Part 5: How to improve soil health

Tillage

Tillage (cultivation) is used to produce a fine seed bed, to control weeds, to incorporate crop residues and to break up compacted soil. However, too much tillage can damage the structure of clay and loam soils. When this happens, large pore spaces are lost—leading to surface sealing; compaction; and poor water, air and nutrient movement into the soil. Tillage may also remove vegetative cover, which allows raindrops to further break down aggregates, and can lead to soil erosion.

Advances in implement design and selective herbicides have meant that less aggressive forms of soil preparation can be used to grow vegetable crops.

A soil with less disturbance will have a greater chance of being healthy and having a functioning ecosystem. Also, thoughtful use of tillage and using the correct implement may help to overcome some of the inherent constraints of the soil.

Some tillage and soil disturbance will always be necessary to produce vegetables. However, by understanding the limitations and benefits of different tillage implements, we can minimise soil disturbance. Some of the implements commonly used on vegetable farms are listed in Table 12, with a description of their benefits and limitations.

Minimum tillage systems have been developed for a number of vegetable crops. The benefits from minimum tillage systems include:

- improved soil structure
- increased nutrient retention
- increased plant-available water capacity
- less soil erosion
- savings in land preparation costs and
- not having to wait for ideal weather conditions to plant crops.

Table 12. General characteristics associated with different tillage implements

Implement	Benefits	Limitations
Rotary implements (hoes, tillers) 	• Thoroughly mixes soil • Surface residue buried • Incorporates weeds and kills old crop • Leaves a fine seedbed	• High soil disturbance, extensive pulverising and shattering of soil aggregates • Destroys natural soil aggregation • High fuel usage
Mouldboard plough 	• Incorporates soil surface residue • Incorporates weeds and kills old crop • Leaves a fine seedbed • Complete inversion of furrow • Very little soil pulverisation	• High soil disturbance completely shatters the soil • Destroys natural soil aggregation • High fuel usage • Compaction at depth if soil is wetter than its plastic limit
Disc implements (ploughs and harrows) 	• Buries a large proportion of surface residue • Effective kill of old crop • Partial inversion of the furrow	• Leaves soil surface rough, requiring secondary tillage • High fuel usage • May not effectively kill all weeds • Can pulverise and shatter soil • Compaction at depth if the soil is wetter than its plastic limit

Table 12. (continued)

Implement	Benefits	Limitations
Tyned implements (chisel ploughs, scarifiers and harrows) 	• Narrow furrows. No subsoil brought to soil surface • No pulverising of the soil and only partially shatters the soil • Very little compaction at depth • Retains soil moisture • Good weed control	• Only moderate surface fineness • Surface trash remains on soil surface • Partial kill of the old crop

Green manures and cover crops

Green manures are crops that are grown to improve the soil. They are not normally harvested or sold, although grain legumes such as soybeans may be harvested for seed but with residues remaining on site. They are usually ploughed back into the soil to add organic matter and to recycle nutrients for the next crop. They are also used as ground covers to protect the soil from erosion during fallow periods.

The return of organic matter from green manure crops benefits soil health by boosting organic carbon levels and stimulating microbial activity.

Legumes are often grown as green manure crops because they have a high nitrogen content that is released for the next crop as the residues decompose.

Growth of forage sorghum as a summer cover crop can produce a lot of biomass and form a thick mulch on the soil surface. (Photo: Rob Pengilley)

Cover crops are often left on the soil surface and not incorporated into the soil. The mulch that forms on the soil surface after growing cover crops not only protects the soil surface from erosion but can also be used to suppress weeds and reduce evaporation of soil moisture. If stubble from green manure crops is left standing, rather than being ploughed back into the soil, it acts as both surface mulch and a slow-release nitrogen source. In the subtropics and tropics, some growers kill the crop with herbicide and leave it to form a surface mulch.

Choosing the right green manure or cover crop is important if the maximum benefits are to be obtained. Ideally, the crop you choose should:

- produce a large amount of biomass
- not carry over pests and diseases
- be easy to kill so it will not compete with the following crop.

It may also be possible to mix a number different species together to increase the benefits from green manures and cover crops. The green manure or cover crop is usually grown when vegetables are not being produced. In areas that produce vegetables all year round, a system where some land is taken out of production to grow the green manure or cover crops in rotation with the vegetable crops may be required. Applied Horticultural Research conducted studies to identify which cover crops are suited to vegetable production in tropical and temperate climates, including both summer or winter growth (Tables 13 and 14).

Green manures and cover crops will benefit soils that are constrained by:

- excessive, prolonged wetness and waterlogging
- low water-holding capacity
- hard-setting and surface sealing
- compaction
- sodicity
- low nutrient retention
- high phosphorus fixation
- low organic matter content.

Table 13. Summer cover crops and their suitability as green manures or cover crops in vegetable production

Cover crop	Establishment	Cover	Killing method	Mulch quality	Comments
Grasses					
Indian blue grass—Hatch	Good	Good	Spray	Good	Can be mowed; very high biomass
Indian blue grass—Keppel	Good	Good	Spray	Good	Expensive seed
Sorghum	Good	Good	Spray	Coarse	Cheap alternative, but coarse mulch
Shirohoe millet	Good	Early seed	Spray and roll	Good	Good winter cover crop
Rye grass	Good	Moderate	Spray and roll		Good winter cover crop
Japanese millet	Good	Early seed	Spray		Seeds too early for thick cover
Legumes					
Clovers	Poor	Poor	Spray	Poor	Poor competition with weeds
Centrosema	Slow	Good	Spray	Good	Excellent cover; hard to kill
Lucerne	Poor	Poor	Spray	No kill	Hard to kill
Verano stylo	Poor	Poor			Poor establishment
Sunn hemp	Good	Moderate	Spray and roll	Poor	Thin stalks, poor seed viability
Villosa mixes	Poor	Poor		Poor	Poor establishment
Biofumigants					
BQ mulch	Good	Good	Spray	Poor	Tissue too watery for good mulch
Rangi rape	Good	Good	Spray	Poor	Tissue too watery for good mulch
Brassica napus	Good	Good	Spray	Poor	Tissue too watery for good mulch
Fumus	Good	Early seed	Spray	Poor	Tissue too watery for good mulch
Mustards	Good	Early seed	Spray	Poor	Tissue too watery for good mulch

Source: Rogers (2001)

Table 14. Winter cover crops and their suitability as green manures or cover crops in vegetable production

Cover crop	Establishment	Cover	Killing method	Mulch quality	Comments
Grasses					
Shirohoe millet	Good	Good	Spray and roll	Good	Good winter cover crop
Rye grass	Good	Good	Spray and roll	Good	Good winter cover crop
Cereals					
Wheat/triticale	Good	Good	Spray and roll	Good	Excellent winter cover crop
Barley	Good	Good	Spray and roll	Good	Good winter cover crop
Oats	Good	Good	Spray and roll	Good	Excellent winter cover crop
Legumes					
Clovers	Good	Moderate	Spray	Poor	Poor competition with weeds
Lucerne	Good	Good	Spray	No kill	Hard to kill
White lupin	Good	Poor			
Biofumigants					
BQ mulch	Good	Good	Spray	Poor	Tissue too watery for good mulch
Rangi rape	Good	Good	Spray	Poor	Tissue too watery for good mulch
Brassica napus	Good	Good	Spray	Poor	Tissue too watery for good mulch
Fumus	Good	Early seed	Spray	Poor	Tissue too watery for good mulch
Mustards	Good	Early seed	Spray	Poor	Tissue too watery for good mulch

Source: Rogers (2001)

Crop rotation

Crop rotation is an important component of soil and pest management. Continual monoculture of the same crop over a long period of time tends to select organisms that survive on that crop. This usually increases organisms that cause plant diseases.

Crop rotation can be simple, such as switching between two crops in alternate years. Some crop rotations can be complex and involve numerous crops over several years. When crops are rotated properly, pest and diseases do not become a problem. However, this may take many years of trial and error to perfect.

Rotating crops can also help manage nutrients and maintain soil structure. Leguminous crops return extra nitrogen to the soil, which benefits crops with a high nitrogen demand (e.g. sweet corn). Rotating crops with different types of root systems, such as tap roots and fibrous roots, can enhance soil structure. Plants with tap roots are able to penetrate deep into the soil, making channels to help with air and water movement. Plants with fine and fibrous roots are able to get in between tightly packed soil particles, helping break them apart or, conversely, holding loosely packed soil particles together.

Growers often obtain yield increases when rotating crops from different genera, compared with a continual monoculture. This is referred to as the rotation effect. The rotation effect is a combination of suppressing pests and diseases, increasing nutrient recycling and improving soil structure.

Some general principles for crop rotation developed at Cornell University (Gugino et al. 2007) include:

- Follow a legume forage crop with a high-nitrogen demanding crop such as sweet corn.
- Grow the same annual crop for only one year and don't rotate with closely related crop species to decrease likelihood of insects, nematodes and diseases becoming a problem.
- Plan the crop sequences that promote healthier crops. Some crops seem to do well following a particular crop; others may have an unfavourable effect.
- Use crop sequences that aid in controlling weeds. Rotating broad leaf and grass crops and using selective herbicides can help keep weed populations low.
- On sloping land or where erosion is a high risk, use perennial crops to protect the soil surface and provide continual cover.
- Use deep-rooted crops (e.g. lucerne) that are able to scavenge the subsoil for water and nutrients. The resulting root channels help with the movement of air and water into the soil profile.
- Include crops that leave a large amount of crop residue to help boost organic matter levels in the soil.
- When growing a wide mix of crops, try grouping them into blocks according to family, type of crop, planting time or crops requiring similar cultural practices.

By developing a good crop rotation system you can address the following soil constraints:

- hard-setting and surface sealing
- compaction
- low nutrient retention
- low organic matter content
- soil-borne diseases
- soil insect pests.

Amendments

Amendments are applied to the soil to overcome a deficiency or to correct an imbalance. They usually need to be applied in large quantities to have an effect on the soil. The cost of application needs to be weighed against the long-term benefits to make sure that amendments are economically viable.

Amendments can either be inorganic or organic. Inorganic amendments are typically applied to correct a nutrient deficiency or imbalance. Examples of inorganic amendments are lime (to correct low soil pH) or gypsum (to correct a calcium imbalance).

Organic amendments can be any material that has been derived from plant or animal origin and include:

- composts
- crop residues
- manures
- municipal and industrial wastes.

Adding organic amendments needs to be viewed as a long term practice. A single application may create only a temporary change in soil properties. Often, repeated applications are required to stabilise soil properties and have a lasting effect.

Amendments may also be used with other soil management practices to speed soil improvement. The application of non-composted organic amendments risks the introduction of pests, disease and weeds, damage to groundwater and risks for human health, so they need to be considered carefully.

Composts

Compost is stable, aerobically decomposed organic matter that is the result of a managed decomposition process. It is a biologically active material mostly of organic origin, which has a succession of aerobic micro-organisms break down and transform organic material, thereby generating heat. The microbial activity decomposes simple organic compounds like sugars and proteins into a range of increasingly complex organic substances. The remaining material is transformed into more complex organic substances referred to as humus. Humus is typically dark brown with an earthy appearance that can vary in smell and texture.

Compost can be made from a number of different sources. However, the level of compost maturity will have the greatest effects on its properties. The availability of nutrients (particularly nitrogen) may decrease temporarily following initial applications of composts. However, with repeated use soil nitrogen levels build up and mineralisation can significantly reduce future nitrogen requirements.

The humus material in composts can increase soil organic carbon (SOC), improve water and nutrient retention, increase soil aggregation and change soil microbial composition (supressing pests and diseases). This is mainly through increased biological activity in the soil, promotion of beneficial organisms that compete with pests and diseases in the soil, production of antibiotics, and increased plant resistance to attack. The effectiveness of composts to suppress pests and pathogens depends on the level of maturity of the compost, what microbes colonise the compost, and the crop being grown.

Composts may also be able to supply some of the nutrients required by plants during vegetable production but be cautious if you intend to use it as a fertiliser as nutrients from compost may take longer to be released than for conventional fertilisers.

In general, rates of 20–30 m^3/ha of compost are initially required to improve soil health of degraded soils. However, follow-up applications are often required. The amount of compost required to maintain soil properties may need to be determined using trials or with a specialist.

The properties of compost will vary between different manufacturers. Not all composts are suited for use in vegetable production. The manufacturer of the compost should be able to provide information about their product, but in general it is recommended (Paulin 2005) that the compost have:

- carbon to nitrogen ratio less than 20
- total nitrogen greater than 1%
- available nitrogen greater than 100 mg/kg
- nitrate to ammonium ratio greater than 0.14.

Crop residues

Crop residues are an important source of organic matter. Some vegetable crops are able to return more residues to the soil than others. As the organic matter from the crop residue decomposes it can help to increase soil carbon and improve the structure of the soil. Crop residues left on the soil surface help protect the soil against erosion, prevent evaporation of soil moisture and protect the soil from surface crusting.

However, crop residues may also carry inoculum that can cause diseases in following crops. Therefore, if crop residues are being retained it is important to rotate crops to different plant families that are non-hosts to any possible pests and diseases that may be carried over. Also, the crop residue should be fully decomposed before replanting the same crop to minimise the potential of losses due to pests and diseases. Incorporating the crop residue into the soil can help speed its decomposition.

Manures

Because of nitrogen leaching, fly breeding, health risks from potential food contamination and odours, raw forms of manure should not be applied to vegetable crops. Furthermore, their low carbon to nitrogen ratio means that any contribution to improving SOC is small compared to their application rate.

Manures can be applied as a solid or liquid. They should be composted before application. The composted forms of manure are more stable than uncomposted manure and do not present the same risks. There is a risk that overuse of manures or manures applied at the wrong time can damage crops and pose an environmental threat to waterways. It is important to know the nutrient content of the manure because this is extremely variable and depends on the age of the manure and the conditions under which it has been stored.

Some customers do not allow use of un-composted manures in some high-risk vegetable crops because of food safety concerns.

Municipal and industrial wastes

Municipal wastes tend to come from households. Using un-composted green waste in vegetable production is highly questionable, as it may have variable composition and quality and can be a source of pests, diseases and weeds. However, it is an excellent source for compost manufacture. Composted municipal green waste has shown to benefit soils in vegetable production.

Similarly, *industrial wastes* are also not often suitable for use in vegetable production without composting or processing first. Even then take care with amendments that have been manufactured from industrial wastes to ensure that they do not contain heavy metals that can contaminate soil, or micro-organisms that may result in food safety violations in harvested product. Check with customers about their food safety requirements before you consider using industrial wastes.

Biosolids such as stabilised sewage should not be used in vegetable production because of food safety risks.

Adding organic soil amendments can address the following soil constraints:

- excessive, prolonged wetness and waterlogging
- low water-holding capacity
- hard-setting and surface sealing
- compaction
- low nutrient retention
- sodicity
- alkalinity
- high phosphorus fixation
- low organic matter content.

Controlled traffic

The movement of machinery and equipment across the soil surface during normal vegetable growing operations (such as land preparation, crop management and harvesting) can cause compaction.

When equipment is allowed to move unrestricted over a paddock it compresses large areas of the soil. The risk of developing serious compaction problems can increase as a result of working and travelling on fields when they are too wet.

Soil does not necessarily compact more with each pass of machinery. This is because the heaviest load (or heaviest machine) causes most of the compaction and the soil does not necessarily compact further when other lighter machines pass.

Controlled traffic aims to restrict the movement of equipment within a field to defined pathways or roadways. Therefore, the wheel track areas receive all of the compaction, and the crops are planted outside the compacted areas. This means the crop does not grow in compacted soil, and there is no hard compacted soil needing cultivation that would add to the wear and tear on machinery and require more fuel.

Adopting controlled traffic lanes typically requires field equipment to have consistent axle widths. It also requires considerable discipline from machinery operators. While guided GPS systems have been developed to assist with controlled traffic operation, it is also possible to use field-based markers to guide machinery operators. The field markers may not be as accurate as GPS, but they can help restrict traffic to the same track in the paddock each time and greatly reduce compaction over the field.

Controlled traffic management is able to reduce the following soil constraints:

- excessive, prolonged wetness and waterlogging
- hard-setting and surface sealing
- compaction
- low organic matter content.

References

Soil health and Australian vegetable production

McMullen, B 2000, *SOILpak for vegetable growers*, NSW Agriculture, Orange, Australia http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/soil/soilpak

Paulin, R 2005, *Identifying the benefits of composted soil amendments to vegetable production*, Horticulture Australia Ltd. final report.

Rogers, G 2001, *Establishment of no-till permanent bed vegetable production systems in major vegetable growing regions in Australia*, Horticulture Australia Ltd. final report.

Whitman, H, Anderson, A, Kelly, J and McKenzie, D 2007, *Healthy soils for sustainable vegetable farms: ute guide*, AUSVEG and Land & Water Australia, Canberra, Australia.

General information

Baker, DE and Eldershaw, VJ 1993, *Interpreting soil analysis for agricultural land use in Queensland*, Department of Primary Industries, Brisbane, Queensland.

Bloem, J, Hopkins, DW and Benedetti, A 2006, *Microbiological methods for assessing soil quality,* CABI publishing, Wallingford UK.

Coleman, DC, Crossley, DA and Hendrix, PF 2004, *Fundamentals of soil ecology* (2nd ed.), Academic Press.

Doran, JW and Jones, AJ 1996, *Methods for assessing soil quality*, Soil Science Society of America, Madison.

EUROCONSULT (eds) 1989, *Agricultural compendium for rural development in the tropics and subtropics*, Elsevier, Amsterdam.

Gugino, BK, Idowu, OJ, Schindelbeck, RR, van Es, H, Wolfe, D, Thies, J and Abawi, GS 2007, *'Cornell soil health assessment training manual'*, (Edition 1.2). Cornell University, Geneva, New York.

Hall, R 2008, *Soil essentials: managing your farm's primary asset*, Landlinks, Collingwood, Victoria, Australia.

Handreck, K 1979, *Organic matter and soils* (Discovering soils; no. 7), CSIRO, Canberra.

Isbell, RF 1996, *The Australian soil classification*, CSIRO Publishing, Melbourne, Victoria.

Jacobsen, C, Keith, K and Kamel, T 1992, *Understanding soil ecosystem relationships*, Department of Primary Industries, Queensland, Australia.

Lawrence, D 2008, *Healthy soils workshop manual*, Department of Primary Industries and Fisheries Queensland, Brisbane, Australia.

Lines-Kelly, R 2001, 'Soil health: the foundation of sustainable agriculture' in *Proceedings of a workshop on the importance of soil health in agriculture,* June 20–21, Wollongbar, Australia (NSW Agriculture), p. 168.

Maas, EV and Hoffman, GL 1977, 'Crop salt tolerance – current assessment', *Journal of the Irrigation and Drainage Division*, vol. 103, pp. 115–30.

Magdoff, F and van Es, H 2000, *Building soils for better crops*, Sustainable Agriculture Network: Beltsville, MD.

Magdoff, F and Weil, RR 2004, 'Soil organic matter management strategies' in *Soil Organic Matter in Sustainable Agriculture* (Eds F Magdoff and RR Weil), CRC Press, New York.

Moody, PW 2007, 'Interpretation of a single-point P buffering index for adjusting critical levels of the Colwell soil P test', *Australian Journal of Soil Research*, vol. 45, pp. 55–62.

Moody, PW and Cong, PT 2008, 'Soil constraints and management package (SCAMP): guidelines for sustainable management of tropical upland soils', Australian Centre for International Agricultural Research, ACIAR monograph No. 130, Canberra, ACT, Australia.

Shaw, JJ 1999, 'Soil salinity – electrical conductivity and chloride' in *Soil analysis: an interpretation manual* (Eds KI Peverill, LA Sparrow and DJ Reuter), CSIRO Publishing, Melbourne.

Shepard, TG 2000, *Visual soil assessment (volume 1): field guide for cropping and pastoral grazing on flat to rolling country*, Horizons.mw & Landcare Research, New Zealand.

Stace, HCT, Hubble, GD, Brewer, R, Northcott, KH, Sleeman, JR, Mulcahy, MJ and Hallsworth, EG 1968, *A handbook of Australian soils*, Rellim Technical Publishers, Glenside, South Australia.

Uphoff, N, Ball, AS, Fernandes, E, Herren, H, Husson, O, Palm, C, Pretty, J, Sanginga, N, Thies, J 2006, 'Issues for more sustainable soil system management' in *Biological approaches to sustainable soil systems*, (Eds N Uphoffet et al.), Taylor & Francis, Boca Raton, FL, USA.

Wolfe, DW 2001, *Tales from the underground*, Perseus Publishing, Cambridge, USA.