The effect of management actions on soil function

Soil organic matter has an essential role in soil function as it affects many soil properties. It is important for stabilising soil structure; aggregating soil particles; increasing water infiltration and overall water holding capacity; storage and release of nutrients; improving cation exchange and buffering capacity. It is also essential for providing a food source for a range of soil organisms, stimulating their activity so they can cycle nutrients, suppress pests and pathogens, and convert active soil organic carbon to a stabilised form.

Soil organic matter (SOM) can be added to or lost from soil. Management practices can

- optimise inputs into soil by growing more biomass (roots and shoots), providing a continuous "in situ" source of organic matter, and adding OM from elsewhere (eg manures).
- decrease losses of soil organic carbon (SOC) from the soil by maximising stabilisation with clay, within aggregates or in chemical complexes, improving soil surface cover and minimising erosion.

Changes to management practices can have multiple benefits and affect the function of the soil.

Table 1 Summary of ways to improve soil function

OPTIMISE OM INPUTS	**MINIMISE SOC LOSS**
Add more OM	**Decrease SOC loss**
• Grow more biomass • Retain more biomass • Grow more roots and exudates • Grow more soil organisms • Add OM from elsewhere	• Maintain OM inputs • Minimise soil erosion • Minimise CO_2 loss from decomposition of OM • Maximise stabilisation of SOC • Maximise production of Humus OC (HOC)
Adjust Management	**Adjust Management**
• Address soil limitations to production where possible • Optimise nutrition • Grow green plants for longer • Optimise plant diversity • Consider growing perennial instead of annual plants • Encourage root growth • Minimise bare ground	• Provide OM inputs to maintain or improve SOC • Minimise bare ground • Minimise soil disturbance • Maximise soil particle?? surface area for capture and stabilisation of HOC • Find ways to optimise decomposition conditions to reduce release of CO_2.

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INCREASE ORGANIC MATTER INPUTS

Grow more biomass

Practise good agronomy: Optimising supply and balance of nutrients and effective control of pests, weeds and disease is important for maximising growth of desired plants. Low SOC levels (below 1% for sands and 2% for clayier soils) reduce a soil's capacity to mineralise nutrients. therefore nutrients from synthetic or organic sources are required. Improving soil nutrition improves plant growth and biomass production. Higher OM inputs into soil increases microbial populations and activity, potentially increasing the amount of decomposition and loss of OC as CO_2 gas. However, improved nutrition assists in the microbial conversion of particulate (active) to humus (more stable) OC.

Growing a diversity of plants within season (where possible) or across seasons can improve resilience to seasonal conditions and climate variability. Different plants have different proportions of carbon (C) and nitrogen (N) in their physiology and different rates of breakdown and nutrient release.. A plant's root structure (architecture) can modify soil physical limitations and associate with specific microbes such as rhizobia or fungi. Different species can extend the length of growing season, remaining green and actively growing for longer periods. Perennials increase the amount of biomass grown above and below ground over a period of time and their roots and shoots continue functioning when annual species have died off. Plant breeding for crop species has selected varieties that maximise grain production rather than total biomass production. effectively reducing SOC inputs. Grazing of pasture removes biomass from the site decreasing inputs into the soil but controlled grazing of pastures can stimulate prolific root growth and exudate production and improve SOC inputs directly to the soil. Hay (and straw bale) production can remove significant amounts of organic material from a paddock, reducing SOC inputs.

Address soil limitations Many agricultural soils have physical and chemical limitations that need to be rectified before plant production and biological processes can be improved. Identification of soil limitations affecting soil function and limiting productivity is the first step. Limitations need to be assessed into those that can be overcome and those that are impractical or uneconomic to address. Soil limitations such as acidity, sodicity, compaction or hard setting layers can be treated.

Soil structure describes the arrangement and organisation of mineral soil particles and the pore spaces surrounding them. In all but loose sands, individual clay, silt and sand particles arrange themselves to form aggregates. Soil aggregates enable more water and air movement in the soil. Organic matter plays a key role in soil structure by providing the 'glue' between particles to maintain pore spaces between silt and sand particles. OM feeds soil biological activity whose secretions and fungal hyphae are important for soil aggregation. The amount and type of clay and the amount, shape and size of sand grains affects the way the soil particles pack together. In sands, fungal hyphae are more important for structure than microbial secretions as they cross-link sand grains in the aggregates. They are also important for accessing moisture stored in micropores.

Changing to a different system Whilst potentially increasing SOC, consideration needs to be given to total farm greenhouse gas emissions. For example, when changing from annual cropping to perennial pastures, SOC is likely to increase due to greater OM inputs and reduced losses but methane emissions from grazing ruminants can outweigh any SOC gains.

Grow more roots and exudates

Plants provides food for microbes through root exudates (plant rhizodeposition). Microbes can colonise roots and assist the plant to take up nutrients and protect it from soilborne pathogens. Increased root biomass, root exudates and sloughing of cells increase soil OC. Availability of root exudates encourage microbes deeper into the soil and can improve conversion of POC to HOC at depth. Roots contribute 2-6 times more OC than shoot residues, mainly because microbes are unable to break down roots that are bound in soil aggregates and the presence of more lignin in roots which is more resistant to decomposition.

Plant growth stage and root architecture affects the amount of exudates produced. The production of plant roots exudates cannot be directly controlled but can be influenced by management practices.

Address soil limitations

Sandy soils enable only minor amounts of SOC to be stabilised as it is difficult to protect OM from microbial decomposition. OC inputs are readily decomposed by microbes and carbon lost as CO_2. Adding clay to sandy soils can overcome water repellence and reduce run-off, patchy plant germination and emergence. Plants are able to utilise more nutrients in wetter soil thereby improving plant productivity and SOC. Tillage processes required for clay amendment (delving, spading, off-set discs) can overcome physical limitations such as high bulk density and soil strength.. This often leads to improved root growth, OC storage and productivity. However, initial tillage can cause losses of 20% of OC stock in topsoils as aggregates are broken up and OC is exposed to microbial decomposition, particularly in the sand component.

Retain more shoots

Keeping as much OM on the soil surface as possible aids rainfall infiltration, reduces evaporation of soil moisture, moderates soil temperatures and provides food, enhancing conditions for microbial activity. Soil (and OC) losses from erosion are reduced. Retaining stubbles and preventing grazing animals from baring out paddocks are measures that will retain more shoots.

Increase number and type of soil microbes

Microbes consume and produce OC, so have a role in both mineralising and stabilising SOC.

Decomposition of OM by microbes releases nutrients, water and CO_2. Microbes also secrete substances that act as glues binding soil particles together into aggregates. As microbes die, they become part of the stabilised HOC pool. POC and HOC are bound into aggregates and are protected from further decomposition unless the aggregates are broken apart by soil disturbance. Fungal hyphae in sandy soils particularly rely on soil aggregation to function so are very vulnerable to soil disturbance e.g. tillage.

Import organic matter

Where it is not possible to grow extra OM on-farm or there are additional needs (e.g. nutrition), obtaining and applying OM from beyond the farm gate is feasible . It is better to apply materials formed from waste products and not from a productive area of land as the latter is “robbing Peter to pay Paul” i.e. increasing OM inputs on one site at the expense of reducing inputs at the other. Large amounts of OM are required to contribute to a measurable change in SOC stores and inputs will need to be maintained and managed to sustain SOC stocks.

REDUCE OC LOSSES

Soil organic carbon constantly cycles from one form to another as microbes and other soil organisms decompose and convert carbon from OM into carbon dioxide (CO_2). Changes in management practices that decrease OM inputs or increase the rate of loss of CO_2 from the soil affect SOC.

Minimise soil disturbance and soil erosion

Soil disturbance breaks apart soil aggregates, damages plant roots, destroys fungal hypha and leaves soil susceptible to erosion.

Reducing the number of tillage operations and using narrow points or discs on seeding machines minimises soil disturbance. Keeping crop and pasture residues and managing them to ensure they do not wash or blow away reduces the risk of soil erosion. Timing soil modification activities such as clay spreading, delving or spading to minimise the length of time soil is left bare reduces erosion risk.

Minimise CO_2 loss on decomposition

Recycling of dead microbes (such as in composted products) diminishes release of CO_2 during decomposition. Selection of OM inputs and encouragement of microbes that process OM without releasing as much CO_2 are in early stages of development as management practices.

Maximise stabilisation of SOC

Protecting SOC The location of OC the soil strongly influences if it will be stored or broken down. OC in the top 10 cm of soil is more likely broken down and cycled by microbes favoured by high inputs of organic matter through shoots and added residues. However, at depths greater than 10 cm it is more likely that OC will be stored in soil as there is much less biological activity.

Stabilisation of OC depends on many factors including clay concentrations clay mineralogy, and formation of stable aggregates. Chemical stabilisation improves aggregation and can limit access of microbes to OC. Chemical stabilisation can occur through binding of OC to hydroxyl groups of iron and aluminium in acidic soils and complexation with calcium carbonate in alkaline soils.

Maximise production of HOC

Microbes require nutrients to efficiently turn organic matter into humus and nutrient deficiencies can limit the transformation of particulate (POC) to humus OC (HOC). Where there are not enough nutrients in the soil, provision of additional nutrients might be required. For every 1000 kg of humus, 80 kg of nitrogen, 20 kg of phosphorus and 14 kg of sulphur is required to enable biological processes to occur.

More information

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Table 2. Summary of management practices and their effect on soil function in agricultural soils

Management	Soil organic carbon	Soil organisms	Nutrient cycle	Water – soil structure	Productivity
OPTIMISE SOIL ORGANIC MATTER INPUTS					
Grow more biomass *Practise good agronomy*	Increased OM inputs do not necessarily translate to increased SOC as biological activity depends on soil moisture, temperature and soil texture. 70-90% of OC that enters the soil is lost as CO_2 during decomposition	Where soil conditions are favourable for growth, improved nutrition can stabilise more OC. Conversion of particulate to humus OC requires nutrients that will be stored with the carbon. 1 tonne of new HOC requires 80kg nitrogen, 20kg phosphorus and 14kg sulphur	Soil organic matter is an important store of nutrients. Increased OM inputs and decomposition by soil organisms provides nutrients in a form available for plant growth.	Increased OM can directly improve waterholding capacity in sandy soils. Microbial secretions create soil aggregates that improve water and air movement.	Increased productivity and (in most cases) profitability. Producing more biomass should result in more grain yield and profit.
Grow more biomass *Plant type and diversity*	Diversity, root architecture and plant C:N ratio can affect the change in SOC	More species increases diversity of food sources and microbes and the roles that microbes perform.	C:N ratio of OM determines nutrient availability for plants. C:N < 20:1 will decompose more quickly than C:N > 30:1.	Different root architectures grow in different directions, concentrations or in different parts of the soil, reaching more water.	Depends on crop or pasture type. Pastures with increased growth for longer periods will improve livestock production
Grow more biomass *Apply irrigation*	Often little if any increase in SOC, especially in soils that offer limited protection for OC from microbial decomposition.	More food and more soil moisture will increase microbial activity. There is a trade-off between increased OC return to soil and increased release of CO_2 but there are other functional benefits from increased biological activity (eg nutrient cycling).	More nutrients required to support more plant growth.	Water availability increases. Soil needs to be managed to ensure waterlogging, sallt or other toxicities do not affect plant growth.	Increased crop/pasture growth expected from reduced reliance on rainfall.
Grow more biomass *Address soil limitations*	SOC can increase, depending on limitation	Can increase activity and diversity depending on limitation	Increase if microbial activity and OM inputs improved	Increased water storage if structural problems addressed and microbial activity improved.	Increase if removal of limitations improves plant growth.

Table 3 continued. Summary of management practices and their effect on soil function in agricultural soils

Management	Soil organic carbon	Soil organisms	Nutrient cycle	Water – soil structure	Productivity
OPTIMISE SOIL ORGANIC MATTER INPUTS					
Grow more biomass *Change to a different system*	Can increase SOC but need to be aware of effect on total greenhouse gas emissions	Expect a change in numbers, activity and diversity.	Depends on OM source, microbial activity and nutrient supply.	Depends on nature of change	Expect an increase
Retain more shoots	Where soils were previously bare, large increase in SOC are possible	Moderated temperatures and additional moisture benefit microbial activity and diversity	Decomposing OM provides nutrients to plants	Increases soil moisture, microbial activity and particulate OM, improves structure	Minor effect but long term gains from protecting soil from erosion
Grow more roots and exudates	Increase SOC. Roots contribute 2-6 times more SOC than shoots	Increase microbial activity	Minor direct effect.	Improved soil structure from increased root growth. Different species have different root exudates or microbial associations including fungal associations. Fungal hyphae are important for soil structure and water access in sandy soils.	Can reduce grain yield as plant's water and nutrients used to grow more biomass at the expense of grain production.
Increase number and type of soil organisms	Will depend on the soil's ability to stabilise SOC. OM unprotected by clay or aggregation is broken down more quickly by microbes.	Increased activity and more functions are provided by more and diverse soil organisms.	Increased decomposition releases more nutrients to plants	Increased microbial secretions should improve aggregation and water holding capacity	Improved productivity from increased microbial activity releasing more nutrients for plants and suppressing diseases
Import OM	Requires high amounts and repeated inputs. Nutrient composition of product important in providing nutritional benefits. Needs to be sourced from a waste stream rather than taking C from land to another place.	Ready food source for soil organisms can stimulate increased activity and might improve diversity. Composted products introduce dead microbes (less release of CO_2 to atmosphere).	Nutrient requirements depend on amount applied and nutrient composition of OM. Additional nutrients might be required to support microbial functions.	Water infiltration and storage should increase. Better soil structure	Increase if sufficient nutrients and other functional benefits

Table 4 continued. Summary of management practices and their effect on soil function in agricultural soils

Management	Soil organic carbon	Soil organisms	Nutrient cycle	Water – soil structure	Productivity
MINIMISE SOIL ORGANIC CARBON LOSSES					
Minimise soil erosion	Increase A loss of 1 t/ha of surface soil with 1% SOC equates to a loss of 10kg/ha of SOC.	Increased diversity and activity with less exposure to dry conditions and, more extreme temperatures.	More nutrients available as less losses of surface soil	Improved soil structure and water infiltration	Increase
Minimise CO_2 loss on decomposition	Increase if more OC can be retained with minimal soil disturbance	May require different functional groups to achieve less CO_2 release during decomposition of plant or microbial OM.	No change	Moisture and structure may improve with minimal soil disturbance	No change
Maximise stabilisation of SOC	Increase Imported materials such as clay or biochar in sandy soils or OM deep in soil profile provide protection to C from breakdown by microbes. No change will occur If decomposition rate outweighs increase in protection	Reduced activity if number of protection sites increases or more roots grow below 10 cm . However, it is possible that amendments will provide a more favourable environment (moisture, temperature) for microbial activity.	Decreased supply if number of protection sites increases. However clay and biochar might hold more nutrients in the soil because of increased cation exchange capacity.	Increased capacity to store more water with clay or biochar in sandy soil	Increase if number of protection sites increases or deeper root growth occurs, providing plants with more nutrients and water.
Maximise production of HOC	Increase due to more stable form in soil	Identification and multiplication of organisms that enhance HOC production (research required)	Will require nutrients to enable transformation from POC to HOC	May increase in sandy soils. Unlikely to be a large benefit in more clayey soils	Minor to no change