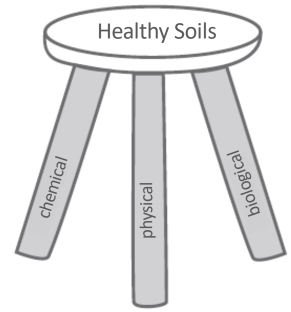
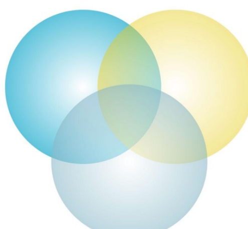


Physics

Texture & Structure
Bulk Density
Aggregation
Porosity
Water Infiltration
Plant available water
Compaction
Surface Sealing



Chemistry

pH & EC
Nutrient availability
Nutrient storage
CEC
Salts

Biology

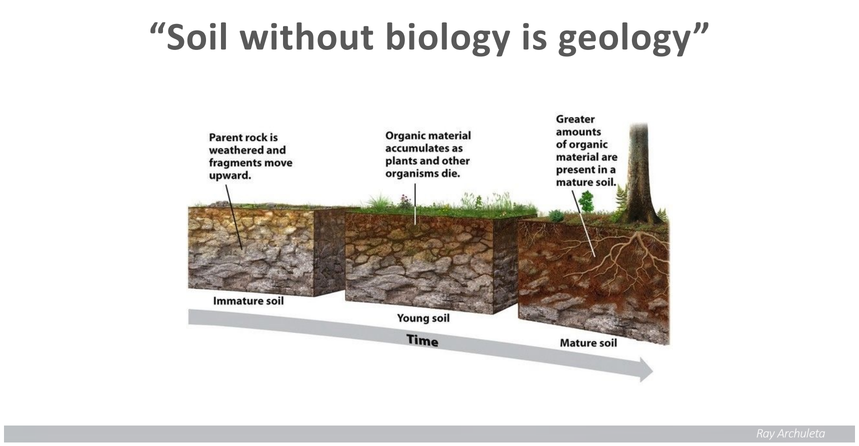
Soil organic matter
Active carbon
Microorganisms
Microbial activity
Micro & Macrofauna
Soil protein
Enzymatic activity

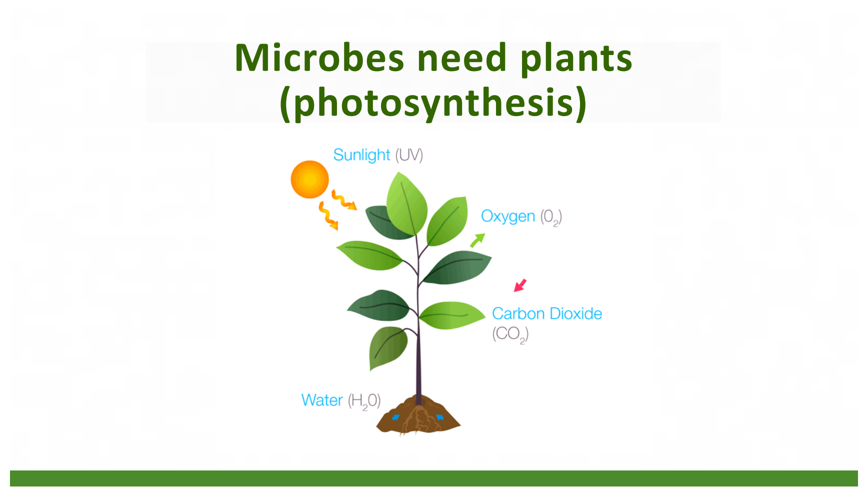
Soil Health

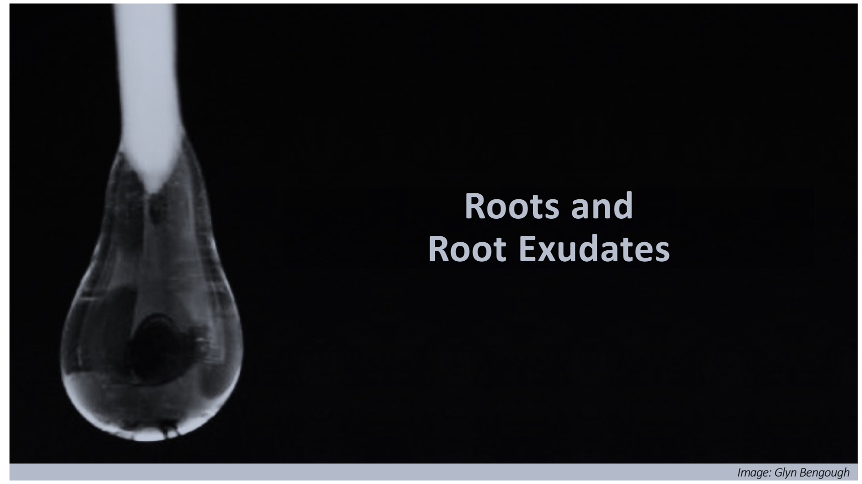
"The capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans"

USDA NRCS


"Feed your soil and
it will feed you"


"Soil without biology is geology"
Parent rock is weathered and fragments move upward.
Organic material accumulates as plants and other organisms die.
Greater amounts of organic material are present in a mature soil.
Immature soil
Young soil
Time
Mature soil
Ray Archuleta


Microbes need plants
(photosynthesis)
Sunlight (UV)
Oxygen (O_2)
Carbon Dioxide
(CO_2)
Water (H_2O)

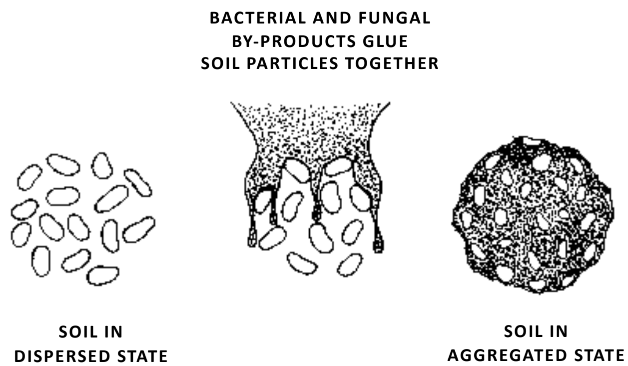


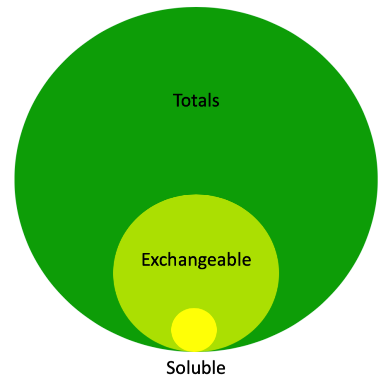
A cocktail of root exudates…

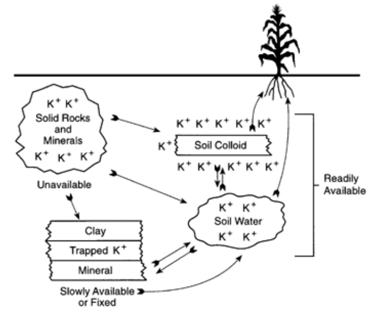
Table 1. Classes of compounds released in plant root exudates

Class of compounds	Single components[a]
Carbohydrates	Arabinose, glucose, galactose, fructose, sucrose, pentose, rhamnose, raffinose, ribose, xylose and mannitol
Amino acids	All 20 proteinogenic amino acids, L-hydroxyproline, homoserine, mugineic acid, aminobutyric acid
Organic acids	Acetic acid, succinic acid, L-aspartic acid, malic acid, L-glutamic acid, salicylic acid, shikimic acid, isocitric acid, chorismic acid, sinapic acid, caffeic acid, *p*-hydroxybenzoic acid, gallic acid, tartaric acid, ferulic acid, protocatacheuic acid, *p*-coumaric acid, mugineic acid, oxalic acid, citric acid, piscidic acid
Flavonols	Naringenin, kaempferol, quercitin, myricetin, naringin, rutin, genistein, strigolactone and their substitutes with sugars
Lignins	Catechol, benzoic acid, nicotinic acid, phloroglucinol, cinnamic acid, gallic acid, ferulic acid, syringic acid, sinapoyl aldehyde, chlorogenic acid, coumaric acid, vanillin, sinapyl alcohol, quinic acid, pyroglutamic acid
Coumarins	Umbelliferone
Aurones	Benzyl aurones synapates, sinapoyl choline
Glucosinolates	Cyclobrassinone, desuphoguconapin, desulphoprogoitrin, desulphonapoleiferin, desulphoglucoalyssin
Anthocyanins	Cyanidin, delphinidin, pelargonidin and their substitutes with sugar molecules
Indole compounds	Indole-3-acetic acid, brassitin, sinalexin, brassilexin, methyl indole carboxylate, camalexin glucoside
Fatty acids	Linoleic acid, oleic acid, palmitic acid, stearic acid
Sterols	Campestrol, sitosterol, stigmasterol
Allomones	Jugulone, sorgoleone, 5,7,4′-trihydroxy-3′, 5′-dimethoxyflavone, DIMBOA, DIBOA
Proteins and enzymes	PR proteins, lectins, proteases, acid phosphatases, peroxidases, hydrolases, lipase

* Badri & Vivanco (2009). doi: 10.1111/j.1365-3040.2009.01926.x



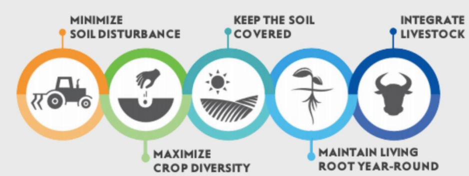


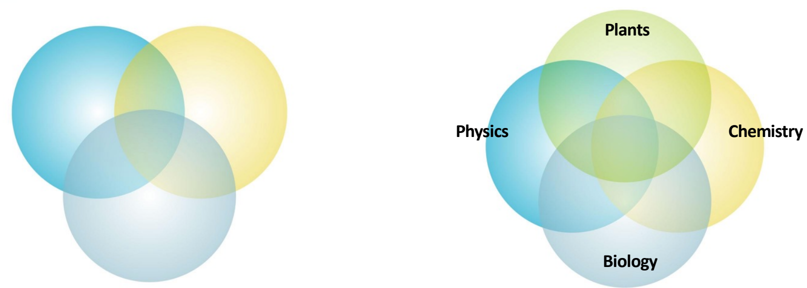


How can we optimise soil health?

** Image: Mike Nestor*

Soil Health Principles





"Modern Agriculture grows plants from soil. Regenerative Agriculture grows soil from plants"

Steve Kenyon

Photosynthesis

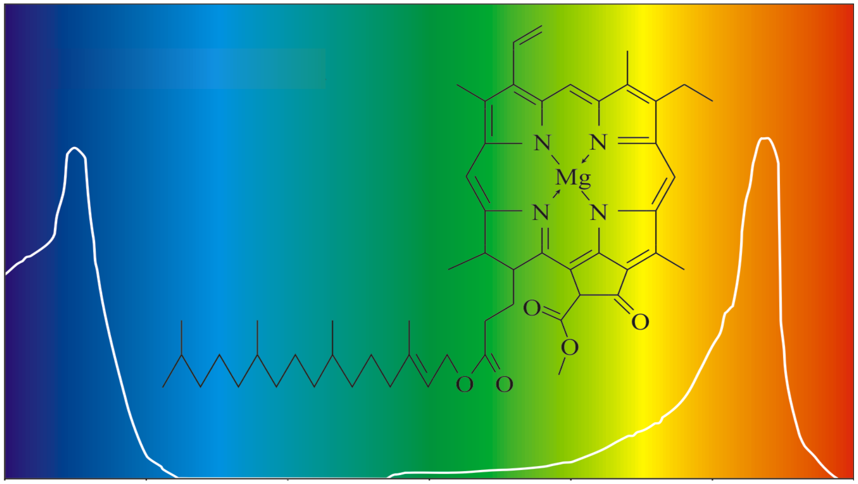
$6CO_2 + 6H_2O$ ----------------> $C_6H_{12}O_6$ (sugar) + $6O_2$

nutrients/enzymes

$C_6H_{12}O_6$ (sugar) ------------------>

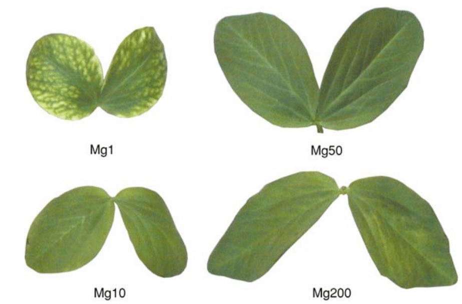
nutrients/enzymes

- ***Complex sugars***
- ***Carbohydrates***
- ***Amino Acids, Proteins***
- ***Fats, Oils, Lipids, Waxes***
- ***Hormones, Vitamins***
- ***Aromatic/volatile compounds***
- ***Defense Chemicals***
- ***Protective Compounds***
- ***Root Exudates***



Magnesium

- Central to chlorophyll (15-20%).
- Majority of Mg in the plant is used to catalyze protein synthesis (75%).



* Karley & White (2009). Moving cationic minerals to edible tissues: potassium, magnesium, calcium, Current Opinion in Plant Biology, Volume 12, Issue 3, pp. 291-298

Iron

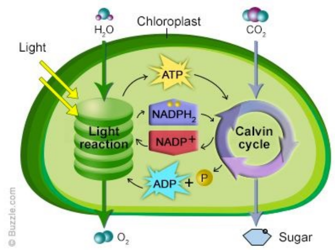
- Chlorophyll synthesis
- Nitrite reductase enzyme
- Fe (& Mo) is key for N_2 fixation – nitrogenase enzyme.

Manganese

- Splits water for photosynthesis (along with calcium).
- Important for seed health and germination.
- Key **disease fighting** nutrient.

Phosphorus

- ATP – energy for all growth processes (along with N).
- Accelerates tissue **maturity** (against soft tissue loving pathogens).
- Root development – crop establishment.

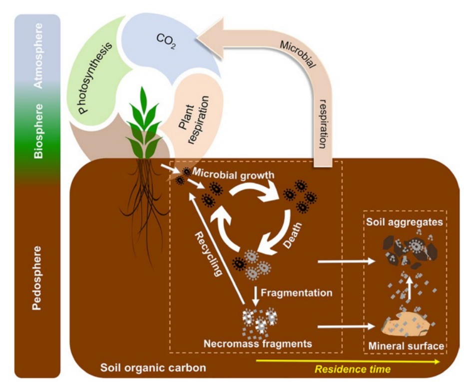


Nitrogen

- Critical for structural components (DNA, chlorophyll) and proteins.
- Too much N without supporting minerals leads to unbalanced crop.

Key Functions of Essential Nutrients

- *N – Chlorophyll, AA, P*
- *P – Energy, root development*
- *K – Enzyme production, sugar movement, N utilisation*
- *Ca – Cell wall strength*
- *Mg – Chlorophyll*
- *S – N utilisation, root development*
- *Si – cell wall strength*
- *B – sugar translocation, reproductive processes*
- *Cu – disease protection*
- *Zn – auxin production, leaf size*
- *Mn – reproductive processes*
- *Fe – chlorophyll production*
- *Mo – N utilisation*
- *Co – N fixation*
- *Ni – urease enzyme*

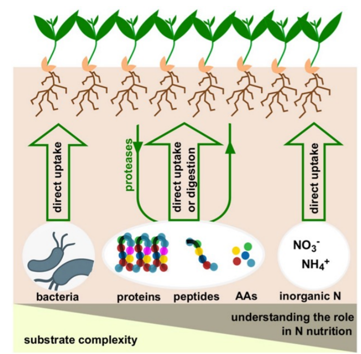


* Liang *et al* (2019). doi.org/10.1111/gcb.14781

Thank you, Questions?

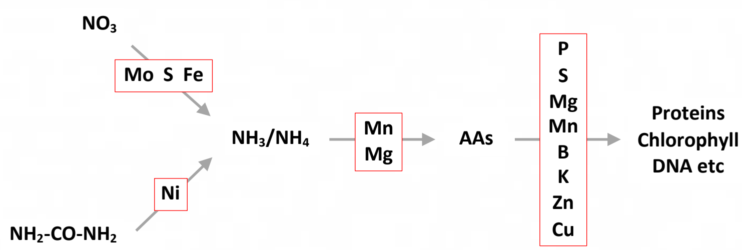
Mailing List, Resources, More info:

www.**integratedsoils**.com
@integratedsoils



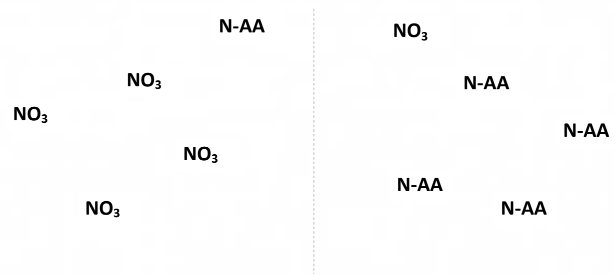
* Adamczyk (2021). doi.org/10.1007/s11104-021-05022-8

N Metabolism

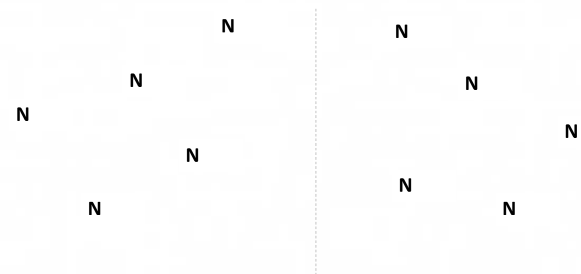


Mineral		Current level	
Total Sugars	%	0,8	1
	%	0,2	2
pH		5,8	1
		5,5	2
EC	mS/cm	12,2	1
	mS/cm	17,7	2
K - Potassium	ppm	3997	1
	ppm	4461	2
Ca - Calcium	ppm	551	1
	ppm	1773	2
K / Ca		7,25	1
		2,52	2
Mg - Magnesium	ppm	380	1
	ppm	553	2
Na - Sodium	ppm	22	1
	ppm	35	2
NH4 - Ammonium	ppm	54	1
	ppm	68	2
NO3 - Nitrate	ppm	3138	1
	ppm	8032	2
N in Nitrate	ppm	708	1
	ppm	1813	2
N - Total Nitrogen	ppm	1458	1
	ppm	2323	2
Cl - Chloride	ppm	417	1
	ppm	178	2
S - Sulfur	ppm	628	1
	ppm	1187	2
P - Phosphorus	ppm	591	1
	ppm	626	2
Si - Silica	ppm	7,2	1
	ppm	13,6	2
Fe - Iron	ppm	0,80	1
	ppm	0,45	2
Mn - Manganese	ppm	4,03	1
	ppm	7,86	2
Zn - Zinc	ppm	1,79	1
	ppm	0,88	2
B - Boron	ppm	0,72	1
	ppm	1,85	2
Cu - Copper	ppm	1,84	1
	ppm	3,20	2
Mo - Molybdenum	ppm	0,06	1
	ppm	0,05	2
Al - Aluminium	ppm	<0,50	1
	ppm	<0,50	2

Measuring Total N



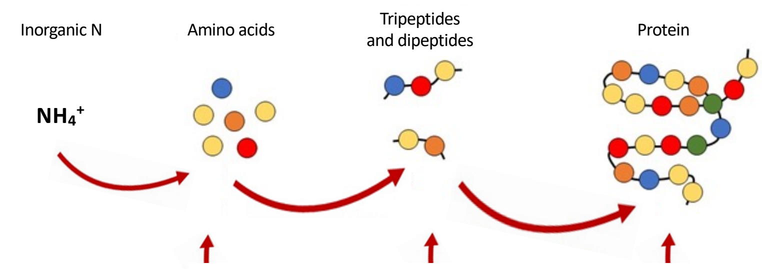
Measuring Total N



Defining NUE

- **Nitrogen uptake efficiency (NUpE)** is defined as the total N in plants relative to the applied N fertilizer.
- **Nitrogen utilisation efficiency (NUtE)** is defined as plant biomass or seed yield relative to total N in the plant, reflecting the capacity of plants to convert acquired N to plant biomass or seed yield.

Metabolic Shortcutting



Plant, Cell & Environment

The carbon bonus of organic nitrogen enhances nitrogen use efficiency of plants

The importance of organic nitrogen (N) for plant nutrition and productivity is increasingly being recognized. Here we show that it is not only the availability in the soil that matters, but also the effects on plant growth. The chemical form of N taken up, whether inorganic (such as nitrate) or organic (such as amino acids), may significantly influence plant shoot and root growth, and nitrogen use efficiency (NUE). We analysed these effects by synthesizing results from multiple laboratory experiments on small seedlings (Arabidopsis, poplar, pine and spruce) based on a tractable plant growth model. A key point is that the carbon cost of assimilating organic N into proteins is lower than that of inorganic N, mainly because of its carbon content. This carbon bonus makes it more beneficial for plants to take up organic than inorganic N, even when its availability to the roots is much lower – up to 70% lower for Arabidopsis seedlings. At equal growth rate, root:shoot ratio was up to three times higher and nitrogen productivity up to 20% higher for organic than inorganic N, which both are factors that may contribute to higher NUE in crop production.

* Franklin *et al* (2016). doi.org/10.1111/pce.12772

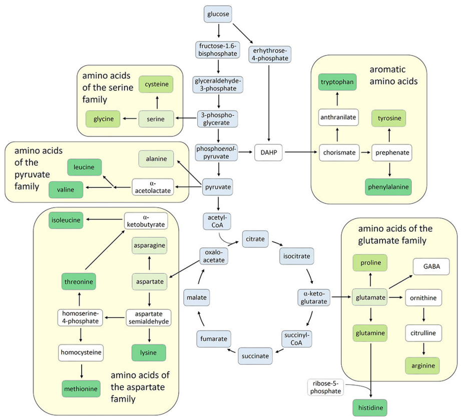
Plant, Cell & Environment

Table 2. Biochemically calculated assimilation costs for different N sources in gC gN^{-1} according to Zerihun *et al*. (1998)

N source	Gross C costs	C bonus[a]	Net N assimilation C cost
NO_3	5.81	0	5.81
NH_4	4.32	0	4.32
Gln	4.30	2.14	2.16
Arg	4.30[b]	1.29	3.02[b]

[a] C bonus is equal to the molecular gC per gN.
[b] Calculated assuming gross C costs (without C bonus) for N assimilation are equal to Gln.

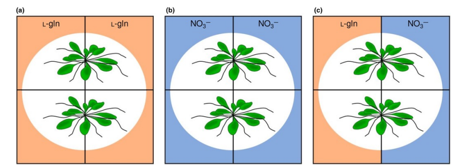
* Franklin *et al* (2016). doi.org/10.1111/pce.12772



* Trovato *et al* (2021). doi.org/10.3389/fpls.2021.772810

New Phytologist

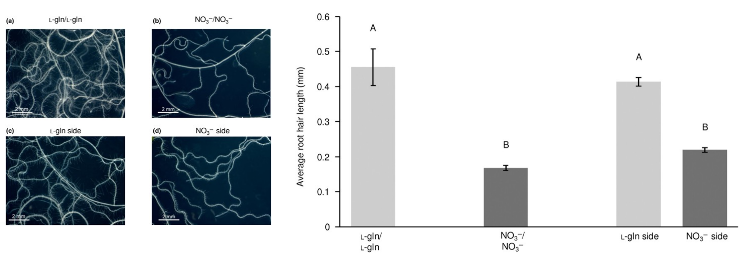
Plant organic nitrogen nutrition: costs, benefits, and carbon use efficiency



* Tünnermann *et al* (2024). doi.org/10.1111/nph.20285

New Phytologist

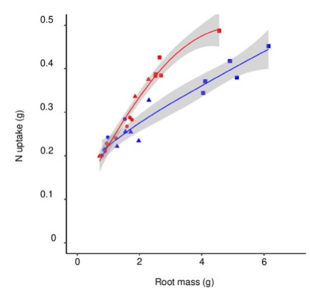
Plant organic nitrogen nutrition: costs, benefits, and carbon use efficiency



* Tünnermann *et al* (2024). doi.org/10.1111/nph.20285

New Phytologist

Plant organic nitrogen nutrition: costs, benefits, and carbon use efficiency

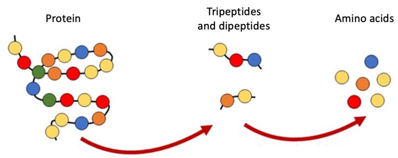


Treatment	Organ	N concentration (% DW)	C concentration (% DW)	No. of replicates
NO_3^-/NO_3^-	Shoot	6.37 (0.09) A	35.01 (0.74) A	5
	Root	4.54 (0.05) a	38.14 (0.21) a	5
L-gln/L-gln	Shoot	6.62 (0.13) A	39.23 (0.33) B	5
	Root	3.14 (0.11) b	40.24 (0.21) b	5
L-gln/NO_3^-	Shoot	6.54 (0.07) A	35.61 (0.49) A	10
	Root L-gln side	3.24 (0.10) b	39.99 (0.36) b	10
	Root NO_3^- side	4.15 (0.24) a	39.92 (0.31) b	10

" The estimated N assimilation costs were 2.63 ± 0.10 g C g^{-1} N for L-gln and 4.56 ± 0.25 g C g^{-1} N for NO_3^- "

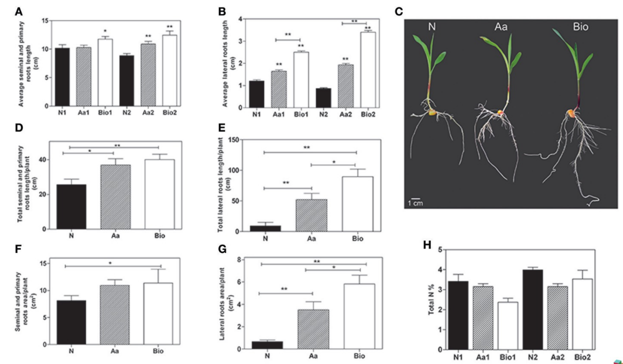
* Tünnermann *et al* (2024). doi.org/10.1111/nph.20285

Protein hydrolysates are mixtures of free amino acids and polypeptides resulting from chemical and enzymatic hydrolysis of agro-industrial protein by-products derived from plant or animal origins.



* El-Sanatawy *et al* (2021). doi.org/10.3390/agronomy11101913

Growth Stimulatory Effects and Genome-Wide Transcriptional Changes Produced by Protein Hydrolysates in Maize Seedlings

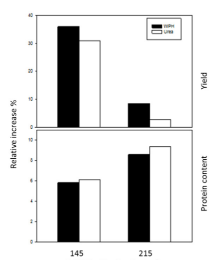


* Santi *et al* (2017). doi.org/10.3389/fpls.2017.00433
frontiers in Plant Science

agronomy

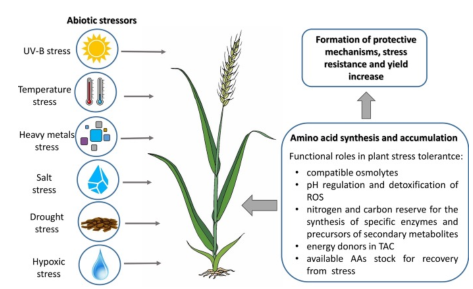
Enhancing Grain Yield and Nitrogen Accumulation in Wheat Plants Grown under a Mediterranean Arid Environment by Foliar Spray with Papain-Released Whey Peptides

Abstract: Due to their beneficial, stimulating impact on plant growth, productivity, and alleviating environmental stresses, protein hydrolysates have recently received increasing attention as a possible substitute. This investigation aimed to explore the effects of foliar application of papain-produced whey protein hydrolysates (WPH) on the yield attributes and nitrogen use efficiency (NUE) of soft wheat. Wheat plants were cultivated under a Mediterranean arid environment and received four soil nitrogen (N) fertilization levels with ammonium nitrate (145, 185, 215, and 250 kg N ha^{-1}) and compared to control treatment and urea foliar application. WPH increased grain yield, yield attributes, and N accumulation in wheat plants. Partial productivity factors of applied nitrogen, as NUE indicators under relatively steady-state cropping systems, were also enhanced by WPH compared to control treatment. WPH significantly improved flag leaf area, spike number m^{-2}, and grain yield compared to urea foliar application. Increasing the soil N fertilization level from 145 up to 215 kg N ha^{-1} was accompanied by significant increases in all yield traits and N accumulation measurements, except for the partial factor productivity of applied N, which decreased. A strong positive association was detected among grain and straw yields, their attributes, and total N uptake. Results highlighted the efficacy of WPH in increasing wheat yield and NUE.



* El-Sanatawy *et al* (2021). doi.org/10.3390/agronomy11101913

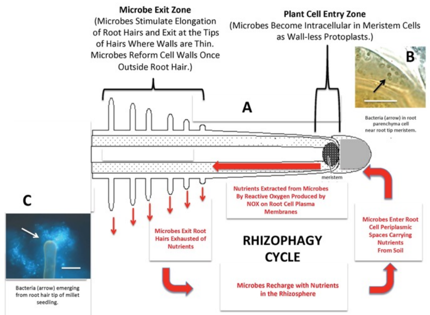
Amino acids in regulation of abiotic stress tolerance in cereal crops: a review



"Metabolic regulation involving AAs is considered the primary strategy for plant protection and survival under adverse living conditions"

* Romanenko *et al* (2024.) doi.org/10.1007/s42976-023-00418-x

Rhizophagy Cycle: An Oxidative Process in Plants for Nutrient Extraction from Symbiotic Microbes



microorganisms

* White *et al* (2018). doi.org/10.3390/microorganisms6030095

Journal of
Applied Microbiology

Endophyte roles in nutrient acquisition, root system architecture development and oxidative stress tolerance

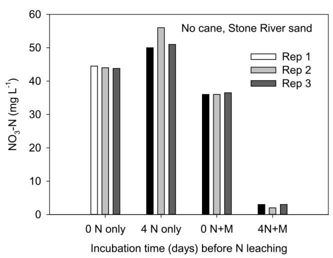
“*Endophytes have been reported to assist plants by transformation and solubilization of nutrients including **nitrogen**, **phosphorous**, **potassium** and other **micro minerals** and make them easily available to plants (Soares et al. 2016; Irizarry and White 2017; White et al. 2019a).*

***Potassium** is likely amongst the first of the nutrients that leak from bacterial cytoplasm through the damaged microbial membranes to the root cell plasma membrane where it may be absorbed into root cell cytoplasm (Demidchik et al. 2014).*

*The loss of cell walls by the microbes may also provide plants with nitrogen in the form of **peptides** present in the bacterial cell walls (White et al. 2018a).*”

* Verma *et al* (2021). doi.org/10.1111/jam.15111

HARNESSING MICROBIAL ‘SLOW-RELEASE’ TO IMPROVE FERTILISER PROFITABILITY AND SUSTAINABILITY



Adding molasses to the nitrate-charging solution at the same concentration as the liquid fertiliser formulation (10% by volume) stimulated microbes in the soil column to immobilise 18% of the nitrate within 2 hours, and 95% of the nitrate by the fourth day of incubation (Figure 1).

“*Nutrient immobilisation occurs when the application of readily available organic matter to soil stimulates the growth of soil microbes, enabling them to take up luxury amounts of nitrogen (N) and phosphorus (P).*

Immobilised N and P stored within microbial cells is released (mineralised) in the plant-available, inorganic form at a later date (organic slow-release)

Our results suggest the molasses-amended liquid formulation can be considered an enhanced efficiency fertiliser, harnessing the N- and P-immobilising capacity of soil microbes [...] with microbial sequestration ensuring proportionally more fertiliser remains in the soil after 17 weeks.”

* https://www.researchgate.net/publication/324706771_Harnessing_microbial_%27slow-release%27_to_improve_fertiliser_profitability_and_sustainability

Carbon Sources

• Molasses & Sugars	5 L/ha
• Humic Acid	Label rates, 3-5 L/ha
• Fulvic Acids	Label rates, 1-2 L/ha
• Amino acids	Label rates, 0.5-1 L/ha
• Protein Hydrolysates	2-5 L/ha
• Seaweed/Kelp Extracts	2-5 L/ha
• Plant Extracts	10+ L/ha
• Compost Extracts	10+ L/ha

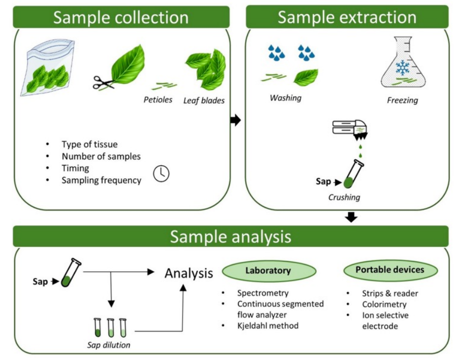
Sap vs Tissue – Sample Type

Sap Testing:

- Sap testing involves extracting the liquid (sap) from plant tissues, typically by pressing or crushing plant parts like leaves or petioles, to obtain a sample for analysis.

Tissue Testing:

- Tissue testing involves collecting plant tissue samples, such as leaves, stems, or roots, which are then dried, ground, and analyzed for nutrient content.



* Esteves *et al* (2021). doi.org/10.3390/HORTICULTURAE7110426

Sap vs Tissue – Analysis Method

Sap Testing:

- The sap is analyzed for nutrient levels, pH, electrical conductivity (EC), and other parameters using specialized equipment or test kits.

Tissue Testing:

- The plant tissue samples are digested and analyzed using various laboratory techniques to determine nutrient concentrations.

Sap vs Tissue – Time

Sap Testing:

- Sap testing provides **real-time** or near real-time information about the nutrient status of the plant at a specific point in time.

Tissue Testing:

- Provides a **cumulative** view of the plant's nutrient status over a period of **time**, as nutrients accumulate in plant tissues as they grow.

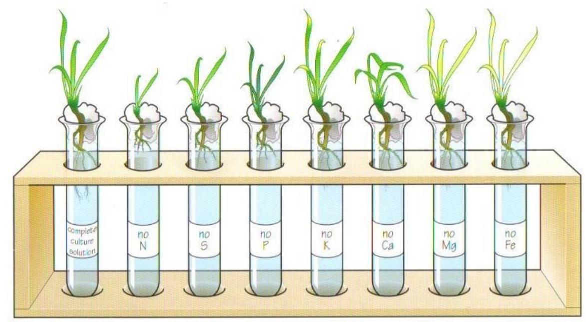
Sap vs Tissue – Advantages

Sap Testing:

- Provides immediate feedback on plant nutrient levels.
- Predicts deficiency before it occurs depending on the nutrient status of the plant.
- Can be useful for monitoring nutrient status during different growth stages.
- Better to assess N balance

Tissue Testing:

- Provides a comprehensive and historical assessment of nutrient levels in the plant.
- Allows for comparisons across different growth stages and plant parts.
- Reliable and widely accepted method for nutrient analysis.



Sap vs Tissue – Limitations

Sap Testing:

- Results can vary depending on the time of day, plant hydration levels, and environmental conditions.

Tissue Testing:

- Time-consuming and requires careful sample collection, preparation, and analysis in a laboratory.
- Does not provide real-time information, making it less suitable for immediate adjustments in nutrient management.

Sap vs Tissue – When to use?

Sap Testing:

- Immediate nutrient status information needed.
- Real-time adjustments in nutrient management are required.
- Monitoring nutrient fluctuations during specific growth stages is necessary.

Tissue Testing:

- Comprehensive nutrient analysis is required.
- Long-term nutrient status assessment is needed.
- Comparison of nutrient levels across different plant parts of growth stages is necessary.

Thank you, Questions?

Mailing List, Resources, More info:

www.**integratedsoils**.com
@**integratedsoils**

Foliar Feeding & Biostimulants

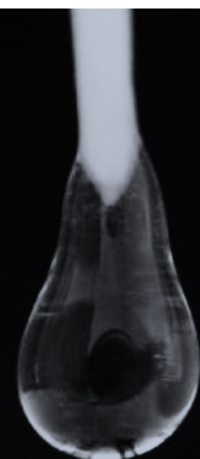
Denmark: 06 Feb 2026

www.**integratedsoils**.com
@**integratedsoils**

Why Foliar Feed?

- Foliar fertilisation strategies can achieve:
  - Higher nutrient use efficiency (& economics)
  - Improve yield, quality and metabolism of crops
  - Reduce the negative impact on the environment
  - Potentially enhance consumer/livestock health benefits

* Niu *et al* (2021). doi.org/10.1007/s42729-020-00346-3



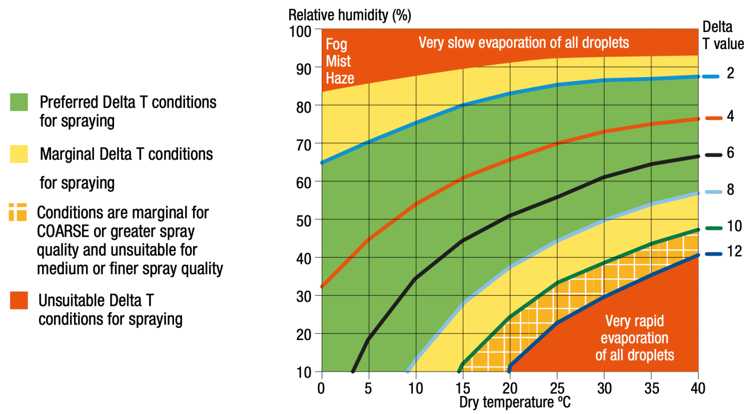
Foliars Enhance Soil Uptake?

- Foliar NH_4^+ increased soil N uptake (cotton)
- Foliar K promoted soil K uptake (potato)
- Foliar urea enhanced soil N and P uptake (potato)
- Mechanism?
  - Foliar nutrients can be translocated to roots and increase root biomass and hence soil uptake.
  - Enhanced root exudation.

* Niu *et al* (2021). doi.org/10.1007/s42729-020-00346-3

Plant response depends on…

- ***Formulation***
- ***Application***
- ***Crop***
- ***Environment***



* https://grdc.com.au/__data/assets/pdf_file/0023/142583/grdc_fs_spray-practical-tips_low-res-pdf.pdf.pdf

Broad Definitions

- ***Biofertilisers***
  - Microbial inoculant to increase biological fertility
  - Modify chemical fertility/nutrient availability
- ***Biopesticides***
  - Direct pesticidal properties
  - Indirect enhancement of plant immunity against pests
- ***Biostimulants***
  - Stimulation via non-nutritional or pesticidal means

Biostimulants

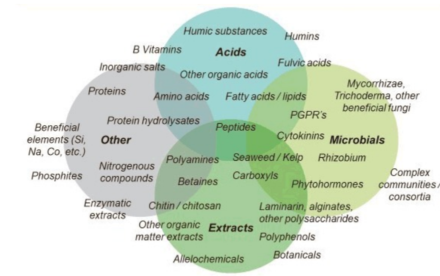
- ***Humic Substances*** – HAs & FAs
- ***Amino Acids & Protein Hydrolysates*** – animal or plant based
- ***Macro & Micro Algae*** – seaweed extracts
- ***Botanicals/Plant Extracts*** – water/alcohol extracts, essential oils, triacontanol
- ***Microbial Inoculants*** – PGPR, AMF, composts/extracts etc
- ***Inorganic compounds*** – Si, Se, Co, Na
- ***Biopolymers*** – polysaccharides, chitosan

- Hormones
- Enzymes
- Biochar

Multiple compounds

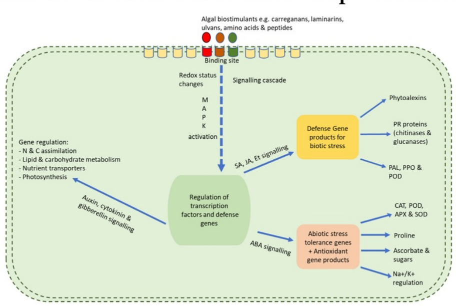
↓

Multiple MoAs



plants

Biostimulant Properties of Seaweed Extracts in Plants: Implications towards Sustainable Crop Production



* Ali *et al* (2021). doi.org/10.3390/plants10030531

In Summary

- Biostimulants – still an emerging technology
- Many complexities in studying such diverse compounds and MoA's
- Molecular studies will help improve field application inconsistencies
- Humics and seaweeds are the most widely studied so far
- Multiple benefits are evident but particularly:
  - Abiotic stress (drought, salinity etc)
  - Nutrient use efficiencies (nutrient access, chelation, uptake)
  - Root and shoot growth
  - Microbial activity

Joel Williams

Integrated Soils

Questions, Discussion?

Resources, more info, mailing list etc:

www.**integratedsoils**.com

@integratedsoils

DIY Protein Hydrolysate

- Add 1 cup of rice to 1 litre of water
- Leave for 3 days with 'loose' fitting lid until water smells 'sour'

- Macerate protein source material (animal or vegetable or mixed)
- Add water to protein with a ratio of 1:1
- Add 20% of total protein bulk as carbohydrate
- Add LACTO inoculant as 7% of total bulk
- Seal with tight fitting lid and fermentation airlock
- Leave for four weeks
- Dilute at least 100:1 when using as foliar

* https://soillandfood.com.au