The P part
of the new NPK

Farming Secrets Online Summit
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- “to be a successful farmer one must first know the nature of the soil” – Xenophon, Oeconomicus, 400BC

What is this about?

- Introducing *the new NPK* concept
- Importance of the P part of the *new NPK*
- VSA – big step toward Healthy Soil?
- VSA – the frontline tool of soil management
- VSA summary
- Q & A

But first the old NPK

- Nitrogen – N
- Phosphorus – P
- Potassium – K

The 3 major elements agronomists and growers measure as the macro growth nutrients required by plants. Most crop budgets are calculated to these numbers- and usually the cheapest form is applied.

The new NPK

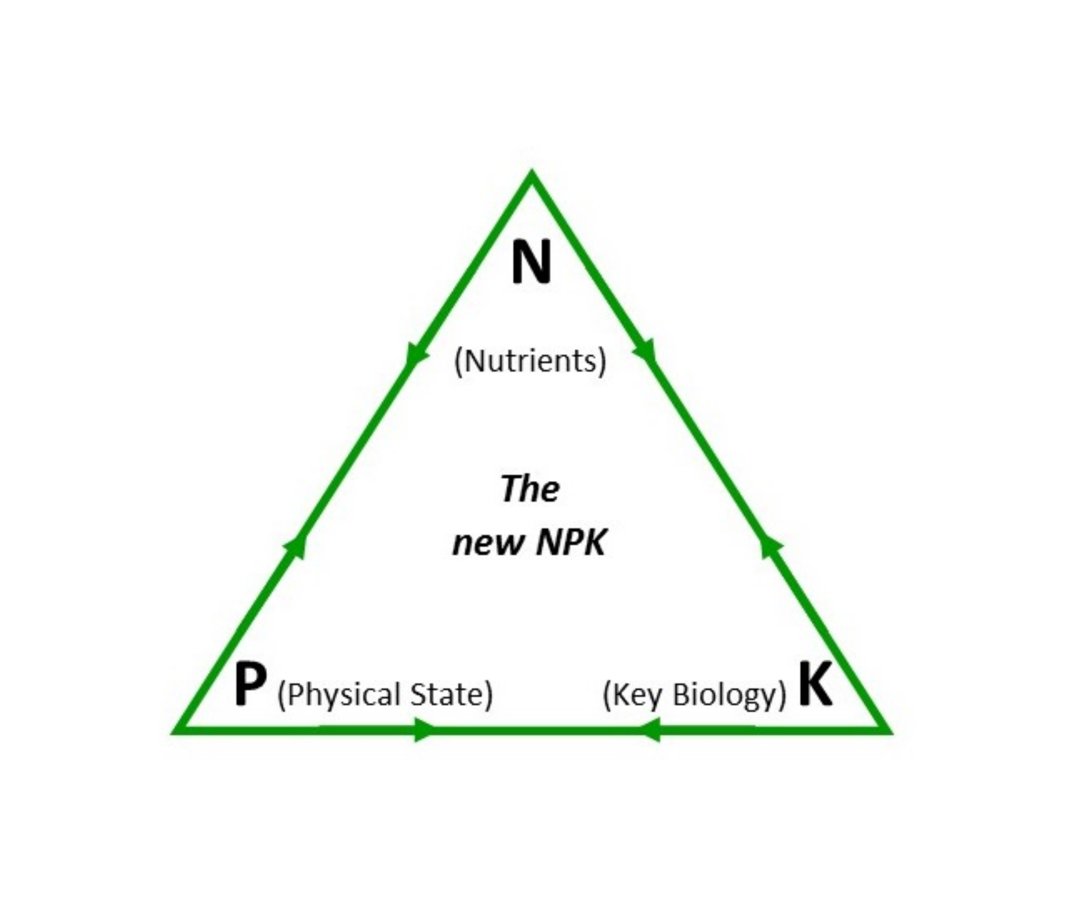
Soil is a highly complex organism comprising 3 essential components to maintain healthy function, resilience and regenerative capacity:

- Nutrients/chemistry- available, exchangeable and total
- Physical condition- structure to hold air & water in the plant rhizosphere/rootzone
- Key biology linking soil with plant roots- bacteria, fungi, protozoa, nematodes, mycorrhizae

The importance of the P

- Need to measure to be able to manage.
- Good Physical structure or condition of soil and plants essential to optimum growth.
- With a little learning and a few basic tools, you can do a Soil Health Physical assessment on the spot.
- VSA connects you with earth's lifeforms.
- Physical Obs of growing environment can be used for immediate decision making.

The new NPK triangle



Measure then manage all realms of soil fertility …

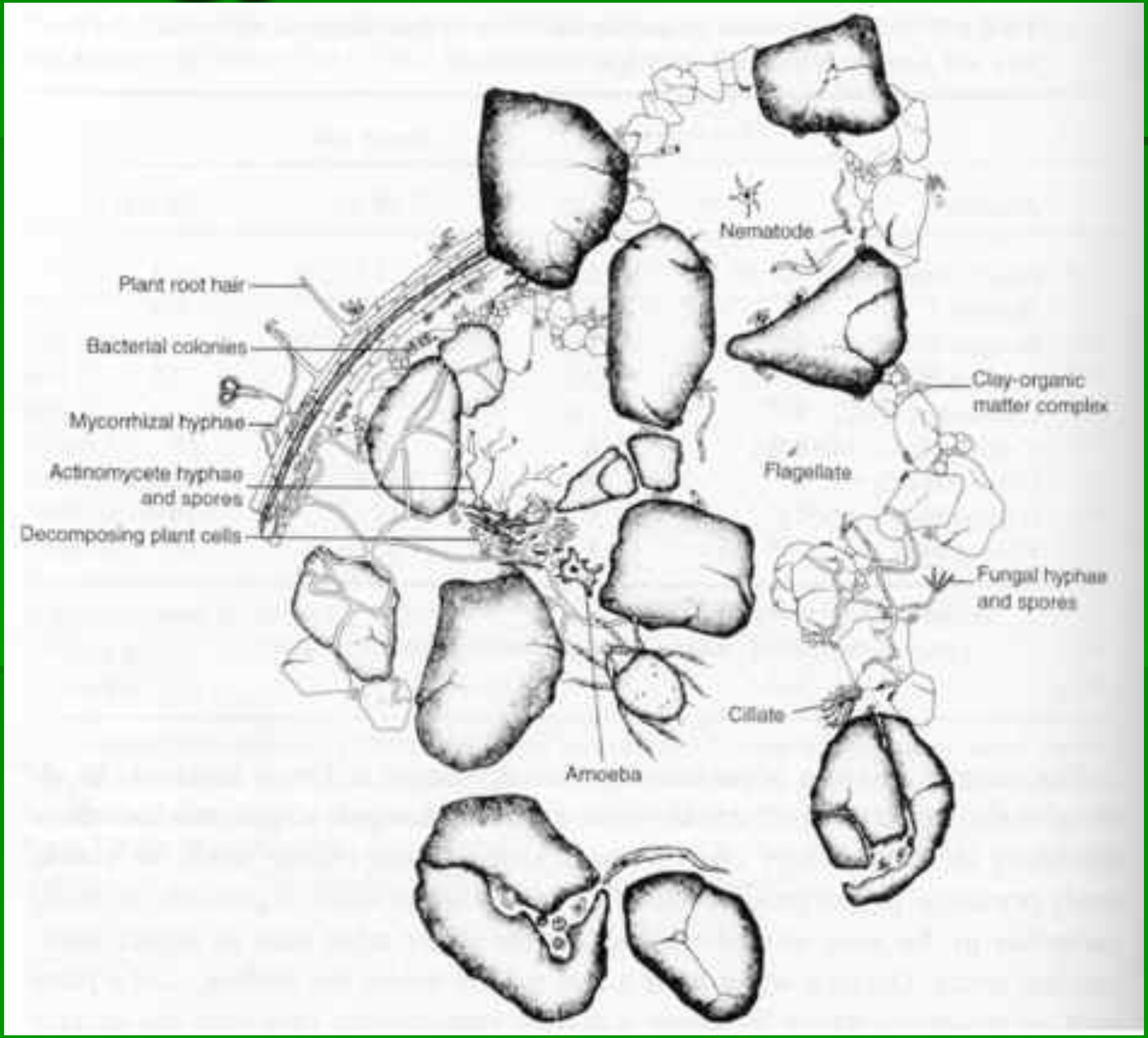
- **N**utrient/chemical – correct ratio of **total**, exchangeable and available soil nutrients (Ca, Mg, N, P, K, S & traces).
- **P**hysical condition – compaction, micro and macro aggregates (good water [25%] and air holding [25%] capacity), OM, & Ca:Mg ratio.
- **K**ey Biology – huge diversity of total and active micro and macro life.

The new NPK is the basis of biological farming!

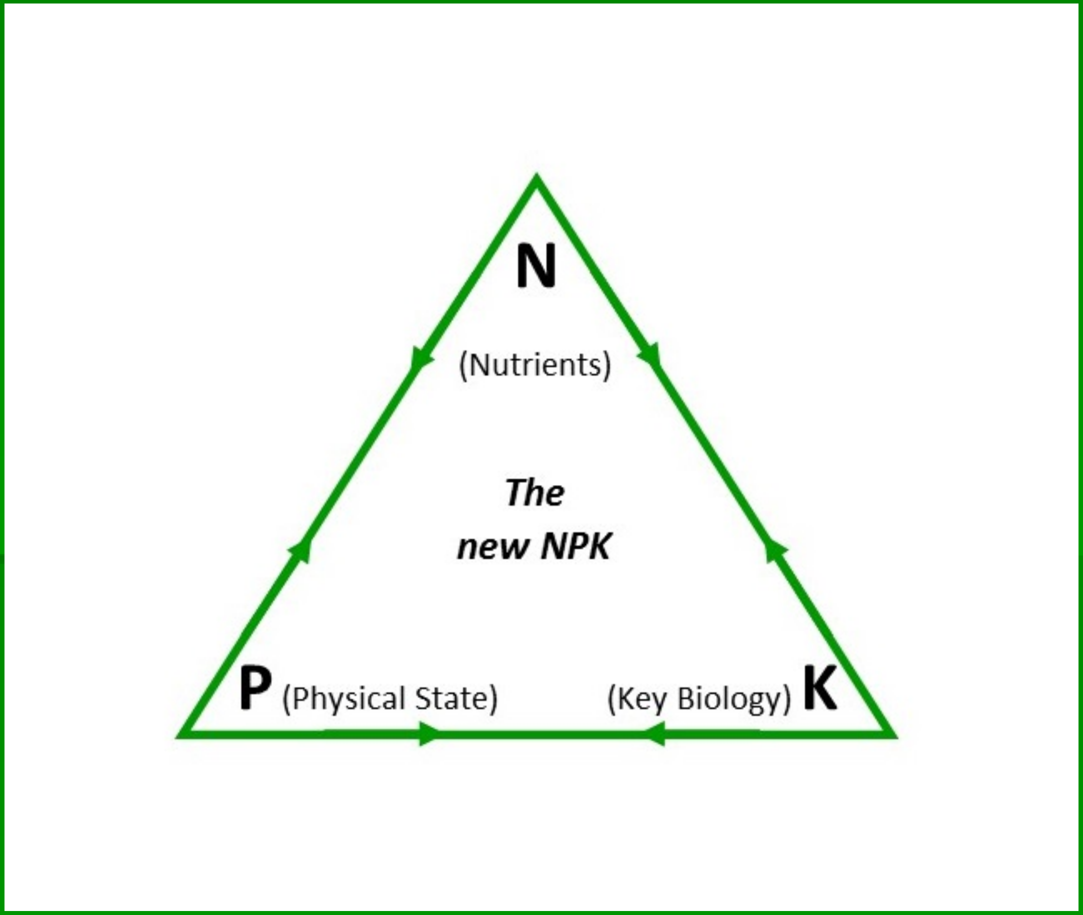
What do we really know about the physical soil?

Not much until we look very closely…..just like pigs do!!!!

Biology – the life in soil!



The new NPK triangle



How do you get the most useful information? By any practical way that works for you and gives meaningful results!

Use a penetrometer to measure soil compaction at depth(left),and a spade to view roots and structure (centre). Dig deep to find out what is ‘down-under’ in acid sulphate soils or soil strata for deep rooted plants.

Use all your senses – look, feel, smell the soil and compost. Use VSA plus relevant lab reports.

Why do VSA?

- It is information only obtainable from the site.
- Thorough physical inspection can reveal details a soil analysis alone can never do.
- Filling a scorecard and taking photos provides a meaningful physical benchmark.
- With practice, can be reliably used to confirm laboratory analyses results.
- Elements of the VSA can provide clues on possible immediate remediation strategies.

SCORE CARD

VISUAL INDICATORS TO ASSESS SOIL QUALITY UNDER PASTORAL GRAZING ON FLAT TO ROLLING COUNTRY

SOIL INDICATORS

Land owner: Land use:
Site location: GPS ref:
Sample depth: Top-soil depth:
Soil type: Soil classification:
Drainage class (p. 19): Date:

Textural group: (upper 1m) ☐ Sandy ☐ Coarse loamy ☐ Fine loamy ☐ Coarse silty ☐ Fine silty ☐ Clayey

Moisture condition: ☐ Dry ☐ Slightly moist ☐ Moist ☐ Very moist ☐ Wet

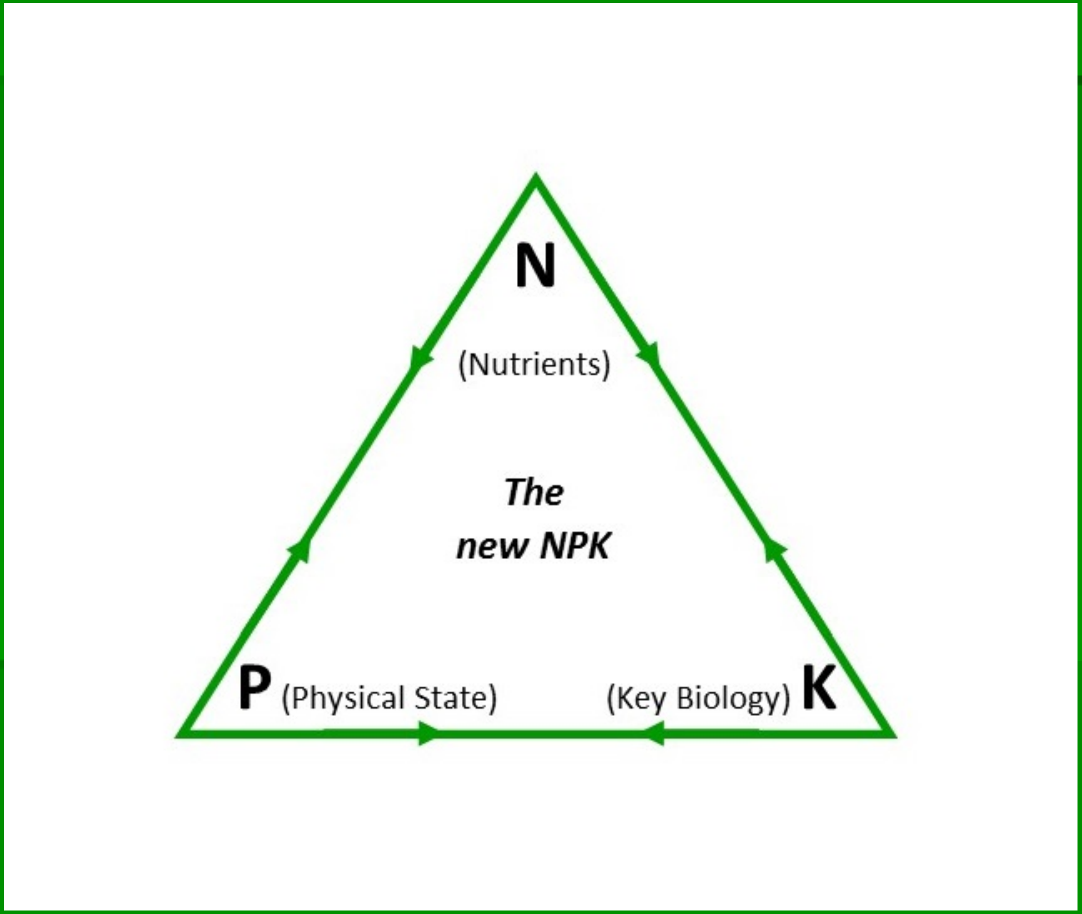
Seasonal weather conditions: ☐ Dry ☐ Wet ☐ Cold ☐ Warm ☐ Average

Visual Indicators of Soil Quality	Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS Ranking
Soil texture (p. 16)		× 3	
Soil structure (p. 17)		× 3	
Soil porosity (p. 18)		× 3	
Number and colour of soil mottles (p. 19)		× 2	
Soil colour (p. 20)		× 2	
Earthworms (Number =) (p.22) (Average size =)		× 3	
Soil smell (p.24)		× 2	
Potential rooting depth (mm) (p. 26)		× 3	
Surface ponding (p. 28)		× 3	
Surface relief (p. 30)		× 1	
SOIL QUALITY INDEX (Sum of VS rankings)			

Soil Quality Assessment	Soil Quality index
Poor	< 20
Moderate	20–35
Good	> 35

If your soil quality assessment is moderate or poor, guidelines for sustainable management are given in Volume 2, Part One

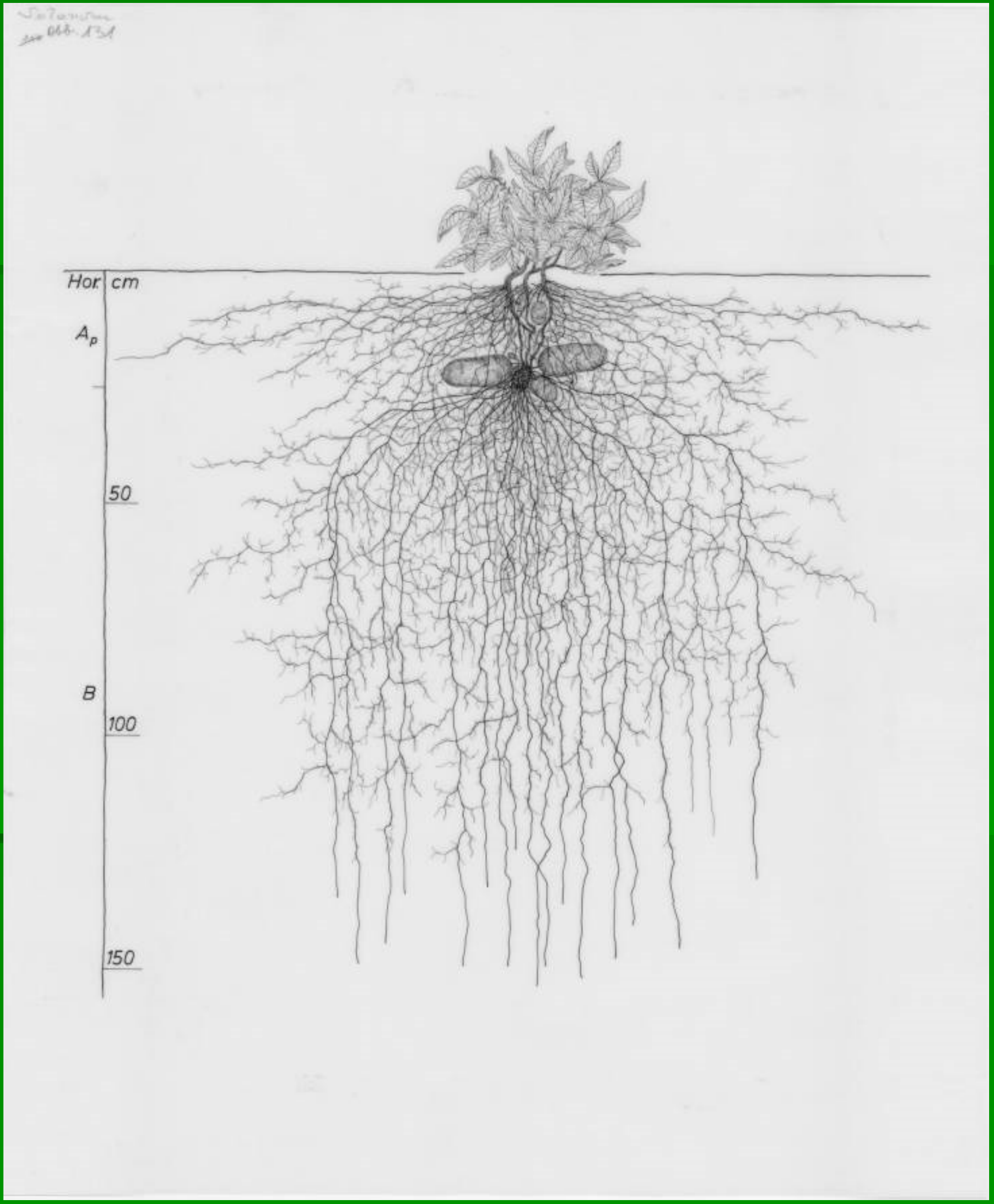
The new NPK triangle



Growing Deeper is Cheaper

Root profile of potato plant with feeder roots reaching down to 1.5 meters.

(Drawing courtesy of Wageningen University & Research Image Collections)



VSA background

- Historically, in-field Soil Assessment at best ad hoc and very subjective – if done at all!
- Consistency and repeatability irregular unless under strict scientific protocols & methods.
- Need for an inexpensive, simple, practical, quick & easily understood transferable system.
- Over a decade in the making and still developing, VSA is a useful tool for Soil Quality, Plant Performance & Environmental Performance measurement.
-

Con't…

VSA background (con’t)

- Soil physical properties often overlooked with nutrients usually the focus above all
- Soil quality decline, along with profitability, can be arrested using techniques such as VSA, holistic grazing management, minimum/no till, etc
- Realistic practical benchmarking using proven scorecards system gives confidence of accurate recording of observations.

VSA – big step toward Healthy Productive Soil?

- VSA categorises elements critical to functional soils & pictorially grades them
- Some visual indicators hold information on nutrient and biological soil conditions well before any laboratory testing taken
- Lab testing may not be required unless data collation & validation essential for accurate benchmarking

SOIL STRUCTURE

- Remove a 200-mm cube of topsoil with a spade. When taking the sample ensure the blade of the spade is inserted vertically to obtain the true volume of soil required for assessment.
- 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. 16), drop the cube of soil once only from a height of 0.5 metres. If the sandy loam is humic (17–29% organic matter), drop the soil twice from 1 metre. Transfer the soil onto the large plastic bag.
- 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.
- Applying only very gently pressure, attempt to part each clod by hand along any exposed cracks or fissures. 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.
- Move the coarsest fractions to one end and the finest to the other end. Arrange the distribution of aggregates 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 6. 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.

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%) 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

PLATE 6. Visual scoring (VS) of soil structure under pasture

Soil structure is important for pastures. It regulates soil aeration and gaseous exchange rates, soil infiltration and erosion, the movement and storage of water, soil temperature, root penetration and development, nutrient supply, and the resistance to structural degradation by compaction and deformation under wheel traffic and stock treading. Good soil structure improves the trafficability of the soil, increasing the window of opportunity for stock grazing and vehicle access without causing compaction. The loss of soil structure can alter seasonal growth patterns and change the botanical composition of pasture including an increase in the number of weeds. Structural degradation can reduce tiller density and canopy cover by 50%, pasture production by 30–50% in spring, and is often a catalyst for diseases. It also reduces the infiltration of water into and through the soil increasing the potential for erosion by sheet wash on sloping ground.

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.

VSA - soil management frontline tool

- Score Cards grade soil texture, structure, porosity, mottles, colour, earthworms, smell, root depth, ponding and relief
- Accurately analysing & allocating physical scores not before recognised as valid visual cues provides an indication of nutrient and biological conditions in your soil
- Opportunity to create realistic benchmarks or reference points to compare future soil improvement/decline without necessarily resorting to soil tests or external consultants

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Soil Quality Assessment	Soil Quality index
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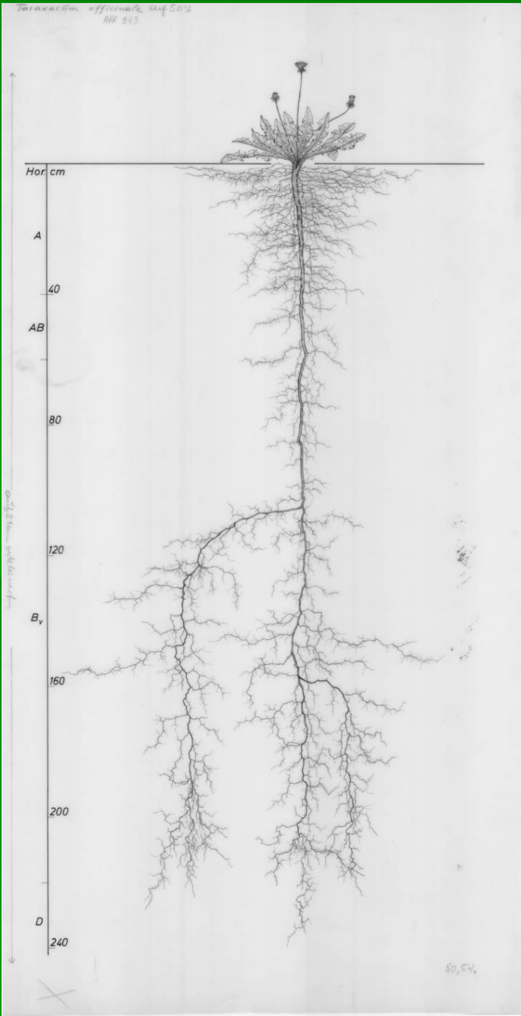
Moderate	20–35
Good	> 35

If your soil quality assessment is moderate or poor, guidelines for sustainable management are given in Volume 2, Part One “we know more about the movement of celestial bodies than about the soil underfoot” – Leonardo DaVinci, circa 1500’s

Weeds? Or wonder workers?



It’s notoriety precedes the humble dandelion. While it might be classified as undesirable by many, its ability to colonise and rebuild soil is second to none. Its roots can extend to 2.4 m, creating pathways for air and water – and it uses free energy from the sun to do this work.

(Drawing courtesy of Wageningen University & Research Image Collections)

Rehabilitator – a quick Fix!

While mechanical aeration may be required to accelerate soil function recovery, it should not be necessary after a few seasons of good regenerative practices. Selection of equipment used is as a result of VSA, and be mindful that this consumes energy to do the work.

The root of the matter is infiltration

Growing deeper is cheaper!

Source: Conservation Research Institute

These are simple grasses – how do your plant roots compare?

SCORE CARD

VISUAL INDICATORS TO ASSESS PLANT PERFORMANCE UNDER PASTORAL GRAZING ON FLAT TO ROLLING COUNTRY

PLANT INDICATORS

Visual Indicators of Plant Performance	Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS Ranking
Pasture quality (Brix =) (p. 34)		× 3	
Clover nodules (p. 38)		× 3	
Weeds (p. 40)		× 2	
Pasture growth (p. 42)		× 3	
Pasture colour and growth relative to urine patches (p.43)		× 3	
Pasture utilisation (p. 45)		× 3	
Root length and root density (p. 46)		× 3	
Area of bare ground (p. 47)		× 2	
Drought stress (p. 48)		× 2	
Production costs to maintain stock-carrying capacity (p. 49)		× 1	
PLANT PERFORMANCE INDEX (Sum of VS Rankings)			

Plant Performance Assessment	Plant Performance Index
Poor	< 20
Moderate	20 – 35
Good	> 35

SUMMARY

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

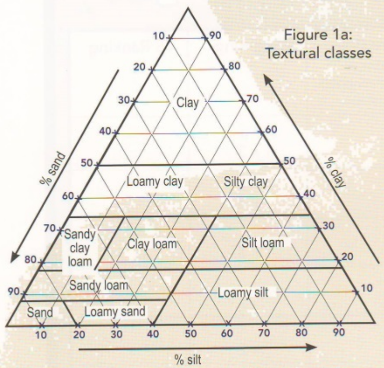
NOTES:

Total available water holding capacity:

SOIL TEXTURE

- 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.
- 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.
- 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 1a). The *textural group* is obtained by comparing the position of the textural class in Figure 1a with Figure 1b (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% 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.



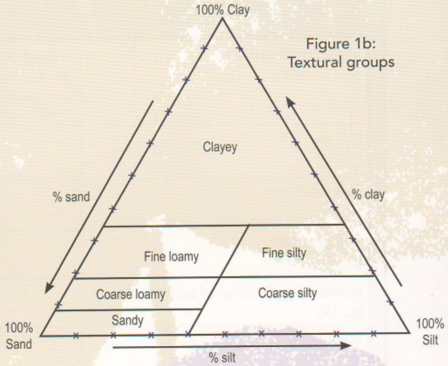


FIGURE 1. Soil textural classes and textural groups

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 between thumb and forefinger
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

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 trafficability and workability, soil life, and the supply and retention of nutrients. Knowledge of both the textural class and potential rooting depth (see p. 26) enables an approximate assessment of the total water holding capacity of the soil, one of the major drivers of pasture production.

EARTHWORMS

Count the earthworms by hand, sorting through the soil sample used to assess soil structure (Plate 6, p. 17 and Plate 11). Note also the number of species present (Plates 12–14) 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.

PLATE 11. Sample for assessing earthworms. Photo shows earthworms present in a 200-mm cube sample of soil

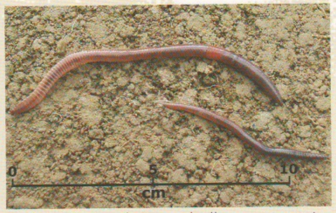


PLATE 12. *Lumbricus rubellus*, a very active surface litter and dung feeding earthworm; commonly red-brown or red-purple in colour with a paler underside; has a distinctly flattened tail; commonly 25–220 mm long

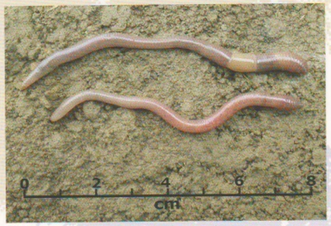


PLATE 13. *Aporrectodea caliginosa*, a medium-sized (40–90 mm) topsoil dwelling earthworm; commonly grey-pink on both the dorsal and ventral surfaces; does not have a flattened tail

PLATE 14. *Aporrectodea 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)	≥ 45 (with preferably 3 or more species)
1.5 (Moderately good)	35–44
1 (Moderate)	25–34 (with preferably 2 or more species)
0.5 (Moderately poor)	15–24
0 (Poor)	< 15 (with predominantly 1 species)

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 humus 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, characteristics that are due in part to the higher enzyme activity in the casts (see p. 25). They can also contain more Ca and plant-available Mo, and have higher pH, organic matter, and water content. In addition, dead earthworms can contribute significant amounts of N to the soil, being 60–70% protein (dry weight) with a N content of 12%. Forty-five earthworms per 200-mm cube of soil (1125/m^2) are roughly equivalent to a biomass of 4 tonnes of earthworm/ha, and could release 43–50 kg N/ha upon their death. The presence of earthworms also increases the mobilisation of nitrate-N by 10 times and that of ammonium-N by 80 times, compared with soils without earthworms. 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. They promote pasture growth by secreting plant-growth hormones and increasing root density and root development through the rapid growth of roots down nutrient-enriched worm channels. They also contribute to nitrogen fixation by promoting nitrogen-fixing microorganisms, nitrogen-fixing nitrogenase enzymes, and the availability of Mo. While earthworms can deposit around 25–30 tonnes of casts/ha/yr on the surface (Plate 15), 70% of their casts are deposited below the surface of the soil. Earthworms can therefore have a major effect on the overall properties and condition of the soil.

Earthworms also increase the population, activity and diversity of soil microbes. The number of beneficial bacteria can increase three-fold from 3 million per gram in soils with no worms to 10 million per gram after colonization by worms. 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 and the supply of nutrients. Earthworms therefore play an important role in pastoral agriculture and can increase pasture production by 10–30%.

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 matter 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% of worm casts are deposited on the surface and 70% below ground, the potential for earthworms to increase soil carbon levels and topsoil depth is substantial. Deposition rates of soil at the surface due mainly to earthworm casts can vary from 2–20 mm/yr.

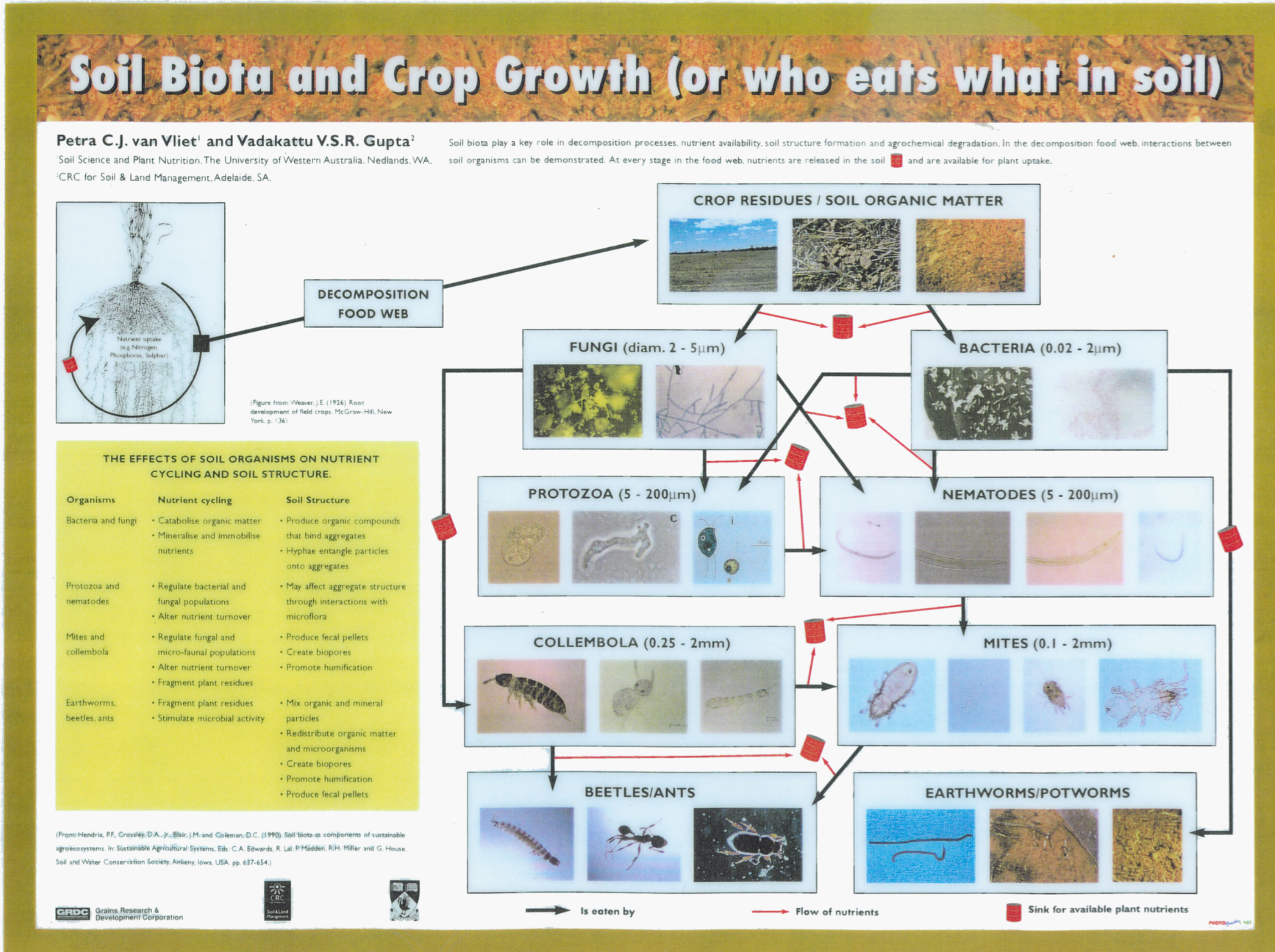
Earthworm numbers (and biomass) are governed by the amount of food available as organic matter and soil microbes, as determined by pasture production and the stocking rate. Their numbers are also governed by soil moisture, temperature, texture, soil aeration, pugging, legume content, pH, soil nutrients (including Ca), and the type and amount of fertiliser and nitrogen used. The over-use of acidifying salt-based fertilisers and ammonia-based products can 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.

Earthworm species can further indicate the overall condition of the soil. For example, significant numbers of yellow-tail earthworms (*Octolasion cyaneum* – Plate 16) can indicate adverse soil conditions.

PLATE 15. Surface of field 'boiling' with worm casts

PLATE 16. Yellow-tail earthworm (*Octolasion cyaneum*)


Soil Biota and Crop Growth (or who eats what in soil)
Petra C.J. van Vliet[1] and Vadakattu V.S.R. Gupta[2]
[1]Soil Science and Plant Nutrition, The University of Western Australia, Nedlands, WA.
[2]CRC for Soil & Land Management, Adelaide, SA.
Soil biota play a key role in decomposition processes, nutrient availability, soil structure formation and agrochemical degradation. In the decomposition food web, interactions between soil organisms can be demonstrated. At every stage in the food web, nutrients are released in the soil and are available for plant uptake.
Nutrient uptake (e.g. Nitrogen, Phosphorus, Sulphur)
(Figure from: Weaver, J.E. (1926) Root development of field crops. McGraw-Hill, New York, p. 136)
DECOMPOSITION FOOD WEB
CROP RESIDUES / SOIL ORGANIC MATTER
FUNGI (diam. 2 - 5µm)
BACTERIA (0.02 - 2µm)
PROTOZOA (5 - 200µm)
NEMATODES (5 - 200µm)
COLLEMBOLA (0.25 - 2mm)
MITES (0.1 - 2mm)
BEETLES/ANTS
EARTHWORMS/POTWORMS
THE EFFECTS OF SOIL ORGANISMS ON NUTRIENT CYCLING AND SOIL STRUCTURE.
Organisms
Nutrient cycling
Soil Structure
Bacteria and fungi
• Catabolise organic matter
• Mineralise and immobilise nutrients
• Produce organic compounds that bind aggregates
• Hyphae entangle particles onto aggregates
Protozoa and nematodes
• Regulate bacterial and fungal populations
• Alter nutrient turnover
• May affect aggregate structure through interactions with microflora
Mites and collembola
• Regulate fungal and micro-faunal populations
• Alter nutrient turnover
• Fragment plant residues
• Produce fecal pellets
• Create biopores
• Promote humification
Earthworms, beetles, ants
• Fragment plant residues
• Stimulate microbial activity
• Mix organic and mineral particles
• Redistribute organic matter and microorganisms
• Create biopores
• Promote humification
• Produce fecal pellets
(From: Hendrix, P.F., Crossley, D.A., Jr., Blair, J.M. and Coleman, D.C. (1990). Soil biota as components of sustainable agroecosystems. In: Sustainable Agricultural Systems, Eds: C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House. Soil and Water Conservation Society, Ankeny, Iowa, USA. pp. 637-654.)
GRDC Grains Research & Development Corporation
CRC Soil & Land Management
Is eaten by
Flow of nutrients
Sink for available plant nutrients

SOIL SMELL

▸▸ 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.

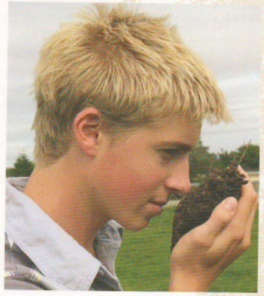


TABLE 3: How to assess soil smell

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

PLATE 17. Sample to assess soil smell under pasture

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. These are often the characteristic smells of forest soils, which are generally rich in fungi. The presence of similar fungal smells in a pastoral soil suggests it is not only well aerated but also has a good, active microbial biomass (Plate 18). This is because it must have large numbers of bacteria to maintain a fungal to bacteria ratio of 0.75:1 (or 1:1) that is necessary to preserve and promote pastoral plants. An imbalance of this ratio along with poor soil nutrition could explain why pastures may show poor persistence and a tendency to revert to other plant species such as woody weeds. Pastoral soils that are intensively grazed and fertilised tend to have a greater abundance of bacteria relative to fungi than soils that are less intensively grazed and fertilised pastures. As a consequence, they are more sensitive to stress such as droughts, are less efficient in terms of uptake, cycling and retention of nutrients including N, and are more susceptible to N leaching.

Biological regimes are sensitive to intensive land uses with the result that soils can have 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 19). 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.

While soils should have good microbial biomass with levels preferably in excess of 1800 mg/kg, and a good microbial quotient (i.e. the ratio of microbial biomass C to total organic C), 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 their respiration, 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% of the humus fraction in pastoral 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. High organic matter and microbial activity further results in a high level of activity of soil enzymes such as urease, protease, phosphatase and sulfatase, which results in a high turnover of N, P and S through the soil organic pool.

In addition, soil microbes and particularly bacteria 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.

Moreover, bacterial- and fungal-feeding protozoa and nematodes release large amounts of N when feeding on their selected prey and are responsible for much of the plant-available N in the majority of soils. 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% 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, 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. Beauvaria fungi, for example, destroy the adult clover root weevil, providing an effective biological control. Soil microbes also produce plant growth hormones and compounds that stimulate root growth and produce B group vitamins, including vitamin B_{12} which is important for rumen function.

The collective benefits of microbes reduce fertiliser requirements and can more than double the growth of ryegrass and clover. They can also significantly improve the sugar content, 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 farming is to ensure the engine remains well-oiled.

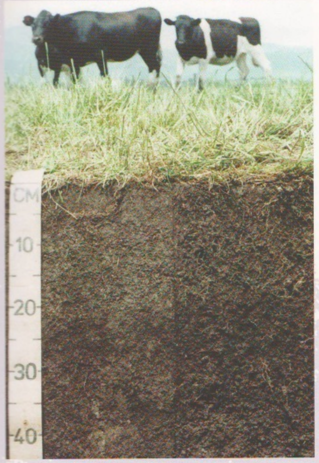


PLATE 18. Soil has a moderately rich, earthy, sweet smell with a smell score of 1.5

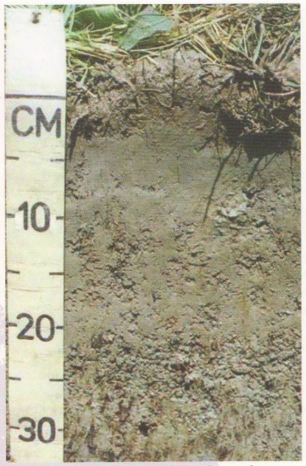


PLATE 19. Soil has a putrid, unpleasant smell of hydrogen sulphide with a smell score of 0

“The nation that destroys its soil destroys itself” – Franklin Delano Roosevelt

VSA - summary

- VSA is for soil toilers large and small – guide to connecting with mother earth.
- VSA for pastures and cropping is a powerful tool any soil manager can learn to use effectively.
- VSA should be used in the early stages of the growing seasons, usually autumn and spring, to get information enabling timely management decisions to be made.
- Soil health and function are essential to successfully meet modern growing demands – VSA goes a long way towards this measure.
- https://orgprints.org/30582/1/VSA_Volume1_smaller.pdf

How do you get the most useful information? By any practical way that works for you and gives meaningful results!

Use a penetrometer to measure soil compaction at depth(left),and a spade to view roots and structure (centre). Dig deep to find out what is ‘down-under’ in acid sulphate soils or soil strata for deep rooted plants.

Use all your senses – look, feel, smell..VSA, and relevant lab reports.

Take home messages….

- Seasonally inspect your soil factory using VSA - then seek laboratory analyses to confirm
- Consider ALL resources at your disposal to enliven the soil eg, herd effect, mulching, green manure cropping, unlock phosphorus with mycorrhizae, etc
- Try natural and 'soft' treatments before reaching for the chemical band-aid. Less harm is done this way.
- Make it a goal to learn, observe and trial new practices regularly – some of the traditional ones are the cause of problems not seen as connected eg, poor grazing, over cultivation, liming.
- Always think in terms of the *new* NPK – Nutrients, Physical structure, Key Biology for healthy soil, plants, animals & people.

"…for only rarely have we stood back and celebrated our soils as something beautiful, and perhaps even mysterious. For what other natural body, worldwide in its distribution, has so many interesting secrets to reveal to the patient observer?"

- Les Molloy, Soils in the New Zealand Landscape: the Living Mantle. 1988).

VSA - checking your soil factory before deciding on laboratory analyses and taking management actions!

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