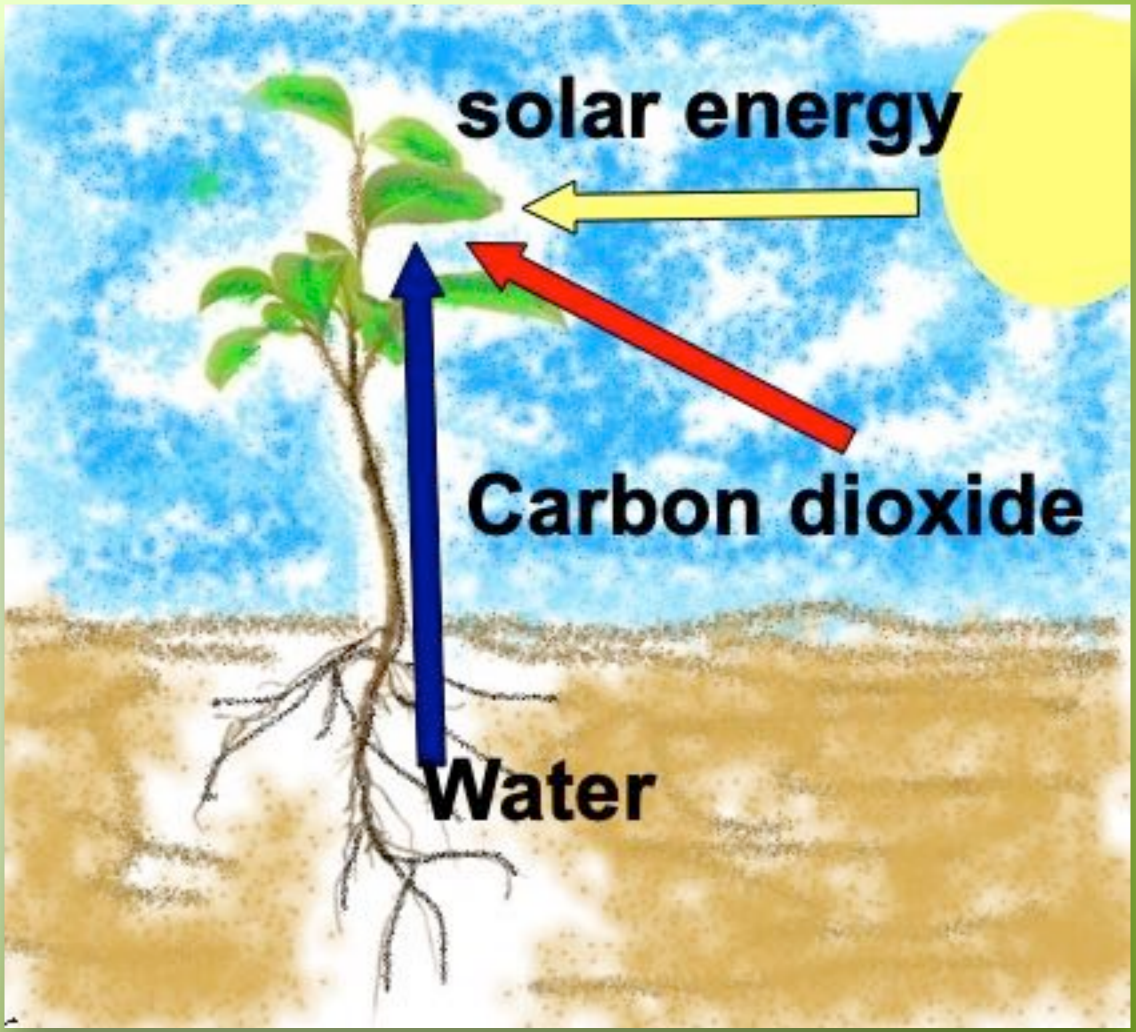
Building Soil Health and Soil Organic Matter

André Leu, International Director
Regeneration International,
Regenerative Agriculture Webinar,
Farming Secrets, September 24, 2020

Maximize Solar Energy

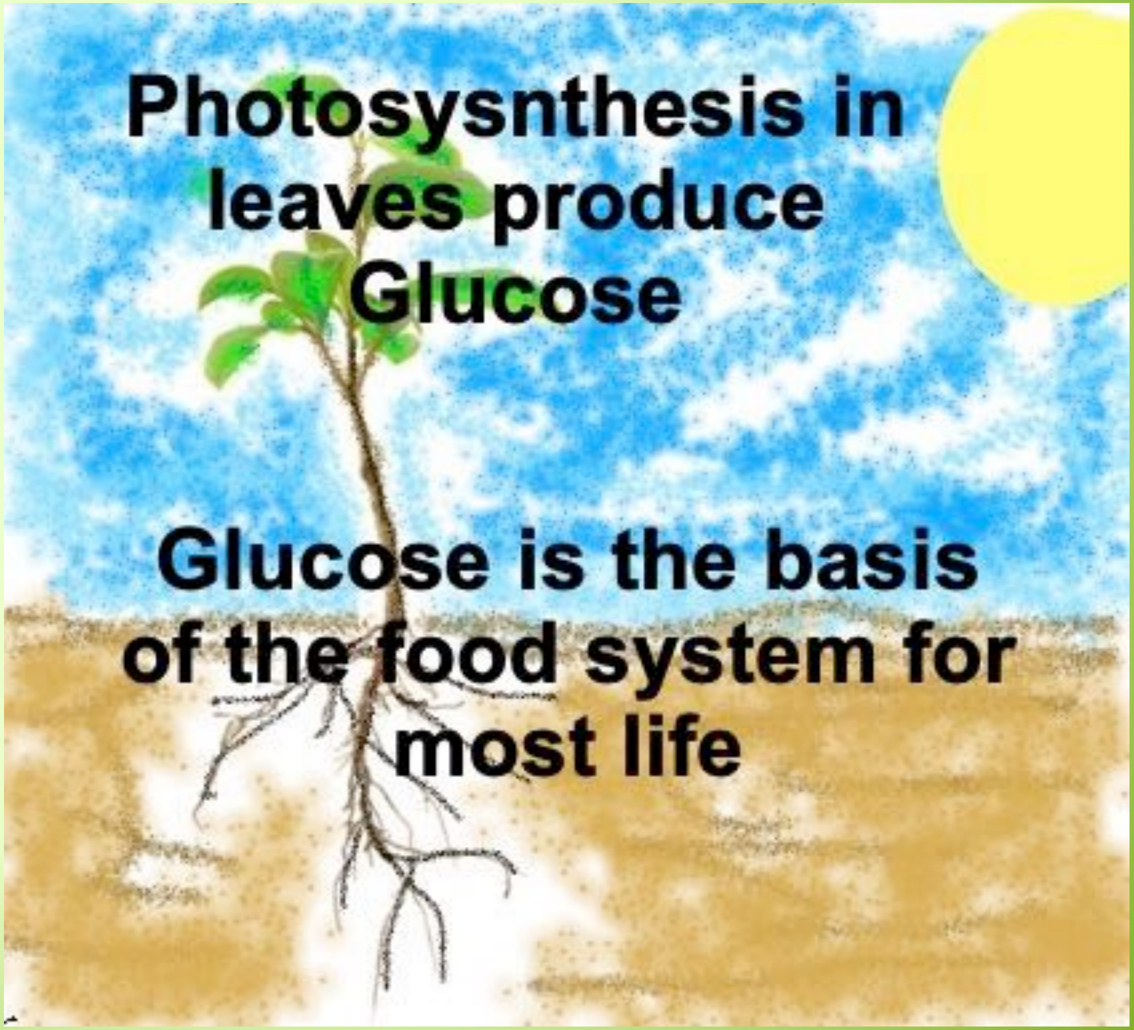
What is the most important thing we do when we farm?



Maximize Solar Energy

We use
solar energy
to power
photosynthesis
to create the
Molecules of Life

Organic matter is constructed from Glucose



Climate Resilience

Soil Organic Matter
Higher Yields in Climate Extremes

Regenerative Organic Systems have higher yields than conventional farming systems in weather extremes such as heavy rains and droughts. (Drinkwater, Wagoner and Sarrantonio 1998; Welsh, 1999; Lotter 2004)

The Wisconsin Integrated Cropping Systems Trials found that organic yields were higher in drought years and the same as conventional in normal weather years. *(Posner et al. 2008)*

The Rodale FST showed that the organic systems produced 30 per cent more corn than the conventional system in drought years. *(Pimentel D 2005, La Salle and Hepperly 2008)*

Organic Matter Increases Infiltration and Soil Stability

Organic

Conventional

Picture: FiBL DOK Trials

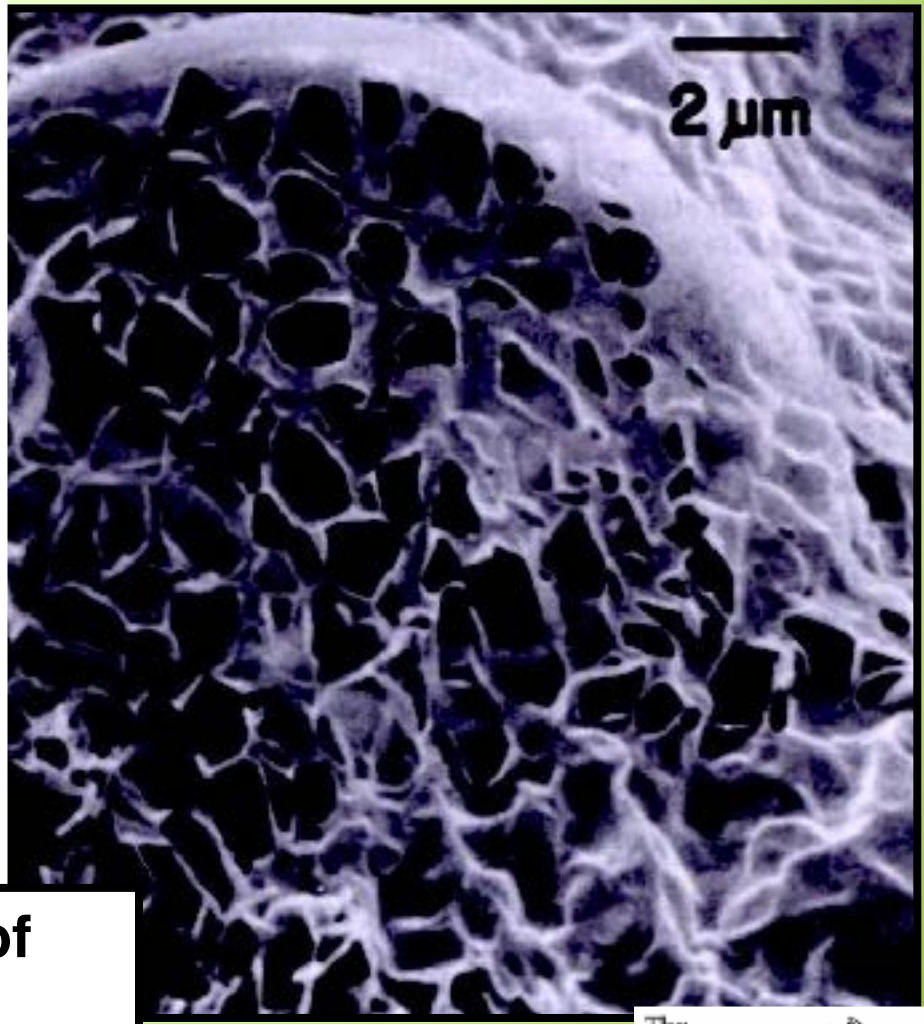
Soil Organic Matter Mitigates and Adapts

- Higher yields in drought years
- Increased soil C and N

- Higher water infiltration
- Higher water holding cap
- Higher microbial activity
- Increased soil stability

Humus and Soil Organic Matter

- Holds up to 30X its weight in water
- Cements soil particles and reduces soil erosion
- Increases nutrient storage & availability
- Humus can last 2000 years in the soil



Electron micrograph of soil humus

Improved Efficiency of Water Use

Research Shows that Organic Systems use Water More Efficiently

Volume of Water Retained /ha (to 30 cm) in relation to soil organic matter (SOM)

0.5% SOM = 80,000 litres (common level Africa, Asia)

1 % SOM = 160,000 litres (common level Africa, Asia)

2 % SOM = 320,000 litres

3 % SOM = 480,000 litres

4 % SOM = 640,000 litres (levels pre farming)

5 % SOM = 800,000 litres (levels pre farming)

6 % SOM = 960,000 litres (levels pre farming)

Adapted from Morris, 2004.

Organic Corn - 1995 Drought

High Yield Regenerative

Organic Agriculture

The average corn yields during the drought years were from 28% to 34% higher in the two organic systems.

The **yields were 6,938 and 7,235 kg per ha** in the organic animal and the organic legume systems, respectively, **compared with 5,333 kg per ha** in the conventional system (Pimentel et al. 2005)

Lbs per Acre = Kg per ha (close enough)

Organic Matter
Living Carbon

Organic matter management is the primary tool in regenerative farming

- Plants are primarily composed of cellulose and lignins
- Cellulose biodegrades into glucose that feeds the microbes of the soil food web
- These microbes break down cellulose and other plant residues releasing nutrients for the crop
- The soil microbes have many other functions such as building good soil structure, unlocking minerals and protecting plants from disease
- The process of making Biochars oxidises the glucose and destroys it so that there is no food to power the soil microbes

Organic Matter
Living Carbon
The Molecules of Life

Organic matter management is the primary tool in organic farming

- **Young plants are primarily composed of cellulose**
- **They can rapidly biodegrade and release nutrients**
- **Older and coarse plants have higher levels of lignins**
- **Lignins are used by microbes to build Humus**
- **The process of making Biochars destroys the lignins**
- **Humus is a very stable polymer that stores minerals and water for plants**
- **All Humus polymers have amino acids attached to them, - an important source of organic nitrogen for plants**
- **It has numerous other important roles in building healthy nutrient rich soils**

Organic Matter

Nutrient availability:

- **Stores anions - 90 to 95% of the nitrogen, 15 to 80% of phosphorus and 20 to 50% of sulphur in the soil**
- **Stores cations - calcium, magnesium, potassium etc and all trace elements**
- **Sand particles do not have charged sites to store ion nutrients, resulting in leaching**
- **Clays mostly have charged sites to store cations**
- **The charged sites in clays tend to repel anions such as nitrate, sulphur causing them to readily leach**

Organic Matter

Nutrient availability:

- Humus has many sites that hold mineral ions and consequently dramatically increases the soils' Total ion Exchange Capacity (TEC)
- These nutrients are available to plants through a process called Ion Exchange
- Humus is critical to preventing leaching and volatization, keeping nutrients in the soil to be available for the crop

Organic Matter

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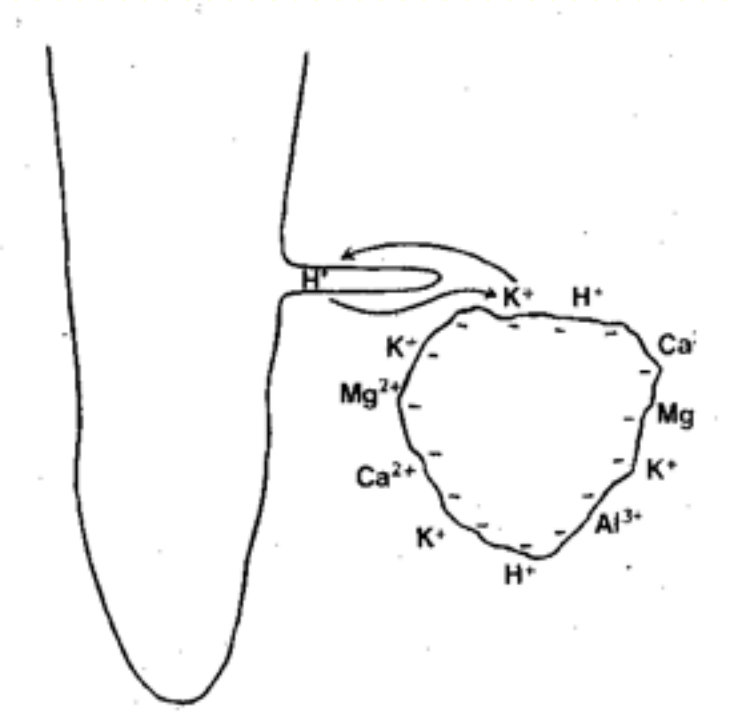
Ion Exchange

The plants split water into its two electrically charged components. The positively charged hydrogen ion (H+) and the negatively charged hydroxyl ion (OH-).

$H_20 = H + OH$



The plants exchange the hydrogen and hydroxyl ions for the ions they need.

Organic Matter

Soil Structure:

- Promotes good soil structure which creates soil spaces for air and water by:
- Assisting with good/strong ped formation
- Feeding macro organisms (ie earthworms and beetles etc) the form pores in the soil
- Promotes high levels of beneficial micro organisms to ensure a healthy soil biology to protect plants and assist with nutrient availability

Organic Matter

Directly assisting plants:

- The spaces allow microorganisms to turn the nitrogen in the air into nitrate and ammonium (air is 78% N)
- Soil carbon dioxide contained in these air spaces increases plant growth
- Helps plant and microbial growth through growth stimulating compounds
- Helps root growth, by making it easy for roots to travel through the soil

Composition of Typical Soils

(for a plow layer 6⅔ inches in depth, approximately 2,000,000 pounds)

COMPONENTS	SANDY LOAM (lbs/acre)	SILT LOAM (lbs/acre)	CLAY LOAM (lbs/acre)
Organic matter	20,000	54,000	96,000
Living portion, microbes earthworms, etc.	1,000	3,600	4,000
Nitrogen	1,340	3,618	6,432
Silicon dioxide	1,905,000	1,570,000	1,440,000
Aluminum oxide	22,600	190,000	240,000
Iron oxide	17,000	60,000	80,000
Calcium oxide	5,400	6,800	26,000
Magnesium oxide	4,000	10,400	17,000
Phosphate	400	5,200	10,000
Potash	2,600	35,000	40,000
Sulfur trioxide	600	8,500	6,000
Manganese	2,500	2,000	2,000
Zinc	100	220	320
Copper	120	60	60
Molybdenum	40	40	40
Boron	90	130	130
Chlorine	50	200	200

(Compiled by J.L. Halbeisen & W.R. Franklin.)

Organic Matter

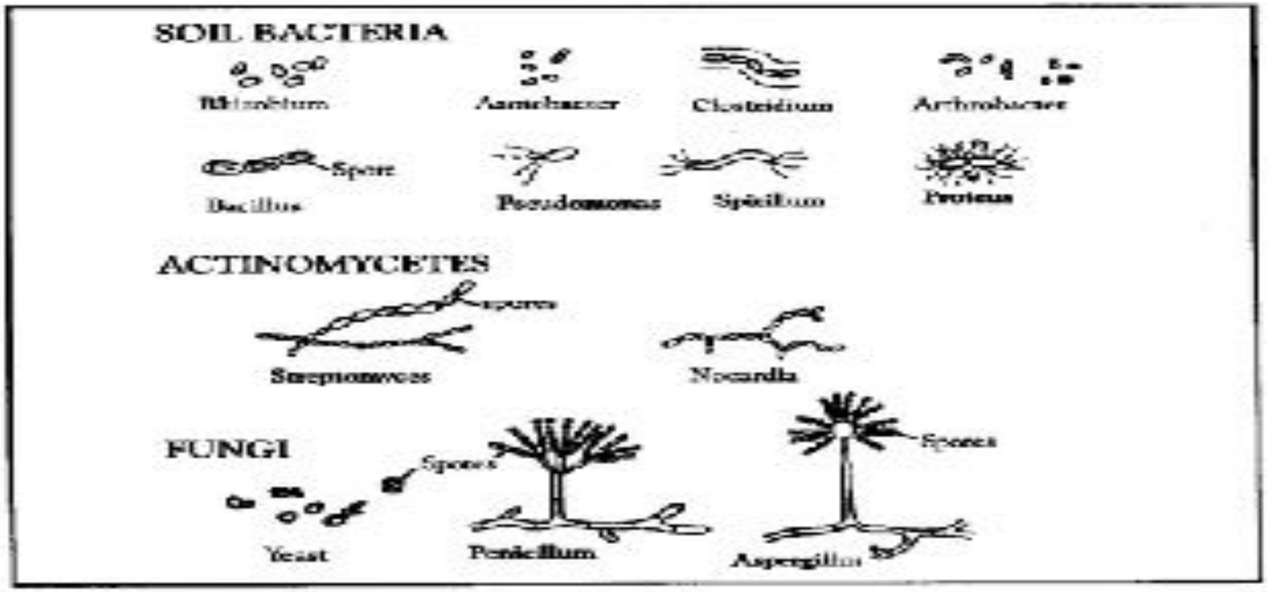
Nutrient availability:

- Organic acids (humic, fulvic, ulmic, acetic, citric etc) help make minerals available by dissolving locked up minerals
- Prevents mineral ions from being locked up
- Encourages a range of microbes that make locked up minerals available to plants.
- Helps to neutralise the pH
- Buffers the soil from strong changes in pH

THE MOLECULES OF LIFE
Feed Soil Biology

ORGANISM	NUMBER PER ACRE	LBS PER ACRE
Bacteria	800,000,000,000,000,000	2,600
Actinomycetes	20,000,000,000,000,000	1,300
Fungi	200,000,000,000,000	2,600
Algae	4,000,000,000	90
Protozoa	2,000,000,000,000	90
Nematodes	80,000,000	45
Earthworms	40,000	445
Arthropods	8,160,000	830

(Adapted from L.M. Thompson & F. Troeh, *Soils & Soil Fertility*, 4th ed., 1978, p. 111.)

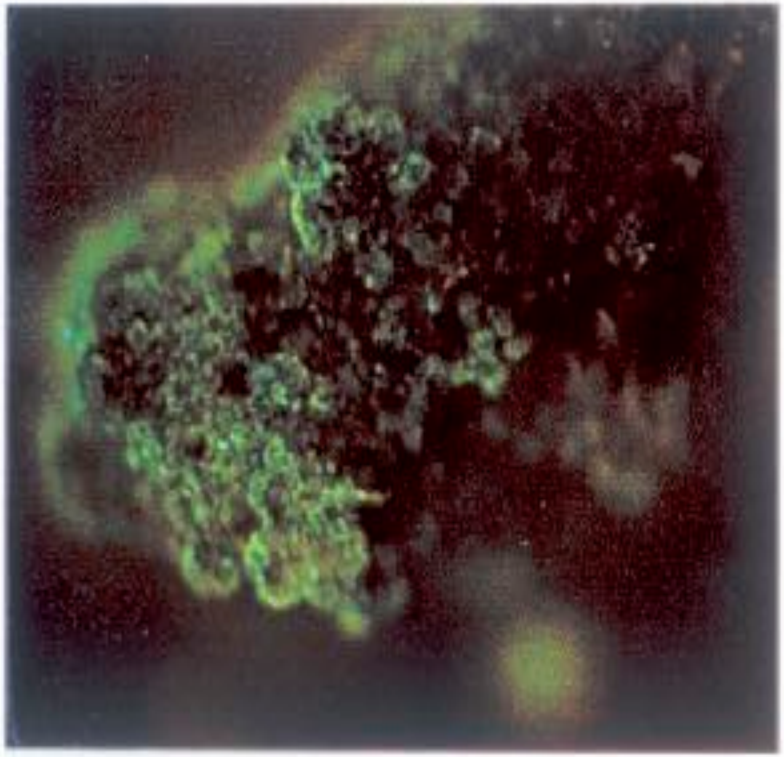


Eco-intensification
Soil Biology

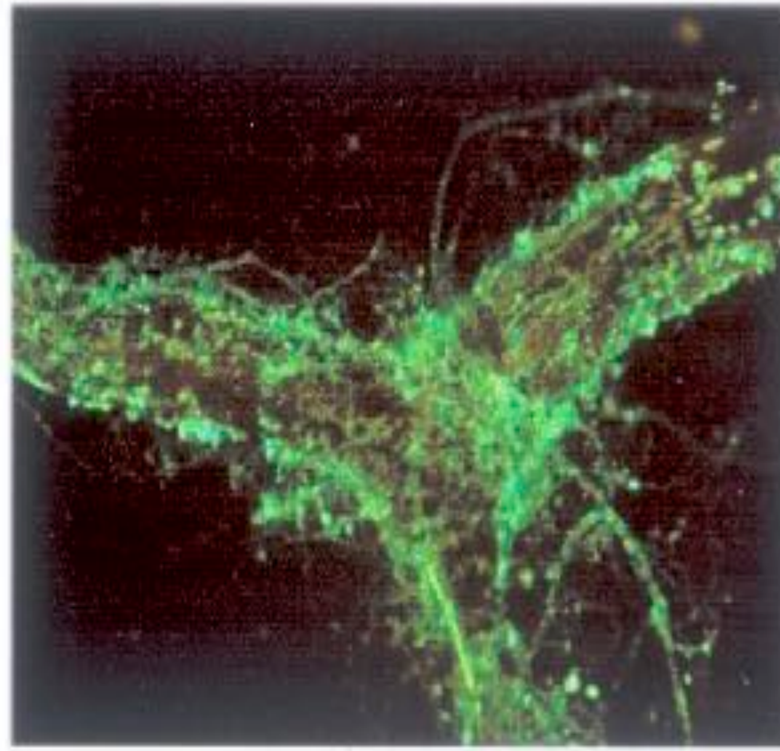
How organisms help plants

- **Make nutrients available**
- **Decompose Organic Matter and release nutrients**
- **Dissolve minerals from rocks**
- **Chelating and complexing nutrients**
- **Free living organisms fixing nitrogen from the soil air into plant available forms – Azobacteria & Cyanobacteria**
- **Protect plants from diseases**
- **Build soil peds (soil aggregates) and good structure**

Soil Aggregation: A Biological Process



Glomalin is the green material on this soil aggregate.



An arbuscular mycorrhizal fungus colonizing a root. Hyphae are the thread-like filaments. The green coating on hyphae is glomalin.

Eco-intensification
Soil Biology

Plant Roots and The Rhizosphere

- The majority of microbes live around plant roots
- This is called ‘The Rhizosphere’
- They feed off root exudates and have important roles in releasing nutrients and protecting plants from diseases
- Roots release enzymes, acids and other compounds that dissolve nutrients from rocks
- Roots build soil structure
- Deep roots build deep soils

MANAGING GROUND COVERS

Rootmass activity stimulates nutrient availability in soil by:

•Root exudates that feed microbe communities

•Root enzymes and acids extract minerals from rocks

•Builds soil structure and deepens soils

•Generates soil carbon and nutrients for the crop through correct management

Managing Groundcovers and Crops

***Soil Comparison between 'Winona' with good root management and nearby property with poor root management** Picture: Christine Jones*

MANAGING GROUND COVERS

Builds Soil Fertility without Synthetic Fertilisers

The following increases in soil mineral fertility have occurred in 10 years at ‘Winona’, with only the addition of a small amount of phosphorus

•calcium 277%, magnesium 138%, potassium 146%, sulphur 157%, phosphorus 151%, zinc 186%, iron 122%, copper 202%, boron 156%, molybdenum 151%, cobalt 179% and selenium 117%.
(Jones 2011, Carbon that Counts)

Organic Matter

Organic matter management and mineral balance

- Plants grown in deficient soils will also suffer deficiencies
- The resulting compost, green manure etc from this organic matter will be deficient
- Some nutrients may need to be added to correct deficiencies

Mineral Balance

The Yield of any Production System is Limited by Mineral/s that are Deficient

- A balanced mineral rich soil is essential to obtain optimum yields
- Conventional Agriculture usually only focuses on 3 elements – NPK
- Plants need around 30 elements
- Just one deficient element will limit yield
- A complete analysis soil test is used to assess the mineral balance of the soil

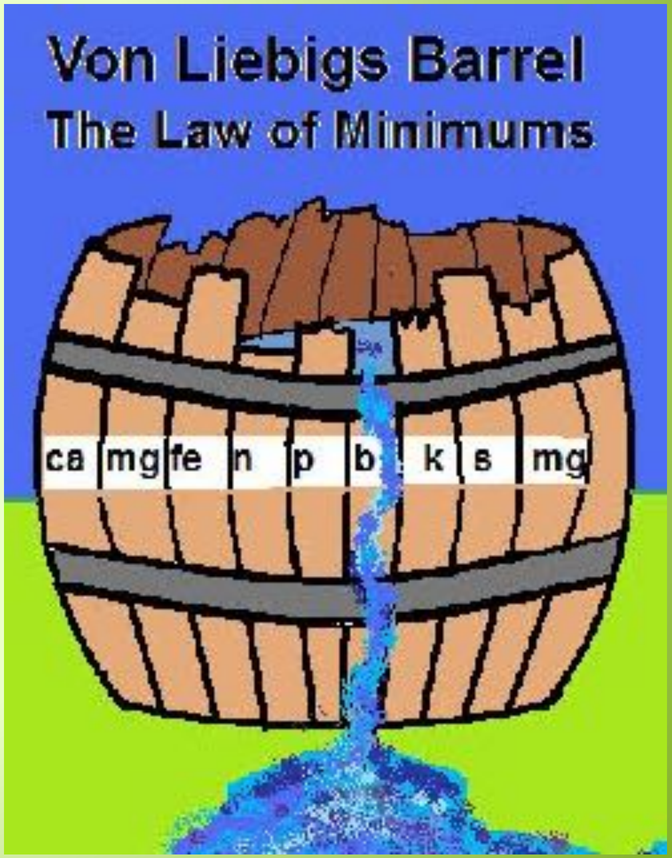
Mineral Balance

The Yield of any Production System is Limited by Mineral/s that are Deficient

- Yield is determined by the mineral/s that are at the least levels i.e. deficient

- Not by the minerals with the greatest levels

- Optimal yield can only be achieved by balance nutrition



Mineral Balance

Soil Test Minimum Nutrient Levels

Macro Nutrients

pH	6.0 - 6.8
Organic matter	3 - 6%
Calcium	1,800 ppm
Phosphorous P1	100 ppm
Phosphorous P2	200 ppm
Nitrogen	60 ppm
Magnesium	300 ppm
Potassium	175 ppm
Sulphur	75 ppm

Mineral Balance

Trace Elements

Zinc	12 ppm
Manganese	20 ppm
Iron	20 ppm
Sodium	20 ppm (Keep below 70ppm)
Copper	5 ppm
Boron	3 ppm
Chlorine	3 ppm
Molybdenum	1 ppm

Mineral Balance

Examples of some critical mineral interactions

Calcium

- High calcium soils have a more friable structure and suppress disease pathogens in soils and plants – makes Potassium available
- Calcium is needed by plants to transport most other minerals around the plant

Boron

- Boron is essential for plants to transport calcium. Calcium is relatively immobile in plant cells
- Low levels of calcium and boron cause multiple sub-nutrient deficiencies

Molybdenum

- Plants need small amounts of Molybdenum as a catalyst in the enzyme that converts nitrate and glucose into amino acids. It increases nitrogen use efficiency

Mineral Balance

The required nutrients are obtained as:

Ground minerals

- Lime, dolomite, gypsum, rock phosphate, basalt and granite dusts

Soluble minerals

- Trace elements and naturally mined potassium sulfate.

Organic sources

- Legumes, animal manure, green manure, organic mulch, compost

Living sources

- Naturally occurring free bacteria for nitrogen, VAM fungi for phosphorus and other nutrient building microbes.

Composting speeds up the process of turning the minerals into plant available forms

Organic Nutrients

Nitrogen

Manure	4-8% dry weight
Compost	1-4% av. 2%
Legumes	20 – 60 kg per hectare
Green manures.	0.5-5% dry weight
Fish emulsion	4-11%
Microorganisms	up 40kg per hectare
Intercropping	20 – 60 kg per hectare

Intercropping

Chilies grown with desmodium and lucerne

Intercropping

Grapes

Intercropping

Maize grown with Desmodium

The desmodium, suppresses weeds, adds nitrogen, conserves the soil, repels pests and provides high protein stock feed

Organic Matter and N

The spaces allow microorganisms to turn the

Free-living bacteria lift soil nitrogen supply

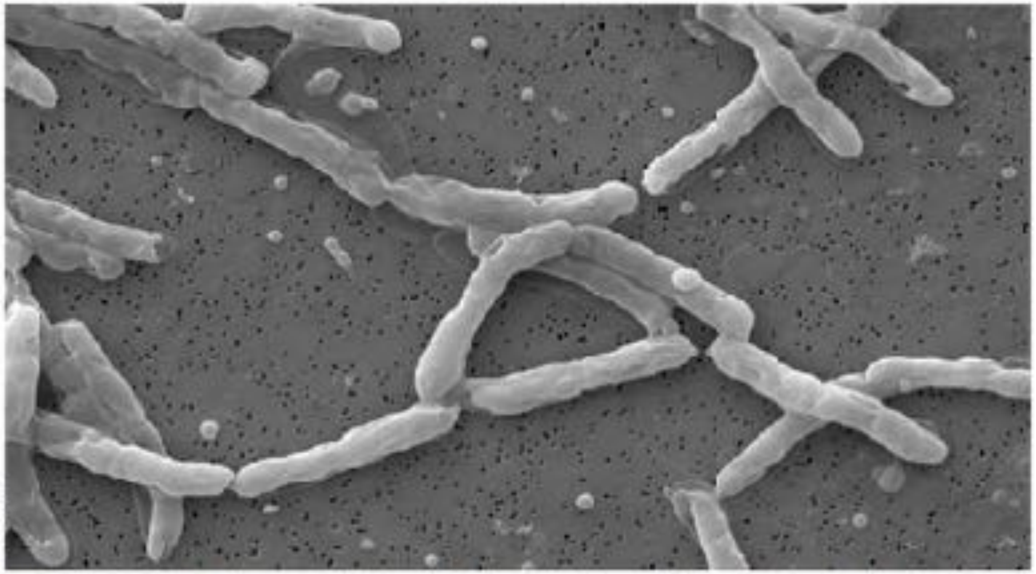
Biological nitrogen fixation is usually associated with symbiotic Rhizobium-legume systems. But as this article shows, there is a wealth of free-living bacteria in soils across Australia that are capable of fixing significant atmospheric nitrogen in the absence of legumes, using crop residues and root exudates as an energy source.

by Gupta Vadakattu,
CSIRO
and Janet Paterson,
KONDININ GROUP

Non-symbiotic nitrogen fixation can contribute significant plant-available nitrogen per hectare per year to intensive farming systems.

For example, in an intensive wheat rotation at Avon, South Australia, non-symbiotic nitrogen fixation contributed 20 kilograms per hectare per year, which met 30–50 per cent of the long-term nitrogen needs of this system.

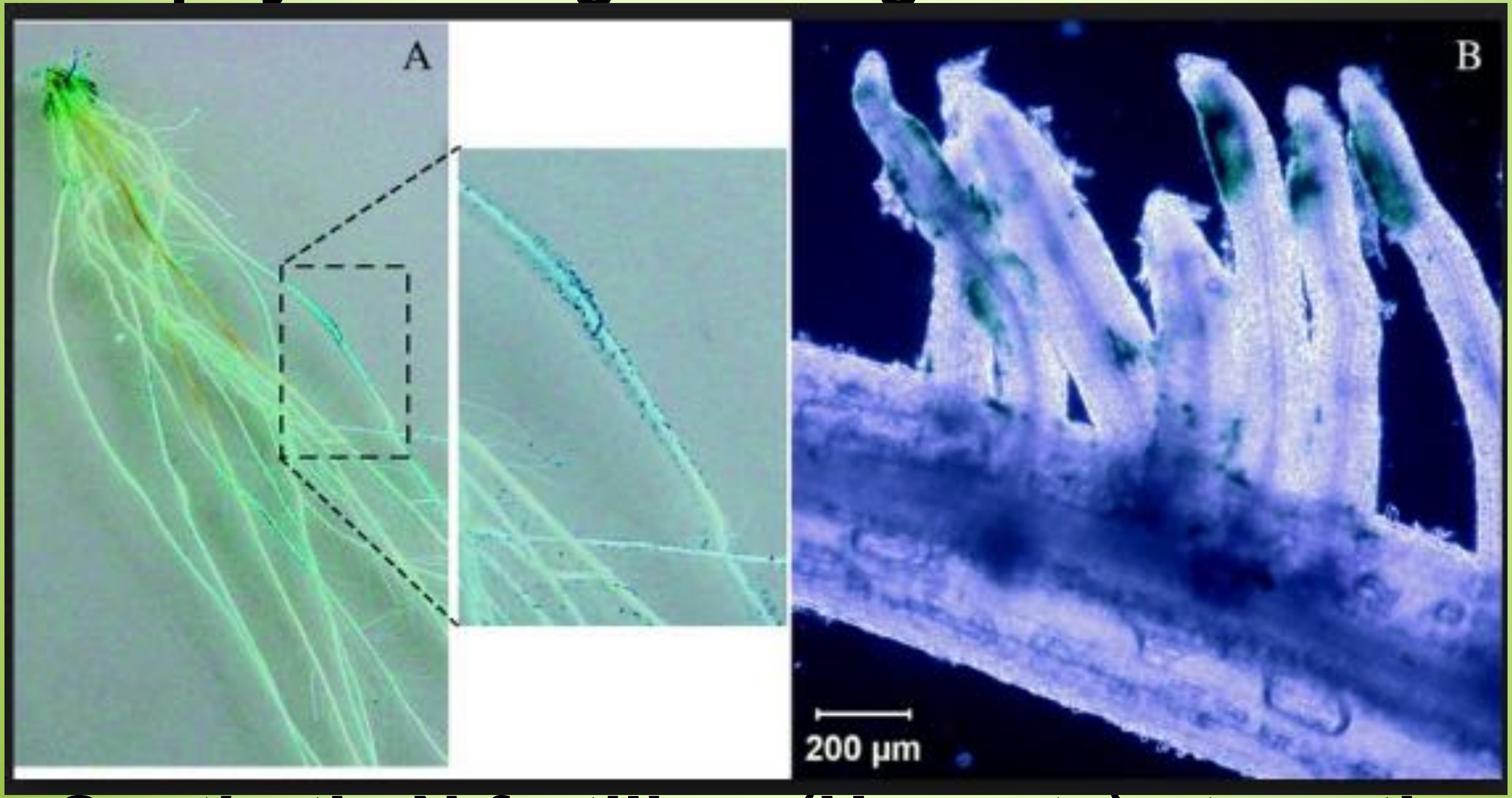
With the potential for non-symbiotic nitrogen fixation to provide a significant amount of farming system nitrogen, a better awareness and understanding of the role of non-symbiotic nitrogen fixation could enable



Biological nitrogen fixation is critical as it provides a source of fixed nitrogen for plant growth that is non-polluting and not dependent on inorganic nitrogen fertilisers produced from fossil fuel use. Pictured is the non-symbiotic nitrogen fixing bacterium Azospirrilum, which is found in cropping soils across Australia.

Organic Matter and N

Endophytic nitrogen fixing bacteria in rice



Synthetic N fertilizer (Urea etc) stops these natural N fixing processes

Organic Nutrients

Nitrogen

- Nitrogen levels increase as Soil Organic Matter (SOM) increases
- SOM Carbon/Nitrogen Ratio = Between 12/1 to 9/1
- Every 1% increase of SOM per 20 cm/Ha holds about 4,000 kgs of N
- Most of this N is in amino acid form
- Numerous scientific studies show that plants directly utilize amino acids and that biologically active soils convert it into nitrate and ammonia
- Building up SOM is the best way to increase soil nitrogen

Organic Matter and Nitrogen

Table of the amount of organic nitrogen held in the soil

1% SOC	2,400 kg of organic N per hectare	1.72% SOM
2% SOC	4,800 kg of organic N per hectare	3.44% SOM
3% SOC	7,200 kg of organic N per hectare	5.16% SOM
4% SOC	9,600 kg of organic N per hectare	6.88% SOM
5% SOC	12,000 kg of organic N per hectare	8.50% SOM

The key to high levels of N is high levels of organic matter

Organic Matter

Synthetic Nitrogen Fertilisers Deplete Carbon

- **Scientists from the University of Illinois analyzed the results of a 50 year agricultural trial and found that synthetic nitrogen fertilizer resulted in all the carbon residues from the crop disappearing as well as an average loss of around 10,000 kg of soil carbon per hectare.**

- **This is around 36,700 kg of carbon dioxide per hectare on top of the many thousands of kilograms of crop residue that is converted into CO_2 every year.**

Organic Matter

Synthetic Nitrogen Fertilizers Deplete Carbon

- **The researchers found that the higher the application of synthetic nitrogen fertilizer the greater the amount of soil carbon lost as CO_2.**
- **This is one of the major reasons why conventional agricultural systems have a decline in soil carbon while organic systems increase soil carbon.**
- **The loss of organic matter makes these farms dependent on synthetic N inputs**

Khan, S. A.; Mulvaney, R. L.; Ellsworth, T. R., and Boast C. W. (2007), The Myth of Nitrogen Fertilization for Soil Carbon Sequestration. Journal of Environmental Quality. 2007 Oct 24; 36(6):1821-1832.

Mulvaney R. L., Khan S. A. and Ellsworth T. R., (2009), Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production, Journal of Environmental Quality 38:2295-2314 (2009): 10.2134/jeq2008.0527, American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America 677 S. Segoe Rd., Madison, WI 53711 USA

Nutrients Sources

Phosphorous

Manure	up to 2% dry weight
Compost	up to 1%
Rock phosphate	24-30%
Bone meal	21-30%
Fish emulsion	1%
VAM fungi	Total

Nutrients Sources

Potassium	
Potassium Sulphate	50%
Basalt dust	4%
Granite dust	3.6-6%
Kelp	4-15%
Wood ashes	7%
Manures	0.3-2% dry weight
Compost	1%
Sawdust	1%
Fish emulsion	**1%**

Nutrients Sources

Magnesium

Dolomite	20%
Granite dust	6%

Sulphur

Elemental Sulphur	100%
Potassium Sulphate	18%
Gypsum	17%
Manures	0.1 – 0.2%

Nutrients Sources

Calcium

Calcium Carbonate (lime)	30-40%
Gypsum	22%
Dolomite	22%
Rock Phosphate	16-30%

Nutrients Sources

Trace Elements

Rock Dusts – basalt, granite, rock phosphate, gypsum, lime and dolomite contain a wide range of trace elements.

Compost

Soluble forms are allowed to correct a recognized deficiency, i.e. zinc sulphate, sodium borate, copper sulphate, iron sulphate etc.

Manures

Seaweed

Fish emulsion

Nutrition for Crops

Amount of nutrient needed

([recommendation] - [soil test level] **)** x 2 =

[amount of nutrient you need apply] kg/ha

2 is a conversion factor based on 150 mm of soil depth

Get soil test in ppm (parts per million) = mg/kg

Nutrition for Crops

Amount of Nutrient to apply

Units of the nutrient ÷ % concentration of nutrient in fertilizer

= amount of fertilizer to be applied per hectare

Nutrition for Crops

<u>Example:</u> Calcium

Soil test indicates 1000 ppm

Recommendation is 1800 ppm

(1800 - 1000) x 2 = 1600 units of Ca needs to be applied

Gypsum contains 22% Ca

1600 Ca ÷ 0.22 = 7,270 kg/ha = 7.3 t/ha Gypsum to be applied

Lime contains 33% Ca

1600 Ca ÷ 0.33 = 4,850 kg/ha = 4.85 t/ha Lime to be applied

Thank You