Authors: Philip Barlow philip@biosoil.co.nz Alan McCurran alan@biosoil.co.nz

True Soil Humus, What is it and How is it Best Measured?
Of what Benefit is It?
Do Organic Kiwifruit *Actinidia Deliciosa & A. Chinensis* Orchards Have Greater Soil Humus Levels Compared with Conventional Kiwifruit Orchards?

Abstract:

This is a review of our 2017 orchard Soil & leaf analytical data comparing both Quantitative and Qualitative methods for measuring soil Carbon reserves on both Organic and Conventional regime Kiwifruit orchards. We also compared the Carbon differences on three distinct soil groups: Ferralitic, Sedimentary and Andesitic Volcanic.
We found that the Loss on Ignition and the Combustion Total C Soil Organic Matter methods were very closely correlated [P = <0.01].
There was no significant correlation between Total C and Soluble C. Indeed, when Soluble C was expressed as a percentage of the Total C, there appears to be a negative relationship, where the high Total C soils having a greater proportion of non-soluble fibrous carbon.
We considered whether there was a difference in Soluble Carbon levels between Organic and Conventional regimes and we found a significant separation between the two sample groups [T=4.009 P =<0.01], whilst at the same time there was no significant difference when comparing the two regimes for Total Carbon [T=0.04 p=0.967]
We considered the benefits to Kiwifruit for having higher soil Carbon by measuring leaf water content. We had a moderately significant result [R^2 0.299 , P=0.013] for Total Carbon Vs water content and in the case of Soluble Carbon we had a highly significant result [R^2 0.473, P= <0.01]
Also leaf phosphorus content is significantly associated with soil water soluble carbon [R^2 0.495, P= <0.01]

Key Words:

Soil Organic Matter, Loss on Ignition, Total Carbon Combustion Method, Water Soluble Carbon, Humus, Kiwifruit, Leaf Water Content.

Introduction:

Frequently we find the word Humus is confused with the more general term Soil Organic Matter [SOM], whereas true soil humus is a specific component of SOM. SOM consists of a whole series of carbonaceous components mainly derived from dead plant material in various stages of decay including easily recognisable partially decayed fibrous material. Whereas Humus is a relatively stable brown/black jelly like material bearing little or no resemblance to the plant material from which it was derived. (Russell's 1988 p564)

The benefits to farmers and growers from good levels of SOM have long been extolled by the soil science community through technology transfer and these benefits are said to include the following:

1. Improved water retention by a factor of 5-10 times the soil mineral fraction (Jackson p391)

2. Improved nutrient retention and availability. (Russell's pp588-607)
3. True humus makes an enormous contribution to the Soil Cation Exchange Capacity [CEC] which when isolated has a CEC in the order of 300 to 550 mEq/100g compared typical bulk soil at 5-20 mEq/100g (Russells pp577-578]
4. Decreased negative effects from aluminium toxicity (Marschner 2002, p614).
5. It neutralises harmful soil bound phytotoxic pollutants including heavy metals and herbicides (Jackson WR 1993, pp280-281) (Russell's pp 585-586)

In general, SOM analysis for farmers and growers has been by non-specific approximations which includes virtually all the soil's carbonaceous components. These tests have included the first three of the following Soil Carbon tests:

1. Walkley Black [Potassium di-chromate] oxidation process (Walkley A & Black C 1934) This test is **non-specific** for all carbon species. The basic principle is the chemical oxidation of organic matter and the titration of the unused Chromate. The test was never a complete measurement and a correction factor was usually needed. The test has been phased out in recent years because the waste products from the test are toxic and disposing of them is expensive.
2. Loss on Ignition [LOI]. (Heiri O 2001) This test is **non-specific** for all carbon species. The basic principle is very simply the weight loss [as CO_2 gas] of a soil that has been dried at 105^oC, after which the soil is heated to 450^oC for several hours. The test is reasonably accurate provided there is no weight loss from common Hydrated minerals such as Gypsum [$CaSO_4(H_2O)_2$] or Limonite [$FeO(OH)(H_2O)$]
3. Total Carbon combustion (Nelson 1996) . This test is a **non-specific** total carbon test where the gaseous fumes are analysed via gas chromatography for both nitrogen and carbon.
4. Haritai Method (1993**) A qualitative** test using the ratio between sodium Hydroxide [Na(OH)] extractable carbon and Sodium Fluoride [NaF] extractable carbon, to distinguish the difference between raw fibrous Soil Organic Matter and true humus. Probably both the complexity of the test and the toxic NaF waste products has led to little general agricultural utilisation.
5. Water Soluble Soil Carbon Extract . **A qualitative test specific to humified Soil Organic Matter.** This method has not been widely used for commercial agriculture however there have been some use in studies with microbial biomass. (McGill 1986)

Objectives

The objective of this study is to compare results from the following Soil Organic Matter tests (SOM):

1. Loss on Ignition (LOI)
2. Combustion Total C.
3. Water Soluble Carbon

Also, to compare Kiwifruit Leaf analysis and harvest data to establish the following Hypotheses:

H1 ... Total soil carbon and/or Soluble soil carbon percentage does have a measurable benefit for kiwifruit growers.

H2 ... Certified Organic orchards have higher levels of Total soil carbon and/or Soluble soil carbon.

Methods & Data Source:

The data for the study was all taken from commercial kiwifruit orchards at the follow locations:

- South Africa [ZA]53 cases, on Hutton Ferralitic iron soil type , 8 Organic 45 Conventional
- Japan 9 cases all on Allophanic Volcanic ash, all Conventional Regime
- New Zealand[NZ]31 Cases all on Allophanic Volcanic ash, 16 organic & 15 Conventional Regime
- California [Ca] 16 Cases all on sedimentary soil type, 3 organic & 16 Conventional Regime

All Soil Analysis via Brookside Laboratories Inc Ohio

For statistical purposes the soil types have been grouped to three basic groups, Volcanic, Sedimentary Loam and Ferralitic.

Leaf analysis:
New Zealand samples Via Hill Labs Hamilton NZ.
South Africa, Japan and USA samples Via Brookside Labs, Ohio.

Leaf size each leaf was measured max length X max width petiole not included (32 Leaves per sample). Leaf water content determined by using a 50mm diameter hole punch (four discs from 7 leaves per sample), weighed, dried (@40°C) & weighed again. From this method we also calculate the specific leaf weight.

Results:

Soil Organic Matter:

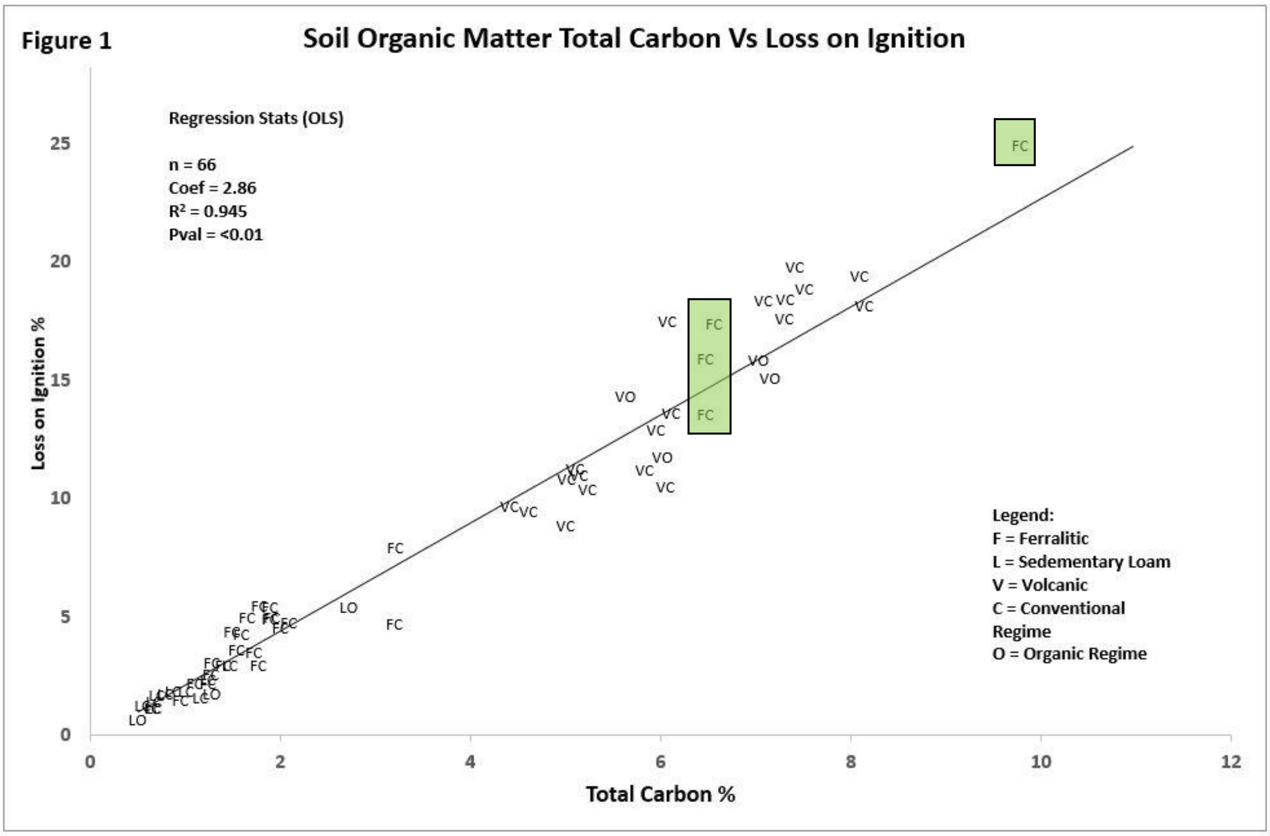
There was an excellent correlation between the two non-specific SOM tests [see figure 1] The Ordinary Least Squares Regression was highly significant **p=<0.01** . Both soil tests concur for all three soil types used in this study.
The data has a very good close fit with the predictive regression line, with a **R^2 of 0.945**.

Table 1	Loss on Ignition				Total Carbon			
	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev
Ferralitic	1.5	25.0	6.4	5.75	0.95	9.8	2.7	2.27
Sedimentary Loam	0.66	5.4	1.9	1.15	0.50	2.7	1.0	0.57
Volcanic	7.52	19.9	13.4	3.85	4.16	11.0	6.2	1.51

Green denotes highest value and Red denotes lowest value

The Coefficient (y = x 2.86) shows that the Loss-on-Ignition (LOI) is consistently measuring a loss of soil mass, 43% higher than if it were only Carbon di-oxide being lost in the furnace. The LOI test is believed to be removing non-liquid water from various hydrated minerals and other gaseous losses, which may or may not be carbon based. Conversely the Total C combustion method (Tot C), has the advantage in being more precise, with only the soil carbon being measured. For this reason, evidently the Total C test is the best choice when one is considering the non-specific carbon compounds in the soil.

It is noteworthy that the volcanic soil type is consistently higher in carbon than all the sedimentary loam samples and most of the Ferralitic cases (see Table 1).



The four cases of Ferralitic soil with high Carbon results (highlighted green) are all from the same semi-organic Orchard in Richmond Natal, South Africa where the farmer has used high organic [Chicken & Cow manure] inputs over many years.
Reasons for the differences in SOM between these three basic soil types is complex and most likely due to the relatively low annual rainfall (515mm) in Sacramento California for the Sedimentary Loam (L) soil type. The Volcanic Allophane (V) soil of the New Zealand and Kyushu Japan orchards receive 1200 – 1500 mm per year. There are two sub groups Volcanic Organic (VO) and Volcanic Conventional (VC). The Ferralitic (FC) samples from Natal South Africa are intermediate, averaging approximately 1000mm rainfall per year. Apart from rainfall, there is also the effect from the formation of Organo-metallic materials with Aluminium in the case of the NZ and Japan and with Iron in the case of the Ferralitic soils of South Africa.

Total Carbon (Tot C) Verses Water Soluble Carbon (Sol C):

When we examined the relationship between Total Carbon and Water Soluble Carbon (Sol C) we found major differences between the soil types and also the regime Organic or Conventional X(See Figure 2).

The Sedimentary Loam had the lowest Mean Total C at 1.02%

The Ferralitic was more than double that found in Sedimentary Loam at 2.7%

The Volcanic was more than six times the Sedimentary Loam at 6.17% Tot C.

The differences in Soluble C, comparing the soil types was not as pronounced as it was for Total C (data in Table 2) The Sedimentary Loam was 179 ppm, The Ferralitic was just a little higher at 187ppm and the Volcanic was 20% higher than the Sedimentary Loam at 224ppm.

It is noteworthy that there is a solubility gradient shown as the higher Total C soils have lower Soluble C when expressed either as a Tot C/Sol C ratio or as a percentage;

Ferralitic soil	0.7% of the Total C was Soluble C
Sedimentary Soil	1.7% of the Total C was Soluble C
Volcanic Soil	0.36% of the Total C was Soluble C

Probably with increasing Total C a greater portion of the Carbon is found as decay resistant fibrous material. Also, in the case of the Sedimentary Loam the soil is slightly alkaline at pH 7.19 and alkalinity is known to increase Carbon solubility. Conversely the other two soil types had very similar mildly acidic average soil pH, Ferralitic pH 6.25 and the volcanic pH 6.28 and soil acidity is well known to cause accumulation of fibrous organic material.

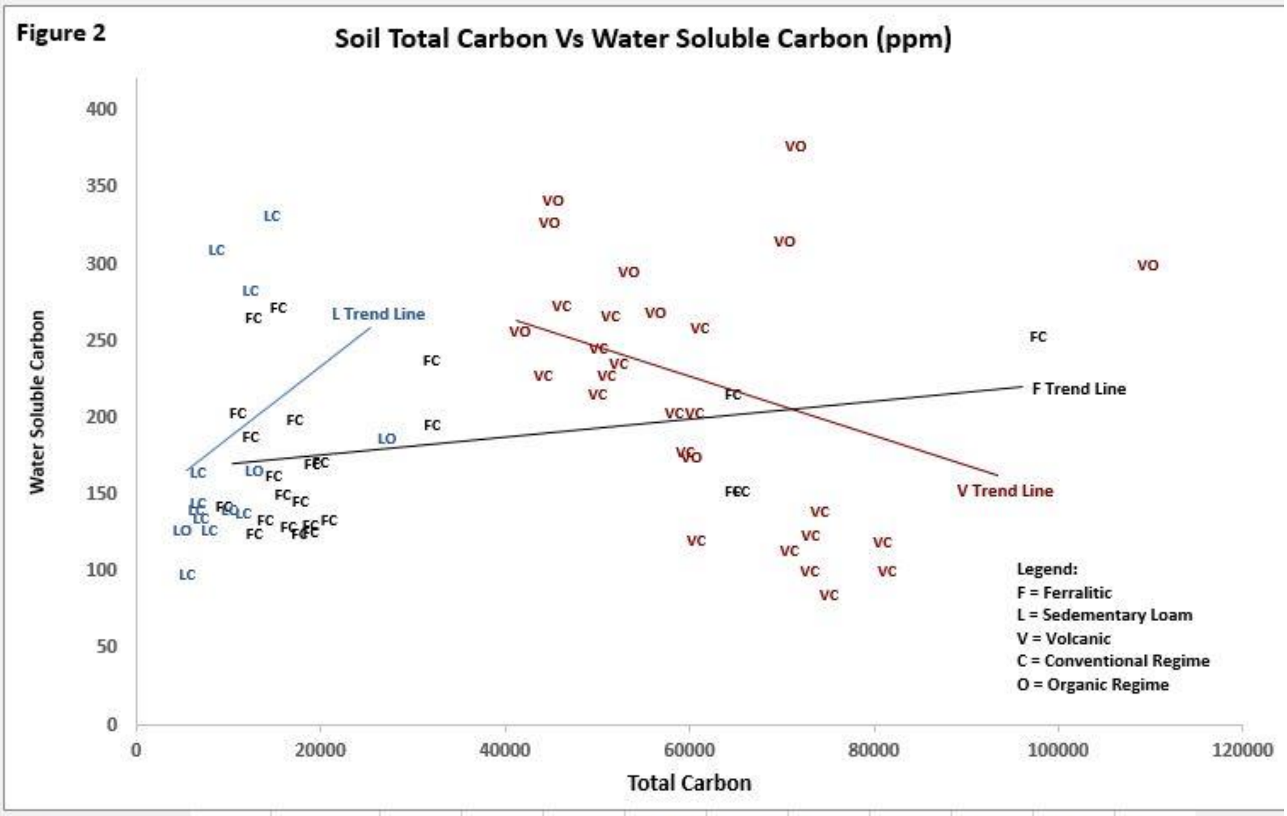


Table 2

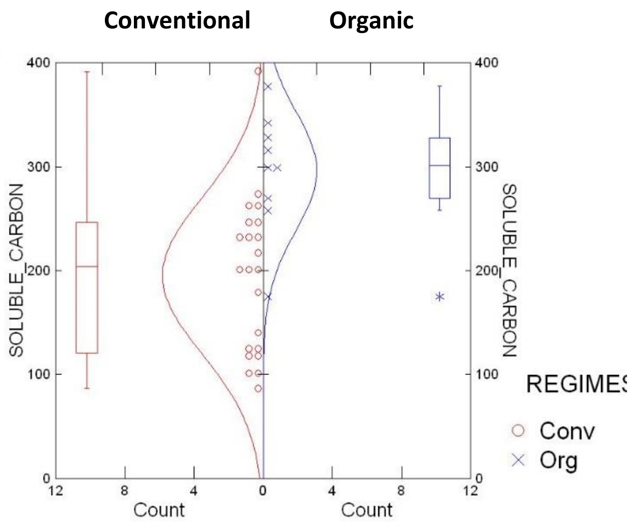
Soil Type	Sample Number	Coefficient	R^2	P value	Total Carbon (ppm) Min	Max	Mean	Std Dev	Water Soluble Carbon (ppm) Min	Max	Mean	Std Dev	TC:WC Ratio
Ferralitic	24	5.94	0.083	0.171	9500	97800	26770	22660	126	304	187	47	143
Sedimentary Loam	14	46.42	0.128	0.208	5000	27200	10200	5740	99	333	179	74	57
Volcanic	28	-18.57	0.116	0.076	41600	109700	61660	15050	86	392	224	84	275

Although the trend lines (Figure 2) are not statistically significant, they do highlight some noteworthy differences in the results of the individual soil groups. For example, the Sedimentary Loam and the Ferralitic both had positive relations when comparing the Soluble C and Total C, whereas we found that the Volcanic group conversely showed a negative trend.

Soluble Carbon Levels, Organic Orchards Verses Conventional Orchards

A close examination of the individual Volcanic data points on Figure 2 indicated a degree of separation between the Organic orchards (VO) and the Conventional Orchards (VC). In order to compare these two groups of data (Organic & Conventional) we used the back to back histogram (**see figure 3)** as produced by the software SPSS Systat.

Figure 3



Visually it is apparent that the data spread for the organic orchards on Volcanic soil have higher Soluble Carbon when compared to the conventional orchards on the same soil type. There was one organic orchard that appears to be an outlier with a result of only 175ppm Soluble Carbon, however we found no logical reason why this orchard should be different to the others and therefore we did not remove the data point, when performing the T Test statistics.

The Students T Test statistic for confirming whether there were different mean averages **(see Table 3a**) is conclusive and organic orchards on Volcanic Soil do have more soluble C than conventional orchards

T = 4.009 & P = <0.01. With the Organic mean for soluble carbon average being 34% higher than conventional.

However, when making a similar comparison for the Total C fraction we found that the mean averages for both samples were virtually the same at 6.18 and 6.14 respectively. The P value being greater than 0.95 can be taken as proof that there is no difference in the Total C levels for both regimes.

Table 3a Comparing Organic and Conventional Regime (Volcanic Soil)

	Total Carbon			Water Sol Carbon	
T Value	0.042			4.009	
P Value	0.967			<0.01	
	Mean (%)	Std Dev		Mean (ppm)	Std Dev
Conventional	6.18	1.20	Conventional	195	75.4
Organic	6.14	2.10	Organic	296	58.1

Highly Significant (p=<0.01)	Significant (p=<0.05)	Not Significant

Table 3b Comparing Soil Type & SOM Mean Averages

	Total Carbon			Water Sol Carbon	
	Mean (%)	Std Dev		Mean (ppm)	Std Dev
Ferralitic	2.68	2.27	Ferralitic	187	47
Sed Loam	1.02	0.57	Sed Loam	179	74
Volcanic	6.17	1.50	Volcanic	224	84

Different Means (T Test Values)	Ferralitic	Sed Loam	Different Means (T Test Values)	Ferralitic	Sed Loam
Sed Loam	3.4		Sed Loam	0.39	
Volcanic	6.43	15.92	Volcanic	2.20	1.83

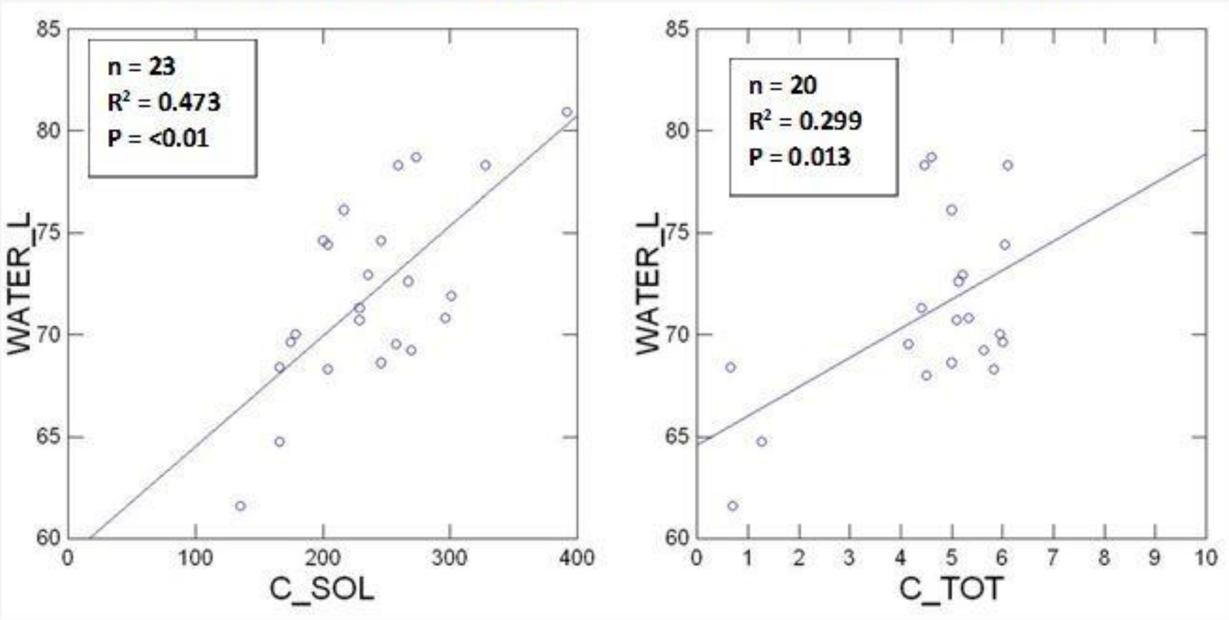
We did not have enough organic samples to determine separate organic verses conventional comparison for Soluble Carbon on the other soil types, however the trends show this is the case and when the data for all soil types were combined we still had a positive T test result (t= 4.1 with p=<0.01)

Differences between soil types comparing Carbon reserves:
We made overall comparisons between the three soil types **(see Table 3b**) by using the T Test Statistic.
For Total Carbon, all three soil types have mean averages that are distinctly different to each other P=<0.01. The Volcanic soil type ranked highest and Sedimentary Loam the lowest.
For Soluble Carbon only the Volcanic and Ferralitic soils can be said to have separate mean averages (p=<0.05) with Volcanic soil having the higher levels.

We have proven our Hypothesis H2 true; Organic orchards do have higher Soluble Carbon than Conventional orchards; Therefore we searched the data for evidence that will either prove or disprove H1 that increased Tot C and/or Soluble C has real benefit to the growers, which could result in financial gain.

Does Soil Organic Matter improve water availability or uptake by the kiwifruit vines?
The answer is a clear yes (**see Figures 4a & 4b**). Although the regression line for Total Carbon does not have the data points as close to the line R^2 = 0.299 compared to Soluble Carbon R^2 = 0.473 we need to remember that volumetrically the Soluble Carbon component of the soil is a very small ppm fraction contained within the Total Carbon. This data does show that by having better humus quality with greater Soluble Carbon there is improved water uptake. And Total Carbon also has benefit but to a very much lesser degree than when compared with Soluble Carbon on a weight for weight basis.

Figure 4 a & 4 b
OLS Regression Leaf Water Content Percent Vs
4 a Soil Carbon Water Soluble (ppm) **4 b Soil Carbon Total %**



The Kiwifruit leaf water content Y axis Figures 4a & 4b needs to be put into context of what is normal and probably the best data available is our own (unpublished data) which is presented in **Table 4.** We have data for two sub-species of kiwifruit *A.Deliciosa & A.Cheninsis* and their leaf morphology is not exactly the same, therefore the leaf water content data for both species are presented. The mean average water content, minus one standard deviation is taken as the minimum that we should be working with. Using the forgoing assumption, the indication is that several orchards have low leaf water content due to low Soil Carbon. The desired minimum Soil Carbon is derived from figures 4a & 4b plus Table 4, using the effect on leaf water content;

Table 4

Kiwifruit Leaf Water Content

Variety	Deliciosa	Chinensis
Count	1766	971
Mean Ave (%)	71.1	73.8
Sdev	2.9	7.3
Low	68.2	66.4
Min Sol C (ppm)	180	175
Target Sol C (ppm)	220	230
Min Tot C (%)	3.4	3.3
Target Tot C (%)	4.8	5.0

Target Soil Soluble Carbon between 220 to 230 ppm

Target Soil Total Carbon between 4.8 or 5.0 Percent

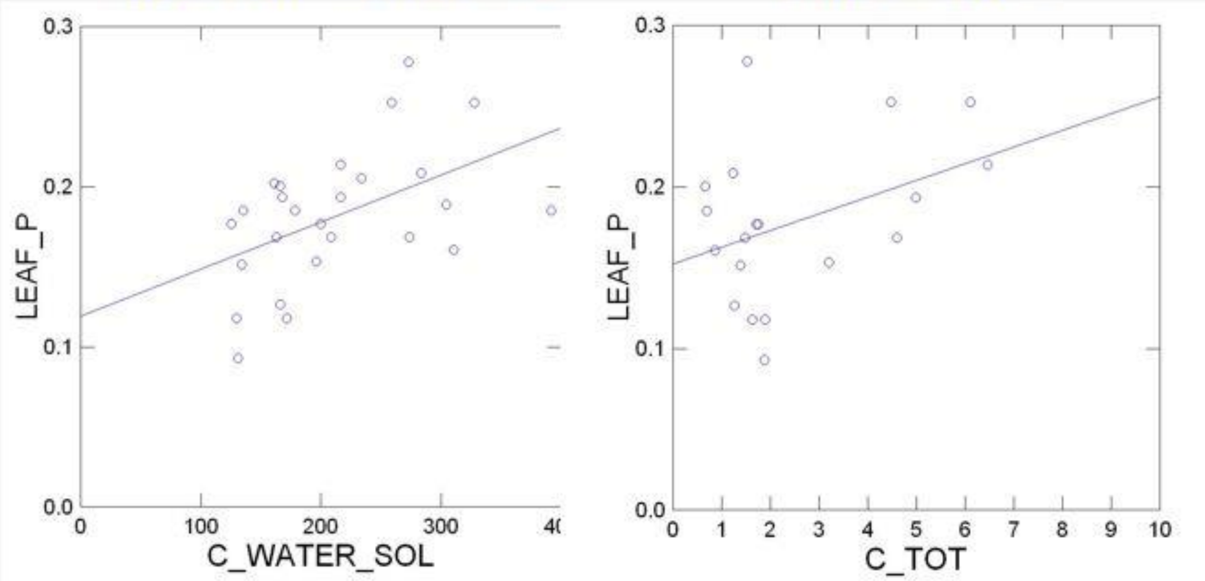
Does Soil Organic Matter improve Nutrient availability or uptake by the kiwifruit vines?

Supplying and maintaining phosphorus availability is a great challenge for kiwifruit production and this has great bearing on both the Leaf Size and the Flower to Bud Ratio. The reason it that there is a strong tendency for phosphorus to rapidly loose solubility, either by being converted to the insoluble minerals Varisite with free Aluminium or Strengtite by soluble Iron. Both of these transformations render phosphorus to be of severely diminished value for the vines. Therefore, we consider whether Soil Organic Matter can hold phosphorus as a protected yet usable reserve for the vines?

Figure 5

Actinida Chinensis Leaf P % Vs Soil Carbon

Soil Carbon Water Soluble (ppm) **Soil Carbon Total %**



OLS Regression Leaf P %			
Vs Water Soluble Carbon			
N	26		
R^2	0.495		
P Val	<0.01	Highly Significant	

OLS Regression Leaf P %		
Vs Water Soluble Carbon		
N	19	
R^2	0.393	
P Val	0.096	Not Significant

Leaf Phosphorus values below 0.18 % are most likely going to cause a significant loss in productivity and levels between 0.22% & 0.3 would be desirable [own unpublished research].

The enhance phosphorus uptake value of water soluble carbon is quite evident from **Figure 5.** Although we see that the Total Carbon appears to have a beneficial trend for improving phosphorus uptake, it is not proven beyond all doubt. Whereas the Soluble Carbon has a strong statistically proven benefit for phosphorus uptake.

Conclusions:

In the science of chemistry, the term Organic means having to do with the properties of carbon particularly when it is in combination with Hydrogen & Oxygen. Therefore, in view of the foregoing study and evidence presented it is fitting to conclude by stating that Soil Organic Matter is all about Carbon with its properties and diverse forms .
To build True Soil Humus means much more than just increasing the Soil Carbon content, for we need to pay close attention to the quality as well as the quantity of the carbon in the soil and the degree of solubility that the Soil Carbon has.

Shifting Total Carbon to True Humus needs to be the primary goal of Certified Organic Crop producers and the tools for doing this are very closely associated with promoting soil microbiology and avoiding the practices and products which are harmful to these eco-cycles

Using both the Dumus Combustion Total Carbon and the Water Extractable Soluble Carbon tests together provides a valuable insight and aid for Farmers, Growers and Agronomists as they work towards having a productive healthy soil.

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