What are the limiting nutrients for crops of high yield potential in the South East of South Australia?

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Abstract
Canola and wheat grain yields in the high rainfall zone (HRZ) of southern Australia are currently less than half of the predicted rainfall limited potential. The main barrier to achieving these potential yields is the application of sufficient nutrients. There has been limited research on nutrient response of crops to soil nutrient status conducted in the HRZ. It was hypothesized that grain yields in the south east of South Australia would be limited at soil test levels higher than those currently accepted, as the current critical soil test levels are based on response studies undertaken in regions of lower yield potential. Nutrient omission experiments were undertaken in the HRZ with wheat and canola to assess the impact of particular nutrients on yield under different rates of N supply. A decile 10 season in 2016 saw grain yield responses to Phosphorus (P) and Sulphur (S) of 17 to 38%, respectively over an unfertilised control, where sufficient Nitrogen (N) was applied to meet the expected yield potential. Across the sites tested, the limiting nutrients were first N, followed by P and S. Relative to the 2016 site and season, the current critical values were suitable for P in wheat and S in canola, but too low for P in canola and S in wheat. A decile 1 season in 2015 did not allow full expression of the yield potential achievable in most seasons in this region, with only an N response observed in canola. Further evidence is required to substantiate these findings in less extreme seasons.

Keywords
Crop nutrient requirements, nutrient omission.

Introduction
The high rainfall zone (HRZ) of southern Australia has high grain yield potential, however, current on-farm yields are often less than half of that expected for crops supplied with non-limiting nutrients (Christy et al. 2015). In the HRZ of South Australia (SA) canola and wheat can potentially produce grain yields over 4 and 8 t/ha, respectively (Christy et al. 2015). Such high yielding crops require a substantial application of inputs. Decisions about fertiliser and rates are generally based on the difference between the nutrients required for a targeted yield and the estimated amount of nutrients supplied by the soil. However, limited research has been conducted in the HRZ relating nutrient response to soil test values, with current soil critical test values having been derived from low and medium rainfall zones with lower yield potential (Christy et al. 2015). It was hypothesised that the higher grain yields in the south east of SA may still be nutrient limited at current recommended soil test levels, and higher critical values may be needed in this environment. To address this, a series of nutrient omission trials were undertaken with canola and wheat, in which the yield of treatments supplied with non-limiting nutrients (N, P, K, S, Cu and Zn) were compared with treatments where one or more of these nutrients were omitted. An improved understanding of this relationship will reduce the risk of either under or over applying fertiliser, helping to maximise returns to growers.

Methods
Field trial details
To investigate interactions and quantify the magnitude of response to a range of nutrients, a series of nutrient omission experiments were established in 2015 and 2016 in the south east of SA. In 2015 the trials comprised canola at Frances and wheat at Bool Lagoon and in 2016 trials consisted of both canola and wheat at Bool Lagoon. Sites were selected on the basis of suspected of being deficient in at least one nutrient. However, soil samples collected immediately prior to sowing indicated some sites had higher levels of available nutrients than initial assessments and exceeded current soil test critical values (Table 1). Based on the soil test values and currently accepted interpretation guidelines (Armstrong et al. 2014, Peverill et al. 1999), grain yield responses of more than 10% would be expected to P in wheat in both years, and to S in

canola in both years. There were low Zn levels at the 2016 site, which were indicative of a response.

All trials had a common experimental design, which consisted of three rates of N in an incomplete factorial combination with other nutrients, where either P, K, S or micro-nutrients Cu and Zn were omitted. Fertiliser treatments (apart from N top-dressing) were drilled at sowing. Fertiliser application rates in 2015 were 25 kg P/ha, 50 kg K/ha, 24 kg S/ha, 1.1 kg Zn/ha and 2.0 kg Cu/ha. In 2016 the P rate was changed to 50 kg P/ha, and S to 20 kg S/ha. The N treatments consisted of a sowing basal of 18 kg N/ha in 2015 and 30 kg N/ha in 2016, with in-crop applications in August and October calculated to achieve either 60% or 100% of the estimated water limited yield potential (Table 2). The N rates were calculated in July from mineral N data from soil samples collected prior to sowing and expected rainfall until the end of the growing season. A low N treatment consisted of no in-crop N, and was only conducted on treatments with all nutrients or no other nutrients added. The N treatments are designated as 30N, 60N and 100N.

Table 1. Initial soil mineral N (nitrate + ammonium) prior to sowing and topsoil (0-10 cm) available P (Colwell), K (ammonium acetate, calculated as equivalent to a Colwell K extract) and S (KCl-40), and critical values at which 90% of maximum grain yield would be expected (Armstrong et al. 2014) and micro-nutrients Cu and Zn (DTPA – extractable) and critical values (Peverill et al. 1999). Soil test values lower than the relevant critical value are shown in bold. Pre-sowing mineral N was sampled to 100 cm at Frances, but was limited to 20 cm at Bool Lagoon in 2015, and 10 cm in 2016, below which was limestone.

Site	N kg/ha	P	K	S	Cu	Zn
2015			mg/kg			
Frances (canola, Sodosol)	76	32	155	**6.7**	0.7	1.4
Bool Lagoon (wheat, Calcarosol)	55	**27**	1017	8.8	0.9	6.2
2016						
Bool Lagoon (canola, Calcarosol)	28	24	1250	**6.2**	0.5	**0.4**
Bool Lagoon (wheat, Calcarosol)	43	**24**	1050	7.2	0.5	**0.3**
Critical Value (canola, all soils)		18	45	8.6	0.2	0.8
Critical Value (wheat, Calcarosol)		34	40	4.5	0.3	0.8

Table 2. The amount of N applied to achieve 60% or 100% yield potential, the low N treatment, sowing basal 30 kg N/ha and the two subsequent in-crop varying application rates in August and October.

Yield Potential	Frances Canola 2015	Bool Lagoon Wheat 2015	Bool Lagoon Canola 2016	Bool Lagoon Wheat 2016
100N	30, 98, 40	30, 79, 40	30, 148, 73	30, 94, 63
60N	30, 55, 0	30, 33, 0	30, 80, 0	30, 38, 0
30N	30, 0, 0	30, 0, 0	30, 0, 0	30, 0, 0

Plots were 8 m long, 1.2 m wide, with a drill row width of 0.15 m, and treatments were replicated 4 times. The canola cultivar sown was Archer CL and the wheat cultivar was Beaufort. Measurements at all sites included biomass at anthesis, grain yield and final biomass. Biomass at anthesis and final biomass were hand harvested in two sections, each 1 m long by 0.6 m wide comprising the middle 4 drill rows of the plot, allowing the outer rows as buffers. Grain yield was machine harvested by a trial plot header.

Data were analysed by REML using GENSTAT (18^{th} Edition, Payne et al. 2009) and treatments compared at the 5% least significant difference.

Results

Growing season rainfall (May to November) in 2015 was decile 1 at both locations and at Bool Lagoon in 2016 decile 10. Rainfall in 2016 at Bool Lagoon was the highest on record and resulted in the trial site experiencing intermittent inundation throughout July to October.

In the 2015 canola trial at Frances, there was a positive grain yield response to N between the 30N and 60N levels, and a negative response to added P at 100N, but no grain yield responses to any of the other nutrients (data not shown). Canola yielded 0.94 t/ha where all nutrients had been applied, but a significantly higher yield of 1.2 t/ha was achieved at the high N level where P had not been applied. This may be an indication that the high N and P nutrition led to excessive vegetative growth, but left insufficient soil water to complete grain-fill in the dry season.

In the 2015 wheat trial at Bool Lagoon, there was no grain yield response to any nutrient, and the treatment with all nutrients achieved a yield of 3.63 t/ha (data not shown). Visual scoring in October revealed a biomass penalty at the 30N and 60N levels if P had not been applied.

In the 2016 season, the canola trial at Bool Lagoon showed responses to N, P and S (Figure 1). Relative to the full nutrient treatment, omitting P led to a 38% yield penalty, omitting S a 30% penalty, and omitting in-crop N a 41% penalty. These P and S effects were only significant at the 100N level, and not at 60N. The treatment to which all nutrients were applied achieved a grain yield of 1.41 t/ha, whereas if no nutrients were applied the yield was 0.66 t/ha.

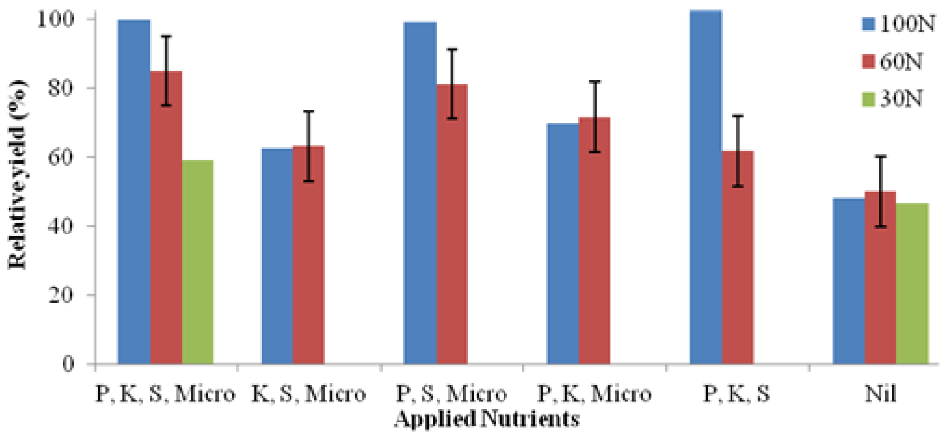

Figure 1. Bool Lagoon 2016, canola relative yield potential of 100N + P, K, S, Micro (Cu and Zn) (1.41 t/ha). Errors bars are the 5% least significant difference (lsd) applicable to all treatments.

The adjacent wheat trial also showed responses to N, P and S (Figure 2), and again the P and S responses were only significant at the 100N level. Relative to the full nutrient treatment, omitting P led to a 24% yield penalty, omitting S a 17% penalty, and omitting in-crop N a 56% penalty. The full nutrient treatment averaged a grain yield of 4.39 t/ha.

In both the canola and wheat trials, visual scoring in July prior to in-crop N application showed a significant response to P, but not to any other nutrient. Biomass cuts at the end of each crop's vegetative stage (mid-September for canola, late October for wheat) showed significant responses only to N. In both crops, the grain yield penalty for the Nil treatment (with neither P nor S) approximated the sum of the P and the S penalty.

Discussion

The decile 1 season in 2015 did not allow full expression of the yield potential achievable in most seasons in this region. The only nutrition response observed was N in canola, demonstrating the higher N requirements of canola compared to wheat. In the 2016 trials there were responses to P and S in canola and wheat of 17-24%, but only at the 100N level. However, at the 60N rate responses to P and S were not statistically significant. Conversely, there was no N response in canola and only a small response in wheat where P or S were limiting. This suggests that when making in-crop N application decisions, higher N rates, similar to that of the 100N rate, should be applied to paddocks where P and S fertility is well above current critical values, whereas lower N rates, such as the 60N rate, are more appropriate where P and S fertility is marginal and closer to the critical values.

Based on critical values reported by Armstrong et al. (2014) and more recent updates using the Better Fertiliser Decisions for Cropping data interrogator (Spiers et al. 2013) using data current at February 2017, a 15% response to P would be expected in wheat at the 2016 site and 5% for canola, compared with experimental responses of 24% and 38% respectively. Equivalent values for S were 2% for wheat and 32% for canola, compared with experimental responses of 17% and 30% respectively. The current critical values therefore appear suitable for P in wheat and S in canola, but too low for P in canola and S in wheat.

Nutrient responses are commonly thought of as the "law of the minimum" (Sinclair 1999). If this law were operating, yields of the Nil treatment would be equal to the yield of the lowest-yielding omitted nutrient.

However, in both of the 2016 trials, this applied to N in canola, but in both crops the P x S interaction meant that the yield penalty of the Nil treatment was the sum of the P and S yield penalties. This highlights the importance of soil testing to check for all potential limiting nutrients.

The trials discussed have been conducted in a decile 1 year that limited expression of the region's yield potential, followed by a decile 10 year where the nutrient responses may have been affected by waterlogging. There has been insufficient trial work to make conclusions about the adequacy of current soil test values for crops in the HRZ with high yield potential. A further series of trials is planned for 2017, which will encompass the south east of SA and high-rainfall parts of Victoria.

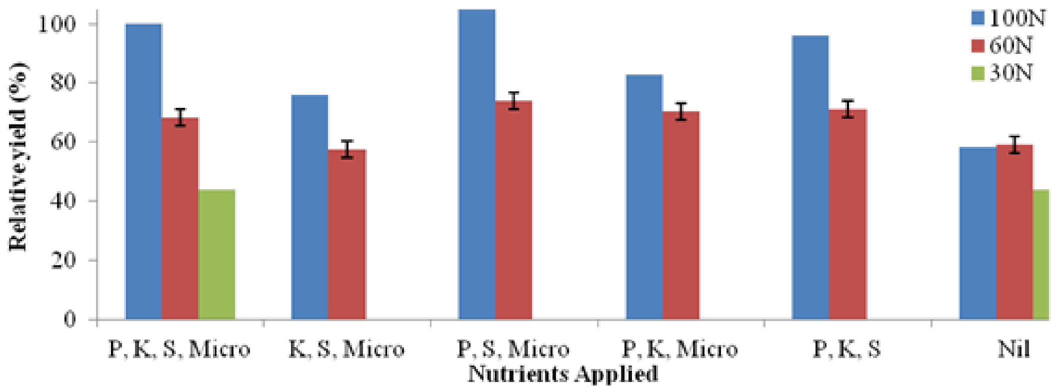

Figure 2. Bool Lagoon 2016, wheat relative yield potential of 100N + P, K, S, Micro (Cu and Zn) (4.39 t/ha). Errors bars are the 5% least significant difference (lsd) applicable to all treatments.

Conclusion

In both years canola has responded to higher N rates, whereas wheat only responded in the wetter season. Both crop types responded to P and S at higher N rates in a decile 10 season. Across the four sites tested, the limiting nutrients were first N, followed by P and S. The responses observed have occurred at soil test values above the critical values that have been largely developed for the medium to low rainfall zones with lower yield potential. In 2017 trials will be repeated to test the consistency of field findings across seasons and locations and if current soil test critical values are appropriate for the HRZ of southern Australia.

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