Knowledge grows

Yara Long-term Regenerative Agriculture trial:

Balanced Crop Nutrition for Sustainable Grain Production

Trial code:	S2023-11-GRAIN-S
Project leader:	Jacques Smith
Locality:	Boland Agricultural school, Wellington
Season:	2023 - 2032
Co-worker:	Boland agricultural school, Altona

Yara SA approach on Regenerative Agriculture.

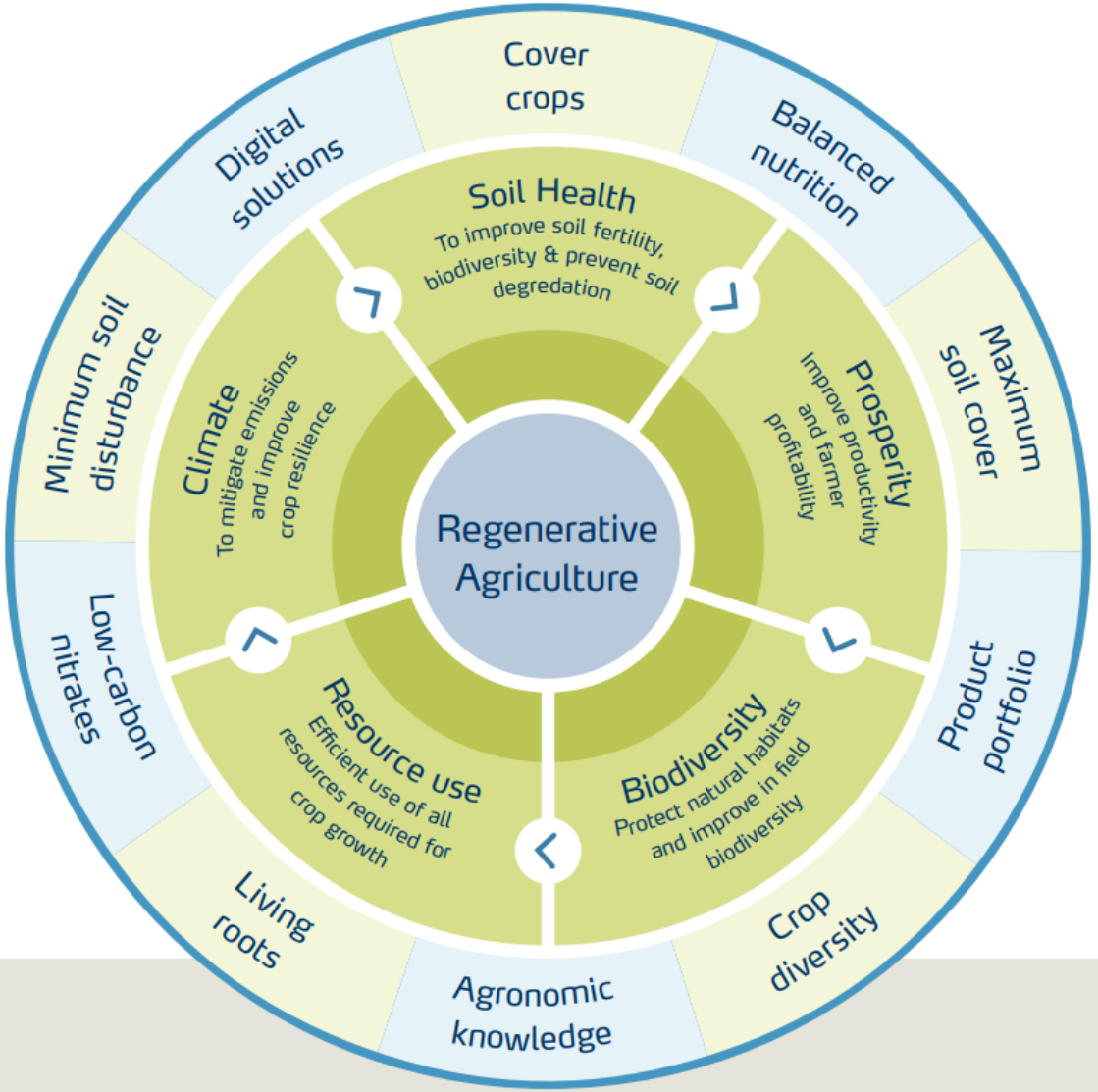
- ***What is Regenerative Agriculture***

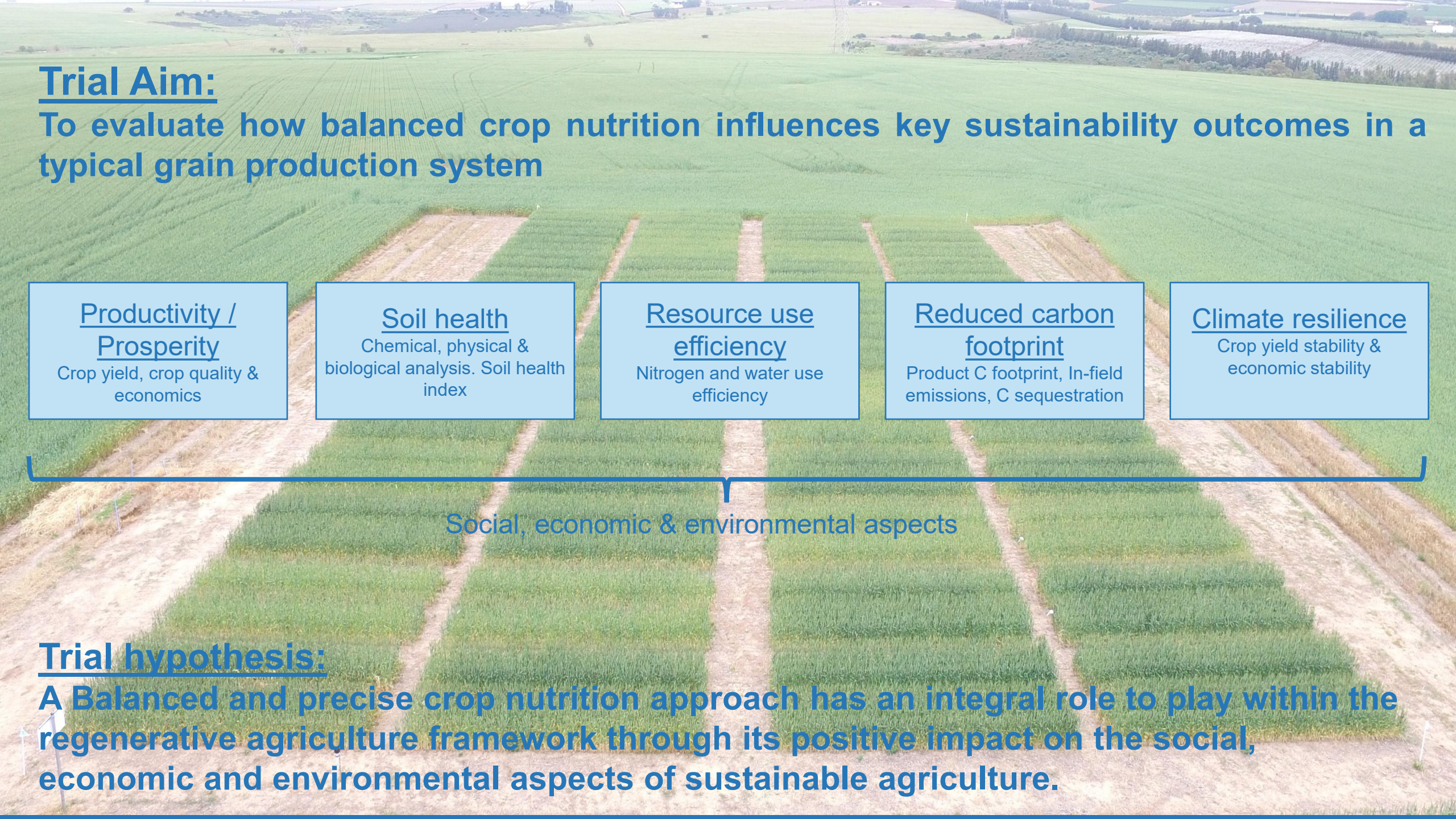
RA is a systematic, outcome-based approach to adopt the best sustainable farming practices that positively affects **soil health**, **climate**, **farmer prosperity**, **resource use**, and **biodiversity**.

- ***Approach:***

Holistic, scientific, context specific & outcome-based.

- ***Examples of Sustainable farming practices / solutions***
  - Maximum soil cover / mulching
  - Crop diversity
  - Minimum soil disturbance
  - Livestock integration
  - Living roots / cover cropping
  - Biotechnology
  - Improved crop genetics
  - **Balanced & precise crop nutrition**





Trial Aim:

To evaluate how balanced crop nutrition influences key sustainability outcomes in a typical grain production system

Productivity / Prosperity	Soil health	Resource use efficiency	Reduced carbon footprint	Climate resilience
Crop yield, crop quality & economics	Chemical, physical & biological analysis. Soil health index	Nitrogen and water use efficiency	Product C footprint, In-field emissions, C sequestration	Crop yield stability & economic stability

Social, economic & environmental aspects

Trial hypothesis:

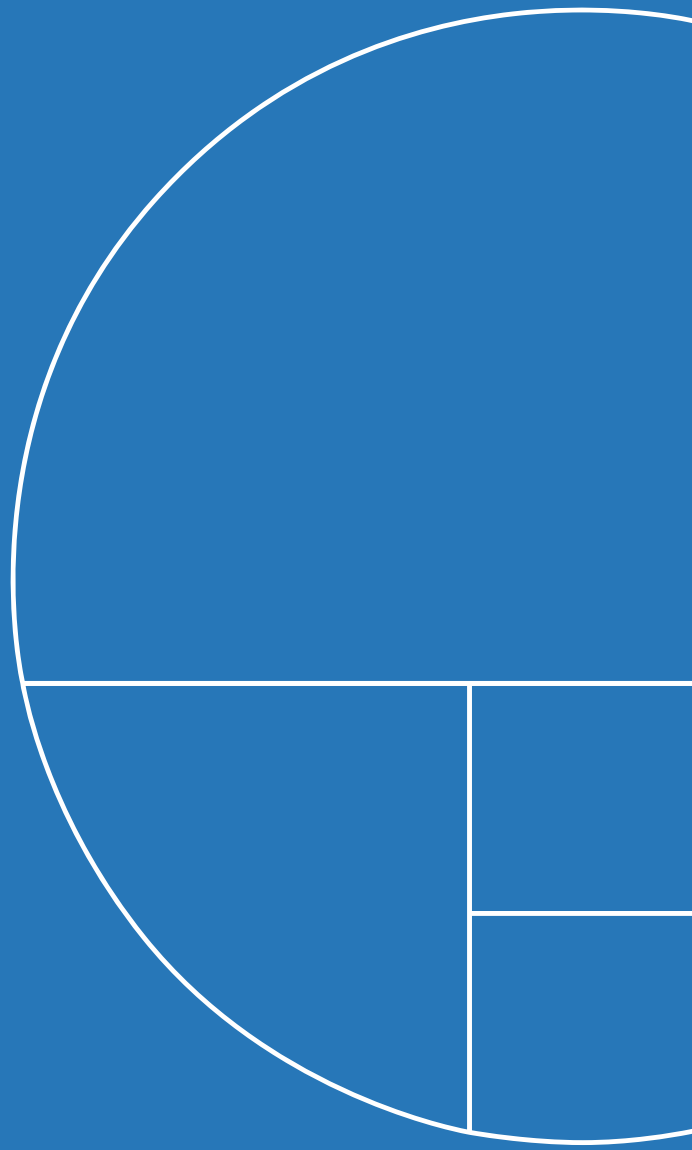
A Balanced and precise crop nutrition approach has an integral role to play within the regenerative agriculture framework through its positive impact on the social, economic and environmental aspects of sustainable agriculture.

Benefits of Long-term (LT) trials

- **Classification of LT trials (Steiner and Herdt 1993):**
  - − **Young (5 – 20 years)**
  - − Medium (20 – 50 years)
  - − Classical (> 50 years)
- **Benefits of LT trials**
  - Main tool to study agricultural sustainability
    - Monitor changes in crop productivity, soil health, interrelation of crop and soil with environment, and crop yield stability and trend
  - Verification and practical application of findings.
  - Play key role in further research and education.

Industry trial: Group visits

TRIAL INFORMATION



Trial site

- Boland Agricultural school situated 10km outside Wellington in the Western Cape, South Africa (33°39’51.79’’S; 18°52’56.22’’)
- Region is known as the Koeberg small grain production area.
- Poorly developed, shallow shale-derived duplex soils with high coarse fragments
- Mediterranean climate, characterized by cold wet winters and hot dry summers. Average rainfall is 450mm per year with 80% of the rainfall from April to October.
- Cropping history: Pastures (lucerne) and grain crops (wheat, oats, canola)
- Conservation agriculture principles applies at trial site:
  - Minimum mechanical soil disturbance
  - Crop rotation
  - Permanent soil organic cover (at least 30%) with crop residues
- Optimal chemical control
- Trial site was established in April 2023

Soil analysis (prior to start of trial in 2023)

- In total 27 referenced composite soil samples was taken within the trial site. One sample per two trial plots (8m x 9m)
- Below is a composite sample analysis per block (one block represents 14 trial plots ~ 28m x 18m)

Camp	Depth	pH	P	K	Ca	Mg	Na	K	Ca	Mg	Na	K	Ca	Mg	Na	K_2SO_4 (H^+)	Ca:Mg	(Ca+Mg)/K	Mg:K	Acid Sat	S-Value	T-Value	Base Sat	Density
		KCl	Bray 1	Amm Acetate				%				meq = cmol(+)/kg					Norms			%	cmol(+)/kg	cmol(+)/kg	%	g/cm^3
			mg/kg	mg/kg													1.5 - 4.5	10 - 20	3 - 4					
Block A	20	5.2	16	89	563	53	21	5.6	69.2	10.7	2.2	0.23	2.82	0.44	0.09	0.50	6.5	14.3	1.9	12.3	3.6	4.1	87.7	1.181
Block B	20	5.3	19	101	638	59	27	5.8	71.5	10.8	2.6	0.26	3.19	0.49	0.12	0.41	6.6	14.2	1.9	9.2	4.0	4.5	90.8	1.203
Block C	20	5.5	13	84	591	54	21	5.3	72.4	10.8	2.2	0.22	2.96	0.44	0.09	0.38	6.7	15.8	2.1	9.3	3.7	4.1	90.7	1.155
Block D	20	5.5	12	97	676	61	23	5.4	73.7	10.9	2.2	0.25	3.38	0.50	0.10	0.36	6.8	15.6	2.0	7.8	4.2	4.6	92.2	1.133

Camp	Depth	Cu	Zn	Mn	Fe	B	S	Ohm	Clay	Silt	Sand	Carbon	Organic Matter	Tot N	C:N
		0.1M HCl				H_2O	Am Ac		Hydrometer			WB	%	LECO	
		mg/kg				mg/kg	mg/kg		%			%		%	
Block A	20	0.58	0.60	14.90	19.86	0.36	9.3	3284	24	24	52	1.16	2.00	0.10	11.72
Block B	20	0.57	0.58	16.29	17.35	0.25	10.7	2561	24	18	58	1.24	2.13	0.13	9.83
Block C	20	0.52	0.48	14.00	20.05	0.14	8.0	3428	22	18	60	1.12	1.93	0.10	10.77
Block D	20	0.53	0.64	16.70	20.36	0.20	10.5	2915	24	18	58	1.18	2.03	0.11	10.83

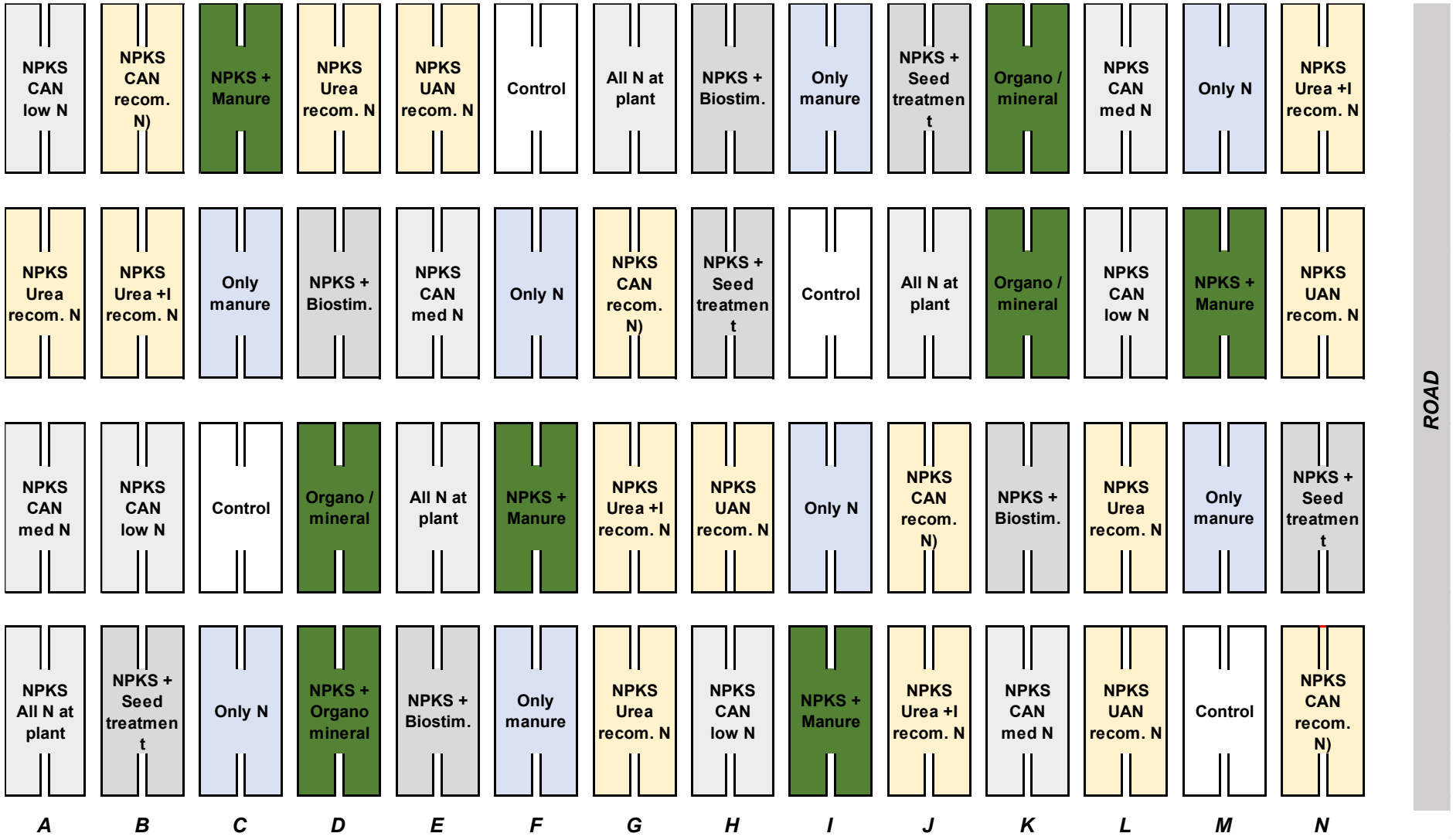
Experimental design & Treatments

- Trial set up: Completely randomized block design
- 14 treatments replicated 4 times
- 2 duplicate plots per treatment (112 plots); Gross plot: 9m x 1.5m (x 2)
- Total trial area: 56m x 36m = 0.2 ha
- **Fertilizer treatments are grouped as follows:**
  - Control (without any fertilizer)
  - Farmyard manure (FYM) alone as organic fertilizer (Organic nutrition)
  - FYM or enriched organic chicken manure pellets and mineral fertilizer together as integrated nutrition
  - NPKS mineral fertilizer application as balanced nutrition
  - Omitting P & K from mineral fertilizer
  - Variation in Nitrogen management (N-sources, N-rates & N-timing) from mineral fertilizer nutrition
  - Seed treatment and biostimulants integrated into balanced NPKS crop nutrition program

Experimental design & Treatments

Nr	Treatment	Treatment details
1	Control (without fertilizer)	No fertilizer
2	Only Manure	Organic fertilizer - unbalanced crop nutrition approach
3	Only N (100% recommended split N-rate)	Mineral fertilizer - unbalanced crop nutrition approach
4	NPKS (All N at planting)	No N-management
5	NPKS (low N)	About 25% of recommended N for season
6	NPKS (medium N)	About 50% of recommended N for season
7	NPKS (recommended split N-rate (CAN)	Balanced mineral fertilizer - CAN as top dress N-source
8	NPKS (recommended split N-rate (Urea)	Balanced mineral fertilizer - Urea as top dress N-source
9	NPKS (recommended split N-rate (Urea + I)	Balanced mineral fertilizer - Amiplus as top dress N-source
10	NPKS (recommended split N-rate (UAN_{Liq})	Balanced mineral fertilizer - UAN as top dress N-source
11	NPKS + seed treatment	Balanced mineral fertilizer & Seedlift as seed treatment
12	NPKS + biostimulants	Balanced mineral fertilizer + OptiNUE & BioNUE
13	NPKS + Manure	Integrated (manure/mineral) balanced crop nutrition approach
14	NPKS + Organo-mineral based fertilizer	Integrated (organo mineral /mineral) balanced crop nutrition approach

Experimental design & Treatments



Trial layout

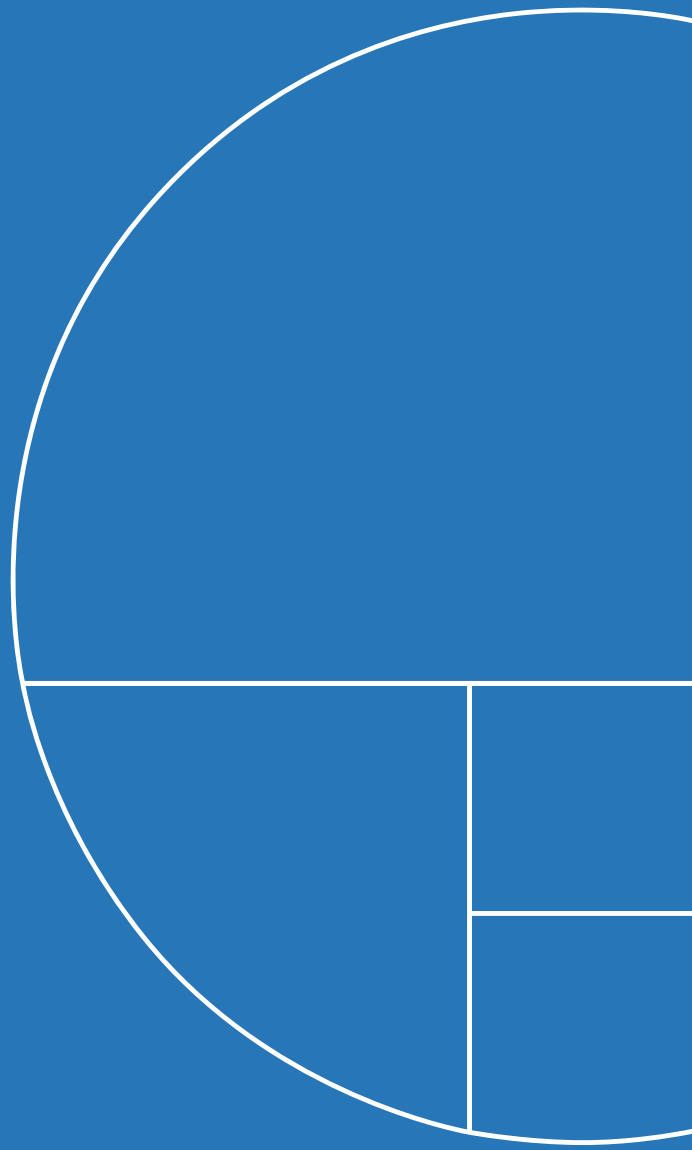
General overview of nutrient application rates

- Soil nutrient levels (P & K) was corrected once-off at start of trial in 2023 based on soil analysis (*refer to soil analysis*).
- Soil pH to be optimized by lime application (additional Ca & Mg) every 3-years to avoid negative effect of pH on nutrient availability
- All crops received specific nutrient input followed local standard practices
- Mineral N, P, K, S fertilizer application rates based on soil analysis, crop removal, and seasonal conditions
- Seasonal recommended N-rate is based on optimized nitrogen management practices
- N, P, K, S contents of chicken manure (FYM) are accounted for in the total nutrient application rate.
- FYM applied annually as chicken manure at 3 - 5m^3 (integrated with mineral fertilizer) or 13 - 15m^3 for FYM only (100% organic) for all crops within crop rotation system.

Measurements

- **Soil measurements**
  - Chemical properties
  - Physical properties
  - Biological properties
- **Agronomic measurements**
  - Crop establishment
  - Leaf / tissue analysis during season
  - N-tester readings
  - Nutrient uptake by grain and straw
  - Final crop yield and seed/grain quality
- **Economical measurements**
  - Gross margins (R/ha)
  - Revenue
- **Environmental measurements**
  - Carbon sequestration
  - Nitrogen use efficiency (NUE) and rainfall use efficiency (RUE)
  - Direct in-field Greenhouse gas emissions (methane, N_20) on selected treatments during the season on a weekly basis.
  - Product Carbon footprint

2023 RESULTS:

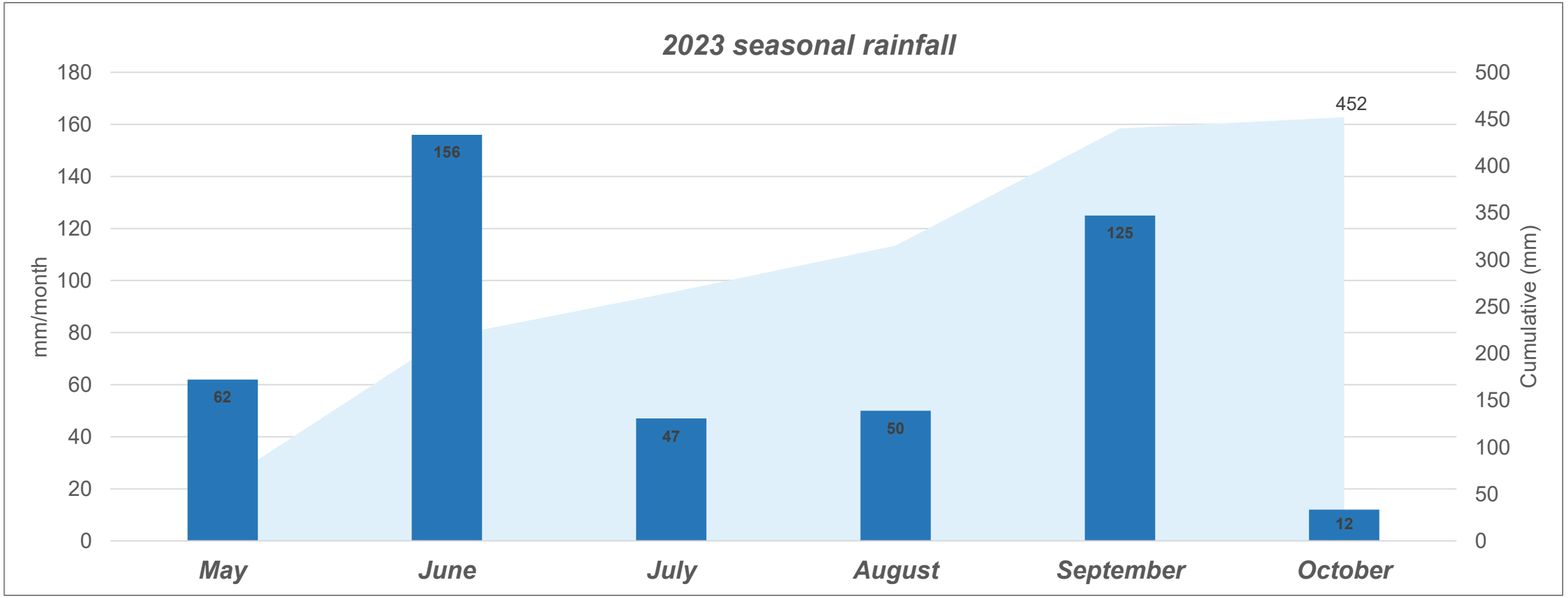


Summary

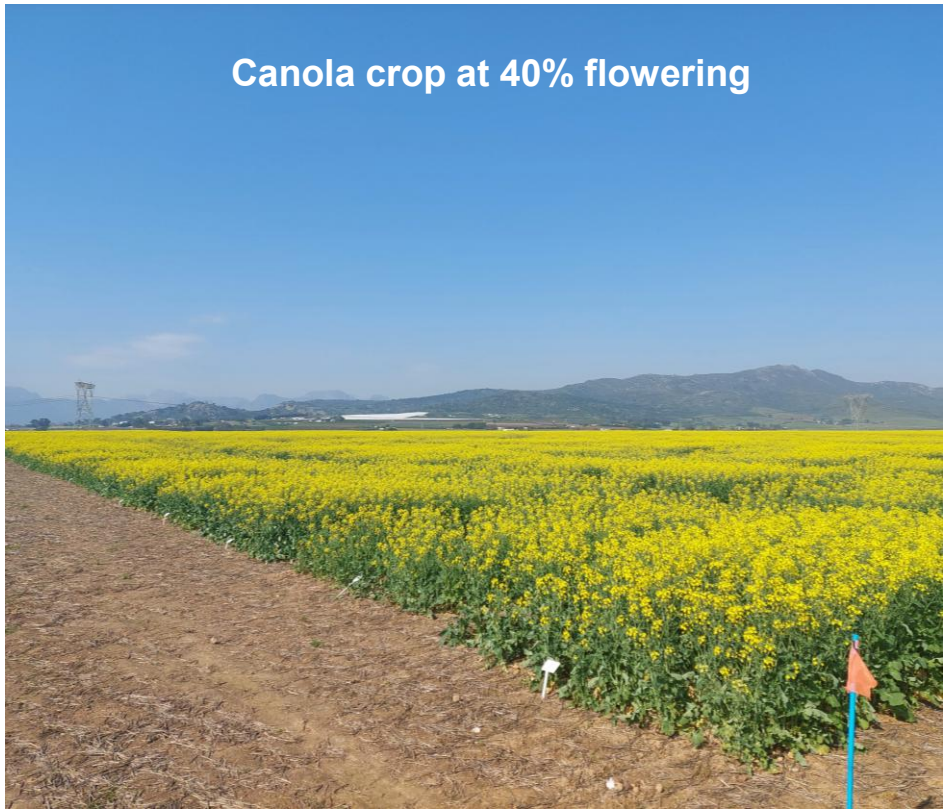
- Canola crop benefitted from the built-up of soil fertility in the recent past, including P and K soil corrections prior to planting, residual fertilizer N from previous years and additional N contribution from legume crop (lucerne in 2020)
- Although very good average canola yield of 2.97 ton/ha was achieved, crop response to various combinations of nutrient applications (organic, integrated (organic & mineral) and mineral fertilizer) was relatively low.
- With low levels of N-input, and high N-output (yield & %N) in the control treatment, nitrogen use efficiency (NUE) was very high, implying a possible depletion of soil N stocks and general soil fertility over the longer term.
- Highest yield of 3.37 ton/ha was achieved in the Amiplus S (as topdressing) treatment, significantly ($P<0.05$) higher compared to the control (2.37 ton/ha), 25% N-rate (2.46 ton/ha) and the 100% manure (2.60 ton/ha) treatments.
- Additional application of bio-stimulants and seed-treatment did not have a significant effect on canola yield.
- Where CAN + S was applied as top dressing, similar yields of 2.94 and 2.97 ton/ha were achieved at a 50% (55N) and 100% N-rate (112N), respectively.

Trial objective (s)	Year 1: Year 2: Evaluate the agronomic and economic effect of crop nutrition management practices on dry land canola production.
Trial type	Long-term (10 years) scientific field trial

Climate data - rainfall



Trial photos



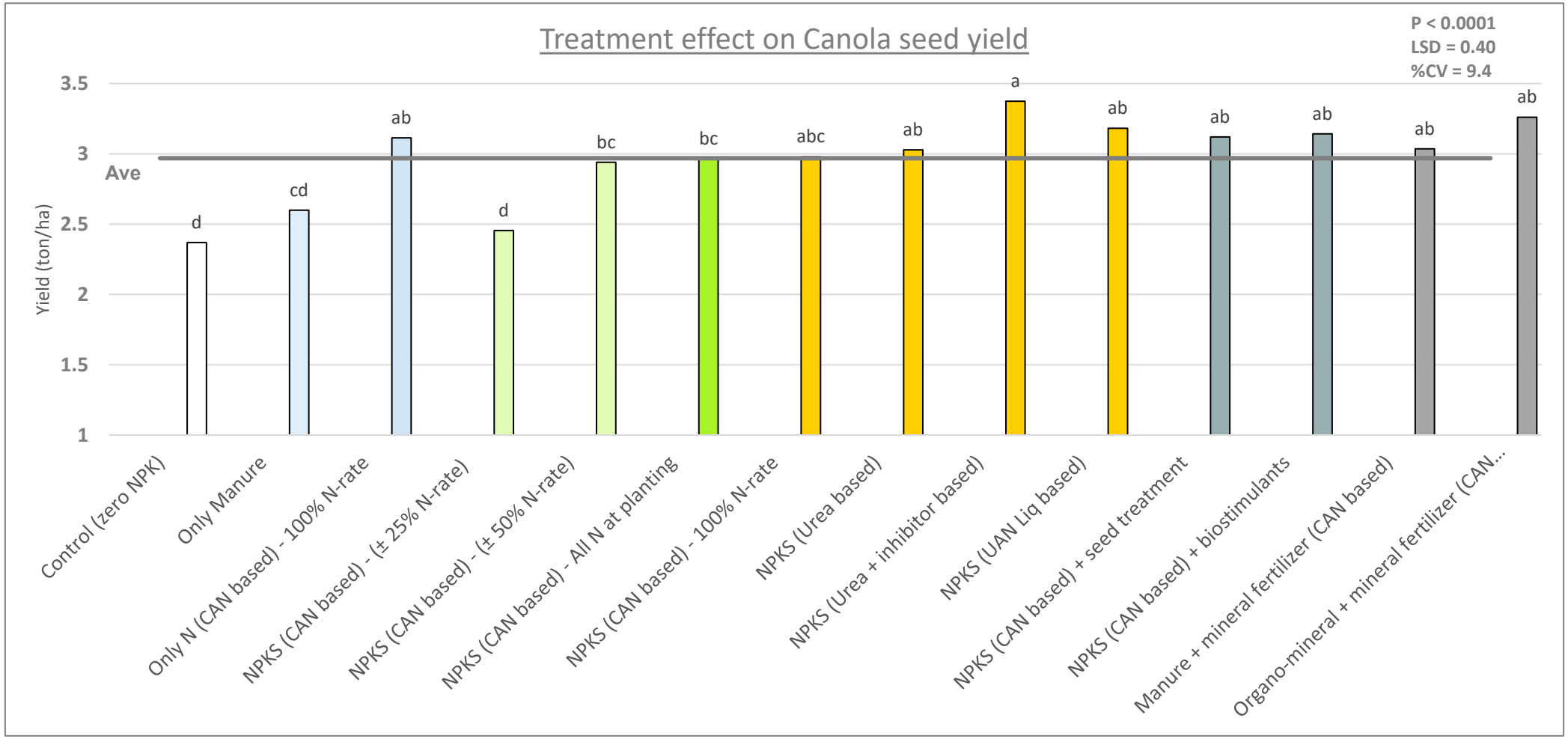
Trial site detail & general practices

- **Previous crop**: Wheat (note; lucerne was grown till 2020 on these fields)
- **Cultivar**: Blazer TT
- **Plant date**: 4 May 2023
- **Planter**: Equalizer no-till tine planter (5 tines x 30cm row width)
- **Plant density:** 4.5 kg/ha ~ 60 plants/m^2 at 80% emergence
- **Fertilization**: Refer to treatments for more detailed information
  Plant: YaraMila Lunar & 7.7.7 (21) enriched chicken manure pellets & broadcasted chicken manure ; YaraVita BioNUE biostimulant applied as per treatment
  1st top dressing: 21 days after emergence (9 June)
  2nd top dressing: At stem elongation (17 July)
  Foliar: YaraVita Biotrac as per treatment and 1L/ha Mancozin + 0.5L/ha Bortrac (17 July)
- **Pest control**: Optimal practices - Triflurex 480 herbicide pre-plant + post emergence Atraflo (triazine) herbicide
- **Harvest**: 9 November 2023 with Plot harvester of University of Stellenbosch

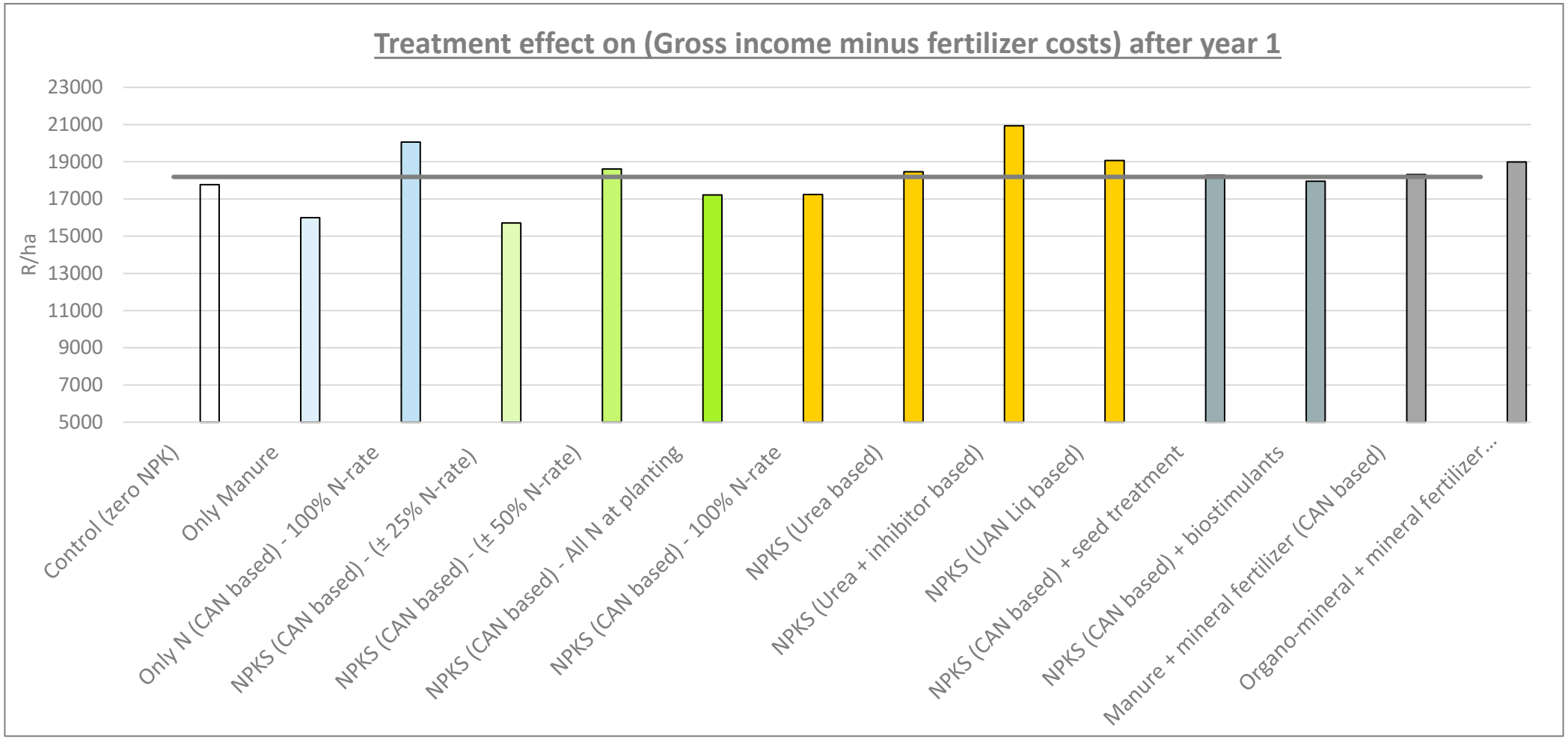
2023 Treatments & nutrient application rates for canola crop

Nr	Treatment	N	P	K	S	Addiitonal information
1	Control (zero NPK)	0	0	0	0	
2	Only Manure (4 ton/ha ~ 14m3)	69	16	90	15	Chicken manure broadcast prior to plant
3	Only N (CAN based) - 100% N-rate	112	0	0	18	100% N-rate - season recommendation
4	NPKS (CAN based) - (± 25% N-rate)	30	17	23	7	
5	NPKS (CAN based) - (± 50% N-rate)	55	17	23	10	
14	NPKS (CAN based) - All N at planting	112	17	23	18	
6	NPKS (CAN based) - 100% N-rate	112	17	23	18	CAN as topdressing N-source
7	NPKS (Urea based)	112	17	23	18.5	Urea as topdressing N-source
8	NPKS (Urea + inhibitor based)	112	17	23	18.5	Amiplus as topdressing N-source
9	NPKS (UAN Liq based)	112	17	23	18	UAN liq as topdressing N-source
10	NPKS (CAN based) + seed treatment	112	17	23	18	12 L/ton Teprosyn Bio
11	NPKS (CAN based) + biostimulants	112	17	23	18	2L/ha BioNUE at plant + 2 x 2L/ha Biotrac at 4 & 6 weeks after emergence
12	Manure (1 ton/ha~3m^3) + mineral fertilizer (CAN based)	112	17	23	17	Chicken manure broadcast prior to plant
13	Organo-mineral + mineral fertilizer (CAN based)	112	17	23	13	Atlantic fertilizer Bio Enrich 7.7.7 (21) as plant fertilizer

Trial results – Agronomic performance

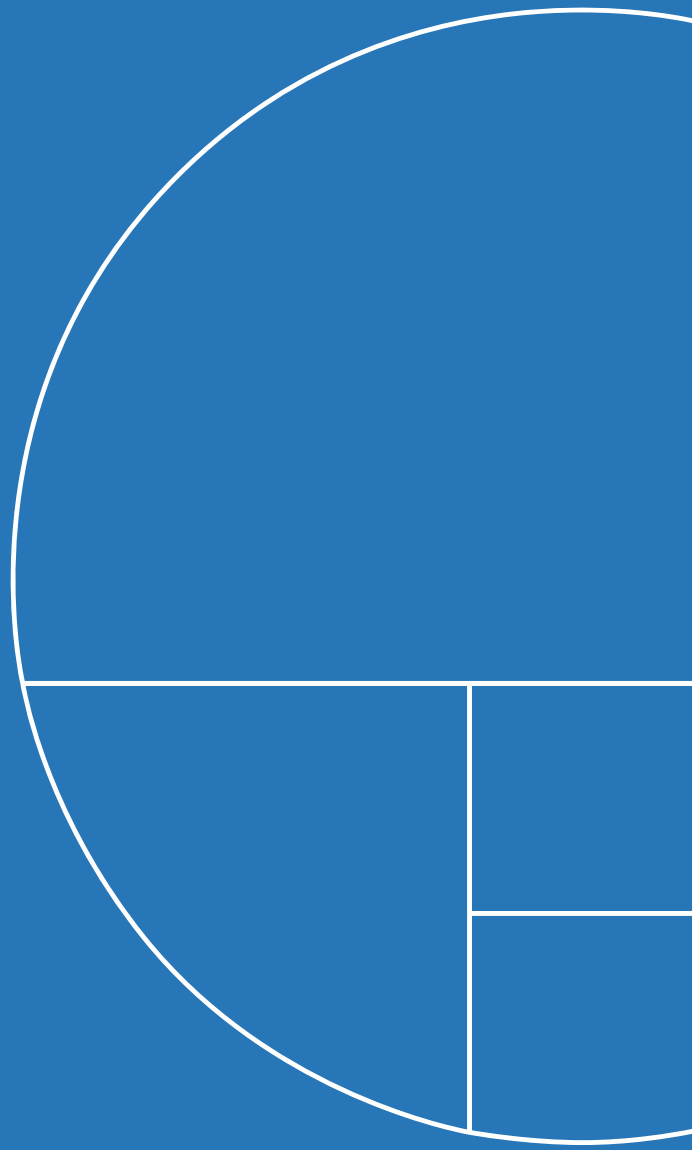


Trial results – Economic performance



Calculations based on May 2023 fertilizer prices and a canola price of R7500/ton

2024 RESULTS

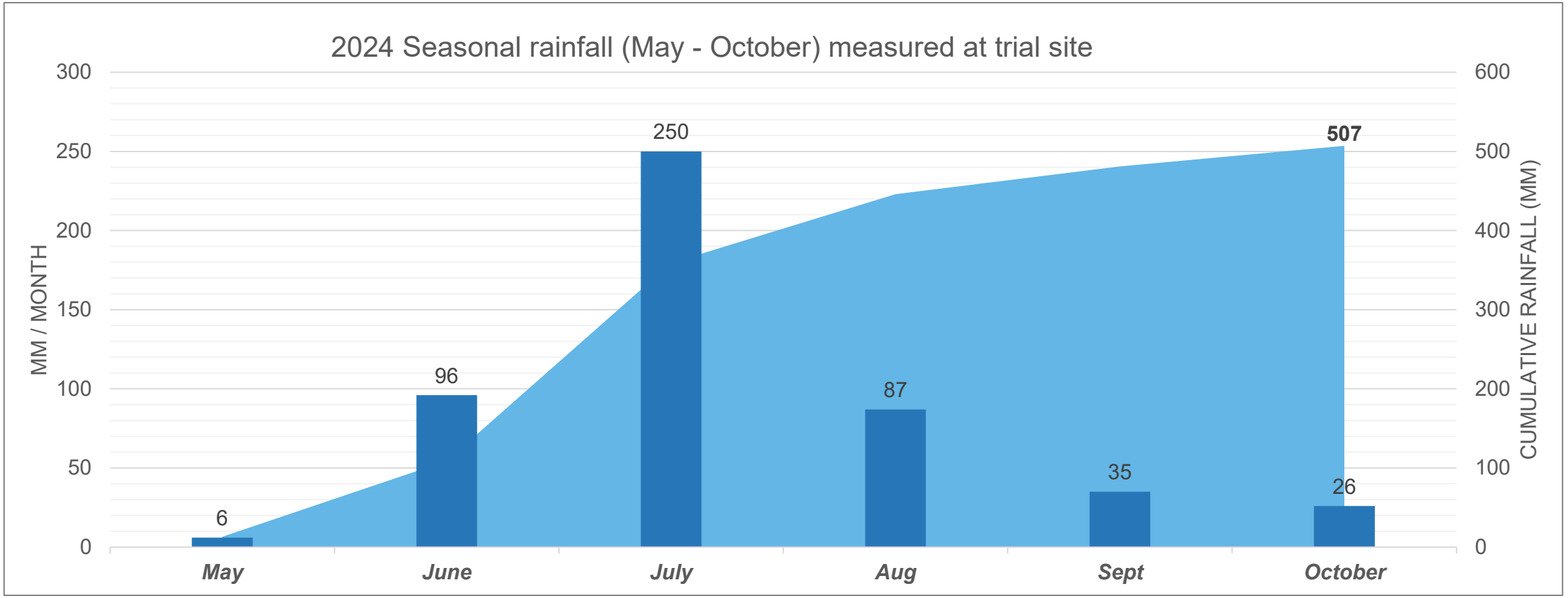


Summary

- An average wheat yield of 4.02 ton/ha and protein content of 9.8% was achieved in this trial. The various fertilizer application strategies had significant (P<0.05) agronomic and economic effects on dry land wheat production.
- Lowest yield and protein content of 2.78 ton/ha and 9%, respectively was obtained in the control (without fertilizer), whilst the highest yield (4.52 ton/ha) and protein content of 10.53% was achieved for the Teprosyn Bio seed treatment. Organo-mineral based fertilizer treatment also resulted in similar high yields of 4.53 ton/ha and 10.1% protein.
- The Teprosyn Bio seed treatment resulted in ± 300kg/ha yield increase, and a 15% revenue increase compared to the balanced mineral fertilizer NPKS program.
- No significant yield or protein differences between the various N-sources (CAN, Urea, Amiplus & UAN24) as top dressing, although a 11% higher revenue was obtained for amiplus and urea N-sources compared to CAN.
- 100% recommended split N-rate (NPKS) program resulted in significantly higher yield and protein compared to control (0N) and 25% N-rate, whilst it also economically outperformed the control, 25% N-rate, 50% N-rate, and all N applied at planting fertilizer strategies.
- Balanced mineral or organic/mineral integrated crop nutrition (NPKS) program resulted in significantly higher yields and revenue compared to manure only (100% organic). Effective use of nutrients in manure is limited by high variability of nutritional composition and uncertainty of nutrient availability

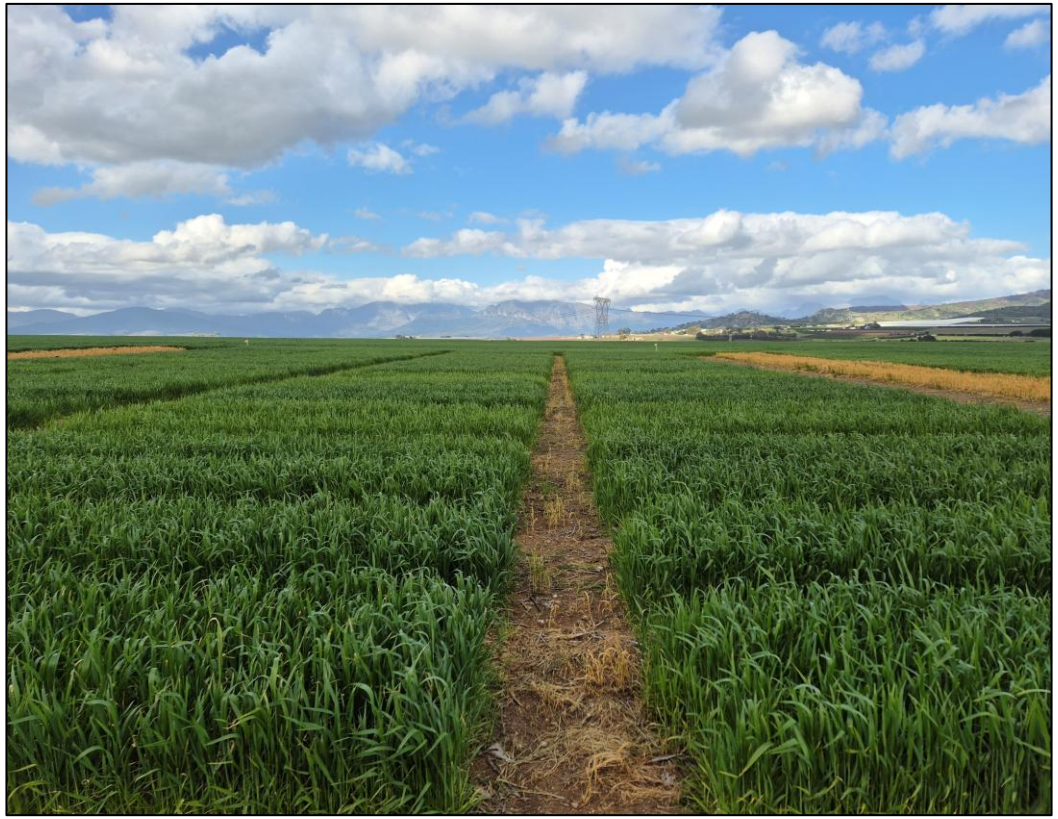
Trial objective (s)	Year 2: Evaluate the agronomic and economic effect of crop nutrition management practices on dry land wheat production.
Trial type	Long-term (10 years) scientific field trial

2024 Climate data



Trial photos

- Wheat crop mid-August.
- Treatment effects clearly visible



- Crop during grain filling

- Harvest, 2 November

2024 Trial detail & general practices

- **Previous crop**: Canola
- **2024 Crop:** Wheat
- **Cultivar**: SST 0187
- **Plant date**: 2 May 2024
- **Planter**: Equalizer no-till tine planter (5 tines x 30cm row width)
- **Plant density:** 93 kg/ha ~ 180 plants/m^2 at 85% emergence
- **Fertilization**: Refer to treatments for more detailed information

  Plant: Alpha 359 (3.3.1. + S) & 7.7.7 (21) enriched chicken manure pellets & broadcasted chicken manure.

  1st top dressing: 4-leaf stage (28th of June)

  2nd top dressing: Flagleaf stage (12th of Aug)

  Foliar: YaraVita Biotrac (Biostimulant) as per treatment and 1L/ha Mancozin + 0.5L/ha Bortrac (17 July) as standard on whole trial.
- **Pest control**: Optimal practices - Herbicides: Sakura at plant; Resolve at 3-leaf stage; Fungicides: Aviator (31 July) & Ceriax (31 August)
- **Harvest**: 2nd of November with Plot harvester

2024 Treatments & nutrient application rates for wheat crop

Treatment (Fertilizer application strategy)	N	P	K	S	Additional information
Control (without fertilizer)	0	0	0	0	
Only Manure	108	23	35	7	13m^3 Chicken manure broadcast pre-plant
Only N (CAN) (recommended split N-rate)	119	0	0	15	100% N-rate - season recommendation
NPKS (CAN) (All N at planting)	110	18	24	17	Pre-season N-recommendation
NPKS (CAN) (low N)	30	18	24	6.5	25% of recommended N-rate
NPKS (CAN) (medium N)	60	18	24	9	50% of recommended N-rate
NPKS (CAN) (recommended split N-rate)	119	18	24	18	CAN as topdressing
NPKS (UREA) (recommended split N-rate) (Urea)	119	18	24	18	Urea as topdressing
NPKS (AMIPLUS)(recommended split N-rate)	119	18	24	18	Amiplus as topdressing
NPKS (UAN24liq) (recommended split N-rate)	119	18	24	17	UAN24liq as topdressing
NPKS (CAN) + seed treatment	119	18	24	17	3 L Teprosyn Bio / ton seed
NPKS (CAN) + biostimulants	119	18	24	17	2 x 2L/ha Biotrac (Kelp-based) at 4 & 8 weeks after emergence
NPKS (CAN) + Manure	129	23	24	17	3m^3 Chicken manure broadcast pre-plant
NPKS (CAN) + Organo-mineral based fertilizer	119	18	25	13	Atlantic fertilizer Bio Enrich 7.7.7 (21) at plant

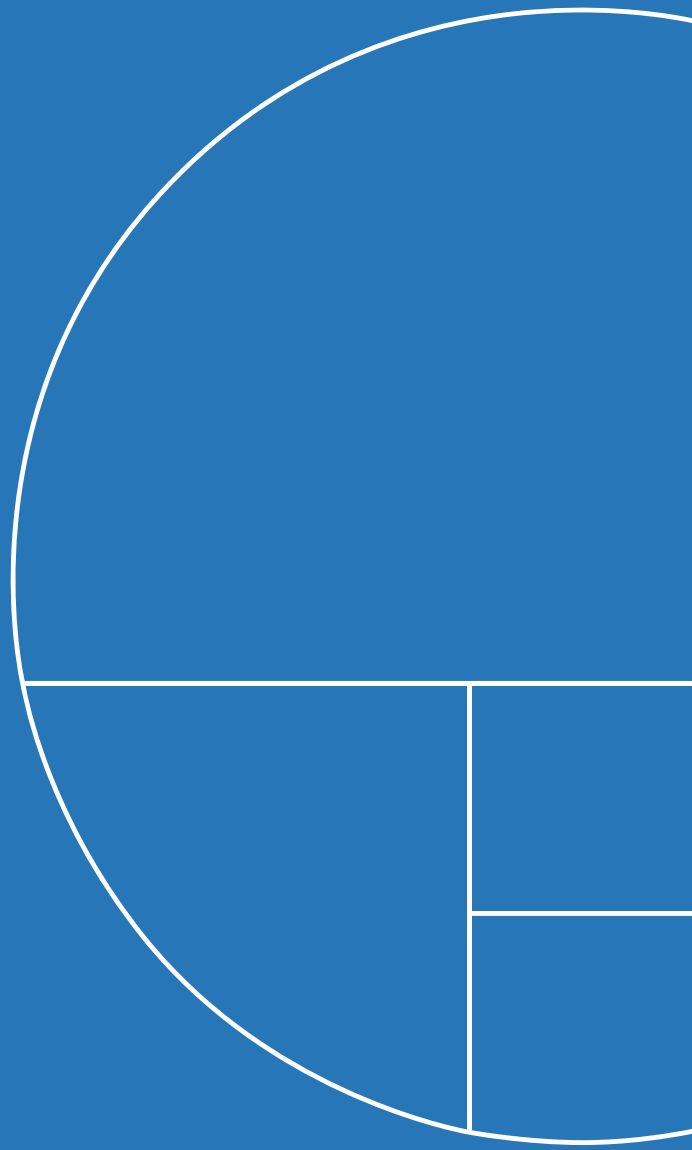
2024 Result summary Table:
Agronomic and economic effect of various fertilizer application strategies on wheat.

Treatment	Yield		Protein		HLM		Grading	Nitrogen & water use efficiency)		Crop revenue minus fertilizer cost	Relative Yield	Relative Revenue	2024 Agronomic ranking	2024 Economic ranking
	ton/ha	P<0.05	%	P<0.05	kg/hl	P<0.05		NUE (%)	WUE					
Control (without fertilizer)	**2.78**	*f*	**9.0**	*e*	**82.3**	*ab*	UT		5.5	R12,655	**100%**	**100%**	14	13
Only Manure	**3.36**	*e*	**9.2**	*e*	**82.2**	*ab*	UT	50	6.6	R11,045	**121%**	**87%**	12	14
Only N (CAN) (recommended split N-rate)	**3.89**	*d*	**10.1**	*bcd*	**82.4**	*a*	B3	58	7.7	R16,378	**140%**	**129%**	11	8
NPKS (CAN) (All N at planting)	**4.06**	*bcd*	**9.7**	*d*	**82.4**	*a*	B3	63	8.0	R16,206	**146%**	**128%**	8	8
NPKS (CAN) (low N)	**3.33**	*e*	**8.8**	*e*	**82.0**	*ab*	UT	172	6.6	R13,219	**120%**	**104%**	12	12
NPKS (CAN) (medium N)	**3.96**	*cd*	**9.1**	*e*	**81.9**	*b*	UT	105	7.8	R15,352	**143%**	**121%**	10	11
NPKS (CAN) (recommended split N-rate)	**4.17**	*abcd*	**10.2**	*abc*	**81.8**	*ab*	B3	63	8.2	R16,484	**150%**	**130%**	7	7
NPKS (UREA) (recommended split N-	**4.40**	*abc*	**10.0**	*bcd*	**82.0**	*ab*	B3	65	8.7	R18,208	**158%**	**144%**	4	3
NPKS (AMIPLUS) (recommended split N-	**4.45**	*ab*	**10.3**	*abc*	**82.3**	*ab*	B3	67	8.8	R18,330	**160%**	**145%**	3	2
NPKS (UAN24) (recommended split N-	**4.40**	*abc*	**10.4**	*ab*	**82.2**	*ab*	B3	67	8.7	R17,588	**158%**	**139%**	4	4
NPKS (CAN) + seed treatment	**4.52**	*a*	**10.5**	*a*	**81.9**	*ab*	B2	70	8.9	R18,950	**163%**	**150%**	1	1
NPKS (CAN) + biostimulants	**4.38**	*abc*	**10.0**	*bcd*	**82.2**	*ab*	B3	64	8.6	R17,087	**158%**	**135%**	4	6
NPKS (CAN) + Manure	**4.05**	*bcd*	**9.9**	*cd*	**82.2**	*ab*	B3	54	8.0	R15,424	**146%**	**122%**	9	10
NPKS (CAN) + Organo-mineral based	**4.53**	*a*	**10.1**	*abc*	**82.2**	*ab*	B3	68	8.9	R17,719	**163%**	**140%**	1	4

Crop renevue: Income based on Yield x average Safex wheat price (Dec 24):
Fertilizer costs: Based on fertilizer prices during 2024 growing season.

NUE: (N removal with crop yield divided by N fertilizer rate) × 100
WUE: kg grain divided by mm rain (May – Oct)

2025 RESULTS



Summary

Seasonal context

- Rainfall: 297 mm (May–Oct), with most rain concentrated in June–July.

Treatments & yield outcomes

- Control (no fertilizer): 2.83 t/ha, lowest yield.
- Manure alone: 3.74 t/ha, moderate improvement but economically weaker.
- Mineral NPKS strategies (CAN, Urea, UAN, Amiplus): Yields ranged 3.82–4.08 t/ha.
- Best yield: **UAN-based NPKS split application (Treatment 10)** at 4.08 t/ha, ranking highest agronomically and economically.
- Biostimulant addition (Treatment 12) also performed strongly (4.03 t/ha), showing agronomic benefit.
- Integrated approaches (manure + mineral, organo-mineral) yielded ~4.0 t/ha, competitive but less profitable.

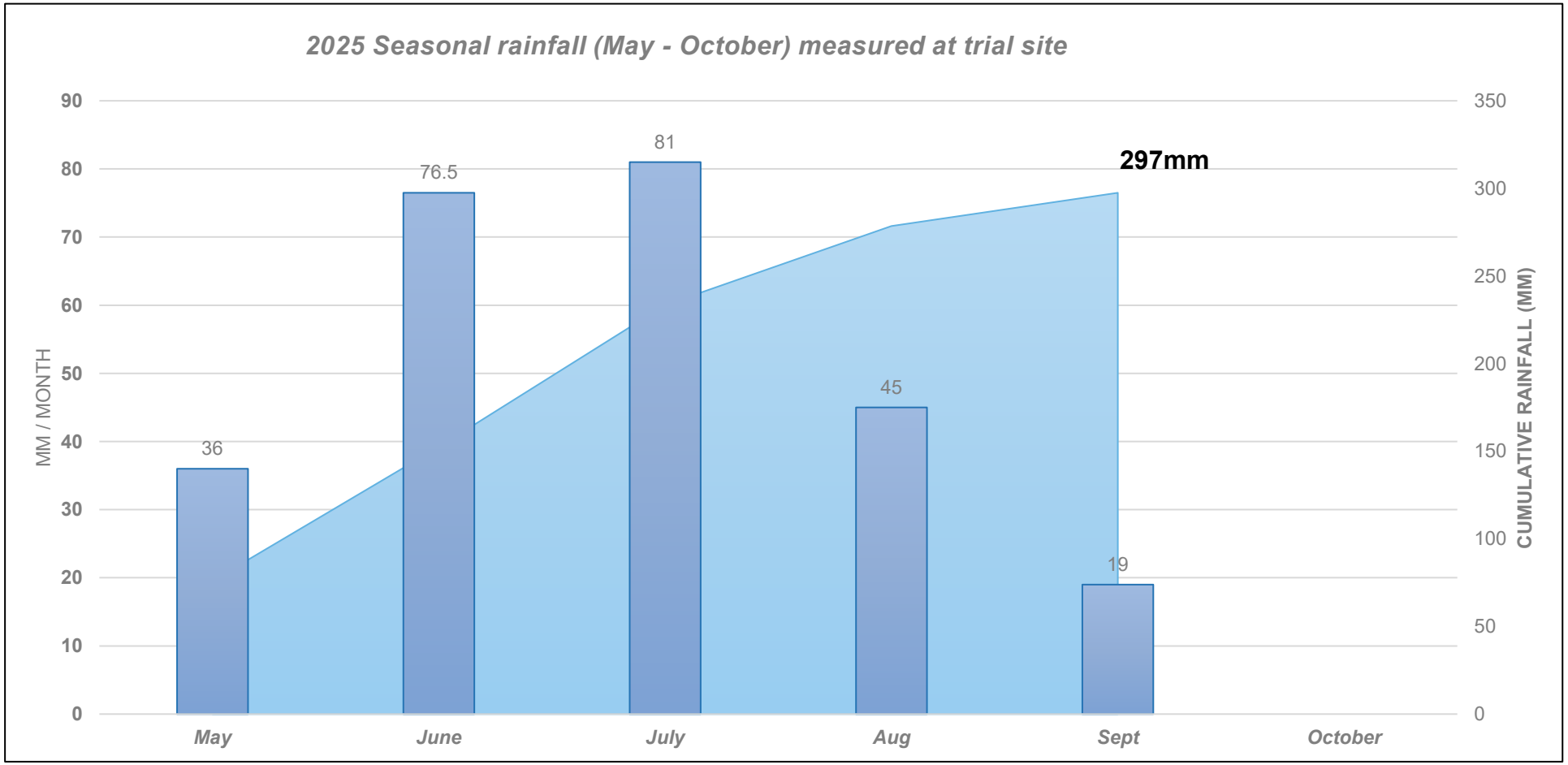
Economic performance

- Net revenue (yield × price – fertilizer cost) was highest for **UAN split NPKS (Treatment 10)** and **medium N-rate CAN-based NPKS (Treatment 6)**.
- Low N rate (Treatment 5) showed very high nitrogen use efficiency (165%) but lower yield and revenue.

Soil health findings (Feb 2026)

- Manure-based treatments improved soil organic carbon and nutrient levels (higher active C, Ca, Mg, Zn).
- Balanced mineral NPKS maintained soil fertility but with less organic matter improvement.
- Integrated strategies (NPKS + manure or organo-mineral) offered a middle ground: good yields with improved soil biological indicators.

2025 Climate data



Trial photos

- Oats crop planted, 23 May

- Crop during stem elongation phase

- Harvest, 10 November

2025 Trial detail & general practices

- **Previous crop**: Wheat
- **2025 Crop:** Oats
- **Cultivar**: SSH 491
- **Plant date**: 23 May 2025
- **Planter**: Equalizer no-till tine planter (5 tines x 30cm row width)
- **Plant density:** 70 kg/ha ~ 150 plants/m^2 at 80% emergence
- **Fertilization**: Refer to treatments for more detailed information

  Plant: Alpha 359 (3.3.1. + S) & 8.8.3 (19) enriched chicken manure pellets & broadcasted chicken manure.

  1st top dressing: 4-leaf stage (30th of June)

  2nd top dressing: Flagleaf- 1 stage (1st of Aug)

  Foliar: YaraVita Optitrac (Biostimulant) as per treatment (4-leaf stage, 23 Jun) and 0.5L/ha (flagleaf-1, 1 Aug) as standard on whole trial.

Mancozin

- **Pest control**: Herbicides: Pre-plant (Scorcher 200); Resolve at 5-leaf stage; Fungicides: Ceriax (9 July & 1 August)
- **Harvest**: 10 November with Plot harvester

2025 Treatments & nutrient application rates for oats crop

Nr	Treatment	N	P	K	S	Addiitonal information
1	Control (zero NPK)	0	0	0	0	
2	Only Manure	144*	25	125	21	5.9 ton/ha / 15m3 Chicken manure broadcast pre-plant
3	Only N (CAN based) - 100% N-rate	91	0	0	0	100% N-rate - season recommendation
4	NPKS (CAN based) - All N at planting	91	17	20	16.5	
5	NPKS (CAN based) - (± 25% N-rate)	30	17	20	6.5	
6	NPKS (CAN based) - (± 50% N-rate)	50	17	20	9	
7	NPKS (CAN based) - 100% N-rate	91	17	20	18	
8	NPKS (Urea based)	91	17	20	18	
9	NPKS (Urea + inhibitor based)	91	17	20	18	
10	NPKS (UAN Liq based)	91	17	20	17	
11	NPKS (CAN based) + seed treatment	91	17	20	17	4L/ton seed Teprosyn Bio
12	NPKS (CAN based) + biostimulants	91	17	20	17	2L/ha fulvic acid at plant + 1 x 2L/ha Biotrac at 5 weeks after emergemce
13	Manure + NPKS mineral fertilizer (CAN based)	134*	25	48	22	5m3 Chicken manure broadcast pre-plant
14	Organo-mineral + mineral fertilizer (CAN based)	91	17	20	15	Atlantic fertilizer Bio Enrich 8.8.3 (19) at plant

2025 Result summary Table:
Agronomic and economic effect of various fertilizer application strategies on wheat.

Nr	Treatment	Yield		HLM		Nitrogen & water use efficiency (%)		Crop revenue minus fertilizer cost (R/ha)	Relative Yield	Relative Revenue	2025 Agronomic Ranking	2025 Economic Ranking
		ton/ha	P<0.05	kg/hl	P<0.05	NUE	WUE					
1	Control (without fertilizer)	**2.83**	*f*	**55.2**	*a*		9.5	15568	**100%**	**100%**	14	14
2	Only Manure	**3.74**	*de*	**54.2**	*abc*		12.6	16838	**132%**	**108%**	12	13
3	Only N (CAN) (recommended split N-rate)	**3.82**	*cde*	**54.7**	*abc*	64	12.9	18579	**135%**	**119%**	11	4
4	NPKS (CAN) (All N at planting)	**3.95**	*abc*	**54.1**	*abc*	67	13.3	18120	**139%**	**116%**	6	7
5	NPKS (CAN) (low N)	**3.55**	*e*	**55.0**	*ab*	165	11.9	17608	**126%**	**113%**	13	12
6	NPKS (CAN) (medium N)	**3.88**	*bcde*	**54.9**	*ab*	109	13.0	18849	**137%**	**121%**	10	1
7	NPKS (CAN) (recommended split N-rate)	**3.89**	*abcd*	**53.6**	*abc*	63	13.1	17803	**138%**	**114%**	8	10
8	NPKS (UREA) (recommended split N-rate)	**3.94**	*abcd*	**53.1**	*c*		13.2	18469	**139%**	**119%**	6	4
9	NPKS (AMIPLUS) (recommended split N-rate)	**3.99**	*abc*	**53.5**	*bc*	67	13.4	18648	**141%**	**120%**	4	3
10	NPKS (UAN24) (recommended split N-rate)	**4.08**	*a*	**54.0**	*abc*		13.7	18865	**144%**	**121%**	1	1
11	NPKS (CAN) + seed treatment	**3.92**	*abcd*	**53.6**	*abc*		13.2	17851	**138%**	**115%**	8	9
12	NPKS (CAN) + biostimulants	**4.03**	*ab*	**53.9**	*abc*		13.6	18283	**142%**	**117%**	2	6
13	NPKS (CAN) + Manure	**4.03**	*ab*	**53.3**	*c*		13.5	17678	**142%**	**114%**	2	10
14	NPKS (CAN) + Organo-mineral based fertilizer	**4.00**	*abc*	**54.3**	*abc*		13.5	18092	**141%**	**116%**	4	7

Crop renevue: Income based on Yield x average oats price (Dec 24):
Fertilizer costs: Based on fertilizer prices during 2024 growing season.

NUE: (N removal with crop yield divided by N fertilizer rate) × 100
WUE: kg grain divided by mm rain (May – Oct)

Grain nutrient analysis, removal and use efficiency

Grain nutrient analysis												
Treatment	**N (%)**	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**Na (mg/kg)**	**Mn (mg/kg)**	**Fe (mg/kg)**	**Cu (mg/kg)**	**Zn (mg/kg)**	**B (mg/kg)**	**S (%)**
Control	**1.48**	0.29	0.43	0.06	0.11	110	44	48	3	25	2	0.21
Only N (CAN) (recommended split N-rate)	**1.68**	0.28	0.41	0.05	0.10	120	37	46	3	21	2	0.23
NPKS (CAN) (recommended split N-rate)	**1.63**	0.32	0.45	0.06	0.11	129	47	49	3	22	1	0.23

Grain nutrient removal														
Treatment	**Yield (t/ha)**	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Mn**	**Cu**	**Zn**	**B**	**NUE**	**PUE**	**KUE**
		kg/ha						**g/ha**						
Control	**2.83**	37.7	7.4	10.9	1.4	2.7	5.3	112.1	7.6	64.5	5.9			
Only N (CAN) (recommended split N-rate)	**3.82**	57.8	9.5	14.0	1.6	3.4	8.0	126.1	9.2	72.2	5.7	63		
NPKS (CAN) (recommended split N-rate)	**3.89**	57.1	11.3	15.8	2.0	4.0	8.1	163.4	10.5	77.0	4.7	63	69	79

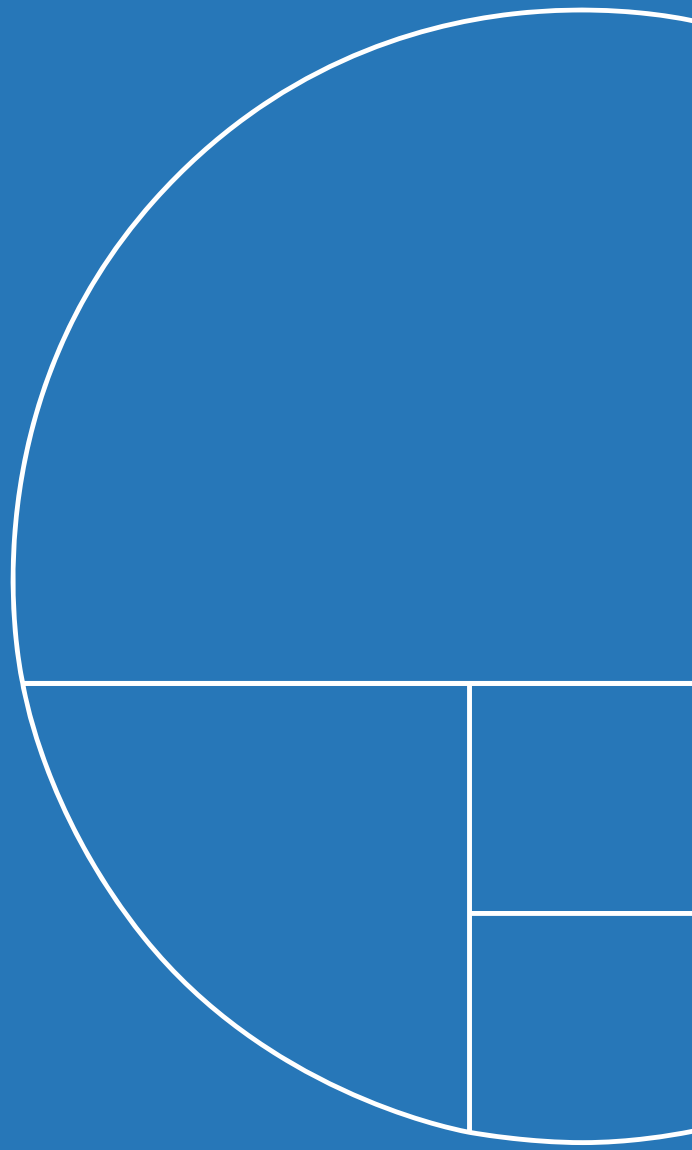
NUE, PUE, KUE - Nitrogen, Phosphorus & potassium use efficiency

Results: Soil health

Soil analysis (Feb 2026) on selected treatments / fertilizer strategies

Fertilizer strategy	Treatment effect	PH_kcl	mg/kg					mg/kg			%	mg/kg	%	mg/kg		
			P	K	CA	MG	NA	CU	ZN	MN	Total C	Active C	Total N	NH4	NO3	Total inorg.N
Control (zero NPK)	Zero fertilizer	5.31	14	101	632	65	22	0.71	0.35	25	0.86	279	0.08	0.9	4.1	5.0
Only Manure	Organic, not balanced	5.49	17	153	731	88	27	2.52	1.73	31	1.11	368	0.10	0.9	8.0	8.9
Only N	Mineral, not balanced	5.45	12	93	679	72	23				0.96		0.09			
Low N	Low Nitrogen	5.21	15	106	645	70	34				0.94		0.09			
NPKS balanced (CAN)	Mineral balanced	5.45	13	104	707	78	41	0.72	0.53	33	1.06	348	0.10	3.2	7.4	10.6
NPKS balanced (AMIP)	Mineral balanced	5.26	14	89	677	74	28				0.99		0.09			
NPKS + Manure	Integrated (mineral/organic)	5.64	14	91	733	80	28	1.16	0.67	27	1.00	364	0.09	2.5	8.9	11.5
NPKS + Organo-mineral	Integrated (mineral/organic)	5.43	15	96	686	70	33				1.00		0.08			
Ave		***5.40***	***14***	***104***	***686***	***75***	***30***	***1.28***	***0.82***	***29***	***0.99***	***340***	***0.09***	***1.9***	***7.1***	***9.0***

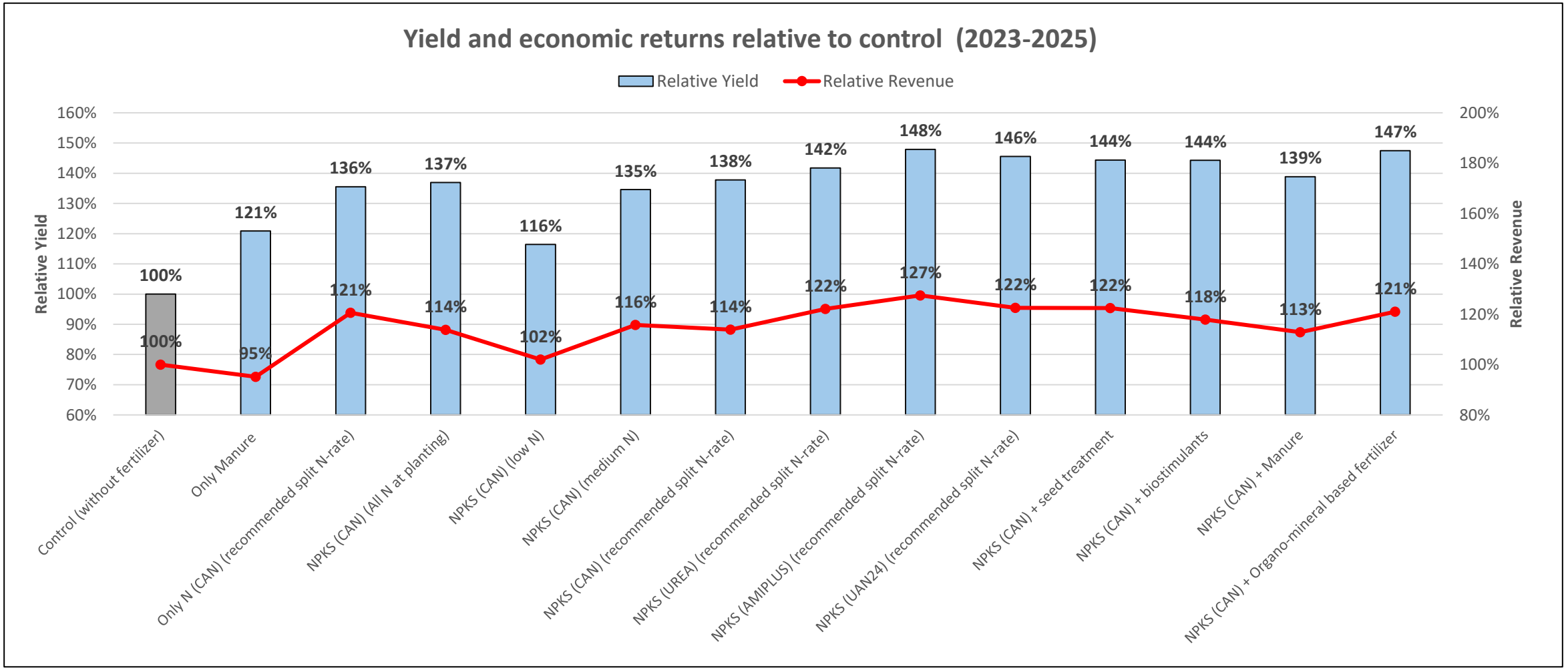
2023 – 2025 RESULTS



Results: Productivity & Prosperity

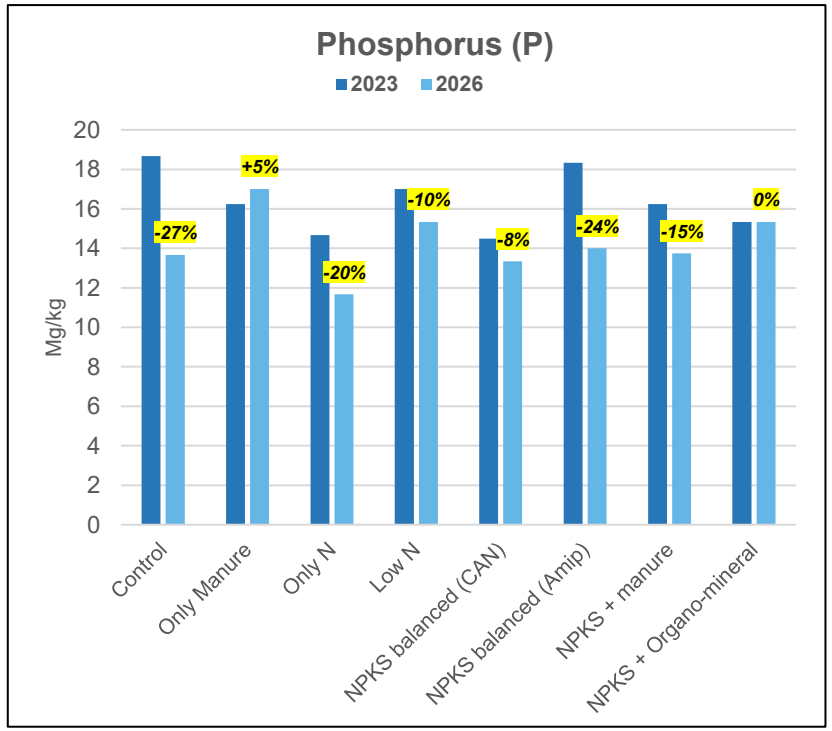
Nr	Fertilizer strategies	2023 Canola				2024 Wheat				2025 Oats				Combined 2023-2025	
		Yield(ton/ha)	Relative yield	Crop Revenue - fertilizer costs	Relative Revenue	Yield	Relative yield	Crop Revenue - fertilizer costs	Relative Revenue	Yield	Relative yield	Crop Revenue - fertilizer costs	Relative Revenue	Relative Yield	Relative Revenue
1	Control (without fertilizer)	2.37	100%	R17,770	100%	2.78	100%	R12,655	100%	2.83	100%	15568	100%	**100%**	**100%**
2	Only Manure	2.60	110%	R15,995	90%	3.36	121%	R11,045	87%	3.74	132%	16838	108%	**121%**	**95%**
3	Only N (CAN) (recommended split N-rate)	3.11	131%	R20,059	113%	3.89	140%	R16,378	129%	3.82	135%	18579	119%	**136%**	**121%**
4	NPKS (CAN) (All N at planting)	2.97	125%	R17,216	97%	4.06	146%	R16,206	128%	3.95	140%	18120	116%	**137%**	**114%**
5	NPKS (CAN) (low N)	2.45	104%	R15,710	88%	3.33	120%	R13,219	104%	3.55	126%	17608	113%	**116%**	**102%**
6	NPKS (CAN) (medium N)	2.94	124%	R18,615	105%	3.96	143%	R15,352	121%	3.88	137%	18849	121%	**135%**	**116%**
7	NPKS (CAN) (recommended split N-rate)	2.98	126%	R17,235	97%	4.17	150%	R16,484	130%	3.89	138%	17803	114%	**138%**	**114%**
8	NPKS (UREA) (recommended split N-rate)	3.03	128%	R18,464	104%	4.40	158%	R18,208	144%	3.94	139%	18469	119%	**142%**	**122%**
9	NPKS (AMIPLUS) (recommended split N-rate)	3.37	142%	R20,934	118%	4.45	160%	R18,330	145%	3.99	141%	18648	120%	**148%**	**127%**
10	NPKS (UAN24) (recommended split N-rate)	3.18	134%	R19,071	107%	4.40	158%	R17,588	139%	4.08	144%	18865	121%	**146%**	**122%**
11	NPKS (CAN) + seed treatment	3.12	132%	R18,274	103%	4.52	163%	R18,950	150%	3.92	139%	17851	115%	**144%**	**122%**
12	NPKS (CAN) + biostimulants	3.14	133%	R17,955	101%	4.38	158%	R17,087	135%	4.03	142%	18283	117%	**144%**	**118%**
13	NPKS (CAN) + Manure	3.04	128%	R18,312	103%	4.05	146%	R15,424	122%	4.03	142%	17678	114%	**139%**	**113%**
14	NPKS (CAN) + Organo-mineral based fertilizer	3.26	138%	R18,989	107%	4.53	163%	R17,719	140%	4.00	141%	18092	116%	**147%**	**121%**
	Average	2.97				4.02				3.83					

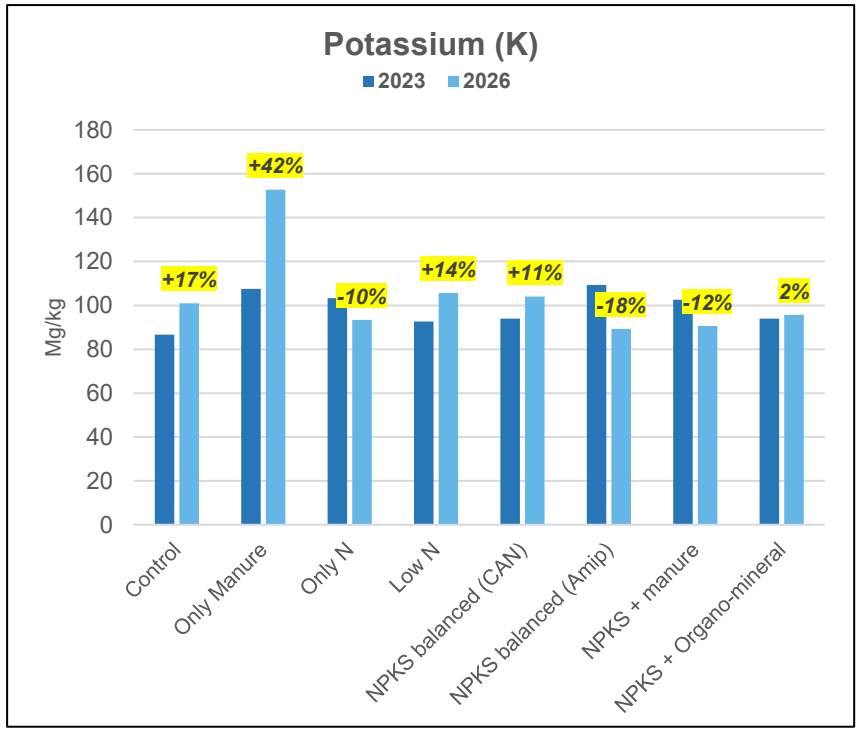
Results: Productivity & Prosperity

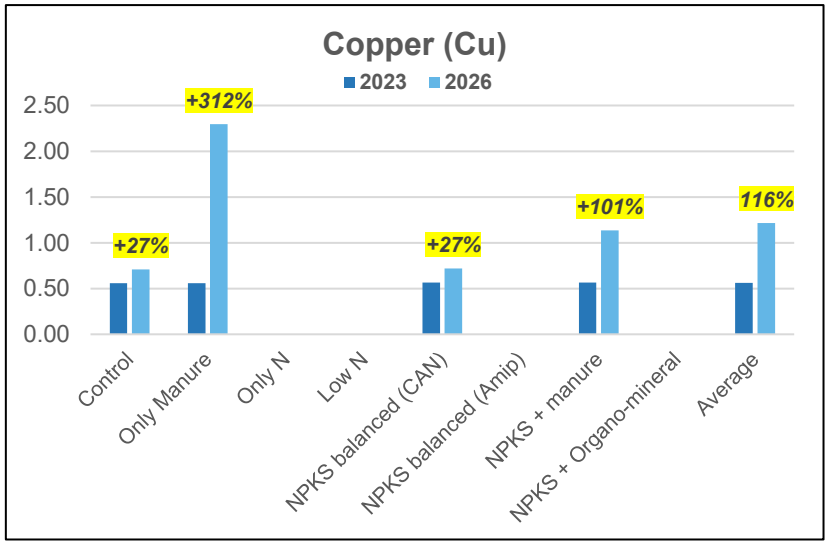


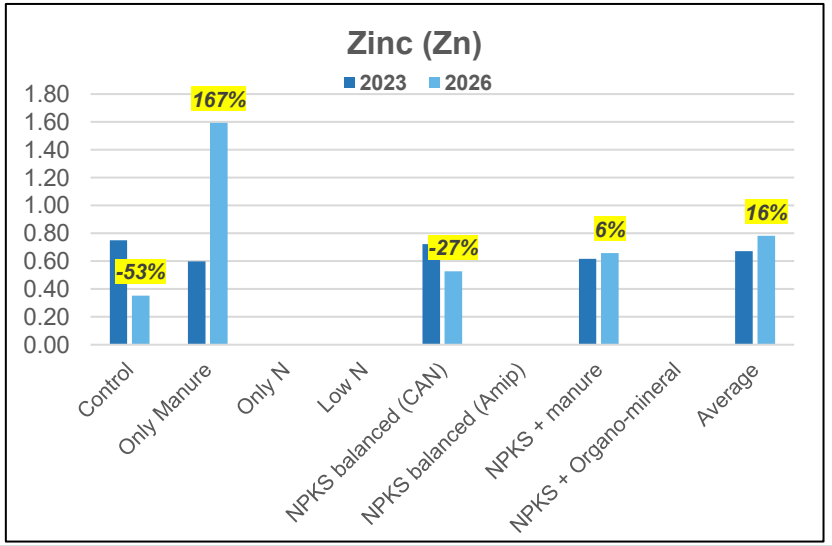
Results: Soil health

Soil nutrient changes (2023 vs. 2026) in selected treatments



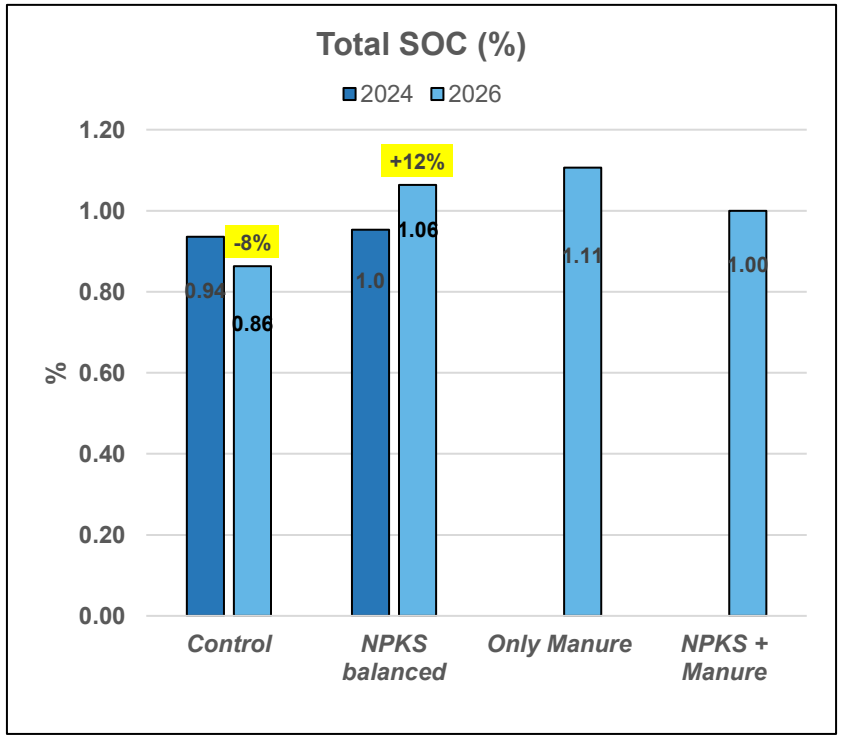


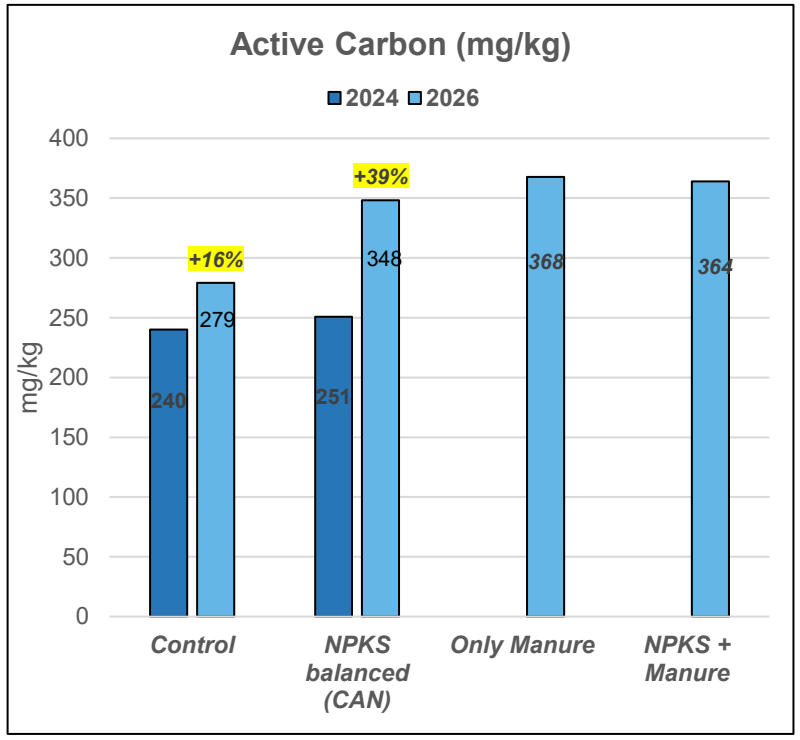


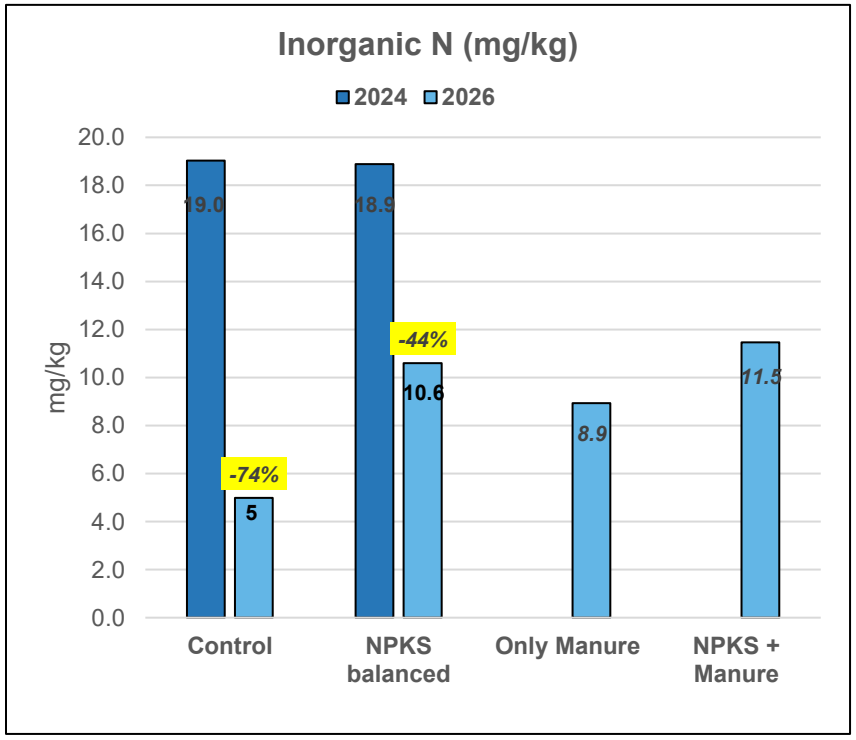


Results: Soil health

Soil organic carbon, active C and inorganic Nitrogen changes (2024 vs. 2026) in selected treatments







Results: Resource use efficiency (RUE)

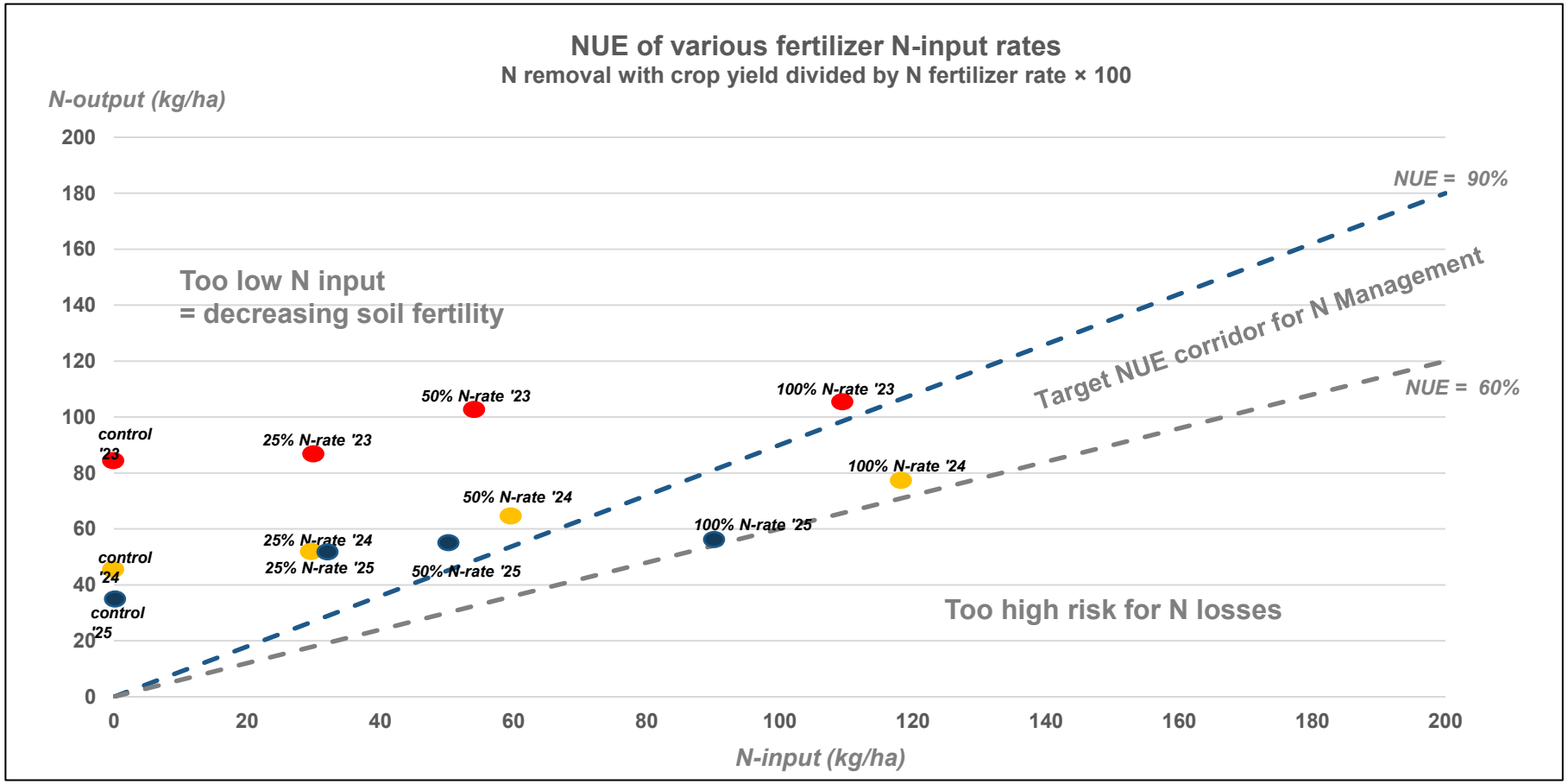
- ***Nutrient use efficiency***

Fertilizer strategy	Fertilizer input / output	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	NUE % (nitrogen use efficiency)	PUE % (Phosphorususe efficiency)	KUE % (potassium use efficiency)
Control	Input 23	0	0	0	0			
	Input 24	0	0	0	0			
	Input 25	0	0	0	0			
	Output 23	87	15	15	10			
	Output 24	45	9	12	2			
	Output 25	38	7	11	5			
	Surplus	**-170**	**-31**	**-38**	**-17**			
NPKS balanced (CAN)	Input 23	112	17	23	18			
	Input 24	119	18	24	19			
	Input 25	91	17	20	18			
	Output 23	109	18	17	14	**75**	**78**	**76**
	Output 24	75	11	18	3			
	Output 25	57	11	16	8			
	Surplus	**81**	**12**	**16**	**30**			

- ***Water use efficiency***

Nr	Fertilizer strategies	kg grain/mm rain			
		2023	2024	2025	2023 - 2025
1	Control (without fertilizer)	5.5	5.5	9.5	**6.8**
2	Only Manure	6.0	6.6	12.6	**8.4**
3	Only N (CAN) (recommended split N-rate)	7.2	7.7	12.9	**9.2**
4	NPKS (CAN) (All N at planting)	6.9	8.0	13.3	**9.4**
5	NPKS (CAN) (low N)	5.7	6.6	11.9	**8.1**
6	NPKS (CAN) (medium N)	6.8	7.8	13.0	**9.2**
7	NPKS (CAN) (recommended split N-rate)	6.9	8.2	13.1	**9.4**
8	NPKS (UREA) (recommended split N-rate)	7.0	8.7	13.2	**9.6**
9	NPKS (AMIPLUS) (recommended split N-rate)	7.8	8.8	13.4	**10.0**
10	NPKS (UAN24) (recommended split N-rate)	7.4	8.7	13.7	**9.9**
11	NPKS (CAN) + seed treatment	7.2	8.9	13.2	**9.8**
12	NPKS (CAN) + biostimulants	7.3	8.6	13.6	**9.8**
13	NPKS (CAN) + Manure	7.0	8.0	13.5	**9.5**
14	NPKS (CAN) + Organo-mineral based fertilizer	7.5	8.9	13.5	**10.0**

Results: Resource use efficiency (RUE)



Results: Balanced crop nutrition effect on key sustainability outcomes after 3 years

Fertilizer strategy	Fertilizer effect	Productivity / Prosperity		Soil health						Resource use efficiency	
		Rel. Yield	Rel. Revenue	SOC	Active C	P	K	Cu	Zn	NUE (%)	WUE (kg/mm)
Control	No fertilizer	100%	100%	0.86	279	14	101	0.71	0.35		**6.8**
Only Manure	organic	121%	95%	1.11	368	17	153	2.52	1.73		**8.4**
NPKS balanced (CAN)	Mineral	138%	114%	1.06	348	13	104	0.72	0.53	**75**	**9.4**
NPKS (CAN) + Manure	organic / mineral	139%	113%	1	364	14	91	1.16	0.67		**9.5**

Concluding remarks based on 2023-2025 results

- This three-year trial demonstrates that balanced and precise crop nutrition plays a pivotal role in advancing productivity, soil health, and sustainability within grain production systems. Across canola, wheat, and oats, balanced fertilizer strategies (mineral and integrated organic-mineral) consistently outperformed the control, both in yield and economic returns. Treatments such as NPKS with nitrogen sources (e.g., AMIPLUS, UAN24) achieved relative yield gains of 40–60% and revenue increases of up to 48% compared to unfertilized controls, underscoring the economic viability of balanced nutrient management.
- Soil health indicators revealed important shifts. Manure-based treatments improved potassium, phosphorus, and micronutrient levels, while balanced mineral fertilization stabilized nutrient availability. Notably, soil organic carbon (SOC) increased under manure and integrated organic-mineral strategies, rising from 0.94% in 2024 to over 1.1% by 2026, while active carbon also improved markedly (from ~250 mg/kg to >360 mg/kg). These changes highlight the synergistic benefits of combining organic and mineral inputs for long-term soil resilience.
- Resource use efficiency further reinforced the sustainability case. Balanced NPKS strategies achieved nitrogen use efficiencies around 75%, while water use efficiency improved to 9–9.5 kg/mm compared to 6.8 kg/mm in the unfertilized control. This indicates that balanced and precise nutrient management not only boosts yields but also enhances input efficiency, reducing environmental footprints.
- After 3 years, the trial validates the hypothesis that balanced crop nutrition is integral to regenerative agriculture. By improving yields, stabilizing farm economics, enhancing soil health, and optimizing resource use, balanced and precise crop nutrition strategies deliver measurable benefits across social, economic, and environmental dimensions.
- The findings provide a strong evidence base for promoting balanced NPKS mineral and integrated organic–mineral approaches as a cornerstone of sustainable grain production systems.


YARA
Knowledge grows