Optimising Foliar Inputs

Joel Williams
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 health benefits

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

agriculture

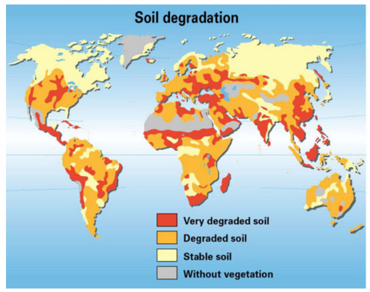
Nutrient	Efficiency (%)
Nitrogen	30–50
Phosphorus	15–20
Potassium	50–60
Sulphur	8–12
Zinc	2–5
Iron	1–2
Copper	1–2
Manganese	1–2
Boron	2–3
Molybdenum	2–5

* Sarkar *et al* (2021). doi.org/10.3390/agriculture11040372

United Nations
Convention to Combat
Desertification

Benefits to Soil?

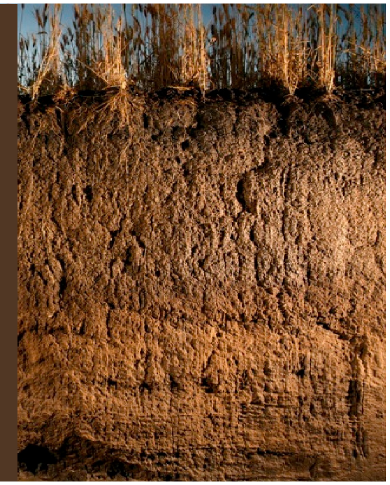
- Worldwide, 20% of cultivated land and 33% of irrigated land is salt-affected and degraded.
- Foliars have been shown to:
  - Reduce soil nitrates
  - Reduce soil salinity
  - Reduce soil acidification



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

Problems with Uptake?

- Soil nutrient supply limited by:
  - Abiotic stresses: temperature, soil moisture, salinity, pH extremes.
  - Biotic stresses: pest and disease, soil biological activity.



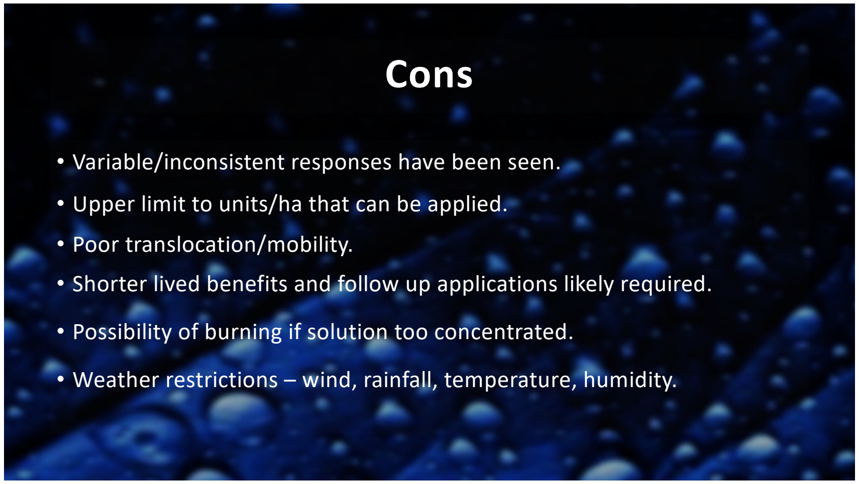
Foliars Enhance Soil Uptake?

- 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.

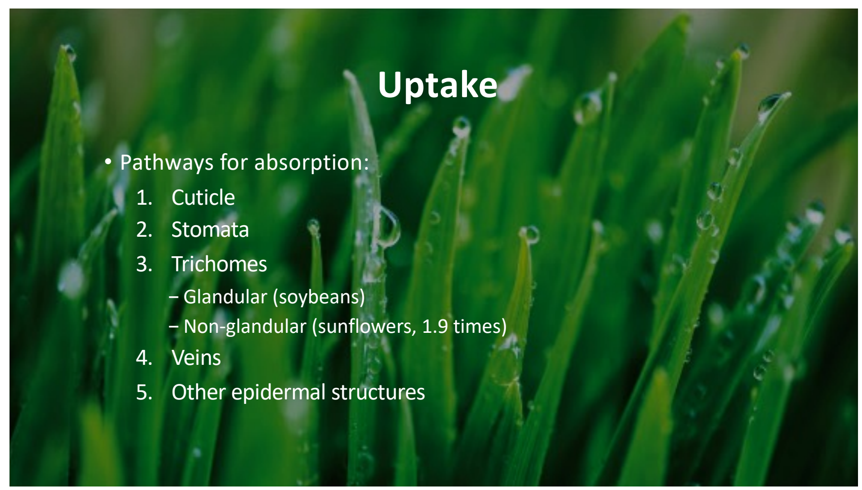
* Niu *et al* (2021). doi.org/10.1007/s42729-020-00346-3

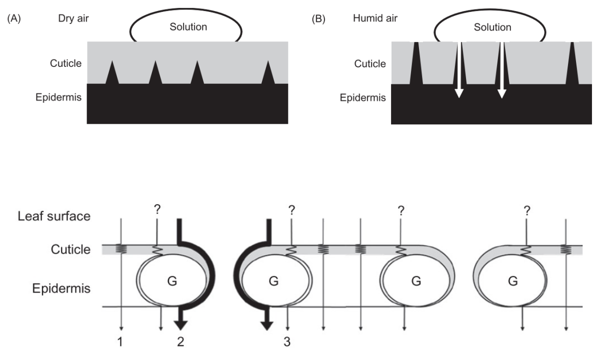
Pros

- More rapid absorption – quicker utilisation/assimilation.
- Faster alleviation of deficiency symptoms.
- Better utilisation of soil-immobile nutrients (Fe, P).
- Reduced run off/nutrient loss (NO_3).
- Ability to use nutrients when roots are impaired (drought, salts etc)
- More uniform applications for trace minerals.
- Top up during peak demand times.
- Opportunity to combine nutrient synergists.


Cons
• Variable/inconsistent responses have been seen.
• Upper limit to units/ha that can be applied.
• Poor translocation/mobility.
• Shorter lived benefits and follow up applications likely required.
• Possibility of burning if solution too concentrated.
• Weather restrictions – wind, rainfall, temperature, humidity.

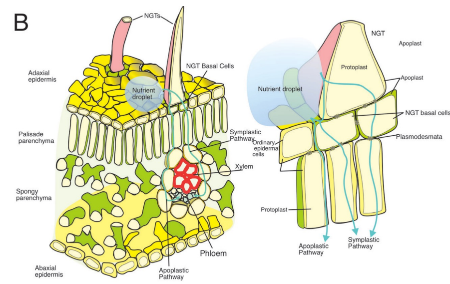

Uptake Pathways


Uptake
• Pathways for absorption:
1. Cuticle
2. Stomata
3. Trichomes
– Glandular (soybeans)
– Non-glandular (sunflowers, 1.9 times)
4. Veins
5. Other epidermal structures



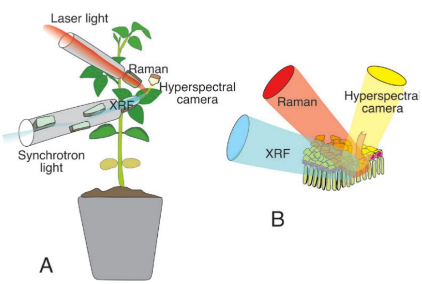
* Eichert & Fernández (2011). doi.org/10.1016/B978-0-12-384905-2.00004-2

Strategies for probing absorption and translocation of foliar-applied nutrients



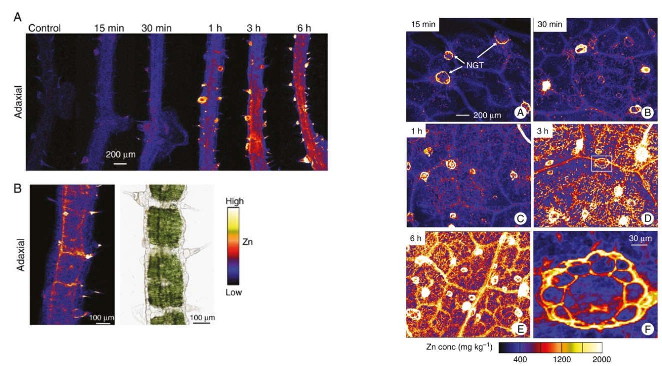
* Otto *et al* (2021). doi.org/10.1093/jxb/erab229

Strategies for probing absorption and translocation of foliar-applied nutrients



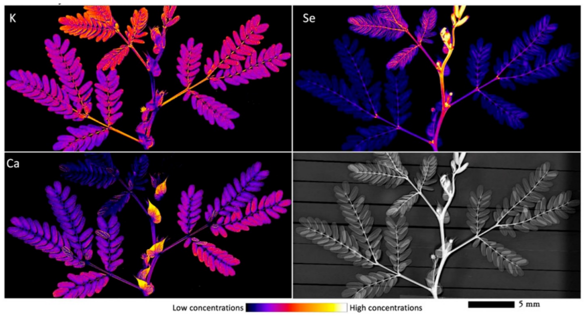
* Otto *et al* (2021). doi.org/10.1093/jxb/erab229

ANNALS OF BOTANY



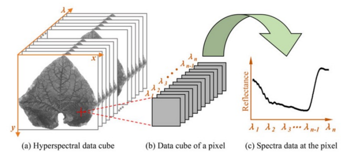
* Li *et al* (2019). doi.org/10.1093/aob/mcy135

Plant Physiology



* Kopittke *et al* (2020). doi.org/10.1104/PP.19.01306

Nondestructive diagnostics of magnesium deficiency based on distribution features of chlorophyll concentrations map on cucumber leaf



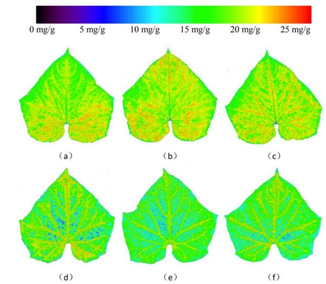


Figure 4. Chlorophyll concentration distribution maps of Control leaves (a, b and c) and Mg deficient leaves (d, e and f).

* Shi *et al* (2019). doi.org/10.1080/01904167.2019.1659332

Avoiding the 'spray and pray' approach

Plant response depends on…

Formulation

Application

Crop

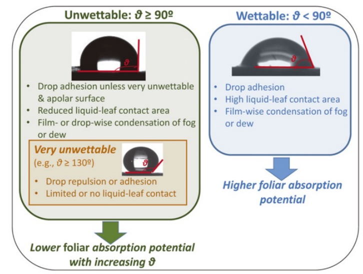
Environment

Plant Response: Formulation

- Formulation
  - Water quality
  - Solubility
  - Molecular size
  - Electrical charge (cations vs anions)
  - pH (<6)
  - EC (electrical conductivity: 1.5-3 mS/cm)
  - Surface tension (spreading capacity)
  - Carbon or chelation

the plant journal

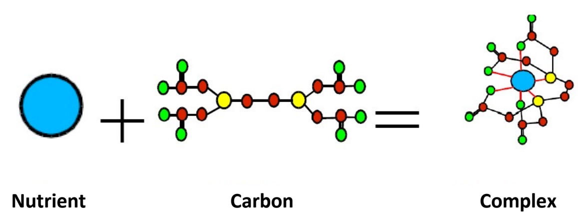
Foliar water and solute absorption: an update



* Fernández *et al* (2021). doi.org/10.1111/tpj.15090

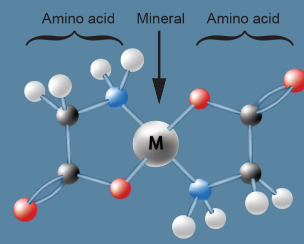
C-based inputs, chelates, adjuvants

Carbon Based Inputs

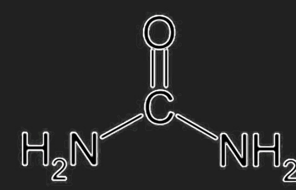


Chelation

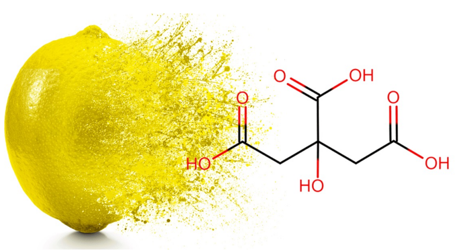
- Chelated minerals generally have:
  - Neutral charge
  - Better absorption (by root or foliar)
  - Better translocation within the plant
  - Lower salt index/less burning
  - Slower release rate (varies)
- Amino chelates are particularly useful.
  - Fish etc

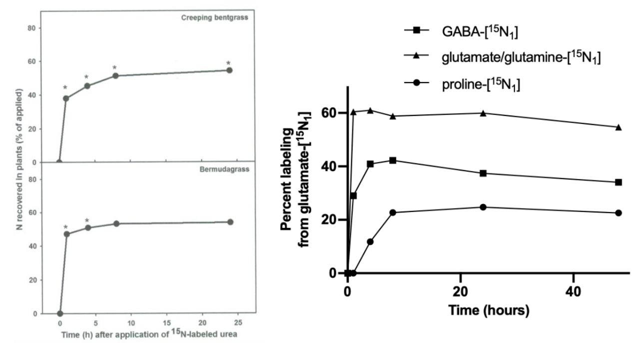


Urea: C-based N



Citric Acid





* Stiegler *et al* (2011). doi.org/10.2135/cropsci2010.06.0377
* McCoy *et al* (2020). doi.org/10.3390/agronomy10030358

Carbon Sources

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

Humic Substances

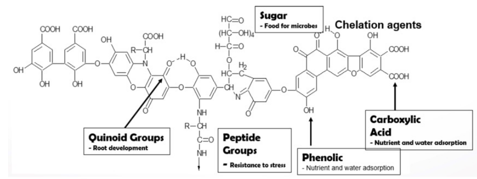


Table 2. Chemical composition of humic and fulvic acids as summarized from the literature.

Characteristic	Humic Acids	Fulvic Acids
Molecular Weight	10,000–100,000 Daltons	1000–10,000 Daltons
	——-% of organic components——	
Carbon	50–60	40–50
Hydrogen	4–6	4–6
Nitrogen	2–6	1–3
Oxygen	30–35	44–50
Sulfur	0–2	0–2

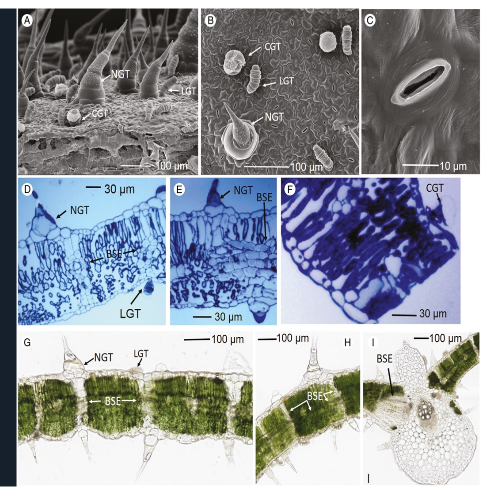
* Sible *et al* (2021). doi.org/10.3390/agronomy11071297

Plant Response: Application

- Nozzle
- Droplet size
- Pressure
- Droplet deflection
- Runoff
- Drift
- Surface area coverage
- Forward speed

Plant Response: Crop

- Crop stage
- Canopy Structure
- Leaf Area Index
- Leaf Chemistry
- Leaf Shape
  - Cuticle
  - Surfaces waxes
  - Leaf hairs, spines etc
- Abiotic and biotic stresses



Plant Response: Environment

- Humidity
  - Time of day (stomata & pores open)
  - 70%+ humidity is ideal
  - Rapid drying can lead to re-crystallization
- Temperature
  - Max 28 C (~25 C)
- Wind
  - 3-15 km/h
- Drought
  - Early vs Late plant stress

Plant, Cell & Environment

Unravelling foliar water uptake pathways: The contribution of stomata and the cuticle

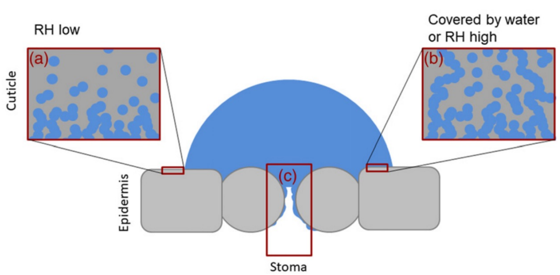
Abstract

Plants can absorb water through their leaf surfaces, a phenomenon commonly referred to as foliar water uptake (FWU). Despite the physiological importance of FWU, the pathways and mechanisms underlying the process are not well known. Using a novel experimental approach, we parsed out the contribution of the stomata and the cuticle to FWU in two species with Mediterranean (Prunus dulcis) and temperate (Pyrus communis) origin. The hydraulic parameters of FWU were derived by analysing mass and water potential changes of leaves placed in a fog chamber. Leaves were previously treated with abscisic acid to force stomata to remain closed, with fusicoccin to remain open, and with water (control). Leaves with open stomata rehydrated two times faster than leaves with closed stomata and attained approximately three times higher maximum fluxes and hydraulic conductance. Based on FWU rates, we propose that rehydration through stomata occurs primarily via diffusion of water vapour rather than in liquid form even when leaf surfaces are covered with a water film. We discuss the potential mechanisms of FWU and the significance of both stomatal and cuticular pathways for plant productivity and survival.

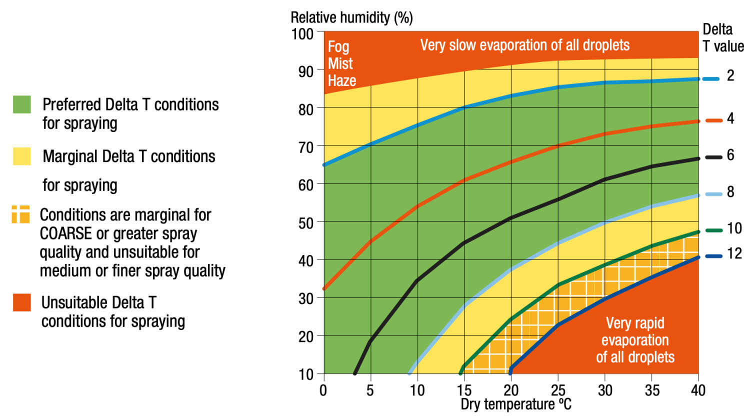
* Guzmán-Delgado *et al* (2021). doi.org/10.1111/pce.14041

the plant journal

Foliar water and solute absorption: an update



* Fernández *et al* (2021). doi.org/10.1111/tpj.15090



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

Foliar Efficiencies

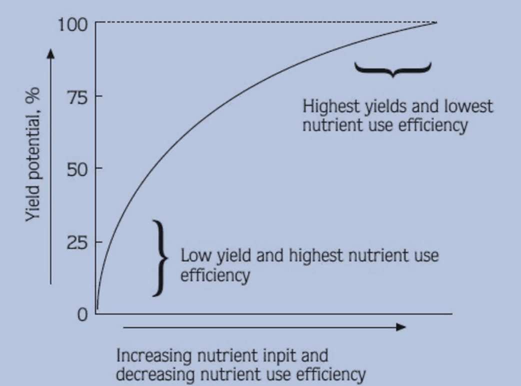
Joel Williams
www.integratedsoils.com
@integratedsoils

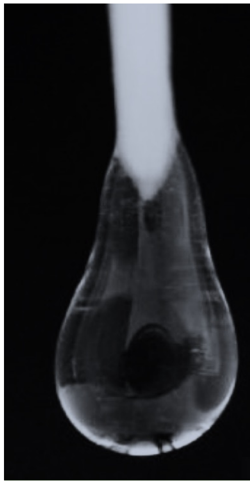
"…it is crucial to develop new methods to increase nitrogen use efficiency (NUE); and it is estimated that, even a 1% increase in NUE could save $1.1 billion US dollar per annum"

* Kant *et al* (2011). doi.org/10.1093/jxb/erq297 * Stuart *et al* (2014). doi.org/10.1016/j.landusepol.2013.08.011

Mechanisms of Efficiency Gains?

- Improved and even coverage vs sporadic granules
- Less nutrient antagonisms/competition vs soil applied
- Less ammonia volatilisation, less nitrate leaching
- Maintain nutrient supply during sub-optimal soil conditions
- Metabolic shortcutting of efficient N forms – more energy left for leaf and root growth





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

Foliar Efficiencies

- Michigan State University
  - 1950's
  - Tukey and Wittwer
  - Radioactive P demonstrated rapid uptake
  - 95% was taken up as compared to 10-20% soil applied
  - 8-10 or 20 times more efficient

* Tukey et al (1952) doi.org/10.1126/science.116.3007.167 * Bukovac & Wittwer (1957) doi.org/10.1104/pp.32.5.428

Foliar Efficiencies

Nutrient	Crop type	Foliar ratio	Soil ratio	Source
Zinc (ZnSO4)	Annual crops	1	12	Lingle & Holmberg (1956)
Phosphorus (H3PO4)	beans, tomatoes	1	20	Wittwer, et al. (1957)
Iron (FeSO4)	Grain, sorghum	1	25	Withee & Carlson (1959)
Magnesium (MgSO4)	Grain, sorghum	1	100	Krantz (1962)
Magnesium (MgSO4)	Celery	1	50-100	Johnson, et al. (1957, 1961)

Approximate ratios of amounts required for comparable crop response.

* https://advancednutrients.com.au/wp-content/uploads/2021/05/Foliar-Fertilisers-White-Paper.pdf

Foliar Calcium Sprays for Apples

Increase in fruit calcium obtained from different treatments. The numbers in parentheses are the actual pounds of calcium applied per acre, assuming that trees required 300 gal dilute spray per acre. All foliar treatments were made with $CaCl_2$. The 8-spray, 5-spray, and 2-spray treatments applied a yearly total of 74, 40, and 18 pounds of technical-grade $CaCl_2$ per acre. Gypsum was applied at approximately one ton per acre, annually.

Treatment	Increase in fruit calcium concentration (ppm)
8 foliar sprays (22 lbs calcium/acre)	45
5 foliar sprays (12 lbs calcium/acre)	25
2 foliar sprays (5 lbs calcium/acre)	10
Gypsum on soil (400 lbs calcium/acre)	12

* Autio & Bramlage. https://ag.umass.edu/sites/ag.umass.edu/files/fact-sheets/pdf/folcalcium.pdf

Foliar *versus* soil phosphorus (P) application for improving P use efficiency in wheat and maize in calcareous soils

ABSTRACT

Phosphorus (P) is the most deficient nutrient in agricultural soils after nitrogen. Additionally, exogenously applied P quickly transforms into less soluble compounds through various chemo-sorption reactions resulting in poor fertilizer use efficiency (15–25%). Therefore, this pot experiment was conducted to investigate the impact of foliar P (0, 45, 90 and 135 mM KH_2PO_4) in conjunction with soil applied P (0, 10 and 20 mg P kg^{-1}) for enhanced growth and P use efficiency of maize and wheat in calcareous soils. There was a linear increase in plant height and biomass both with the increasing application of soil and foliar P in both wheat and maize crop. However, the effect of foliar P was more pronounced in P deficient condition compared to 10 or 20 mg P kg^{-1}. Soil applied P at 10 and 20 mg P kg^{-1} increased plant dry biomass by 10.8 and 16.8% in maize and by 29.9 and 35.5% in wheat over control, respectively. Foliar P application didn't improve soil phosphorus. The interaction between soil and foliar P was significant ($p \leq .05$) showing that increase of either foliar or soil P application, tissue P content of both maize and wheat increased. In both season the higher foliar P solution resulted in higher P uptake though the increase in wheat were lower than maize. Therefore, the low recovery of soil P associated with poor soil characteristics could be corrected through its foliar application if administered at proper growth stage with suitable concentration strength and appropriate source.

Table 3. Total uptake and P use efficiency of maize and wheat crop as affected by different levels of phosphorus both soil and foliar applied P.

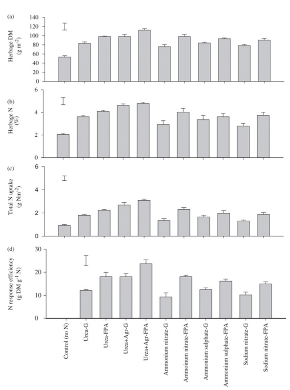
	Total P uptake (mg pot^{-1})		P use efficiency (%)	
Treatments	Maize	Wheat	Maize	Wheat
Soil applied P (mg P kg^{-1} soil)				
0	122.62 c	45.06 b		
10	160.08 b	67.59 a	7.90	4.43
20	179.86 a	75.94 a	4.16	2.31
$LSD_{(0.05)}$	13.34	8.65		
Foliar P (mM KH_2PO_4)				
0	118.35 c	45.84 c		
45	148.18 b	59.44 b	37.96	19.96
90	163.68 ab	64.52 ab	19.88	10.50
135	186.52 a	81.66 a	14.21	7.92
$LSD_{(0.05)}$	15.40	9.98		
Interaction				
SP × FP	0.68	0.86		

* Rafiullaha *et al* (2021). doi.org/10.1080/01904167.2021.1871744

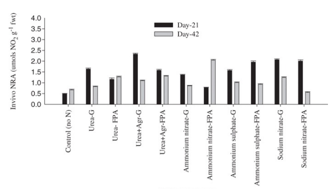
Urease inhibitor reduces N losses and improves plant-bioavailability of urea applied in fine particle and granular forms under field conditions

A field lysimeter/mini plot experiment was established in a silt loam soil near Lincoln, New Zealand, to investigate the effectiveness of urea fertilizer in fine particle application (FPA), with or without the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT – "Agrotain"), in decreasing nitrogen (N) losses and improving N uptake efficiency. The five treatments were: control (no N) and ^{15}N-labelled urea, with or without NBPT, applied to lysimeters or mini plots (unlabelled urea), either in granular form to the soil surface or in FPA form (through a spray) at a rate equivalent to 100 kg N ha^{-1}. Gaseous emissions of ammonia (NH_3) and nitrous oxide (N_2O), nitrate (NO_3^-) leaching, herbage dry-matter (DM) production, N-response efficiency, total N uptake and total recovery of applied ^{15}N in the plant and soil varied with urea application method and with addition of NBPT. Urea with NBPT, applied in granular or FPA form, was more effective than in application without NBPT: N_2O emissions were reduced by 7–12%, NH_3 emissions by 65–69% and NO_3^- leaching losses by 36–55% compared with granular urea. Urea alone and with NBPT, applied in FPA form increased herbage DM production by 27% and 38%, respectively. The N response efficiency increased from 10 kg DM kg^{-1} of applied N with granular urea to 19 kg DM kg^{-1} with FPA urea and to 23 kg DM kg^{-1} with FPA urea plus NBPT. Urea applied in FPA form resulted in significantly ($P < 0.05$) higher ^{15}N recovery in the shoots compared with granular treatments and this was improved further when urea in FPA form was applied with NBPT. These results suggest that applying urea with NBPT in FPA form has potential as a management tool in mitigating N losses, improving N-response efficiency and increasing herbage DM production in intensive grassland systems.

* Dawar *et al* (2011) doi.org/10.1016/j.agee.2011.08.007



Applying urea with urease inhibitor (N-(n-butyl) thiophosphoric triamide) in fine particle application improves nitrogen uptake in ryegrass (Lolium perenne L.)



25 kg N ha^{-1}

Urea applied with Agrotain in FPA form increased the N-response efficiency (N-RE) by ~31% and ~96%, respectively, compared with FPA urea or granular urea.

* Dawar *et al* (2011) doi.org/10.1080/00380768.2012.680050

Comparing Soil vs. Foliar Nitrogen Supply of the Whole Fertilizer Dose in Common Wheat

Abstract: Late-season N application through foliar spraying is recognized as an efficient agronomic practice for improving grain quality in common wheat, although the major part of N is still supplied by soil fertilization. This study assessed the impact of various N doses entirely applied by repeated foliar sprayings on wheat growth, yield and quality, in comparison with conventional soil fertilization management with a recommended dose of 160 kg N ha^{-1} as ammonium nitrate (C-M). Doses of 96, 104 and 120 kg N ha^{-1} as both UAN (urea-ammonium-nitrate) and urea applied by foliar spraying were evaluated in a 2-year field trial in Northern Italy in a silty loam soil with 1.7% organic matter. Here, it was demonstrated that the canopy greenness was similar in all treatments, with slight grain yield increases by the lowest foliar N dose vs. C-M. The higher N foliar doses mainly improved the grain protein content and both high- and low-molecular-weight glutenin subunits (HMW-GS, LMW-GS), particularly with urea. It is concluded that in our fertile soil, managing N fertilization exclusively through foliar spraying is feasible without compromising grain yield and ameliorating quality at the same time. Improved nutrient use efficiency and beneficial environmental effects are also expected by reducing the nitrogen load on the agricultural fields by 25–40%.

* Ferrari *et al* (2021). doi.org/10.3390/agronomy11112138

Table 1. Dates and growth stages of N application (kg ha^{-1}).

Year	Date	Phenological Stage	Treatment								
			UAN					UREA			
			0N	C-M	F-96	F-104	F-120	C-M	F-96	F-104	F-120
2018–2019	20 October 2018	Pre-sowing	32 (s)	32 (s)	32 (s)	32 (s)	32 (s)	32 (s)	32 (s)	32 (s)	32 (s)
	25 February 2019	Tillering (ZDS 26)	-	58 (s)	16 (f)	8 (f)	8 (f)	58 (s)	16 (f)	8 (f)	8 (f)
	21 March 2019	Stem elongation (ZDS 37)	-	58 (s)	16 (f)	16 (f)	16 (f)	58 (s)	16 (f)	16 (f)	16 (f)
	24 April 2019	Booting (ZDS 40)	-	-	16 (f)	32 (f)	32 (f)	-	16 (f)	32 (f)	32 (f)
	7 May 2019	Flowering (ZDS 62)	-	12 (f)	16 (f)	16 (f)	32 (f)	12 (f)	16 (f)	16 (f)	32 (f)
2019–2020	22 October 2019	Pre-sowing	32 (s)	-	-	-	-	32 (s)	32 (s)	32 (s)	32 (s)
	25 February 2020	Tillering (ZDS 27)	-	-	-	-	-	58 (s)	16 (f)	8 (f)	8 (f)
	28 March 2020	Stem elongation (ZDS 37)	-	-	-	-	-	58 (s)	16 (f)	16 (f)	16 (f)
	24 April 2020	Booting (ZDS 40)	-	-	-	-	-	-	16 (f)	32 (f)	32 (f)
	7 May 2020	Flowering (ZDS 62)	-	-	-	-	-	12 (f)	16 (f)	16 (f)	32 (f)
Total N dose			32	160	96	104	120	160	96	104	120
N saving (%) vs. C-M treatment			80%	Ref.	40%	35%	25%	Ref.	40%	35%	25%

s = soil. C-M = conventional N management; F = foliar N spraying. ZDS: Zadok's Phenological Stage [25].

* Ferrari *et al* (2021). doi.org/10.3390/agronomy11112138

Year	Fertilizer	Treatment	Yield DW (kg ha^{-1})		Harvest Index (%)		TSW (g)		Testing Weight (kg hL^{-1})	
2018–2019		0N	5570 ± 9.70		34.3 ± 0.51		28.9 ± 0.26		80.9 ± 0.73	
	UAN	C-M	6407 ± 76.5	b	35.7 ± 1.11	a	29.0 ± 0.69	a	80.5 ± 0.23	b
		F-96	6635 ± 107.1	ab (+4)	35.9 ± 0.83	a (+1)	28.8 ± 0.43	a (−1)	81.7 ± 0.38	ab (+1)
		F-104	6789 ± 76.2	a (+6)	36.8 ± 1.36	a (+3)	30.3 ± 1.26	a (+5)	82.4 ± 0.49	a (+2)
		F-120	6357 ± 121.2	b (−1)	33.7 ± 3.24	a (−6)	27.8 ± 2.39	a (−9)	80.6 ± 0.90	ab (=)
	UREA	C-M	6386 ± 41.7	ab	33.1 ± 0.96	a	27.7 ± 0.72	a	79.5 ± 0.19	b
		F-96	6527 ± 96.5	a (+2)	35.8 ± 0.69	a (+8)	29.4 ± 0.36	a (+6)	81.9 ± 0.36	a (+3)
		F-104	6193 ± 95.6	b (−3)	36.0 ± 1.47	a (+9)	29.1 ± 0.44	a (−1)	80.4 ± 0.69	b (+1)
		F-120	6524 ± 69.0	a (+2)	33.9 ± 0.62	a (+2)	28.9 ± 0.66	a (−1)	81.8 ± 0.31	a (+3)
2019–2020		0N	5914 ± 758.4		41.0 ± 1.69		35.5 ± 0.57		80.9 ± 0.56	
	UREA	C-M	6129 ± 436.0	a	39.9 ± 1.75	a	34.5 ± 0.51	a	82.5 ± 0.19	b
		F-96	6828 ± 286.8	a (+11)	44.7 ± 0.36	a (+12)	38.3 ± 0.64	a (+10)	83.2 ± 0.38	ab (+1)
		F-104	6214 ± 643.9	a (+1)	39.9 ± 3.72	a (=)	35.1 ± 2.77	a (+2)	82.8 ± 0.38	ab (=)
		F-120	6259 ± 287.7	a (+2)	41.3 ± 3.14	a (+3)	35.2 ± 1.51	a (+2)	83.8 ± 0.38	a (+1)

* Ferrari *et al* (2021). doi.org/10.3390/agronomy11112138

Year	Fertilizer	Treatment	GPC (%)		Zeleny Index (%)		Wet Gluten (%)	
2018–2019		0N	11.4 ± 0.53		33.5 ± 2.12		27.6 ± 1.31	
	UAN	C-M	14.0 ± 0.64	a	42.8 ± 5.88	a	31.4 ± 1.68	ab
		F-96	13.1 ± 0.37	a (−6)	35.9 ± 2.40	a (−16)	29.4 ± 0.80	b (−6)
		F-104	13.4 ± 0.26	a (−4)	37.9 ± 3.29	a (−11)	30.0 ± 0.61	ab (−4)
		F-120	14.5 ± 0.45	a (+4)	48.3 ± 3.40	a (+13)	33.3 ± 1.13	a (+6)
	UREA	C-M	14.3 ± 0.61	ab	44.9 ± 5.28	ab	32.5 ± 1.56	ab
		F-96	13.2 ± 0.44	b (−8)	36.7 ± 4.39	b (−18)	30.0 ± 1.10	b (−8)
		F-104	14.7 ± 0.32	a (+3)	49.2 ± 1.50	a (+10)	33.4 ± 0.61	a (+3)
		F-120	14.5 ± 0.19	ab (+1)	48.6 ± 0.80	a (+8)	32.8 ± 0.54	ab (+1)
2019–2020		0N	9.9 ± 0.41		21.6 ± 2.66		15.8 ± 0.96	
	UREA	C-M	13.2 ± 0.33	b	32.9 ± 2.66	bc	26.8 ± 1.19	b
		F-96	12.0 ± 0.15	c (−9)	29.1 ± 1.02	c (−12)	23.3 ± 0.48	c (−13)
		F-104	13.9 ± 0.35	ab (+6)	40.4 ± 5.34	ab (+23)	30.0 ± 1.27	a (+12)
		F-120	14.2 ± 0.13	a (+8)	46.3 ± 0.69	a (+41)	31.0 ± 0.23	a (+16)

* Ferrari *et al* (2021). doi.org/10.3390/agronomy11112138

USING HUMIC COMPOUNDS TO IMPROVE EFFICIENCY OF FERTILISER NITROGEN

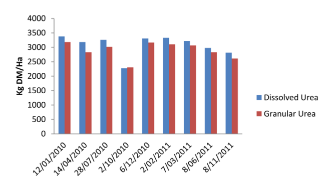


Figure 2. Pasture production at nine harvest dates from plots treated with dissolved urea and humic compounds or granular urea

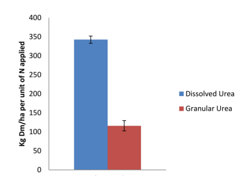
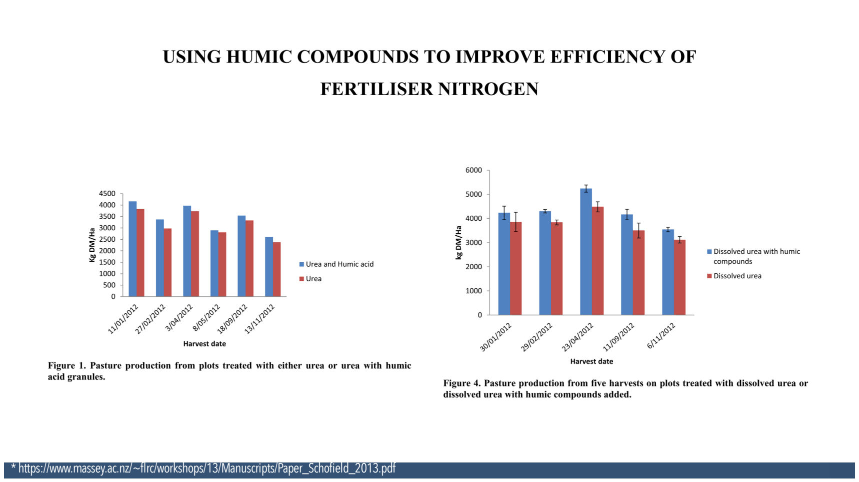


Figure 3. Average pasture production per unit of N fertiliser applied at nine harvest dates from plots treated with dissolved urea and humic compounds or granular urea

* https://www.massey.ac.nz/~flrc/workshops/13/Manuscripts/Paper_Schofield_2013.pdf


USING HUMIC COMPOUNDS TO IMPROVE EFFICIENCY OF FERTILISER NITROGEN
Kg DM/Ha
4500
4000
3500
3000
2500
2000
1500
1000
500
0
11/01/2012
27/02/2012
3/04/2012
8/05/2012
18/09/2012
13/11/2012
Harvest date
Urea and Humic acid
Urea
Figure 1. Pasture production from plots treated with either urea or urea with humic acid granules.
kg DM/Ha
6000
5000
4000
3000
2000
1000
0
30/01/2012
29/02/2012
23/04/2012
11/09/2012
6/11/2012
Harvest date
Dissolved urea with humic compounds
Dissolved urea
Figure 4. Pasture production from five harvests on plots treated with dissolved urea or dissolved urea with humic compounds added.
* https://www.massey.ac.nz/~flrc/workshops/13/Manuscripts/Paper_Schofield_2013.pdf


Thank you, Questions?
Mailing List, Resources, More info:
www.integratedsoils.com
@integratedsoils


Plant Nutrition
Joel Williams
www.integratedsoils.com
@integratedsoils

Photosynthesis

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

nutrients/enzymes

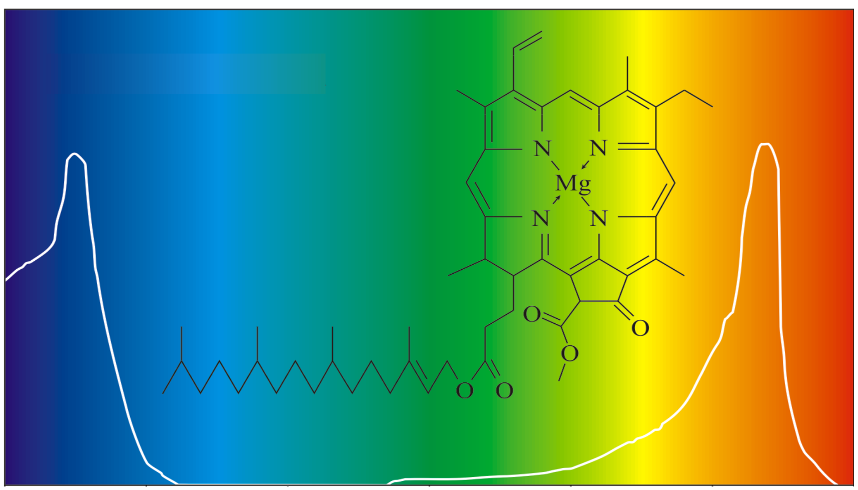
$C_6H_{12}O_6$ (sugar) ------------------>

nutrients/enzymes

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

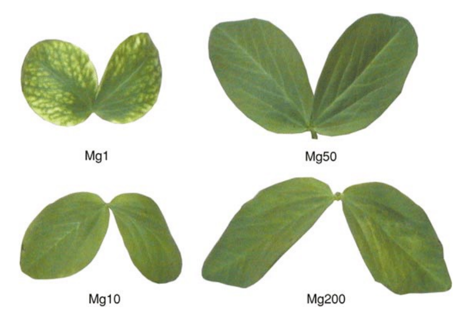
Key Functions of Essential Nutrients

- *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*



Magnesium

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



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

Iron

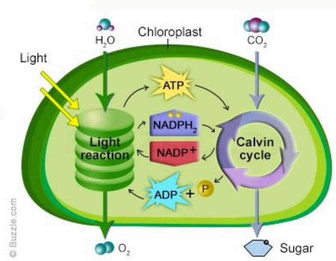
- Chlorophyll synthesis
- Nitrite reductase enzyme
- Fe (& Mo) is key for N_2 fixation – nitrogenase enzyme.

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 and immune responses.
- 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.

Photosynthesis

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

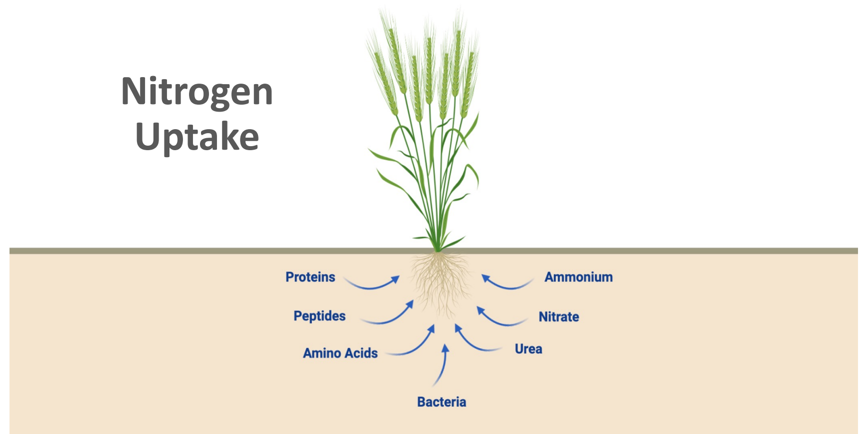
nutrients/enzymes

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

nutrients/enzymes

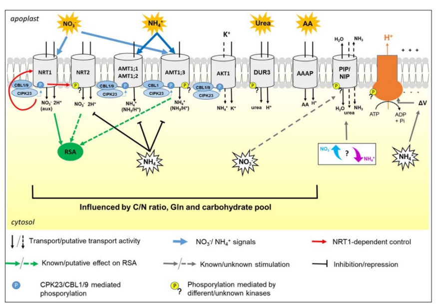
- *Complex sugars*
- *Carbohydrates*
- *Amino Acids, Proteins*
- *Fats, Oils, Lipids, Waxes*
- *Hormones, Vitamins*
- *Aromatic/volatile compounds*
- *Defense Chemicals*
- *Protective Compounds*
- *Root Exudates*

Nitrogen Uptake



plants

Nitrogen Uptake in Plants: The Plasma Membrane Root Transport Systems from a Physiological and Proteomic Perspective



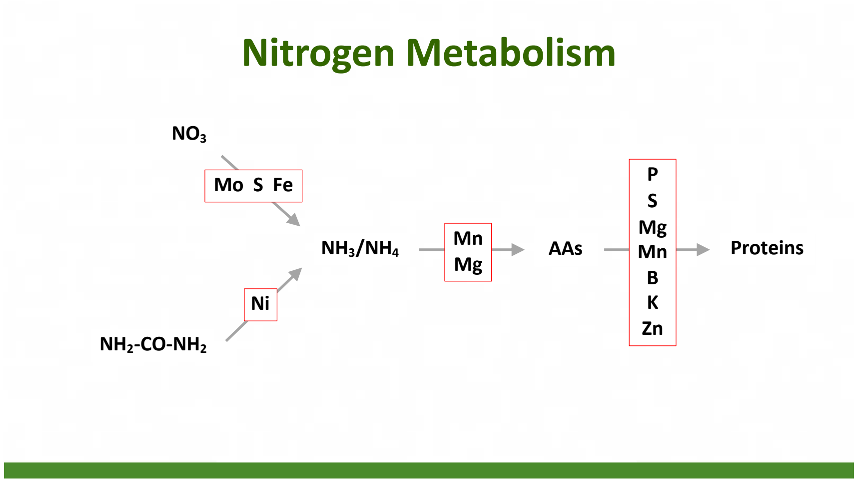
* Muratore *et al* (2021). doi.org/10.3390/plants10040681

Nitrogen Metabolism

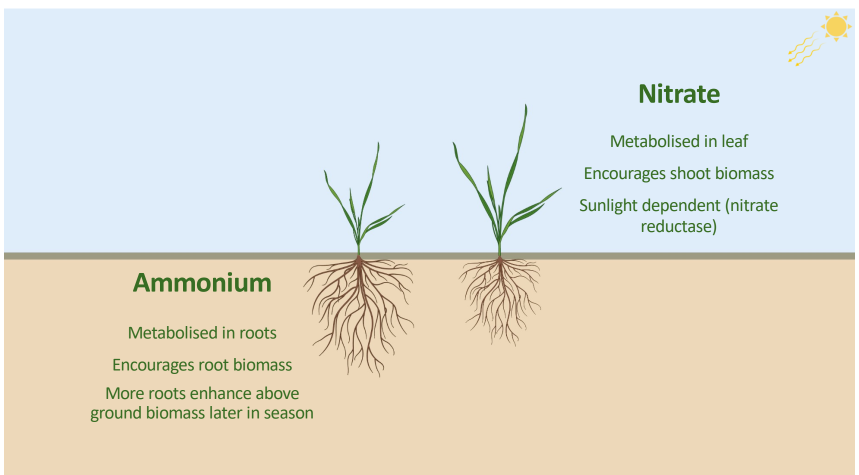
NO_3 → NH_3/NH_4

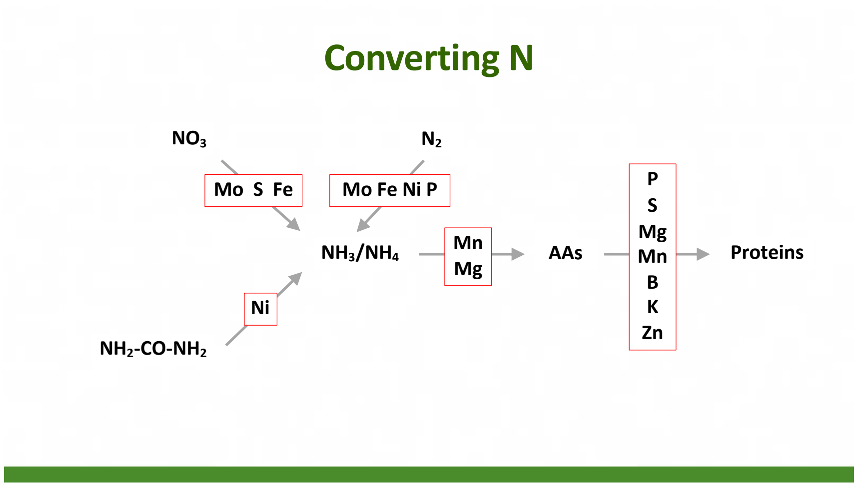
NH_2-CO-NH_2 → NH_3/NH_4

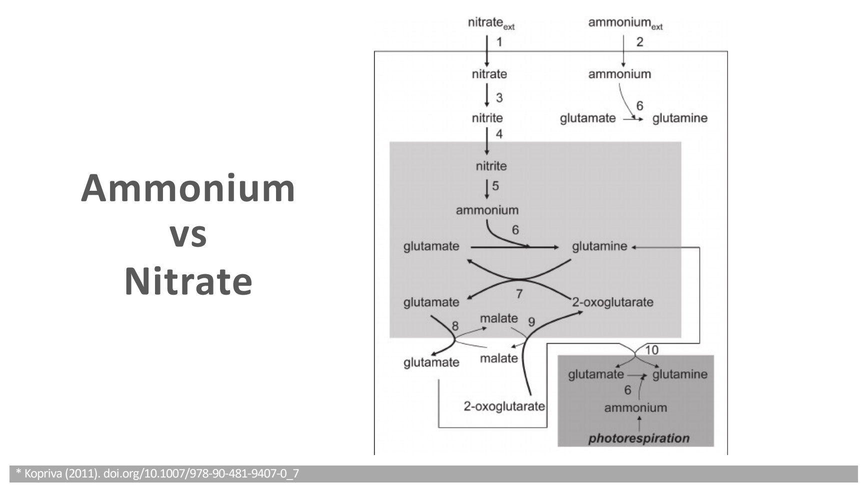
NH_3/NH_4 → Amino Acids → Proteins

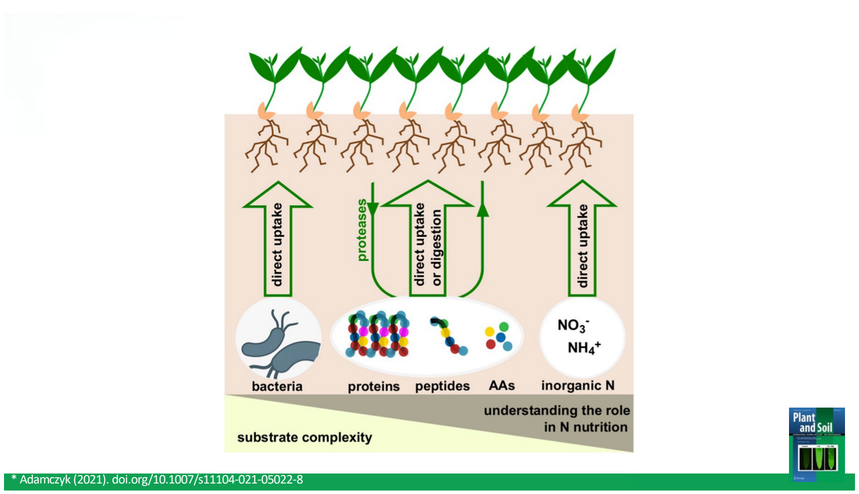


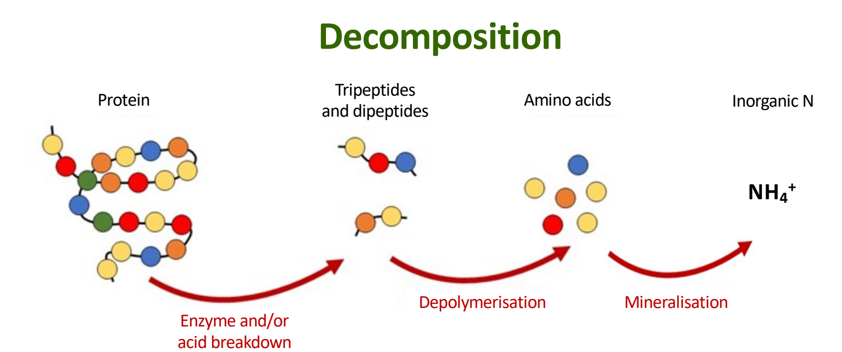
Mineral		Current level	
Total Sugars	%	0,8	1
	%	0,2	2
pH		5,8	1
		5,5	2
EC	mS/cm	12,2	1
	mS/cm	17,7	2
K - Potassium	ppm	3997	1
	ppm	4461	2
Ca - Calcium	ppm	551	1
	ppm	1773	2
K / Ca		7,25	1
		2,52	2
Mg - Magnesium	ppm	380	1
	ppm	553	2
Na - Sodium	ppm	22	1
	ppm	35	2
NH4 - Ammonium	ppm	54	1
	ppm	68	2
NO3 - 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



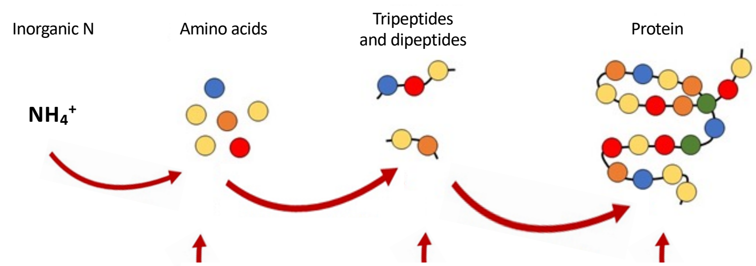

Converting N
NO3
N2
Mo S Fe
Mo Fe Ni P
NH3/NH4
Mn
Mg
AAs
P
S
Mg
Mn
B
K
Zn
Proteins
Ni
NH2-CO-NH2


Ammonium
vs
Nitrate
nitrate ext
ammonium ext
nitrate
ammonium
nitrite
glutamate
glutamine
nitrite
ammonium
glutamate
glutamine
glutamate
2-oxoglutarate
malate
glutamate
malate
2-oxoglutarate
glutamate
glutamine
ammonium
photorespiration
* Kopriva (2011). doi.org/10.1007/978-90-481-9407-0_7


direct uptake
proteases
direct uptake or digestion
direct uptake
NO3-
NH4+
bacteria
proteins
peptides
AAs
inorganic N
understanding the role in N nutrition
substrate complexity
Plant and Soil
* Adamczyk (2021). doi.org/10.1007/s11104-021-05022-8


Decomposition
Protein
Tripeptides
and dipeptides
Amino acids
Inorganic N
NH4+
Enzyme and/or
acid breakdown
Depolymerisation
Mineralisation

Metabolic Shortcutting



Plant, Cell & Environment

Original Article | Open Access

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

Oskar Franklin, Camila Aguetoni Cambui, Linda Gruffman, Sari Palmroth, Ram Oren, Torgny Näsholm

First published: 31 May 2016

The importance of organic nitrogen (N) for plant nutrition and productivity is increasingly being recognized. Here we show that 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, O., *et al.*, (2016). doi: 10.1111/pce.12772

Plant, Cell & Environment

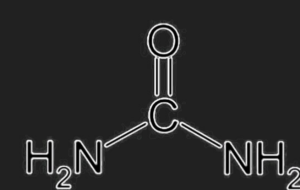
Table 2. Biochemically calculated assimilation costs for different N sources in gC gN^{-1} according to Zerihun *et al.* (1998)

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, O., *et al.*, (2016). doi: 10.1111/pce.12772

Urea: C-based N



Molybdenum

- Protein synthesis
- 2 key enzymes convert nitrate into nitrite then into ammonia/ammonium before it is used to synthesise amino acids.
- N_2 fixing bacteria also require Mo (& Fe) to access N_2 gas from the air.

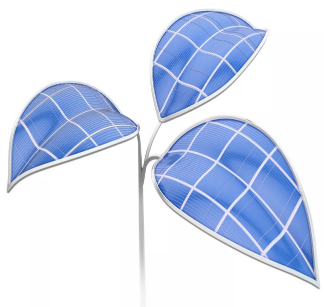
Nickel

- Ni is part of the ***urease enzyme*** which splits the urea molecule liberating the N for plant metabolism.
- Without Ni/urease, urea can build up in plant tissues and become toxic.
- Plants specifically fed urea without Ni can be ‘functionally N deficient’
- ***Nickel sulphate*** at 0.2% solution in barley – around 20-50 g/ha can be effective.

Sulphur

- Amino acids
- Protein synthesis
- Root development
- Disease resistance
- Nodulation in legumes

Zinc



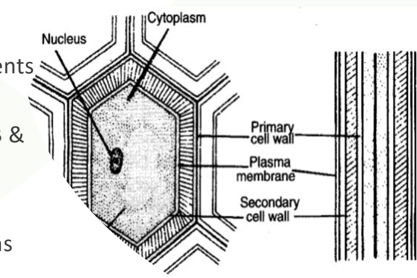
- Zinc determines **leaf size** – solar panel.
- Chlorophyll synthesis.
- Nitrogen metabolism.

Copper

- Cu responsible for **lignin** production (primary defence) and **antimicrobial** compounds (secondary defence).
- Disease resistance.
- Metabolism of proteins and carbohydrates.
- Respiration.

Calcium

- Ca is deposited in **cell walls** and improves nutrient uptake of all elements into the cells.
- Ca is a cell strengthener (along with B & Si) improving pest and disease resistance.
- Highly immobile (deficiency symptoms on young leaves).

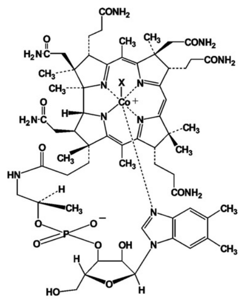


Boron

- Much plant B is also found deposited in cell walls.
- Plays a key role in **synthesis** of structural compounds (lignin, polyphenols) = primary defences.
- Root growth.
- Growing tips (very immobile).
- Reproductive processes!

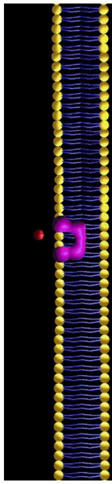
Cobalt

- Vitamin B12 – cell division.
- N fixing in legumes.
- Inputs
  - Cobalt sulphate



VITAMIN B_{12}

Nitrogen as Foliar



- Plants can absorb nitrogen via foliage.
- Speed of absorption – aa > urea > ammonium > nitrate.
- Protein hydrolysates and urea are ideal.
- Urea can improve uptake of trace elements when combined together – Zn.

* Witte, C.P. (2011). doi: 10.1016/j.plantsci.2010.11.010

In Summary – Principles

- Plants can make use of many N forms – manage them all.
- Different N forms work synergistically – combine iN and oN.
- C-based N (oN) is more efficient for plant metabolism.
- N is not an island – needs other synergistic nutrients.
- Excess N (or imbalanced N) compromises plant health.
- Foliar N (aa & urea) - rapidly absorbed, less losses, lower rates, efficiency gains.

In Summary – Practice

- Nitrate best used during vegetative stages only.
- High analysis, embedded C and rapid absorption gives urea a key advantage for foliar applications.
- Include nutrient synergists – ideally determine via plant analysis.
- Include carbon and pH modification.

1. ***Nitrogen source(s)***
   – Urea at 10-20 kg/ha
   – UAS/UAN at 10-20 L/ha
   – Ammonium sulphate at 5-7 kg/ha
2. ***Use tissue/sap analysis*** to determine optimum combinations of synergistic nutrients to go with nitrogen.
3. ***Carbon source(s)***
   – Fulvic acid at 1-2 L/ha
   – Fish Hydrolysate at 2-5 L/ha
4. ***pH adjustment*** – citric acid to pH 5-5.5
5. ***Wetter Sticker***

Designing Foliar Nitrogen

Base N form		Inorganic-N forms		Organic-N forms		Synergists
Urea	+	Ammonium sulphate Ammonium thiosulphate Urea-Ammonium sulphate Urea-Ammonium nitrate Ammonium nitrate	+	Protein hydrolysates (fish etc) Amino acids Plant extracts Compost leachates	+	C source (fulvic, molasses, kelp etc) Citric acid Multi-trace package (esp Fe, Zn, Mn, Mo)

Foliar N Combinations

- General/All purpose:
  – Urea at ~20 kg/ha
  – Multi-trace element package at label rates

  – Carbon source, pH adjustment, wetter/sticker*

Foliar N Combinations

- Diversity of N:
  – UAN or UAS at ~20 L/ha
  – Fish Hydrolysate at 3-5 L/ha

  – Urea at ~20 kg/ha
  – Ammonium sulphate at ~5 kg/ha
  – Protein Hydrolysate at 3-5 L/ha

  – Carbon source, pH adjustment, wetter/sticker*

Foliar N Combinations

- Photosynthesis Primer:
  - Urea at ~20 kg/ha
  - Magnesium sulphate at 5-7 kg/ha
  - Iron sulphate at 0.5-1 kg/ha
  - Manganese sulphate at 0.5-1-2 kg/ha
  - Carbon source, pH adjustment, wetter/sticker*

Foliar N Combinations

- Grain Fill:
  - Urea at ~20 kg/ha
  - Potassium sulphate at 3-5 kg/ha
  - Carbon source, pH adjustment, wetter/sticker*

Organic Foliar N

- Certified Organic
  - Protein hydrolysate at 3-10 L/ha
  - Approved amino acid product at label rates or protein hydrolysate at ~5 L/ha
  - Trace elements (use plant analysis to confirm limitation)
  - Carbon source, pH adjustment, wetter/sticker*

Trace Elements

Zinc sulphate [Zn]	1 kg/ha (lbs/ac)
Iron sulphate [Fe]	1 kg/ha (lbs/ac)
Manganese sulphate [Mn]	1 kg/ha lbs/ac)
Copper sulphate [Cu]	0.5-1 kg/ha (lbs/ac)
Sodium borate [B]	0.5-1 kg/ha (lbs/ac)
Sodium molybdate [Mo]	50-200 g/ha (1.7-7 oz/ac)
Nickel sulphate [Ni]	50-100 g/ha (1.7-3.5 oz/ac)
Cobalt sulphate [Co]	100 g/ha (3.5 oz/ac)

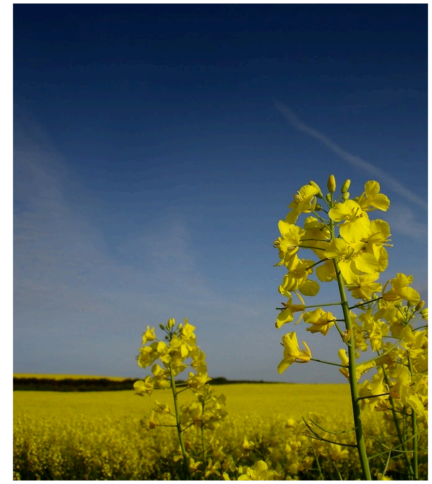
- Cropland: 1% solution [1 lbs per 12 gal of water]
- Horticulture: 0.1% solution [3.5 oz per 12 gal of water]

Timings – Cereals

- Just ahead of flag leaf
- End of flowering
- (tillering, stem elongation and booting also somewhat beneficial)

Timings – Canola

- Pre flowering
- Post flowering
- Include sulphur
  - Urea + SOA etc

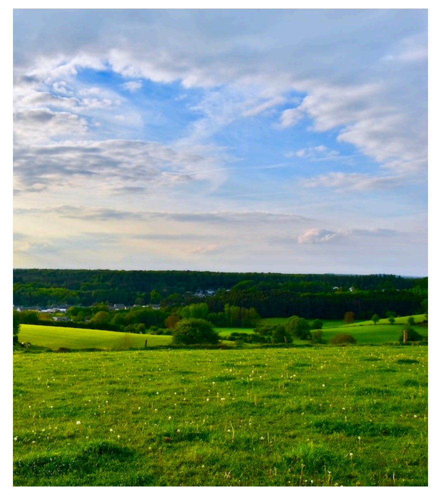


Timings – Pulses

- After flowering during pod set
- 5-10 kg/ha

Grasslands

- 20-25 kg/ha (lbs/ac)
- Dairy
  - Every 3-4 weeks
  - Around 7 days after each grazing event
- Beef
  - 3 to 4 applications per growing season



Solubilising Urea Tips

- Melting urea is an endothermic reaction, warm water helps.
- Leave water in tank for a few days to allow sun warming – black tank etc.
- Slowly feed the urea with an auger/conveyor into moving water, the more circulation the better.
- Direct the return of the circulation down and around the bottom of the tank preventing any urea to settle (can become difficult to solubilise).

Minimising Scorch

- If dissolving urea, be sure it is low biuret (<1%).
- Nickel sulphate at ~20-50 g/ha
- Apply with high humidity (evening, night, heavy dew).
- Avoid bright sunny days and windy conditions.
- Low spray pressure (<50 psi)
- Low temperatures (<0C) or significant temperature fluctuations can increase burn.
- Dilute with additional water if necessary.

In Closing: Foliar N Tips

- Combine inorganic and organic N sources
- Always include a carbon source (AAs)
- Drop pH to 5-5.5
- Use tissue tests and plant health assessments to determine synergist inputs.
- FACE – Formulation and Environment

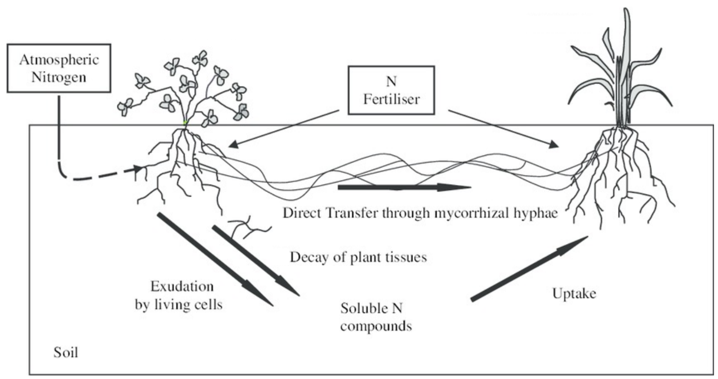
Foliar Nitrogen

The live lectures for Foliar Nitrogen have ended, the recordings are available to purchase as an on demand course.

Access to Foliar Nitrogen includes:

- Permanent access to the 10 lecture online course (detailed outline below)
- Factsheets and articles summarising key take home learnings from the course
- Case studies of farmers around the world implementing foliar nitrogen strategies
- Further reading – a compiled reading list of lay articles and academic papers relevant to and referenced in the course
- A pdf of powerpoint slides

* www.integratedsoils.com/foliar-nitrogen



* Paynel, F., et al (2008). doi: 10.1051/agro:2007061

Agriculture Ecosystems & Environment

Grass-legume mixtures can yield more nitrogen than legume pure stands due to mutual stimulation of nitrogen uptake from symbiotic and non-symbiotic sources

Concerted use of legumes and of functional diversity in grassland forage systems can provide major contributions to the challenges of agricultural systems being productive yet environmental friendly. Acquisition and transformation of nitrogen (N) resources by legumes and grasses were studied in a temperate grassland experiment near Zurich (Switzerland) to investigate mechanisms driving effects of functional diversity in mixed swards and to optimise mixtures for efficient resource use.

Grass–legume interactions and N availability were varied by manipulating legume percentage of the sward (0–100%) and N fertiliser application (50, 150 or 450 kg of N ha^{-1} $year^{-1}$). ^{15}N technology quantified N derived from symbiotic (Nsym) and non-symbiotic (Nnonsym) sources.

Generally, acquisition of Nsym by the entire mixture was stimulated by grasses. As a result, strong overyielding of Nsym occurred (e.g. 75 and 114% for year 1 and 2 at N150) and mixtures with only 60% and 37% legumes (year 1 and 2) already attained the same Nsym yield as pure legume stands. Legumes stimulated Nnonsym acquisition by the entire mixture, largely via increased uptake by the grass component. Thus, overyielding of Nnonsym of 31% occurred in year 1 (N150).

Mutual grass–legume interactions stimulated acquisition of Nsym, acquisition of Nnonsym and efficient transformation of N into biomass compared to either monocultures. These effects of functional diversity can substantially contribute to productive and resource efficient agricultural grassland systems and were maximised in mixtures with 40–60% legumes.

- We describe how legume proportion modifies N acquisition from different sources.
- Symbiotic N_2 fixation was stimulated in mixtures compared to monocultures.
- Uptake of N from soil N pools was stimulated in mixtures compared to monocultures.
- The acquired N was used more efficiently by mixtures for biomass production.

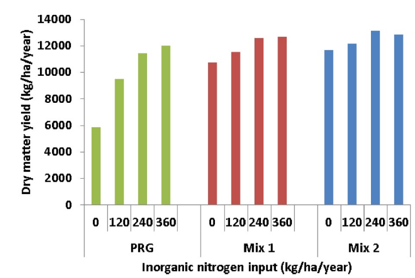
* Nyfeler *et al* (2011). doi.org/10.1016/j.agee.2010.11.022

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.

Irish Journal of Agricultural and Food Research

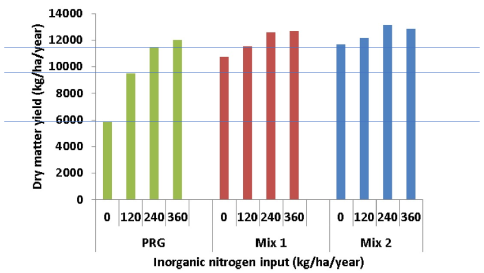
Yield of binary- and multi-species swards relative to single-species swards in intensive silage systems



* Moloney, T., *et al.*, (2020). doi: 10.2478/ijafr-2020-0002

Irish Journal of Agricultural and Food Research

Yield of binary- and multi-species swards relative to single-species swards in intensive silage systems

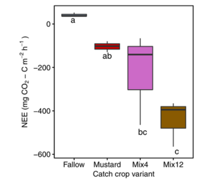


* Moloney, T., *et al.*, (2020). doi: 10.2478/ijafr-2020-0002

Biology and Fertility of Soils

Catch crop diversity increases rhizosphere carbon input and soil microbial biomass

- Mustard (mono) vs 4-way mix or 12-way mix
- CO_2 uptake 2x higher in mix-4 and 3x higher in mix-12
- Total microbial biomass 8% higher in mix-4 and 18% higher in mix-12
- Fungal and actinobacteria most responsive
- C residence time increased with mixture by up to 1.8 times



> *The results of this study suggest positive impacts of plant diversity on C cycling by higher atmospheric C uptake, higher transport rates towards the rhizosphere, higher microbial incorporation and prolonged residence time in the soil environment.*

* Gentsch *et al* (2020). doi.org/10.1007/s00374-020-01475-8


Questions, Discussion?
more info, mailing list:
www.integratedsoils.com
@integratedsoils