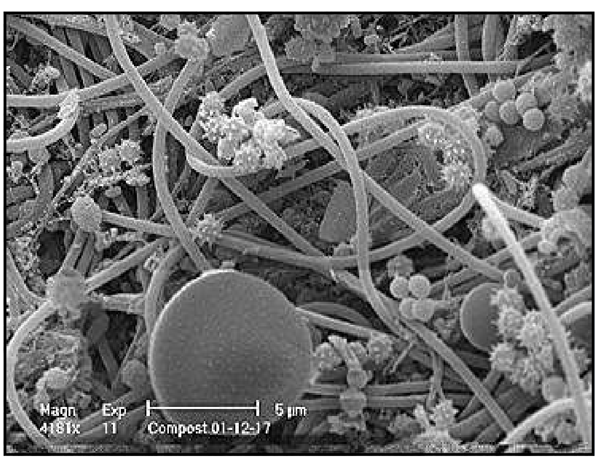
What is Compost?

- **Aerobic** decomposition of organic materials into humus.
- Original materials are unidentifiable in well humified (humus rich) compost .
- Good quality compost contains all macro and micro nutrients, all in stabilised, slow release form.
- Compost is also rich in beneficial humic substances which condition soil, improve nutrient uptake and feed soil microbes.

Compost is alive!

- But most importantly, compost is alive! It is a **living** fertiliser (biofertiliser).
- Quality compost is teeming with beneficial microbes (many of which are same species as found in soils).
- Organic carbon in compost is also a 'house' for microbes, being both a **house** and a **food** source for them.
- Therefore, compost is an ideal way to inoculate soils with beneficial microbes.



Types of Compost

- **Vermi Composting** – composting with worms (cold composting).
- **Passive/Static Composting** – slow, unmanaged decomposition.
- **Thermophilic Composting** – actively managed, rapid, hot composting.

Passive Compost

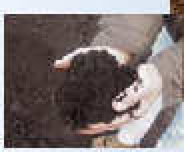
- Left relatively **unmanaged**, undisturbed for a long time.
- Takes longer to finish the compost and runs risk of poor quality if not constructed/managed properly.
- Safer method is to **go very heavy on carbon** (dry/browns) as too much nitrogen (greens) will putrefy.
- Consequence is longer production time (12+ months).

Thermophilic Compost

- Actively managed compost pile to ensure a **heating phase** is present.
- Higher temperatures speed up decomposition and eliminate weed seeds and disease spores.
- Balance of browns and greens again important (*see C:N ratio slide*).
- Regular **turning** required to sequentially cool the pile down.
- Typically, rapid production time (8-12 weeks).

Compost

- Compost quality depends on:
  - Food sources (C:N)
  - Moisture
  - Temperature
  - Oxygen
  - Toxins



C:N Ratio

- Balance of ingredients is important:
  - **carbon** rich woody materials (browns)
  - **nitrogen**-rich green leafy matter or manures (greens)
  - must be balanced = C:N Ratio.
- **Browns** – stubble, straw, dry grass, woodchips/shavings, autumn leaves, newspaper, tree prunings.
- **Greens** – manures, chicken litter, fresh grass, green leaves, vegetable waste, blood and bone, legume hay.

C:N Ratio

Ingredient	%N	%C
(High in carbon)		
non-legume hay	1.3	42
tree prunings	1.0	50
straw	0.7	56
woodchip/shavings	0.1	50
newspaper	0.04	25
(High in nitrogen)		
blood and bone meal	13	42
vegetable wastes	3	30
chicken litter	2.7	38
grass clippings	3.4	58
cattle (dairy) manure	2.7	48
horse manure	1.6	48

Constructing The Pile

- Piles **too small** will:
  - Struggle to heat up (not sufficient body mass)
  - Can dry out easier
  - Can become waterlogged easier
- Piles **too big** will be difficult to manage.
- 2m high x 2-3m wide
- **Moisture** may need to be added at construction stage.

Moisture

- If too wet or dry, microbial activity declines.
- To test:
  - Take a handful of compost material
  - The sample should feel **moist** and **glisten** with water
  - When squeezed, excess water should **not** drip out

Temperature

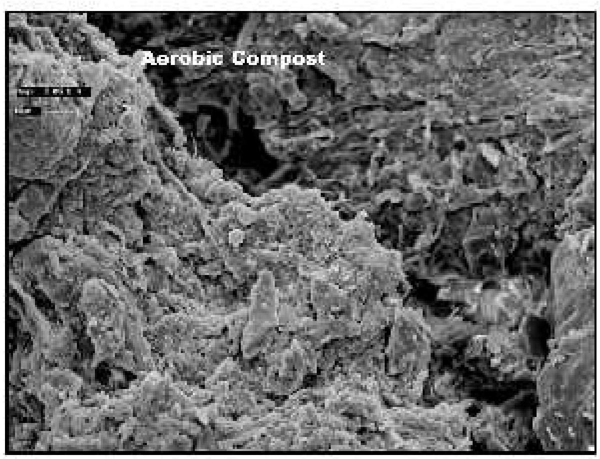
- Temperature should reach between **50-65°C** (now a thermophilic compost).
- Temperatures much reach 60°C to sanitise weeds and pathogens.
- Once the pile temperature is approaching **65-70°C**, turn the pile.
- Check moisture content!

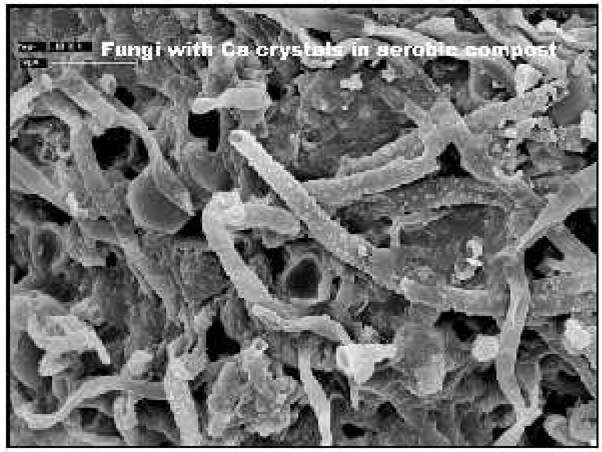
Turning

- '**Lift**' the pile and drop down using an excavator or telehandler.
- A **gentle mixing** is preferred rather than an aggressive, vigorous turning.
- Number of turnings will depend on inputs used.
- Turn more in first half and less in second half of composting cycle.

Oxygen – aerobic compost

- Oxygen is critical to ensure **beneficial** decomposer microbes (aerobes) thrive in the compost.
- Use different **size** and **shaped** particles to maintain structure.
- Larger woody materials will take longer to break down but prevent slumping and encourage ongoing **oxygen diffusion.**





Finished Compost?

- If used, **unfinished** compost will scavenge nutrients from the soil (esp N) to finish its decomposition **before** it releases anything back to the soil.


Finished Compost?

- When compost is ready, it has the following characteristics:
  - **Smell**: earthy, not putrid, sour etc.
  - **Feel**: moist and earthy, not sloppy or powdery.
  - **Appearance**: chocolate brown and humified.
  - **Temperature**: ambient.
  - **C:N Ratio**: 15-20 : 1
  - **Microbial Analysis**: microbial biomass can highlight compost quality and suitability.
  - CO_2 evolution.

Maturation

- After the thermophilic cycle is complete, woodlands or woodland borders are ideal sites for **undisturbed** compost **maturation.**
- Provides a perfect **microclimate.**
- Fungal rich environment to encourage fungal development throughout the compost.
- Ideally **cover** to maintain **humidity** and prevent water logging in wet season particularly important for small piles.

Manures

- Manures are an amazing ingredient in compost piles but be careful as they will require more turning.
- Higher risk of putrification (high N).
- To further enhance the microbial diversity of fresh manures, they should be well aged at a minimum and ideally composted.

Manures

- Manures are high N (green) inputs, balance them with additional C (browns) and compost to improve aerobic microbial diversity.
- Manures can be spiked with zeolite or humic acid to stabilise the highly soluble/available nutrients contained within.

Organisms in Compost

	Total Fungi (µg/g)	Total Bacteria (µg/g)	Protozoa (#/g)	Total Nematodes (#/g)	Fungal / Bacterial Ratio
Compost 1	60.1	1736	1351	0.1	0.03
Compost 2	442	835	12002	0.1	0.53
Compost 3	984	1188	7948	0.3	0.83
Compost 4	482	393	17206	14.4	1.22

1- 40% Farm manure, 10% wood, 50% Green waste

2- 20% Zoo manure, 20% wood, 60% Green waste

3- 35% wood, 65% Green waste

4- 50% wood, 50% Green waste

Beneficial Fungi

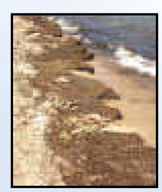
Thick strands

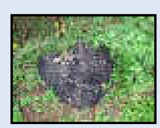
Color can be variable – pink, orange, brown, tan, white

Enriching Your Compost

There are several ingredients that can boost the fertiliser power of your compost including:

- **Zeolite** – for N and K retention.
- **Clay** – for humus stabilisation
- **Seaweed** – growth promotants and trace minerals.
- **Humates** – brown coal is a great input.
- **Bonemeal** and **seed meal** – N source.
- **Wood Ash** – great source of potassium.
- **Rock phosphate** – if P is needed.
- **Rock Dusts** – activate the relatively inert minerals.





Microbially Fortified Compost

- Compost can be enriched with microbes during the composting process to either aid **decomposition** or improve **disease** suppressivness.
- Numerous published studies have examined the effects of inoculating microbes at the start or at the end of the composting process.

Fortified Compost

- Key cellulose digesting and carbon degrading organisms can be added at the start to enhance humificiation.
- Disease suppressive organisms are ideally added toward the end during the cooling maturation phase.
- *Trichoderma* is an ideal candidate as it is both a cellulose digester and an antagonist against pathogens.

Compost and Disease

- **Sterilized** and **unsterilized** vermicompost was added to potting media to investigate suppression of *Fusarium*.
- Sterilized (dead) compost resulted in no suppression while unsterilized (alive) compost reduced *Fusarium* incidence.
- This suggested a biotic factor (living factor) was the suppressive agent and not an abiotic (chemical) factor in this instance.

Vermi Compost and Disease

Vermi Compost and Pests

- Edwards *et al** investigated the effect of **aqueous extracts** of vermicast on insect pests (aphids, mealybug, mites).
- **Soil** applied liquid cast suppressed pest establishment and caused some pests to die when compared to a water control.
- They suggested an abiotic factor (chemical factor – phenolic compounds) were absorbed by plant tissues making them unattractive to the pests.

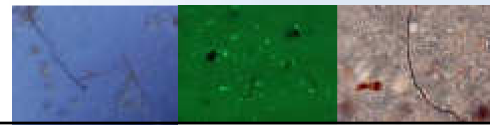
Liquid Vermicast and Pests

Keys to Success!

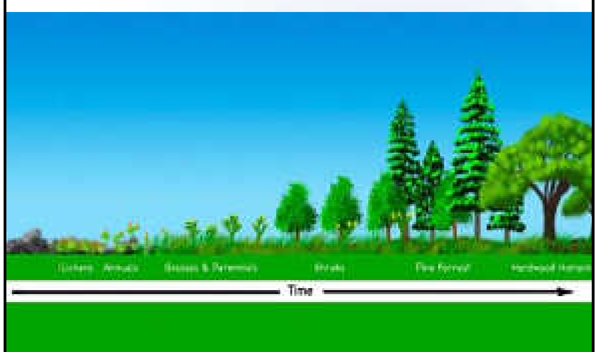
- If **hot** composting – turn the pile **more** in the **first half** of its life and **less** in the **second half**.
- If **static** composting – go **very heavy** with **carbon** and leave the pile for significantly longer.
- **Mature** the pile along the edge of a **woodland**.
- Inoculate at start or at end with *Trichoderma* or with an inoculum of mature, finished compost.

Bacteria and Fungi

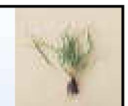
- All microbes play an important role in soil function, however, as bacteria and fungi are at the start of the food chain, they're role is of particular importance!



Ecological Succession



A Sports Turf Example



- Golf courses prefer **perennial** grass species as they are finer = better playing surface.
- These perennials are later successional species.
- *Poa annua* is an **annual** early successional grass that is less desirable.
- By shifting the microbial community in a slightly more fungal direction we create an environment in which *Poa* does not thrive and select for perennial finer grasses to outcompete the *Poa*.

Sports Turf - Shift Your Succession

- A greater fungal level in soil increases fine grass health and reduces weed growth.
- "Arbuscular mycorrhizal fungi (AMF) can be used as biological control agents of *P. annua*, acting to reduce its growth while increasing that of desirable perennial grasses".*
- AMF may also directly antagonize *Poa*.*
- However, natural levels of AM fungi in amenity turf are very low.*

*Journal of Applied Ecology, Volume 36, Number 6, December 1999 , pp. 909-919 (11)

Soil Biology and Carbon

- Plants release ~30% of their total photosynthetic energy into the root zone as root exudates – sugars, carbohydrates etc.
- Depending on what is happening in the rhizosphere, these exudates can potentially be sequestered into the soil carbon pool.

Bacteria, Fungi and Carbon

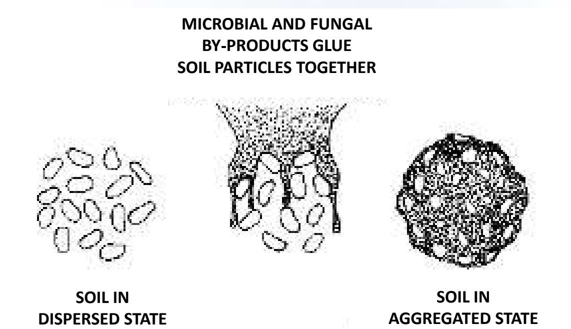
- Current understanding suggests fungi are more important than bacteria for carbon sequestration in soils:
  1. Fungi store more C in their biomass than bacteria.
  2. Fungal metabolites/by-products are more resistant to degradation.
  3. Fungal hyphae promote soil aggregation which physically protects soil organic matter.

* Rillig, M.C. & Mummey, D.L. (2006). Mycorrhizas and soil structure. *New Phytologist* .171: 41–53
* Six, J., Frey, S.D., Thiet, R.K & Batten, K.M. (2006). Bacterial and Fungal Contributions to Carbon Sequestration in Agroecosystems. Soil Sci. Soc. Am. J. 70:555–569.

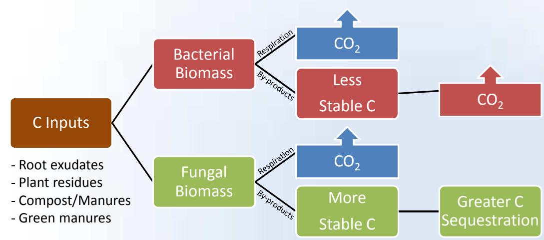
Mycorrhiza and Glomalin

- AMF also produce an extremely **stable** compound called **glomalin** which may resist degradation for up to 40 years*.
- Glomalin is a sticky sugar-protein which also **improves** soil aggregation and **protects** other soil organic matter.

* Six, J., Frey, S.D., Thiet, R.K & Batten, K.M. (2006). Bacterial and Fungal Contributions to Carbon Sequestration in Agroecosystems. *Soil Sci. Soc. Am. J.* 70:555–569
* Wright, S.F. and Upadhyaya, A. (1996) Extraction of an abundant and unusual protein from soil and comparison with hyphal protein of arbuscular mycorrhizal fungi. *Soil Science* 161: 575–586.



Fungi:Bacteria and Carbon Sequestration



Carbon Protection

- The most important ways to preserve soil carbon is to **protect** it once it has been sequestered!
- Maintaining **soil aggregation** critical to soil carbon protection.

Mycorrhiza and Soil Structure

- Soil structure is influenced by many factors!
- A long term study* found a highly significant correlation with **AMF abundance** and **soil aggregation**.
- They also found **fungicide** applications **reduced** AMF and water-stable macroaggregates.

* Wilson, G.W.T., Rice, C.W., Rillig, M.C., Springer, A. and Hartnett, D.C. (2009) Soil aggregation and carbon sequestration are tightly correlated with the abundance of arbuscular mycorrhizal fungi: results from long-term field experiments. *Ecology Letters*. 12(5):452–461.

Enhancing AMF - Environment

- Soil **Cover** – always maintain host plants and a flow of root exudates (food source) for AMF.
- **Avoid fallows** or keep them as tight as possible if unavoidable.
- Mineral Balance – optimise plant **nutrient** requirements to ensure adequate photosynthesis and hence **C flow** to roots.

Enhancing AMF – Fertility Ley

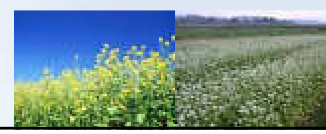
- Fertility building leys are an ideal method to repopulate soils with AMF.
- Dense seeding rates encourage AMF spread throughout the field through root-root contact.
- Uncultivated period of time is ideal for AMF establishment.
- Choose strongly mycorrhizal legumes – clovers, medics and vetches.
- Available P (from AMF) enhances N_2 fixation if using legumes.

Enhancing AMF – Crop Rotation

- If using an AMF-building rotational ley:
- Rotate straight into a mycorrhizal crop.
  - Rotating into a non-mycorrhizal crop will waste the opportunity of the built up soil inoculum.
- Non- and weakly-mycorrhizal crops (brassicas, beets) should be grown later in the rotation (nutrient needs met with soil amendments).

AMF – Crop Rotation

- AMF potential is reduced by:
  - A non-mycorrhizal green manure – mustards, canola, buckwheat.
  - Long term stubble
  - Fallow
- It is not ideal to grow a crop that is AMF dependent straight after these (or be sure to inoculate).



Enhancing AMF - Inoculation

- **Direct** inoculation onto plants has been shown to be most effective for disease control*
  - Seed treatment
  - Liquid Inject
  - Seedling drench
- Within a rotation, two ideal times to inoculate:
  - At start of a ley
  - When rotating from a non-AMF crop to an AMF-dependent crop.
- Don't wait until after establishment!

* Torres-Barragán, A., Zavaleta-Mejía, E., González-Chávez, C., and Ferrera-Cerrato, R.(1996). The use of arbuscular mycorrhizae to control onion white rot (*Sclerotium cepivorum* Berk.) under field conditions. *Mycorrhiza* 6(4): 253-257

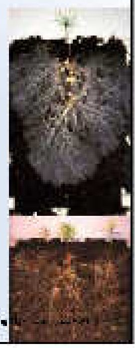
Suppressing Mycorrhiza

- Fertilisers – soluble salt fertilisers (esp N & P) suppress AMF activity.*
- Nutrient Excesses – surplus plant available P (often from excess P fertiliser application+) will reduce the plants need to form AMF associations.
- Pesticides – various fungicides, herbicides and nematicides have been shown to suppress AMF colonisation and sporolation.*
- Cultivation – slices hyphal networks and buries spores below root zone delaying colonisation.
- Manures!

* Gosling, P., Hodge, A., Goodlass, G., and Bending G.D. (2006) Arbuscular mycorrhizal fungi and organic farming. *Agriculture, Ecosystems and Environment* 113: 17–35
+ Jordan, N.R., Zhang, J., and Huerd, S. (2000). Arbuscular-mycorrhizal fungi, potential roles in weed management. *Weed Res*. 40:397-410.

Nutrient and Moisture Access

- AMF are well documented to access soil reserves of P beyond the root zone.
- They also assist other macro-nutrient access – Ca, Mg, K and N.*
- And micro-nutrients – Zn, Cu, Fe.*
- AMF also increase drought resistance by accessing moisture in soil micro-pores that roots cannot access.^
- AMF can also increase tolerance to salinity and heavy metals.'



Cultivation

- In the **absence** of inversion and with minimal soil disturbance:
  - Soil **structure** is maintained/erosion reduced.
  - **Soil-water** dynamics are improved (infiltration, WHC).
  - Soil **biology** (earthworms, fungi) improve.
  - Soil organic **carbon** (SOC) levels improve (?).

Tillage and Carbon

- Research has highlighted that when compared to conventional tillage, no tillage:
  - Increases soil C
  - Increases C residence time
  - Improves the quality of surface layer
- However, this research only investigated surface horizons!

Tillage and Carbon

- More recent research looked at SOC deposition at depth and found no significant difference in **total** C between till vs no-till.
- The **distribution** of that C however, was altered:
  - No-Till accumulates C on **surface** horizon.
  - Conventional tillage incorporates C more evenly **throughout** the profile.

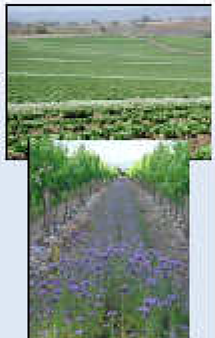
Cultivation

- There is one thing we know without a shred of doubt:
- Not a single method of cultivation **improves** soil **aggregation**!
- Aggregation is key for soil structural stability and SOC protection and **AMF health**.
- Conservation tillage must be considered/investigated/integrated or offset!
- Practicalities?

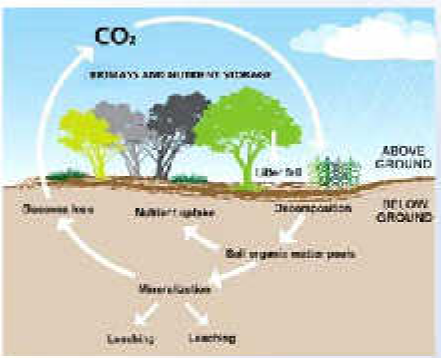
To till or not to till?

- Some evidence suggests that…
  - soil amendments such as animal and green manures; and
  - plant diversity (crop rotations/mixed cropping)

… may be more important in maintaining soil microbial **activity** and **diversity** than conservation tillage in monocultural systems.



Soil Carbon Sequestration

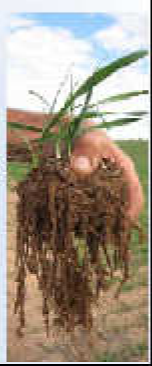


Soil Carbon Sequestration

- It is estimated that there is presently 3-4 times more carbon stored in soils than there is in all terrestrial plant biomass.*
- Hence, soil represents a vast potential for sequestering carbon (especially considering SOC have declined since intensive agriculture).
- Agro-ecosystems must play a key role in this process.
- Understanding soil microbial processes in our **agricultural soils** is fundamental to achieving this.

Soil Biology and SCS

- Plants release ~30% of their total photosynthetic energy into the root zone as root exudates – sugars, carbohydrates etc.
- Depending on what is happening in the rhizosphere, these exudates can potentially be sequestered into the soil carbon pool.



Green Manures

- Green manures are an important means to feed soil life.
- Add Organic Matter
  - Grasses
    - Adds bulk/fine root mass
  - Oats
    - Quick establishment for narrow windows
  - Lupins / Legumes
    - Add nitrogen
  - Brassicas
    - Biofumigation

Green Manures

- Living soil cover keeps **root exudates** flowing into the system feeding microbial biomass (particularly mycorrhiza).
- **Young**, fresh green manures feed **bacteria**, while more **mature**, fibrous green manures feed **fungi** when incorporated.
- Add microbial (fungal) inoculants when shallow incorporating/slashing/rolling etc.

Simple Rules for Biology

- Soil **Cover** – always maintain host plants and a flow of root exudates (food source) for biology.
- Mineral Balance – optimise plant **nutrient** requirements to prevent excess nutrient.
- **Feed** the soil – green manures are not a waste of time out of production. Invest in soil fertility! Apply carbon based fertilisers.
- **Protect** soil life from disruption (cultivation) and toxins (chemicals).

Fertilisers – Organic vs Inorganic

- 200 kg/ha of nitrogen was added to the soil in the form of:
  - Ammonium nitrate, or
  - Dairy manure
- Soil respiration and enzyme activity were higher in the organically amended soil*.
- Increasing carbon in your fertiliser program will increase microbial health irrespective of nutrient content.

Manures

- Of course animal manures are a valuable source of organic matter and nutrients.
- These materials are also inoculated with microbes from the animals digestive system.
- To further enhance the microbial diversity of fresh manures, they should be well aged at a minimum and ideally composted.
- Manures are high N (green) inputs, balance them with additional C (browns) and compost to improve aerobic microbial diversity.

Summary

- Composting is an ideal way to cycle waste materials and produce a valuable soil conditioner that is much more than just **carbon** and **nutrients**.
- On-farm composting can take time to master, but following a few simple rules will improve success.
- Be realistic with your **time** management – indulge in passive, **lazy composting**!

Summary

- Keep soil covered – carbon flow
- Minimise soil disturbance
- Inoculate or support AMF

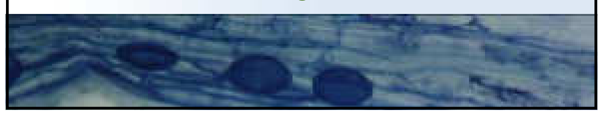
Future Research

- What are the most suitable methods to:
  - Optimise microbial abundance in agro-ecosystems?
  - Optimise sequestration of plant biomass and/or root exudates into the stable carbon pool?
  - Optimise microbes' ability to acquire and supply nutrients?
- What are the optimum soil characteristics that shift microbial communities toward these processes (chemistry, physics, biology)?
- What are the key microbe groups that are most efficient for these processes and how best to use them in agro-ecosystems?

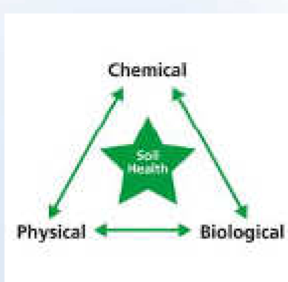
Making the Most of Your Soil: Getting higher quality and yield with fewer inputs

EFAO, Ontario
6th Dec 2014

Joel Williams
BioLife Agricultural



What is a healthy soil?



What drives a healthy soil?