Author Philip Barlow philip@biosoil.co.nz

Comparing Soil Phosphorus Tests and Their Predictive Ability for P uptake (Leaf analyses) in Actinidia Chinensis

To give the very best advice for kiwifruit growers we at Bio Soil & Crop Ltd (BSC) need the best predictive soil testing technology available. We have been using Mehlich III, Bray II and Olsen soil phosphate testing methods for more than twenty years and found the Mehlich III extract to give the most consistent results for accurately predicting the rate of phosphorus uptake by various crops.
One might wonder why not just leave out the soil testing component and just use leaf nutrient analysis? Because plant root mass is variable according to the age and growth stage of the plants. We cannot solely depend on leaf analysis alone to determine when we have adequate phosphate soil reserves. Also with many nutrients, excess of a nutrient in the soil may at the same time be accompanied by poor uptake of the same nutrient and it would be counter-productive to keep applying the nutrient to even greater excess. Therefore, we need to determine the precise levels of deficiency, sufficiency and excess using soil tests calibrating by correlating leaf analysis for each specific soil type and crop. In doing so we should maximise crop productivity and fertiliser efficiency for our clients, while at the same time avoiding wastefulness and environmental soil & water pollution.

Constantly we seek to obtain the ideal balance of nutrients for maximum profit and promote tasty, health giving fruit for consumers. We at BSC understand that the agronomic tools that we have been working with, although better than preceding technologies, are not yet perfect. Therefore, we welcome new ideas and methods.

In 2006 Haney R and associates published work announcing a new multi-nutrient soil extractant formula "H3A" which is said to be superior to our current Mehlich III method. H3A extraction solution is composed of organic root exudates, lithium citrate, and two synthetic chelators (DTPA, EDTA).
In 2014 Brookside Laboratories combined the H3A extract with the Solvita CO2 Respiration test and a Water Extractable Soluble Carbon test to produce the Soil Health Tool.

Bio Soil & Crop New Zealand in association with Rory Milbank [Eco-Agri consultants] South Africa have been compiling field and laboratory analytical data for both soil and leaf analysis so that the relative merits of the more recent soil test methods may be compared.

Using statistical Ordinary Least Squares (OLS) Regression hypothesis testing we compared the Leaf phosphate levels of Actinidia Chinensis (Gold Kiwifruit) with both our current soil test methods and the new H3A method.

Soil Type	Sample Origin Detail	Sample No
Ash	Allophanic Volcanic [New Zealand & Ja]	40
Peat	Acidic Raw Waikato New Zealand	3
Sedementary	New Zealand & North California	13
Ferisol	Mainly South Africa	40

The soil types included in the study are as per the table above.
Soil sampling was from the top 150mm and were collected autumn or winter 2015 to 2017.
All soil analysis was via Brookside Laboratories Inc Ohio USA. Leaf analysis was via Hill Laboratories New Zealand, Brookside Laboratories Ohio and Labserve Laboratory South Africa.

Soil Analysis Extraction methods being compared.

H3A extractant is composed of organic root exudates, lithium citrate, and two synthetic chelators (DTPA, EDTA
(1) H3A Tot P H3A extract is used and all phosphorus species are measured
(2) H3A Min H3A Extract is used and Specally the Phosphate ion is measured
(3) H3A Org P. This is simply calculated by subtraction of (1) - (2) above.
Meh P is the Mehlich III extract
Bray P is the Bray II extract
Olsen P Standard USDA method
Leaf P Standard USDA method for tissue samples.

Note of clarification for H3A Tot P. This is not a total Phosphorous (P) soil extract in the usual sense but is the mild acid extractable P in all forms, both mineral and organic combined.

The Trustworthiness of the regression results Table 1.

Table 1

P Val "How Trustworthy are the Results" >0.05 = Not significant, <0.05 = Significant, <0.01 = Highly Significant.

	Olsen P	Bray P	Meh P	H3A Org P	H3Aa Min P	H3a TotP
H3Aa Min P						<0.01
H3A Org P					<0.01	<0.01
Meh P				<0.01	<0.01	<0.01
Bray P			<0.01	0.256	<0.01	<0.01
Olsen P		<0.01	<0.01	<0.01	<0.01	<0.01
Leaf P	0.272	<0.01	<0.01	<0.01	<0.01	<0.01

In predicting Leaf Uptake of phosphorus all the tests except for the Olsen P test were Highly significant.
It is no surprise that Olsen P does not work well under these soil conditions for it is a test intended for alkaline soil types and the mean average pH for the kiwifruit orchard soils was pH6.25 which is mildly acidic.
The graph below sets out the relative predictive angle for each of the soil test methods:

Regression OLS Analysis Predictive Lines (Figure 1):

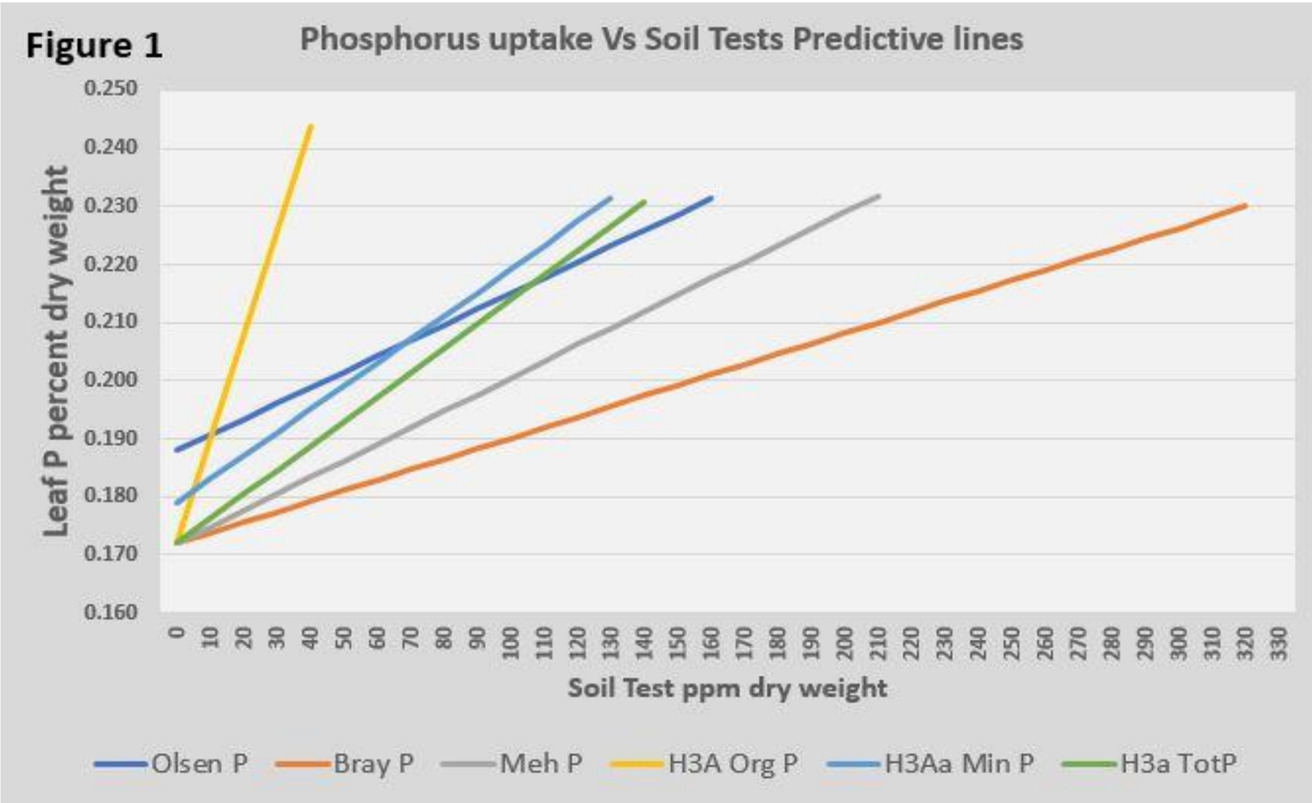


Table 2

Regression Coefficient B = (X'X)-1X'Y [Angle of Predictive Line]

	Olsen P	Bray P	Meh P	H3A Org P	H3Aa Min P	H3a TotP
Leaf P	0.0003	0.0002	0.0003	0.0018	0.0004	0.0004

Table 3

Y Axis Intercept Point (Constant)

	Olsen P	Bray P	Meh P	H3A Org P	H3Aa Min P	H3a TotP
Leaf P	0.188	0.172	0.172	0.172	0.179	0.172

The Olsen P predictive line above has an ideal angle (see Table 2) for making extrapolations, however table 1 shows that this test must be rejected and the key reason was that in the lower Olsen P soil test values the predictive results tended to overestimate, hence the high intercept point on the Y axis (see Table 3)

Just having the angle of the predictor lines and their respective intercept points is not enough, we need to know the spread or scatter of the respective data points for each line of which there are 46 matched soil and leaf samples. The measure of this spread is called the $\mathbf{R^2}$ value and the nearer to 0.99 the result the tighter the spread (Table 4).

Table 4

OLS Regression Analysis Comparing Leaf P levels with Different Soil Tests

R Squared (How close are the data points to the predictive line).

Left column Anderson Darling p values	Leaf P Residual Normallity	Olsen P	Bray P	Meh P	H3A Org P	H3Aa Min P	H3a TotP
H3a TotP	0.0023						
H3Aa Min P	0.0088						0.936
H3A Org P	0.1160					0.194	0.427
Meh P	0.0237				0.253	0.766	0.773
Bray P	0.1918			0.569	0.014	0.357	0.288
Olsen P	0.2400		0.612	0.673	0.123	0.447	0.477
Leaf P		0.0364	0.156	0.227	0.324	0.161	0.244

The Leaf P (LP) versus Soil Test P (SP) regression analysis $\mathbf{R^2}$ values are presented on the bottom row of table 4 . These $\mathbf{R^2}$ values represent the percentage of variation in the Leaf P results and that is explained by each particular soil test method. For example Bray II P has an $\mathbf{R^2}$ of 0.156 the soil test would account for 15.6% of the leaf variability.

Table 4 confirms that we would be wise to reject the Olsen P test as the spread of data points was very wide.

The best LP vs SP $\mathbf{R^2}$ result proved to be the H3A Organic fraction $\mathbf{R^2}$ = 0.324. However this result on its own is somewhat misleading for much of the data was constrained in to the lower left sector of the plot and the predictive value would be limited (see figure 2). To confirm whether to accept or reject the $\mathbf{R^2}$ value we need one more statistic, for which we measure the distance of each data point to the predictor line and this data is referred to as the 'residuals'. Each soil test data set of residuals are then measured for "Normal Distribution", and for this we used the Anderson Darling (A-D) test for Normal Distribution. With this test, we can accept that the value is trustworthy if the result is less than 0.05. Normal distribution means data when presented as a scatterplot, it has a bell-shaped curve which is neither skewed or with a double peak

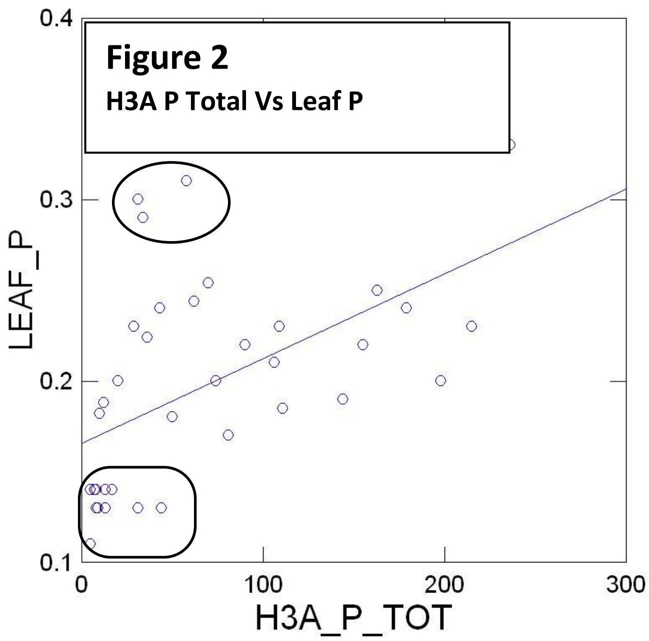
The A-D p values for the LP Vs SP residuals are in column 1 of Table 4 and this confirms that we should reject the H3A Organic P fraction as a predictor of P uptake. Olsen P has the greatest A-D p value; therefore rejection of that test is appropriate.

An additional soil test which we reject as a P uptake predictor, due to not having a Normal Distribution of Residuals is the Bray II soil test.

However, apart from being used for predicting phosphorus uptake, the Bray II P test has other merits, such as for measuring the reserve mineral phosphate in the soil and also for assessing the degree of P solubility by using a comparison with other soil phosphate tests. Additionally, because the Bray II test measures the soluble P, plant available P and mineral soil P, it is a very useful tool for assessing P overload in over fertilised soil cases.

The Mehlich III soil test has a predictor line (Figure 1) that is useful for extrapolation of P uptake and the low Y axis intercept means that the test is also good for Low soil Phosphorus situations. Table 4 shows that Mehlich III has an acceptable $\mathbf{R^2}$ and the A-D p value is a pass mark. The Mehlich III test has proven to be a reliable old 'work horse' that has not let us down and these statistics confirm our good reasons for confidence in this test.

The H3A Total phosphorus result has a good usable angle (Figure 2) for a predictive line and the data spread had an $\mathbf{R^2}$ = 0.244, which was a slightly better value than the Mehlich III test. The Anderson Darling test for normal distribution in the residuals of H3A P Total was the best for all of the tests compared and was a near perfect result A-D p val= <0.01.



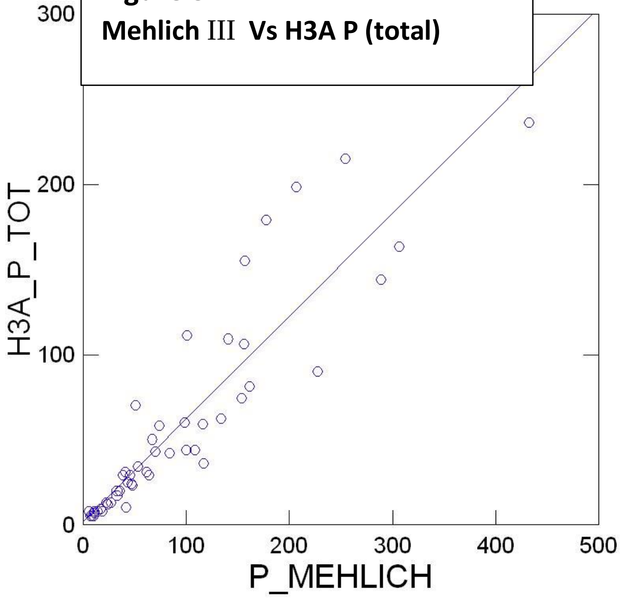
The diagonal lines (Figure 1 & 2) represent the calculated prediction of how the soil test value should correspond to leaf phosphorus concentration. Ideally, we would wish to have the scatter of data points near that line and with a high $\mathbf{R^2}$ value (see table 4 bottom row). Strong $\mathbf{R^2}$ results are not common when working with every day agronomic data which was not from a closely controlled experimental design.

Key reasons why the data scatter tends to be fairly wide (with low $\mathbf{R^2}$ even though they are consistent with good p values) include:

1. Five different cultivars of Kiwifruit Chinensis were included.
2. Three Major Soil Groups were covered, including Sedimentary, Andesitic, and Ferrallitic.
3. Four to six months intervened between soil sampling and leaf sampling, during which time fertilisers were applied. For example, the three cases circled (Figure 2) were heavily fertilised after soil sampling with Di-ammonium Phosphate. Those in the rectangle are from newly established orchards on strongly Allophanic ash soils in Kyoto Japan and, as Allophane is aluminium rich, it rapidly takes soluble phosphate and converts it into the insoluble Aluminium phosphate mineral Varisite. This is not plant available and neither do these soil tests extract the phosphorus.

The H3A mineral P_2O_5 test result had a good normal distribution A-D p val = <0.01 but the $\mathbf{R^2}$ = 0.161 was not particularly good compared to the H3A total P result and this was because this soil fraction did not include any organic phosphorus.

Figure 3
Mehlich III Vs H3A P (total)



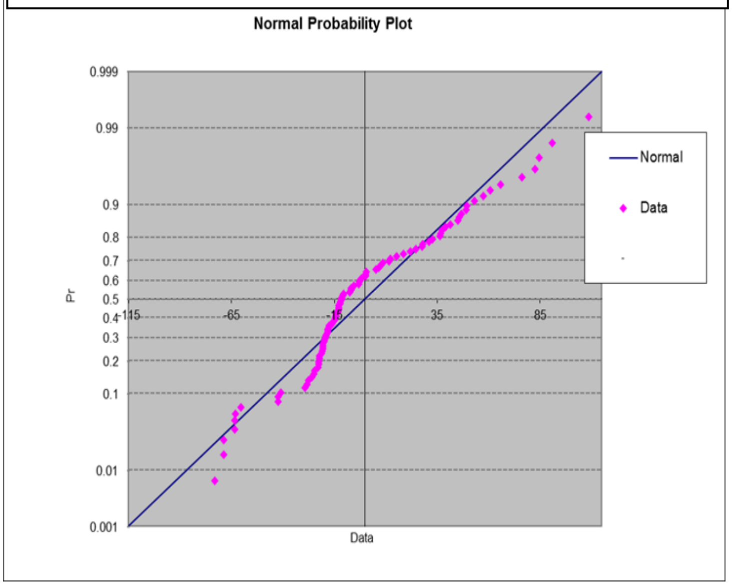
Comparing the soil analysis one with each other:

We have a wealth of Mehlich III data that has been correlated with most specific soil types that we work with. Therefore, if we were to move on to the new H3A soil extraction technology, we need to find the best correlated bridge between the old and new technologies. The H3A Total P test has a near to perfect relationship with Mehlich III $\mathbf{R^2}$ = 0.936.

The regression line prediction coefficient indicates that we should divide the Mehlich III result by 1.3 to predict the corresponding H3A P level.

The A-D Normal Distribution test p value was also near perfect p= <0.0005 (**See figure 4)**

Figure 4 Residuals from Mehlich III Vs H3A P



Conclusions:

The poor p Value result for the soil test Olsen P raises the question - why continue using the Olsen P test?
We have been doing so for the benefit of other organisations who are still locked into the old 1950s way of doing things, but after the confirmation of this test's limitations, we shall probably be only using the Olsen P test in cases of Alkaline soil types.

Both soil tests Mehlich III and H3a Total P and H3A Mineral P2O5 fractions have good predictive value for agronomic use. The H3A Total Soluble P being the best predictor of the two. And both have excellent correlation with each other. Therefore, we may use this study's **regression coefficient** to convert our existing Mehlich III desired ranges into their equivalent levels for the H3A extract.

The H3A extract is a Multi-nutrient extract, therefore our next task is to make a similar study to this one for each of the other plant nutrients.

Additionally, because the Brookside Soil Health Tool (based on the H3A extract) also has soluble carbon and soluble organic N & P, we shall be looking at the implications of the three-way C:N:P ratio to see if there is any way that we can gain greatest benefit through optimising this ratio in orchard soils.

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