VISUAL SOIL ASSESSMENT

FIELD GUIDE

Wheat

BioAgriNomics

UNIVERSITÀ DEGLI STUDI DI TERAMO

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FIELD GUIDE

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Wheat

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List of acronyms

AEC	Adenylate energy charge
Al	Aluminium
ATP	Adenosine triphosphate
B	Boron
Ca	Calcium
CO_2	Carbon dioxide
Cu	Copper
Fe	Iron
K	Potassium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
P	Phosphorus
RSG	Restricted spring growth
S	Sulphur
VS	Visual score
VSA	Visual Soil Assessment
Zn	Zinc

Visual Soil Assessment

Introduction

The maintenance of good soil quality is vital for the environmental and economic sustainability of wheat cropping. A decline in soil quality has a marked impact on yield and grain quality, production costs and the risk of soil erosion, and 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. Safeguarding soil resources for future generations and minimizing the ecological footprint of cropping wheat 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 quality;
- the effect of land management decisions on soil quality.

Soil type and the effect of management on the condition of the soil are important determinants of the productive performance of wheat 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 wheat. Soils with good VSA scores will, by and large, give the best production with the lowest establishment and operational costs.

The VSA method

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

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

Visual scoring

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

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

The VSA tool kit

The VSA tool kit (Plate 1) comprises:

- **A SPADE** – to dig a soil pit and to take a 200-mm cube of soil for the drop shatter soil structure test;
- **A PLASTIC BASIN** (about 450 mm long x 350 mm wide x 250 mm deep) – to contain the soil during the drop shatter test;
- **A HARD SQUARE BOARD** (about 260x260 x20 mm) – to fit in the bottom of the plastic basin on to which the soil cube is dropped for the shatter test;
- **A HEAVY-DUTY PLASTIC BAG** (about 750x500 mm) – on which to spread the soil, after the drop shatter test has been carried out;
- **A KNIFE** (preferably 200 mm long) to investigate the soil pit and potential rooting depth;
- **A WATER BOTTLE** – to assess the field soil textural class;
- **A TAPE MEASURE** – to measure the potential rooting depth;
- **A VSA FIELD GUIDE** – to make the photographic comparisons;
- **A PAD OF SCORECARDS** – to record the VS for each indicator.

PLATE 1 **The VSA tool kit**

The procedure

When it should be carried out

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

Setting up

Time

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

Reference sample

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

Sites

Select sites that are representative of the field. The condition of the soil in wheat fields is site specific. Avoid areas that may 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 indicator scorecard.

Carrying out the test

Initial observation

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

Take the test sample

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

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

The drop shatter test

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

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

The plant indicators

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

Format of the booklet

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

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

Landowner:

Land use:

Site location:

GPS ref:

Sample depth:

Date:

Soil type:

Soil classification:

Drainage class:

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

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

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

Assessment

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

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

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

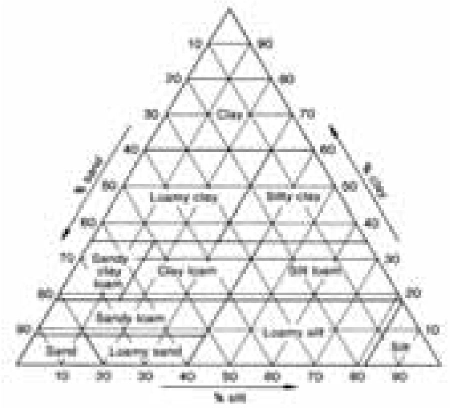
There are also occasions when the assignment of a textural score will need to be modified because of the specific preference of a crop for a particular textural class. For example, asparagus prefers a soil with a sandy loam texture and so the textural score is raised by 0.5 from a score of 1 to 1.5 based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

Importance

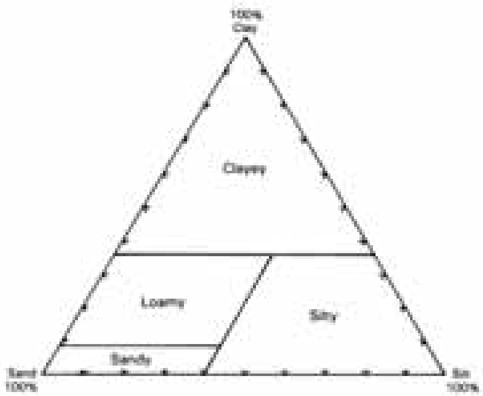
SOIL TEXTURE defines the size of the mineral particles. Specifically, it refers to the relative proportion of the various size-groups in the soil, i.e. sand, silt and clay. Sand is that fraction that has a particle size >0.06 mm; silt varies between 0.06 and 0.002 mm; and the particle size of clay is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

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

FIGURE 2 **Soil texture classes and groups**



Textural classes.



Textural groups.

TABLE 1 **How to score soil texture**

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

Assessment

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

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

Importance

SOIL STRUCTURE is extremely important for grain 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 optimal soil conditions.

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

PLATE 2 How to score soil structure

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

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

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

Assessment

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

Importance

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

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

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

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

PLATE 3 **How to score soil porosity**

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

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

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

Assessment

1. Compare the colour of a handful of soil from the field site with soil taken from under the nearest fenceline or a similar protected area.
2. Using the three photographs and criteria given (Plate 4), compare the relative change in soil colour that has occurred.

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

Importance

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

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

PLATE 4 **How to score soil colour**

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

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

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

Assessment

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

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

Importance

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

Poor aeration reduces the uptake of water by plants and can induce wilting. It can also reduce the uptake of plant nutrients, particularly N, P, K, S and Cu. Moreover, poor aeration retards the breakdown of organic residues, and can cause chemical and biochemical reduction reactions that produce sulphide gases, methane, ethanol, acetaldehyde and ethylene, which are toxic to plant roots. In addition, decay and dieback 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 mottles is ≤1, you need to aerate the soil.

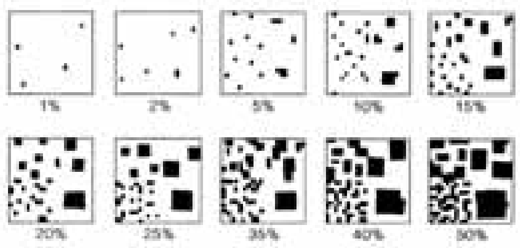


PLATE 5 **How to score soil mottles**

GOOD CONDITION VS = 2
Mottles are generally absent.

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

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

Assessment

1. Count the earthworms by hand, sorting through the soil sample used to assess soil structure (Plate 7) and compare with the class limits in Table 2. Pay particular attention to the turf mat. Earthworms vary in size and number depending on the species and the season. Therefore, for year-to-year comparisons, earthworm counts must be made at the same time of year when soil moisture and temperature levels are good. Earthworm numbers are reported as the number per 200-mm cube of soil. Earthworm numbers are commonly reported on a square-metre basis. A 200-mm cube sample is equivalent to 1/25 m^2, and so the number of earthworms needs to be multiplied by 25 to convert to numbers per square metre.

Importance

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

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

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

Earthworms also increase the population, activity and diversity of soil microbes. Actinomycetes increase 6–7 times during the passage of soil through the digestive tract of the worm and, along with other microbes, play an important role in the decomposition of organic matter to humus. Soil microbes such as mycorrhizal fungi play a further role in the supply of nutrients, digesting soil and fertilizer and unlocking nutrients, such as P, that are fixed by the soil. Microbes also retain significant amounts of nutrients in their biomass, releasing them when they die. Moreover, soil microbes produce plant-growth hormones and compounds that

PLATE 6 **(a): earthworm casts under crop residue; (b): yellow-tail earthworm (*Octolasion cyaneum*)**

stimulate root growth and promote the structure, aeration, infiltration and water-holding capacity of the soil. Micro-organisms further encourage a lower incidence of pests and diseases, 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 fertilizer requirements.

Earthworm numbers (and biomass) are governed by the amount of food available as organic matter and soil microbes, as determined by the amount and quality of surface residue (Plate 6a), the use of cover crops including legumes, and the cultivation of interrows. Earthworm populations can be up to three times higher in undisturbed soils compared with cultivated soils. Earthworm numbers are also governed by: soil moisture, temperature, texture, soil aeration, pH, soil nutrients (including levels of Ca), and the type and amount of fertilizer and N used. The overuse of acidifying salt-based fertilizers, anhydrous ammonia and ammonia-based products, and some insecticides and fungicides can further reduce earthworm numbers.

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

Earthworms species can further indicate the overall condition of the soil. For example, significant numbers of yellow-tail earthworms (*Octolasion cyaneum* – Plate 6b) can indicate adverse soil conditions.

TABLE 2 **Visual scores for earthworms**

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

PLATE 7 **Sample for assessing earthworms**

Assessment

❶ Dig a hole to identify the depth to a limiting (restricting) layer where present (Plate 8), and compare with the class limits in Table 3. As the hole is being dug, note the presence of roots and old root channels, worm channels, cracks and fissures down which roots can extend. Note also whether there is an over-thickening of roots (a result of a high penetration resistance), and whether the roots are being forced to grow horizontally, otherwise known as right-angle syndrome. Moreover, note the firmness and tightness of the soil, whether the soil is grey and strongly gleyed owing to prolonged waterlogging, and whether there is a hardpan present such as a human-induced tillage or plough pan, or a natural pan such as an iron, siliceous or calcitic pan (pp 16–17). An abrupt transition from a fine (heavy) material to a coarse (sandy/gravelly) layer will also limit root development. A rough estimate of the potential rooting depth may be made by noting the above properties in a nearby road cutting or an open drain.

Importance

The **POTENTIAL ROOTING DEPTH** is the depth of soil that plant roots can potentially exploit before reaching a barrier to root growth, and it indicates the ability of the soil to provide a suitable rooting medium for plants. The greater is the rooting depth, the greater is the available-water-holding capacity of the soil. In drought periods, deep roots can access larger water reserves, thereby alleviating water stress and promoting the survival of non-irrigated 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 fertilizer efficiency, increases leaching, and decreases yield. A high resistance to root penetration can also increase plant stress and the susceptibility of the plant to root diseases. Moreover, hardpans impede the movement of air, oxygen and water through the soil profile, the last increasing the susceptibility to waterlogging and erosion by rilling and sheet wash.

The potential rooting depth can be restricted further by:

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

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

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, promote 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 fertilizer and N to generate growth, and available nutrients are more likely to be taken up, so reducing losses by leaching into the environment.

PLATE 8 **Hole dug to assess the potential rooting depth**

The potential rooting depth extends to the bottom of the arrow, 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.

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

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

Identifying the presence of a hardpan

Assessment

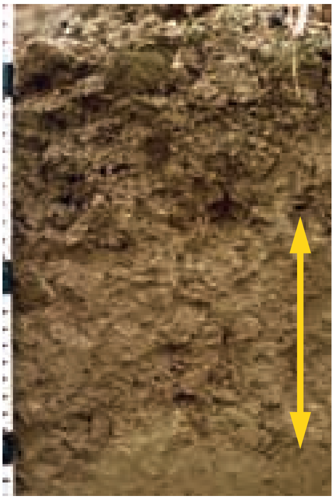
❶ Examine for the presence of a hardpan by rapidly jabbing the side of the soil profile (that was dug to assess the potential rooting depth) with a knife, starting at the top and progressing systematically and quickly down to the bottom of the hole (Plate 9). Note how easy or difficult it is to jab the knife into the soil as you move rapidly down the profile. A strongly developed hardpan is very tight and extremely firm, and it has a high penetration resistance to the knife. Pay particular attention to the lower topsoil and upper subsoil where tillage pans and plough pans commonly occur if present (Plate 10).

❷ Having identified the possible presence of a hardpan by a significant increase in penetration resistance to the point of a knife, gauge how strongly developed the hardpan is. Remove a large hand-sized sample and assess its structure, porosity and the number and colour of soil mottles (Plates 2, 3 and 5), and also look for the presence of roots. Compare with the photographs and criteria given in Plate 10.

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

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

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



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

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

Assessment

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

Importance

SURFACE PONDING and the length of time water remains on the surface can indicate the rate of infiltration into and through the soil, a high water table, and the time the soil remains saturated. Prolonged waterlogging depletes oxygen in the soil causing anaerobic (anoxic) conditions that induce root stress, and restrict root respiration and the growth of roots. Roots need oxygen for respiration. They are most vulnerable to surface ponding and saturated soil conditions in the spring when plant roots and shoots are actively growing at a time when respiration and transpiration rates rise markedly and oxygen demands are high. They are also susceptible to ponding in the summer when transpiration rates are highest. Moreover, waterlogging causes the death of fine roots responsible for nutrient and water uptake. Reduced water uptake while the crop is transpiring actively causes leaf desiccation and the plant to wilt. Prolonged waterlogging also 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 insect pest attack such 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 results in a series of undesirable chemical and biochemical reduction reactions, the by-products of which are toxic to roots. Plant-available nitrate-nitrogen (NO_3^-) is reduced by denitrification to nitrite (NO_2^-) and nitrous oxide (N_2O), a potent greenhouse gas, and plant-available sulphate-sulphur (SO_4^{2-}) is reduced to sulphide, including hydrogen sulphide (H_2S), ferrous sulphide (FeS) and zinc sulphide (ZnS). Iron is reduced to soluble ferrous (Fe^{2+}) ions, and Mn to manganous (Mn^{2+}) ions. Apart from the toxic products produced, the result is a reduction in the amount of plant-available N and S. Anaerobic respiration of micro-organisms also produces carbon dioxide and methane (also greenhouse gases), hydrogen gas, ethanol, acetaldehyde and ethylene, all of which inhibit root growth when accumulated in the soil. Unlike aerobic respiration, anaerobic respiration releases insufficient energy in the form of adenosine triphosphate (ATP) and adenylate energy charge (AEC) for microbial and root/shoot growth.

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

Prolonged surface ponding makes the soil more susceptible to damage under wheel traffic, so reducing vehicle access. As a consequence, waterlogging can delay ground preparation and sowing dates significantly. Sowing can further be delayed because the seed bed is below the crop-specific critical temperature. Increases in the temperature of saturated soils can be delayed as long as water is evaporating.

PLATE 11 **Surface ponding in a wheat field**

TABLE 4 **Visual scores for surface ponding**

VSA score (VS)	Surface ponding due to soil saturation	
	Number of days of ponding *	Description
2 [Good]	≤1	No evidence of surface ponding after 1 day following heavy rainfall on soils that were already at or near saturation.
1 [Moderate]	2–3	Moderate surface ponding occurs for 2–3 days after heavy rainfall on soils that were already at or near saturation.
0 [Poor]	>5	Significant surface ponding occurs for longer than 5 days after heavy rainfall on soils that were already at or near saturation.

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

Assessment

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

Importance

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

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

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

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

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

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

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 Plate 13.

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.

Overcultivation 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 overcultivation can also give rise to significant soil loss by wind erosion of exposed ground.

PLATE 13 **How to score soil erosion**

GOOD CONDITION VS = 2
Little or no *water erosion*. Topsoil depths in the footslope areas are <150 mm deeper than on the 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 for assessing plant performance in wheat**

Visual indicators of plant performance		Visual score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS ranking
Crop establishment	pg. 26		x 2	
Tillering	pg. 28		x 3	
Leaf colour	pg. 30		x 3	
Variability of crop performance along the row	pg. 34		x 3	
Root development	pg. 36		x 3	
Root deseases	pg. 38		x 2	
Crop growth & height at maturity	pg. 40		x 2	
Kernel size	pg. 42		x 2	
Crop yield	pg. 44		x 3	
Production costs	pg. 46		x 1	
PLANT QUALITY INDEX (sum of VS rankings)				

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

SUMMARY

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

Notes:

Land use management & history:

Total available water-holding capacity:

Assessment

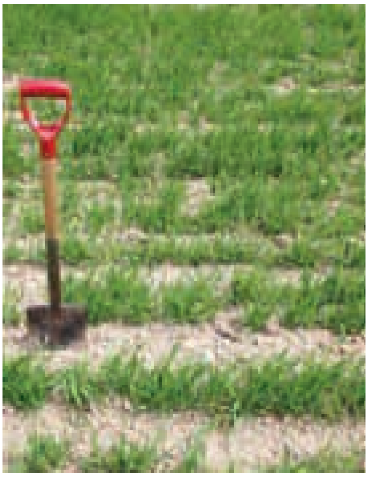
1. Assess the degree and uniformity of crop establishment within a month of sowing by comparing the number and height of established plants with the three photographs provided (Plate 14).

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 increased soil-borne pathogens and areas low in oxygen (anaerobic zones). Anaerobic zones produce chemical and biochemical reduction reactions, the by-products of which are toxic to plants. Poor soil aeration and soil-borne pathogens can give rise to poor germination, poor pre- and post emergence, poor plant vigour and even death. While emergence may be slow, recovery can also be limited and plants often appear sickly. Poor plant emergence, bare patches and poor and uneven early leaf and tiller growth are commonly observed throughout paddocks and result in crop thinning and low plant populations. Young plants can also show discolouration of leaves, leaf blemishes and moisture stress.

The loss of soil condition can reduce crop establishment from 300 to 130 plants/m^2 and grain yields from 8 to 5 tonnes per hectare. Seedling mortality can be high if the soil is waterlogged for more than 3 to 4 days between germination and emergence.

PLATE 14 **How to score crop establishment**



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

MODERATE CONDITION VS = 1
Moderate emergence and 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 emergence and 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 and plants often appear sickly.

Assessment

1. Measure the number of tillers at the end of the tillering stage and compare with the photographs (Plate 15) and class limits below.

Importance

THE NUMBER OF TILLERS play a fundamental role in determining the number of ears (spikes) per square metre and consequently the final yield. The potential number of tillers varies with the genotype, particularly among winter genotypes which have the greatest number. The new semi-dwarf wheat varieties normally have 2–3 tillers per plant to permit the development and grouping of tillers and ears that are contemporary, i.e. are equal in all vegetative, reproductive and ripening stages in order to maximise yields. Although this character is genetically determined and strongly influenced by planting density, it is also an expression of plant vigour and general plant growth which are firstly regulated by nutrient and water availability and the condition of the soil.

Soils in good health with good structure, porosity, organic matter levels, soil life, soil fertility and rooting depth favour the release and uptake of water and nutrients and subsequently the development of a greater number of tillers and there contemporary development.

PLATE 15 **How to score tillering**

GOOD CONDITION VS = 2
Depending on the cultivar the plant has 3 well developed tillers with little variability compared to the main stem (i.e., main culm).

MODERATE CONDITION VS = 1
Depending on the cultivar the plant has 2–3 tillers with moderate variability compared to the main stem (or culm).

POOR CONDITION VS = 0
The plant has 1 or no tillers at all with significant differences in terms of development to the main stem (or culm).

Assessment

1. Assess the leaf colour of the crop when all other factors favour rapid growth, and compare with the three photographs (Plate 16). 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 assessment can be done at any time prior to leaf senescence but ideally from four to six weeks after plant emergence to grain filling, avoiding very cold and wet weather.

Importance

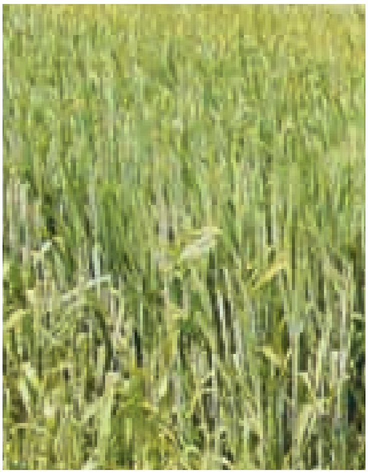
LEAF COLOUR prior to completion of grain filling can provide a good indication of the water and nutrient status and condition of the soil. Under normal environmental conditions the higher the soil fertility, the greener the crop. Plant vigour and colour is strongly related to soil water and nutrient availability, especially nitrogen (N). Discolouration of the foliar and blemishes on the leaf can also result from a deficiency or excess of phosphorus (P), potassium (K), sulphur (S), magnesium (Mg), manganese (Mn), zinc (Zn), copper (Cu) and boron (B) – Plate 17. Chlorosis (or yellowing of crops) due to the inadequate formation of chlorophyll, commonly occurs as a result of low N, K, S, Fe, Mg and Cu levels in the soil, low soil and air temperatures, prolonged cloudy days and poor soil aeration due to compaction and waterlogging.

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

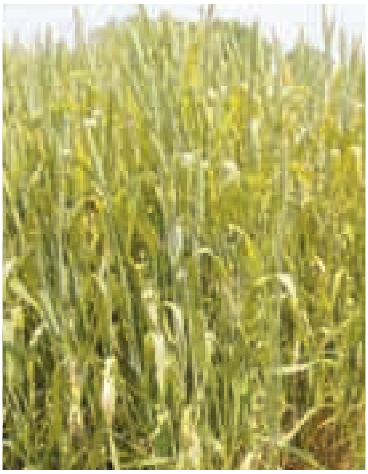
The aeration status of the soil can further affect the uptake of nutrients. Phosphorus, copper and cobalt for example cannot be efficiently utilised by the plant under anaerobic conditions.

PLATE 16 **How to score 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.



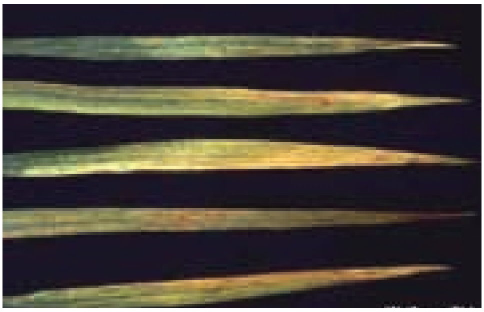
MODERATE CONDITION VS = 1
Leaf colour is yellowish green; i.e. has a distinct yellowish tinge. Few colour blemishes on leaves may occur within a wide area.



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

PLATE 17 Common symptoms of leaf discolouration due to nutrient deficiencies in wheat

Nitrogen deficiency on the left



Phosphorus deficiency

Potassium deficiency

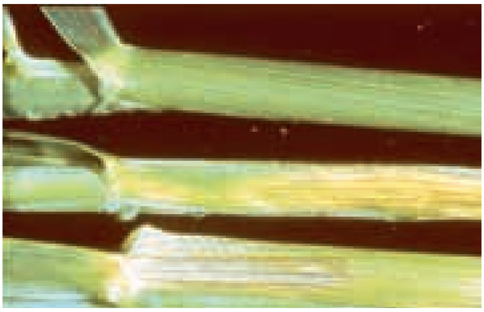
Sulphur deficiency on the right

PLATE 17 **Common symptoms of leaf discolouration due to nutrient deficiencies in wheat** ***(cont'd)***

Magnesium deficiency on the left

Manganese deficiency

Copper deficiency



Zinc deficiency

Assessment

1. Cast your eye along the row and observe any variability in crop performance (in terms of crop height, plant and leaf density, stem thickness, leaf colour) and compare with the class limits in the 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 attack 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 (Plates 18–21). 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 have 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 enabling a site specific investigation as to why and what remedial action may be taken. This may include variable rate application of fertiliser by GPS guided ground spreaders.

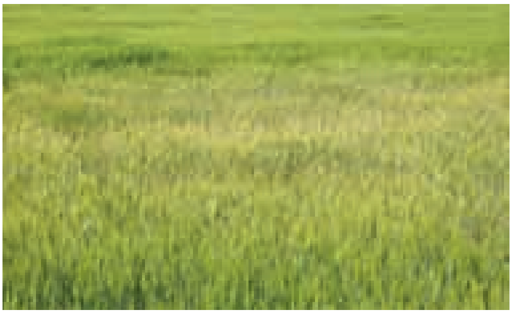
PLATE 18 **Variable crop performance due to soil aeration and wetness**

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

PLATE 19 Variable crop performance due to soil compaction

Variable crop performance due to differences in soil compaction.

PLATE 20 Variable crop performance due to an iron pan



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

PLATE 21 Variable crop performance due to water repellency

Concentric rings of poor wheat growth due to severely water repellent (hydrophobic) soils. Areas of stronger wheat growth occur on non-water repellent soils.

TABLE 5 **Visual scores for 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 row
1 [Moderate]	Crop performance is moderately variable along the row
0 [Poor]	Crop performance is extremely variable along the row

Assessment

❶ Examine the upper part of the hole dug to assess the potential rooting depth of the soil. With the help of a knife, carefully loosen the soil around the roots to expose the root system *in-situ* (Plate 22). Alternatively, dig out a 250–300 mm deep slice of soil around a group of plants and gently tap the sample against the edge of the hole to expose the root system. Use a knife to help loosen the soil if required. Assess both the length and the density of the roots and compare with the class limits in the Table 6. Root length and root density is best assessed at or just prior to crop maturity.

Importance

THE ROOT LENGTH AND ROOT DENSITY provides a good indication of the condition 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. Tillering, ear development and grain filling is therefore likely to be greater, crops are less likely to suffer wind throw, and they will be less susceptible to drought stress. Crops with a dense, deep, vigorous root system are also more likely 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 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 and density can be restricted by the mechanical impedance of roots and the lack of soil pores due to soil compaction or a hardpan. Restrictions can also occur due to low soil moisture, soil temperature and pH, aluminium toxicity, salinity, sodicity, nutrient deficiencies, low mycorrhizal fungi levels, soil-borne pathogens, a high or fluctuating water table and low oxygen levels. Anaerobic (anoxic) conditions due to prolonged waterlogging and deoxygenation restrict root length and density as a result of the accumulation of toxic levels of sulphides, carbon dioxide, methane, ethanol, acetaldehyde and ethylene, by-products of chemical and biochemical reduction reactions (see pg 18).

PLATE 22 **Root development**

Photo showing good root development in the upper 150 mm of soil only. The root distribution and root density in the 150–300 mm zone is poor.

TABLE 6 **Visual scores for root development**

Visual score (VS)	Root development
2 [Good]	Good root length and root density in the upper 250–300 mm of soil
1 [Moderate]	Moderate root length & density in the upper 250–300 mm of soil
0 [Poor]	Poor root length & density in the upper 250–300 mm of soil with the root system being restricted to limited areas

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 visual evidence of root diseases at or any time before crop maturity. Make your assessment based on the class limits in Table 7.
2. Consider also how commonly root diseases occur in a particular field from season to season.

Importance

ROOT DISEASES encouraged by the degradation of soil quality include take-all (*G. graminis* var. *tritici*), dryland root rot (*Fusarium graminearum* and many others), *Rhizoctonia* root rot (*Rhizoctonia solani*) and *Pythium* root rot (*Pythium* spp.) (Plates 23–26). Their presence can cause severe yield loss and reduction in grain quality. Symptoms of root diseases include pre- and post emergence plant death in seedlings resulting in crop thinning, stunting and reduced tillering, discolouration of and blemishes (lesions) on stems, tillers and leaves, bleached heads and premature death. Infected plants have sparse root development and characteristically a brown-black rot can be seen at the crown and extending to the base.

Poor soil aeration, soil saturation and high penetration 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.

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 straw residues further limit pathogen survival.

PLATE 23 ***Pythium* root disease** **[from Compendium of Wheat Diseases by M.V. WIESE]**

Wheat seedlings damaged by *Pythium* species in wet soil.

PLATE 24 **Take-all root disease [from Compendium of Wheat Diseases by M.V. WIESE]**

Root rot and darkened stem bases due to take-all (*G. graminis* var. *tritici*).

PLATE 25 ***Fusarium* root disease [from Compendium of Wheat Diseases by M.V. WIESE]**

Secondary root emerging from crown and invaded by *Fusarium culmorum*.

PLATE 26 **Root rot [from Compendium of Wheat Diseases by M.V. WIESE]**

Wheat crown on the left damaged by common root rot; healthy crown (right).

TABLE 7 **Visual scores for root disease**

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

Assessment

1. Assess crop growth and crop height when the crop has reached maturity and preferably two weeks after ear emergence (Plate 27). Compare with the class limits in Table 8. Your observations of crop growth and vigour during the growing season may also provide a useful indication of seedbed conditions. In a good season under non-limiting conditions, a particular cultivar should grow to a certain height with about a 10–15% variation. Allowances should be made for exceptionally good seasons and for poor seasons.

Importance

CROP GROWTH AND CROP HEIGHT AT MATURITY can be useful visual indicators of soil quality. They are also dependent on a number of other factors including climate, cultivar, nitrogen application and soil fertility, time of sowing, fungicide applications and the use of plant growth regulators to reduce straw length. Crop growth and crop height are however particularly helpful indicators of soil quality if agronomic factors have not limited crop emergence and development during the growing season. The growth and vigour of grain crops depend in part on the ability of the seedbed to maintain an adequate 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 27 **Crop height at maturity**

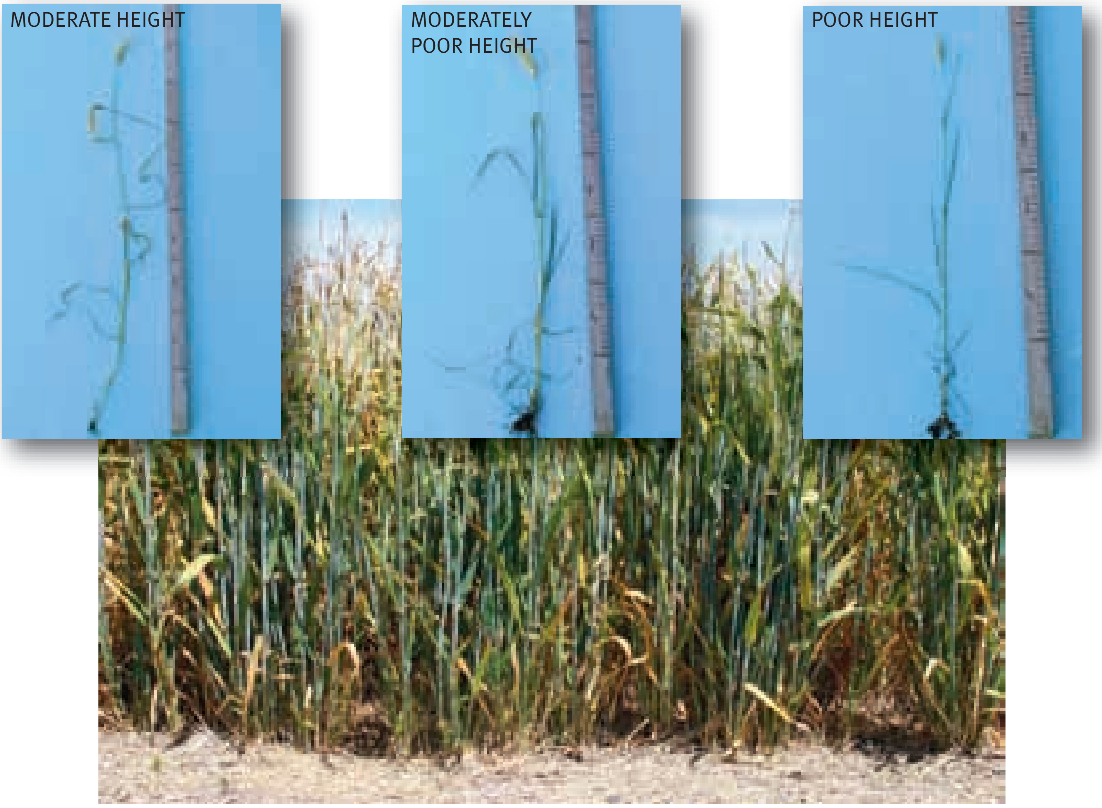


TABLE 8 **Visual scores for crop growth and height at maturity**

Visual score (VS)	Crop growth and crop height at maturity
2 [Good]	Crop growth is good and crops are at or near maximum height, with little variability in height at maturity. Semi-dwarf varieties commonly have a crop height at maturity of >1000 mm
1 [Moderate]	Crop growth is moderate. Crops show moderate variability in height at maturity and are significantly below maximum (700–900 mm)
0 [Poor]	Crop growth is poor and plants can appear sickly. Crop height is uneven and patchy and well below maximum at maturity (400–600 mm)

Assessment

1. Measure the size of the kernels just before harvesting and compare them with the photographs and criteria given (Plate 28).

While there is a strong association between kernel number and yield, kernel size and dry weight are also strong determinants of the final yield. In making the assessment, consideration must be given to the plant population, tiller density and weather conditions and in particular the rainfall and sunlight hours. High plant populations and tiller densities will reduce the size of the kernel, and dry conditions and prolonged cloudy weather will reduce photosynthesis and subsequently the formation of carbohydrates and starch.

Importance

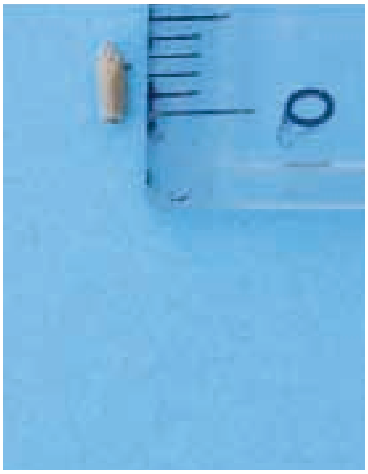
KERNEL development starts immediately after floret fertilization with cellular division during which the endosperm cell and amyloplasts are formed. This period is known as the lag phase and lasts for about 20 to 30 percent of the grain filling period. This is followed by a phase of cell growth, differentiation and starch deposition in the endosperm which takes 50 to 70 percent of the grain filling period. Good availability of carbohydrate is essential to be maintained during the crop cycle avoiding any shortage especially during the grain filling period. 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. The grain filling period is prolonged as a result and an increase in kernel size is achieved. Good crop management practices including the adoption of widely spaced rows and good residue cover between rows to conserve water in dry zones also help to maximise the size of the kernel.

KERNEL SIZE is a useful determinant of grain quality by measuring the weight of unscreened grain, the screening loss and the weight of 1000 grains of clean seed.

PLATE 28 **How to score kernel size**

GOOD CONDITION VS = 2
Depending on the variety, kernels are large, completely filled and well shaped with few or no moisture stress features apparent.

MODERATE CONDITION VS = 1
Kernels are of moderate size, may show occasional incomplete grain filling and stress features are often apparent.



POOR CONDITION VS = 0
Kernels are generally very small with an irregular shape and stress features are very common.

Assessment

1. Assess relative crop yield based on the class limits in Table 9. Assessments can be made for all varieties of crops by counting or estimating the number and size of ears (spikes) per square metre, the number of kernels (grains) per ear, and the degree of grain filling. Harvested yield monitors could also be employed. Compare these with an 'ideal' crop (Plates 29). In making the assessment, consideration must be given to the variety of wheat, 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 (Plates 30–31), and adverse temperatures. Toxic chemicals can also build up and root growth be impeded owing to chemical reduction reactions 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.

PLATE 29 **Crop yield**

Good crop yield with large ear development and complete grain filling.

PLATE 30 **Effect of boron deficiency on crop yield**

Small ear development on the left due to boron deficiency.

PLATE 31 **Effect of copper deficiency on crop yield**

White tipping and incomplete ear development due to copper deficiency.

TABLE 9 **Visual scores for crop yield**

Visual score (VS)	Crop yield
2 [Good]	Crops have >500 ears per square metre. The ears are large with a spike length >90% of maximum for the variety. Ears have >50 kernels (grains) per ear and show complete grain filling with few signs of stress, pests or diseases. Harvested yield is greater than 8 tonnes per hectare
1 [Moderate]	Crops have 300–400 ears per square metre. The ears are of medium size with the spike length varying from 60–80% of maximum for the variety. Ears have 30–40 kernels (grains) per ear and show moderate and occasional uneven grain filling. Stress, pest and disease evidence is moderately common. Harvested yield is 6–7 tonnes per hectare
0 [Poor]	Crops have <200 ears per square metre. The ears are generally small and vary in length. Spike length is commonly <50% of maximum for the variety. Ears have <20 kernels (grains) per ear and grain filling is poor and often uneven. Stress, pest and disease features are very common. Harvested yield is less than 5 tonnes per hectare

Assessment

❶ Assess whether production costs have increased because of increased tillage/fertilizer requirements and herbicide/fungicide application over the years (Figure 4 and Table 10). This assessment can be based on perceptions, but reference to annual balance sheets will give a more precise answer.

Importance

Ground preparation, fertiliser, herbicide and pesticide inputs account for some of the highest costs in any cropping operation, and can increase significantly with increasing soil degradation. As degradation increases, the density and strength of the soil increases and, as a result, the soil becomes more resistant to tillage forces. Plough resistance increases so that larger tractors are required to avoid excessive wheel slip and the need 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 is 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. As a result, conventional tillage costs can increase by over 300 percent.

Continuous cropping using conventional cultivation techniques can also give rise to a significant loss of organic matter and, as a result, can substantially reduce soil fertility and the ability of the soil to supply nutrients. Higher amount of fertilizer are needed to compensate for the loss of these nutrients. The loss of organic carbon under continuous conventional cultivation could further incur a possible carbon tax in the future.

Reductions in crop yield are often not recognised as the result of the degradation of soil structure. Growers often assume that soil fertility is at fault and increase their production costs by applying extra amounts of fertilisers.

FIGURE 4 **Assessment of production costs**

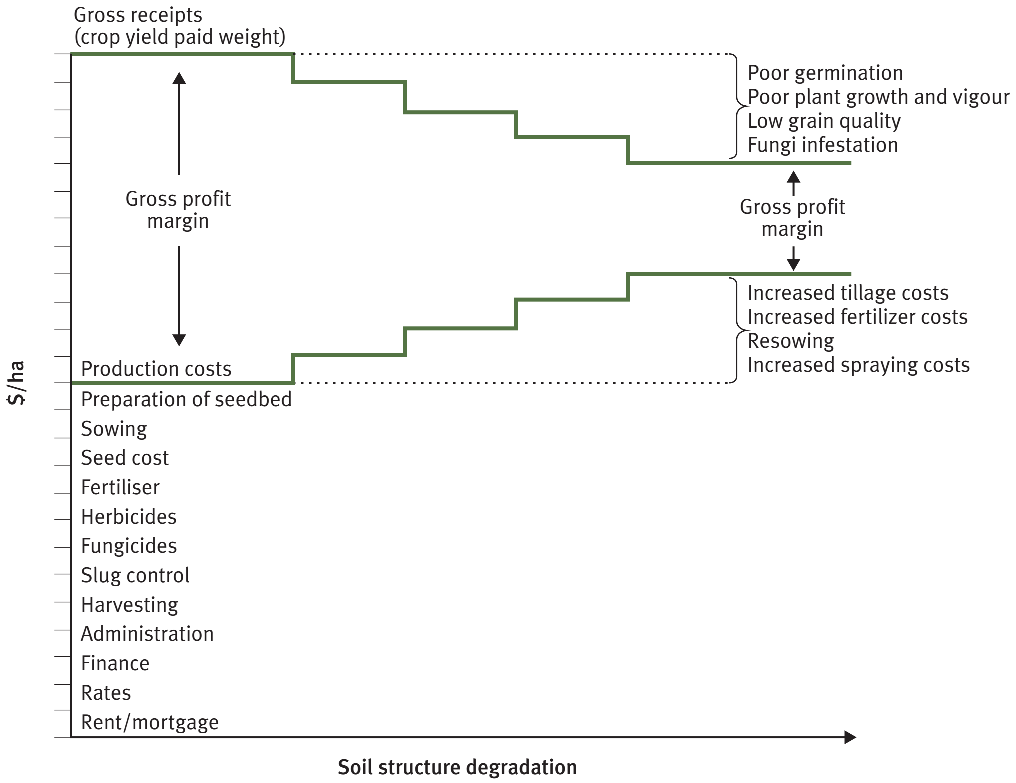


TABLE 10 **Visual scores for production costs**

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

Soil management of wheat crops

Good soil management practices are needed to maintain optimal growth conditions for producing high crop yields, especially during the crucial periods of plant development. To achieve this, management practices need to maintain soil conditions that are good for plant growth, particularly aeration, temperature, nutrient and water supply. The soil needs to have a soil structure that promotes an effective root system that can maximise water and nutrient utilisation. Good soil structure also promotes infiltration and movement of water into and through the soil, minimising surface ponding, runoff and soil erosion.

Conservation tillage practices, including no-tillage and minimum tillage that incorporate the establishment of temporary cover crops and crop residues on the surface (Plates 32–34), provide soil management systems that conserve the environment, minimise the risk of soil degradation, enhance the resilience and quality of the soil, and reduce production costs. Conservation tillage protects the soil surface reducing water runoff and soil erosion. It improves soil physical characteristics, reduces wheel traffic which lessens wheel traffic compaction, and does not create tillage pans or plough pans. It improves soil trafficability and provides opportunities to optimise sowing time, being less dependent on climatic conditions in spring and autumn. Conservation tillage also encourages soil life and biological activity (including earthworm numbers) and increases micro-organism biodiversity. It retains a greater proportion of soil carbon sequestered from atmospheric carbon dioxide (CO_2) and enables the soil to operate as a sink for CO_2. Soil organic matter levels build up as a result and create the potential to gain 'Carbon Credits'. Conservation tillage also uses smaller amounts of fossil fuels, generates lower greenhouse gas emissions and has a smaller ecological footprint on a region, thereby raising marketplace acceptance of produce.

On the other hand, conventional tillage can impact negatively on the environment, with a greater food eco-footprint on a region and a country. It reduces the organic matter content of the soil by microbial oxidation, increases green house gas emissions (including the release of 5-times more CO_2), uses more fossil fuels (i.e., 6-times more consumption of fuel), degrades soil structure, increases soil erosion, and adversely alters microflora and microfauna by reducing both the number of species and their biomass. The fundamental difference between conventional tillage and conservation tillage is their relative environmental and economic sustainability. The long-term affects of conventional tillage are cumulatively negative whereas the long-term affects of conservation tillage are cumulatively positive.

PLATE 32 **No-till drilling a wheat crop into an erosion-prone field protected by herbicided pasture** [BAKER NO-TILLAGE LTD]

PLATE 33 **Strip-tillage planting of an annual crop protected by good residue cover**

PLATE 34 **Harvesting a wheat crop followed immediately by no-till seeding the next crop into stubble** [BAKER NO-TILLAGE LTD]

References

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

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

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