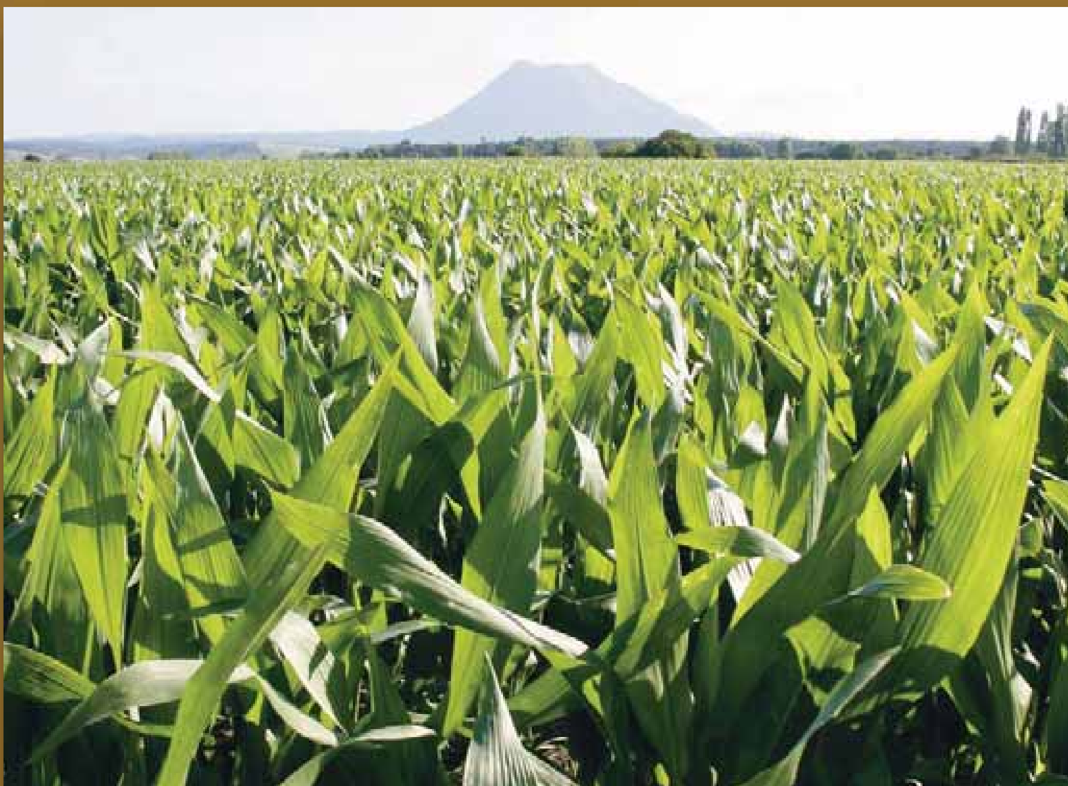
VISUAL SOIL ASSESSMENT

FIELD GUIDE

part 1

Maize



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FIELD GUIDE

Maize

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Contents

List of tables

List of figures

List of plates

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List of acronyms

AEC	Adenylate energy charge
Al	Aluminium
ASC	Anion storage capacity
ATP	Adenosine triphosphate
B	Boron
C	Carbon
Ca	Calcium
Ca^{2+}	Calcium cation
CEC	Cation exchange capacity
CH_4	Methane
CO_2	Carbon dioxide
qCO_2	Metabolic quotient
Co	Cobalt
Cu	Copper
Fe	Iron
FeS	Ferrous sulphide
Fe^{3+}	Ferric iron
Fe^{2+}	Ferrous iron
GHG	Greenhouse Gas
H_2S	Hydrogen sulphide
K	Potassium
K^+	Potassium cation
Mg	Magnesium
Mg^{2+}	Magnesium cation
Mn	Manganese
Mn^{3+}	Manganic ions
Mn^{2+}	Manganous ions
Mo	Molybdenum
N	Nitrogen
N_2	Nitrogen gas
NO_3^-	Nitrate
NO_3^--N	Nitrate-nitrogen
NO_2^-	Nitrite
N_2O	Nitrous oxide
Na	Sodium
Na^+	Sodium cation
NH_3	Ammonia
NH_4^+	Ammonium
O_2	Oxygen
P	Phosphorus
PO_4^{3-}	Phosphate
pH	Concentration of H^+ ions (Soil acidity/alkalinity)
RSG	Restricted spring growth
S	Sulphur
SO_4^{2-}-S	Sulphate-sulphur
SO_4^{2-}	Sulphate
SO_3^{2-}	Sulphide
VS	Visual score
VSA	Visual Soil Assessment
WFPS	Water-filled pore space
Zn	Zinc
ZnS	Zinc sulphide

Visual Soil Assessment

Introduction

The maintenance of good soil quality is vital for the environmental and economic sustainability of maize cropping. A decline in soil quality has a marked impact on yield and quality of maize for grain and silage, production costs, the risk of soil erosion, nutrient loss into the groundwater and waterways, carbon sequestration and green-house gas emissions. It can therefore have significant consequences for society and the environment. A decline in soil physical properties in particular takes considerable time and cost to correct. Soil physical properties control the movement of water and air into and through the soil, the ease with which roots penetrate the soil, the number, type and activity of soil organisms, and the availability and uptake of soil nutrients. Damage to the soil can change these properties and reduce plant growth, food quality and environmental outcomes, regardless of nutrient status. Safeguarding soil resources for future generations and minimizing the ecological footprint of maize cropping is an important task 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, crops and food quality;
- the effect of land management decisions on soil quality, plant performance and environmental outcomes.

Soil type and the effect of management on the condition of the soil are important determinants of the productive performance of maize cropping and have profound effects on long term profits. Land managers need reliable, quick and easy to use tools to help them assess the condition of their soils and their suitability for growing crops, and make informed decisions that will 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 maize. Scoring is out of 54: the higher the score, the better the condition of the soil and the performance of the plant. Soils with good VSA scores will, by and large, give the best production with the lowest establishment and operational costs.

In addition, the VSA provides a quick, low cost method for estimating the potential for nutrient loss into the groundwater and waterways, C sequestration, and the emission of greenhouse gases.

The VSA method

While the name Visual Soil Assessment implies a focus on the soil, the method is equally about assessing both the soil and the plant. Visual Soil Assessment is based on the visual assessment of key soil 'state' and plant performance indicators of soil quality, presented on a score card. 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 score card. With the exception of soil texture, the soil and plant indicators are dynamic indicators, i.e. they are 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, 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 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 scores 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** (flat-faced) – 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 x 350 x 250 mm) – to contain the soil during the drop shatter test;
- **A HARD SQUARE BOARD** (about 260 x 260 x 20 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 750 x 500 mm) – on which to spread the soil, after the drop shatter test has been carried out;

PLATE 1 **The VSA tool kit**

- **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 sampling depth, topsoil depth, potential rooting depth, crop height, and the length of ears;
- **A VSA FIELD GUIDE** – to make the photographic comparisons;
- **A PAD OF SCORECARDS** – to record the visual score (VS) for each indicator.

The procedure

When should it be carried out?

The test should be carried out when the soils are moist and suitable for grazing. If you are not sure, apply the 'worm test' (p. 63). For **silty soils**, if you can roll a worm 10 mm wide x 40 mm long between the palms of your hands (7 mm x 40 mm for **clayey soils**) without it cracking, the soil is too wet to test. If the worm cracks when it is 10 mm wide for silty soils (7 mm wide for clayey soils), the soil is ready to test.

Setting up

Time

Allow 40 minutes per site. For a representative assessment of soil quality, sample four sites over a 5 hectare area.

Reference sample

Take a small sample of soil (about 100 x 50 x 150 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 field. The condition of the soil in maize fields is site specific. Avoid areas that have had heavier traffic than the rest of the field and sample between wheel traffic lanes. VSA can also be used however, to assess the effects of high traffic on soil quality 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 indicators score card.

Carrying out the test

Initial observation

Dig a small hole about 200 x 200 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 200 x 200 x 100 mm samples 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 200 x 200 x 100 mm samples. Note that taking a 200 mm cube immediately below the topsoil can also give valuable information about the condition of the subsoil and its implications for plant growth and crop management.

The drop shatter test

Drop the test sample a maximum of three times onto the wooden square in the plastic basin. The number of times the sample is dropped and the height it is dropped from, depends on the texture of the soil, and the degree to which the soil breaks up, as described on pp. 2–4.

Systematically work through the score card, assigning a visual score (VS) to each indicator by comparing it to 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 ranking in the right-hand column of the scorecard.

Format of the booklet

The soil and plant scorecards are given in Figures 1 and 3, respectively, and list the key indicators required 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.

"Despite mankind's lofty aspirations and many notable achievements, our survival depends on a six-inch layer of topsoil and the fact that it rains"

anonymous

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

Landowner:

Land use:

Site location:

GPS ref:

Sample depth:

Topsoil depth:

Soil type:

Soil classification:

Drainage class:

Date:

Textual group: (upper 1 m) ☐ Sandy ☐ Coarse loamy ☐ Fine loamy ☐ Coarse silty ☐ Fine 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 3	
Soil porosity	pg. 6		x 3	
Number and colour of soil mottles	pg. 8		x 2	
Soil colour	pg. 10		x 2	
Earthworms (Number =) (Av. size =)	pg. 14		x 3	
Soil smell	pg. 18		x 2	
Potential rooting depth (m)	pg. 22		x 3	
Surface ponding	pg. 26		x 3	
Surface cover and surface crusting	pg. 30		x 2	
Soil erosion (wind/water)	pg. 32		x 1	
SOIL QUALITY INDEX (sum of VS rankings)				

Soil Quality Assessment	Soil Quality Index
Poor	< 20
Moderate	20–37
Good	> 37

Assessment

1. Take a sample of soil half the size of your thumb from the topsoil to assess the ***soil texture***. Take also a sample/s that is/are representative of the subsoil to assess the overall ***textural group*** of the soil profile.
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 and then squeezing it between the thumb and forefinger. 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 2a). The *textural group* is obtained by comparing the position of the textural class in Figure 2a with Figure 2b (e.g., silt loam = fine silty).

   There are occasions when the assignment of a textural score will need to be modified because of the nature of a textural qualifier. For instance, if the soil has a reasonably high content of organic matter, i.e. is humic with 17–29 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.

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, while 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 workability and trafficability, soil life, and the supply and retention of nutrients. A knowledge of both the textural class and potential rooting depth (p. 22) enables an approximate assessment of the total water holding capacity of the soil, one of the major drivers of crop yield.

FIGURE 2 **Soil texture classes and groups**

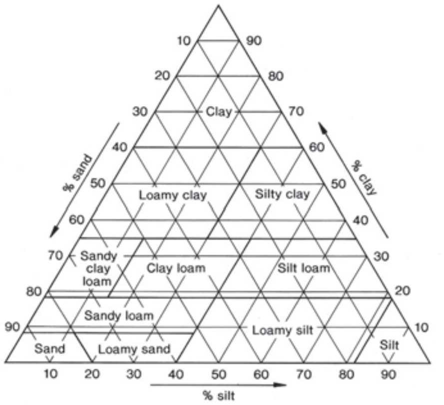


Figure 2a
Textural classes.

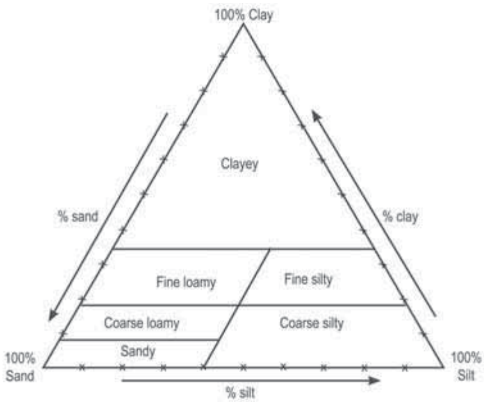


Figure 2b
Textural groups.

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 which fissures when squeezed flat.
1.5 [Moderately good]	Clay loam	Very smooth, sticky and plastic. Moulds into a cohesive ball which deforms without fissuring when squeezed flat.
1 [Moderate]	Loamy silt	Smooth feel, non sticky, no grittiness. Moulds into a cohesive ball which fissures when squeezed between thumb and forefinger.
	Sandy loam	Slightly gritty, faint rasping sound. Moulds into a cohesive ball which fissures when squeezed between thumb and forefinger.
0.5 [Moderately poor]	Silty clay & Clay	Very smooth, very sticky, very plastic. Moulds into a cohesive ball which deforms without fissuring when squeezed flat.
0 [Poor]	Loamy sand	Gritty and rasping sound. Will almost mould into a ball but disintegrates when squeezed between thumb and forefinger.
	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 one metre 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. Don't drop any piece of soil more than three times. For soils with a sandy loam texture (p. 3), drop the cube of soil once only from a height of 0.5 metres. If the sandy loam is humic (17–29 percent organic matter), drop the soil twice from 1 metre. Transfer the soil onto the large plastic bag.
3. 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.
4. Applying only very gently pressure, attempt to part each clod by hand along any exposed cracks or fissures if present. If the clod cannot be easily parted, do not apply further pressure because the cracks and fissures are probably not continuous and therefore unable to readily conduct oxygen, air and water.
5. 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 and criteria given in Plate 2.

The method is valid over 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 grain maize crops. 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, controlled traffic or conventional cultivation under optimum 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, sub-angular and sub-rounded (nutty) aggregates. Those with poor structure have large, dense, very firm, angular or sub-angular blocky clods that fit and pack closely together and have a high tensile strength.

PLATE 2 **Visual scoring (VS) of soil structure**

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

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

Assessment

1. Remove a spade slice of soil (approximately 100 mm wide × 150 mm long × 200 mm deep) from the side of the hole and break in half.
2. Examine the exposed fresh face of the sample for soil porosity by comparing against the three photographs and criteria in Plate 3. Look for the spaces, gaps, holes, cracks, 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

SOIL POROSITY is important to assess along with soil structure. 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 or coarse micropores within the large clods, thus restricting their drainage and aeration.

Poor aeration leads to the build up of methane, sulphide gases and alcohol, and reduces the ability of plants to take up water and nutrients, particularly nitrogen, phosphorus, potassium, sulphur, zinc, copper and cobalt. Poorly aerated and compacted soils reduce plant-available N in the form of nitrate-nitrogen (NO_3^--N) and ammonium (NH_4^+) to nitrite (NO_2^-), nitrogen (N_2) gas and nitrous oxide (N_2O), a potent greenhouse gas. Plant-available sulphate-sulphur (SO_4^{2-}-S) is also reduced to sulphite (SO_3^{2-}) and sulphides, rendering N and S unavailable to the plant. Sulphur (S) and nitrogen (N) can only be utilised by plants in the oxygenated sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) form and therefore plants require aerated soils for the efficient uptake and utilisation of S and N. Furthermore, plants can only utilize N if S is present in the oxygenated sulphate form. The number, activity and biodiversity of micro-organisms and earthworms are also greatest in well-aerated soils and 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. Roots are unable to penetrate and grow through firm, tight, compacted soils, severely restricting the ability of the plant to utilise the available water and nutrients in the soil. A high penetration resistance not only limits plant uptake of water and nutrients, but greatly reduces fertiliser efficiency and increases the susceptibility of the plant to root diseases.

Soils with good porosity will also tend to produce less greenhouse gases. The greater the porosity the better the drainage and therefore the soil pores will be less likely to be water-filled to the critical levels required to accelerate the production of greenhouse gases (see p. 82–83). Aim to keep the porosity score above 1.

PLATE 3 **Visual scoring (VS) of 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 in parts of the soil on close examination. 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 cracks or holes, and can have sharp angles.

number and colour of soil mottles

Assessment

1. Assess the number, size and colour of soil mottles by taking a sample of soil (approximately 100 mm wide × 150 mm long × 200 mm deep) from the side of the hole and comparing it with the three photographs and criteria in Plate 4. The percentage chart below will help you determine the percentage of the soil occupied by mottles.

Mottles are patches of different colour interspersed within the dominant (background) 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 early warnings of a decline in soil structure as a result of compaction under wheel traffic and over-cultivation. The loss of soil structure reduces 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 iron (Fe) and manganese (Mn) from their *brown/orange* oxidised 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 due to varying degrees of oxidation and reduction of Fe and Mn. As oxygen depletion increases, orange, and ultimately grey mottles predominate. The 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 indicate the soil is moderately well drained, and no mottles indicate 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, S, Zn, Cu and Co (p. 6). While Olsen P levels of 22 mg/L are generally adequate for optimum crop production on most soils in good condition, degraded, poorly aerated soils with relatively high Olsen P levels (40–50 mg/L) can show a positive crop response to applied P. Moreover, poor aeration retards the breakdown of organic residues, and can cause chemical and biochemical reduction reactions that produce sulphide gases, methane, alcohol (ethanol and ethylene), acetaldehyde and formaldehyde, which are toxic to plant roots. In addition, decay and die-back of roots can occur as a result of fungal diseases such as *Rhizoctonia, Pythium and Fusarium* root rot, foot rot, and crown rot in soils that are strongly mottled and poorly aerated. Fungal diseases and reduced nutrient and water uptake give rise to poor plant vigour and ill-thrift. If your visual score for the number and colour of soil mottles is one or less, you need to aerate the soil.

Percentage chart

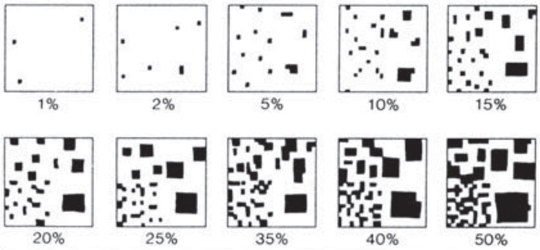


PLATE 4 **Visual scoring (VS) of the number and colour of soil mottles**

GOOD CONDITION VS = 2
Mottles are generally absent.

MODERATE CONDITION VS = 1
Soil has many (10–20 percent) fine and medium orange and grey mottles.

POOR CONDITION VS = 0
Soil has profuse (50 percent) medium and coarse orange and particularly grey mottles.

Assessment

1. Compare the moist colour of a handful of soil from the field site with soil taken from under the nearest fenceline or a similar protected area (Plate 5). If the soil is dry, pour water over the surface of the sample.
2. Using the three photographs and criteria given in Plate 6, 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 so easily and accurately assessed; in general, the darker the colour, the greater the amount of organic matter and humus 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, collectively determining soil health. It promotes infiltration, the movement and retention of water, helps develop and stabilise soil structure, cushions the impact of wheel traffic and cultivators, reduces the potential for wind and water erosion, and indicates whether

PLATE 5 **Soil colour under the fenceline**

Soil colour under the fenceline on the left compared with that in the field on the right. The comparative difference in soil structure and porosity is also a useful observation to make.

PLATE 6 **Visual scoring (VS) of soil colour**

GOOD CONDITION VS = 2
Dark coloured topsoil that is similar to, or darker than that under the fenceline.

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

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

the soil is functioning as a carbon ‘sink’ or as a source of greenhouse gases. Organic matter acts as a major reservoir of organic carbon in the soil, carbon that is sequestered by microorganisms and from CO_2 in the atmosphere by plants. Organic matter also provides an important food resource for soil organisms and is an important source and major reservoir of plant nutrients. Its decline reduces the fertility and nutrient-supplying potential of the soil; nitrogen, phosphorus, potassium and sulphur requirements of crops increase markedly, and other major and minor elements are more readily leached. The result is an increased dependency on fertiliser input to maintain nutrient status.

Soil colour (compared with that under the fenceline) can be a useful indicator of whether soils on a farm or in a field are becoming darker due to gaining (sequestering) carbon. If the soil is paler, it could possibly be losing carbon, i.e. becoming C negative. If there is no colour difference, the soil carbon regime may be in a steady (C neutral) state, i.e. neither losing nor gaining carbon. Soil colour, along with soil texture, clay mineralogy, earthworm numbers, root development, potential rooting depth, the amount and form of fertiliser applied, and the method of cultivation can collectively provide a good indication as to whether a particular management practice or landuse is carbon positive, neutral or negative. A farm that has similar or darker coloured topsoils in the field relative to the fenceline, with fine silty or clayey textures, good earthworm numbers, root development, potential rooting depth, crop yields, and is applying no-till technology and carbon-friendly forms of fertiliser and nitrogen will sequester significant amounts of carbon (see carbon sequestration, pp. 72–79). Farms will therefore be C positive and in a position to potentially gain ‘Carbon Credits’ rather than possibly pay a carbon tax.

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 markedly influenced 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 oxidised form of ferric (Fe^{3+}) and manganic (Mn^{3+}) oxides. Grey or grey-blue colours can indicate 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. Ferrous and manganous oxides are more soluble than their oxidised forms and are therefore more readily taken up by the plant. High levels of soluble Fe and Mn in the soil can however suppress the availability and uptake of other elements.

In addition to the production of toxic levels of Fe^{2+} and Mn^{2+} ions, poor aeration and waterlogging, gives rise to a further series of chemical and biochemical reduction reactions that produce toxins such as hydrogen sulphide, methane, alcohol (ethanol and ethylene), acetaldehyde and formaldehyde that damage the root system. This, and the effect of waterlogging, reduces the ability of plants to take up water and nutrients (particularly

N, P, K, S, Zn, Cu and Co), causing poor crop growth and vigour. Decay and die-back of roots can also occur as a result of pests and diseases including *Rhizoctonia*, *Pythium* and *Fusarium* root rot in soils prone to waterlogging. Furthermore, the concentration of divalent cations such as Ca^{2+} and Mg^{2+} increases towards the exchange surface of the roots during prolonged soil wetness reducing the ability of the monovalent cations such as Na^+ and K^+ to be absorbed by the roots. As a result, crops typically struggle to take up nutrients such as Na that are necessary to make carbohydrates, and K required for complete kernel filling.

What is more, soil colour can indicate the potential of a soil to convert plant-available forms of nutrients into unavailable forms. Soils that are distinctly grey in colour due to being anaerobic and waterlogged reduce plant-available N in the form of nitrate (NO_3^-) and ammonium (NH_4^+) to nitrite (NO_2^-) and nitrous oxide (N_2O), a potent greenhouse gas. Plant-available S in the form of sulphate-sulphur (SO_4^{2-}-S) is reduced to plant unavailable sulphite (SO_3^{2-}) and sulphides. Sulphur and nitrogen can only be utilised by plants in the oxygenated sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) form and therefore plants require aerated soils for the efficient uptake and utilisation of S and N. Plants also need S in the sulphate form to utilise N.

Dark coloured soils further suggest that the microbial biomass is predominantly aerobic enabling the efficient decomposition of organic matter to humus and the retention, immobilisation and release of soil nutrients.

earthworms

Assessment

❶ Count the earthworms by hand, sorting through the soil sample used to assess soil structure (Plate 2, p. 5 & Plate 7). Note also the number of species present (Plates 8–10) and compare with the criteria given in Table 2. Earthworms vary in size and number depending on the species, maturity, and the season. For year-to-year comparisons, therefore, earthworm counts must be made at the same time of year (preferably late winter to early spring), and when soil moisture and temperature levels are good; avoid dry conditions. Earthworm numbers are reported as the number per 200-mm cube of soil. Earthworm numbers are commonly reported on a square-metre basis. As a 200-mm cube sample is equivalent to 1/25 square metre, 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, digesting, and casting, earthworms have a major effect on the chemical, physical, and biological properties of the soil; they shred and decompose plant residue converting it to organic matter and 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. In addition, dead earthworms can contribute significant amounts of N to the soil, being 60–70 percent protein (dry weight) with a N content of 12 percent. Thirty-five earthworms per 200-mm cube of soil (875/m^2) are roughly equivalent to a biomass of 3 tonnes of earthworm/ha, and could release 32–38 kg N/ha upon their death. Earthworms also act as biological aerators and physical conditioners of the soil, improving soil porosity, aeration, soil structure, soil aggregate stability, water retention, water infiltration, and drainage, and reducing surface runoff and erosion.

PLATE 7 **Sample for assessing earthworms**

Photo shows earthworms present in a 200-mm cube sample of soil.

PLATE 8 ***Lumbricus rubellus***

A very active surface litter and dung feeding earthworm; commonly red-brown or red-purple in colour with a paler underside; has a distinctly flattened tail; commonly 25–220 mm long.

PLATE 9 ***Aporectodea caliginosa***

A medium-sized (40–90 mm) topsoil dwelling earthworm; commonly grey-pink on both the dorsal and ventral surfaces; does not have a flattened tail.

PLATE 10 ***Aporectodea longa***

A long (90–180 mm) deep burrowing earthworm; commonly dark grey-brown with a black head; tail end is paler and slightly flattened. Underside is paler than the dorsal surface.

Photos of *L.rubellus* and *A.caliginosa* – courtesy of Ross Gray, AgResearch Ltd.

TABLE 2 **Visual scores (VS) for earthworms**

Visual score (VS)	Earthworm numbers (per 200 mm cube of soil)
2 [Good]	35 (with preferably 3 or more species)
1.5 [Moderately good]	29–35
1 [Moderate]	22–28 (with preferably 2 or more species)
0.5 [Moderately poor]	15–21
0 [Poor]	< 15 (with predominantly 1 species)

They promote plant growth by secreting plant-growth hormones and increasing root development and root density through the rapid growth of roots down nutrient enriched worm channels. While earthworms can deposit around 25–30 tonnes of casts/ha/yr on the surface (Plate 11), 70 percent of their casts are deposited below the surface of the soil. Earthworms therefore play an important role in arable cropping and can increase growth rates, crop yields and protein levels 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 fertiliser 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. Microorganisms further encourage a lower incidence of pests and diseases, and promote a more rapid breakdown of organic herbicides. The collective benefits of microbes can increase crop production markedly while at the same time reducing fertiliser requirements.

Earthworms can increase the depth of topsoil and the carbon content of both topsoil and subsoil by their burrowing, digesting, reworking, and mixing of soil and plant residues (bioturbation), and by the deposition of worm casts. High numbers of earthworms ingest considerable amounts of soil and plant material, building up soil C levels by converting C to more stable organic compounds bonded to clay particles. Organic matter gradually works down to the subsoil and so increases the depth of topsoil. The burrowing, casting, and incorporation of organic mater into the soil contributes to increasing topsoil depth by decreasing soil density and increasing the porosity, and therefore the volume of soil. Given that 30 percent of worm casts are deposited on the surface and 70 percent below ground, the potential for earthworms to increase soil carbon levels and topsoil depth is substantial.

Earthworm numbers (and biomass) are governed by the amount of food available as organic matter and soil microbes, as determined by the crops grown, the amount and quality of surface residues, the use of cover crops and the method of tillage. Earthworm populations can be up to three times higher under no-tillage than conventional cultivation. 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 fertiliser and nitrogen used. The over-use of acidifying salt-based fertilisers, anhydrous ammonia, and ammonia-based products, and some insecticides and fungicides can further reduce earthworm numbers.

PLATE 11 **Earthworm casts under crop residue**

PLATE 12 **Yellow-tail earthworm *(Octolasion cyaneum)***

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 and decompose 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. Earthworm species can further indicate the overall condition of the soil. For example, significant numbers of yellow-tail earthworms (*Octolasion cyaneum* – Plate 12) can indicate adverse soil conditions.

Assessment

❶ Remove a spade slice of soil (approximately 100 mm wide × 100 mm long × 100 mm deep) and break in half. Place the exposed face of the soil close to your nose, take three deep sniffs, and compare with the criteria given in Table 3. Soil smell can be assessed on the same sample used to assess soil porosity. The test is best carried out when the soil is moist, including during or immediately after the wet months of the year.

Importance

SOIL SMELL, while very dependent on the water content and aeration status of the soil, is also a good indicator of the amount and the activity of soil life and therefore soil health. Soil smell is determined principally by the gases given off by the aerobic or anaerobic respiration of soil microbes, and by the type and amount of organic matter and humus present in the soil. Aerobic respiration by soil fungi, bacteria, yeast, protozoa (i.e. single cell animals), nematodes, arthropods (mites, beetles, millipedes, etc.), and earthworms produce distinctive odours. The degree and nature of the odours are determined by the composition and activity of the soil biology which in turn is governed in part by the available food supply in the form of organic matter and humus. Soils rich in fungi, for example, produce aromatic compounds and organic acids that give an earthy, rich, sweet, fresh or sometimes musty smell (Plate 14). These are often the characteristic smells of forest soils, which are generally rich in fungi. The presence of similar fungal smells in a cropping soil suggests it is not only well aerated but also has a good, active microbial biomass with a fungal to bacteria ratio of 3:1. Such a ratio is necessary to preserve and promote a good biological environment for crops. Intensively cropped and fertilised soils have a greater abundance of bacteria relative to fungi than soils that are less intensively cropped and fertilised. As a consequence, they are more sensitive to plant stress, are less efficient in terms of uptake, cycling and retention of nutrients including N, and are more susceptible to N leaching. An imbalance of the ratio of fungi to bacteria, along with poor soil nutrition could explain why crops may show consistently poor growth and vigour.

TABLE 3 **How to assess soil smell**

Visual score (VS)	Soil smell
2 [Good]	Soil has a distinct rich, earthy, sweet, wholesome or fresh smell.
1 [Moderate]	Soil has a slight earthy, sweet odour or a “mineral” smell.
0 [Poor]	Soil has a putrid, sour, chemical or unpleasant smell.

Biological regimes are very sensitive to intensive conventional cultivation practices with the result that well aerated soils can have very little or no soil smell. Anaerobic respiration of micro-organisms (including anaerobic bacteria and yeast) in saturated, poorly aerated soils produce methane and nitrous oxide (greenhouse gases), alcohol (ethanol and ethylene), acetaldehyde and formaldehyde, and putrid sulphide gases including hydrogen sulphide (H_2S), ferrous sulphide (FeS), and zinc sulphide (ZnS), all of which inhibit root growth when accumulated in the soil (Plate 15). 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.

PLATE 13 **Sample to assess soil smell**

While soils should have good microbial biomass with levels preferably in excess of 1 600 mg/kg, to be beneficial, soil microbes also need to be active. The level of activity and therefore functionality of the microbial biomass is something that must always be kept in mind when assessing the status of the soil biological community. The activity and energy status of soil microbes can be assessed by measuring the level of their respiration relative to their biomass (i.e. the respiration to biomass ratio or the metabolic quotient qCO_2), and their AEC, which should be 0.8. Microbial viability is maintained at AEC values between 0.8 and 0.5 – the cells die at values below 0.5.

Soil microbes, including actinomycetes and mycorrhizal fungi, play an important role in the decomposition of organic matter to humus. Mycorrhizal fungi decompose organic matter to form glomalin, an important organic compound that comprises up to 30 percent of the humus fraction in soils. Soil organisms also play a key role in the promotion and maintenance of soil fertility through nutrient and carbon cycling, and their role in the N and S cycle. Microbes immobilise and retain significant amounts of nutrients in the humus they produce and in their biomass, releasing them when they die. Moreover, soil microbes, including mycorrhizal fungi, play a major role in the supply of plant-available nutrients, digesting soil and fertiliser, and unlocking nutrients such as phosphorus that are fixed by the soil.

Where legumes are cropped, soil microbes and particularly bacteria also play a major role in the fixation and supply of nitrogen. *Rhizobium* bacteria in clover nodules fix N directly from the atmosphere. The ammonia produced by N-fixation is taken up by the plant to produce protein and organic N compounds that are then mineralised by a further range of bacteria and fungi, releasing N in the form of plant available ammonium (NH_4^+) when the plant dies. Under aerobic conditions, the ammonium is converted by nitrosomonas and nitrobacter bacteria to nitrate (NO_3^-), another plant available form of N (a process known as nitrification). Free-living aerobic *Azotobacter* bacteria and anaerobic (*Clostridium*) bacteria in the soil further promote the fixation and supply of plant available N.

PLATE 14 **Sample of a moderately good soil smell**

Soil has a moderately rich, earthy, sweet smell with a smell score of 1.5.

In addition, bacterial- and fungal-feeding protozoa and nematodes release large amounts of N when feeding on their selected prey and are responsible for a large amount of plant-available N. The predator-prey interaction of protozoa on bacteria releases 5 units of plant-available N in the form of ammonium for every six bacteria consumed. The feeding of nematodes on bacteria releases 19 units of N for every 20 bacteria consumed. Given that bacterial numbers should be greater than one million per gram for all agricultural soils, and nearer 100 million per gram for productive soils, the potential storage and release of N from bacteria is considerable. Between 40 and 80 percent of the N in plants can come from the predator-prey interaction of protozoa with bacteria.

In addition to adding organic matter to the soil, soil organisms play a key role in soil formation by developing and promoting the structure, aggregate stability, porosity, aeration, infiltration and water-holding capacity of the soil, and reduce waterlogging and runoff from the topsoil. Soil microbes also play an important role in purifying water and filter, buffer, degrade, immobilise, and detoxify organic and inorganic pollutants. Moreover,

PLATE 15 **Sample of a poor soil smell**

Soil has a putrid, unpleasant smell of hydrogen sulphide with a smell score of 0.

they suppress pests and diseases, producing compounds that inhibit the growth of, or are toxic to pathogens, reducing the invasion of the plant by a pathogen. Soil microbes further produce plant growth hormones and compounds that stimulate root growth and produce B group vitamins including vitamin B_{12}.

The collective benefits of microbes reduce fertiliser requirements and can give significant increases in crop yield. They can also significantly improve the nutrient density and health of the plant. Soil life can therefore be effectively described as the ‘engine room’ of the farm. The trick to smart and sustainable cropping is to ensure the engine remains well-oiled.

Assessment

❶ Assess the potential rooting depth by digging a hole to identify the depth to a limiting (restricting) layer if present (Plate 16), and compare with the class limits in the Table 4. 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 overthickening of roots (a result of a high penetration resistance), and whether the roots are forced to grow horizontally, otherwise known as right-angle syndrome. Moreover, note the firmness and tightness of the soil, whether the soil is grey and strongly gleyed due to prolonged waterlogging, and whether there is a hard pan present such as a strongly developed human-induced tillage or plough pan (pp. 24–25), or a strongly developed natural pan such as an iron, silica or calcitic pan. An abrupt transition from a fine textured 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 or an open drain.

Importance

POTENTIAL ROOTING DEPTH is the depth of soil plant roots can potentially exploit before reaching a barrier to root growth, and indicates the ability of the soil to provide a suitable rooting medium for plants. The greater 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 crops. 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 crop. 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 fertiliser 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, hard pans impede the movement of air, oxygen and water through the soil profile, the latter 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, methane, alcohol (ethanol and ethylene), acetaldehyde and formaldehyde, by-products of chemical and biochemical reduction reactions.

Crops with a deep, vigorous root system help to raise soil organic matter levels and soil life at depth. The physical action of the roots and soil fauna and the glues they produce, promotes soil structure, porosity, water storage, soil aeration, and drainage at depth. A deep, dense root system provides huge scope for raising production while at the same time having significant environmental benefits. Crops are less reliant on frequent and high application rates of fertiliser and nitrogen to generate growth, and available nutrients are more likely to be taken up, so reducing losses by leaching into the environment.

PLATE 16 **Potential rooting depth**

Hole dug to assess the potential rooting depth.
The potential rooting depth extends to the base of the arrow at 350 mm below which the soil is extremely firm and very tight with no roots or old root channels, no worm channels, and no cracks and fissures down which roots can extend. Note the root mat at the bottom of the arrow. Compare the potential rooting depth of this soil with that in Plate 53, p.91

TABLE 4 **Visual scoring (VS) of potential rooting depth**

VSA score (VS)	Potential rooting depth (mm)
2.0 [Good]	800
1.5 [Moderately good]	600–800
1.0 [Moderate]	400–600
0.5 [Moderately poor]	200–400
0 [Poor]	< 200

Identifying the presence of a hardpan

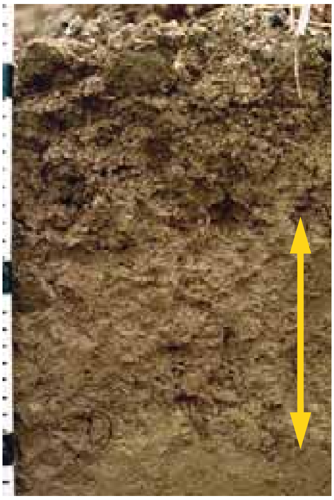
Assessment

1. Examine for the presence of a hard pan such as a strongly developed tillage or plough pan by rapidly jabbing the side of the soil profile (dug to assess the potential rooting depth) with a knife, starting at the top and progressing systematically to the bottom of the hole (Plate 17). Note how easy or difficult it is to jab the knife into the soil as you move rapidly down the profile. Pay particular attention to the lower topsoil and upper subsoil where tillage pans and plough pans commonly occur if present (see photos below).
2. Having identified the possible presence of a tillage or plough pan by a significant increase in penetration resistance to the point of a knife, gauge how strongly developed the pan is. A strongly developed pan is very tight and extremely firm and has a high penetration resistance to the knife. Confirm also its presence or absence by removing a large, hand-sized sample and assess its structure, porosity and the number and colour of soil mottles (by referring back to pp. 4, 6 and 8). In addition, look for the presence or absence of roots. Compare with the photos and criteria given in Plate 18. Only a strongly developed hardpan will restrict all root development and its presence will determine the potential rooting depth.

PLATE 17 **Identifying the presence or absence of a hardpan with a knife**

PLATE 18 **Visual assessment of a hard pan**

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 based on your observation or general recollection of the time ponded water takes to disappear after a wet period, particularly during early growth, and compare with the photographs and criteria given in Plate 19.

Importance

SURFACE PONDING and the length of time water remains on the surface can indicate the infiltration rate into and through the soil, a high water table, and the time the soil remains saturated. Roots need oxygen for respiration, and prolonged waterlogging depletes oxygen in the soil causing anaerobic (anoxic) conditions that induce root stress and restrict root respiration and growth. Roots are most vulnerable to surface ponding and saturated soil conditions in the spring when respiration and transpiration rates rise markedly, oxygen demands are high, and plant roots and shoots are actively growing. Such waterlogging causes the death of the fine roots responsible for nutrient and water uptake. Roots are also susceptible to ponding in the summer when transpiration rates are highest – reduced water uptake while the crop is actively transpiring causes leaf desiccation and the wilting of plants.

Prolonged waterlogging increases the likelihood of pests and diseases, including *Rhizoctonia*, *Pythium* and *Fusarium* root rot, and reduces the ability of roots to overcome the harmful effects of topsoil-resident pathogens. Plant stress induced by poor aeration and prolonged soil saturation can render crops less resistant to attack from such insect pests as aphids, armyworm, cutworm, and wireworm. Crops decline in vigour, have restricted spring growth (RSG) as evidenced by poor shoot and stunted growth, become discoloured, and die.

Waterlogging and deoxygenation also result in a series of undesirable chemical and biochemical reduction reactions, the by-products of which are either toxic to roots or are in a form that is unable to be taken up by the plant, e.g.:

- iron is reduced to soluble ferrous (Fe^{2+}) ions and Mn to manganous (Mn^{2+}) ions;
- plant-available nitrate-nitrogen (NO_3^--N) is reduced by denitrification to nitrite (NO_2^-) and nitrous oxide (N_2O), a potent greenhouse gas;
- plant-available sulphate-sulphur (SO_4^{2-}-S) is reduced to unavailable sulphite (SO_3^{2-}) and sulphides, including hydrogen sulphide (H_2S), ferrous sulphide (FeS), and zinc sulphide (ZnS).

Sulphur (S) and nitrogen (N) can only be utilised by plants in the oxygenated sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) form and therefore plants require aerated soils for the efficient uptake and utilisation of S and N. Furthermore, plants can only utilize N if S is present in the oxygenated sulphate form.

PLATE 19 **Visual scoring (VS) of surface ponding**

GOOD CONDITION VS = 2
No surface ponding of water evident after 1 day following heavy rainfall on soils that were at or near saturation[1].

MODERATE CONDITION VS = 1
Moderate surface ponding occurs for 2 days after heavy rainfall on soils that were at or near saturation.

POOR CONDITION VS = 0
Significant surface ponding occurs for 4 or more days after heavy rainfall on soils that were at or near saturation.

[1] Assuming little or no air is trapped in the soil at the time of ponding.

PLATE 20 **Sample of prolonged waterlogging**

Prolonged waterlogging can severely damage a crop in the early stages of growth.

In addition to N and S, waterlogging and poor aeration reduces the availability and uptake of P, K, Zn, Cu, and Co. This is partly because prolonged ponding of water kills off mycorrhizal fungi, soil organisms that facilitate the efficient uptake and utilisation of soil nutrients.While Olsen P levels of 22 mg/L are generally adequate for optimum crop production on most soils in good condition, degraded, poorly aerated soils with relatively high Olsen P levels (40–50 mg/L) can show a positive crop response to applied P. Furthermore, the concentration of divalent cations such as Ca^{2+} and Mg^{2+} increases towards the exchange surface of the roots during prolonged soil wetness, thus reducing the ability of the monovalent cations such as Na^{+} and K^{+} to be absorbed by the roots.

Anaerobic respiration of micro-organisms in waterlogged and poorly aerated soils produces methane (greenhouse gases), hydrogen gas, alcohol (ethanol and ethylene), acetaldehyde, and formaldehyde, all of which inhibit root growth when accumulated in the soil. As a result, crops often show poor vigour and ill-thrift. 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 by-products of anaerobic respiration and the lack of oxygen in poorly aerated and waterlogged soils also prevent the decay of organic material in the soil. As the soil becomes progressively degraded, the amount of CO_2 increases relative to O_2 and reaches a point where plant residues and kernels cannot decay; instead they begin to ferment, producing alcohol, formaldehydes and methane, which make proper decay and the turnover of organic matter impossible.

Prolonged surface ponding makes the soil more susceptible to damage under wheel traffic, which reduces trafficability and vehicle access. Waterlogging can expose soils to severe wheel rutting and soil structural damage during pre-plant and side-dressing of fertiliser. It can also cause structural damage at sowing and harvesting, and result in significant delays to the timing of these activities. In addition, surface ponding reduces the workability of the soil, decreasing the number of spring-field work-days when the soil is suitable for cultivation. As a consequence, waterlogging can delay ground preparation. Sowing can be further delayed because the seedbed is below the crop-specific critical temperature. Increases in the temperature of saturated soils can be delayed as long as water is evaporating.

Waterlogged topsoils on sloping ground are also prone to erosion by sheetwash and rilling. Soils susceptible to surface ponding therefore need to be carefully managed to minimise the effects of such ponding on soil, crop yield and quality, and the environment.

The tolerance of the root system to surface ponding and waterlogging depends on a number of factors, including the time of year and the cultivar. Tolerance of waterlogging also depends on soil and air temperatures, soil type and condition, fluctuating water tables, and the rate of onset and severity of anaerobiosis (or anoxia), a factor governed by the initial soil oxygen content and oxygen consumption rate.

Assessment

1. Observe the degree of surface cover and surface crusting and compare with the photographs and criteria given in Plate 21. 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. It also reduces aeration, causing anaerobic conditions by creating a barrier to gas exchange. Crusting cuts off oxygen to soil organisms and prevents the release of CO_2 from the soil to the plant canopy, thus reducing the uptake of photosynthetic CO_2 by the stomata on the crop leaf. The reduced availability of both water and CO_2 significantly limits crop yield. Crusting also prolongs water retention near the surface, which can hamper access by machinery for months. In addition, crusting can inhibit or deform cotyledon emergence. Crusting is most pronounced in fine-textured, poorly structured soils with low organic matter, low aggregate stability, high levels of Na and/or Mg and a dispersive clay mineralogy.

SURFACE COVER after harvesting and before canopy closure of the next crop helps prevent crusting by minimising the dispersion of the soil surface by rain or irrigation. It also helps reduce crusting by intercepting the large rain droplets before they strike and compact the soil surface. In addition, vegetative cover and its root system, together with surface residue, return organic matter to the soil and promote soil life. Earthworm and microbial biomass are strongly correlated to the amount of surface residue present: the greater the surface residue, the greater the biomass of earthworms and soil microbes. Earthworm biomass can be 80 percent of the weight of surface residue. The physical action of the roots and soil fauna, and the glues they produce, promote the development of soil structure, aeration and drainage, and help break up surface crusting. As a result, infiltration rates and the movement of water through the soil increase, which decrease runoff, soil erosion and the risk of flash flooding. The root system also reduces soil erosion by stabilising the soil surface, holding the soil in place during heavy rainfall events. Surface cover reduces soil erosion by intercepting high impact raindrops, thus minimising rain-splash and saltation, and serves as a sponge, retaining rainwater long enough for it to infiltrate the soil. Water storage for plant use thus increases, and water quality downstream is improved through lower sediment loading, and nutrient and coliform content.

The adoption of conservation tillage practices with good surface cover can reduce soil erosion by up to 90 percent and water runoff by up to 40 percent. The surface needs to have at least 70 percent cover to give good protection while ≤ 30 percent cover provides poor protection. In addition, surface cover markedly reduces the risk of wind erosion by protecting the soil surface. The practice of 'pasture cropping' where annual crops are direct-drilled into perennial pastures was developed in part to utilise the benefits of maintaining a good surface cover.

PLATE 21 **Visual scoring (VS) of surface cover and surface crusting**

GOOD CONDITION VS = 2
Surface cover is ≥ 70 percent with little or no surface crusting.

MODERATE CONDITION VS = 1
Surface cover is 30 percent and < 70 percent.
Surface crusting is 2–3 mm thick and is broken by significant cracking.

POOR CONDITION VS = 0
Surface cover is ≤ 30 percent.
Surface crusting
is 5 mm thick and is virtually continuous with little cracking.

Surface cover photos: courtesy of A. Leys

Assessment

1. Assess the degree of soil erosion based on current visual evidence and on your knowledge of what the site looked like in the past relative to the three photographs and criteria given Plate 22.

Importance

SOIL EROSION reduces the productive potential of soils 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.

Over-cultivation 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 water eroded by gullying, rilling and sheet wash. 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 of water through the soil;
- the slope and the nature of the underlying subsoil strata and bedrock.

The loss of organic matter and soil structure as a result of over-cultivation can also give rise to significant soil loss by wind erosion of exposed ground.

PLATE 22 **Visual scoring (VS) of soil erosion**

GOOD CONDITION VS = 2
Little or no *water erosion*. Topsoil depths in the footslope areas are < 150 mm deeper than on crest.
Wind erosion is not a concern; only small dust plumes emanate from the cultivator on a windy day. Most wind-eroded material is contained in the field.

MODERATE CONDITION VS = 1
Water erosion is a moderate concern with a significant amount of rilling and sheet erosion. Topsoil depths in the footslope areas are 150–300 mm greater than on crests, and sediment input into drains/streams may be significant.
Wind erosion is of moderate concern where significant dust plumes can emanate from the cultivator on windy days. A considerable amount of material is blown off the field but is contained within the farm.

POOR CONDITION VS = 0
Water erosion is a major concern with severe gullying, rilling and sheet erosion occurring. Topsoils in footslope areas are more than 300 mm deeper than on the crests, and sediment input into drains/streams may be high.
Wind erosion is a major concern. Large dust clouds can occur when cultivating on windy days. A substantial amount of topsoil can be lost from the field and deposited elsewhere in the district.

Water erosion photos: courtesy of J. Quinton and A. Leys

FIGURE 3 **Plant scorecard – visual indicators to assess plant performance in maize**

Visual indicators of plant performance		Visual score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS ranking
Crop establishment	pg. 36		x 3	
Crop height at maturity	pg. 38		x 3	
Leaf colour	pg. 40		x 3	
Variability of crop performance along the row	pg. 44		x 3	
Root development	pg. 46		x 3	
Root deseases	pg. 48		x 2	
Weeds	pg. 50		x 2	
Ear size	pg. 54		x 3	
Crop yield	pg. 58		x 3	
Production costs	pg. 60		x 1	
PLANT QUALITY INDEX (sum of VS rankings)				

Plant Quality Assessment	Plant Quality Index
Poor	< 20
Moderate	20–37
Good	> 37

SUMMARY

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

Notes:

Total available water-holding capacity:

Assessment

❶ Assess the degree and uniformity of crop establishment within a month of sowing by comparing the number and height of established plants with the three photographs and criteria in Plate 23. In making the assessment, consideration must be given to the possible influence of disease, insect attack, poor seed viability, residual herbicides, surface scouring by water erosion, and grazing by ducks, hares, rabbits, etc.

Importance

GOOD SEED GERMINATION, PLANT EMERGENCE AND CROP ESTABLISHMENT depend on factors that include the quality of soil tilth at the time of sowing and during the weeks immediately following. Soils that have poor structure through compaction and over-cultivation can resettle and consolidate rapidly after the seed bed has been prepared. Impeded water and air movement through the soil can give rise to small areas low in oxygen (anaerobic zones). These produce chemical and biochemical reduction reactions, the by-products of which are toxic to plants. These anaerobic zones and poor soil aeration reduce seed germination and plant emergence. As a result, bare patches and poor and uneven early growth are commonly observed throughout paddocks that have poor soil structure. Young plants can also show discolouration of leaves and moisture stress.

The loss of soil structure can reduce crop establishment of barley from 315 to 130 plants/m^2 and grain yields from 6.7 to 3.9 tonnes per hectare. Seedling mortality of winter cereals can be high if the soil is waterlogged for more than 3–4 days between germination and emergence. Corn germination also slows, and plant populations decrease. Maize plants can decrease from approximately 100 000/ha to 60 000–80 000/ha.

PLATE 23 **Visual scoring (VS) of crop establishment**

GOOD CONDITION VS = 2
Good crop establishment, with few gaps along the row. Crop showing a good, even height.

MODERATE CONDITION VS = 1
Moderate crop establishment, with a significant number of gaps along the row and a significant variation in seedling height. Emergence may also be moderately slow but recovers somewhat.

POOR CONDITION VS = 0
Poor crop establishment, with a large number of gaps along the row and a large variation in seedling height. Emergence may also be slow with limited recovery.

Assessment

1. Measure crop height when the crop has reached maturity and compare with the three photographs and criteria in Plate 24. Your observations of crop growth and vigour during the growing season may also provide a useful indication of seedbed condition. In a good season, under non-limiting conditions, a cultivar should grow to a particular height, with about a 10–15 percent variation. Allowances should be made for exceptionally good seasons and for poor seasons.

Importance

CROP HEIGHT AT MATURITY, while dependent on climatic factors, the cultivar, soil fertility and time of sowing, can be a useful visual indicator of soil quality and plant performance. Crop height is particularly useful if agronomic factors have not limited crop emergence and development during the growing season. The growth and vigour of crops depend in part on the ability of the seedbed to maintain an adequate soil tilth throughout the growing season. Poor soil aeration and resistance to root penetration as a result of structural degradation reduce plant growth and vigour, and delay maturity.

PLATE 24 **Visual scoring (VS) of crop height at maturity**

GOOD CONDITION VS = 2
Crops are at or near maximum height at crop maturity. Maize crops, for example, are generally between 2.3 and 2.7 m at maturity.

MODERATE CONDITION VS = 1
Crop heights are significantly below maximum at crop maturity. Crop height for maize, for example, is generally between 1.8 and 2.2 m at maturity.

POOR CONDITION VS = 0
Crop heights are well below maximum height at crop maturity. Crop height for maize, for example, is generally between 1.2 and 1.7 m at maturity (chest height).

Assessment

❶ Note the leaf colour of the crop when all other factors favour rapid growth, and compare with the three photographs and criteria in Plate 25. In making the assessment, consideration must be given to the cultivar, the stage of growth, the soil moisture and temperature conditions, and the presence of pests and diseases (e.g., nematodes). The best time to carry out the assessment is 4–6 weeks after plant emergence, avoiding very cold and wet weather.

Importance

LEAF COLOUR can provide a good indication of the nutrient status and condition of the soil and the crop. The colour of the foliar and blemishes on the leaf are dependent on a number of factors including a deficiency or excess of nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B). Chlorosis (or yellowing of crops) due to the loss or inadequate formation of chlorophyll, commonly occurs as a result of low N, S, Mg, Fe, Mn, Cu and Zn levels in the soil, low soil and air temperatures, prolonged cloudy days and poor soil aeration due to compaction and waterlogging.

A deficiency in N and S is a common cause of the yellowing of leaves. Sulphur and N can only be utilised by plants in the oxygenated sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) form. If the soil is, or becomes poorly aerated and waterlogged, plant-available forms of N and S reduce to plant unavailable forms as discussed on pp. 6, 13 and 26. Soils therefore need to be adequately aerated to enable N and S to remain in a plant available form thereby enabling maximum uptake and utilisation of the N and S present. Plants can also only utilize N if S is present in the oxygenated sulphate form. Put simply, poorly aerated and waterlogging soils reduce the amount of plant-available N and S (and Zn).

The frequent and excessive application of N (especially during dry conditions) and certain types of fertilisers and pesticides to crops can adversely affect the biological regime and nitrogen cycle of the soil, and also suppress the supply and utilisation of other elements. As a result, crops can become dependent on an additional ‘fix’ of nitrogen or fertiliser to stimulate the colour of the crop and growth. In other words, the engine room of the soil, as discussed on p. 21, has become rusty and no longer has the ‘horse power’ to produce the yield required without the significant addition of N and fertiliser.

In addition to a yellowing of the crop, discolorations or blemishes on the leaf can also indicate mineral deficiencies (Plates 26–31). Nutrient deficiencies or excesses can suppress the availability of other nutrients. For example, high P levels can suppress the uptake of S, Zn and Cu, while high S levels can suppress the uptake of P and Mg. Excess N can strip Ca from the soil, block Mn, Zn, B and Cu uptake, and cause the plant to luxury feed on K, which in turn can also tie up Mn and B, and suppress the utilisation of Ca and Mg by the animal.

PLATE 25 **Visual scoring (VS) of leaf colour**

GOOD CONDITION VS = 2
Leaf colour is uniformly deep green. The odd colour blemish on leaves may be apparent within a broad area.

MODERATE CONDITION VS = 1
Leaf colour is yellowish green; i.e. has a distinct yellowish tinge. Few colour blemishes on leaves may occur within a wide area.

POOR CONDITION VS = 0
Leaf colour is quite yellow over a wide area. Colour blemishes on leaves may commonly occur.

PLATE 26–28 Common symptoms of leaf discolouration due to nutrient deficiencies in maize

26. Phosphorus deficiency – purpling of leaves.

27. Nitrogen deficiency on left.

28. Potassium deficiency.

PLATE 29–31 **Common symptoms of leaf discolouration due to nutrient deficiencies in maize**

29. Sulphur deficiency on the right.

30. Magnesium deficiency.
Red and purple tints on leaves with intervenal chlorosis and necrosis.

31. Zinc deficiency.

Assessment

1. Cast your eye along the row at crop maturity and observe any variability in crop performance in terms of crop height, stem numbers, stem thickness, leaf colour, leaf density etc. (Plates 32–35), and compare with the class limits in Table 5. In making the assessment, consideration must also be given to other factors that may affect the performance of a crop, such as pest and disease attacks that are not related to the condition of the soil.

Importance

VARIABILITY OF CROP PERFORMANCE ALONG THE ROW can be a good visual indicator of the condition of the soil. In particular, the linear variability in crop performance can be strongly related to the availability of water and nutrients, and the texture of the soil (e.g., whether clayey, silty, loamy or sandy). Also, soils in good condition with good structure and porosity, and a deep, well-aerated root zone 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 show an active biological and chemical process, favouring the release and uptake of water and nutrients and consequently the growth and vigour of the crop.

The spatial variability of crop performance along the row is also a useful indicator because it highlights those areas of the field that are under-performing, thus enabling a specific investigation as to why and what remedial action may be taken.

PLATE 32 **Variable crop performance due to differences in rooting depth to an iron pan**

Variable crop performance due to differences in rooting depth to an iron pan.

PLATE 33 **Variable crop performance due to soil compaction**

Variable crop performance due to soil compaction.

PLATE 34 **Variable crop performance due to differences in soil aeration and soil wetness**

Variable crop performance due to differences in soil aeration and soil wetness.

PLATE 35 **Variable crop performance due to differences in the degree of water repellency**

Variable crop performance due to differences in the degree of water repellency (i.e. hydrophobicity).

TABLE 5 **Visual scoring (VS) of variability of crop performance along the row**

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

Assessment

❶ Determine the size and development of the root system by carefully prising the plant out of the soil with a spade and gently shaking it or tapping the sample against the edge of the hole to remove adhering soil from the roots. Use the point of a knife to help loosen the soil if required. Assess both the length and the density of the roots and compare against the three photographs and criteria in Plate 36. Root length and root density is best assessed at or just before crop maturity.

Importance

ROOT LENGTH AND ROOT DENSITY provide a good indications of the development of the plant root system. Crops with deep roots and a high root density are able to explore and utilise a greater proportion of the soil for water and nutrients compared to crops with a shallow, thin root system. Shoot and leaf growth, kernel development and grain filling is therefore likely to be greater, crops are less likely to suffer windthrow, and they will be less susceptible to drought stress. Crops with a dense, deep, vigorous root system will also add (sequester) greater amounts of organic matter to the soil and increase the level of soil life. The physical action of the roots and soil fauna, and the glues they produce, further promote the development of soil structure, soil aeration and drainage.

A deep, dense root system provides huge scope for raising production while at the same time having significant environmental benefits. Crops are less reliant on high application rates of fertiliser and nitrogen to generate growth, and available nutrients are more likely to be sapped up reducing losses by leaching into the groundwater and waterways.

Root length, root density, plant growth and vigour can be restricted by the mechanical impediment of roots and the reduction of soil pores as a result of soil compaction or a hardpan. High mechanical resistance to roots limits plant uptake of water and nutrients, restricts the production of several plant hormones in roots necessary for growth, and increases the susceptibility of the crop to windthrow. Restrictions can also occur due to low soil moisture, soil temperature and pH, aluminium toxicity, salinity, sodicity, nutrient deficiencies, the application of excess nitrogen causing lazy plants, low mycorrhizal fungi levels, soil-borne pathogens, a high or fluctuating water table and poor soil aeration. Anaerobic (anoxic) conditions due to prolonged water-logging and deoxygenation restrict root length and density as a result of the accumulation of toxic levels of sulphides, methane, alcohol (ethanol and ethylene), acetaldehyde and formaldehyde, by-products of chemical and biochemical reduction reactions (p. 8, 12 and 26).

PLATE 36 **Visual scoring (VS) of root development**

GOOD CONDITION VS = 2
Unrestricted root development with the main large root bulb up to 250 mm wide and 200–250 mm deep.

MODERATE CONDITION VS = 1
Vertical and lateral root development is moderately restricted with right-angle syndrome not uncommon. The main root bulb is commonly 150 mm wide and 150–180 mm deep.

POOR CONDITION VS = 0
Vertical and lateral root development is severely restricted with root systems showing either stunted growth, right-angle syndrome, over-thickening, or growth down coulter channels.

Assessment

1. Assess the presence of root diseases by pulling a number of stems out of the soil and carefully examining the root system for evidence of root diseases at, or any time before, crop maturity (Plates 37–38).
2. Consider also how commonly root diseases occur in the field from season to season and make your assessment based on the class limits in Table 6.

Importance

POOR SOIL AERATION, soil saturation and high mechanical resistance to root development due to soil structural degradation can increase root rot and soil-borne pathogens. They can also reduce the ability of the root system to overcome the harmful effects of pathogens resident in the topsoil. Root diseases that commonly occur as a result of the loss of soil quality include take-all (*G. graminis var. tritici*), Rhizoctonia crown and brace root rot (*Rhizoctonia solani*), and Pythium root rot (*Pythium* spp.). *Fusarium* spp. root rot can also occur when the plant is stressed because of poor aeration and the inadequate allocation of photosynthate to the roots. The presence of root diseases can cause severe yield loss and reduction in grain quality. Symptoms include pre- and post-emergence plant death in seedlings resulting in crop thinning, stunting and reduced tillering/leaf growth, discolouration of and blemishes (lesions) on stems, tillers and leaves, bleached heads, and premature death. Plants may also lean or lodge because the root system is anchored poorly in the soil. Infected plants have sparse root development and characteristically a brown-black rot can be seen at the crown and extending to the base.

The conservation of soil moisture, amelioration of soil compaction, the build up of organic matter and the promotion of good soil life (in terms of microbial biomass, diversity and activity) are factors that contribute to the development of healthy plants and the suppression of soil-borne diseases. They also help enable the plant to better resist the pressure of disease and insect attack. Soil biota, and especially those micro-organisms that enhance cellulytic breakdown and decomposition of maize/straw residues, further limit pathogen survival.

TABLE 6 **Visual scoring (VS) of root diseases**

Visual score (VS)	Occurrence of root diseases due to soil conditions
2 [Good]	Root diseases are rare
1 [Moderate]	Root diseases are common
0 [Poor]	Root diseases are very common

PLATE 37 **Pythium root rot**

Pythium root rot where the rotted cortex has pulled away from the stele. (White DG, 1999. Compendium of Corn Diseases).

PLATE 38 **Rhizoctonia root rot**

Root rot resulting from rhizoctonia fungal infestation on compacted, poorly aerated soils on the left. Healthy root development on uncompacted, well aerated soils on the right.

Assessment

❶ Assess the degree of weed infestation by visually estimating the number of weeds between rows before canopy closure. Consider also how often a given level of weed infestation occurs in the paddock from season to season, and at what level it is perceived to be a problem. Make your assessment according to the photos and criteria given in Plate 39 on the basis of what the field would look like without significant weed control measures.

In making the assessment, consider those factors that can contribute to weed infestation including, for example, the introduction of seeds from cultivation and harvesting machinery. The timing of sowing, whether early or late, may also play a significant role. Weeds are often less of a problem if the crop is sown early enough and a good, early canopy cover is established. Warmer climate weeds such as those of summer crops respond directly to temperature and light so they germinate and grow faster in warmer conditions with more light. On the other hand, the growth of cooler climate weeds of both winter and summer cereal crops is independent of temperature and the weeds usually grow best when soil moisture is high. Consider also the use and timing of weed control measures, including shallow inter-row cultivation and pre- and post-emergent herbicide sprays. Weed control measures should be implemented at an early stage when the young weeds are easy to control, i.e. before they get to the seedling stage. In addition, consider whether weeds have become more resistant to a herbicide, and whether the persistence of herbicides is reduced, for example, by their strong absorbance by clayey, allophanic, humic or peaty soils. Soils with a high microbial activity can also give rise to a faster than normal dissipation of herbicides. Herbicides can also degrade quicker if applied at higher temperatures, which renders them less effective. They are also less effective when applied to cloddy than to a fine soil tilth.

Importance

A HIGH WEED population uses a lot of the water and nutrients that would otherwise be available to the crop. Actively growing weeds can also grow over and smother the crop, intercepting light and shading the crop, resulting in suppressed growth and poor crop quality with small, stressed kernels and ears (Plate 40). The rampant growth of tall woody and grass weeds (such as broomcorn millet) interfere with harvesting by contaminating the grain with seed heads and berries (Plate 41). In addition, the extra growth is difficult to pass through the knife rolls, overloading the harvester and damaging the nose cones.

While weeds can occur for a number of reasons, they can be useful indicators of the condition of the soil, including level of compaction, soil aeration and waterlogging, nutrient fertility, pH, the amount and type of organic matter, and the microbial biomass. It is commonly believed healthy soils support weeds and crops equally well. In the same way that insect infestation indicates unhealthy plants with a nutritional imbalance, a weed infestation indicates something is not right with the soil, which is suppressing the growth of crops and providing an environment favouring weeds. Soil structural degradation resulting from over-cultivation, wheel traffic, or soil dispersion due to a low Ca:Mg ratio

PLATE 39 **Visual scoring (VS) of weeds**

GOOD CONDITION VS = 2
Weeds are not common in most seasons and are not considered to be a problem. Inter-rows may be protected by a mulch or short grass.

MODERATE CONDITION VS = 1
Weeds are common in most seasons and are a moderate problem.
Photo: Courtesy of Trevor James

POOR CONDITION VS = 0
Weeds are extremely common in most seasons and are a serious problem.
Photo: Courtesy of Trevor James

or high Na levels, reduces soil aeration, soil drainage, available water-holding capacity, nutrient uptake, and the rooting potential of the crop, allowing weeds to establish and compete with the crop. Warmer climate weeds also use water more efficiently than the crop itself, and so are very competitive when there is reduced moisture. Lighter soils with a coarser textural class can have more weeds than heavier soils with a finer textural class, while acidic soils can have a greater variety of weeds than non-acid soils.

Weeds will also develop and thrive in soils that have a poor mineral and microbial balance. Weeds will grow and proliferate where there is a Ca and P deficiency and an excess of K and Zn. They will develop where there is an imbalance of Fe to Mn, a lack of biologically available Ca, a lack of biologically active carbon including humus and humic acids, and where there are high nitrate levels, and a lack of bacteria or fungi. Cropping soils need to maintain a good, active microbial biomass with a fungal to bacteria ratio of approximately 3:1 for maize, and 2:1–3:1 for wheat and barley. Such ratios are necessary to preserve and promote a good biological environment for crops. An imbalance of these ratios along with poor soil nutrition could explain why crops may show poor growth and a tendency to be infested with weeds.

Bristle-grass may become prominent in compacted soils and where soils are deficient in Ca, P, Se, vitamin C, and have excess Mg with a narrow Ca:Mg ratio. Their occurrence is exacerbated by Mg, Zn, and the excessive use of K (muriate of potash), which also further suppresses Ca levels. Excess Zn along the maize plant row can cause the proliferation of Shepherds purse. Barnyard grass, goosegrass (crowfoot grass), summer grass and broomcorn millet like a soil environment that is low in Ca, P, humus and soil microbes, and high in K. Witch grass likes heavier, sticky soils with very low Ca levels and possibly high Al.

The condition and properties of the soil have a major bearing on whether the crop is able to grow in a sufficiently vigorous way to out-compete, and prevent or restrict the establishment and growth of weeds. Competitive suppression by vigorous crop growth plays a major role in preventing weed establishment. Weed suppression can also occur after a crop is sown by the production of auxins (or plant growth hormones) when the seed germinates. Auxins limit or stop the germination of seeds from other weeds. While this suppression lasts for only 1–2 days in poor quality soils, it can last for 6–8 weeks in biologically active, well-aerated soils, thus providing an effective, natural weed control. The application of liquid calcium incorporating a form of organic carbon such as molasses, or humic/fulvic acids (to act as a food supply for soil microbes), along with the addition of an organic form of phosphorus and selected trace elements such as B, Co and Se, can help alter the soil environment in such a way that weeds do not want to grow. Changing the soil environment can successfully deal with any weed problem and can provide a more effective solution than the application of straight herbicides, which gives a short-term and often limited response. However, where weeds are an initial problem, the incorporation of herbicides into a solution containing ammonium humate or fulvic/humic acids with a pH modifier, can provide good weed control. Such a mixture enables the amount of herbicide used to be reduced by 25–35 percent, and also helps buffer the effect of the herbicide on soil life. The regular use of herbicides and pesticides have an adverse effect on soil microbes (including mycorrhizal fungi), which are responsible for maintaining the nutrient balance and availability of nutrients in the soil. The quick-kill approach using chemical herbicides only addresses the symptoms and does nothing to rectify the underlying cause.

PLATE 40 **Severe weed infestation**

Severe weed infestation of Rough bristle-grass suppressing maize growth.

PLATE 41 **Severe weed infestation**

Severe weed infestation of Broomcorn millet reducing crop yield and preventing harvesting.

Photos: Courtesy of Trevor James

Assessment

1. Assess the size of the ears just before harvesting and compare them with the photographs and criteria in Plate 42.

While there is a strong association between kernel number and yield, ear size and dry weight are also strong determinants of the final yield. In making the assessment, consideration must be given to the hybrid and crop agronomy including plant population, soil fertility, weather conditions and in particular the rainfall, temperature, and sunlight hours. High plant populations will reduce the size of the ears, and dry conditions and prolonged cloudy weather will reduce photosynthesis and the subsequent formation of carbohydrates and starch required for grain filling.

Importance

EAR SIZE is governed by a number of factors, including the availability of water, nitrogen and other nutrients, and the production of carbohydrate, starch and protein (Plate 43). It is essential that these be maintained during the crop cycle, particularly avoiding any shortage especially during the grain filling period. Small ears are often a sign of poor soil quality, including low fertility. They may also be due to asynchrony between pollen shed and silking caused by high rainfall, low temperatures, drought, or earworm damage. Soils in good condition with good structure, porosity, organic matter levels, soil life, soil fertility, and rooting depth help ensure the supply and availability of water and nutrients, and the duration of photosynthate producing green leaves. The grain-filling period is prolonged as a result and an increase in ear size is achieved.

Ear size is a useful determinant of grain quality in terms of grain size and shape distribution, grain hardness, grain weight, broken (or damaged) corn, moisture content, and the number of grains affected by disease.

PLATE 42 **Visual scoring (VS) ear size**

GOOD CONDITION VS = 2
Ears are large, varying in length between 180–220 mm. Ears show good grain filling of kernels and tips, and few stress features are apparent

MODERATE CONDITION VS = 1
Ears are of medium size, varying in length between 150–180 mm. Ears often show incomplete filling of kernels and tips, and stress features are often apparent.

POOR CONDITION VS = 0
Ears are small, varying in length from 100–150 mm. Kernels are often undeveloped and poorly filled at the tips. Stress features are very common.

PLATE 43 **Small ears due to nutrient and water deficiency**

Ears with poorly filled tips and loose chaffy kernels due to potassium deficiency.

Small ears with twisted and undeveloped kernels due to phosphate deficiency interfering with pollination and kernel fill.

PLATE 43 **Small ears due to nutrient and water deficiency (*continued*)**

Small ears with a low protein content and kernels at the tip not filling because of a nitrogen deficiency at critical times. Nitrogen is essential throughout the growing season.

Dry weather slows silking behind tasseling; kernels are not pollinated.

Photos from White, D. 1999. Compendium of Corn Diseases, 3rd Ed, APS Press

Assessment

1. Assess crop yield based on the criteria given in the Table 7. Crop yields are best assessed by noting the harvested dry weight (Plate 44). Maize yields can also be estimated by counting the number and size of ears per square metre and the degree of grain filling. The yield of cereal crops can also be estimating by noting the number and size of ears (spikes) per square metre, the number of kernels (grains) per ear, and the degree of grain filling. In making the assessment, consideration must be given to the variety of the crop, the number of plants per square metre, the soil moisture, air temperature and sunshine hours during the growing season, and pests and diseases not associated with the condition of the soil.

Importance

WITH A DECLINE IN SOIL QUALITY, crops can come under stress as a result of poor soil aeration, water-logging, moisture stress (due to either soil saturation or a reduced available water-holding capacity), a lack of available nutrients, and adverse temperatures. Toxic chemicals can also build up and root growth be impeded owing to chemical reduction reactions (pp. 8 & 26) and a high penetration resistance to root development. This results in poor germination and emergence, poor plant growth and vigour, the need for redrilling, delays in drilling, root diseases, pest attack, and consequently lower crop yields. Plant stress induced by structural degradation can further affect the quality of grain by changing the amount and type of protein and starch formed, and the enzymic potential. These affect the amount of fermentable carbohydrate, the baking quality of wheat, and the malting potential of barley. Under good soil conditions with adequate water and nutrients, the ripening period is prolonged and the starch accumulation inside the kernel is delayed and more gradual. This increases yield with a higher starch and protein percentage and quality.

Compacted, poorly aerated soils can be partially ameliorated by artificial aeration (Plates 46 & 47, p. 63). Aerating the soil can increase crop production by 10–20 percent on moderately compacted ground, and by up to 40 percent on severely compacted ground. Spending money on diesel to aerate compacted soils instead of additional fertiliser will often give better crop yields.

For good crop yields, the plant requires the following nutrients in adequate amounts:

- N, S, Mg, Fe, Mn, Zn, and Cu for chlorophyll production
- N, P, K, Fe, Mn, Cu for photosynthesis
- N, P, K, Zn, Cu and B to aid the production and use of carbohydrates and starch
- N, K, S, Fe, Cu – to form amino acids, essential for protein synthesis
- N, P, K, S, Mg, Fe, Mn, Zn, Cu and Mo, constituents of several enzyme systems involved in building and converting amino acids to proteins.
- N and P to supply the source of energy, energy storage and transfer in the plant
- N, P, Ca, Fe and B for cell division and enlargement, vital for plant growth
- Ca and Co for growth of shoots and shoot tips
- Ca, P and B for root formation and growth

PLATE 44 **Harvesting maize for silage and grain**

Harvesting a 20 t/ha maize silage crop (top) and a good maize grain crop with a yield of 15.2 tonnes/ha (bottom).

TABLE 7 **Visual scoring (VS) crop yield**

Visual score (VS)	Crop yield
2 [Good]	Crops have 40 ears per square metre. The ears are large (180–220 mm in length) and show complete grain filling and few signs of stress, pests or diseases. Harvested yield is 14 tonnes/ha for maize grain and 25 tonnes/ha for maize silage.
1 [Moderate]	Crops have 20–30 ears per square metre. The ears are of medium size (150–150 mm in length), with moderate grain filling, but are often poor at the tips. Stress, pest, and disease evidence is moderately common. Harvested yield is 10–12 tonnes/ha for maize grain and 19–22 tonnes/ha for maize silage.
0 [Poor]	Crops have < 20 ears per square metre. The ears are generally small (100–180 mm in length) and show uneven and poor grain filling, particularly at the tips. Stress, pest and disease features are very common. Harvested yield is < 8 tonnes/ha for maize grain and < 16 tonnes/ha for maize silage.

Assessment

1. Assess whether production costs have increased because of increased tillage, fertiliser, herbicide and fungicide requirements over the years (Figure 4) and refer to the class limits given in Table 8. This assessment can be based on perceptions but reference to annual balance sheets will give a more precise answer.

Importance

FERTILISER, GROUND PREPARATION, HERBICIDE AND PESTICIDE INPUTS account for some of the highest costs in any cropping operation, and can increase significantly with increasing soil degradation. While fertiliser is one of the major costs associated with cropping, the amount, type and therefore cost of applied fertiliser can be significantly influenced by the condition of the soil. Soil condition can have a major effect on fertiliser use efficiency, including the up-take of N and S. For example, poorly aerated and waterlogged soils reduce plant available nitrate-nitrogen (NO_3^--N) to nitrite (NO_2^-) and N_2 gas, and sulphate-sulphur (SO_4^{2-}-S) to sulphite (SO_3^{2-}) and sulphides, rendering the N and S unavailable to the plant. The N cycle also cannot work if the S cycle is not working, i.e. plants need sulphur in sulphate form to utilize N. It is partly for this reason that farmers commonly apply more N and S than would otherwise be the case in an attempt to overcome the losses incurred by the chemical reduction effect of soils in poor condition.

Poorly aerated and waterlogged soils also decrease the uptake of phosphorus. Degraded soils with relatively high Olsen P levels (40–50 mg/L) can show a positive yield response to applied P. Again, to boost production, farmers will often apply more phosphorus than normally would be required.

In addition, continuous cropping using conventional cultivation techniques can give rise to a significant loss of organic matter (see Figs 6 & 7, p. 77) and, as a result, can substantially reduce soil fertility and the ability of the soil to supply nutrients. Higher amounts of fertiliser are needed to compensate for the loss of these nutrients. Moreover, the loss of organic carbon could incur a possible carbon tax, further increasing costs.

Reductions in crop yield are often not recognised as the result of the degradation of soil structure, the loss of organic matter, and a reduction in the number and activity of soil microbes. Rather, growers assume that soil fertility is at fault and increase their production costs by applying extra fertiliser.

Do you use fertiliser to grow the plant, or do you use fertiliser to feed the soil to grow the plant?

FIGURE 4 **Assessment of production costs**

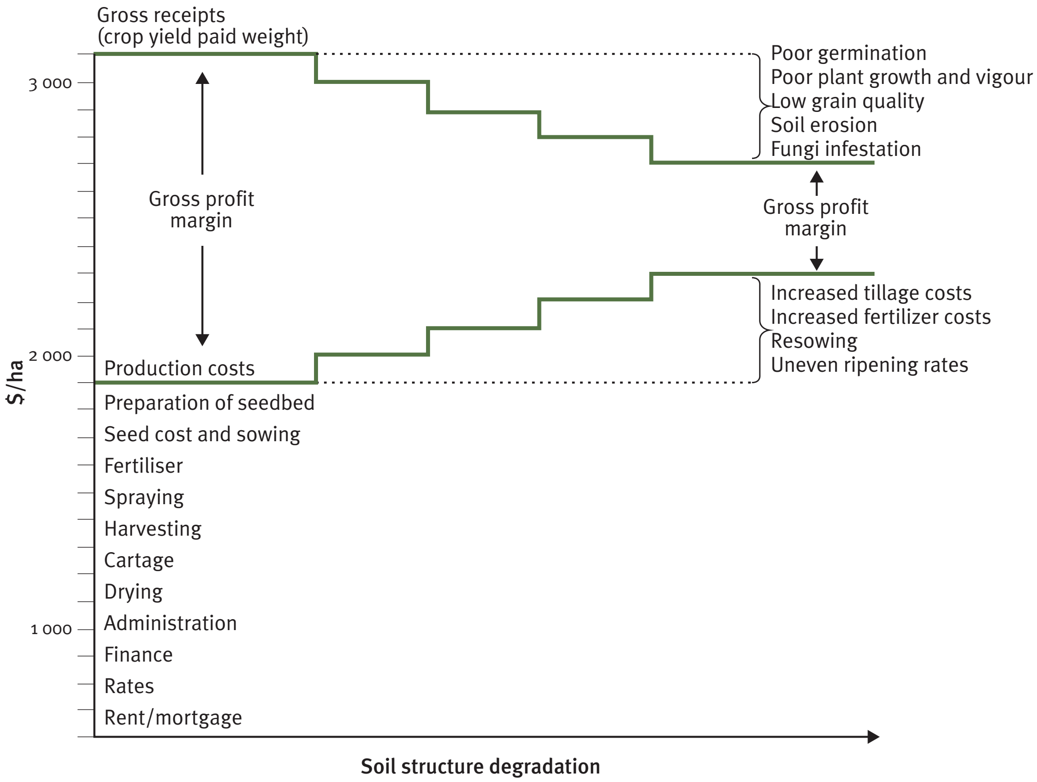


TABLE 8 **How to score production costs**

Visual score (VS)	Production costs
[Good]	Production costs including fertiliser, ground preparation, herbicide and pesticide requirements have not increased.
1 [Moderate]	Production costs including fertiliser, ground preparation, herbicide and pesticide requirements have increased moderately.
0 [Poor]	Production costs including fertiliser, ground preparation, herbicide and pesticide requirements have increased greatly.

In addition to soil fertility issues, soils in poor physical condition can have a significant effect on the cost of preparing a seedbed. As degradation increases, the density and strength of the soil increases and, as a result, the soil becomes more resistant to tillage forces, effectively creating 'Sunday Soils' – too wet to cultivate on Saturday and too dry on Monday. Plough resistance increases so that larger (more costly) tractors are required to avoid excessive wheel slip and to operate at lower ground speeds in a lower gear. The size, density, and strength of soil clods also increase with increasing loss of soil structure, and careful timing and additional energy are needed to break them down to a seedbed. This energy is generally applied by using more intensive methods of cultivation and by making a greater number of passes (often referred to as 'recreational tillage'). As a result, tillage costs can increase by over 300 percent using conventional cultivation. No-till technology can reduce overall costs by 40–50 percent.

Production costs can be reduced if soils are well aerated and the seedbed is prepared with a minimum number of passes. Cultivating at the optimum water content for maximum breakdown of soil clods to form a seedbed not only reduces the number of passes required, but helps preserve the structure of the soil (Plate 45). Compacted soils should also be artificially aerated when they are sufficiently moist and crumbly to give maximum fracturing (Plate 46). Cultivating and aerating the soil at the optimum water content to give the best results can be achieved by applying the 'worm test' (Plate 47).

PLATE 45 **Cultivating the soil at the right water content**

Cultivating at the optimum water content to achieve maximum breakdown of soil clods to form a seedbed in one pass.

PLATE 46 **Artificial aeration**

Photo: Courtesy of James Engineering

Artificial aeration of a compacted topsoil at the optimum water content to achieve maximum fracturing of the soil profile.

PLATE 47 **The worm test**

a) Roll a soil worm between the palms of your hands.
b) For **silty soil**, if you can roll a worm 10 mm wide x 40 mm long between the palms of your hands (7 mm x 40 mm for **clayey soils**) without it cracking, the soil is too wet to aerate. If the worm cracks when it is 10 mm wide for silty soils (7 mm wide for clayey soils), the soil is ready to aerate.

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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