VISUAL SOIL ASSESSMENT

FIELD GUIDE

Vineyards

BioAgriNomics

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List of acronyms

AEC	Adenylate energy charge
Al	Aluminium
ATP	Adenosine triphosphate
B	Boron
Ca	Calcium
Cu	Copper
Fe	Iron
K	Potassium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
P	Phosphorus
RSG	Restricted spring growth
S	Sulphur
VS	Visual score
VSA	Visual Soil Assessment
Zn	Zinc

Visual Soil Assessment

Introduction

The maintenance of good soil quality is vital for the environmental and economic sustainability of vineyards. A decline in soil quality has a marked impact on vine growth, grape quality, production costs and the risk of soil erosion. Therefore, it can have significant consequences on society and the environment. A decline in soil physical properties in particular takes considerable time and cost to correct. Safeguarding soil resources for future generations and minimizing the ecological footprint of viticulture are important tasks for land managers.

Often, not enough attention is given to:

- the basic role of soil quality in efficient and sustained production;
- the effect of the condition of the soil on the gross profit margin;
- the long-term planning needed to sustain good soil quality;
- the effect of land management decisions on soil quality.

Soil type and the effect of management on the condition of the soil are important determinants of the character and quality of wine, and have profound effects on long-term profits. Land managers need tools that are reliable, quick and easy to use in order to help them assess the condition of their soils and their suitability for growing grapes, and to make informed decisions that lead to sustainable land and environmental management. To this end, the Visual Soil Assessment (VSA) provides a quick and simple method to assess soil condition and plant performance. It can also be used to assess the suitability and limitations of a soil for viticulture. Soils with good VSA scores will usually give the best production with the lowest establishment and operational costs.

The VSA method

Visual Soil Assessment is based on the visual assessment of key soil ‘state’ and plant performance indicators of soil quality, presented on a scorecard. Soil quality is ranked by assessment of the soil indicators alone. Plant indicators require knowledge of the growing history of the crop. This knowledge will facilitate the satisfactory and rapid completion of the plant scorecard. With the exception of soil texture, the soil and plant indicators are dynamic indicators, i.e. capable of changing under different management regimes and land-use pressures. Being sensitive to change, they are useful early warning indicators of changes in soil condition and plant performance and as such provide an effective monitoring tool.

Plant indicators allow you to make cause-and-effect links between management practices and soil characteristics. By looking at both the soil and plant indicators, VSA links the natural resource (soil) with plant performance and farm enterprise profitability. Because of this, the soil quality assessment is not a combination of the ‘soil’ and ‘plant’ scores. Rather, the scores should be looked at separately, and compared.

Visual scoring

Each indicator is given a visual score (VS) of 0 (poor), 1 (moderate), or 2 (good), based on the soil quality and plant performance observed when comparing the soil and plant with three photographs in the field guide manual. The scoring is flexible, so if the sample you are assessing does not align clearly with any one of the photographs but sits between two, an in-between score can be given, i.e. 0.5 or 1.5. Because some soil and plant indicators are relatively more important in the assessment of soil quality and plant performance than others, VSA provides a weighting factor of 1, 2 and 3. The total of the VS rankings gives the overall Soil Quality Index and Plant Performance Index for the site. Compare these with the rating scale at the bottom of the scorecard to determine whether your soil and plants are in good, moderate or poor condition.

Placing the soil and plant assessments side by side at the bottom of the plant indicator scorecard should prompt you to look for reasons if there is a significant discrepancy between the soil and plant indicators.

The VSA tool kit

The VSA tool kit (Plate 1) comprises:

- **A SPADE** – to dig a soil pit and to take a 200-mm cube of soil for the drop shatter soil structure test;
- **A PLASTIC BASIN** (about 450 mm long x 350 mm wide x 250 mm deep) – to contain the soil during the drop shatter test;
- **A HARD SQUARE BOARD** (about 260x260 x20 mm) – to fit in the bottom of the plastic basin on to which the soil cube is dropped for the shatter test;
- **A HEAVY-DUTY PLASTIC BAG** (about 750x 500 mm) – on which to spread the soil, after the drop shatter test has been carried out;
- **A KNIFE** (preferably 200 mm long) to investigate the soil pit and potential rooting depth;
- **A WATER BOTTLE** – to assess the field soil textural class;
- **A TAPE MEASURE** – to measure the potential rooting depth;
- **A VSA FIELD GUIDE** – to make the photographic comparisons;
- **A PAD OF SCORECARDS** – to record the VS for each indicator.

PLATE 1 **The VSA tool kit**

The procedure

When it should be carried out

The test should be carried out when the soils are moist and suitable for cultivation. If you are not sure, apply the 'worm test'. Roll a worm of soil on the palm of one hand with the fingers of the other until it is 50 mm long and 4 mm thick. If the soil cracks before the worm is made, or if you cannot form a worm (for example, if the soil is sandy), the soil is suitable for testing. If you can make the worm, the soil is too wet to test.

Setting up

Time

Allow 25 minutes per site. For a representative assessment of soil quality, sample 4 sites over a 5-ha area.

Reference sample

Take a small sample of soil (about 100x50x150 mm deep) from under a nearby fence or a similar protected area. This provides an undisturbed sample required in order to assign the correct score for the soil colour indicator. The sample also provides a reference point for comparing soil structure and porosity.

Sites

Select sites that are representative of the vineyard. The condition of the soil in vineyards is site specific. Sample sites that have had little or no wheel traffic (e.g. near the vine). The VSA method can also be used to assess compacted areas by selecting to sample along wheel traffic lanes. Always record the position of the sites for future monitoring if required.

Site information

Complete the site information section at the top of the scorecard. Then record any special aspects you think relevant in the notes section at the bottom of the plant indicator scorecard.

Carrying out the test

Initial observation

Dig a small hole about 200x200 mm square by 300 mm deep with a spade and observe the topsoil (and upper subsoil if present) in terms of its uniformity, including whether it is soft and friable or hard and firm. A knife is useful to help you assess this.

Take the test sample

If the topsoil appears uniform, dig out a 200-mm cube with the spade.

You can sample whatever depth of soil you wish, but ensure that you sample the equivalent of a 200-mm cube of soil. If for example, the top 100 mm of the soil is compacted and you wish to assess its condition, dig out two samples of 200x200x100 mm with a spade. If the 100–200-mm depth is dominated by a tillage pan and you wish to assess its condition, remove the top 100 mm of soil and dig out two samples of 200x200x100 mm. Note that taking a 200-mm cube sample below the topsoil can also give valuable information about the condition of the subsoil and its implications for plant growth and farm management practices.

The drop shatter test

Drop the test sample a maximum of three times from a height of 1 m onto the wooden square in the plastic basin. The number of times the sample is dropped and the height it is dropped from, is dependent on the texture of the soil and the degree to which the soil breaks up, as described in the section on soil structure.

Systematically work through the scorecard, assigning a VS to each indicator by comparing it with the photographs (or table) and description reported in the field guide.

The plant indicators

Many plant indicators cannot be assessed at the same time as the soil indicators. Ideally, the plant performance indicators should be observed at the appropriate time during the season. The plant indicators are scored and ranked in the same way as soil indicators: a weighting factor is used to indicate the relative importance of each indicator, with each contributing to the final determination of plant performance. The Plant Performance Index is the total of the individual VS rankings in the right-hand column.

Format of the booklet

The soil and plant scorecards are given in Figures 1 and 3, respectively, and list the key indicators required in order to assess soil quality and plant performance. Each indicator is described on the following pages, with a section on how to assess the indicator and an explanation of its importance and what it reveals about the condition of the soil and about plant performance.

FIGURE 1 **Soil scorecard – visual indicators for assessing soil quality in vineyards**

Landowner:

Land use:

Site location:

GPS ref:

Sample depth:

Date:

Soil type:

Soil classification:

Drainage class:

Textual group (upper 1 m):	☐ Sandy	☐ Loamy	☐ Silty	☐ Clayey	☐ Other
Moisture condition:	☐ Dry	☐ Slightly moist	☐ Moist	☐ Very moist	☐ Wet
Seasonal weather conditions:	☐ Dry	☐ Wet	☐ Cold	☐ Warm	☐ Average

Visual indicators of soil quality		Visual score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS ranking
Soil texture	pg. 2		x 3	
Soil structure	pg. 4		x 2	
Soil porosity	pg. 6		x 3	
Soil colour	pg. 8		x 1	
Number and colour of soil mottles	pg. 10		x 2	
Earthworms (Number =) (Av. size =)	pg. 12		x 3	
Potential rooting depth (m)	pg. 14		x 3	
Surface ponding	pg. 18		x 2	
Surface crusting and surface cover	pg. 20		x 2	
Soil erosion (wind/water)	pg. 22		x 2	
SOIL QUALITY INDEX (sum of VS rankings)				

Soil Quality Assessment	Soil Quality Index
Poor	< 15
Moderate	15–30
Good	> 30

Assessment

1. Take a small sample of soil (half the size of your thumb) from the topsoil and a sample (or samples) that is (or are) representative of the subsoil.
2. Wet the soil with water, kneading and working it thoroughly on the palm of your hand with your thumb and forefinger to the point of maximum stickiness.
3. Assess the texture of the soil according to the criteria given in Table 1 by attempting to mould the soil into a ball.

With experience, a person can assess the texture directly by estimating the percentages of sand, silt and clay by feel, and the textural class obtained by reference to the textural diagram (Figure 2).

There are occasions when the assignment of a textural score will need to be modified because of the nature of a textural qualifier. For example, if the soil has a reasonably high content of organic matter, i.e. is humic with 15–30 percent organic matter, raise the textural score by one (e.g. from 0 to 1 or from 1 to 2). If the soil has a significant gravelly or stony component, reduce the textural score by 0.5.

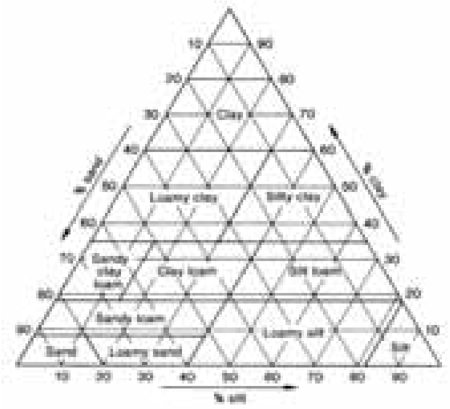
There are also occasions when the assignment of a textural score will need to be modified because of the specific preference of a crop for a particular textural class. For example, asparagus prefers a soil with a sandy loam texture and so the textural score is raised by 0.5 from a score of 1 to 1.5 based on the specific textural preference of the plant.

Importance

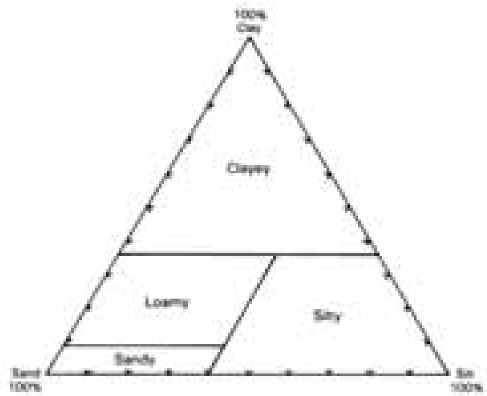
SOIL TEXTURE defines the size of the mineral particles. Specifically, it refers to the relative proportion of the various size-groups in the soil, i.e. sand, silt and clay. Sand is that fraction that has a particle size > 0.06 mm; silt varies between 0.06 and 0.002 mm; and the particle size of clay is < 0.002 mm. Texture influences soil behaviour in several ways, notably through its effect on: water retention and availability; soil structure; aeration; drainage; soil trafficability; soil life; and the supply and retention of nutrients.

A knowledge of both the textural class and the potential rooting depth enables an approximate assessment of the total water-holding capacity of the soil, one of the major drivers of crop production.

FIGURE 2 **Soil texture classes and groups**



Textural classes.



Textural groups.

TABLE 1 **How to score soil texture**

Visual score (VS)	Textural class	Description
2 [Good]	Silt loam	Smooth soapy feel, slightly sticky, no grittiness. Moulds into a cohesive ball that fissures when pressed flat.
1.5 [Moderately good]	Clay loam	Very smooth, sticky and plastic. Moulds into a cohesive ball that deforms without fissuring.
1 [Moderate]	Sandy loam	Slightly gritty, faint rasping sound. Moulds into a cohesive ball that fissures when pressed flat.
0.5 [Moderately poor]	Loamy sand Silty clay Clay	Loamy sand: Gritty and rasping sound. Will almost mould into a ball but disintegrates when pressed flat. Silty clay, clay: Very smooth, very sticky, very plastic. Moulds into a cohesive ball that deforms without fissuring.
0 [Poor]	Sand	Gritty and rasping sound. Cannot be moulded into a ball.

Assessment

1. Remove a 200-mm cube of topsoil with a spade (between or along wheel tracks).
2. Drop the soil sample a maximum of three times from a height of 1 m onto the firm base in the plastic basin. If large clods break away after the first or second drop, drop them individually again once or twice. If a clod shatters into small (primary structural) units after the first or second drop, it does not need dropping again. Do not drop any piece of soil more than three times. For soils with a sandy loam texture (Table 1), drop the cube of soil just once only from a height of 0.5 m.
3. Transfer the soil onto the large plastic bag.
4. For soils with a loamy sand or sand texture, drop the cube of soil still sitting on the spade (once) from a height of just 50 mm, and then roll the spade over, spilling the soil onto the plastic bag.
5. Applying only very gently pressure, attempt to part each clod by hand along any exposed cracks or fissures. If the clod does not part easily, do not apply further pressure (because the cracks and fissures are probably not continuous and, therefore, are unable to readily conduct oxygen, air and water).
6. Move the coarsest fractions to one end and the finest to the other end. Arrange the distribution of aggregates on the plastic bag so that the height of the soil is roughly the same over the whole surface area of the bag. This provides a measure of the aggregate-size distribution. Compare the resulting distribution of aggregates with the three photographs in Plate 2 and the criteria given.

The method is valid for a wide range of moisture conditions but is best carried out when the soil is moist to slightly moist; avoid dry and wet conditions.

Importance

SOIL STRUCTURE is extremely important for vineyards. It regulates:

- soil aeration and gaseous exchange rates;
- soil temperature;
- soil infiltration and erosion;
- the movement and storage of water;
- nutrient supply;
- root penetration and development;
- soil workability;
- soil trafficability;
- the resistance of soils to structural degradation.

Good soil structure reduces the susceptibility to compaction under wheel traffic and increases the window of opportunity for vehicle access and for carrying out no-till, minimum-till or conventional cultivation between rows under optimal soil conditions.

Soil structure is ranked on the size, shape, firmness, porosity and relative abundance of soil aggregates and clods. Soils with good structure have friable, fine, porous, subangular and subrounded (nutty) aggregates. Those with poor structure have large, dense, very firm, angular or subangular blocky clods that fit and pack closely together and have a high tensile strength.

PLATE 2 **How to score soil structure**

GOOD CONDITION VS = 2
Soil dominated by friable, fine aggregates with no significant clodding. Aggregates are generally subrounded (nutty) and often quite porous.

MODERATE CONDITION VS = 1
Soil contains significant proportions (50%) of both coarse clods and friable fine aggregates. The coarse clods are firm, subangular or angular in shape and have few or no pores.

POOR CONDITION VS = 0
Soil dominated by coarse clods with very few finer aggregates. The coarse clods are very firm, angular or subangular in shape and have very few or no pores.

Assessment

1. Remove a spade slice of soil (about 100 mm wide, 150 mm long and 200 mm deep) from the side of the hole and break it in half.
2. Examine the exposed fresh face of the sample for soil porosity by comparing against the three photographs in Plate 3. Look for the spaces, gaps, holes, cracks and fissures between and within soil aggregates and clods.
3. Examine also the porosity of a number of the large clods from the soil structure test. This provides important additional information as to the porosity of the individual clods (the intra-aggregate porosity).

Importance

It is important to assess **SOIL POROSITY** along with the structure of the soil. Soil porosity, and particularly macroporosity (or large pores), influences the movement of air and water in the soil. Soils with good structure have a high porosity between and within aggregates, but soils with poor structure may not have macropores and coarse micropores within the large clods, restricting their drainage and aeration.

Poor aeration leads to the build up of carbon dioxide, methane and sulphide gases, and reduces the ability of plants to take up water and nutrients, particularly nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). Plants can only utilize S and N in the oxygenated sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) forms. Therefore, plants require aerated soils for the efficient uptake and utilization of S and N. The number, activity and biodiversity of micro-organisms and earthworms are also greatest in well-aerated soils and they are able to decompose and cycle organic matter and nutrients more efficiently.

The presence of soil pores enables the development and proliferation of the superficial (or feeder) roots throughout the soil. Vine roots are unable to penetrate and grow through firm, tight, compacted soils, severely restricting the ability of the plant to utilize the available water and nutrients in the soil. A high penetration resistance not only limits plant uptake of water and nutrients, it also reduces fertilizer efficiency considerably and increases the susceptibility of the plant to root diseases.

Soils with good porosity will also tend to produce lower amounts of greenhouse gases. The greater the porosity, the better the drainage, and, therefore, the less likely it is that the soil pores will be water-filled to the critical levels required to accelerate the production of greenhouse gases. Aim to keep the soil porosity score above 1.

PLATE 3 **How to score soil porosity**

GOOD CONDITION VS = 2
Soils have many macropores and coarse micropores between and within aggregates associated with good soil structure.

MODERATE CONDITION VS = 1
Soil macropores and coarse micropores between and within aggregates have declined significantly but are present on close examination in parts of the soil. The soil shows a moderate amount of consolidation.

POOR CONDITION VS = 0
No soil macropores and coarse micropores are visually apparent within compact, massive structureless clods. The clod surface is smooth with few or no cracks or holes, and can have sharp angles.

Assessment

❶ Compare the colour of a handful of soil from the field site with soil taken from under the nearest fenceline or a similar protected area.

❷ Using the three photographs and criteria given (Plate 4), compare the relative change in soil colour that has occurred.

As topsoil colour can vary markedly between soil types, the photographs illustrate the degree of change in colour rather than the absolute colour of the soil.

Importance

SOIL COLOUR is a very useful indicator of soil quality because it can provide an indirect measure of other more useful properties of the soil that are not assessed so easily and accurately. In general, the darker the colour is, the greater is the amount of organic matter in the soil. A change in colour can give a general indication of a change in organic matter under a particular land use or management. Soil organic matter plays an important role in regulating most biological, chemical and physical processes in soil, which collectively determine soil health. It promotes infiltration and retention of water, helps to develop and stabilize soil structure, cushions the impact of wheel traffic and cultivators, reduces the potential for wind and water erosion, and maintains the soil carbon 'sink'. Organic matter also provides an important food resource for soil organisms and is an important source of, and major reservoir of, plant nutrients. Its decline reduces the fertility and nutrient-supplying potential of the soil; N, P, K and S requirements of vines increase markedly, and other major and minor elements are leached more readily. The result is an increased dependency on fertilizer input to maintain nutrient status.

Soil colour can also be a useful indicator of soil drainage and the degree of soil aeration. In addition to organic matter, soil colour is influenced markedly by the chemical form (or oxidation state) of iron (Fe) and manganese (Mn). Brown, yellow-brown, reddish-brown and red soils without mottles indicate well-aerated, well-drained conditions where Fe and Mn occur in the oxidized form of ferric (Fe^{3+}) and manganic (Mn^{3+}) oxides. Grey-blue colours can indicate that the soil is poorly drained or waterlogged and poorly aerated for long periods, conditions that reduce Fe and Mn to ferrous (Fe^{2+}) and manganous (Mn^{2+}) oxides. Poor aeration and prolonged waterlogging give rise to a further series of chemical and biochemical reduction reactions that produce toxins, such as hydrogen sulphide, carbon dioxide, methane, ethanol, acetaldehyde and ethylene, that damage the root system. This reduces the ability of plants to take up water and nutrients, causing poor vigour and ill-thrift. Decay and dieback of roots can also occur as a result of the *Phylloxera* aphid and fungal diseases such as *Phytophthora* root rot and black foot rot in soils prone to waterlogging.

In general, dark-coloured soils are more favourable for red wine quality (owing to an increase in polyphenol and terpens).

PLATE 4 **How to score soil colour**

GOOD CONDITION VS = 2
Dark coloured topsoil that is not too dissimilar to that under the fenceline.

MODERATE CONDITION VS = 1
The colour of the topsoil is somewhat paler than that under the fenceline, but not markedly so.

POOR CONDITION VS = 0
Soil colour has become significantly paler compared with that under the fenceline.

Assessment

1. Take a sample of soil (about 100 mm wide × 150 mm long × 200 mm deep) from the side of the hole and compare with the three photographs (Plate 5) and the percentage chart to determine the percentage of the soil occupied by mottles.

   Mottles are spots or blotches of different colour interspersed with the dominant soil colour.

Importance

The **NUMBER AND COLOUR OF SOIL MOTTLES** provide a good indication of how well the soil is drained and how well it is aerated. They are also an early warning of a decline in soil structure caused by compaction under wheel traffic and overcultivation. The loss of soil structure decreases and blocks the number of channels and pores that conduct water and air and, as a consequence, can result in waterlogging and a deficiency of oxygen for a prolonged period. The development of anaerobic (deoxygenated) conditions reduces Fe and Mn from their brown/orange oxidized ferric (Fe^{3+}) and manganic (Mn^{3+}) form to grey ferrous (Fe^{2+}) and manganous (Mn^{2+}) oxides. Mottles develop as various shades of orange and grey owing to varying degrees of oxidation and reduction of Fe and Mn. As oxygen depletion increases, orange, and ultimately grey, mottles predominate. An abundance of grey mottles indicates the soil is poorly drained and poorly aerated for a significant part of the year. The presence of only common orange and grey mottles (10–25 percent) indicates the soil is imperfectly drained with only periodic waterlogging. Soil with only few to common orange mottles indicates the soil is moderately well drained, and the absence of mottles indicates good drainage.

Poor aeration reduces the uptake of water by plants and can induce wilting. It can also reduce the uptake of plant nutrients, particularly N, P, K and S. Moreover, poor aeration retards the breakdown of organic residues, and can cause chemical and biochemical reduction reactions that produce sulphide gases, methane, ethanol, acetaldehyde and ethylene, which are toxic to plant roots. Decay and dieback of roots can also occur as a result of the *Phylloxera* aphid and fungal diseases such as *Phytophthora* root rot and black foot rot in strongly mottled, poorly aerated soils. Root rot and reduced nutrient and water uptake give rise to poor plant vigour and ill-thrift. If your visual score for mottles is ≤1, you need to aerate the soil.

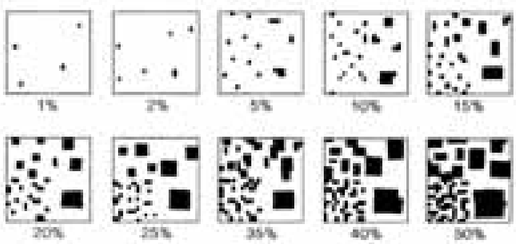


PLATE 5 **How to score soil mottles**

GOOD CONDITION VS = 2
Mottles are generally absent.

MODERATE CONDITION VS = 1
Soil has common (10–25%) fine and medium orange and grey mottles.

POOR CONDITION VS = 0
Soil has abundant to profuse (> 50%) medium and coarse orange and particularly grey mottles.

Assessment

1. Count the earthworms by hand, sorting through the soil sample used to assess soil structure (Plate 6) and compare with the class limits in Table 2. Pay particular attention to the turf mat. Earthworms vary in size and number depending on the species and the season. Therefore, for year-to-year comparisons, earthworm counts must be made at the same time of year when soil moisture and temperature levels are good. Earthworm numbers are reported as the number per 200-mm cube of soil. Earthworm numbers are commonly reported on a square-metre basis. A 200-mm cube sample is equivalent to 1/25 m^2, and so the number of earthworms needs to be multiplied by 25 to convert to numbers per square metre.

Importance

EARTHWORMS provide a good indicator of the biological health and condition of the soil because their population density and species are affected by soil properties and management practices. Through their burrowing, feeding, digestion and casting, earthworms have a major effect on the chemical, physical and biological properties of the soil. They shred and decompose plant residues, converting them to organic matter, and so releasing mineral nutrients. Compared with uningested soil, earthworm casts can contain 5 times as much plant available N, 3–7 times as much P, 11 times as much K, and 3 times as much Mg. They can also contain more Ca and plant-available Mo, and have a higher pH, organic matter and water content. Moreover, earthworms act as biological aerators and physical conditioners of the soil, improving:

- soil porosity;
- aeration;
- soil structure and the stability of soil aggregates;
- water retention;
- water infiltration;
- drainage.

They also reduce surface runoff and erosion. They further promote plant growth by secreting plant-growth hormones and increasing root density and root development by the rapid growth of roots down nutrient-enriched worm channels. While earthworms can deposit about 25–30 tonnes of casts/ha/year on the surface, 70 percent of their casts are deposited below the surface of the soil. Therefore, earthworms play an important role in vineyards and can increase growth rates and production significantly.

Earthworms also increase the population, activity and diversity of soil microbes. Actinomycetes increase 6–7 times during the passage of soil through the digestive tract of the worm and, along with other microbes, play an important role in the decomposition of organic matter to humus. Soil microbes such as mycorrhizal fungi play a further role in the supply of nutrients, digesting soil and fertilizer and unlocking nutrients, such as P, that are fixed by the soil. Microbes also retain significant amounts of nutrients in their biomass, releasing them when they die. Moreover, soil microbes produce plant-growth hormones and compounds that stimulate root growth and promote the structure, aeration, infiltration and water-holding capacity of the soil. Micro-organisms further encourage a lower incidence of pests and diseases. The collective benefits of microbes reduce fertilizer requirements and improve vine and grape quality.

Earthworm numbers (and biomass) are governed by the amount of food available as organic matter and soil microbes, as determined by the amount and quality of surface residue, the use of cover crops including legumes, and the cultivation of interrows. Earthworm populations can be up to three times higher in undisturbed soils compared with cultivated soils. Earthworm numbers are also governed by: soil moisture, temperature, texture, soil aeration, pH, soil nutrients (including levels of Ca), and the type and amount of fertilizer and N used. The overuse of acidifying salt-based fertilizers, anhydrous ammonia and ammonia-based products, and some insecticides and fungicides can further reduce earthworm numbers.

Soils should have a good diversity of earthworm species with a combination of: (i) surface feeders that live at or near the surface to breakdown plant residues and dung; (ii) topsoil-dwelling species that burrow, ingest and mix the top 200–300 mm of soil; and (iii) deep-burrowing species that pull down and mix plant litter and organic matter at depth.

TABLE 2 **Visual scores for earthworms**

Visual score (VS)	Earthworm numbers (per 200-mm cube of soil)
2 [Good]	> 30 (with preferably 3 or more species)
1 [Moderate]	15–30 (with preferably 2 or more species)
0 [Poor]	< 15 (with predominantly 1 species)

PLATE 6 **Sample for assessing earthworms**

Assessment

❶ Dig a hole to identify the depth to a limiting (restricting) layer where present (Plates 7 and 8), and compare with the class limits in Table 3. As the hole is being dug, note the presence of roots and old root channels, worm channels, cracks and fissures down which roots can extend. Note also whether there is an over-thickening of roots (a result of a high penetration resistance), and whether the roots are being forced to grow horizontally, otherwise know as right-angle syndrome. Moreover, note the firmness and tightness of the soil, whether the soil is grey and strongly gleyed owing to prolonged waterlogging, and whether there is a hardpan present such as a human-induced tillage or plough pan (Plate 8), or a natural pan such as an iron, siliceous or calcitic pan. An abrupt transition from a fine (heavy) material to a coarse (sandy/gravelly) layer will also limit root development. A rough estimate of the potential rooting depth may be made by noting the above properties in a nearby road cutting, gully, slip, earth slump or an open drain.

Importance

The **POTENTIAL ROOTING DEPTH** is the depth of soil that plant roots can potentially exploit before reaching a barrier to root growth, and it indicates the ability of the soil to provide a suitable rooting medium for plants. The greater is the rooting depth, the greater is the available-water-holding capacity of the soil. In drought periods, deep roots can access larger water reserves, thereby alleviating water stress and promoting the survival of non-irrigated vineyards. Under irrigation, the majority of roots are in the top 1 m of soil. The exploration of a large volume of soil by deep roots means that they can also access more macronutrients and micronutrients, thereby accelerating the growth and enhancing the yield and quality of the grapes. Conversely, soils with a restricted rooting depth caused by, for example, a layer with a high penetration resistance such as a compacted layer or a hardpan, restrict vertical root growth and development, causing roots to grow sideways. This limits plant uptake of water and nutrients, reduces fertilizer efficiency, increases leaching, and decreases yield. A high resistance to root penetration can also increase plant stress and the susceptibility of the plant to root diseases. Moreover, hardpans impede the movement of air, oxygen and water through the soil profile, the last increasing the susceptibility to waterlogging and erosion by rilling and sheet wash.

The potential rooting depth can be restricted further by:

- an abrupt textural change;
- pH;
- aluminium (Al) toxicity;
- nutrient deficiencies;
- salinity;
- sodicity;
- a high or fluctuating water table;
- low oxygen levels.

Anaerobic (anoxic) conditions caused by deoxygenation and prolonged waterlogging restrict the rooting depth as a result of the accumulation of toxic levels of hydrogen sulphide, ferrous sulphide, carbon dioxide, methane, ethanol, acetaldehyde and ethylene, by-products of chemical and biochemical reduction reactions.

Grapevines with a deep, dense, vigorous root system raise soil organic matter levels and soil life at depth. The physical action of the roots and soil fauna and the glues they produce promote soil structure, porosity, water storage, soil aeration and drainage at depth. For rainfed vineyards, the depth of a restricting layer should ideally be deeper than 2.5 m, with a soil depth of preferably not less than 600 mm. Stony soils are acceptable under irrigation systems, particularly where the depth of the soil is less than 1 m. Furthermore, grapevines need a sufficient rooting depth to provide adequate anchorage for the vines at maturity.

PLATE 7 **Potential rooting depth** **[L. VAN HUYSSTEEN in VAN ZYL 1988]**

PLATE 8 **Restricted root penetration through plough pan at 25 cm [L. VAN HUYSSTEEN]**

TABLE 3 **Visual scores for potential rooting depth**

VSA score (VS)	Potential rooting depth (m)
2.0 [Good]	> 0.8
1.5 [Moderately good]	0.6–0.8
1.0 [Moderate]	0.4–0.6
0.5 [Moderately poor]	0.2–0.4
0 [Poor]	< 0.2

Identifying the presence of a hardpan

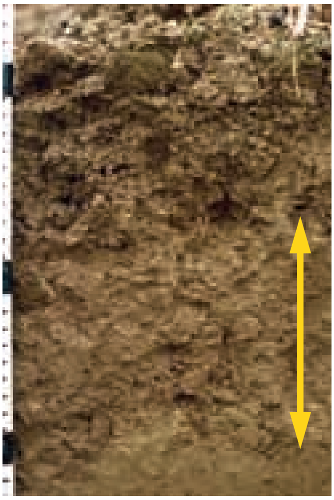
Assessment

1. Examine for the presence of a hardpan by rapidly jabbing the side of the soil profile (that was dug to assess the potential rooting depth) rapidly with a knife, starting at the top and progressing systematically and quickly down to the bottom of the hole (Plate 9). Note how easy or difficult it is to jab the knife into the soil as you move rapidly down the profile. A strongly developed hardpan is very tight and extremely firm, and it has a high penetration resistance to the knife. Pay particular attention to the lower topsoil and upper subsoil where tillage pans and plough pans commonly occur if present (Plate 10).
2. Having identified the possible presence of a hardpan by a significant increase in penetration resistance to the point of a knife, gauge how strongly developed the hardpan is. Remove a large hand-sized sample and assess its structure, porosity and the number and colour of soil mottles (Plates 2, 3 and 5), and also look for the presence of roots. Compare with the photographs and criteria given in Plate 10.

PLATE 9 **Using a knife to determine the presence or absence of a hardpan**

PLATE 10 **Identifying the presence of a hardpan**

NO HARDPAN
The soil has a low penetration resistance to the knife. Roots, old root channels, worm channels, cracks and fissures may be common. Topsoils are friable with a readily apparent structure and have a soil porosity score of ≥1.5.



MODERATELY DEVELOPED HARDPAN
The soil has a moderate penetration resistance to the knife. It is firm (hard) with a weakly apparent soil structure and has a soil porosity score of 0.5–1. There are few roots and old root channels, few worm channels, and few cracks and fissures. The pan may have few to common orange and grey mottles. Note the moderately developed tillage pan in the lower half of the topsoil (arrowed).

STRONGLY DEVELOPED HARDPAN
The soil has a high penetration resistance to the knife. It is very tight, extremely firm (very hard) and massive (i.e. with no apparent soil structure) and has a soil porosity score of 0. There are no roots or old root channels, no worm channels or cracks or fissures. The pan may have many orange and grey mottles. Note the strongly developed tillage pan in the lower half of the topsoil (arrowed).

Assessment

❶ Assess the degree of surface ponding (Plate 11) based on your observation or general recollection of the time ponded water took to disappear after a wet period during the spring, and compare with the class limits in Table 4.

Importance

SURFACE PONDING and the length of time water remains on the surface can indicate the rate of infiltration into and through the soil, a high water table, and the time the soil remains saturated. Grapevines generally require free-draining soils. Prolonged waterlogging depletes oxygen in the soil causing anaerobic (anoxic) conditions that induce root stress, and restrict root respiration and the growth and development of roots. Roots need oxygen for respiration. They are most vulnerable to surface ponding and saturated soil conditions in the spring when plant roots and shoots are growing actively at a time when respiration and transpiration rates rise markedly and oxygen demands are high. They are also susceptible to ponding in the summer when transpiration rates are highest. Moreover, waterlogging causes the death of fine roots responsible for nutrient and water uptake. Reduced water uptake while the vine is transpiring actively causes leaf desiccation and tip-burn. Prolonged waterlogging also increases the likelihood of pests and diseases, including the *Phylloxera* aphid and *Phytophthora* fungal root rot, and reduces the ability of roots to overcome the harmful effects of topsoil-resident pathogens. Vines decline in vigour, have restricted spring growth (RSG) as evidenced by poor shoot and stunted growth, and eventually die.

Waterlogging and deoxygenation also result in a series of undesirable chemical and biochemical reduction reactions, the by-products of which are toxic to roots. Plant-available nitrate-nitrogen (NO_3^-) is reduced by denitrification to nitrite (NO_2^-) and nitrous oxide (N_2O), a potent greenhouse gas, and plant-available sulphate-sulphur (SO_4^{2-}) is reduced to sulphide, including hydrogen sulphide (H_2S), ferrous sulphide (FeS) and zinc sulphide (ZnS). Iron is reduced to soluble ferrous (Fe^{2+}) ions, and Mn to manganous (Mn^{2+}) ions. Apart from the toxic products produced, the result is a reduction in the amount of plant-available N and S. Anaerobic respiration of micro-organisms also produces carbon dioxide and methane (also greenhouse gases), hydrogen gas, ethanol, acetaldehyde and ethylene, all of which inhibit root growth when accumulated in the soil. Unlike aerobic respiration, anaerobic respiration releases insufficient energy in the form of adenosine triphosphate (ATP) and adenylate energy charge (AEC) for microbial and root/shoot growth.

The tolerance of vine roots to waterlogging is dependent on a number of factors, including the time of year, the rootstock, soil and air temperatures, soil type, the condition of the soil, fluctuating water tables and the rate of onset and severity of anaerobiosis (or anoxia), a factor governed by the amount of entrapped air and the oxygen consumption rate by plant roots. Prolonged surface ponding increases the susceptibility of soils to damage under wheel traffic, so reducing vehicle access.

PLATE 11 **Surface ponding in a vineyard** **[CWi Technical Ltd]**

TABLE 4 **Visual scores for surface ponding**

VSA score (VS)	Surface ponding due to soil saturation	
	Number of days of ponding *	Description
2 [Good]	≤ 1	No evidence of surface ponding after 1 day following heavy rainfall on soils that were already at or near saturation.
1 [Moderate]	2–3	Moderate surface ponding occurs for 2–3 days after heavy rainfall on soils that were already at or near saturation.
0 [Poor]	> 4	Significant surface ponding occurs for longer than 4 days after heavy rainfall on soils that were already at or near saturation.

* Assuming little or no air is trapped in the soil at the time of ponding.

Assessment

❶ Observe the degree of surface crusting and surface cover and compare with Plate 12 and the criteria given. Surface crusting is best assessed after wet spells followed by a period of drying, and before cultivation.

Importance

SURFACE CRUSTING reduces infiltration of water and water storage in the soil and increases runoff. Surface crusting also reduces aeration, causing anaerobic conditions, and prolongs water retention near the surface, which can hamper access by machinery for months. Crusting is most pronounced in fine-textured, poorly structured soils with a low aggregate stability and a dispersive clay mineralogy.

SURFACE COVER helps to prevent crusting by minimizing the dispersion of the soil surface by rain or irrigation. It also helps to reduce crusting by intercepting the large rain droplets before they can strike and compact the soil surface. Vegetative cover and its root system return organic matter to the soil and promote soil life, including earthworm numbers and activity. The physical action of the roots and soil fauna and the glues they produce promote the development of soil structure, soil aeration and drainage and help to break up surface crusting. As a result, infiltration rates and the movement of water through the soil increase, decreasing runoff, soil erosion and the risk of flash flooding. Surface cover also reduces soil erosion by intercepting high impact raindrops, minimizing rain-splash and saltation. It further serves to act as a sponge, retaining rainwater long enough for it to infiltrate into the soil. Moreover, the root system reduces soil erosion by stabilizing the soil surface, holding the soil in place during heavy rainfall events. As a result, water quality downstream is improved with a lower sediment loading, nutrient and coliform content. The adoption of managed cover crops has in some cases reduced sediment erosion rates from 70 tonnes/ha to 1.5 tonnes/ha during single large rainfall events. The surface needs to have at least 70 percent cover in order to give good protection, while ≤30 percent cover provides poor protection. Surface cover also reduces the risk of wind erosion markedly.

PLATE 12 **How to score surface crusting and surface cover**

GOOD CONDITION VS = 2
Little or no surface crusting is present; or surface cover is ≥70%.

MODERATE CONDITION VS = 1
Surface crusting is 2–3 mm thick and is broken by significant cracking; or surface cover is >30% and <70%.

POOR CONDITION VS = 0
Surface crusting is >5 mm thick and is virtually continuous with little cracking; or surface cover is ≤30%.

Photos of surface cover: courtesy of A. Leys;
Photo of severe crusting: courtesy of M. Speyer

Assessment

1. Assess the degree of soil erosion based on current visual evidence and, more importantly, on your knowledge of what the site looked like in the past relative to Plate 13.

Importance

SOIL EROSION reduces the productive potential of a vineyard through nutrient losses, loss of organic matter, reduced potential rooting depth, and lower available-water-holding capacity. Soil erosion can also have significant off-site effects, including reduced water quality through increased sediment, nutrient and coliform loading in streams and rivers.

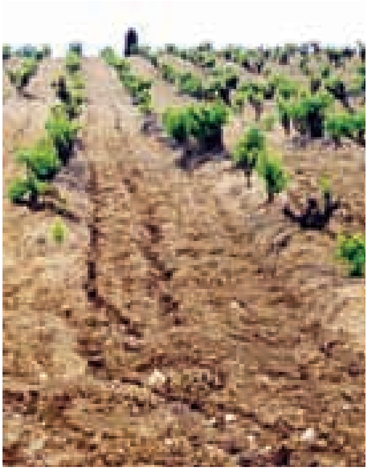
Overcultivation of interrows can cause considerable soil degradation associated with the loss of soil organic matter and soil structure. It can also develop surface crusting, tillage pans, and decrease infiltration and permeability of water through the soil profile (causing increased surface runoff). If the soil surface is left unprotected on sloping ground, large quantities of soil can be removed by slips, flows, gullying and rilling, or it can be relocated semi-intact by slumping. The cost of restoration, often requiring heavy machinery, can be prohibitively expensive.

The water erodibility of soil on sloping ground is governed by a number of factors including:

- the percentage of vegetative cover on the soil surface;
- the amount and intensity of rainfall;
- the soil infiltration rate and permeability;
- the slope and the nature of the underlying subsoil strata and bedrock.

PLATE 13 **How to score soil erosion**

GOOD CONDITION VS = 2
Little or no evidence of soil erosion. Little difference in height between the mounded row and interrow. The root system is completely covered.



MODERATE CONDITION VS = 1
Moderate soil erosion with a significant difference in height between the mounded row and interrow. Part of the upper root system is occasionally exposed.

POOR CONDITION VS = 0
Severe soil erosion with deeply incised gullies or other mass movement features between rows. The root system is often well exposed and the vine trunk totally undermined in places.

Photos: courtesy of C. Llewellyn and M. Greener

FIGURE 3 **Plant scorecard – visual indicators for assessing plant performance in vineyards**

Visual indicators of plant performance		Visual score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS ranking
Wood production	pg. 26		x 3	
Shoot lenght	pg. 28		x 3	
Leaf colour	pg. 30		x 3	
Yield	pg. 34		x 2	
Variability of vine performance along the row	pg. 36		x 2	
Production costs	pg. 38		x 1	
PLANT PERFORMANCE INDEX (sum of VS rankings)				

Plant Performance Assessment	Plant Performance Index
Poor	< 10
Moderate	10–20
Good	> 20

SUMMARY

Comparison of soil & plant assessments		Do the soil and plant assessments differ? If so, why?
Soil indicators	Plant indicators	

Notes:

Total available water-holding capacity:

Assessment

❶ Estimate wood production per metre cord by assessing fresh wood weight at pruning (Plate 14). In making the observation, consideration must be given to the cultivar, pruning and age of the vine.

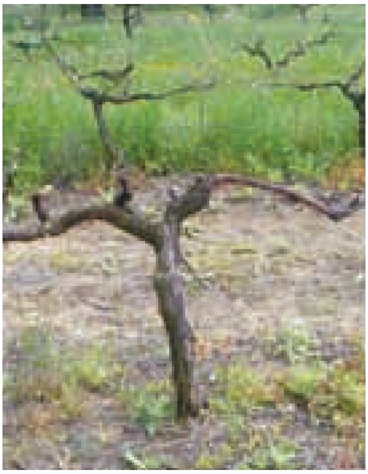
Importance

While climate factors, cultivar and agricultural practices all influence **WOOD PRODUCTION**, wood production at flowering is a good indicator of plant vigour and the fertility and physical condition of the soil (including its nutrient and water status). Therefore, it is a useful indicator of soil quality.

Soil degradation resulting from the loss of organic matter, soil compaction, poor aeration or soil erosion restricts root growth and limits the movement and storage of water, the cycling of nutrients and the efficient uptake of fertilizers. Plant roots either cannot reach the fertilizer, or the applied nutrients remain unavailable in the compacted soil because of impaired water movement or preferential flow through the soil, by-passing much of the soil volume. As a result, plant growth and vigour are poor.

PLATE 14 How to score wood production

GOOD CONDITION VS = 2
Depending on the cultivar, vineyards of seven years of age have 0.8 kg of vine-shoots per metre cord at pruning.



MODERATE CONDITION VS = 1
Depending on the cultivar, vineyards of seven years of age have 0.6–0.8 kg of vine-shoots per metre cord at pruning.

POOR CONDITION VS = 0
Depending on the cultivar, vineyards of seven years of age have <0.6 kg of vine-shoots per metre cord at pruning.

Assessment

❶ Measure or visually assess shoot length and compare with the criteria given (Plate 15) at veraison. In making your assessment, consideration must be given to the cultivar, pruning and age of the vine, and the weather conditions at bud break. Poor weather will promote a high number of leaf buds rather than flowering buds and give rise to many shoots and leaves rather than flowers.

Importance

SHOOT LENGTH is also influenced by the bud position on the trunk and cordon, and by bud orientation with respect to the vertical direction. It is related strongly to the physical and chemical fertility of the soil, which in turn is influenced by soil management. Shoot length is an expression of plant vigour and general plant growth, which are also regulated by the availability of water and nutrients and by the aeration status of the soil. Waterlogging and poor drainage can restrict spring growth and give rise to poor shoot growth and dieback. Soils in good condition with good structure and porosity, and with a deep, well-aerated rootzone, enable the unrestricted movement of air and water into and through the soil and the development and proliferation of superficial (feeder) roots. Furthermore, soils with good organic-matter levels and soil life show an active biological and chemical process, favouring the release and uptake of water and nutrients and, consequently, shoot growth.

PLATE 15 **How to score shoot length**

GOOD CONDITION VS = 2
Vine-shoots are at or near the maximum length, with a little variability depending on the position of the shoot on the branch.

MODERATE CONDITION VS = 1
Vine-shoot length is moderately below maximum and shows moderate variability depending on the position of the shoot on the plant.

POOR CONDITION VS = 0
Vine-shoot length is significantly below the maximum length.

Assessment

1. Assess the colour of the mature leaves at the base of the vine-shoots by comparing with Plate 16 and the criteria given. In making the observation, consideration must be given to the cultivar, the stage of growth, pests and diseases, and recent weather conditions. Prolonged cold and cloudy days with little sunlight can give rise to chlorosis (or yellowing of the leaf) owing to the inadequate formation or loss of chlorophyll.

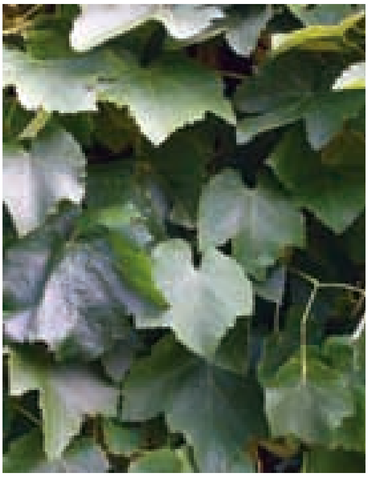
Importance

LEAF COLOUR can provide a good indication of the nutrient status and condition of the soil. The higher is the soil fertility, the greener is the leaf colour. Leaf colour is related primarily to water and nutrient availability, especially N. Leaf colour can also indicate a deficiency or excess of P, K, S, Ca, Mg, Fe, Mn, zinc (Zn), copper (Cu) and boron (B). Chlorosis can further occur as a result of low N, K, S, Fe, Mg and Cu levels in the soil, low soil and air temperatures, and poor soil aeration caused by compaction and waterlogging. A deficiency or excess of one or more essential elements in a plant can also produce visual symptoms of necrosis of leaf margins, stunted growth of shoots, irregular fruit-set and small berries. Premature leaf senescence can further indicate plant stress.

Nutrient deficiencies or excesses can suppress the availability of other nutrients. For example, high P levels can suppress the uptake of Zn and Cu. Excess N can suppress B and Cu and cause the plant to luxury feed on K, which in turn can suppress the utilization of Ca and Mg. Sulphur can also only be utilized by plants in the sulphate (SO_4^{2-}) form. Under poorly aerated conditions, S will reduce to sulphur dioxide (SO_2) and sulphides (e.g. hydrogen sulphide [H_2S], and ferrous sulphide [FeS]). Sulphides and SO_2 cannot be taken up by the plant, are toxic to plant roots and micro-organisms, and suppress N uptake. Plants can only utilize N where S is present in the oxygenated (sulphate) form. Like S, N can also only be utilized by the plant under aerobic conditions in the nitrate (NO_3^-) or ammonium form (NH_4^+).

Plate 17 shows some of the most common symptoms of nutrient deficiencies.

PLATE 16 **How to score leaf colour**



GOOD CONDITION VS = 2
Leaves have an intense dark green colour.

MODERATE CONDITION VS = 1
Leaves have a yellowish-green or medium green colour.

POOR CONDITION VS = 0
Leaves have a distinct yellowish colour or turn opaque green.

PLATE 17 **Visual symptoms of nutrient deficiency in vines**

Phosphorus

Potassium

PLATE 17 **Visual symptoms of nutrient deficiency in vines *(continued)***

Boron

Iron

Zinc

Assessment

❶ Assess relative crop yield by visual estimation of fruit number and size and by comparing with Plate 18 and the criteria given, or alternatively estimate or measure the weight of grapes per metre cord. In making your assessment, consideration must be given to the cultivar, pruning and age of the vine. Consideration must also be given to the weather conditions (e.g. whether warm and dry, or cold and wet) at pollination, fertilization, flowering and fruit-set. Pollination is best when the weather is dry, while fertilization is most successful when temperatures are warm. Poor weather during flowering can give rise to poor fruit-set. Warm weather at fruit-set will give good yields while cold wet weather will give poorer yields. Compare your assessment or measurement against the mean of the last 3 or 4 years.

Importance

YIELD can be a good visual indicator of the properties and condition of the soil. The physical condition of the soil (in terms of its texture, structure, porosity, aeration and drainage) has a significant effect on the root system, aeration status and water and nutrient availability at critical times of the year. It also plays an important role in vine growth and vigour, grape quality and yield.

Appropriate soil management, including the adoption of a managed cover crop between rows, and avoiding wheel traffic when the soil is wet, helps to promote the physical condition and overall fertility of the soil and sustainable long-term production.

PLATE 18 **How to score yield**

GOOD CONDITION VS = 2
Depending on the cultivar, pruning and age of the vine, yields are good.

MODERATE CONDITION VS = 1
Depending on the cultivar, pruning and age of the vine, yields are moderate.

POOR CONDITION VS = 0
Depending on the cultivar, pruning and age of the vine, yields are poor.

Assessment

1. Cast your eye along the rows and observe any variability in vine performance (in terms of vine height, stem thickness, canopy volume and density, leaf colour, early senescence of leaves, etc.) and compare with the class limits in Table 5. In making the assessment, consideration must be given to pruning and to diseases that are not soil-related (Plates 19–22).

Importance

VARIABILITY OF VINE PERFORMANCE ALONG THE ROW can be a very good visual indicator of the properties and condition of the soil. In particular, the linear variability of vine performance is often related to the availability of water and nutrients, and the texture of the soil (e.g. whether clayey, silty, loamy, sandy or gravelly). Moreover, soils in good condition with good structure and porosity, and with a deep, well-aerated rootzone, enable the unrestricted movement of air and water into and through the soil, the development and proliferation of superficial (feeder) roots, and unrestricted respiration and transpiration. Furthermore, soils with good organic-matter levels and soil life (including mycorrhizae) show an active biological and chemical process, favouring the release and uptake of water and nutrients and, consequently, the growth and vigour of the vine.

The spatial variability of vine performance along the row is also a useful indicator because it highlights those vines that are underperforming compared with the majority, enabling a specific investigation as to why those are struggling and what remedial action may be taken.

PLATE 19 **Effect of soil texture, organic matter and mycorrhizae on vine performance** [D. MUNDY]

Poor-performing vines on the left are on coarse-textured soils with low organic matter and a low mycorrhizal colonization of 40%. Well-performing vines on the right are the result of better utilization of water and nutrients on a siltier soil with more organic matter and a 90% colonization of mycorrhizae.

PLATE 20 **Effect of soil aeration and drainage on vine performance** [D. MUNDY]

Poor-performing vines in the hollows are due to root (black foot) rot associated with poor drainage, while the better-performing vines on higher ground further along the row are on freer-draining, better-aerated soil.

PLATE 21 **Effect of soil-borne pathogens on vine performance** [D. MUNDY]

Poor-performing vines in the centre row owing to a soil-borne pathogen.

PLATE 22 **Variable crop vigour and leaf colour** [S. GREEN]

Variable crop vigour and leaf colour along the row owing to differences in water and nutrient availability associated with differences in soil texture and soil depth.

TABLE 5 **Visual scores for variability of vine performance along the row**

Visual score (VS)	Variability of vine performance along the row
2 [Good]	Vine performance is good and even along the row
1 [Moderate]	Vine performance is moderately variable along the row
0 [Poor]	Vine performance is extremely variable along the row

Assessment

1. Assess whether production costs have increased because of increased tillage/subsoiling, fertilizer requirements and pesticide application over the years (Figure 4 and Table 6). This assessment can be based on perceptions, but reference to annual balance sheets will give a more precise answer.

Importance

Continuous tillage between rows using conventional cultivation techniques can give rise to a marked decline in soil structure, porosity and organic matter. The result is a reduction in root growth owing to a decline in soil aeration, an increase in penetration resistance to root development, a reduction in water storage and plant-available water, and a reduction in soil fertility and the ability of the soil to supply nutrients. Higher amounts of fertilizer are required in order to compensate for the loss of these nutrients and the decline in soil quality. Higher and more frequent applications of chemical sprays are also needed because of increased disease and pest attack in vineyards with degraded soils. The quantity and quality of the final product can often be reduced, with a lower income as a consequence.

Soil compaction under wheel traffic between rows increases the size, density and strength of soil clods, and increases the penetration resistance to lateral root development. Apart from decreasing infiltration and increasing runoff, the increased tillage resistance of compacted lanes often requires a greater number of passes and careful timing with the cultivator in order to break down the large clods. Subsoiling may also be necessary to ameliorate compaction in the subsoil in order to improve aeration and root development.

FIGURE 4 **Assessment of production costs**

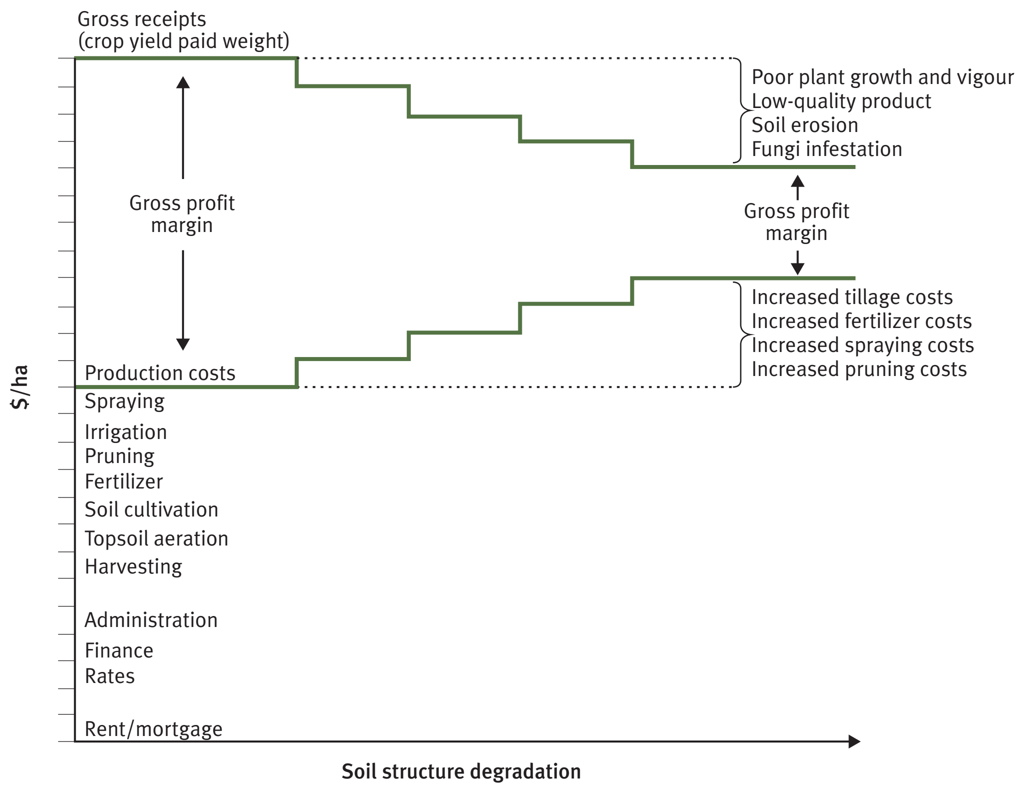


TABLE 6 **Visual scores for production costs**

Visual score (VS)	Production costs
2 [Good]	Spraying, fertilizer and tillage/subsoiling requirements have not increased significantly
1 [Moderate]	Spraying, fertilizer and tillage/subsoiling requirements have increased moderately
0 [Poor]	Spraying, fertilizer and tillage/subsoiling requirements have increased greatly

Soil management in vineyards

Soil management plays a key role in achieving good high-quality vineyard production while at the same time safeguarding the environment and minimizing the ecological footprint of viticulture on a region and the country.

One of the aims of the farmer should be soil conservation. This does not only mean having healthy plants and high grape quality, but achieving this with less fertilizer, chemical input and soil tillage. In general, conventional soil management in vineyards can have a negative impact on the environment. It enhances chemical residues, alters microflora and microfauna by reducing both the number of species and their biomass, reduces soil organic matter content and exposes the soil to accelerated soil erosion. Thus, the loss of soil and soil quality in vineyards contributes to the food eco-footprint.

Cover crops play an important role in protecting the soil surface and enhancing soil quality, so preserving the environment, reducing production costs and enhancing the quality of wine. Recent experiments have shown that the nutritional status of vineyards can have a strong influence on the chemical and organoleptic characteristics of wine.

Cover cropping not only helps in reducing water runoff and soil erosion but also improves soil physical characteristics, enriches soil organic matter content, reduces inorganic fertilization and root mortality, and suppresses soil-borne disease by increasing micro-organism activity and biodiversity.

One of the limiting factors of cover crops in vineyards is the competition for nutrients and plant-available water where the management is inadequate. This can affect the amount of available N to the plant and the N content and alcoholic fermentation of the wine. In order to solve this problem, a different mix of cover crops including leguminous species such as clover and lucerne that supply N (fixed from the atmosphere) should be evaluated in different areas, reducing the problem of N deficiency. The input of biologically fixed N is also an important component of the N cycle.

In addition to legumes, the mix of cover crops in the interrows could include annual and perennial species, grasses and other broadleaf plants. Winter annuals can be grown in order to protect the soil from erosion during winter and to improve the ability of the soil to resist compaction when wet. Grasses, with their fibrous root system, are also more effective at improving soil structure, and generally add more organic matter to the soil than do legumes. Where allowed to seed in early summer, a seed bank for subsequent regeneration is built up. In order to reduce competition, cover crops or natural weeds can be controlled by herbicide application or by mowing 2–3 times during the period of major water and nutrient demand. Grass should also be kept short in order to reduce insect and bird numbers. Where the grass cover crop extends along and under the vine row, ensure that the length of grass is kept short in order to reduce not only the competition for water and nutrients but also the possibility of fungal diseases.

In addition to the adoption of managed cover crops, the physical condition and overall fertility of the soil can be promoted by avoiding wheel traffic between rows when the soils are wet.

The application of mulches along the vine rows in the form of grass mowings, compost, bark chips and cereal straw shade the soil, so reducing temperature and soil evaporation during the summer. Mulches also encourage biological activity, especially earthworms. They suppress weeds and prevent the breakdown of the soil structure under the impact of rain, so enhancing water infiltration. The application of crushed glass as a ‘mulch’ enhances the availability of understorey light, so providing more energy from the rays of the sun to the ripening fruit, lifting the flavour, and ripening the fruit earlier. However, glass mulch does nothing to enhance the biological life of the soil.

References

Shepherd, T. G., Stagnari, F., Pisante, M. and Benites, J. 2008. *Visual Soil Assessment – Field guide for vineyards*. FAO, Rome, Italy.

The present publication on **Visual Soil Assessment** is a practical guide to carry out a quantitative soil analysis with reproduceable results using only very simple tools. Besides soil parameters, also crop parameters for assessing soil conditions are presented for some selected crops. The **Visual Soil Assessment** manuals consist of a series of separate booklets for specific crop groups, collected in a binder. The publication addresses scientists as well as field technicians and even farmers who want to analyse their soil condition and observe changes over time.

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