Soil characterisation project findings

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In the Winter 2021 Avoscene, NZ Avocado introduced and outlined the soil characterisation project, a project to better understand what the soil looks like on some of our most productive orchards across the different regions. This article shares the findings from the project and gives insight into some of the variables that correlated with high yielding orchards.

Supporting growers to increase yields to an average of 15 t/ha of high-quality fruit is an industry goal because improving yield is seen as a key driver of grower profitability. However, any increase needs to be both environmentally and economically sustainable. Many growers are looking more closely at their soil and asking questions about what they can do to improve it. This project is the first attempt to understand soil chemical (nutritional), biological and physical attributes across our main growing regions, and how these attributes correlate with high yields.

Although predictors of yield were identified within the orchards in this study, many of these results were counterintuitive to industry knowledge. This article focuses on the variables identified and discusses their potential relevance to orchard production. Growers are encouraged to view the full results of this project to compare their own orchards soil characteristics to orchards achieving greater than 15t/ha in their region and consider if there are potential areas of improvement that may impact yield. The full report with details of the averages and ranges of all the results recorded across the regions is available to download from the NZ Avocado industry website under 'Research reports'.

1 Methodology

Twenty nine growers participated in this project;

- 17 Bay of Plenty growers from the Avovantage project with four year average yields ranging from 7.6t/ha to 26.5t/ha.
- Two Bay of Plenty orchards that are part of the new cultivar assessment trial with four year average yields of 17.6t/ha and 18.1t/ha.
- Five orchards in the Far North and five from the Mid North with four year average yields ranging from 15t/ha to 21.4t/ha.

From each orchard, ten trees were selected (the Avovantage orchards had pre-selected trees), and soil, root, leaf and fruit samples were taken during autumn 2021 and sent for biological and nutrient testing.

A visual soil assessment was also carried out to provide information about the physical properties of the soil.

Statistical analysis was undertaken by Plant & Food Research.

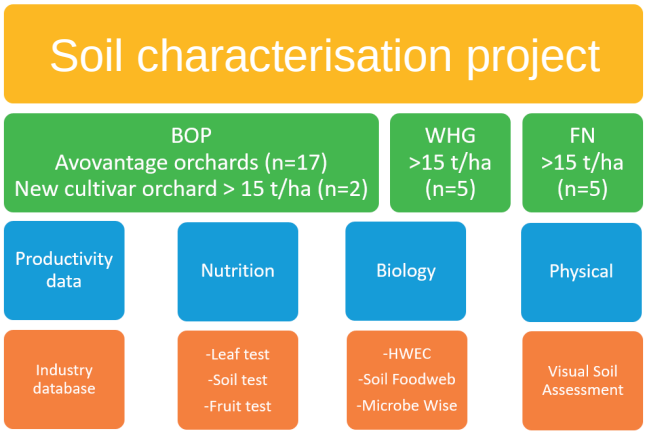

Figure 1. Overview of the Soil characterisation project with the different sources of information.

2 The yield predictors identified in this study

All of the individual variables were analysed for correlation with orchard yield. Orchards were divided into two groups; high yielding orchards that were achieving greater than or equal to 15t/ha average over four years, and low yielding orchards achieving less than 15t/ha average over four years. Variables were assessed as to whether they acted as predictors of the orchards being in the high or low yield classification. Biological variables assessed included results from Soil Foodweb (15 variables), Linnaeus-MicrobeWise (32 variables) and Hills Laboratories Hot Water Extractable Carbon (HWEC). Hills Laboratories soil and leaf nutrient tests included 38 variables and visual soil assessment of physical properties included seven variables. Only 10 variables acted as predictors of whether an orchard would be in the high or low yielding classification. Some of these correlations were counterintuitive to what we currently understand contributes positively to soil performance and their meaning, in terms of orchard production, is unclear. However, this study is a start to understanding what soil looks like holistically on our orchards and provides a benchmark for growers to build knowledge of their own orchards soils. For a full breakdown of all the results across the regions for all the variables, you can find the full report on the NZ Avocado website under 'Research reports'. It is important to note that the sample size is small, with only 29 orchards, and a more extensive set of data may increase the confidence in these conclusions or change the results.

Soil attribute	Stakeholder	Variables	Units	High yield /Average (min-max)	Low yield /Average (min-max)	Target of test provider
Nutrition	Hill Laboratories	Iron (Mehlich 3)	mg/L	105 (67-189)	75 (52-156.0)	NA
Nutrition	Hill Laboratories	Aluminium (Mehlich 3)	mg/L	1,349 (739-1,926)	1,551 (1,338-1,704)	NA
Nutrition	Hill Laboratories	C/N ratio	NA	13.3 (10.3-24.7)	11.3 (10.2-12.1)	NA
Biology	Soil Foodweb	Dry weight	NA	0.67 (0.50-0.85)	0.61 (0.57-0.68)	0.45-0.85
Biology	Soil Foodweb	Total bacteria (TB)	mg/kg	330 (237-535)	362 (245-483)	>300
Biology	Soil Foodweb	Total fungi (TF)	mg/kg	328 (137-911)	384 (205-513)	>1500
Biology	Soil Foodweb	Flagellates	number/g	11,182 (782-44,249)	17,276 (2,038-55,500)	>5,000
Biology	Soil Foodweb	Ciliates	number/g	366 (38-836)	177 (43-472)	<334
Biology	Linnaeus	Gram negative bacteria	mg/kg	6 (3-9)	7 (4-14)	11
Visual (Biology)	NZ Avocado	Earthworms	Count in per 800cm^3 of soil	11.19 (6.81-18.39)	21.66 (12.61-37.18)	NA

Table 1. Variables that acted as predictors of whether an orchard was likely to fall into the high (15t/ha or higher) or low yielding (less than 15t/ha) classification.

The strongest predictors of yield are shown in Table 1. With results discussed in more detail below.

Key findings of the study include:

- Aspects of soil chemical (3), biological (6), and physical/visual (1) composition showed importance in classifying whether an orchard was high yielding or not.
- A combination of Hill Laboratories nutrients and the Soil Foodweb biological variables showed the highest classification accuracy with a maximum of 79% accuracy. The statistical analysis shows that nutrient variables had higher importance than biological variables in classifying orchard performance within the orchards in this study.
- None of the leaf nutrient results correlated with yield classification.
- Some counterintuitive correlations have been observed. For example, high levels of ciliates and low levels of earthworms in high yielding orchards were highlighted. Soil nutrient correlations, that are deemed extremely unlikely to be relevant to orchard yield, were identified. These results indicate that further studies are needed before firm conclusions can be made about what are the best soil characteristics for growing avocados.
- It is important to be consistent with the laboratory selected for biological testing as there were differences in the shared variables of total fungi and total bacteria between the two laboratories. In addition, following a detailed sampling procedure with some consistency to the time of year is also important, as biological populations will change with different environmental conditions.

2.1 Soil chemistry predictors (nutrients)

Historically in avocado orchards the main focus has been on the chemical aspect of the soil and what fertiliser should be applied to achieve nutrient levels that support yield and fruit quality. This study identified three nutritional variables that were strong predictors of yield classification; Carbon to Nitrogen (C:N) ratio, Iron (Mehlich 3) and Aluminium (Mehlich 3).

Carbon to Nitrogen (C:N) ratio: High yielding orchards had a slightly higher C:N ratio value than lower-yielding orchards (13.3 to 11.3, respectively). C:N ratio is a ratio of the mass of carbon to the mass of nitrogen in soil. The values are reported as a single figure and as a ratio are expressed as 13.3:1, that is 13.3 units of carbon to one unit of nitrogen. The C:N ratio is significant as microorganisms need a good balance of carbon and nitrogen in order to remain active. An imbalance in the C:N ratio can impact the amount of nitrogen in the soil. Values greater than 25 indicate that microbes need more nitrogen to utilise carbon as an energy source and are likely to pull nitrogen from the soil, creating a deficit and therefore making nitrogen less available to the tree. Conversely, C:N ratios below 25 mean there is excess nitrogen for the trees to take up and for microbes to decompose high carbon residues in the soil, such as wood chips. The values reported by the Hills Laboratories range from 10.2 to 24.7 across both yield classifications indicating that more, rather than less, nitrogen is available to the trees. It is unclear if this concentration of nitrogen is considered excessive for avocado orchard soils.

Iron (Mehlich 3): Higher iron levels correlated with high yielding orchards. Table 1 shows that all values were within ranges used by industry consultants of 40 to 400mg/L of iron - Mehlich 3 (NZAGA, 2018). However, iron is not a nutrient actively managed in New Zealand, and the relevance of this result is unclear.

Aluminium (Mehlich 3): Lower levels of aluminium correlated with high yielding orchards. Aluminium toxicity may start to become a problem below pH 5.5. The average pH of high yielding orchards was 5.9, and the low yielding orchards 5.7 indicating that aluminium

levels are irrelevant in this context. Five orchards had a pH lower than 5.5 and further work is being undertaken on these orchards to understand if there is a history of low pH and if they are showing any signs of aluminium toxicity.

2.2 Soil biology predictors

Avocado trees have shallow roots that predominate in the first 30cm of the topsoil. The zone where the tree roots and microorganisms interact is called the rhizosphere, and several essential symbiotic relationships happen in this space. This study identified six soil biological variables that correlate with high and low yielding orchards.

Dry weight (Soil Foodweb): High yielding orchards had higher dry weight than low yielding orchards on average (0.67 and 0.61, respectively), but both were within the ideal target range indicated by Soil Foodweb of 0.45 to 0.85. Dry weight is obtained by drying the soil sample and dividing the dry weight by the original weight. The resulting ratio is closely related to the levels of organic matter in a sample as high organic matter soils will hold more water. Therefore, a lower value is associated with high moisture content and higher organic matter is inferred. In addition to organic matter's important water holding role, it has a role in holding onto nutrients within the soil and releasing them to the tree when needed. With the positive role organic matter has in soil, it is unexpected that high yielding orchards had higher dry weight because this implies lower organic matter levels compared to low yielding orchards. The average content of organic matter as measured by Hill Laboratories in high and low yielding orchards was similar (approximately 13%) therefore the difference between the Soil Foodweb results is likely negligible despite it acting as a predictor of yield.

Bacteria: Two bacterial variables were identified as predictors of yield classification; Total bacteria (Soil Foodweb) and Gram-negative bacteria (Linnaeus). In both cases, high yielding orchards had lower levels of these variables. Both high and low yielding orchards had Total bacteria values within the Soil Foodweb target range of >300mg/kg at 330 and 362 respectively. There was little difference in the Gram-negative bacteria value for high and low yielding orchards at 6mg/kg and 7mg/kg respectively. Both groups were below Linnaeus' target value of 11mg/kg. Bacteria play several positive roles in soil (e.g. Actinomyces make phytohormones, metabolise difficult to break down compounds, Pseudomonas help with phosphate solubilisation and nitrifying and denitrifying bacterias play an essential role in the nitrogen cycle).

It is unclear why lower levels of total bacteria and gram-negative bacteria are associated with high yielding orchards in this project given the positive role bacteria can play in the soil. It is important to note that the total bacteria results for both high and low yielding orchards were above the published Soil Foodweb range so are potentially not limiting. The balance of bacteria to fungi is also important in the soil, with fungal dominated soils being more common in perennial tree crop soils with more difficult to breakdown woody material in the soil. Bacterial dominated soils are more common in leafy green pasture or annual cropping soils where the woody material is less prevalent. The ratio of total fungi to total bacteria (TF:TB) was not identified as a predictor of yield but higher TF:TB values were seen on high yielding Bay of Plenty orchards compared to low yielding ones with average values of 1.47 to 1.09 respectively. Soil Foodweb has a target range of 5-10 for avocado orchards, indicating that soils may be bacterially dominant for a perennial tree crop across all the orchards.

Total fungi (Soil Foodweb): High yielding orchards had lower total fungi levels than low yielding orchards (328mg/kg and 384mg/kg, respectively). However, both were below Soil Foodweb's target of >1500mg/kg. Values ranged from 137 to 911mg/kg. Fungi play a positive role in supporting plant growth through opening soil structure, cycling nutrients, improving water availability and suppressing diseases and therefore it would be expected that high yielding orchards would have a high Total fungi result. Further investigation is required to understand the implications of orchards management on fungal populations and the optimum range of fungi for productivity in orchards.

Protozoans: Two variables relating to protozoa were identified as correlating to yield classification; Ciliates and Flagellates, both measured in the Soil Foodweb test. High yielding orchards had higher levels of Ciliates and lower Flagellates compared to lower yielding orchards. In the case of ciliates, higher yielding orchards had an average of 336mg/kg, exceeding the suggested limit of <334mg/kg. This was compared to 177mg/kg for lower yielding orchards, which was within the indicated range. Ciliates and flagellates have a predatory behaviour to bacteria. Consequently, both microbial groups are related to nutrient cycling, making nutrients available for plants while feeding on bacteria. Within ciliates, some members can survive, even thrive, in anaerobic environments and feed on other microorganisms. Therefore, high levels of ciliates may indicate waterlogging or soil compaction, but it is not a straightforward relationship. Studies have shown higher ciliate abundance correlates with higher soil moisture, organic matter, available nitrogen, phosphorous, copper, zinc, nickel and total microbial biomass. High levels should be interpreted with caution as ciliates may not be an accurate indicator of water logging or anaerobic conditions, as they also play an important role in nutrient cycling. Flagellate levels across both high and low yielding orchard classifications were well above the target (>5000mg/kg), with high yielding orchards having slightly lower numbers. High levels of flagellates are not deemed to be negative due to their support of nutrient cycling.

Figure 2. Left: Avocado soil with desirable soil structure, which is friable and almost no agglomeration. Right: Avocado soil with a poor structure where aggregates are predominant.

2.3 Soil physical property predictors

Soil physical properties such as compaction and poor structure negatively impact avocado tree health, therefore it was unexpected, but encouraging, not to identify these issues in lower-yielding orchards. According to the visual soil assessment methodology (Shepherd, 2019), the soil quality indexes of the 29 avocado orchards range from 29 to 36, categorising all participating orchards in a top soil category (greater than 28 points). It may be that the scoring system used in this study does not provide the resolution to identify problematic physical soil properties and more direct measures of soil physical properties are needed. Part of the rationale of using the visual soil assessment was that it could be done by a grower without the need for complicated equipment. A more detailed physical assessment of soils may reveal differences between high and low yielding orchards. The only visual indicator that was a statistically significant predictor of orchard yield in this study was the Total earthworm count (number of worms per 800cm3 of soil), where high yielding orchards had a lower number of earthworms than low yielding orchards (11.2 and 21.7 earthworms/800cm3 respectively). Earthworms help to make some essential nutrients available (nitrogen, phosphorus, potassium and magnesium) and enhance soil structure by improving porosity, aeration and water mobility. They also play an essential role in transforming organic matter into humus by bonding carbon to clay particles. Lower earthworms on higher yielding orchards is counterintuitive with common knowledge of how beneficial these organisms are in the soil.

3 Conclusions from the study

Considering the limited dataset and the narrow timeframe of this project, caution is required when interpreting the results. However, the study provides some key metrics of successful orchards that can be built on.

Although predictors of yield were identified within the orchards in this study, many of these results were counterintuitive to industry knowledge. As mentioned in the introduction, growers are encouraged to view the full results of this project to compare their own orchard's soil characteristics to orchards achieving greater than 15t/ha in their region and consider if there are potential areas of improvement that may impact yield. The key findings are set out on page 28 and the full report with details of the averages and ranges of all results recorded across the regions, is available to download from the NZ Avocado industry website under 'Research reports'.

Further investigation with more orchards across a greater range of yields would increase the confidence in results, as would sampling across multiple seasons to better understand the variability in results from year to year.

References:

Acosta-Mercado, Dimaris, and Denis H. Lynn. 2004. "Soil Ciliate Species Richness and Abundance Associated with the Rhizosphere of Different Subtropical Plant Species." The Journal of Eukaryotic Microbiology 51(5):582–88. doi: 10.1111/j.1550-7408.2004.tb00295.x.

Grover, Minakshi, Shrey Bodhankar, Maheswari Mandapaka, and Srinivasrao Ch. 2016. "Actinomycetes as Mitigators of Climate Change and Abiotic Stress." Pp. 203–12 in Plant Growth Promoting Actinobacteria: A New Avenue for Enhancing the Productivity and Soil Fertility of Grain Legumes.

Kumar, Ajay, Hariom Verma, Vipin Singh, Prem Singh, Sandeep Singh, Waquar Ansari, Akhilesh Yadav, Pawan Singh, and Kapil Pandey. 2017. "Role of Pseudomonas Sp. in Sustainable Agriculture and Disease Management." Pp. 195–215 in Agriculturally Important Microbes for Sustainable Agriculture.

Luu, Hai Thi Thuy. 2019. "Biodiversity of Ciliated Protozoa in Soil Ecosystems and Assessment of Their Potential as Bio-Indicators of Soil Quality." PhD, Bournemouth University.

NZ Avocado Growers' Association Inc. 2018. Avocado Growers Manual.

Pepper, Ian L., Jerry J. Gentry, and Charles P. Gerba. 2015. Environmental Microbiology. Third Edition. Elsevier.

Shepherd, Graham. 2019. Visual Soil Assessment. Vol. 1. Second Edition.