Addendum- Increased wheat plant population: the interaction with variety, Fusarium crown rot and nitrogen

2024 Trials

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Take home messages

- Increasing plant populations had either positive impacts on wheat yield or no impact
- Fusarium crown rot (FCR) was the major driver of yield loss in wheat across sites and seasons
- There were interactions between variety, N nutrition and FCR with increased wheat plant populations but overwhelmingly better outcomes were achieved at high plant populations
- Under high levels of FCR infection, a higher plant population provided improved yield compared with a lower plant population under reduced levels of FCR infection.

Background

This paper is an addendum to a 2024 GRDC Update paper to introduce a further year's data to previous trials investigating the interaction of wheat plant populations, variety choice, nitrogen and FCR. This adds to experimentation conducted in 2023 as previously presented (Street *et al*. 2024).

Other research undertaken by GOA has shown that increased wheat plant populations, aimed primarily to increase weed competition, did not adversely impact yield and quality (screenings %) as often expected by growers, even in low yielding, marginal rainfall environments (Street *et al.* 2025)

However, growers often reported their experiences to be the opposite. It was hypothesised that increased FCR or high N rates (contributing to classical haying off) may explain farmer observations. During the winter of 2024, GOA, with the support of the GRDC, initiated 3 further trials investigating if higher N nutrition, and/or FCR disease changed the relationship between wheat plant populations and grain yield and quality.

Following on from 2023, similar trials were repeated in 2024 based on the same hypothesis. Does increasing levels of FCR or higher N nutrition change the key finding that higher plant populations does not negatively impact of yield and quality outcomes?

Full details of the individual 2024 trials can be accessed at: www.grainorana.com.au/documents

The field trials

Three small-plot trials were established in 2024. At the Coonamble and Narromine sites, trials were randomised, complete block factorial designs and at Ganmain trials were a split-plot (with nitrogen as main block), factorial design, all examining the 4 variables outlined in Table 1.

Table 1. Treatments implemented in 2024 trials at Ganmain, Coonamble and Narromine, NSW.

Wheat variety	**Target plant population (pl/m²)**	**N strategy**	**FCR inoculum**
Beckomⓓ	Moderate (targeting 70 plants/m²)	-N (32 kg/ha added at Ganmain, 25 kg/ha at Narromine and Coonamble)	-FCR (background level)
LRPB Flankerⓓ			
LRPB Lancer ⓓ	High (targeting 150 plants/m²)	+ N (122 kg/ha added at Ganmain, 100 kg/ha at Narromine and Coonamble)	+FCR (plots inoculated)
LRPB Raiderⓓ			

Plant varieties and populations

Seed was accessed from the GRDC experimental seed supply program to ensure trueness to type and was not treated with any seed dressings. Seeding rates were calculated based on individual variety germination rates, seed size (1000 seed weight) and assumed establishment percentages. Individual sowing rates are outlined in Table 2.

Table 2. Seeding rates used for wheat varieties tested at two contrasting plant populations in 2024 at Coonamble, Ganmain and Narromine, NSW.

Variety	**Seeding rate (kg/ha)**	
	Moderate	**High**
Beckomⓓ	33	71
LRPB Flankerⓓ	37	80
LRPB Lancer ⓓ	38	81
LRPB Raiderⓓ	39	115

Predicta® B tests were conducted at all sites (Table 4). Coonamble and Narromine tested 'high' for background FCR inoculum levels. This was despite a double break of chickpea grown in 2023 and canola in 2022 at Narromine. Coonamble was fallow in 2023 and barley in 2022. Consequently, even the uninoculated (-FCR) treatments at both of these sites in 2024 were already at a high risk of yield impact by FCR, the additional inoculation elevated FCR infection levels even further. Ganmain tested below detection limits (BDL) for FCR, which had barley as the previous crop in 2023.

FCR

The +FCR plots were inoculated at sowing with non-viable wheat seed colonised by *F. pseudograminearum* (mixture of 5 isolates) at the rate of 1.4 g/m row (100 grams/plot) to establish a medium to high disease pressure (Forknall *et al.,* 2019). This inoculation was done to create the circumstance of an increased FCR risk. The -FCR plots received no artificial inoculation.

Nitrogen

Rates of N applied to the -N treatment was designed to achieve water limited yields at all sites, the +N treatment were designed to apply non-water limited yield potential levels of N with rates detailed in Table 3.

Table 3. Nitrogen fertiliser applied to -N and + N treatments

	Starting N (kg/ha)	**N fertiliser applied kg N/ha**	
Site	(0–60 cm)	-N	+N
Narromine	~120	25	100
Coonamble	~88	25	100
Ganmain	94	40 +32[#]	130 + 32[#]

N was applied as urea, broadcast and incorporated by sowing.
At Ganmain a further topdressing of 32 kg/ha of N as urea was applied over the site in August.

Chicken litter was applied to the site after soil tests were taken at Ganmain which may negate the soil tests values below and impact on the N responsiveness of this site.

Table 4. Site details for the 3 trials in 2024. FCR status, BDL = below detection limit, GSR = growing season rainfall

Trial location	FCR risk rating/levels	Sowing date	GSR (May–Sept)
Coonamble	High 2.5 log(pg DNA/g)	17/5/2024	186 mm
Narromine	High 2.6 log(pg DNA/g)	16/5/2024	243 mm
Ganmain	BDL	14/5/2024	157 mm

Results summary

The results were analysed using ASReml, references to differences are statistically significant (*P*<0.05) unless stated otherwise.

Results with both one, two and three-way interactions are presented below. Results with the same letter are not significantly different.

Reference to high or increased FCR levels are referring to +FCR treatments, low FCR refers to -FCR. High N status refers to +N and low N refers to -N treatments.

Narromine

Table 5. Factorial analysis of wheat yield - Narromine 2024

Factor	denDF	p- Value
Population	92	0.00002
Variety	92	0.00000
FCR	92	0.00000
N nutrition	92	0.00000
Populations * Variety	92	0.87
Populations * FCR	92	0.06
Variety * FCR	92	0.06
Population * N	92	0.002
VARIETY *N	92	0.73
FCR * N	92	0.00001
Population * Variety * FCR	92	0.05
Population * Variety * N	92	0.21
Population * FCR * N	92	0.39
Variety * FCR * N	92	0.23
Population * Variety * FCR * N	92	0.61

As detailed in Table 5 all four factors were highly significant with the individual results displayed in Table 6. Key outcomes are:

- Increasing plant populations from moderate to high increased yields by 0.26 t/ha.
- Higher FCR reduced yields by 0.77 t/ha (~16% yield loss from FCR).
- Higher N increased yields by 0.75 t/ha.

- Overall, LRPB Lancerⓓ yielded the lowest, Beckomⓓ, LRPB Flankerⓓ and LRPB Raiderⓓ yielded higher and were not significantly different from each other.

Table 6. Factorial analysis of the one-way impacts of FCR, N nutrition, plant populations and variety on yield (t/ha) - Narromine 2024

Factor		**Yield (t/ha)**	
Population	Moderate	4.31	b
	High	4.57	a
Crown rot	-FCR	4.82	a
	+FCR	4.05	b
Nitrogen	-N	4.06	b
	+N	4.81	a
Variety	Beckomⓓ	4.68	a
	LRPB Flankerⓓ	4.55	a
	LRPB Lancer ⓓ	3.91	b
	LRPB Raiderⓓ	4.61	a

At Narromine there were several more interactions with multiple variables (Table 7, Table 8 and Table 9). Both population * N (p= 0.00228) and FCR * N (p=0.00001) were highly significant. There were two weak interactions of FCR * population and FCR * variety (p<0.06).

- The highest yield was achieved under high N and high populations.
- Although the site responded to higher N under both populations, yields increased by 0.93 t/ha with high populations and only 0.57 t/ha with moderate populations.
- High populations increased yields with high FCR by 0.37 t/ha but had no effect at low FCR.

Table 7. Factorial analysis of the two-way interaction of plant populations with FCR, and N nutrition, and variety on yield (t/ha) - Narromine 2024

Factor	**Yield (t/ha)**				
Nitrogen	**Moderate population**		**High population**		**Δ**
-N	4.02	c	4.10	c	**Ns**
+N	4.59	b	5.03	a	**0.44**
Δ	**0.57**		**0.93**		
FCR					
-FCR	4.75	a	4.89	a	**Ns**
+FCR	3.87	c	4.24	b	**0.37**
Δ	**-0.88**		**-0.65**		

All four varieties responded to higher FCR but to differing levels. LRPB Flankerⓓ suffered the highest yield reduction with -1.01 t/ha or close to 20% yield loss, Beckomⓓ -0.78 t/ha, LRPB Raiderⓓ -0.69 t/ha and LRPB Lancerⓓ lost the least at 0.57 t/ha (~ 14%). Despite the large reduction, LRPB Flankerⓓ with high FCR, still outyielded LRPB Lancerⓓ with low FCR.

There was also an interaction of FCR and N. Under lower FCR, yields increased by 1.02 t/ha under high N but with higher FCR yield still increased but only by 0.48 t/ha with high N inputs.

Table 8. Factorial analysis of the two-way interaction of FCR and variety on yield (t/ha) - Narromine 2024

Factor	**Yield (t/ha)**				
Variety	**-FCR**		**+FCR**		**Δ**
Beckomⓓ	5.07	a	4.29	b	-0.78
LRPB Flankerⓓ	5.05	a	4.04	c	-1.01

LRPB Lancerⓟ	4.20	bc	3.63	d	-0.57
LRPB Raiderⓟ	4.95	a	4.26	bc	-0.69
Nitrogen					
-N	4.31	b	3.81	c	-0.50
+N	5.33	a	4.29	b	-1.04
Δ	1.02		0.48		

The only significant 3-way interaction was between variety, FCR and population detailed in **Table** 9.

- For LRPB Flankerⓟ and LRPB Raiderⓟ under higher FCR, yield reductions were less under higher populations than moderate populations when compared to lower FCR. Yield loss from FCR in LRPB Flankerⓟ went from 1.27 t/ha down to 0.76 t/ha and LRPB Raiderⓟ went from 0.97 t/ha down to 0.41 t/ha. In both cases yield reductions were ~0.5 t/ha less at higher plant populations.
- In Beckomⓟ and LRPB Lancerⓟ yield loss from FCR were similar under both plant populations.

Table 9. Factorial analysis of the three-way interaction of variety, FCR and plant populations on yield (t/ha) - Narromine 2024

Variety	**FCR**	**Moderate population**	**High population**	**Δ**
Beckomⓟ	-FCR	4.96 a	5.19 a	ns
Beckomⓟ	+FCR	4.19 cd	4.38 bc	0.19
Δ		-0.77	-0.81	
LRPB Flankerⓟ	-FCR	5.07 a	5.03 a	ns
LRPB Flankerⓟ	+FCR	3.80 ef	4.27 bcd	0.47
Δ		-1.27	-0.76	
LRPB Lancerⓟ	-FCR	4.00 de	4.40 bc	0.4
LRPB Lancerⓟ	+FCR	3.51 f	3.75 ef	ns
Δ		-0.49	-0.65	
LRPB Raiderⓟ	-FCR	4.95 a	4.95 a	ns
LRPB Raiderⓟ	+FCR	3.98 de	4.54 b	0.57
Δ		-0.97	-0.41	

Coonamble

Table 10. Factorial analysis of yield - Coonamble 2024

Factor	denDF	p-Value
Population	88	0
Variety	88.1	0
FCR	88.4	0.00001
N	88.4	0.07
Population * Variety	88.2	0.27
Population * FCR	88	0.02
Variety * FCR	88.2	0.12
Population * N	88	0.71
Variety * N	88.2	0.02
FCR * N	88.1	0.55
Population * Variety * FCR	88.3	0.53
Population * Variety * N	88.3	0.42
Population * FCR * N	88	0.90
Variety * FCR * N	88.1	0.05
Population * Variety * * FCR * N	88.2	0.57

As detailed in Table10, population, variety and FCR were all significant ($p<0.05$) at Coonamble, N had a weaker impact at $p<0.07$.

Table 11. Factorial one-way analysis of the impacts of FCR levels, N nutrition, plant populations and variety on yield (t/ha) - Coonamble 2024

Factor		Yield (t/ha)	
Population	Moderate	4.62	b
	High	5.01	a
Crown rot	+FCR	4.66	b
	-FCR	4.97	a
Nitrogen	+N	4.76	ns
	-N	4.87	ns
Variety	Beckom⦶	5.11	a
	LRPB Flanker⦶	4.40	c
	LRPB Lancer⦶	5.15	a
	LRPB Raider⦶	4.60	b

- Increasing plant population increased yields by 0.39 t/ha.
- High FCR reduced yield by 0.31 t/ha (~6% yield loss from FCR).
- LRPB Lancer⦶ and Beckom⦶ yielded equally the highest of the wheat varieties tested, LRPB Raider⦶ was lower at 4.60 t/ha and LRPB Flanker⦶ the lowest at 4.40 t/ha.

At Coonamble there were several interactions with multiple variables detailed in Table 12, Table 13, and Table 14.

Table 12. Factorial analysis of the two-way interaction of plant populations and FCR on yield (t/ha) - Coonamble 2024

Factor	**Yield (t/ha)**				**Δ**
Crown rot	**Moderate population**		**High population**		
-FCR	4.85	b	5.08	a	0.23
+FCR	4.40	c	4.93	ab	0.53
Δ	-0.45		-0.15		

- Yield increased with higher plant populations regardless of FCR levels, but increases were greater under high populations at 0.53 t/ha compared to 0.23 t/ha with lower FCR.
- Yield loss from increased FCR was also greater under moderate plant populations at 0.45 t/ha than under high plant populations where reductions were only 0.15 t/ha.

Table13. Factorial analysis of the two-way interaction of N nutrition and variety on yield (t/ha) - Coonamble 2024

Factor	**Yield t/ha**				**Δ**
Variety	**-N**		**+N**		
Beckom⟇	5.14	ab	5.07	ab	**ns**
LRPB Flanker⟇	4.54	c	4.26	d	**-0.27**
LRPB Lancer ⟇	5.29	a	5.01	b	**-0.28**
LRPB Raider⟇	4.49	cd	4.71	c	**ns**

There was a 3-way interaction between variety, FCR and N detailed in Table 14.

- Only LRPB Flanker⟇ and LRPB Raider⟇ responded to FCR, N and population.
- For both varieties, at both rates of N, increasing populations increased yield.
- In LRPB Flanker⟇ +N reduced yield under a moderate population but had no effect under the high population.
- For LRPB Raider⟇, +N increased yield under moderate populations but it had no impact at the higher population.

Table 24. Factorial analysis of the 3-way interaction of variety, FCR and plant populations on yield (t/ha) - Coonamble 2024

Variety	N	Moderate population		High population		Δ
Beckom⟇	-N	4.99	bcd	5.30	ab	ns
Beckom⟇	+N	4.97	bcd	5.18	abc	ns
Δ		ns		ns		
LRPB Flanker⟇	-N	4.33	fg	4.75	de	0.42
LRPB Flanker⟇	+N	3.95	h	4.58	ef	0.63
Δ		-0.38		ns		
LRPB Lancer⟇	-N	5.17	abc	5.41	a	ns
LRPB Lancer⟇	+N	4.86	cde	5.15	abc	ns
Δ		ns		ns		
LRPB Raider⟇	-N	4.17	gh	4.82	de	0.65
LRPB Raider⟇	+N	4.56	ef	4.86	cde	0.30
Δ		0.40		ns		

Ganmain

Table 35. Factorial analysis of yield (t/ha) - Ganmain 2024

	denDF	p-Value
Population	90	0
Variety	90	0
FCR	90	0
N	90	0.41
Population * Variety	90	0.002
Population * FCR	90	0.69
Variety * FCR	90	0.14
Population * N	90	0.87
Variety * N	90	0.72
FCR * N	90.1	0.34
Population * Variety * FCR	90	0.12
Population * Variety * N	90	0.10
Population * FCR * N	90	0.13
Variety * FCR * N	90	0.25
Population * Variety * FCR * N	90.1	0.02

At Ganmain only population, variety and FCR impacted yield as outlined in Table 16. Population * variety was the only significant 2-way interaction. Population * Variety * FCR * N was also significant. Key findings are-

- High plant populations increased wheat yield by 0.52 t/ha.
- Higher FCR levels reduced yield by average of 0.26 t/ha (~6% yield loss from FCR).
- Beckom$^{\phi}$ and LRPB Raider$^{\phi}$ yielded the highest and were not different followed by LRPB Flanker$^{\phi}$ and LRPB Lancer$^{\phi}$ with 0.85 t/ha difference between the highest and lowest yielding wheat varieties.

Table 16. Factorial analysis of significant 1-way interactions of plant populations and variety on yield (t/ha) - Ganmain 2024

Factor		Yield	
Population	Moderate	4.31	b
	High	4.83	a
Crown rot	-FCR	4.70	a
	+FCR	4.44	b
Variety	Beckom$^{\phi}$	4.89	a
	LRPB Flanker$^{\phi}$	4.56	b
	LRPB Lancer$^{\phi}$	4.04	c
	LRPB Raider$^{\phi}$	4.80	a

- All varieties responded positively to increased populations ranging from 0.25 t/ha up to 0.71 t/ha as shown in Table 17.

Table 47. Factorial analysis of significant 2-way interactions of plant populations and variety on yield (t/ha) Ganmain 2024

	Yield (t/ha)				
Variety	Moderate population		High population		Δ
Beckomⓟ	4.53	bc	5.24	a	0.71
LRPB Flankerⓟ	4.44	cd	4.69	b	0.25
LRPB Lancerⓟ	3.80	e	4.28	d	0.48
LRPB Raiderⓟ	4.49	c	5.11	a	0.62

- Increased population for all combinations of N and FCR resulted in positive yield benefits for Beckomⓟ and LRPB Raiderⓟ (Table 18).
- For LRPB Flankerⓟ and LRPB Lancerⓟ only two combination of N and FCR were significant but in both, increasing population increased yield.

Table 58. Factorial analysis of the 4-way interaction of variety, FCR and plant populations on yield (t/ha) - Ganmain 2024

			Yield (t/ha)				
Var	**N**	**FCR**	**Moderate population**		**High population**		**Δ**
Beckomⓟ	+N	+CR	4.38	ghijkl	5.15	bc	0.77
		-CR	4.78	def	5.36	ab	0.59
	-N	+CR	4.36	hijkl	4.89	cde	0.53
		-CR	4.61	efghi	5.57	a	0.96
LRPB Flankerⓟ	+N	+CR	4.23	jklm	4.60	efghi	0.37
		-CR	4.62	efghi	4.67	efgh	ns
	-N	+CR	4.37	ghijkl	4.34	hijkl	ns
		-CR	4.53	fghij	5.12	bc	0.59
LRPB Lancerⓟ	+N	+CR	3.59	p	4.30	ijkl	0.71
		-CR	3.91	mnop	4.53	fghij	0.63
	-N	+CR	3.81	op	4.13	lmno	ns
		-CR	3.89	nop	4.16	klmn	ns
LRPB Raiderⓟ	+N	+CR	4.50	fghijk	5.07	bcd	0.57
		-CR	4.61	efghi	5.08	bcd	0.47
	-N	+CR	4.14	lmno	5.20	bc	1.06
		-CR	4.70	efg	5.11	bcd	0.4

Discussion

Across all sites in 2024, analysis showed that all 4 factors tested (variety, population, N nutrition and FCR) impacted on wheat yields. Increases in FCR infection levels had the most negative impact on yield as a single factor at all three sites. Narromine was reduced on average by 0.77 t/ha or 16%, Coonamble by 0.31 t/ha or 6% and Ganmain 0.26 t/ha or 6%.

Overall, increasing N nutrition had either a positive impact or none. The strongest response to added N was at Narromine in 2024, and this was despite coming off the back of a chickpea crop in 2023. Yields increased by 0.75 t/ha (~ 18%) through the additional N applied. At Coonamble the response was only weak (p=0.07) and Ganmain had no response to increased N. Because of this lack of response for both sites the +N treatments represented luxury N nutrition levels, a circumstance primed for 'haying off' from high populations, yet there was no evidence of this.

Varietal choice had a large impact on yield outcomes with differences between wheat varieties at most sites ranging from 0.75 t/ha up to 0.85 t/ha.

Increasing plant populations was only associated with positive impacts on yield at all sites in 2024. At Narromine, yield increased by 0.26 t/ha (6%), Coonamble 0.36 t/ha (9%) and Ganmain 0.52 t/ha (12%).

However, the main aim of this work was to investigate if increased FCR or higher N nutrition interacted with increased populations, which in turn reduced or negated their benefits to wheat yield and/or quality.

Where there were interactions between FCR, population and variety, without exception, yield was greater under the higher population than at the moderate population. Additionally, there were many cases where there were no interactions. That is, increased FCR infection levels or increased N nutrition had no impact on the positive or negative outcomes associated with increased populations.

However as first identified in the 2023 trials there were some interesting and valuable interactions between FCR and wheat plant population at all sites.

- Within any one variety and site, the highest yield, or equal highest, were attained under the high plant population where there was a lower level of FCR infection.
- Under increased FCR infection, yield was at least the same or higher than when employing only moderate wheat plant populations.
- Yield in the presence of higher levels of FCR infection were highest under high populations albeit not as high as under lower levels of FCR infection.

This relationship is illustrated in Figure 1 below. The graph details the yield results for the two least tolerant FCR varieties tested, Beckom⦶ and LRPB Flanker⦶, under two populations and FCR levels.

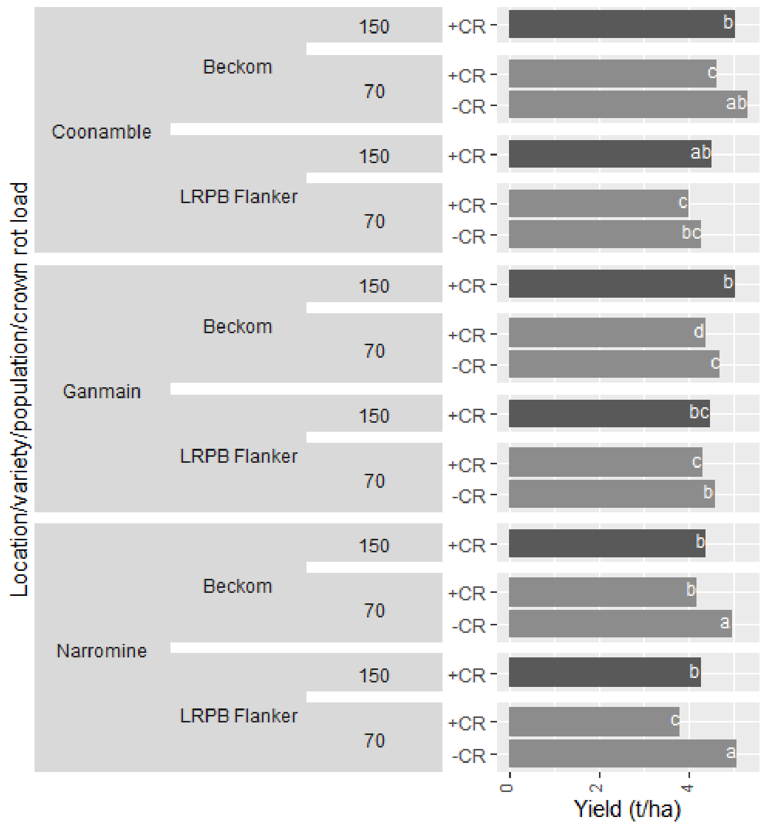

Figure 1. Impact of increased plant population at high and low FCR pressure, regardless of nitrogen rate on yield of various varieties at Narromine and Coonamble, 2024. Results with the same letter within a site and variety are not significantly different (P < 0.05).

The mechanisms for this relationship are not clear and may be worthy of further investigation. However, growers could consider that under higher levels of FCR risk, increasing wheat plant populations could be beneficial in reducing the impacts of this disease on yield.

Conclusions

Growers are being encouraged to increase crop competition by increasing plant populations to aid in weed control. These trials have continued to reinforce that concerns around higher wheat plant populations resulting in decreased yield and quality, particularly in lower yielding environments, are not well founded.

Consecutive years of research in 2023 and 2024 reiterate the significant effect that FCR can have on wheat in both low and moderate yielding situations and has shown that out of the factors tested, it is the largest driver of poor yield outcomes.

Overwhelmingly, increased plant populations have resulted in either positive outcomes or no impact on yield, regardless of the FCR infection level or nitrogen status. There was little to no evidence of negative outcomes from increased wheat plant populations.

This additional year of research in 2024 reiterates the advantages that higher wheat populations under increased FCR infection appear to have in maintaining yield and may be an avenue that can be exploited by growers amongst the other additional benefits including improved weed competition.

Variety choice had expected results when considering FCR but further interactions with populations and N management were also interesting. Choosing a wheat variety with higher tolerance to FCR can reduce the yield penalties, however if the variety is not well suited to the environment or sowing window, then better adapted wheat varieties with a higher yield potential remain a better option.

Overall, based on this research growers should feel confident that increasing wheat plant populations to aid in weed control will not introduce any significant disadvantages but rather appears to provide more advantages. Improved yield is key with higher wheat populations but there is also evidence from this research of increased N efficiency and improved outcomes under higher FCR risk.

Reference

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