Evaluating impacts of applied nitrogen on grain yield and quality in wheat and barley

Myfanwy Purslow and Rebekah Allen
Hart Field-Site Group

Key findings

- Seasonal conditions at Hart in 2024 were dry, reducing water availability and nitrogen (N) uptake of crops.
- There is a strong correlation showing that increased biomass contributed to reduced grain yield (t/ha) for Compass barley (up to 61%). This result indicates a haying-off effect in dry seasonal conditions for this variety. No yield penalty was observed for Maximus CL, although biomass increased with application of N.
- Maximus CL had a slight reduction in retention when N was applied, however rates from 30-180 kg N/ha still exceeded minimum receival standards (70%). Screenings slightly increased as nitrogen rates increased, however differences were small, and all treatments achieved <7% screenings.
- No differences were observed for screenings and retention across N rate for Compass barley.
- There was no yield differences observed for any wheat variety or nitrogen rate.
- A minimum application of 30 kg N/ha was required for wheat varieties to meet a minimum protein threshold of 13%. All wheat varieties and N rates met minimum receival standards for H1 (76 kg/hL), however higher N did contribute to lower test weights. No differences were observed for wheat screenings.

Introduction

Nitrogen (N) is an essential nutrient required in broadacre cropping systems and is a primary contributor to match crop demands for grain yield (Baldock et.al, 2018). Systems without an adequate nitrogen balance will not match water-limited yield in most years, leading to reduced productivity and profitability on-farm, in addition to declining soil organic N balances (Baldock et.al, 2018).

Matching crop N demand to seasonal forecasts is challenging and over-application of N has been shown to cause negative crop effects including haying off in dry conditions, as well as lodging in favourable seasons. Haying off causes the grain filling process to end too early in the season after utilising water and nutrient resources for crop biomass production. As the season progresses and grain filling begins, the plant does not have access to required soil moisture due to this premature uptake (Herwaarden et al., 1998).

There is a consensus that the concentration of grain yield and grain protein is negatively correlated. As grain yield increases, protein concentration can decrease. This relationship suggests that higher yields may incur lower protein levels in the grain (Bogard et al., 2010). The range of the negative correlation is under researched and not well understood.

A trial established in the Mid North at Kybunga, SA in 2022 has shown negative haying-off effects resulting from high nitrogen application in barley (2023 Kybunga results). This trial is a series of long-term experiments across the Southern region, aiming to evaluate the productivity (yield and protein), profitability (gross margin) and sustainability (soil organic matter, carbon and N losses) of long-term N management systems. This is done by matching nitrogen rates to seasonal yield potential, targeting nitrogen rates to maintain baseline fertility (nitrogen banking), and comparing both to the national average of 45 kg N/ha.

To better understand relationships between grain yield, grain quality and nitrogen, a field trial was established at Hart, SA in 2024 to investigate wheat and barley variety response to increasing rates of nitrogen.

Methodology

Trial design and treatments

Two adjacent wheat and barley trials were established at the Hart field site in 2024 to investigate the effect of increasing rates of nitrogen on lodging and haying off (Table 1). Each trial had two varieties of wheat (Scepter and Calibre) or barley (Compass and Maximus CL) (Table 2). Both trials were designed in Genstat 24th Edition, as a two-way factorial with two varieties, seven nitrogen rates and three replicates.

Compass barley and Scepter wheat were selected as current benchmark varieties for the Mid North region. Compass (erect plant type) was selected due to observations of a higher lodging frequency and was compared to Maximus CL. Maximus CL was selected as it is well-suited to the environment at Hart and surrounding regions. It was assumed that Maximus CL would behave differently to Compass as it's not as free tillering and has a reduced plant height, providing a good comparison. Scepter wheat was selected as it's both widely grown and has been observed to stand upright well. Comparison variety Calibre, may lean with high yields but is not commonly seen to lodge. Both varieties have similar maturities.

Table 1. Trial details for 2024 wheat and barley nitrogen trials located at Hart, SA.

Harvested plot size	0.92 m x 10 m	**Starting soil N**	36.4 kg N/ha (0-70 cm)
Seeding date	May 14, 2024	**Fertiliser**	Seeding: MAP at 100 kg/ha
Location	Hart, SA		July 19: Nitrogen treatments applied
Harvest date	Barley: October 30, 2024		
	Wheat: November 14, 2024		
Previous crop	Kingbale oaten hay		
Growing season rainfall	Decile 2 (176 mm)		

Seven rates of nitrogen were applied on July 19 to both trials. Rates applied were 30, 60, 90, 120, 180 and 240 kg N/ha, including a nil treatment (0 kg N/ha). Low N rates were applied to intentionally limit N availability to crops and exaggerate the effects of nitrogen deficiency. In contrast, high rates of N were applied to demonstrate the effect of haying off in dry conditions or lodging in wet conditions. Nitrogen treatments were applied as granular urea at tillering. Nitrogen was spread uniformly across each plot and was absorbed into the soil, following 9.2 mm rainfall shortly after application, with another 8.0 mm received four-days later.

Table 2. Crop type, variety and sowing rates for 2024 nitrogen trials at Hart, SA.

Trial	Varieties	Sowing rate
Wheat	Calibre Scepter	180 plants/m^2
Barley	Maximus CL Compass	150 plants/m^2

Site selection and rainfall

Soil mineral N levels were low in 2024, following the previous year's oaten hay crop with a total of 36.4 kg N/ha (0-70 cm). To measure baseline soil N, twelve soil cores were taken on April 9 across each trial prior to seeding. Cores were sampled to a depth of 70 cm and sectioned by depths of 0-10 cm, 10-40 cm and 40-70 cm for analysis.

The Hart field site received below average annual rainfall of 240.2 mm in 2024, compared to the long-term average of 400 mm. Growing season rainfall received was also low with 176 mm of April to October rain (average of 300 mm) (Figure 1). This contributed to poor nitrogen availability and uptake by plants.

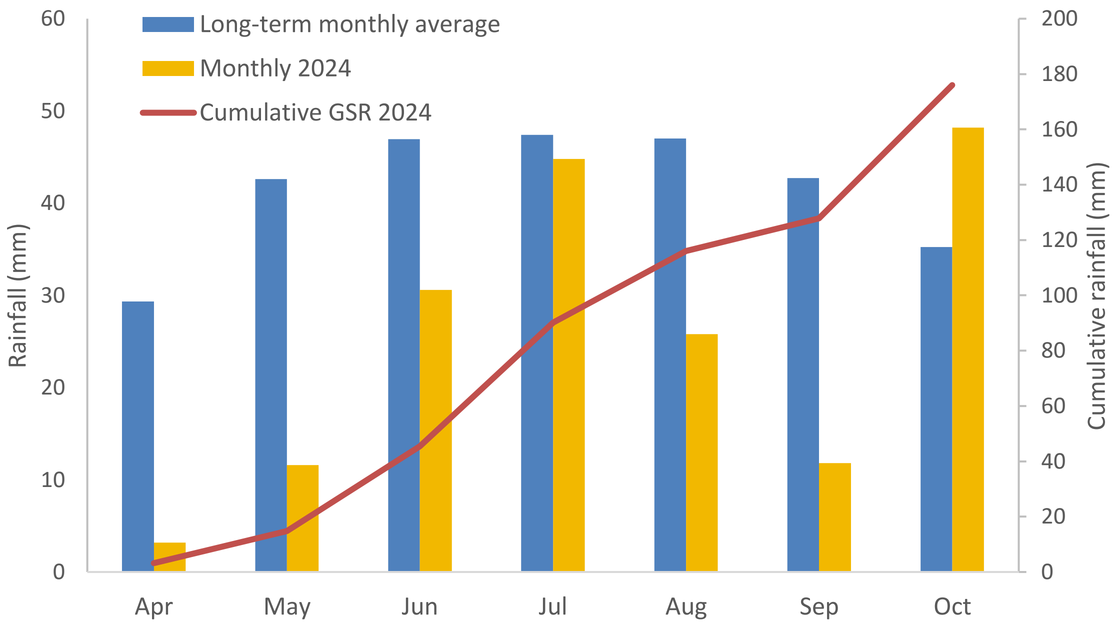

Figure 1. Growing season rainfall at Hart, SA in 2024.

Measurements

In addition to starting soil N, trial measurements conducted include Normalised Difference Vegetation Index (NDVI), grain yield (t/ha), protein (%), screenings (%), test weight (kg/hL), retention (%) (barley only), 1000 grain weight (g) and post-harvest soil N. Severe water stress in 2024 resulted in a strong edge row effect. Edge rows were therefore removed prior to harvest, to accurately determine grain yield results from the middle four crop rows (0.92 m x 10 m).

Normalised difference vegetation index (NDVI) data was collected as a measure of plant growth (higher NDVI values indicate less exposed soil and greener vegetation). Three NDVI measurements were conducted in each plot on July 19 at early-tiller (prior to N application), August 20 (first node) and September 11 (50% flower). This data was recorded using a handheld Green seeker, measured at a constant height. All assessment data was analysed as a REML spatial model (Regular Grid) with Bonferroni test and post-harvest soil N was analysed using a REML spatial model (Irregular Grid) with Bonferroni test using Genstat 24th Edition.

Results and discussion

Crop biomass (NDVI)

Throughout the growing season, Compass barley showed greater vigour, indicated by higher NDVI values compared to Maximus CL (Table 3). There is a strong correlation showing that this increased biomass contributed to reduced grain yield (Figure 2), as biomass production contributed to reduced availability of resources during grain fill. The higher NDVI values observed for Compass are supported by varietal traits which are characterised by rapid and vigorous early growth (Matthews et al., 2023). While biomass for Maximus CL slightly increased as nitrogen increased (NDVI 1 & 2 in Table 3), a yield penalty was not observed.

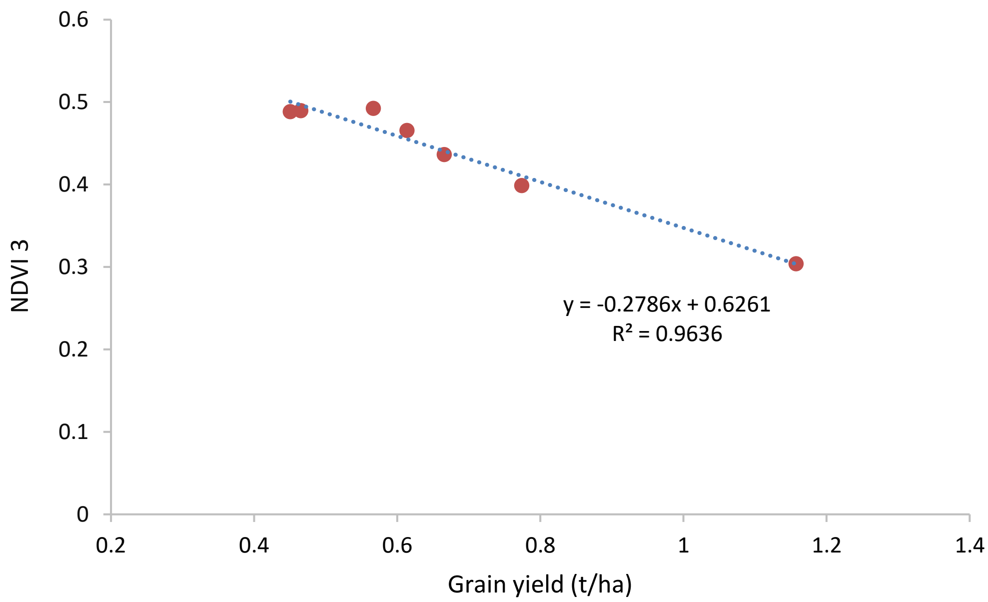

Figure 2. Correlation between Compass grain yield (t/ha) and biomass at Hart in 2024.

Table 3. NDVI values for barley and wheat from 2024 nitrogen trials at Hart, SA. Shaded values in each column indicate higher biomass.

Variety	N rate kg N/ha	NDVI 1	NDVI 2	NDVI 3	Variety	N rate kg N/ha	NDVI 1	NDVI 2	NDVI 3
	240	0.28^{d}	0.61^{d}	0.49^{f}		240	0.24^{b}	0.37^{a}	0.29^{a}
	180	0.28^{d}	0.62^{d}	0.49^{f}		180	0.23^{ab}	0.33^{a}	0.29^{a}
	120	0.28^{cd}	0.61^{d}	0.49^{f}		120	0.23^{ab}	0.39^{a}	0.32^{a}
Compass	90	0.27^{d}	0.59^{d}	0.47^{ef}	Scepter	90	0.22^{ab}	0.36^{a}	0.30^{a}
	60	0.26^{bcd}	0.57^{d}	0.44^{def}		60	0.22^{ab}	0.38^{a}	0.29^{a}
	30	0.28^{d}	0.54^{cd}	0.40^{cde}		30	0.23^{ab}	0.34^{a}	0.28^{a}
	0	0.29^{d}	0.47^{bc}	0.30^{ab}		0	0.22^{ab}	0.31^{a}	0.25^{a}
	240	0.21^{ab}	0.46^{bc}	0.37^{bcd}		240	0.19^{a}	0.40^{a}	0.33^{a}
	180	0.21^{ab}	0.49^{bc}	0.37^{bcd}		180	0.21^{ab}	0.41^{a}	0.30^{a}
	120	0.19^{a}	0.45^{b}	0.34^{abc}		120	0.22^{ab}	0.40^{a}	0.34^{a}
Maximus CL	90	0.21^{ab}	0.44^{b}	0.36^{bc}	Calibre	90	0.21^{ab}	0.38^{a}	0.33^{a}
	60	0.20^{ab}	0.43^{ab}	0.33^{abc}		60	0.22^{ab}	0.38^{a}	0.27^{a}
	30	0.21^{abc}	0.41^{ab}	0.27^{a}		30	0.24^{ab}	0.39^{a}	0.30^{a}
	0	0.20^{ab}	0.35^{a}	0.26^{a}		0	0.20^{ab}	0.33^{a}	0.26^{a}
P Value (≤0.05)		**<0.001**	**<0.001**	**<0.001**	**P Value (≤0.05)**		**0.01**	**0.005**	**0.025**

Grain yield (t/ha)

Compass barley resulted in a significant yield penalty with in-season applications of nitrogen from 30-240 kg N/ha, reducing grain yield by up to 0.71 t/ha (61%) (Table 4). These results indicate a haying-off effect in dry seasonal conditions, associated with increased biomass production as shown above (Figure 2). No yield penalty was observed for Maximus CL, despite biomass increasing with high applications of N. There was no difference observed for any wheat variety and nitrogen rate.

Grain quality

Irrespective of barley variety, protein (%) increased as nitrogen rate increased (Table 4). Due to dry conditions, even treatments with no in-crop N applied (starting soil N 36.4 kg/ha) exceeded the maximum threshold of 12% protein for Malt 1 receival standards due to low crop yields.

For Maximus CL there was a slight reduction in retention when nitrogen was applied, however rates from 30-180 kg N/ha still exceeded minimum receival standards (70%). Screenings also slightly increased as nitrogen rates increased, however differences were small, and all treatments achieved <7% screenings. No differences were observed for screenings and retention across N rate for Compass barley. This contrasts with results from a nitrogen banking trial conducted in 2023 at Kybunga, SA, (Compass barley phase), showing that the highest nitrogen rate applied (144 kg N/ha) led to the highest screenings (22.6%) (Allen et.al 2024). Similarly to the 2024 trial at Hart, the highest nitrogen rate did not result in the highest yield (on 275 mm GSR), supporting the concept of haying off in this variety.

Test weight was high for all treatments (>65 kg/hL) and was not influenced by increasing N rate.

A minimum application of 30 kg N/ha was required for wheat varieties to meet a minimum protein threshold of 13% for H1 receival standards. Similar trends to barley were observed for test weight of wheat, with all varieties and N rates meeting minimum receival standard for H1 (76 kg/hL), however higher N did contribute to lower test weights. No differences were observed for wheat screenings.

Similar wheat and barley trials were conducted at Hart over three years, from 2017 to 2019. The growing season rainfall for these years was comparable to 2024 (176 mm), with recorded GSR of 191, 160 and 162 mm, respectively. The three-year trial tested Spartacus CL and La Trobe barley and Scepter and Mace wheat. While the three-year trial had similar growing season rainfall each year, grain yield in 2017 (Spartacus CL) and 2018 (La Trobe) increased, but plateaued with applications of 40 kg N/ha applied, when compared to the nil treatment (Rose and Noack, 2019). This is in contrast to the 2024 barley trial where any application of nitrogen at 30 kg N/ha or above saw either a decline (Compass), or no response (Maximus CL) in grain yield (t/ha) (Table 4). Only slight decreases in screenings were observed in high N treatments, however these were negligible. Differences in results may be attributed to environmental conditions and timing of rainfall experienced across seasons.

In 2018 and 2019, where Scepter was trialed, trends showed that grain yield increased with increased rates of N. No response was observed in 2024 due to dry winter conditions. Further investigation into timing of N and rainfall would need to be considered to make further comparisons between trials.

Table 4. Barley grain yield and quality results from Hart in 2024.

Variety	Nitrogen rate kg N/ha	Grain yield t/ha	Protein %	Test weight kg/hL	Screenings %	Retention %
	240	0.45^{a}	19.4^{def}	73.7^{abcd}	3.0^{abc}	85.9^{bc}
	180	0.47^{ab}	20.6^{f}	73.7^{ab}	3.1^{abc}	85.6^{bc}
	120	0.57^{abc}	19.6^{ef}	74.3^{a-i}	2.9^{abc}	85.9^{bc}
Compass	90	0.61^{abc}	18.3^{cde}	74.0^{a-i}	2.8^{abc}	87.6^{bc}
	60	0.67^{a-d}	18.3^{cde}	74.9^{bgi}	2.4^{abc}	89.0^{bc}
	30	0.77^{a-d}	16.7^{bc}	74.9^{b-i}	1.9^{abc}	89.9^{bc}
	0	1.16^{f}	12.8^{a}	74.8^{b-i}	1.2^{a}	93.5^{c}
	240	0.82^{b-f}	18.4^{cde}	73.6^{a}	4.1^{c}	68.0^{a}
	180	0.79^{a-e}	18.1^{cde}	73.9^{a-h}	3.5^{bc}	73.2^{a}
	120	0.89^{c-f}	17.9^{cde}	73.8^{a-f}	4.0^{bc}	71.3^{a}
Maximus CL	90	0.85^{c-f}	17.6^{bcd}	73.7^{abc}	3.7^{bc}	73.2^{a}
	60	0.92^{c-f}	17.1^{bc}	73.7^{abc}	3.4^{bc}	75.1^{a}
	30	1.01^{def}	15.8^{b}	73.8^{a-e}	3.3^{abc}	74.0^{a}
	0	1.11^{ef}	12.9^{a}	73.9^{a-g}	1.8^{ab}	83.8^{b}
Malt 1 Receival standards			9-2%	>65	<7.0	>70
P Value (≤0.05)		**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Table 5. Wheat grain yield and quality results from Hart in 2024.

Variety	Nitrogen rate kg N/ha	Grain yield t/ha	Protein %	Test weight kg/hL	Screenings %
Scepter	240	0.67	15.1^{cde}	81.4^{de}	2.9^{ab}
	180	0.66	15.1^{de}	81.5^{cde}	2.7^{ab}
	120	0.67	15.0^{b-e}	81.4^{cde}	2.1^{ab}
	90	0.63	14.8^{b-e}	81.5^{cde}	2.2^{ab}
	60	0.69	14.2^{bcd}	81.9^{e}	2.4^{ab}
	30	0.68	13.3^{b}	82.3^{ef}	2.0^{a}
	0	0.67	11.1^{a}	83.4^{f}	2.6^{ab}
Calibre	240	0.64	15.9^{e}	78.6^{a}	3.9^{b}
	180	0.69	15.6^{de}	79.4^{ab}	3.2^{ab}
	120	0.68	15.4^{de}	79.4^{ab}	3.1^{ab}
	90	0.68	15.1^{de}	79.6^{ab}	2.6^{ab}
	60	0.70	14.7^{b-e}	80.0^{abc}	2.3^{ab}
	30	0.69	13.6^{bc}	80.2^{bcd}	2.5^{ab}
	0	0.62	11.5^{a}	81.1^{cde}	3.1^{ab}
H1 receival standards			>13	>76	<5
P Value (≤0.05)		**NS (0.135)**	**<0.001**	**<0.001**	**<0.001**

Post-harvest N

Post-harvest soil samples were conducted on December 4 to measure carry-over nitrogen from various treatments. Samples were taken from one variety of each crop type at three rates: 0 (nil), 90 and 240 kg of applied N/ha. Available nitrogen measured post-harvest was greater than initial soil N of 36.4 kg N/ha due to dry conditions experienced at Hart in 2024. Available nitrogen increased by 14.2 (N rate 0)–138.7 (N rate 240) kg N/ha in wheat and 4.2 (N rate 0) –151.8 (N rate 240) kg N/ha in barley.

Table 6. Soil nitrogen available post-harvest. Samples were conducted on December 4 at 0-0 cm, 10-40 cm and 40-70 cm.

Calibre		Maximus CL	
N rate	**Post-harvest N (kg/ha)**	**N rate**	**Post-harvest N (kg/ha)**
0 (nil)	50.6^{a}	0 (nil)	40.6^{a}
90	110.1^{ab}	90	114.1^{ab}
240	175.1^{b}	240	188.2^{b}
P Value (≤0.05)	**0.042**	**P Value (≤0.05)**	**0.033**

Summary

In 2024, the Hart site experienced below average annual rainfall with 240.2 mm, almost half of the long-term average (400 mm). Only 176 mm was received during the growing season (April-October), contributing to poor water availability and uptake of nitrogen by crops. In very dry conditions, the application of nitrogen, especially at higher rates, may cause haying-off effects leading to a reduction in grain yield and quality, particularly in barley as observed in 2024. Increasing nitrogen rates in dry conditions is likely to also increase the concentration of protein. These trials will be continued at Hart across several seasons, to develop a better understanding of the grain yield and quality response associated with applied N in field conditions. This will provide further information to support nitrogen decisions.

Acknowledgements

The Hart Field-Site Group would like to acknowledge the generous support of our sponsors who provide funding that allows us to conduct this trial. Proceeds from Hart's ongoing commercial crop also support Hart's research and extension program. We would like to thank the support of local advisors contributing to trial treatment design. We would also like to thank InterGrain, and growers Rob Dall and Scott Weckert for providing seed to conduct this trial.

References

Bogard, M., Allard, V., Brancourt-Hulmel, M., Heumez, E., Machet, J.-M., Jeuffroy, M.-H., Gate, P., Martre, P. and Le Gouis, J. (2010). Deviation from the grain protein concentration – grain yield negative relationship is highly correlated to post-anthesis N uptake in winter wheat. *Journal of Experimental Botany*, [online] 61(15), pp.4303–4312. doi: https://doi.org/10.1093/jxb/erq238.

Herwaarden, A.F. van, Farquhar, G.D., Angus, J.F., Richards, R.A. and Howe, G.N. (1998). 'Haying-off', the negative grain yield response of dryland wheat to nitrogen fertiliser. I. Biomass, grain yield, and water use. Australian Journal of Agricultural Research, 49(7), p.1067. doi: https://doi.org/10.1071/a97039.

Maheswari, M., Murthy, A.N.G. and Shanker, A.K. (2017). *12 - Nitrogen Nutrition in Crops and Its Importance in Crop Quality*. [online] ScienceDirect. Available at: https://www.sciencedirect.com/science/article/abs/pii/B9780128118368000124 [Accessed December 3. 2024]

Matthews, P., McCaffery, D. and Jenkins, L. (2023). *Winter crop variety sowing guide 2023*. [online] *Department of Primary Industries NSW Government*, NSW Department of Primary Industries (NSW DPI), p.44. Available at: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/1454188/Winter-crop-variety-sowing-guide-2023.pdf [Accessed December 13, 2024].

Poole, N., The Grains Research and Development Corporation (GRDC), Southern Farming Systems, Birchip Cropping Group/Wimmera Farming Systems/CropFacts, Harden Management Group and Foundation for Arable Research (FAR) (2005). *Cereal Growth Stages*. [online] *The Grains Research and Development Corporation (GRDC)*, The Grains Research and Development Corporation (GRDC), p.7. Available at: https://grdc.com.au/__data/assets/pdf_file/0031/364594/Cereal-growth-stages.pdf [Accessed December 13, 2024].

Rose, J. and Noack, S. (2019). Managing your fertiliser dollar in wheat and barley - a study across three seasons. [online] Hart Field Site, Clare, SA: Hart Field-Site Group, pp.61–63. Available at: https://www.hartfieldsite.org.au/media/2019%20TRIAL%20RESULTS/2019_HART_Trial_Results_Managing_your_fertiliser_dollar_in_wheat_and_barley.pdf [Accessed January 28, 2025].