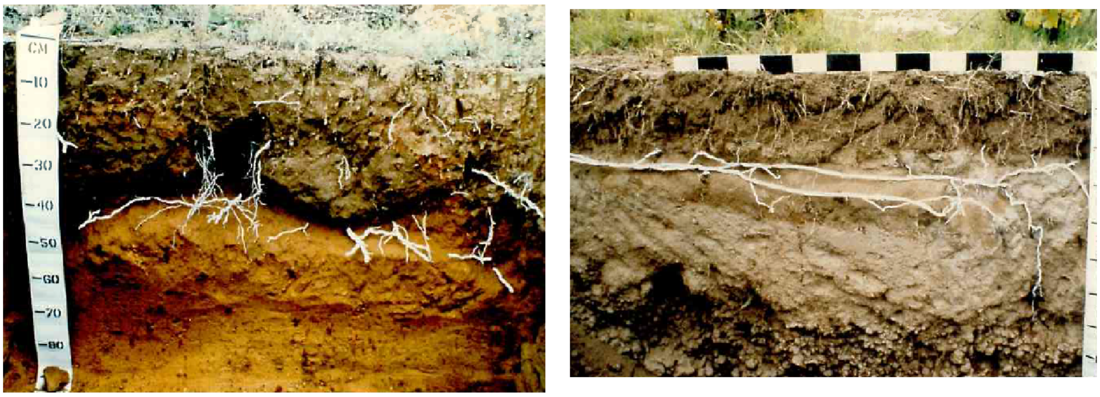

Fig. 2: Shallow grapevine rooting due to natural compaction in the subsoil (left) and a traffic pan (right). The vineyard on the right had to be uprooted due to poor performance (Photo's: ARC Infruitec-Nietvoorbij).

3.2 Detection of root impediments

Penetrometer resistance and bulk density were used in a pot experiment to determinethe effects of soil compaction in five soils on the performance of Chenin blanc/99R, (Van Huyssteen, 1988). The lower half of 85 dm^3 containers was filled with soil compacted to bulk densities between 1300 – 1700 kg/m^3 while the upper half was loosely filled with the same soil and allowed to consolidate naturally. Root penetration into the subsoil decreased with increasing compaction, but no critical bulk density or penetrometer resistance were found at which root growth stopped abruptly. This experiment clearly demonstrated the favourable effect of loose soil with regard to root growth and also above-ground grapevine performance(Figure3).

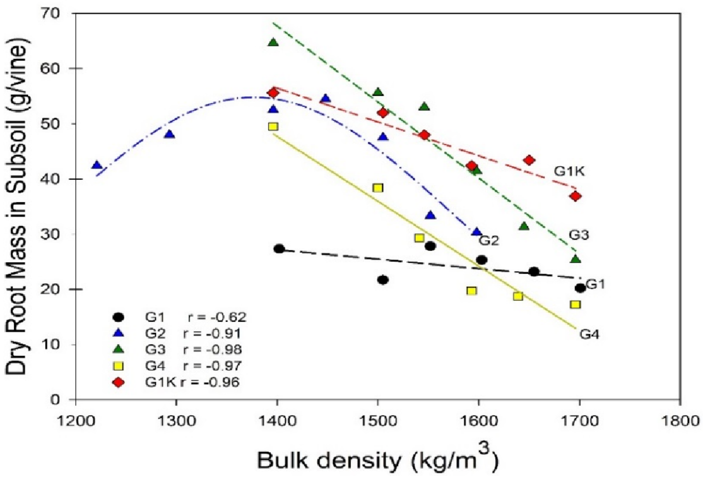

Fig. 3: Relationship between dry root mass and bulk density for five soil types: G1-Glenrosa, G2-calcareous Hutton, G3-Estcourt, G4-Hutton, and G1K-Limed Glenrosa (redrawn after Van Huyssteen, 1988).

A difficulty experienced in some of the early soil preparation field trials was the inability of implements to penetrate to the specified soil depth. In a follow-up study, a penetrometer was used to assess the accuracy of the treatments with regard to effective soil depth in the Stellenbosch and Robertson experiments mentioned above. Effective soil depth determined by the penetrometer showed a highly significant correlation with grapevine performance (Table 1). This linear relationship however, did not indicate an optimum soil depth for vine performance.

Table1: Relationship between effective soil depth and grapevine performance established in soil preparation trials conducted at Stellenbosch and Robertson (adapted from Van Huyssteen, 1988).

Locality	Soil form	Average soil texture in B horizon			Relationship	Correlation coefficient
		Sa	Si	Cl		
Stellenbosch	Hutton/Clovelly	62.3	11.3	26.4	Y = 0.79x + 73.5 Z = 0.13x + 13.7	0.72** 0.81**
Robertson	Hutton/Sterkspruit	57.6	11.4	31.0	Y = 1.01x + 135.7	0.68** 0.67**

Sa: Total sand fraction (%) (2.0-0.02 mm); Si: Silt (%) (0.02-0.002 mm); Cl: Clay (%) (<0.002 mm)
Y = cumulative grape yield (t/ha)
Z = cumulative pruning mass (t/ha)
X = soil depth (cm)

Penetrometer measurements are easy and rapid to do and enable the user to easily measure soil strength in many places per plot. In contrast, bulk density and other measurements of soil compaction are laborious and time-consuming, a fact that leaves little choice as to the preferred method to determine the degree, position and extent of compaction.Generally, root penetration decreases approximately linearly with increasing penetrometer resistance. Values of 2000 to 2500 kPa have been reported in many studies as the critical penetrometer resistance for various crops and penetrometer probes *e.g.* by Taylor & Burnett (1964) and Bengough *et al*. (2011).A value of 2000 kPa is being used in South Africa as the critical penetrometer resistance for grapevines. This value can be reached either by increasing soil compaction or by decreasing water content of the soil, *i.e.* by drying of the soil.

An instrument that measures the bulk electrical conductivity of the soil, namely the EM38 apparatus, is also increasingly used to determine root restricting layers in the soil. More formal experiments are, however, needed to determine its effectivity in detecting and quantifying root restrictions in vineyard soils.

3.3 Recompaction

A key question regarding deep soil preparation has always been, "will the soil re-compact and how long will it take?"The positive effects of deep soil preparation can become undone through re-compaction which can either be man-made or due to natural processes. Wheel tractors normally used in vineyards can have a marked effect on soil compaction (Van Huyssteen, 1983). He showed that the first passage of tractor wheels over loose soil of granitic origin caused a 15% drop in the soil surface under the tracks, as well as a significant increase in soil strength down to 45 cm (Figure 4). A second passage of the tractor wheels significantly increased the soil strength in the 0-15 cm depth only. Most of the re-compaction occurred within the first few months after the vineyard was planted. Consequently, wheel tractors should not be used on newly-prepared soil for at least one year after planting, *i.e.* until rootshave exploited the entire available soil volume.

Soil re-compaction is clearly a function of time and, amongst others, also of soil type. In a study to determine the long-term effects of deep soil preparation in the coastal region of South Africa, root distribution still reflected the positive effect of deep soil preparation 26 years after it had been carried out(Hoffman *et al*., 2016). An explanation for this long-term benefit of soil preparation is the fact that roots can explore the full potential rooting depth within 2 years after planting thus establishing the root frame very early, *i.e.* before re-compaction normally takes place. Thereafter rooting depth remains constant, but rooting density increases with time.At this stage, the recommendation to growers is to redo soil preparation on all soils after the productive life time (20 – 25 years) of a vineyard has expired.

3.4 Root response to soil conditions

Grapevine root distribution is the most reliable, direct and accurate indicator of soil conditions. Unfavourable conditions in the soil, *e.g.* compaction and low pH, will be indicated by roots that cannot adequately penetrate such horizons, while roots which are well distributed laterally and vertically are proof of favourable soil properties.

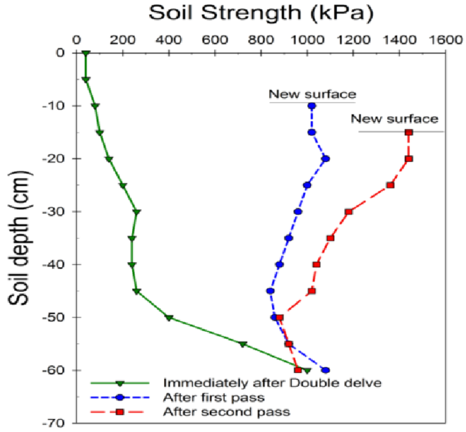

Fig. 4: Re-compaction due to a varying number of passes by tractor wheels on loose soil (redrawn after Van Huyssteen, 1983).

Smart *et al.* (2006) found, on average, over all species and hybrids of grapevines, that 63.2% of grapevine roots were in the upper 60 cm of soil and 79.6 % within the upper 1.0 m. This analysis provides supporting evidence for the observation of Saayman & Van Huyssteen (1983) that a rooting depth of less than 60 cm was not amenable to developing a root system capable of sustaining productivity under dryland conditions. Currently this view is still being observed in South Africa. Root studies, as well as routine inspections of grapevine root distribution in vineyards, almost never show a complete stop of root penetration at a specific depth in thesubsoil. A few roots will almost always penetrate deeper along fissures and cracks in the soil profile. Such roots will probably not contribute to the normal performance of a vineyard, but they do become important during periods of drought or under dryland conditions, *i.e.* they will help the grapevine to survive.

In a South African pot experiment withChenin blanc/99R, the ratio of aboveground to belowground dry mass remained constant irrespective of the soil compaction levels(Van Huyssteen, 1988). These ratios did however, vary quite considerably among soil types, namely from 0.23-0.49. The potted vines therefore did not show compensatory root growth in the loose topsoil because of the compact subsoil. The ability of grapevines to establish a balance between aboveground and belowground growth seems to be an important mechanism for the vine to adapt to diverse soil conditions.

The root systems of grapevines in South Africa are almost without exception shaped by soil conditions and cultivation practices such as tillage and planting density instead of the genetic traits of the rootstock. A comprehensive analysis and review of grapevine rooting systems by Smart *et al*. (2006) supported this conclusion. Assessment of grapevine root distribution in existing vineyards can, therefore, give an excellent indication of which type of soil preparation would be necessary when vineyards have to be replanted. Similarly, root distribution will clearly show how effective soil preparation was before planting (Figure 5).

Fig. 5: Good root distribution in a vineyard after effective deep soil preparation. Root ends were painted white for better visibility (Photo: ARC Infruitec-Nietvoorbij).

3.5 Root studies

Mapping of the vertical and horizontal distribution of roots against a profile wall is a very simple method that has been widely used for grapevine root studies. The assumption here that the three-dimensional root distribution around a grapevine is uniform may not always be true. Nevertheless, the profile wall method answers most of the basic questions regarding soil conditions, *i.e.* the maximum depth that roots can grow to and the presence of soil layers that do not allow exploitation by roots. Several other methods have also been used for studying root distribution in vineyards, namely core sampling (Brink, 2005), glass wall method (Van Zyl, 1984) and root excavation (Saayman & Van Huyssteen, 1980). Mini-rhizotrons, consisting of underground transparent tubes and a camera system have so far only been used on fruit trees in South Africa.

A further innovation used successfully to study root growth recently, demonstrated that technology will undoubtedly make it ever easier and cheaper to study roots in future. In a study on apples, Stofberg (2018) used an ordinary document scanner to successfully scan roots against the walls of perspex chambers in a young apple orchard (Figure 6). Before installation, a grid that showed the exact position of the roots was engraved on the perspex sides of the chamber. The scanner was inserted into the chamber and the sides scanned in sections while images were captured on a laptop computer.

Fig. 6: Perpex chamber permanently installed in the soil (left) and quality of root images (right) scanned inside the chamber using an ordinary document scanner (Stofberg, 2018) (Photo's: JE. Hoffman).

3.6 Root pruning

The partial cutting of roots (root pruning) deprives the grapevine of access to water and nutrients, but stimulates formation of new roots close to the severed ends(Van Zyl & Van Huyssteen, 1987). As a consequence, root pruning can either be used to curb excessive vegetative growth or increase performance of declining vineyards when such a decline is due to compaction.Grapevine response to root pruning depends particularly on its timing and severity. In South Africa root pruning is recommended after harvest in autumn to improve shoot growth and yield of vineyards that decline as a result of soil compaction. Optimum irrigation and fertilisation programmes should be maintained after root pruning in order to enhance root regeneration and growth into the loosened soil. Root pruning should be done on one side of the vine row in the first year, followed by ripping the other side of the row in the following year. This process should not be repeated more regularly than once in five years, and only if re-compaction dictates it.

The presence or absence of roots in the inter-row area will also affect grapevine response to root cutting(McCarthy *et al*., 2010). In experiments with no or only few roots in the mid-row area, grapevine performance showed little change initially and then surpassed the yield of a control within three years. A decrease in canopy size and yield can be expected following ripping of the inter-row when a significant number of roots were already present prior to root pruning. Grapevines should, however, improve above their initial performance in the third vintage after root pruning and thereafter show increased yield and vigour. The longevity of root pruning benefits is still uncertain.

New results showed a large beneficial effect on grapevine performance when root pruning was combined with the incorporation of compost.Root pruning *per se* had no positive effect on vegetative growth and yield, but when compost was combined with the two tillage operations, yield and cane mass improved significantly during the two consecutive seasons immediately after the treatments were applied (Moffat, 2017).

Loosening of compacted soil between vine rows should be done to a depth of 50-60 cm. An excavator is the ideal implement, when compost is to be incorporated into the soil. Rippers will also accomplish the task, but cannot incorporate any ameliorant into the soil.The loosening of the inter-row area and the inevitable pruning of roots, to improve performance, should only be done when poor performance is due to soil compaction.

3.7 Plant holes

It is not uncommon to see young vineyards growing poorly and/or unevenly. Such unwanted results may have many causes, but root studies showed that this is often caused by re-compaction of wheel traffic on loosened soil before the vineyard was established or by inadequate plant holes. In a case study, the reasons for uneven growth problems were investigated by means of root studies and the use of a penetrometer and bulk density determinations (Louw & Van Huyssteen, 1993). Their study showed that soil compaction, high soil strengths, and smeared planes are the main causes of problems with plant holes. Roots having to grow from loose soil in a plant hole to more compact soil outside must force soil particles out of the way through longitudinal growth. The medium from which the root is growing has consequently to be firm enough to support the root section behind the tip, otherwise the root will buckle (so-called root buckling stress) (Figure7) and grow in another direction (Dexter & Hewitt, 1978).A good preventative measure will consequently be lightly stamping down the soil with which the plant holes are filled to support the roots.

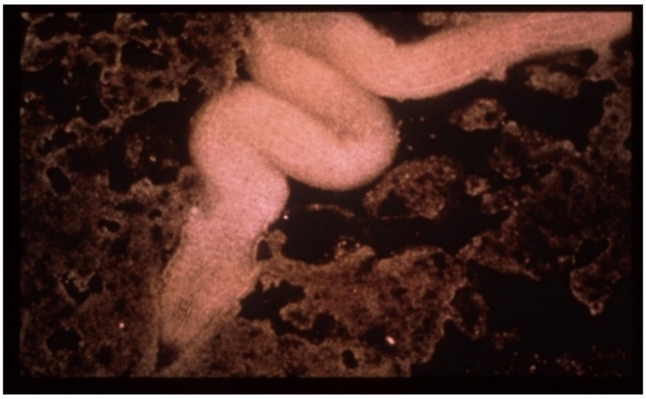

Fig. 7: Buckling of root because growth medium behind root tip is not firm enough to support the root (Photo: WE Wildman, Univ. California, Davis).

In the past, to save time and costs, growers have tried planting grapevines in small furrows made by a spade (Figure 8) or directly in ripper furrows and even, using crowbars, in holes having the diameter of the crowbar shaft. These practices restrict root development and shoot growth suffers as a consequence. In most soils, except on very loose and sandy ones, a fork should be used to dig plant holes since it causes less compaction than a spade (Archer & Hunter, 2010). When spades are used to dig plant holes, a fork can be employed to just loosen the sides and bottom of the hole. This will allow roots to easily expand in all directions and use the soil volume maximally.

A potting effect can also be created by plant holes with smeared sides, round plant holes (Westwood, 1978; Louw & Van Huyssteen, 1993) and plant holes in heavy-textured soils filled up with different soil of a lighter texture, e.g. sand. Smearing and compaction of the sides of plant holes can be minimised by not working in soils which are too wet. As a rule of thumb, plant holes should not be dug while the soil still sticks to the spade. Furthermore, plant holes should not be re-filled with material - including organic material and inorganic fertilizer - other than what was removed while digging them. This will eliminate the risk of roots being restricted to lighter-textured porous material used to fill up plant holes in clayey soils (Westwood, 1978; Nicolosi & Fretz, 1980). A disadvantage of round plant holes is the angle of incidence between root tips and the side of the hole. The larger the angle of incidence, the easier a root will grow parallel to the soil layer instead of penetrating it. Square plant holes with uneven sides are the best.

Sophisticated grapevine machine planters are available on the market and will replace the manual planting of grapevines in future. The principles that are involved to prevent root restrictions, however, remain the same.

Fig. 8: Confined root systems shaped by compaction outside the plant hole (left) and a small furrow made by a spade. The spade caused compaction on the sides of the furrow.

4. Conclusion

The particular technique used in soil preparation*i.e*. modification of the soil profile by deep tillage or other methods, is determined by soil type and the nature of the root impediments present. In addition to soil profile inspection, instruments such as the penetrometer can be used to accurately and easily detect soil compaction in vineyards. Root distribution is the most accurate and direct indicator of soil conditions and therefore a good knowledge of root behaviour is essential when soil preparation is considered. Soils that were loosened re-compact again, but prediction of the longevity of soil loosening by deep tillage before re-compaction sets in again, is still lacking. Uneven growth of young vineyards is a typical sign of re-compaction caused by vehicle traffic or of inadequate plant holes. In the end it will be important to decide which kind of implement will be best suited to rectify a specific soil condition. Soil preparation can improve a soil, but if poor subsoil is *e.g.* ploughed to the surface, the end will be worse than the beginning.

5. Acknowledgements

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