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Comments on papers relating to soil phosphorus testing in 'Making Better Fertiliser Decisions for Cropping Systems in Australia' in *Crop & Pasture Science* 64, 435–441, 461–498 (2013)

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Testing soils for plant nutrient contents has long been a controversial topic in the research literature. Because of its widespread deficiency and finite natural resource, phosphorus (P) is possibly the most researched plant nutrient, but the most accurate method of assessment for predicting P deficiency and fertilizer requirement remains unclear. The studies reported in the above special issue of *Crop and Pasture Science*, entitled 'Making better fertiliser decisions for cropping systems in Australia', are an attempt to collate and interpret all the relevant research data in Australia to achieve this purpose. Having published several research papers on soil P testing, which impinge on the current studies, I would like to make the following comments on some of the papers reporting soil P testing for wheat.

In an introductory methodology paper (pp. 435–441), Dyson and Conyers (2013) gave a detailed description of the biometrical methodology used in these studies. For fitting yield response curves to applied fertiliser rate experiments, the Mitscherlich and two quadratic equations were proposed. Although the authors suggest that the first equation is particularly appropriate for rate of P response curves, the text does not state which of these equations was used, and there is no indication of the relative goodness-of-fit of the used equation. One may question whether all these equations would give the same values of Y0 and Ymax and whether the same equation was used for all sets of data.

Their methodology for calibrating relative yield against soil test value is extraordinarily complex (p. 437–439), whereas an exponential equation, as used by Holford *et al*. (1985) would more simply and adequately describe the relationship and give the variance accounted for by the soil test. No measure of goodness-of-fit is given by Dyson and Conyers (2013), and their fitted calibration curve for the Colwell test in Fig. 3 (p. 438) does not appear to be a good fit and would underestimate the soil test value at 90% of maximum yield. The inaccuracies of this curve and derived critical value (cv) are demonstrated by the fact that, of the 23 soils which had soil test values above the critical value (22 mg/kg), 16 (or 70%) of them were responsive to fertiliser P! Incidentally, the Mitscherlich function is not conventionally used for soil test calibration curves, as claimed in Fig. 3, although in this case it would have given a better fit and a more realistic cv similar to that given by a logarithmic curve (~40 mg/kg). However, the widespread distribution of points in Fig. 3 demonstrates the inability of the Colwell test to reliably differentiate between responsive and non-responsive soils.

In the first soil P testing paper, Moody *et al*. (2013) list seven soil tests (Table 2, p. 463) which they consider reflect the soil P pools and processes controlling P availability in soils. They do not, however, differentiate between the first four tests (Colwell, BSES, Olsen, and Mehlich 3), which aim to give a measure of the quantity of available P, and the other three tests ($CaCl_2$, DGT, and FeO) which measure other aspects of available P. The qualitative term, 'P availability', is not the same as 'available P' (a quantitative term), but it is used throughout these papers, whether or not 'available P' is meant.

Although the Colwell test is the most widely used soil test in Australia, the other three quantity tests poorly represent the range of tests that have been researched in Australia. The alkaline Olsen and Colwell modification both use the same sodium bicarbonate extractant at pH 8.5 and therefore extract soil P from the same sources.

The acidic BSES test was developed for use on sugarcane growing soils in a different soil and climatic environment to wheat, and the Mehlich 3 test has not been widely used in Australia. There is no discussion or justification for the use of these soil tests or the omission of other tests which have been shown to be more accurate in predicting yield response. For example, two acidic anionic extractants (lactate and fluoride) were found to much more accurately predict responses to fertiliser P than the Colwell test in four separate studies (256 experiments) on slightly acid to alkaline soils representing the central western plains, the central western slopes, and north-western slopes of NSW (Holford and Cullis 1985*a*; Holford and Doyle 1992; Holford *et al*. 1985, 1988).

Speirs *et al*. (2013), in the following paper (pp. 469–479), used 164 soil samples from south-eastern Australia to evaluate six of the previously mentioned soil tests (FeO-P was omitted). According to Table 4 (p. 473), DGT-P was the most accurate soil test accounting for 30% of the variance in relative yield, while the Colwell test accounted for only 21%. In the four studies mentioned above from central and northern NSW, the Colwell test accounted for 19 to 36% of the variance, but all other soil tests accounted for much more of the variance, the lactate test accounting for 44–72%; the lactate test also had the same cv in all four studies. For the 33 Calcarosols from the group in Table 5 (p. 474), Colwell P was the least accurate soil test, accounting for only 13% of the variance in relative yield. For a soil test to be regarded as reasonably accurate, it should account for at least 50% of the variance in relative yield. This study, as well as those from central and northern NSW, showed that the Colwell test falls far short of this standard, and its continuing use is probably responsible for the lack of confidence in P soil testing by many farmers.

The study by Bell *et al*. (2013) had similar aims to that of Speirs *et al*. (2013) but used a much larger dataset, concentrated on differences between Soil Orders and suborders, and was limited to the Colwell test. The Colwell test accounted for much more of the variance in relative yield when separate calibrations were done for each soil order or suborder, except for Calcarosols and Grey Vertosols (Table 2, p. 483). However the cv's at 90% of maximum yield were very low (25 mg/kg or less), possibly because of the unusual procedure used to calculate calibration equations (pp. 437–439). Furthermore, one may question the practicality of identifying the Soil order for every soil received for laboratory testing.

In their re-examination of published estimates of critical P values (para. 2 and 3, p. 491), Bell *et al*. (2013) made factual errors which negate their conclusions about Colwell cv's. In para. 2, they claim that the calculated cv of 57 mg/kg in Holford and Cullis (1985*a*) was for 39 sites whereas it was actually based on 49 sites, as stated in the Appendix. Their claim that the correct cv was 25 mg/kg was actually for another study on 44 acidic soils (pH <5.5) from southern NSW (Holford and Cullis 1985*b*), which was not cited. R. Bell *et al*. (2013) quote another study (para. 3, p.491), derived from the *BFDC Interrogator*, on 126 acidic soils also from southern NSW which gave a similar cv (27 mg/kg) to the above study. These results indicate that the Colwell cv is much lower on moderately to very acid soils (~26 mg/kg) than it is on slightly acid to alkaline soils (~55 mg/kg) in central and northern NSW.

Bell *et al*. (2013) also aimed to examine factors affecting the cv of the Colwell test. However, their study was generally inconclusive even though several papers have been published showing the strong effect of P buffer capacity on Colwell cv's, such as Bolland *et al*. (1994) and Holford (1980). The latter study showed that the cv on moderately buffered soils was double that on weakly buffered soils and that including buffer capacity significantly increased the variance in relative yield accounted for by the Colwell test. The important effect of soil moisture or rainfall on cv's and accuracy of the soil test has also been overlooked in these papers; for example Holford *et al*. (1985) found that the Colwell cv was only 27 mg/kg in experiments receiving low rainfall compared with 53 mg/kg in the higher rainfall experiments. By excluding the 13 low rainfall experiments, the variance accounted for by the Colwell test in 44 experiments of adequate rainfall was increased from 19 to 39%, whereas the accuracy of the lactate test (variance 50%) was unaffected.

The underlying aim of the current studies appeared to be to establish reliable yield response calibration curves for the Colwell test so that the soil test value can be used to predict fertilizer responsiveness. However it is more important to be able to predict the fertiliser P requirement (PR) than just responsiveness. PR is not a direct function of responsiveness because it is also affected by the fertiliser effectiveness (PE). The real importance of P buffer capacity (BC) is its effect on PE – not on the soil test cv; the greater the BC the lower the PE and the higher the PR. The only appropriate measure of PE is the yield response curvature (C) – the lower the curvature, the lower the PE and the higher the PR. The Mitscherlich equation not only gives a measure of responsiveness but also a measure of curvature, thus providing the two parameter values required for predicting PR (Holford *et al*. 1985). A study by Holford and Cullis (1985*a*) on 39 soils from northern NSW showed a strong inverse relationship ($r = -0.67$) between C and BC (or sorption index), and including a measure of BC increased the variance in PR accounted for by the lactate test from 32 to 75%.

There is no reference to or discussion of these important principles for 'making better fertiliser decisions' in these current papers, and there is no recognition of the importance of the Mitscherlich equation in the methodology for predicting PR. Nor is there any evidence that the Mitscherlich equation was used for fitting yield response curves as there were no reported measures of curvature. Although not stated, it is likely that the square root quadratic equation was used for fitting yield response curves, but this equation and other statistical equations, regardless of their goodness-of-fit, do not give a meaningful measure of C. An important implication of the above principles is that it is not necessary to determine soil test cv's because they are not required for calculating PR. In view of this, and the demonstrated inaccuracy and intrinsic problems of the Colwell test, one must question the value of much of the content of these four papers and the BFDC database, which are based largely on the continuing use of this inferior soil test. I would suggest that the largest potential for improving the accuracy of fertiliser advice is to apply the above principles to soil test (including the lactate test) and yield response data from other states, and do further research on the relationship between response curvature and buffer capacity (or sorption index).

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