

SLAKES: a cost-effective measure of soil structural stability

A report prepared for Te Ahikawariki – Vegetable Industry Centre of Excellence



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1 Overview

1.1 Project purpose

The Te Ahikawariki/VICE project involved growers and soils in four regions: Pukekohe, Gisborne, Hawke's Bay, and Manawatu/Levin. Results from Slakes assessments were compared with results from the LRMW wet-sieve aggregate stability test and correlated with visual soil assessment (VSA) scores, soil bulk density, and total soil carbon levels.

A key part of the project was to engage with growers to demonstrate and support valid paddock sampling and the proper use of the Slakes app, ensuring the knowledge is retained within each regional community. The intent was for a standardised assessment methodology consistent with Soil Health Institute (SHI) guidelines to be understood and made available for growers if needed. Assuming the Slakes testing methodology proved valid and was found to be easily usable by growers, these sectors would have an improved, cost-effective way to assess soil health using a key indicator. All it would require is a little of a grower's time and a free smartphone app, and it could be integrated into industry BMP or sustainability guidelines.

A follow-on project could extend to other regions to engage with growers with other soil types, crop types, and agronomy practices. There has also been interest from growers in a project that determines Slakes aggregate stability index thresholds, identifying where aggregate stability has decreased enough to affect productivity, and going beyond which might aggravate soil recovery.

1.2 Soil aggregate stability

Soil aggregate stability describes the ability of soil aggregates or "peds" to resist degradation and to maintain structure when being affected by external forces such as rainfall, vehicle traffic, tillage, and wind erosion¹. It is recognised by the Soil Health Institute (SHI) as one of three key soil health indicators, alongside soil organic carbon concentration and carbon mineralisation potential².

Soils with stable aggregates are usually found to be more productive than soils with poor aggregate stability³. Soils with stable aggregates have more organic matter present, which acts as a glue holding aggregates together⁴. As an indicator of soil structural quality, Shepherd et al⁵ reported that soil carbon was linearly correlated to aggregate stability, a finding supported by Thompson-Morrison et al⁶. Soils with higher carbon and more stable aggregates retain more moisture and have higher infiltration rates, and plant roots can penetrate deeper into the soil, which means crops will be more drought tolerant and have better productivity⁷.

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Aggregate stability is correlated with soil erosion, water retention, aeration, root growth, soil microorganisms, and carbon sequestration⁸. During rain events, soils containing unstable aggregates will disperse and collapse, filling pore spaces and making the soil susceptible to erosion and compaction⁷. Eroding soil takes nutrients with it, reducing soil fertility⁹. Soil carbon and nitrogen levels are reduced as they are no longer protected inside the aggregates¹⁰. Compaction can cause aeration reduction, waterlogging and root disease, which will affect crop health¹¹.

On-farm management practises affect the soil's aggregate stability. Soil is likely to have better aggregate stability under pasture than under cultivated cropping soil¹². Increasing the organic matter in the soil will increase biological activity, which helps to improve the aggregate stability as it binds aggregates together⁴. Aggregate stability can also be improved by having crops that cover the soil's surface, as this will reduce the impact from raindrops³ and continue to introduce carbon into the soil system⁶. Conventional tillage breaks aggregates and increases organic matter decomposition, which decreases aggregate stability¹⁰. Conversely, using practises that reduce soil disturbance, such as strip-till, no-till and zone tilling, will reduce the degradation of aggregates⁷. Heavy machinery and stock treading on soil will break apart soil aggregates, compacting the soil and reducing aggregate stability¹³.

1.3 Aggregate stability measurement

Many methods have been used to measure aggregate stability, including Cornell University's wet aggregate stability, Yoder's wet sieving and Landcare Research – Manaaki Whenua's (LRMW) wet sieving. However, these methods are time consuming and costly. The Soil Health Institute recommends a soil slaking method, using the "Slakes" smartphone app, which was developed by the University of Sydney¹⁴, and which can be completed by growers with minimal time and equipment.

In setting provisional targets for soil quality indicators in New Zealand, Sparling et al¹⁵ identified four soil-quality categories: significant (adverse) impact; potential impact (and therefore of concern); within the target range; and above target range, and where possible suggested boundary points or thresholds for each soil-quality category and upper and lower target range limits. The acceptable range in a soil property was defined as the limit between the 'no significant impact' value, and the 'above target range' value.

Aggregate stability rankings were constructed for cropping and horticulture on Recent Soils and followed the pattern that 'more is better'. An aggregate stability > 2 mm mean weight diameter was considered necessary for optimal soil quality. Small mean weight diameters (< 1 mm) were more detrimental when considering environmental rather than production criteria. They stated that decreased aggregate stability is reflected in decreased production, or increased costs, but soil management can mask the effect of

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decreased stability, so loss of stability does not necessarily impact production. Loss of aggregate stability increases the risk to the environment, e.g. more erosion, more CO₂ production. While unsure how much environmental risk is caused by a loss of stability, they suggested concern if MWD < 1.5 mm.

1.4 Soil slaking

Soil slaking is a dispersal-based method assessing the collapse of aggregates when exposed to hydraulic pressures, including raindrop impact or expansion when soil is rewetted or, as a laboratory test, the degree to which dried peds collapse when placed in water.

The SHI Slakes method uses image analysis of sets of three aggregates, initially dry and again after they have been submerged in water for 10 minutes¹⁶. The free Slakes app produces an aggregate stability value without having to send samples away to be analysed¹⁷. The images are processed to determine aggregate area (as a substitute for aggregate size) and a modelled function including initial to final aggregate area and time is used to calculate an Aggregate Stability Index. The Slakes aggregate stability index ranges from 0.1 – 1, with greater aggregate stability being closer to 1¹⁶. Details are available at <https://soilhealthinstitute.org/our-work/initiatives/slakes/#overview> (see Appendix).

The Slakes method was investigated by Flynn et al¹⁸ who reported that the simplified method for “rating and quantifying soil health is viable for anyone with a portable electronic device and is much less tedious than traditional lab-based methods”. Slaking was also investigated by FAR¹⁹ who reported that “the SLAKE application results correlated well with the Plant & Food Research laboratory method of assessing aggregate stability ($R^2=0.8233$, Figure 6), but patience was required to carry out the trial”. Of note is that the SLAKE method used in the FAR work was the initial complex method reported by Fajardo¹⁷ which is significantly different to, and more difficult than, the new smartphone based Slakes app used for the work presented in this report.

2 Methods

Two farms were visited within each region, with two samples being taken from each farm. Apart from the first-visited Pukekohe farms, a sample was taken from an uncropped and cropped area within the same paddock.

2.1 Slakes aggregate stability index

The Slakes procedure published by the SHI recommends extracting clods of soil from the top 5 cm of the profile and extracting “pea sized” aggregates. A number of clods can

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be taken across an area to obtain a paddock average, similar to any other soil test sampling. This project included comparing Slakes with other testing methods, including the LRMW mean weight diameter and VSA, so Slakes pedes were collected from the upper 20 cm of soil.

Samples were collected by taking another three ~5 cm thick slabs of soil 20 cm deep from the sides of a hole left after a cube had been excavated for VSA testing. The slabs of soil were split into two depths; 0 – 10 cm and 10 – 20 cm. The samples were broken up by hand along the soil's natural fractures, and 30 aggregates of approximately 5 mm diameter were collected and weighed. The selected aggregates were dried in a microwave for 2 minutes, then reweighed. The samples continued to be dried for one minute intervals until there was no significant change in weight.

Three dry aggregates were placed evenly in a white dish, and a phone was set up 10 cm above the dish (Figure 2-1).

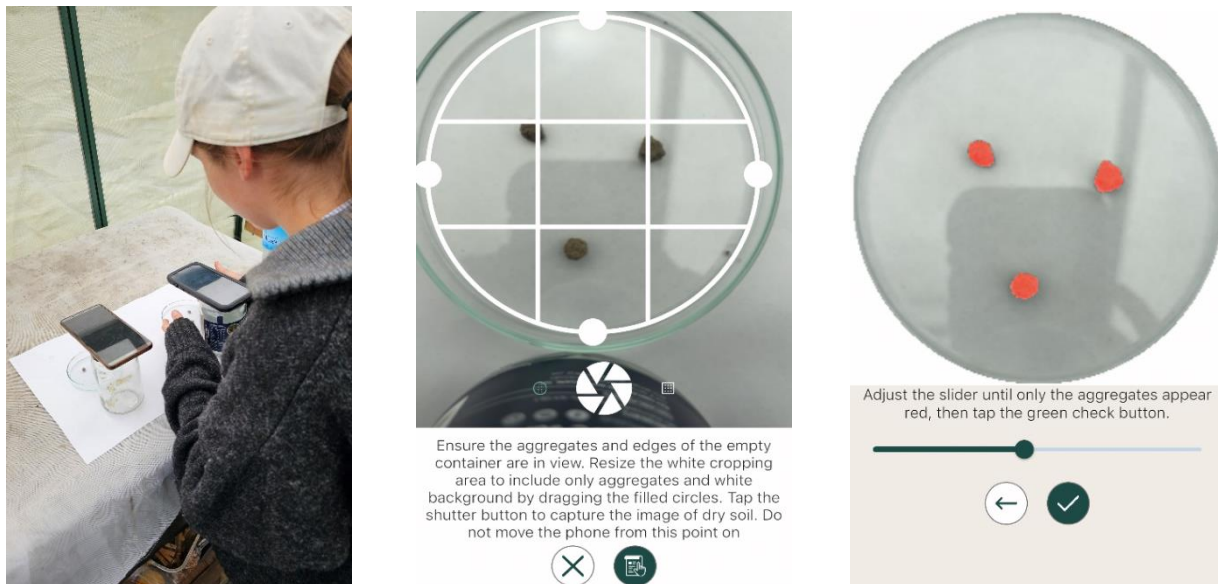


Figure 2-1 Left: Test set up, smartphone 10 cm above dishes. Centre: Screenshot of Slakes app with aggregates placed evenly in the dish. Right: Slakes app adjustment slider, showing only the aggregates in red.

The sample name was entered in the Slakes app, and an initial photo was taken. In the resulting photo, the aggregates and some surrounding area initially appeared in red. A colour sensitivity adjustment slider in the app was used to modify the image until only the three aggregates were red (Figure 2-1).

The white dish containing the dry aggregates was replaced with a white dish full of water. The three aggregates were placed evenly spaced into the water, and a second photo was taken. Taking the second photo started a 10 minute timer after which a final photo was taken automatically (Figure 2-2), and the Slakes aggregate stability index was

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produced. The process was repeated three times for each sample, capturing results from nine individual aggregates.



Figure 2-2 Left: Initial photo of the dry aggregates taken by the Slakes app. Right: Final photo taken automatically by the Slakes app ten minutes later.

2.2 LRMW Mean weight diameter

Three ~5 cm thick slabs of soil were taken from three sides of the VSA hole and sent to LRMW for wet sieving aggregate stability testing. LRMW references Gradwell and Birrell as the method used²⁰.

Analysis is carried out on the 2.00 – 4.00 mm aggregate fraction of an air-dried sample. 50 g of soil, oven-dried equivalent weight, is placed on the top sieve of a 2.0, 1.0, and 0.5 mm sieve stack, submerged in water and sieved mechanically for 30 minutes. The aggregates retained on each sieve are collected, oven-dried and weighed. Aggregates are dispersed and any remaining primary particles are sieved and weighed in a similar manner. Aggregates minus their primary particles are calculated as weight fractions of the soil initially taken and results reported as mean weight diameter (MWD).

Mean weight diameter results can be interpreted according to guidelines from LRMW, whereby $MWD < 1$ means the soil aggregates are weak and $MWD > 2$ means the aggregates are stable (Shane Cox, 2024 pers. com).

2.3 Visual Soil Assessment

A VSA was completed first at each site. A 20 cm cube of soil was excavated (Figure 2-3) and dropped from waist height onto a board three times. The soil lumps from the broken up cube were sorted from largest to smallest and scored using the VSA v1.0 method. Factors assessed were the soil structure, porosity, soil colour, number of mottles, the presence of a tillage pan, total earthworm number, and grower-reported clod development and susceptibility to erosion when cultivated.

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Figure 2-3 VSA hole after a 20cm cube of soil had been removed for testing.

In the VSA method, factors are given weightings and a combined score used as an overall soil health score. Soil structure and porosity are weighted by 3, the degree of clod development is weighted by 1, and the rest are weighted by 2. The sum of the weighted scores gives a ranking score for the sample, which is compared to the soil quality assessment ranking. A score of less than 10 is considered “poor”, between 10-15 is “moderate”, and a score higher than 25 is considered “good”.

2.4 Total soil carbon

Ten cores 15 cm deep were taken from around the VSA hole (Figure 2-4) and sent to Hill Labs to determine the total carbon percentage. Combined with the soil bulk density, this allows the total amount of carbon to be calculated.



Figure 2-4 Ten soil cores were taken around the VSA hole and sent for laboratory testing to determine the total carbon concentration.

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2.5 Soil bulk density

A 7.5 cm deep x 9.8 cm diameter bulk density ring was pressed into the soil beside the VSA hole to collect a sample of known volume (Figure 2-5). The sample was oven dried for 72 hours at 100 degrees Celsius. The dry soil weight and volume of the bulk density ring were used to calculate the soil's bulk density.



Figure 2-5 Collecting a soil bulk density sample

2.6 Earthworm presence

During completion of the VSA assessments, additional time was spent finding and saving earthworms. The earthworms were identified and weighed by Nicole Schon at AgResearch, as part of a separate project.

3 Results

The Slakes aggregate stability index results were compared with results from the LRMW wet-sieve aggregate stability test, VSA structure score, bulk density and total soil carbon concentration measured in percentage. The total soil carbon was also compared to the bulk density.

3.1 Slakes vs LRMW

The Slakes' aggregate stability index and LRMW mean weight diameter results (Table 3-1) show the same trend. Cropped areas have lower aggregate stability than uncropped areas, within the same paddock (Site 4 onwards) (Figure 3-1).

Table 3-1 Average aggregate stability index and the LRMW mean weight diameter aggregate stability (0 – 20 cm). In the site name, the number indicates the site. C indicates the paddock was being cropped, C indicates the paddock had been cropped in the past but had been in grass for at least a season, and U indicates the sample was taken in an uncropped area.*

Sample Name	Site Name	Average Slakes Aggregate Stability Index (0 – 20 cm)	LRMW Mean Weight Diameter aggregate stability (0 – 20 cm)
Pukekohe 1 Broccoli	1 C	0.43	0.76
Pukekohe 1 Cabbage	1 C	0.27	0.64
Pukekohe 2 Watermelons	2 C	0.61	1.32
Pukekohe 2 Union Uncropped	2 C*	0.82	2.13
Otane 1 Uncropped	3 U	0.75	2.46
Otane 1 Grass	3 C*	0.91	2.46
Manawatu 1 Uncropped	4 U	0.84	2.26
Manawatu 1 Celery	4 C	0.40	0.34
Manawatu 2 Uncropped	5 U	0.83	1.59
Manawatu 2 Celery	5 C	0.33	0.32
Gisborne 1 Uncropped	6 U	0.76	1.49
Gisborne 1 Spinach	6 C	0.29	0.28
Gisborne 2 Uncropped	7 U	0.80	1.39
Gisborne 2 New grass after seed maize	7 C	0.52	0.40
Otane 2 Uncropped	8 U	0.77	2.27
Otane 2 Carrots	8 C	0.41	0.55

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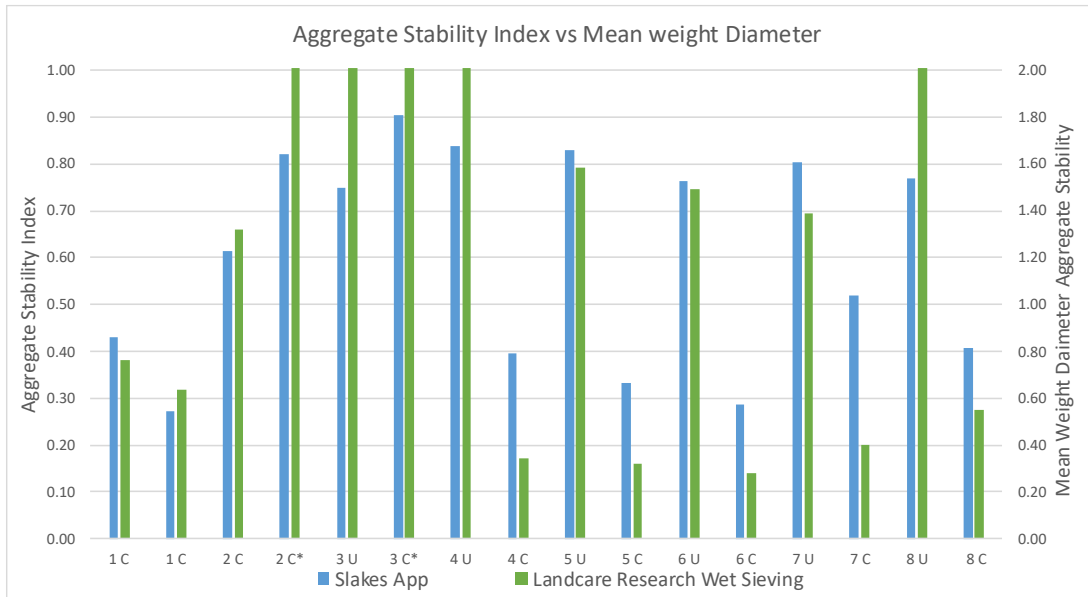


Figure 3-1 Bar graph comparing the average aggregate stability index and the LRMW mean weight diameter aggregate stability (0 – 20 cm). The number indicates the site. C indicates the paddock was cropped, C* indicates the paddock has been cropped in the past but has been in grass for at least a season, and U indicates the sample was taken in an uncropped area.

There was a strong relationship between the Slakes Index and the LRMW wet sieving mean weight diameter ($R^2 = 0.81$) (Figure 3-2).

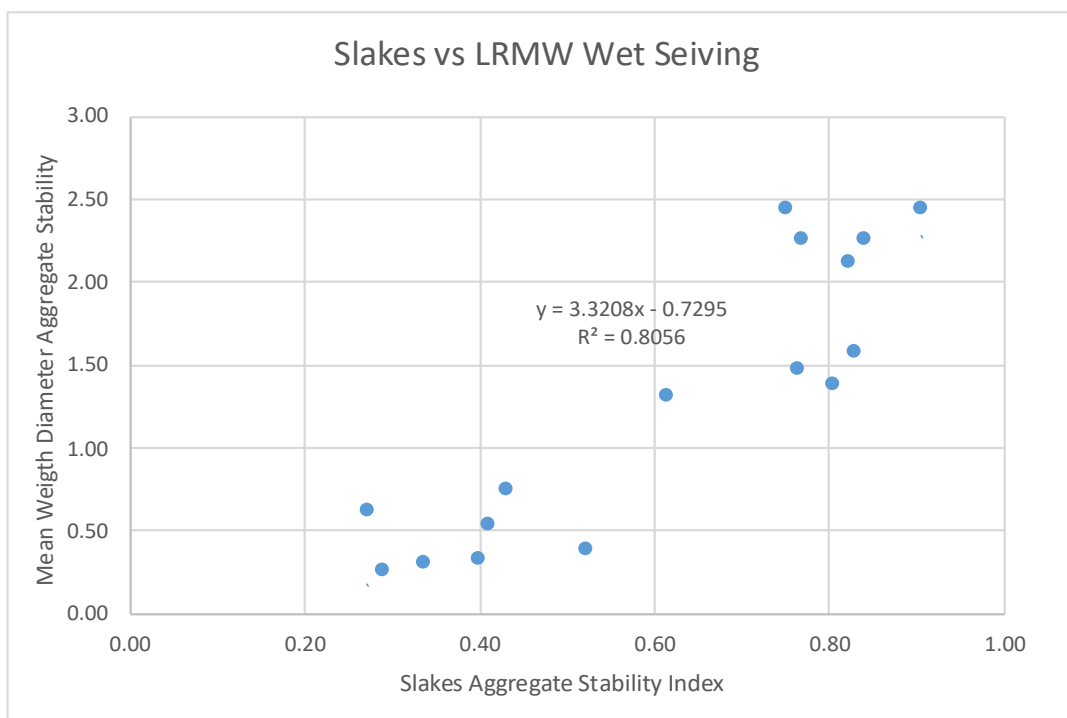


Figure 3-2 Scatter plot indicating there is a strong relationship between the Slakes aggregate stability index and LRMW wet sieving mean weight diameter aggregate stability.

3.2 Slakes vs LRMW vs VSA structure score

Most of the cropped areas had moderate to good VSA structure scores but low Slakes aggregate stability indexes and low LRMW mean weight diameter scores. The differences are less marked in the uncropped areas.

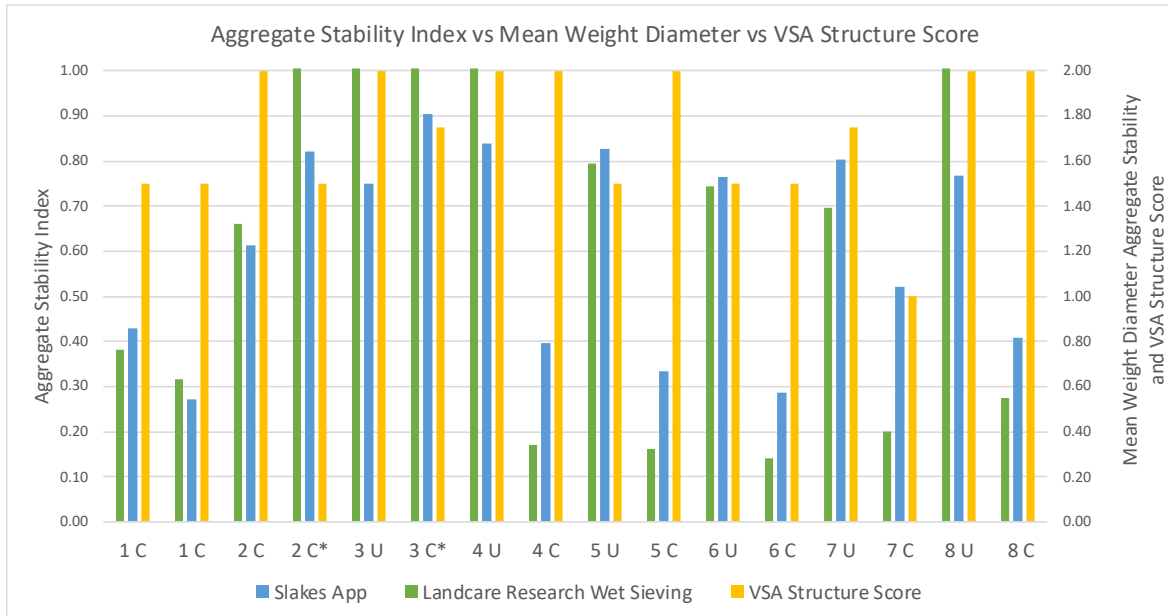
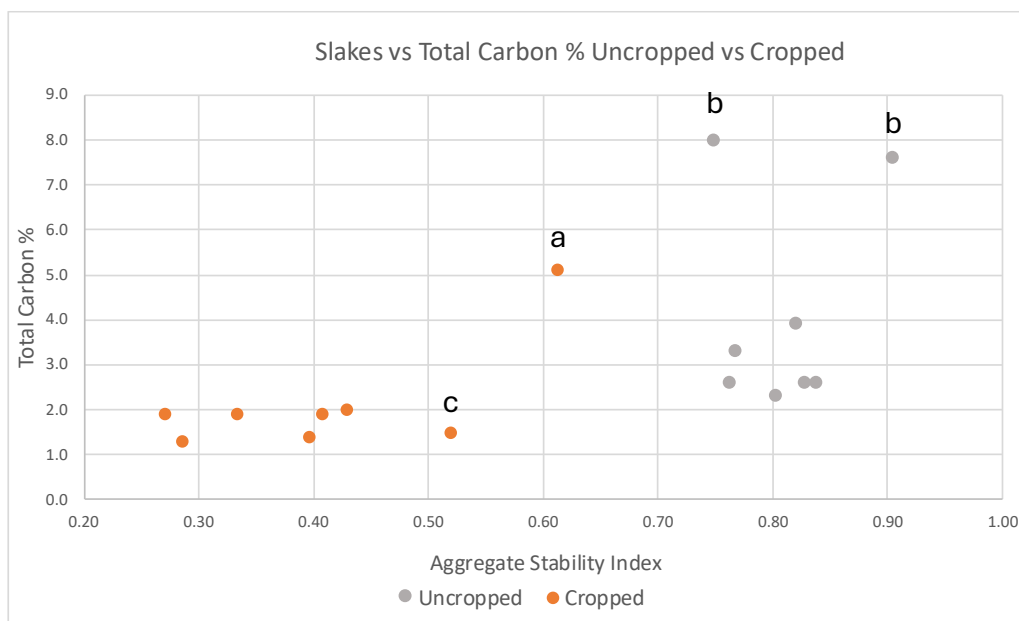


Figure 3-3 Bar graph that compares the Slakes aggregate stability index to LRMW and VSA structure score.

3.3 Slakes vs soil carbon concentration

There is a very clear separation between cropped and uncropped sites when comparing total soil carbon concentration and the Slakes aggregate stability index (Figure 3-4).



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Figure 3-4 Scatter plot comparing the Slakes aggregate stability index and total carbon concentration, showing there is a clear separation between cropped and uncropped areas.

Three points in Figure 3-4 stand separately to the rest. The point labelled “a” is a site from which watermelons had been harvested after growing in a polythene mulch for a full season. The two points labelled “b” were at a site with peat soil, so the soil carbon levels were very high. The rest of the sites had mineral soils. Point “c” was newly planted in ryegrass following a crop of seed maize.

When “a” and “b” sites were removed from analysis, a moderate relationship ($R^2 = 0.61$) was found between soil carbon concentration and Slakes aggregate stability index (Figure 3-5).

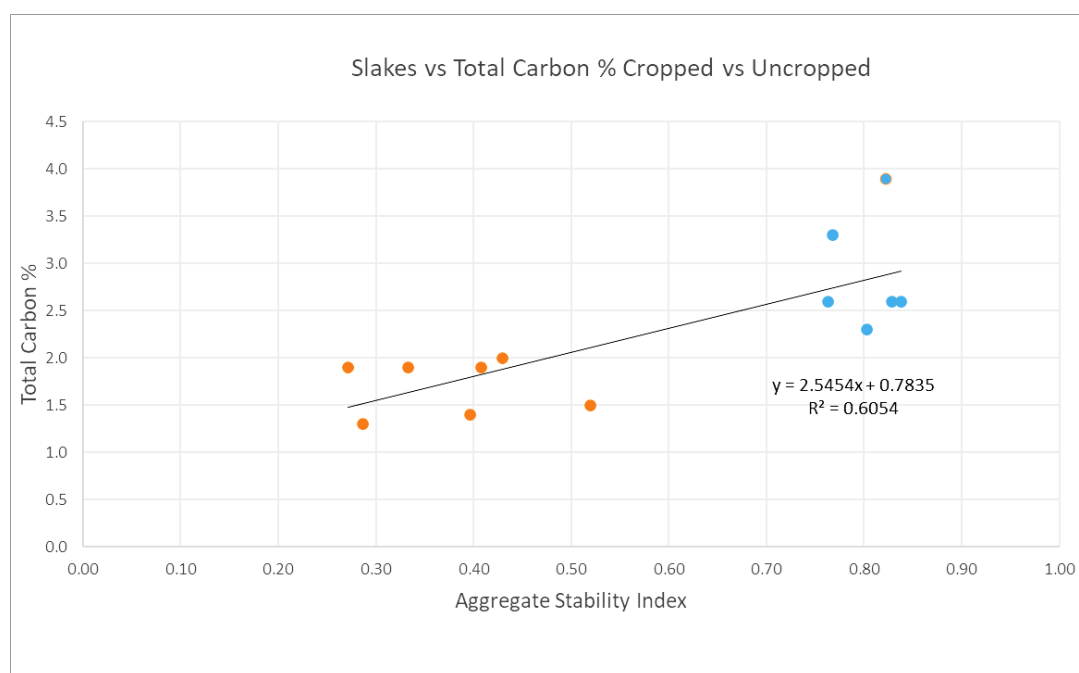


Figure 3-5 Scatter plot showing the relationship between Slakes aggregate stability index and total carbon concentration in cropped and uncropped areas on mineral soils without the influence of plastic mulch.

3.4 Slakes vs bulk density

The soil bulk density data indicate slightly higher density (more compaction) in the cropped areas than the uncropped areas at the two Gisborne sites (Table 3-2), but overall, there is no significant difference ($p=0.42$).

When cropped and uncropped areas are considered as separate groups, there is a moderate relationship between soil bulk density at the cropped sites ($R^2 = 0.60$) and a weaker relationship at uncropped sites ($R^2 = 0.43$) as shown in Figure 3-6. At uncropped sites the Slakes stability was around 0.8, but soil bulk density ranged from 0.82 to 1.2. In the cropped areas, bulk density increased from 0.86 to 1.24 as Slakes stability dropped from 0.61 to 0.29.

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Table 3-2 Bulk density, by site.

Sample Name	Site Name	Bulk Density (g/cm ³)
Pukekohe 1 Broccoli	1 C	0.99
Pukekohe 1 Cabbage	1 C	1.06
Pukekohe 2 Watermelons	2 C	0.86
Pukekohe 2 Union Uncropped	2 C*	0.88
Otane 1 Uncropped	3 U	0.77
Otane 1 Grass in headland	3 C*	0.82
Manawatu 1 Uncropped	4 U	1.19
Manawatu 1 Celery	4 C	1.19
Manawatu 2 Uncropped	5 U	1.07
Manawatu 2 Celery	5 C	1.10
Gisborne 1 Uncropped	6 U	0.97
Gisborne 1 Spinach	6 C	1.24
Gisborne 2 Uncropped	7 U	1.04
Gisborne 2 New grass after seed maize	7 C	1.28
Otane 2 Uncropped	8 U	1.09
Otane 2 Carrots	8 C	1.03

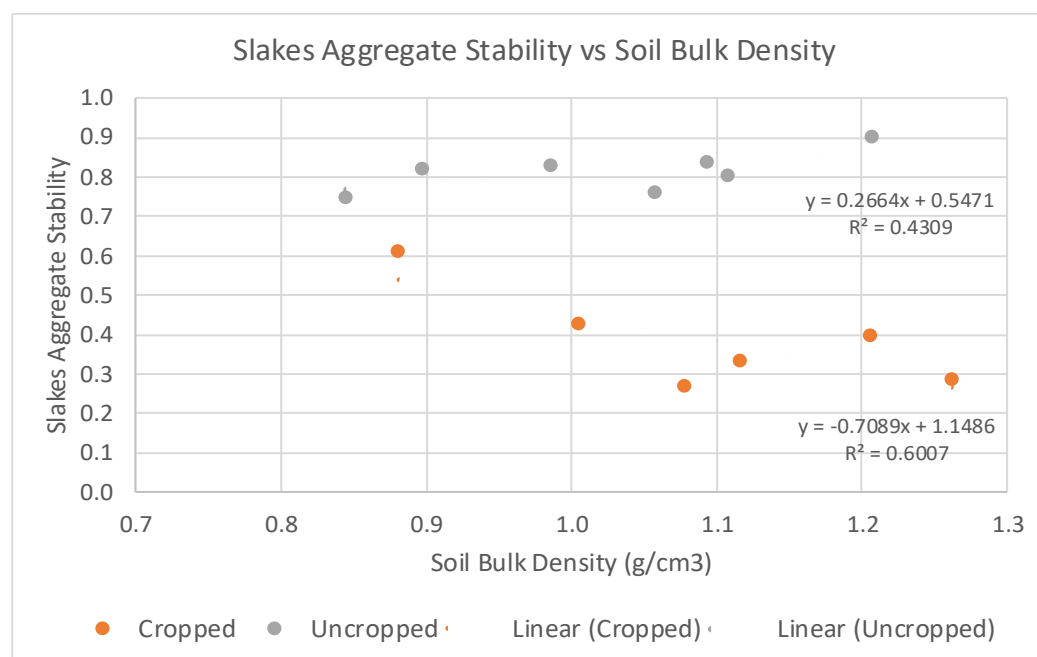


Figure 3-6 Scatter plot of soil bulk density versus Slakes aggregate stability showing moderate relationship at cropped sites and a weaker relationship at uncropped sites.

There is a moderate relationship between soil bulk density and total soil carbon ($R^2 = 0.69$) as shown in Figure 3-7.

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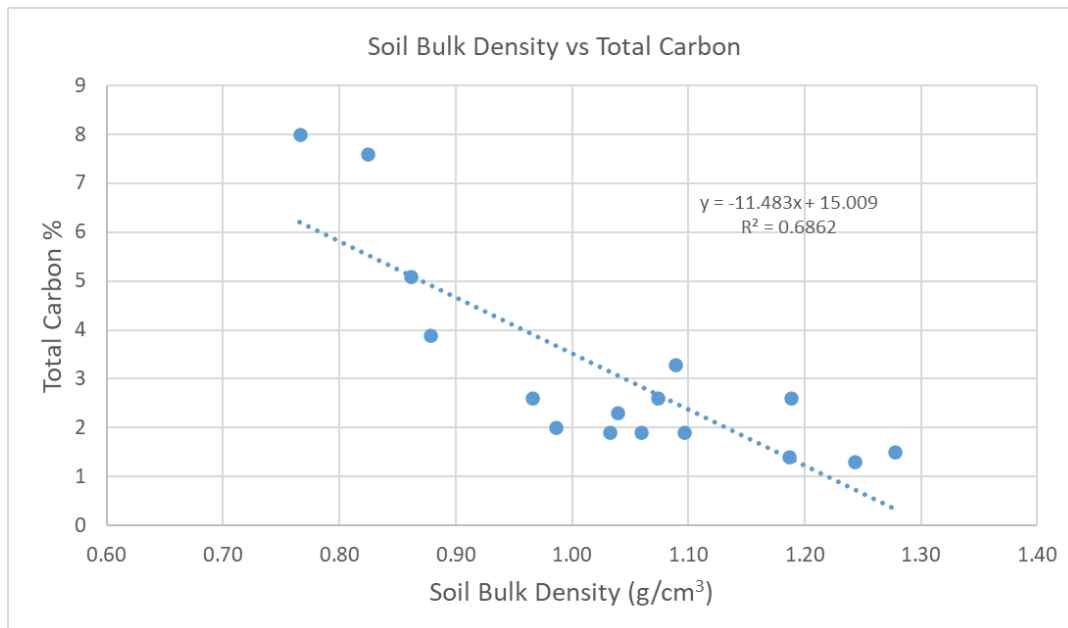


Figure 3-7 Scatter plot of soil bulk density versus total soil carbon showing a moderate relationship.

Similar strength relationships are found when data are split into cropped and uncropped sites as shown in Figure 3-8.

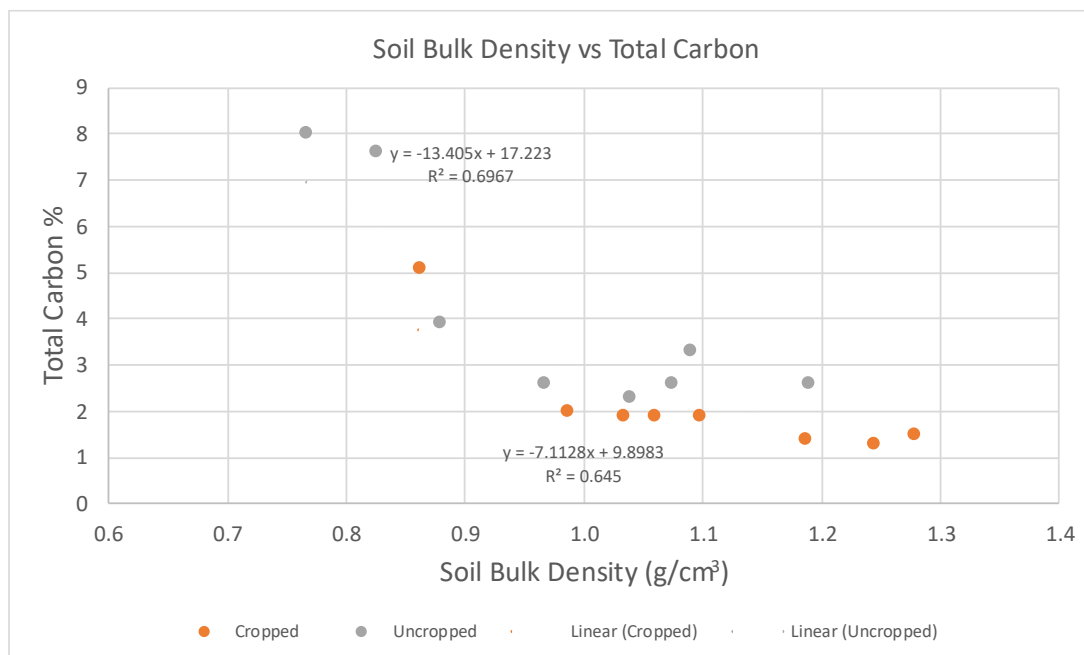


Figure 3-8 Scatter plot of soil bulk density versus total soil carbon showing moderate relationships in both cropped and uncropped sites.

3.5 Slakes vs earthworm number

No earthworms were found at five of the nine cropped sites, but were found at all the uncropped sites. One uncropped site had a much lower number of earthworms than the others. That site was very close to a drain and showed signs of wetness and major

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soil disturbance at some time in the past, possibly during drain construction or maintenance. With that site and those sites with no earthworms excluded from analysis, there was a good correlation between the Slakes Index and total Earthworm number. The best relationship was exponential ($r^2 = 0.79$) with earthworm numbers increasing rapidly at Slakes Index scores greater than about 0.75 (Figure 3-9).

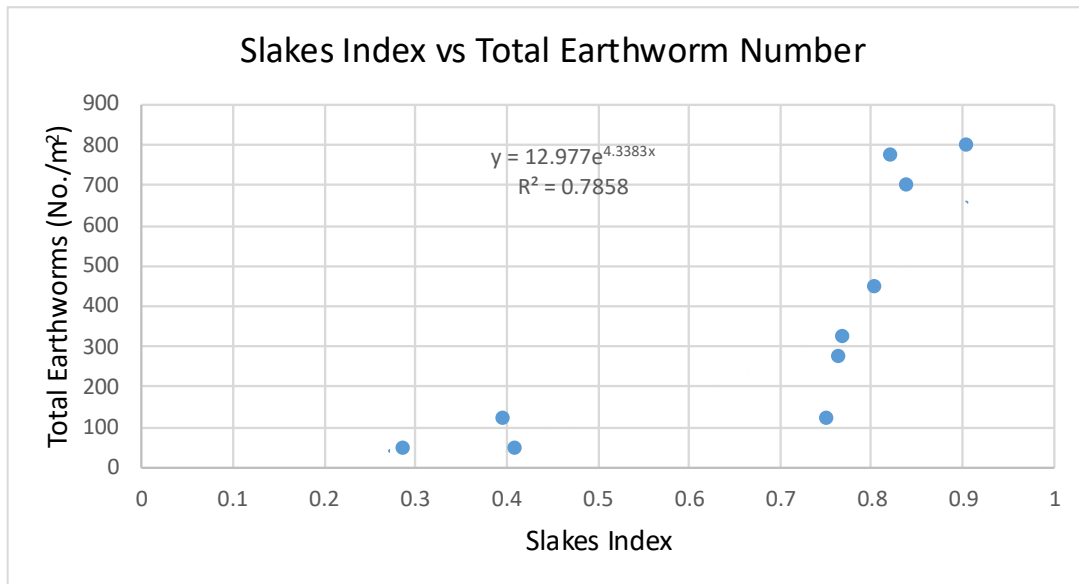


Figure 3-9 Slakes Index versus total earthworm number for sites where earthworms were present

There was a slightly lower exponential correlation ($r^2 = 0.61$) between the Slakes index and earthworm wet biomass, mainly due to one site “a” where few but large earthworms were found (Figure 3-10).

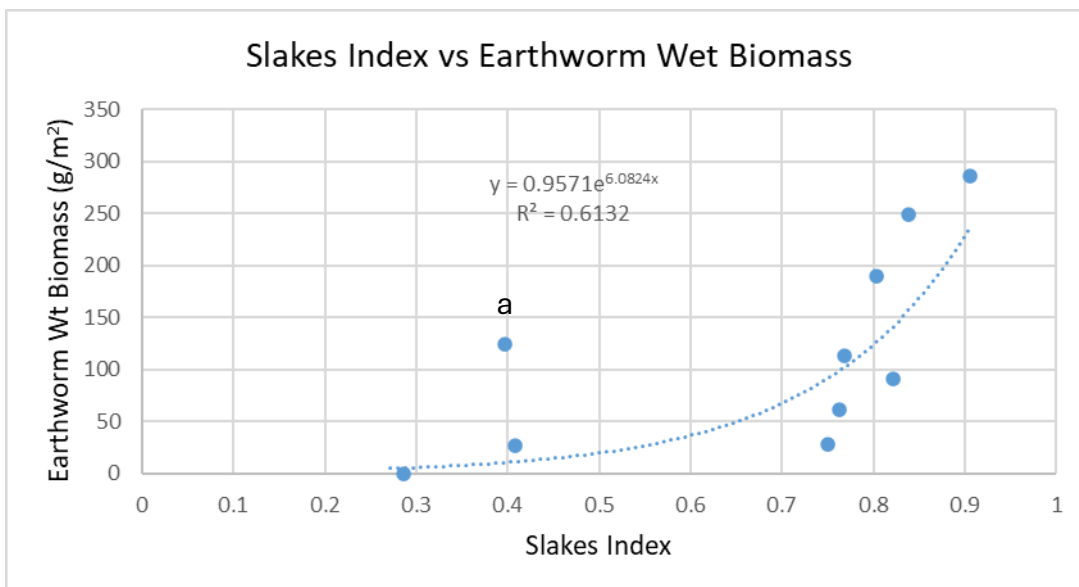


Figure 3-10 Slakes Index versus earthworm wet biomass for sites where earthworms were present

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Earthworm count is a key factor in the VSA soil health assessment method. However, we did not find a correlation between Slakes Index and VSA earthworm score ($r^2 = 0.003$) or the overall VSA score ($r^2 = 0.09$). Similarly, there was a very weak correlation between earthworm numbers and soil bulk density ($r^2 = 0.10$).

4 Discussion

While there is considerable evidence from literature and experts that soil aggregate stability is of fundamental importance in soil health, we found little guidance on the use of measures for management decision support. Sparling et al¹⁵ attempted through a consultation of experts to define threshold values for a number of soil health indicators included aggregate stability, but they indicated low confidence in findings. Horrocks et al¹⁹ found good correlation between Slakes and the PFR aggregate stability test results, and indicated that Slakes was a useful tool, but did not offer threshold values.

4.1 Slakes vs LRMW

The Slakes aggregate stability index and the LRMW mean weight diameter aggregate stability test gave comparable results. This agrees with the FAR work comparing the old SLAKES method aggregate stability results with those from Plant and Food Research Mean Weight Diameter results.

Trendline analysis shows that the LRMW stability indication boundaries of > 2 for stable aggregates and < 1 for unstable aggregates correspond to Slakes Index scores of approximately 0.78 and 0.54, respectively. A Slakes Index < 0.66 would indicate cause for concern, based on the Sparling et al¹⁵ proposed MWD < 1.5 . Fully stable aggregates, Slakes index = 1.0 would equate to a MWD ~ 3 .

This project supports adoption of the Slakes method as a test for aggregate stability and suggests that an aggregate stability index above 0.80 indicates the aggregates are stable and soil is in good condition. Scores between 0.80 and 0.65 indicate structure is somewhat degraded, a value below 0.65 indicates cause for concern, and below 0.55 indicates that aggregates are unstable and there is heightened production and environmental risk (Figure 4-1).

MWD	3.0	2.0	1.5	1.0	0.50
Soil status	Stable	Good condition	Concerning	Unstable	Increasing risk
Slakes	1.0	0.8	0.65	0.55	0.40

Figure 4-1 Suggested limits for soil stability status according to Mean Weight Diameter and equivalent Slakes Index scores.

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4.2 Slakes vs MWD vs VSA structure score

There was a marked difference between cropped and uncropped sites when comparing the VSA score with soil aggregate stability. The aggregate stability scores from both MWD and Slakes' aggregate testing from cropped sites were relatively very low compared to those from the uncropped areas. The VSA structure score of soil samples rated "good" at most cropped soil sites, whereas the MWD and Slakes Index scores indicated "unstable" or "increasing risk. This suggests that in cropped areas, the VSA structure assessments were scored too highly, possibly because cultivation tilth was interpreted as natural soil aggregates or peds. Given its good correlation with other recognised physical indicators, the Slakes method is a useful addition to VSA. The VSA method reports other factors including semi-objective assessments of porosity, poor aeration, compaction and erosion risk.

4.3 Slakes vs soil carbon concentration

The two uncropped sites on peat soil stood apart, as did the cropped site which had been under polyethylene mulch for a season. Data from the remaining sites on mineral soil without plastic mulch fitted into two separate clusters representing the cropped and uncropped sites. This can be explained by the cropped soils losing carbon and organic matter because of cultivation, with soils under pasture likely to have better aggregate stability than under cultivated cropping soil¹². The soil aggregates are weaker, as there is less organic matter to bind them together⁴.

The data suggest a cut-off at about 2% total soil carbon, below which aggregate stability is greatly reduced. This is not inconsistent with published data^{7, 8, 10} although suggested threshold values were not identified in literature.

4.4 Slakes vs bulk density

The relationship between Slakes Index and soil bulk density is notably different in cropped areas compared to uncropped areas. The uncropped sites showed little difference in Slakes aggregate stability as bulk density increased, with some possibility of a slight positive relationship. Some uncropped sites have histories of vehicle trafficking, which may be affecting results.

The cropped sites, by contrast, show a clear negative relationship, with bulk density increasing as Slakes aggregate stability decreases, pointing to lower porosity. This shows that the Slakes stability index is a potential indicator of increased risk of poor aeration and drainage and susceptibility to adverse compaction effects.

While there is some difference between cropped and uncropped areas, soil bulk density is negatively associated with soil carbon concentration. This further links loss of soil

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carbon with increased risk of poor aeration and drainage and susceptibility to adverse compaction effects.

4.5 Slakes vs earthworms

Earthworm assessments showed that cultivation was strongly related to earthworm reduction, with no earthworms found at half of the cropped sites. There was a good correlation between earthworm numbers and the Slakes Index ($r^2 = 0.79$). This is in line with general findings of earthworms and other soil organisms being related to soil carbon and soil stability. All the sites with high earthworm numbers were uncultivated, and few or no earthworms were found in the cropped sites. The data collected show that there was a rapid increase in the number of earthworms found as the Slakes Index increased above about 0.75. This may be related to several factors, including the lack of cultivation at sites with higher earthworm numbers. Other factors may include more soil organic matter providing more food, better structure providing better aeration, and better structure allowing easier movement through the soil, although earthworm numbers and soil bulk density were very weakly related.

5 Outreach

5.1 Grower feedback

Overall, participating growers and agronomists found the Slakes workshops beneficial and said they would use the skills they had learnt.

There was mixed feedback surrounding the Slakes method itself. Most growers indicated they would use the slakes app in spring before cultivation starts. One grower hoped to add it to their soil monitoring program to identify paddocks that need a break from vegetable production. A few growers said they would not use the Slakes method as it was too time-consuming.

Growers expressed interest in a commercial testing option, such as adding Slakes aggregate stability testing to a basic soil test, depending on the cost. However, they would like to see case studies carried out to compare lab Slakes testing to doing it independently on-farm.

Growers had questions regarding the Slakes aggregate stability index results and what the results show about their soil health. This led them to ponder if there is an aggregate stability index threshold where aggregate stability has decreased enough to affect productivity. There was discussion about the possibility of a “tipping point” past which soil recovery might be slower or more difficult.

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5.2 Regional project interactions

In all the regions we visited, we had groups of growers willing to participate in the paddock sampling, sample processing, and using the Slakes app.



Figure 5-1 Demonstrating the Slakes app at grower engagement days in Pukekohe and Gisborne.

5.3 Hortcentre Soil Health Seminar – Cronin Rd

LandWISE ran an afternoon seminar discussing soil health, minimum tillage and strip tillage for Hortcentre-invited growers in Pukekohe. As part of that, we presented information about Slakes and explained the process and gave examples.

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Figure 5-2 Presenting Slakes to growers at the LandWISE Horticulture Soil Health Seminar in Pukekohe.

5.4 LandWISE conference

Olivia presented an overview of the Slakes Project and the results to around 80 people at the LandWISE conference lecture sessions on Day 1. There was positive feedback about her presentation and a lot of interest in the Slakes app. The presentation was followed by practical demonstrations at the conference field event on Day 2.



Figure 5-3 Presentation at the LandWISE Conference (left) and demonstrating at the associated Field Event (right).

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5.5 Young Horticulturists' training days

During a training event for the Young Horticulturists held at the Centre for Land and Water, we presented and demonstrated the Slakes method and app. We had good engagement with these future leaders from across the sectors.



Figure 5-4 Demonstrating the Slakes method to Young Horticulturists at their development workshop at the Centre for Land and Water in Hastings.

6 Conclusion

Aggregate stability is one of three soil health indicators recommended by the Soil Health Institute. It measures the ability of soil aggregates or “peds” to resist degradation and maintain structure when being affected by external forces. Aggregate stability is essential as it is associated with moisture retention, root growth, soil erosion, water infiltration rates, aeration, soil microorganisms, and carbon sequestration.

This project included working with growers and agronomists in four regions: Pukekohe, Gisborne, Hawke’s Bay, and Manawatu/Levin. We also shared the method with many others through a variety of events and found a high level of interest. For the regional testing, two samples were taken from each farm, with two farms being visited within each region. Apart from the first visits in Pukekohe, a sample was taken from an uncropped and cropped area within the same paddock. We compared Slakes Index aggregate stability results with LRMW Mean Weight Diameter (MWD) from wet-sieve aggregate stability testing and correlated the results with visual soil assessment (VSA) scores, soil bulk density, and total soil carbon levels.

There was a strong relationship ($R^2 = 0.81$) between the Slakes Index and the LRMW MWD results, with uncropped areas having higher aggregate stability than cropped areas. Based on this analysis, we suggest a Slakes index > 0.8 is a suitable boundary indicating strong aggregate stability and high health. A Slakes index between 0.80 and 0.65 indicates structure is somewhat degraded, a value below 0.65 indicates cause for concern. A Slakes index < 0.55 provides a lower boundary and should be seen as indicating significant degradation and increased risk of adverse agronomic factors associated with poor aeration, drainage, and susceptibility to compaction. This relationship appears to be valid across the sites tested.

The VSA structure scores in cropped areas were moderate to good, whereas the aggregate stability results from Slakes and LRMW indicated stability was low and was of concern. The difference is likely due to cultivation in cropped areas creating tilth rather than structure. We suggest using the Slakes method as a useful addition when doing a VSA on cropped soils, as it will provide a better representation of soil structural strength.

There was a clear separation between cropped and uncropped areas when comparing the Slakes Index and total carbon concentration. Cultivation of cropped soils results in them losing organic matter and carbon, and subsequently having reduced aggregate stability. Excluding the samples taken on peat soils and from soil under polyethylene mulch, there was a moderate relationship between the Slakes Index and total carbon concentration ($R^2 = 0.61$). The data indicated there is a threshold at about 2% total soil carbon, below which aggregate stability is reduced.

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The cropped areas had slightly but not significantly higher bulk density compared to uncropped areas. Cropped sites had decreasing Slakes Indexes with increasing bulk density. Therefore, Slakes could indicate compaction effects on aeration and drainage.

Cropped and uncropped areas also showed differences in the number of earthworms present, and there was a good correlation between earthworm number and Slakes Index.

This Project has confirmed the utility of the Slakes method as an indicator of soil health status. It showed the method correlated well with other indicators, such as the MWD method and was better than the VSA method at identifying weak soil structure in cropped areas. The relationships with soil carbon concentration and bulk density are consistent with expectations.

7 Recommendations

1. Promote Slakes to other growers

The growers and agronomists who participated in the project found the Slakes workshops beneficial and said they would use the skills they had learnt. They indicated they perceived Slakes had a place in informing management decisions. One grower planned to add it to their soil monitoring program to identify paddocks that need a break from vegetable production.

Recommendation:

Include presentations about Slakes at events where soil health is discussed

2. Identify laboratories or agronomists that might offer a Slakes testing service

A few growers said they were unlikely to use the Slakes method as it was seen as too time-consuming. They did express interest in a commercial option, such as adding Slakes aggregate stability testing to a basic soil test, depending on the cost. However, they would like to see case studies carried out to compare lab Slakes testing to doing it independently on-farm.

Recommendation:

Ask commercial laboratories if provision of a Slakes test might be offered

3. Propose Slakes as a component of NZGAP-EMS

Slakes is recommended by the Soil Health Institute as one of three key soil health assessments. The findings from this research confirm that Slakes was correlated with other recognised but expensive soil health related indicators. The simplicity and cost effectiveness of the Slakes Index suggest it could be included in the environmental management system add-on parameters of NZGAP.

Recommendation:

Discuss with the GAP EMS managers and advisors possible integration of Slakes.

4. Further research needed

Growers sought more information about the utility of Slakes testing as a tool to guide soil management. The current project could not supply answers to all their questions, but additional trialling should be able to collect the information needed to do so.

a. Compare Slakes results from paddock sampling at different times

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This project collected data in autumn from a relatively small number of selected sites. Freshly cultivated paddocks were generally avoided, although some were in the first month or so of a new crop. As with any soil testing, results may vary depending on time of year or stage in a cropping cycle.

Recommendation:

Select sites to monitor and compare results from repeated Slakes testing across seasons, and before, during, and at the end of each crop, with attention to timing relative to cultivation.

b. Establish relationships with crop productivity or crop failure

In identifying sites for this project, one grower avoided a paddock in which they had experienced two years of crop failure. They had a failure, took the block out of production, had a second crop failure and had taken it out of production again. Currently in restorative grass, they wanted to know if a Slakes test might show when it was “safe” to start cropping again. Despite the grower’s expectations, the paddock had not responded sufficiently to a usual period of restorative grass.

Recommendation:

Select suites of paddocks on the same soil types that have managed for different durations with similar production systems. Compare Slakes Indices with yield and quality parameters and grower identified risks of crop failure.

Test the proposed threshold values suggested by Sparling et al¹⁵ and the results from this research to ask:

- *Is there a Slakes Index threshold beyond which aggregate stability has decreased enough to affect productivity?*
- *Is it a straight line relationship or does productivity drop beyond a certain point?*
- *At what point is it preferable to put a paddock into restoration rather than keep cropping?*
- *How long might it take for a site to recover from different states of aggregate stability?*
- *Is there a “tipping point” past which soil recovery might be slower or more difficult?*

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9 Appendices

9.1 Soil Health Institute Slakes overview

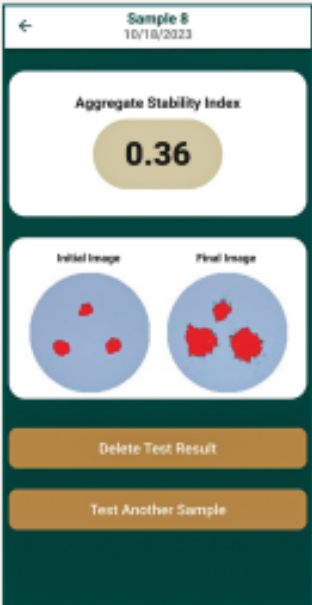


Slakes: A Free Smartphone App to Measure Aggregate Stability

Now Available in Google Play and the App Store.



The Slakes app uses image analysis to measure the ability of dry soil aggregates to resist dispersion once rewetted. Weaker aggregates will slake (or break apart) more easily, while stronger aggregates will slake less, indicating better soil aggregation and healthier soil.



Sample 8
10/18/2023

Aggregate Stability Index
0.36

Initial Image Final Image

Delete Test Result






Test Another Sample

Introduction

Aggregate stability is one of the most common indicators of soil health. Soils with greater aggregate stability are more resistant to wind and water erosion, and are linked to improved water capture, infiltration, and storage. The Soil Health Institute (SHI) recommends measuring aggregate stability using the Slakes app as part of a minimum suite of measurements to assess management induced changes in soil health.

The Slakes app uses a smartphone camera to take a picture of three dry soil aggregates before and after exposing them to water for 10 minutes. The app then automatically calculates an aggregate stability value.

Materials Needed:

Android or iOS Smartphone	3 Soil Aggregates	2 Clear Plastic Dishes	Tap Water	Smartphone Mount
		 (Petri Dishes Recommended)		 (Tripod or 4-6" Can or Jar)

Analyzing Aggregate Stability with the Slakes App

- Collect and Dry Aggregates:** Remove an intact clod from the top 2 inches of the soil, gently break apart into pea-sized aggregates, and dry overnight.
- Set-up:** Mount smart phone approximately 4 - 6 inches above empty clear plastic dish, select 3 aggregates and place in dish. Fill the second dish with water.
- Start Test:** Tap 'Start Aggregate Stability Test' to enter sample ID and capture initial image of dry soil in dish. Move the second dish filled with water into camera view, gently transfer aggregates to the water filled dish, and take pic to start test.
- Complete Test and Receive Results:** After ten minutes, the app will automatically capture the final image and display the aggregate stability index value for the sample.
- Export & Interpret Data:** On the My Results Tab, tap 'Export Test Results'. Upload results to a computer, add management and location data, and track changes in aggregate stability index values.

Figure 1. Screenshot of aggregate stability test results in the Slakes app.

9.2 Site descriptions

Sample Name	Site Name	Crop	Previous crop	Soil texture	Cultivation practices	Irrigated or dryland	Soil moisture condition	Seasonal weather	Seasonal temperature conditions
Pukekohe 1 Broccoli	1 C	Broccoli	Cover crop - vetch, Phacelia, linseed, Persian clover, crimson clover, tic beans, and buck wheat after a lettuce crop	Volcanic Clay Loam	Ripped, jumbo buster x2, rotary hoe x2	Irrigated	Dry	Dry	Warm
Pukekohe 1 Cabbage	1 C	Cabbage	Potatoes after onions	Volcanic Clay Loam	Fallow over winter, then harrowed	Irrigated	Dry	Dry	Warm
Pukekohe 2 Watermelons	2 C	Watermelon	Grass	Silt loam	Disced, Power harrowed in September	Irrigated (tape irrigation)	Moist-Dry	Dry	Warm
Pukekohe 2 Union Uncropped	2 C*	Grass	Cropped last in 2021	Clay loam	No cultivation since 2021	Irrigated	Moist	Dry	Warm
Otane 1 Uncropped	3 U	Grass	Never cropped	Poukawa peat	No cultivation	Irrigated	Moist-Dry	Typical, Dry summer, now rain every week	Warm, cool
Otane 1 Grass in headland	3 C*	Grass	Next to a carrot seed crop	Poukawa peat	No cultivation for 1 season	Irrigated	Moist	Typical, Dry summer, now rain every week	Warm, cool
Manawatu 1 Uncropped	4 U	Grass	Never cropped	Silt loam	No cultivation	Irrigated	Moist	Dry	Warm
Manawatu 1 Celery	4 C	Celery	lettuce after cauliflower	Silt loam	Chisel plough, hoe	Irrigated	Moist-Dry	Dry	Warm

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Manawatu 2 Uncropped	5 U	Grass	Never cropped but drain influence	Silt, clay loam	No cultivation	Irrigated	Mosit	Dry Summer, wetter more recently	Warm
Manawatu 2 Celery	5 C	Celery	Grass after cabbage	Silt, clay loam	2x Chisel plough, x3-4 rotary hoe, x2 power harrow	Irrigated	Dry	Dry Summer, wetter more recently	Warm
Gisborne 1 Uncropped	6 U	Grass	Never cropped	Heavy silt loam	No cultivation	Irrigated	Moist	Multi seasonal, wet and cool from December onwards	Cool
Gisborne 1 Spinach	6 C	Spinach	Squash	Heavy silt loam	hoe, discs	Irrigated	Moist	Multi seasonal, wet and cool from December onwards	Cool
Gisborne 2 Uncropped	7 U	Grass	Never cropped	Silt loam	No cultivation	Dryland	Moist	Multi seasonal, wet and cool from December onwards	Cool
Gisborne 2 New grass after seed maize	7 C	Grass	Seed maize	Silt loam	2x discs, power harrow,	Dryland	Moist	Multi seasonal, wet and cool from December onwards	Cool
Otane 2 Uncropped	8 U	Grass	Never cropped	Hastings silt loam	No cultivation	Irrigated	Moist	Typical, Dry summer, now rain every week	Warm, cool
Otane 2 Carrots	8 C	Carrots	Grass after Squash	Hastings silt loam	Ripped, disced, rotary hoe x2 to make it into beds	Irrigated	Moist	Typical, Dry summer, now rain every week	Warm, cool

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9.3 Raw data

9.3.1 Slakes aggregate stability index

Sample Name	Site Name	Aggregate Stability Index A (0-10 cm)	Aggregate Stability Index B (0-10 cm)	Aggregate Stability Index C (0-10 cm)	Aggregate Stability Index A (10-20 cm)	Aggregate Stability Index B (10-20 cm)	Aggregate Stability Index C (10-20 cm)	Average aggregate stability (0-20 cm)
Pukekohe 1 Broccoli	1 C	0.27	0.27	0.39	0.39	0.69	0.57	0.43
Pukekohe 1 Cabbage	1 C	0.28	0.24	0.33	0.25	0.23	0.3	0.27
Pukekohe 2 Watermelons	2 C	0.69	0.66	0.79	0.39	0.62	0.53	0.61
Pukekohe 2 Union Uncropped	2 C*	0.89	0.94	0.86	0.61	0.77	0.86	0.82
Otane 1 Uncropped	3 U	0.72	0.69	0.78	0.78	0.78	0.75	0.75
Otane 1 Grass in headland	3 C*	1.00	0.85	0.86	0.88	0.98	0.86	0.91
Manawatu 1 Uncropped	4 U	0.96	1.00	0.81	0.74	0.82	0.7	0.84
Manawatu 1 Celery	4 C	0.34	0.53	0.58	0.3	0.35	0.28	0.40
Manawatu 2 Uncropped	5 U	0.8	0.79	0.74	0.95	0.98	0.71	0.83
Manawatu 2 Celery	5 C	0.29	0.35	0.3	0.36	0.38	0.32	0.33
Gisborne 1 Uncropped	6 U	0.9	1.00	0.87	0.68	0.68	0.44	0.76
Gisborne 1 Spinach	6 C	0.32	0.31	0.28	0.3	0.27	0.24	0.29
Gisborne 2 Uncropped	7 U	0.87	0.76	0.94	0.73	0.76	0.76	0.80
Gisborne 2 New grass after seed maize	7 C	0.59	0.38	0.44	0.59	0.59	0.53	0.52
Otane 2 Uncropped	8 U	0.78	0.73	0.78	0.8	0.73	0.79	0.77
Otane 2 Carrots	8 C	0.37	0.4	0.36	0.36	0.51	0.45	0.41

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9.3.2 Landcare Research Manaaki Whenua mean weight diameter aggregate stability

Sample Name	Site Name	Net % aggregates (cumulative) > 2mm (0-20 cm)	Net % aggregates (cumulative) > 1mm (0-20 cm)	Net % aggregates (cumulative) > 0.5mm (0-20 cm)	Mean Weight Diameter Aggregate stability (0-20 cm)
Pukekohe 1 Broccoli	1 C	3	24	57	0.76
Pukekohe 1 Cabbage	1 C	2	16	48	0.64
Pukekohe 2 Watermelons	2 C	26	48	64	1.32
Pukekohe 2 Union Uncropped	2 C*	55	81	90	2.13
Otane 1 Uncropped	3 U	73	87	92	2.46
Otane 1 Grass in headland	3 C*	73	87	92	2.46
Manawatu 1 Uncropped	4 U	66	78	86	2.26
Manawatu 1 Celery	4 C	2	4	7	0.34
Manawatu 2 Uncropped	5 U	39	57	65	1.59
Manawatu 2 Celery	5 C	1	2	7	0.32
Gisborne 1 Uncropped	6 U	33	56	67	1.49
Gisborne 1 Spinach	6 C	0	1	3	0.28
Gisborne 2 Uncropped	7 U	33	49	56	1.39
Gisborne 2 New grass after seed maize	7 C	2	7	11	0.40
Otane 2 Uncropped	8 U	66	81	86	2.27
Otane 2 Carrots	8 C	6	11	27	0.55

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9.3.3 Visual Soil Assessment score

Sample Name	Site Name	Soil Structure	Soil Porosity	Soil Colour	No. + colour of mottles	Earthworm	Tillage Pan	Degree of Clod Development	Soil Erosion	VSA Ranking score
Pukekohe 1 Broccoli	1 C	1.5	0.5	1.0	2.0	0.0	1.0	1.0	2.0	Moderate
Pukekohe 1 Cabbage	1 C	1.5	0.5	1.0	2.0	0.0	1.0	1.0	2.0	Moderate
Pukekohe 2 Watermelons	2 C	2.0	1.5	1.5	2.0	0.0	1.0	1.5	1.5	Moderate
Pukekohe 2 Union Uncropped	2 C*	1.5	2.0	1.5	2.0	2.0	2.0	1.5	2.0	Good
Otane 1 Uncropped	3 U	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	Good
Otane 1 Grass in headland	3 C*	1.8	1.8	1.8	2.0	1.0	2.0	2.0	1.5	Good
Manawatu 1 Uncropped	4 U	2.0	2.0	2.0	2.0	0.0	2.0	2.0	2.0	Good
Manawatu 1 Celery	4 C	2.0	1.5	1.5	1.5	0.0	1.5	1.0	1.0	Moderate
Manawatu 2 Uncropped	5 U	1.5	1.5	2.0	1.8	2.0	1.5	1.0	2.0	Good
Manawatu 2 Celery	5 C	2.0	2.0	2.0	2.0	0.0	2.0	1.0	1.5	Good
Gisborne 1 Uncropped	6 U	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	Good
Gisborne 1 Spinach	6 C	1.5	1.5	1.5	2.0	0.0	1.0	2.0	2.0	Moderate
Gisborne 2 Uncropped	7 U	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	Good
Gisborne 2 New grass after seed maize	7 C	1.0	1.0	1.8	2.0	1.0	1.5	1.0	2.0	Moderate
Otane 2 Uncropped	8 U	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	Good
Otane 2 Carrots	8 C	2.0	1.5	2.0	2.0	0.0	2.0	2.0	2.0	Good

9.3.4 Bulk density

Sample Name	Site Name	Bulk density wet weight (g)	Bulk density dry weight (g)	Bulk density (g/cm ³)
Pukekohe 1 Broccoli	1 C	716.75	572.81	0.99
Pukekohe 1 Cabbage	1 C	757.73	615.03	1.06
Pukekohe 2 Watermelons	2 C	657.97	500.25	0.86
Pukekohe 2 Union Uncropped	2 C*	765.88	509.97	0.88
Otane 1 Uncropped	3 U	639.73	445	0.77
Otane 1 Grass in headland	3 C*	657.37	478.98	0.82
Manawatu 1 Uncropped	4 U	863.2	690.14	1.19
Manawatu 1 Celery	4 C	829.8	688.94	1.19
Manawatu 2 Uncropped	5 U	858.57	623.63	1.07
Manawatu 2 Celery	5 C	742.08	637.01	1.10
Gisborne 1 Uncropped	6 U	815.76	561.1	0.97
Gisborne 1 Spinach	6 C	891.53	722.11	1.24
Gisborne 2 Uncropped	7 U	888.57	603.31	1.04
Gisborne 2 New grass after seed maize	7 C	929.37	742.13	1.28
Otane 2 Uncropped	8 U	861.02	632.38	1.09
Otane 2 Carrots	8 C	775.96	599.67	1.03

9.3.5 Total Carbon percentage

Sample Name	Site Name	HWEC (mg/kg)	Estimated Microbial Biomass Carbon (mg/kg)	Total Carbon (%)
Pukekohe 1 Broccoli	1 C	< 250	< 60	2
Pukekohe 1 Cabbage	1 C	< 250	< 60	1.9
Pukekohe 2 Watermelons	2 C	729	121	5.1
Pukekohe 2 Union Uncropped	2 C*	634	108	3.9
Otane 1 Uncropped	3 U	2,987	414	8
Otane 1 Grass in headland	3 C*	1,115	171	7.6
Manawatu 1 Uncropped	4 U	1,014	158	2.6
Manawatu 1 Celery	4 C	397	78	1.4
Manawatu 2 Uncropped	5 U	718	119	2.6
Manawatu 2 Celery	5 C	414	80	1.9
Gisborne 1 Uncropped	6 U	1,179	179	2.6
Gisborne 1 Spinach	6 C	450	85	1.3
Gisborne 2 Uncropped	7 U	1,332	199	2.3
Gisborne 2 New grass after seed maize	7 C	656	111	1.5
Otane 2 Uncropped	8 U	1,962	281	3.3
Otane 2 Carrots	8 C	736	122	1.9

