Critical Colwell P values for wheat and canola in the high rainfall zone

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Abstract
Soil test interpretation criteria for cropping in the high rainfall zone (HRZ) have been derived from empirical experiments in areas of lower rainfall. To derive Colwell P values for the HRZ at which 90% of maximum yield could be expected, a series of P response experiments were conducted in southern Victoria and adjacent regions. These covered 12 site-years for wheat and 10 site-years for canola, and were combined with 4 site-years for wheat that had been conducted previously in the region. The critical Colwell-P value was 37 mg/kg for wheat and 41 mg/kg for canola. These values are higher than those derived from trials in areas of Australia's grain belt receiving lower rainfall than the HRZ (21 and 20 mg/kg respectively). For wheat the difference appears to be related to a higher phosphate buffering index (PBI) in soils of the HRZ, while for canola possible reasons include a combination of high PBI, high yield potential and its poor waterlogging tolerance.

Key Words
BFDC, Better Fertiliser Decisions for Cropping, phosphorus, soil testing

Introduction
Soil test interpretation criteria for grain crops in Australia are based on trials collated into a national database, "Better Fertiliser Decisions for Cropping Systems in Australia" (BFDC). By March 2019 the database held 1701 site-years of data comparing wheat yield with the 0-10cm Colwell-P test (NSW DPI 2012). While such a large number of trials would normally lead to a high level of confidence in critical soil test values calculated from these data, most of the trials were conducted in the low and medium rainfall zones, and few from the high rainfall zone (HRZ). Characteristics of the HRZ that may favour higher critical soil test values are a higher P buffering index (PBI), a much higher yield potential, and more frequent waterlogging. For example, commercial wheat yields exceeding 6 t/ha are common in the HRZ, but only 11 of the 1701 trials in the database exceeded this yield on the treatment with non-limiting nutrients. There were only 4 trials of P response in wheat (*Triticaum aestivum*) in the Victorian HRZ and none for canola (*Brassica napus*).

To determine whether higher critical values should be recommended for the HRZ, a series of fertilizer response experiments were conducted on wheat and canola between 2015 and 2018. This paper summarizes relationships between the Colwell P test and relative yield from these experiments and the 4 already in the database to determine critical values appropriate to the region.

Methods
Field experiments
Experimental sites were selected in the south-east of South Australia, western Victoria south of the Divide, and at Rutherglen (Table 1). Soils were either Chromsols or Sodosols, apart from a site at Bool Lagoon on a Calcarosol. Experimental design was either a factorial combination where nutrients were added at different rates, or an omission design where one treatment was supplied with non-limiting rates of all nutrients from which responses could be expected (N, P, K, S, Cu, Zn) and in other treatments one or more of these nutrients were omitted. Some experiments were sown into the Long-term Phosphate Experiment (LTPE) on the Agriculture Victoria research station at Hamilton, where separate experiments were located within larger grazing paddocks that had a wide range of starting P fertility. Each treatment was replicated 4 times. Prior to sowing, soil tests were taken from the 0-10cm layer and analysed for plant-available P by the method of Colwell (1963), and PBI by the method of Burkitt et al. (2002). For most experiments plots were 10m in

length and sown with 8 drill rows at a spacing of 0.15 or 0.2m, from which an area 2m x 6 rows was harvested by hand at maturity.

Statistical analysis

Each experiment was analysed separately to calculate the yield of the highest-yielding treatment (which was in most cases the treatment fully supplied with nutrients), and the yield of the equivalent treatment to which no P had been applied. This was to ensure that responses were only to P, and that other nutrients such as N, K and S were supplied at optimal rates. In P rate experiments, all the applied rates were used to calculate yield at nil and the highest rate of P, by regressing yield against the logarithm of the P rate to linearise the P rate response. Data were analysed by Genstat (18^{th} Edition) using the REML and linear regression procedures. Data from the LTPE were analysed by REML of multiple experiments.

Table 1. Details of experimental sites, growing season rainfall (1 April to 15 November), experimental design, starting Colwell P, PBI and grain yield of the highest-yielding treatment. LTPE refers to the Long-Term Phosphate Experiment and Hamilton, Victoria, and its plot number.

Trial no.	Location	Year	GSR (mm)	Decile	Design	Colwell P (mg/kg)	PBI	Max grain yield (t/ha)
				Wheat				
1	Gnaware	2001	491	9	P x S	45	-	4.97
2	Hamilton	2001	618	9	P x N x S	60	-	5.79
3	Streatham	2001	481	8	P x S	39	64	7.53
4	Buangor	2008	290	1	P rate	56	91	4.39
5	Bool Lagoon	2015	334	1	Omission	27	190	3.63
6	Glenthompson	2015	269	1	Omission	54	41	4.32
7	Bool Lagoon	2016	661	10	Omission	24	104	4.40
8	Inverleigh	2016	481	9	Omission	84	50	10.50
9	Bool Lagoon	2017	527	8	P x N	29	120	2.64
10	Rutherglen	2017	318	3	P x S	22	46	6.98
11	LTPE-1	2018	477	4	P x N	34	188	8.66
12	LTPE-2	2018	477	4	P x N	15	215	8.97
13	LTPE-12	2018	477	4	P x N	106	173	9.47
14	LTPE-13	2018	477	4	P x N	57	233	9.80
15	LTPE-16	2018	477	4	P x N	11	245	7.66
16	LTPE-18	2018	477	4	P x N	21	223	5.81
				Canola				
1	Francis	2015	262	1	Omission	32	50	0.93
2	Inverleigh	2015	252	1	Omission	58	108	1.82
3	Bool Lagoon	2016	661	10	Omission	24	107	1.41
4	Rutherglen	2016	592	10	Omission	19	46	0.73
5	LTPE-1	2017	459	3	P x N	53	188	5.75
6	LTPE-2	2017	459	3	P x N	18	215	5.67
7	LTPE-6	2017	459	3	P x N	143	173	5.56
8	LTPE-13	2017	459	3	P x N	74	233	5.75
9	LTPE-16	2017	459	3	P x N	14	245	5.01
10	LTPE-18	2017	459	3	P x N	21	223	5.17

The critical Colwell soil test values at which 90% of maximal yield would be expected were calculated from the cross-experiment data set by the method of Dyson and Conyers (2013), which was developed for BFDC and used for consistency with other values published from the database:

$$\ln(P_{Colwell}) = a + b.arcsin\sqrt{RY} - arcsin\sqrt{0.9} + \mathcal{E}$$

where $P_{Colwell}$ (mg/kg) is the site average Colwell-P prior to sowing, a and b are coefficients fitted to either wheat or canola by linear regression, RY the relative yield calculated as (yield without P)/(maximum yield), and $\mathcal{E}$ experimental error. The procedure has two stages, the first which uses all the data to determine an initial critical value, while in the second stage soil test values that exceed twice the initial critical value are omitted because their inclusion can lead to erroneously high critical values. Since ($arcsin\sqrt{0.9}$) is subtracted from each value prior to the regression analysis, the critical Olsen P for 90% of maximal yield can be calculated as (Critical P) $= exp(a)$, and its 70% confidence range $exp(a \pm SE)$, where SE is the standard error of a. An equivalent mean and range were calculated for the Colwell soil test value corresponding to 95% of the maximal yield. These calculations were conducted in Genstat 18th Edition.

BFDC comparison values

Comparison critical Colwell-P values from the BFDC database were sought from soils that were most similar to those on which the trials were conducted in the HRZ. For wheat these were calculated the yellow, brown and grey suborders of Chromosols and Sodosols. This grouping is based on Bell et al. (2013), who reported their critical values similar provided their red sub-orders were excluded. The red suborders have higher critical values, and there were none within our HRZ data set. For canola there were only 9 trials that fulfilled these soil criteria, so critical values were calculated for all soils instead.

Results

Rainfall and growing conditions

Rainfall in 2015 was well below average, with all sites recording rainfall in the first decile (Table 1). By contrast 2016 was well above average with all sites in the 9th or 10th decile. Canola crops at Bool Lagoon and Rutherglen experienced sustained periods of surface water during the growing season, and achieved yields of below 2 t/ha for treatments supplied with all nutrients. The following year the wheat crop at Bool Lagoon was flooded from late June until mid-November, and an adjacent canola experiment was abandoned. On the LTPE surface water (but not long-term flooding) was noted on the canola crop between 27 July and 18 September 2017, and on the wheat crop between 6 July and 4 September 2018. No other sustained periods of flooding or surface water were noted. One experiment (LTPE-18) was inadvertently grazed to a residual of 15cm by sheep in September 2018.

HRZ critical values

The 90% critical Colwell P value for HRZ wheat was much higher than from BFDC (37 vs 21 mg P/kg) (Table 2). There were no obvious outliers in the relationship, and HRZ points from the Calcarosol (points 5 and 9) were within the group from Chromosols and Sodosols (Fig 1a). For HRZ canola the critical 90% was also much higher than from BFDC (41 vs 20 mg P/kg) (Table 2), but there were 2 groups of trials. Those with low maximum yields tended toward the lower end of the common relationship, while those with high maximum yields were at the higher end (Fig 1b). Trials with a maximum yield exceeding 2 t/ha were all from the LTPE, and had a 90% critical value of 78 mg P/ha. The 95% critical values were higher and had a wider confidence range.

Table 2. Critical Colwell P values (mg/kg) and their 70% confidence range for 90% and 95% of maximum grain yields from this study, and from BFDC for wheat on brown, grey or yellow Chromosols and Sodosols, and canola on all soils.

Crop	Source	No. of trials	90% critical (± SE)	95% critical (± SE)	R
Wheat	this study	16	37 (33-42)	44 (38-51)	0.69
	BFDC	172	21 (18-24)	25 (21-30)	0.70
Canola	this study - all	10	41 (33-51)	44 (35-57)	0.60
	this study > 2t/ha	6	78 (71-87)	105 (91-121)	0.98
	BFDC	50	20 (18-23)	25 (21-29)	0.88

Discussion

Our study has shown a critical Colwell for wheat in the HRZ of 37 mg/kg value for 90% of grain production, which is much higher than the value of 21 mg/kg from sites from similar soil types currently in BFDC. One possible reason for the higher critical value is a higher PBI in the HRZ. Of the 172 wheat-P trials in the BFDC database there were 38 with accompanying PBI data, the majority of which were in the very low category (36-70), and none were above 140. Moody (2007) showed that the critical Colwell for wheat is affected by PBI, and recommended a value of 38 mg/kg for soils in their moderate PBI category of 141-280, which covers many of the sites in our study. Their recommendation was based on only 3 trials with a PBI exceeding 120, but nevertheless supports our finding of higher critical values in the HRZ.

The critical Colwell-P values for HRZ canola were 41 mg/kg for all trials, or 78 mg/kg for trials that exceeded a yield of 2 t/ha. The latter value was from 6 adjacent trials on the LTPE, and requires further confirmation before it can be accepted more widely. Both values are much higher than the 20 mg/kg critical value from canola trials currently in BFDC. Possible reasons include the higher PBI, higher yield potential, and canola's poor tolerance of waterlogged conditions restricting its uptake of nutrients. Our trials were unable to explain which of these factors were responsible.

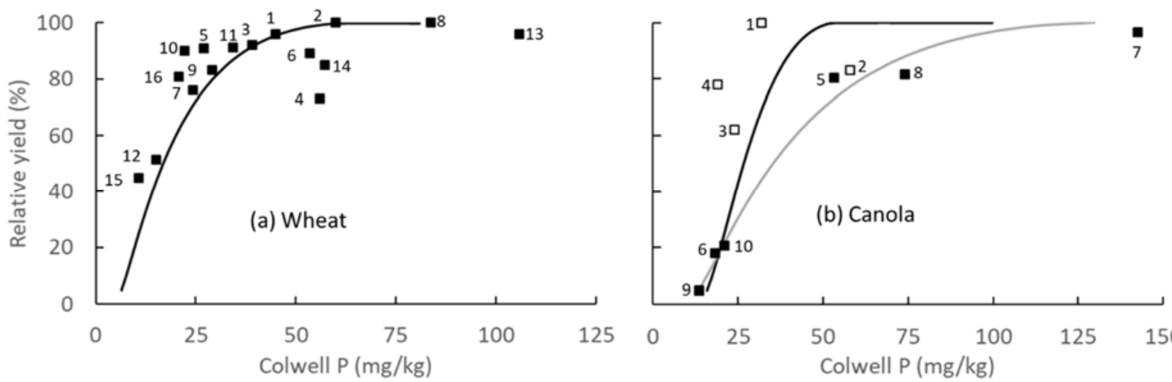

Figure 1. Relative yield of (a) wheat and (b) canola from trials conducted in the high rainfall zone of Victoria. Numbers refer to the trials listed in Table 1. Black lines show back-transformed Dyson-Conyers fitted relationships for all data for each crop, and the grey line canola trials where the maximum yield exceeded 2 t/ha.

Conclusion

The critical Colwell-P value from these HRZ trials was 37 mg/kg for wheat and 41 mg/kg for canola, and are higher than those from the BFDC database (21 and 20 mg/kg respectively). For wheat the difference appears to be related to a higher PBI in soils of the HRZ, while for canola possible reasons include a combination of high PBI, high yield potential and its poor waterlogging tolerance limiting its uptake of nutrients.

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