

Assessing the Slakes Cell Phone Application against the Eijkelkamp Wet Sieving Method and other Soil Indicators in Western Cape Soils of South Africa

Anélia Marais¹; Annemarie Van Der Merwe¹ and Marieta Van Der Rijst²

¹Directorate Plant Sciences, Western Cape Department of Agriculture, South Africa. ²ARC Biometry, Private Bag X5013, Stellenbosch, 7599, South Africa.

Corresponding author: Anelia.marais1@gmail.com

DOI: <https://doi.org/10.62154/ajasfr.2026.023.01020>

Abstract

Soil has chemical, physical and biological aspects. Aggregate stability is an indicator of erosion susceptibility and is influenced by, amongst others, management practices and climate. The Slakes App measures aggregate stability by measuring the slaking speed of aggregates, providing a stability index. It is an easy and cost-effective way to measure an aspect of soil quality. The aim of this study was to compare the Slakes App with the Eijkelkamp[®] wet sieving aggregate method in three different locations in the Western Cape. Various other tests were simultaneously conducted on the samples. The results showed significant correlation between the two methods for aggregate stability ($r=0.60$, $p < 0.0001$). It showed correlations with other soil health aspects tested, making it a good choice for an indicator that seems to link many soil functions. The results obtained with this free cell phone application correlated well with an acknowledged laboratory-based method; thus, farmers can monitor an essential aspect of soil, knowing that it was validated in African conditions. It is recommended that slakes should not be used in isolation and comparisons should be within the same soil, management practice and season.

Keywords: Aggregates, Eijkelkamp, Microbes, Slakes App, Soil Health.

Introduction

Soil consists of various chemical, physical and biological components, with its numerous dynamic processes underlying life itself on earth (Kibblewhite et al., 2008; Louw et al., 2014). Since ecosystem services such as clean air and water, the cycling of nutrients and habitat for life are all provided by soil, humans need to nurture and preserve soils, since our very life depends upon it (Kibblewhite et al., 2008).

South Africa is a water scarce country (Matchaya et al., 2019) and water is inextricably linked to soil (Kibblewhite et al., 2008). Climate change and soil degradation are real (le Roux & Smith, 2014), ultimately impacting food and water security.

The western parts of South Africa, including the Western Cape Province, are dry and especially prone to erosion when natural vegetation is removed, as happens in most farming enterprises (le Roux & Smith, 2014; Bega, 2021 reporting in *The Green Guardian*). Carrizo et al. (2015) found that aggregate stability was enhanced in soils with permanent

live roots, one of the principles of conservation agriculture (CA). Annual soil loss under grain crops is much more than soil formation and although CA combats this loss to some extent, it was estimated that CA was adopted by only 51% of the commercial farmers in the Western Cape by 2021 (Smith et al., 2022)

Many methods exist to monitor soil degradation. If soil is stable, it will be less prone to erosion (Pati et al., 2016). Soil aggregates are dynamic and ever-changing, consisting of various mineral and organic particles arranged in groups (Six et al., 2000; Howe & Smith, 2021). Aggregate stability is sensitive to climate (Dowdeswell-Downey et al., 2023), land use type, particle size of soil, soil organic carbon and nitrogen (Li et al., 2023) and other factors. Soil aggregates are part of the physical properties of soils, but they play a big role in most of the ecosystem functions (Kibblewhite et al., 2008, Howe & Smith, 2021), thus linking the physical (soil structure), biological (habitat for microbes) and chemical (nutrient cycling) aspects, making it a valuable tool for monitoring soil health. Microbes play a role in the formation and stability of aggregates (Dowdeswell-Downey et al., 2023, Lynch & Bragg, 1985, Moncada et al., 2015). Since soils low in organic matter, as many of the Western Cape's soils are, tend to have fewer stable aggregates, such soils are often more prone to compaction (FAO and ITPS, 2015). The stability of soil aggregates can thus be used as an indicator for soil quality (Moncada et al., 2015, Liu et al., 2019), possibly also giving some insight into the effects of climate change (Dowdeswell-Downey et al., 2023), even if only at a local scale.

Soil testing is often the least prioritised on farms with ever increasing input costs. Thus, the Slakes cell phone application (Fajardo et al., 2016) seems the perfect solution for cash-strapped, but environmentally conscious farmers. In a study to evaluate mobile applications for soils, Sinclair et al. (2024) chose Slakes as one of 32 viable options from a possible 337 alternatives. They found only three applications that met some of their criteria, with Slakes as the number one cell phone application for functionality, having the ability to quantify soil properties automatically from an image.

A review of soil testing services in South Africa revealed limited options for testing soil aggregates for agricultural needs. Soil aggregates come in different shapes and sizes and continuously change from one size to another (Six et al., 2000). They can be classified on size (Zhang et al., 2016) or origin (dos Reis Ferreira et al., 2020). In this study, origin was not taken into consideration, while both methods (Eijkelkamp® as well as Slakes), only measure macro aggregates (> 1 mm) (Six et al., 2000).

Just because a soil test performs adequately in a specific part of the globe, does not automatically make it applicable to the rest of the world with different climates and soils. The aim of this study was to evaluate the capability of the Slakes cell phone application for measuring soil aggregate stability in the Western Cape agricultural soils of South Africa. The first objective was to compare the Slakes application to the Eijkelkamp® wet sieving method for aggregate stability. The second objective was to find possible links between soil aggregates and other soil health indicators (soil moisture, soil particular fractions, % soil

organic carbon, % soil ammonia nitrate, active carbon parts per million (ppm) and microbial activity (ppm)).

Materials and Methods

The Western Cape Province of South Africa mainly experiences a typical Mediterranean climate with hot, dry summers and cool, wet winters in the west and a milder climate in the east receiving rain all year. Three research farms of the Western Cape Department of Agriculture (Western Cape Department of Agriculture research farms, n.d.) were selected as sites for the testing of the Slakes cell phone application. The farms are located far apart with different soil types and farming enterprises and experience different climates.

Outeniqua (33.987630 S, 22.420645 E) is located near George in the Eden district and known for dairy research on planted pastures. The topsoil horizon is dark and rich in organic material, on top of grey-coloured sandy soil with signs of wetness. These soils are acidic by nature and have a low buffering capacity and clay content. The underlying material consists of yellow-red clay with dark reddish brown cutans with signs of mottles (Meldal-Johnson, 2011). Annual precipitation of around 700 mm occurs throughout the year.

Langgewens (33.276981 S, 18.703856 E) is located near Moorreesburg, in the Swartland in one of the most important dryland wheat producing areas in the Western Cape. The predominant soil forms are Oakleaf, Swartland, Glenrosa and Klapmuts. The soils are shallow to medium deep, with limited pedological development and a high coarse fragment. The underlying parent material is comprised of Malmesbury and Bokkeveld shales. The clay content varies between 15 and 35% (Soil Classification Workgroup, 1991). The soil has good lateral drainage, but weak vertical drainage (Wiese et al., 2015). Average precipitation is under 400 mm per year, of which about 80% occurs during April to September.

Tygerhoek (34.150364 S, 19.904785 E) is located near Riviersonderend, in the Rûens area. It is in a mixed farming area with annual precipitation of around 445 mm occurring throughout the year. The soils are shallow, shale-derived with a loamy texture and a high concentration of coarse fragments (Smith, 2014). Glenrosa soil form (Orthic A – Lithocutanic B) is the dominant soil form, while Oakleaf soil form (Orthic A – Neocutanic B unconsolidated material without signs of wetness), also occurs. The A-horizon is bleached with a clay content ranging between 15 and 25%. The parent material, from the Ceres sub-group, consists of mud-rock, shale, siltstone and sedimentary rock (Smith, 2014).

Five plots under different management practices were identified on each farm. The control, “veld”, was as natural and undisturbed by agriculture as could be found on each farm (Table 1).

Table 1: Description of the different management practices as well as the percentage organic carbon (C), ammonium nitrogen (N) and particle size ratio (Part = sand: silt: clay) of the five plots per farm as used in this study. KAN = potassium ammonium nitrate; NPK = nitrogen/phosphorous/potassium.

OUTENIQUA 33.987630 S, 22.420645 E Veld – undisturbed, natural area, some alien plants sometimes utilised by cattle and naturally occurring wildlife. Sand: silt: clay 69:14:17 % C = 3.73; %N = 0.23 MW – manure water Kikuyu pasture, grazed by cattle, irrigated with dairy waste mixed with river water. KAN after every grazing event. Sand: silt: clay 69:17:14 % C = 2.97; %N = 0.34 M – mixed pasture Chicory/red clover/tall fescue/plantain/lucerne. Irrigated and fertilised when required. Sand: silt: clay 71:16:13 % C = 2.3; %N = 0.23 DL = dryland Fescue/ryegrass/clover mixture. No irrigation, no agrochemicals. Sand: silt: clay 65:17:18 % C = 2.68; %N = 0.25 GC – grazing camp Irrigated kikuyu/ryegrass mixture. KAN and pesticides when required. Sand: silt: clay 71:16:13 % C = 2.68; %N = 0.29	TYGERHOEK 34.150364 S, 19.904785 E Veld – undisturbed, natural area, some alien plants sometimes utilised by cattle and naturally occurring wildlife. Sand: silt: clay 81:5:14 % C = 2.09; %N = 0.08 WWWW – wheat monoculture Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime when required. Sand: silt: clay 48:23:29 % C = 1.84; %N = 0.23 WMWM – wheat/medic pasture rotation Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime when required. Sand: silt: clay 45:21:34 % C = 1.7; %N = 0.21 WCWL –wheat/canola/wheat/ lupine rotation Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime. when required. Sand: silt: clay 45:25:30 % C = 1.6; %N = 0.21 WLWC – wheat/lupine/wheat/ canola rotation Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime when required. Sand: silt: clay 45:23:32 % C = 1.55; %N = 0.2	LANGGEWENS 33.276981 S, 18.703856 E Veld – undisturbed, natural area, some alien plants sometimes utilised by cattle and naturally occurring wildlife. Sand: silt: clay 69:12:19 % C = 1.3; %N = 0.11 WWWW – wheat monoculture Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime when required. Sand: silt: clay 64:14:22 % C = 1.19; %N = 0.1 WMWM – wheat/medic pasture rotation Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime when required. Sand: silt: clay 63:15:22 % C = 0.86; %N = 0.14 WCWL –wheat/canola/wheat/ lupine rotation Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime when required. Sand: silt: clay 64:13:23 % C = 1.2; %N = 0.09 WLWC – wheat/lupine/wheat/ canola rotation Reduced tillage last 16 years. Pesticides, NPK fertiliser and lime when required. Sand: silt: clay 59:17:24 % C = 0.82; %N = 0.11
---	---	--

The initial study was conducted in the rainy season of 2023. This however proved to be impractical, since the values from the same plots varied widely. Soil moisture decreases aggregation in sandy loam soils (Dowdeswell-Downey, et al. 2023). Liu et al., (2024) later reported that increased incidences of dry-wet cycles stimulated the breakdown of macroaggregates, which was possibly the reason why we had difficulties in the wet season. Since the focus of the study was the Slakes app, and not the formation of aggregates, it was decided to conduct the study in the dry season of the Western Cape (January of 2024). Three sites (replicates) were selected at each plot (management practice) on each of the farms. At each site, five randomly selected soil samples (each 40 mm diameter and 100 mm

deep) were collected, bulked and mixed to provide one sample for each site (experimental unit) for all analyses. A portion of each sample was stored in a fridge at 4 °C until analyses (FDA and moisture), while the rest was air-dried for all other analyses.

The Slakes cell phone application was downloaded onto a Huawei Nova Y71 smartphone (Huawei Technologies Co., Ltd., China), with a 48 MP rear camera. All procedures were carried out in accordance with the detailed instructions available on the application.

Three soil aggregates (2 - 10 mm in diameter) were selected from each sample. Similarly sized and shaped aggregates were chosen per sample, as instructed in the protocol. A retort stand with clamp was used to suspend the smartphone to a height that allowed a 90 mm diameter Petri dish to encompass the entire viewing frame of the phone. The dish was placed on the white base of the retort stand to provide the necessary sharp contrast between the aggregates and the background. Lighting included the laboratory's overhead fluorescent lights as well as natural light from the window. The three chosen aggregates were placed inside an empty Petri dish, and a reference image was captured. Tap water was slowly added to the Petri dish with a 20 ml syringe, care being taken to not move the aggregates. The protocol suggested moving the aggregates to another Petri dish filled with water, but this often caused aggregates to disintegrate when handled, thus it was decided to deviate slightly from the suggested protocol. The 10-minute imaging period was initialised by pressing the "start" button on the Slakes application. After 10 minutes, the stability index (between 0 and 1) was displayed on the cell phone. This was replicated three times for each sample, using three sets of aggregates, and the average was used in the statistical analyses. If a result seemed to be an outlier (stability index >1), it was repeated, since small rock fragments covered in silt in many samples, were easily confused with aggregates.

Wet aggregate stability (%) was determined following the procedure obtained from the website (www.royaleijkelkamp.com) of the machine's manufacturers. Four grams of previously air-dried and sieved (between 1 - 2 mm diameter) soil samples were placed in an Eijkelpkamp® wet soil sieving machine and moistened before being moved up and down by ways of the apparatus, first in distilled water, which washed out the unstable aggregates, then in a NaOH solution (2 g in 1000 ml), which washed out the stable aggregates. These soil solutions were then dried in an oven at 100°C for 24 hours after which the mass was determined. The percentage of stable aggregates was determined using the specified formula. This was duplicated for each soil sample, while the averages were used in the statistical analyses.

Adam and Duncan (2001) proposed the spectrophotometric determination of the hydrolysis of fluorescein diacetate (FDA) as a quick and sensitive method for the estimation of total microbial activity in soil by measuring three enzyme classes (lipases, esterases, and proteases) which occur abundantly in soil (Patle et al., 2018; Daunoras et al., 2024) and are actively involved in the microbial conversion of substrates. The procedure was done in triplicate for each sample, providing the averages that were used in the statistical analyses. Active carbon (ActC) is the fraction of carbon that represents the microbial metabolites (Culman et al., 2012). A modified procedure of the KMnO_4 oxidation method (Marais et al.,

2020) was followed and was duplicated for each soil sample. The averages were used in the statistical analyses.

Soil moisture was determined gravimetrically and expressed as mass of water per mass of dry soil. Soil particular fractions (hydrometer method), % soil organic carbon (Walkley Black method) and % soil ammonia nitrate (Kjeldahl method) was determined according to standard protocols (The Non-affiliated Soil Analyses Work Committee, 1990).

Statistical Analyses

Variables (observed soil characteristics) were subjected to one-way ANOVA to test for sample effects (management practice on each farm), using the GLM (General Linear Models) Procedure of SAS software (Version 9.4; SAS Institute Inc., Cary, NC, USA). Fisher's least significant difference was calculated at the 5% level to compare treatment means (Ott, 1998). A probability level of 5% was considered significant for all significance tests. Correlations between variables were established using Pearson correlation coefficients. Principal component analysis (PCA), employing the correlation matrix, was performed on sample means to clarify the association amongst samples and variables. To verify groupings observed on the PCA plot, PCA factor scores were subjected to agglomerative hierarchical clustering (AHC – results not shown) using Ward's method of linkage. Multivariate techniques were conducted using XLStat (Version 2024; XLSTAT statistical and data analysis solution; Lumivero) <https://www.xlstat.com/en>.

Results and Discussion

Aggregate stability

The instructions on the Slakes cell phone application were clear. It was sometimes difficult to find aggregates around 2-10 mm in size, since all three farms have soils with high sand and low to moderate organic carbon content (Table 1) (Zhang et al., 2016). The overall dryness of the soils could also have played a role, since aggregate formation is influenced by season (dos Reis Ferreira, 2020; Xiao et al., 2021). Many "aggregates" turned out to be rock fragments covered in silt. This only became clear once the 10-minute time-lapse on the Slakes cell phone application was concluded, often leading to outlier results (index >1). It seems plausible that small rock fragments played a role in the formation of larger aggregates in these soils, but most published research on soil aggregates focusses on clay and organic matter as drivers of aggregation [Pati et al., 2016; Zhang et al., 2016; Chan et al., 1994]. Though this is only a theory at this stage, it is quite possible, since rock fragments or pebbles are not inert and have been proven to play an active role in the water cycle (Tetegan et al., 2015) as well as other ecosystem services such as nutrient cycling and habitat for microbial life (Dittrich et al., 2024). These authors concluded that rock fragments provided a stable habitat for microbes, especially fungi which often act as the glue that holds aggregates stable.

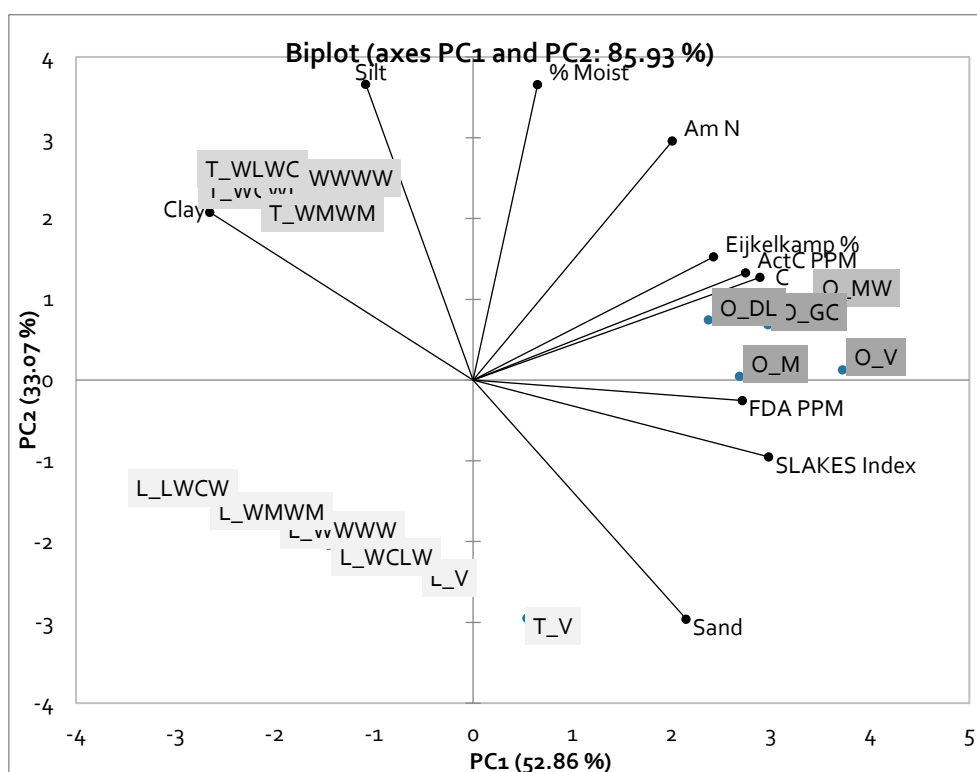


Figure 1: Principal component analysis (PCA) biplot showing the relationship between the soil variables measured on the three farms. PC1 separated Outeniqua from the other farms, while PC2 separated Langgewens and the veld samples (TV) from Tygerhoek (refer to Table 1 for explanation of abbreviations).

Agglomerative hierarchical clustering (AHC – results not shown) on PC1 and PC2 factor scores confirmed that three clusters can be distinguished, indicated on the PCA bi-plot in different shades of grey (Figure 1). Outeniqua separated from the other two farms on PC1. This separation was driven by the Outeniqua soils' positive association with organic (C) as well as active carbon (ActC), microbial activity (FDA), Slakes index and Eijkelkamp % values. Tygerhoek samples were separated by PC2 from Langgewens based on the Tygerhoek soils' positive association with moisture %, silt and clay and negative association with sand. The Tygerhoek veld samples (TV₁₋₃) were the exception. These samples were taken on the other side of the farm from where the pastures were located, that has a different soil type (Table Mountain sandstone vs Bokkeveld shale). It was, however, the only site which could be found on Tygerhoek that was not subjected to cultivation of any kind. These samples associated positively with % sand and negatively with silt on the PCA (Figure 1). Associations of samples with soil characteristics as observed on the PCA are confirmed by the comparison of means in Table 2.

Table 2: Table of means for the five plots under different management practices on each farm. Values in columns followed by the same letter do not differ significantly ($p < 0.05$) according to Fisher's least significant difference test. %C = percent organic carbon; %Am N = percent ammonium nitrogen; ActC ppm = active carbon parts per million; FDA ppm = microbial activity parts per million; % Moist = percent soil moisture (refer to Table 1 for explanation of the sample abbreviations).

PLOT	C	Sand	Silt	Clay	Am N	ActC PPM	FDA PPM	% Moist	SLAKES %	Eijkelkamp %
O_MW	2.97 a	69 bc	17 b	14 gh	0.34 a	799 a	90 b	7.46 cde	83 abcd	86 ab
O_GC	2.68 bc	71 b	16 bc	13 h	0.29 b	691 a	81 bc	9.67 ab	84 ab	89 a
O_V	3.73 a	69 bc	14 bc	17 fgh	0.23 cd	695 a	128 a	5.99 ef	84 ab	94 a
O_M	2.30 cd	71 b	16 bc	13 h	0.23 cd	662 a	90 b	8.07 bcde	86 a	93 a
O_DL	2.68 bc	66 bcd	17 b	18 efgh	0.25 bc	781 a	90 b	7.3 de	71 cde	86 ab
T_WWWW	1.84 ef	48 e	23 a	28 bc	0.23 cd	434 b	51 defg	9.39 abcd	35 hi	82 abc
T_WMWM	1.71 ef	45 e	21 a	34 a	0.21 cd	407 b	34 g	9.78 ab	46 gh	66 de
T_WCWL	1.60 fg	45 e	25 a	30 ab	0.21 cd	442 b	36 g	9.46 abc	45 gh	68 cde
T_WLWC	1.55 fg	45 e	23 a	32 ab	0.20 d	423 b	40 efg	10.66 a	37 hi	75 bcd
T_V	2.09 de	81 a	5 d	14 gh	0.08 f	337 b	36 g	5.01 f	71 cde	83 ab
L_WWWW	1.19 ghi	64 bcd	14 bc	22 de	0.10 ef	451 b	60 cdef	1.25 g	57 fg	54 ef
L_WMWM	0.86 hi	63 cd	15 bc	22 de	0.14 e	440 b	62 cde	2.42 g	40 hi	27 g
L_WCLW	1.20 ghi	64 bcd	13 bc	22 de	0.09 ef	399 b	52 defg	1.08 g	61 ef	47 f
L_LWCW	0.82 i	59 d	17 b	24 cd	0.11 ef	374 b	52 defg	2.77 g	32 i	25 g
L_V	1.27 gh	69 bc	12 c	19 efg	0.11 ef	329 b	73 bcd	0.67 g	72 bcde	74 bcd
LSD (P=0.05)	0.44	8	4	5	0.05	163	24	2.15	13	14
Pr > F(Model)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

When all three the farms and all the variables were analysed together (Table 3), there were many significant correlations evident. The two tested methods, namely the Slakes cell phone application and Eijkelkamp® wet sieving apparatus, correlated significantly and positively with each other ($r=0.60$, $p < 0.0001$) in the tested soils, fulfilling the first objective of this study.

Table 3: Correlation matrix (Pearson) when all variables were analysed for the soils from all three farms. Numbers in bold depict significant p -values ($p < 0.05$). %C = percent organic carbon; %Am N = percent ammonium nitrogen; ActC ppm = active carbon parts per million; FDA ppm = microbial activity parts per million; % Moist = percent soil moisture.

VARIABLES	% C	% Sand	% Silt	% Clay	% Am N	ActC ppm	FDA ppm	% Moist	SLAKES index	Eijkelkamp %
% C	1	0.317	-0.054	-0.468	0.707	0.784	0.654	0.453	0.695	0.759
% Sand		1	-0.892	-0.942	-0.104	0.254	0.474	-0.450	0.689	0.221
% Silt			1	0.689	0.431	0.078	-0.194	0.617	-0.459	-0.003
% Clay				1	-0.153	-0.465	-0.616	0.265	-0.764	-0.352
% Am N					1	0.788	0.444	0.683	0.360	0.562
ActC ppm						1	0.665	0.301	0.591	0.466
FDA ppm							1	-0.056	0.641	0.372
% Moist								1	-0.003	0.540
SLAKES index									1	0.603
Eijkelkamp %										1

Most other variables tested correlated significantly between the two aggregate stability tests. The exceptions were silt that did not correlate significantly with Eijkelkamp®, while percentage moisture did not significantly correlate with Slakes (Table 3). From these results it seems that aggregate stability is indeed a link between many soil aspects (Kibblewhite et al., 2008) and that the Slakes cell phone application can be a useful tool in monitoring an aspect of soil health, thus fulfilling the second objective of this study.

The farms were also analysed separately, since the climate and soils are quite different (Table 1). At Outeniqua (Table 4) and Langgewens (Table 5), the two methods tested for aggregate stability were significantly and positively correlated ($r=0.56$, $p=0.031$ and $r=0.66$, $p=0.008$ respectively), seeming to indicate that the two methods deliver comparable results, while for Tygerhoek the correlation between the two aggregate stability tests was not significant ($r=0.28$, $p=0.31$; Table 6). It is suspected that the three veld samples at Tygerhoek (TV1-3) could have been the samples driving this unexpected result. These were strongly associated with % sand and high sand content is not generally associated with stable aggregates (Dittrich et al., 2024; Borůvka et al., 2002; Han et al., 2007; Kodešová et al., 2009; Adetsu et al., 2024).

Table 4: Correlation matrix (Pearson) when all variables were analysed for Outeniqua soils. Numbers in bold depict significant p -values ($p < 0.05$). % C = percent organic carbon; % Am N = percent ammonium nitrogen; ActC ppm = active carbon parts per million; FDA ppm = microbial activity parts per million; % Moist = percent soil moisture.

VARIABLES	% C	% Sand	% Silt	% Clay	% Am N	% ActC ppm	FDA ppm	% Moist	SLAKES index	Eijkelkamp %
% C	1	0.064	-0.582	0.323	0.172	0.391	0.550	-0.376	0.293	0.325
% Sand		1	-0.361	-0.782	0.082	-0.087	-0.017	0.370	0.705	0.541
% Silt			1	-0.299	0.289	0.168	-0.237	0.147	-0.257	-0.497
% Clay				1	-0.277	-0.024	0.176	-0.477	-0.550	-0.221
% Am N					1	0.586	-0.176	0.225	0.119	-0.288
% ActC ppm						1	0.023	-0.281	0.194	-0.038
FDA ppm							1	-0.396	0.130	0.506
% Moist								1	0.110	-0.223
SLAKES index									1	0.557
Eijkelkamp %										1

This study found a positive correlation between both methods for aggregate stability and organic carbon at Langgewens (Table 5), while Marais and Booyse (2024) found a significant negative correlation ($p = 0.024$) between organic carbon and aggregate stability (Eijkelkamp® method) at Langgewens (four of the five sites were the same in both studies). The two studies were however conducted in different seasons, possibly explaining the differences in the results of the two studies (Li et al., 2023). Eijkelkamp® aggregates were influenced by organic carbon and percentage moisture. Though both methods tested macroaggregates, the Eijkelkamp® method measures aggregate between 1 and 2 mm, while Slakes uses aggregates larger than 2 mm. This may be the explanation for the differences in results between the two methods.

Percentage moisture was correlated negatively with both methods at Langgewens and Tygerhoek, but not at Outeniqua, yet again highlighting the differences between the sites. These results were similar to those of Dowdeswell-Downey et al. (2023). These researchers found significant negative correlations between soil aggregates and soil moisture in sandy loam soils, while the correlation in clay soils were positive (not significant).

Table 5: Correlation matrix (Pearson) when all variables were analysed for Langgewens soils. Numbers in bold depict significant values ($p < 0.05$). %C = percent organic carbon; %Am N = percent ammonium nitrogen; ActC ppm = active carbon parts per million; FDA ppm = microbial activity parts per million; % Moist = percent soil moisture.

VARIABLES	% C	% Sand	% Silt	% Clay	% Am N	ActC ppm	FDA ppm	% Moist	SLAKES index	Eijkelkamp %
% C	1	0.547	-0.422	-0.547	-0.265	0.132	0.321	-0.680	0.591	0.543
% Sand		1	-0.880	-0.900	0.029	-0.267	0.361	-0.821	0.825	0.720
% Silt			1	0.586	0.000	0.146	-0.041	0.803	-0.729	-0.667
% Clay				1	-0.049	0.321	-0.580	0.666	-0.740	-0.618
% Am N					1	0.253	0.358	0.267	-0.231	-0.400
ActC ppm						1	-0.101	0.265	-0.297	-0.442
FDA ppm							1	-0.269	0.373	0.142
% Moist								1	-0.909	-0.755
SLAKES index									1	0.657
Eijkelkamp %										1

At Tygerhoek, the negative correlation with moisture was only significant in the case of the Slakes method. Moisture can have an indirect effect on aggregates, since it influences vegetation growth and soil organic carbon (Li et al., 2023) possibly explaining the differences at the three farms.

Table 6: Correlation matrix (Pearson) when all variables were analysed for Tygerhoek soils. Numbers in bold depict significant values ($p < 0.05$). %C = percent organic carbon; %Am N = percent ammonium nitrogen; ActC ppm = active carbon parts per million; FDA ppm = microbial activity parts per million; % Moist = percent soil moisture.

VARIABLES	% C	% Sand	% Silt	% Clay	% Am N	ActC ppm	FDA ppm	% Moist	SLAKES index	Eijkelkamp %
% C	1	0.477	-0.463	-0.466	-0.420	0.113	0.156	-0.393	0.622	0.335
% Sand		1	-0.973	-0.972	-0.893	-0.567	0.016	-0.905	0.731	0.421
% Silt			1	0.892	0.910	0.593	0.018	0.878	-0.790	-0.382
% Clay				1	0.826	0.510	-0.050	0.882	-0.631	-0.437
% Am N					1	0.662	0.304	0.789	-0.816	-0.369
ActC ppm						1	0.296	0.435	-0.401	-0.434
FDA ppm							1	-0.024	-0.318	0.225
% Moist								1	-0.670	-0.282
SLAKES index									1	0.281
Eijkelkamp %										1

Soil Particle Size

At all the farms, whether analysed together (Figure 1, Table 3), or separately (Tables 4 - 6), sand correlated positively with both tested aggregate stability methods, while % silt and clay were mostly negatively correlated. This was unexpected, since high sand content in soil is usually negatively correlated with aggregate stability, while clay and silt are positively correlated with stable aggregates (Dittrich et al., 2024; Borůvka et al., 2002; Han et al., 2007; Kodešová et al., 2009; Adetsu et al., 2024). However, Borůvka et al. (2002) found that the different sizes of silt and sand had different effects on aggregate stability, as had the speed of wetting of the aggregates. This may explain the results, but these aspects were not investigated in the current study. Specific types of organic matter as well as clay mineralogy, both quite possibly different at the different farms, but neither tested in this study, could also have influenced the results (Fernández-Ugalde et al., 2013).

Sand correlated negatively with soil moisture at all the sites, except Outeniqua (Table 4), where it had a non-significant positive trend. Sand correlated positively with organic carbon at all the sites, but it was only significant in the combined analyses (Table 3) and at Langgewens (Table 5). When all the farms were analysed together (Table 3), sand was significantly and positively correlated with microbial activity ($p = 0.001$), though this significance was not apparent at the individual farms (Tables 4 - 6).

Percentage silt correlated positively with clay at all sites (Tables 3, 5 and 6) except Outeniqua, where it had a negative trend (Table 4). Silt also correlated positively with ammonium nitrogen (Tables 3 - 6), though this was not significant at Outeniqua and Langgewens. Silt and soil moisture correlated positively, but this was not significant at Outeniqua. Silt and organic carbon correlated negatively, but it was only significant at Outeniqua (Table 5; $p = 0.023$). Silt correlated positively with active carbon, but it was only significant at Tygerhoek (Table 6; $p = 0.020$). The different trends at the different sites could probably be explained by the differences in the soils and local climate of the different farms (Table 1).

When all the farms were analysed together (Table 3), the clay was negatively correlated with microbial activity ($p < 0.0001$) as well as with both organic and active carbon ($p = 0.001$). Although this was unexpected, Poeplau et al. (2024) also reported negative correlation trends between organic carbon and clay in their study in Germany. The possible explanation given by these authors, was the neutral to low pH of their soils, which is also the case in the Western Cape soils (Liebenberg et al., 2020). In another South African study, Mbanjwa et al. (2022) also reported that soil organic carbon correlated negatively with clay and positively with sand. These authors speculated that the type of clay in the soil could play a role, as was also reported by Fernández-Ugalde et al. (2013). Since it is impossible to measure all the possible variables in soil, one can but speculate. The analyses of the individual farms resulted in quite different trends, with clay correlating significantly and negatively with organic carbon and microbial activity only at Langgewens (Table 5).

Other Variables

Many of the variables tested correlated significantly amongst each other when all the farms and all the variables were analysed together (Table 3). Organic carbon correlated positively with microbial activity ($p = 0.034$). Marais and Booyse (2024) also found significant positive correlation between %C and microbial activity as tested at Langgewens (4 of the 5 sites were the same in both studies), as well as on another farm in the Western Cape. Organic carbon also correlated positively with ammonium nitrogen ($p < 0.0001$), active carbon ($p < 0.0001$), microbial activity ($p < 0.0001$) as well as percentage soil moisture ($p = 0.002$). All these variables are closely related with the biological fraction of the soil (Chen et al., 2003; Bertini & Azevedo, 2022; Geng et al., 2023), so this was expected.

At Outeniqua (Table 4), active carbon and ammonium nitrogen were positively correlated ($p = 0.022$), as was also found by Marais and Booyse (2024). At Outeniqua, the organic carbon (highest in this study), was correlated significantly and positively with microbial activity (Table 4). Nitrogen and carbon are both closely associated with microbial activity, since microbes are vital for the cycling of these elements (Chen et al., 2003). Geng et al. (2023) also reported that these two elements were linked in nutrient cycling.

At Langgewens, organic carbon was negatively correlated with soil moisture (Table 5). It is interesting to note that Kerr and Ochsner (2020) found that soil moisture was the best predictor of soil organic carbon. Maybe that is why, at Langgewens, the farm with the lowest organic carbon (Table 1), as well as the lowest rainfall of the three farms studied, this correlation was negative.

Also noteworthy, was that none of the tested variables correlated significantly with the Eijkelkamp® method for aggregate stability at Tygerhoek (Table 6). There were, however, many significant correlations with the Slakes application (positively with sand and organic carbon; negatively with silt, clay, ammonium nitrogen as well as soil moisture). It may be that the three veld samples (TV1-3), with the highest sand content in this study, could be the reason for this unexpected result. Dowdeswell-Downey et al. (2023) reported significant differences in different soils regarding microbial influence on soil aggregation, possibly providing an explanation for the differences found in this study between the three farms. Aggregates are known to be very unstable in sandy soils, since these soils often have a low carbon content and low microbial activity (Han et al., 2007; Zhang et al., 2016). The mechanical action of the Eijkelkamp machine possibly had a disruptive effect on these fragile sandy aggregates, while the slaking of the Slakes method was less disruptive.

Conclusions

The Slakes cell phone application showed potential in measuring the stability of soil macro aggregates in three different soil types in the Western Cape, when compared to the Eijkelkamp® method. The two methods correlated significantly at two of the three sites, highlighting the differences in the sites. It is recommended that the Slakes aggregate stability – or any other soil health measurement - should not be used in isolation. Aggregate stability (both methods tested), correlated with many different aspects of soil and seems to

be a link between the physical (soil particles), chemical (ammonium nitrogen and organic carbon) and biological (microbial activity and active carbon) as measured in this study. It is recommended that the results should be compared within sites, within season, within management practice and within land use type, since all these can influence the aggregate stability of a soil. In light of the results from the veld samples in Tygerhoek, the results in sandy soils, should be interpreted with caution. Measuring aggregate stability with the Slakes application seems to be an easy and cost-effective way of monitoring some aspects of soil health, but it should not take the place of proper laboratory-bound soil tests.

Conflicts of interest

The authors declare no conflicts of interest. All authors have read and agreed with this document and the statements it contains.

Acknowledgements

The authors would like to thank the Department of Agriculture, Western Cape for the financial support in this study.

The authors declare that artificial intelligence was not used in writing this manuscript.

References

- Adam, G. & Duncan, H. (2001). Development of a sensitive and rapid method for the measurement of total microbial activity using fluorescein diacetate (FDA) in a range of soils. *Soil Biology and Biochemistry*, 33:943-951. [https://doi.org/10.1016/S0038-0717\(00\)00244-3](https://doi.org/10.1016/S0038-0717(00)00244-3)
- Adetsu, D.V., Arthur, E., Fu, Y., Cornelis, W. & Lamandé, M. (2024). Exploratory assessment of the SLAKES method to characterize aggregate stability across diverse soil types. *Soil Science Society American Journal*, 88(4):1086-1099. <https://doi.org/10.1002/saj2.20674>
- Bega, S. (2021, June 26). Southern Africa's 'water tower' slipping towards ecosystem collapse. *The Green Guardian*. <https://mg.co.za/the-green-guardian/2021-06-26-southern-africas-water-tower-slipping-towards-ecosystem-collapse/>
- Bertini, S.C.B. & Azevedo, L.C.B. (2022). Chapter 3 - Soil microbe contributions in the regulation of the global carbon cycle. In A. Kumar, J. Singh, L. Fernando & R. Ferreira (Eds.), *Microbiome Under Changing Climate*. (pp 69-84). Woodhead Publishing. <https://doi.org/10.1016/B978-0-323-90571-8.00003-1>
- Borůvka, L., Valla, M., Donátová, H. & Nimeček, K. (2002). Vulnerability of soil aggregates in relation to soil properties. *Rostlinná Výroba*, (48)8:329-334. <http://doi.org/10.17221/4376-PSE>
- Carrizo, M.E., Alesso, C.A., Cosentino, D. & Imhoff, S. (2015). Aggregation agents and structural stability in soils with different texture and organic carbon content. *Scientia Agricola*, 72:75-82. <http://dx.doi.org/10.1590/0103-9016-2014-0026>
- Chan, K.Y., Heenan, D.P. & Ashley, R. (1994). Seasonal changes in surface aggregate stability under different tillage and crops. *Soil and Tillage Research*, 28(3-4):301-314. [https://doi.org/10.1016/0167-1987\(94\)90137-6](https://doi.org/10.1016/0167-1987(94)90137-6)
- Chen, G., Zhu, H., & Zhang, Y. (2003). Soil microbial activities and carbon and nitrogen fixation. *Research in Microbiology*, 154:393-398. [https://doi.org/10.1016/S0923-2508\(03\)00082-2](https://doi.org/10.1016/S0923-2508(03)00082-2)
- Culman, S.W., Hurisso, T. & Wade, J. (2012). Permanganate oxidizable carbon: An indicator of biologically-active soil carbon. In D.L. Karlen, D.E. Stott, M.M. Mikha, (Eds.), *Soil health series: laboratory methods for soil health analysis*;(2):152-157. ASA, CSSA, and SSSA. <https://doi.org/10.1002/9780891189831.ch9>

- Daunoras, J., Kačergius, A. & Gudiukaitė, R. (2024). Role of soil microbiota enzymes in soil health and activity changes depending on climate change and the type of soil ecosystem. *Biology*, 13(2):85. <https://doi.org/10.3390/biology13020085>
- Dittrich, F., Klaes, B., Brandt, L., Groschopf, N. & Thiele-Bruhn, S. (2024). The stonesphere in agricultural soils: A microhabitat associated with rock fragments bridging rock and soil. *European Journal of Soil Science*, 76(2). <https://doi.org/10.1111/ejss.70025>
- dos Reis Ferreira, C., da Silva Neto, E.C., Pereira, M.G., do Nascimento Guedes, J., Rosset, J.S. & dos Anjos, L.H.C. (2020). Dynamics of soil aggregation and organic carbon fractions over 23 years of no-till management. *Soil Tillage Research*, 198:104533. <https://doi.org/10.1016/j.still.2019.104533>
- Dowdeswell-Downey, E., Grabowski, R.C. & Rickson, R.J. (2023). Do temperature and moisture conditions impact soil microbiology and aggregate stability? *Journal of Soils and Sediments*, 23:3706–3719. <https://doi.org/10.1007/s11368-023-03628-2>
- Fajardo, M., McBratney, A.B., Field, D.J., & Minasny, B. (2016). Soil slaking assessment using image recognition. *Soil and Tillage Research*, 163:119–129. <https://doi.org/10.1016/j.still.2016.05.018>
- FAO and ITPS. (2015). Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy. <https://openknowledge.fao.org/handle/20.500.14283/i5199e>
- Fernández-Ugalde, O., Barré, P., Hubert, F., Virto, I., Girardin, C., Ferrage, E., Caner, L. & Chenu, C. (2013). Clay mineralogy differs qualitatively in aggregate-size classes: clay-mineral-based evidence for aggregate hierarchy in temperate soils. *European Journal of Soil Science*, 64(4):410–422. <https://www.bing.com/search?q=%20https%3A%2F%2Fdoi.org%2F10.1111%2Fejss.12046&form=IPRV10>
- Geng, Y., Ding, Y., Zhou, P., Wang, Z., Peng, C. & Li, D. (2023). Soil microbe-mediated carbon and nitrogen cycling during primary succession of biological soil crusts in tailings ponds. *Science of the Total Environment*, 894:164969. <https://doi.org/10.1016/j.scitotenv.2023.164969>
- Han, K.-H., Cho, H.-J., Lee, H.S., Oh, D.S. & Kim, L.Y. (2007) Stable macro-aggregate in wet sieving and soil properties. *Korean Journal of Soil Science and Fertility*, 40(4):255–261.
- Howe, J.A. & Smith, A.P. (2021). Chapter 2 - The soil habitat. In T.J. Gentry, J.J. Fuhrmann & D.A. Zuberer. (Eds.), *Principles and Applications of Soil Microbiology* (3rd edn). (pp. 23–55) Elsevier. <https://doi.org/10.1016/B978-0-12-820202-9.00002-2>
- Kerr, D.D. & Ochsner, T.E. 2020. Soil organic carbon more strongly related to soil moisture than soil temperature in temperate grasslands. *Soil Science Society of America Journal*, 84(2):587–596. <https://doi.org/10.1002/saj2.20018>
- Kibblewhite, M.G., Ritz, K. & Swift, M.J. (2008). Soil health in agricultural systems. *Philosophical Transactions of the Royal Society London B Biological Sciences*, 363: 685–701. <https://doi.org/10.1098/rstb.2007.2178>
- Kodešová, R., Rohošková, M. & Žigová, A. (2009). Comparison of aggregate stability within six soil profiles under conventional tillage using various laboratory tests. *Biologia*, 64(3):550–554. <https://doi.org/10.2478/s11756-009-0095-6>
- le Roux, J.J. & Smith, H.J. (2014, November). Soil erosion in South Africa – its nature and distribution. *Grain SA*. <http://www.grainsa.co.za>
- Li, H., Chang, L., Wei, Y. & Li, Y. (2023). Interacting Effects of Land Use Type, Soil Attributes, and Environmental Factors on Aggregate Stability. *Land*, 12(7): 1286. <https://doi.org/10.3390/land12071286>
- Liebenberg, A., van der Nest, J. R., Hardie, A. G., Labuschagne, J., & Swanepoel, P. A. (2020). Extent of Soil Acidity in No-Tillage Systems in the Western Cape Province of South Africa. *Land*, 9(10), 361. <https://doi.org/10.3390/land9100361>

- Liu, M.; Han, G. & Zhang, Q. (2019). Effects of soil aggregate stability on soil organic carbon and nitrogen under land use change in an erodible region in Southwest China. *International Journal of Environmental Research and Public Health*, 16(20): 3809. <https://doi.org/10.3390/ijerph16203809>
- Liu, S. Huang, X.J. Gan, L. Zhang, Z.B., Dong, Y., & Peng, X.H. (2024). Drying-wetting cycles affect soil structure by impacting soil aggregate transformations and soil organic carbon fractions, *Catena*, 243, 108188 <https://doi.org/10.1016/j.catena.2024.108188>
- Louw, S.vdM., Wilson, J.R.U., Janion, C., Veldtman, R., Davies, S.J. & Addison, M. (2014). The unknown underworld: Understanding soil health in South Africa. *South African Journal of Science*, 110(5/6):1-4. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0038-23532014000300002&lng=en&nrm=iso
- Lynch, J.M. & Bragg, E. (1985). Microorganisms and soil aggregate stability. In B.A. Stewart, (Ed.), *Advances in Soil Science* 2. (pp 133–171) Springer, New York, NY. https://doi.org/10.1007/978-1-4612-5088-3_3
- Marais, A. & Booyse, M. (2024). Evaluation of the microBIOMETER® field test kit and other soil health indicators in three different soils of the Western Cape Province. *Suid-Afrikaanse tydskrif vir Wetenskap en Tegnologie/South African Journal of Science and Technology*, 43(1): 102-113. <https://doi.org/10.36303/SATNT.2024.43.1.975E>
- Marais, A., Kotzé, E., Labuschagne, J., Visser, L. & Morris, C.D. (2020). Proposed adaptation of the KMnO₄ oxidation method for determining active carbon for South African soils. *South. African Journal of Science*, 116(1/2). <https://doi.org/10.17159/sajs.2020/6443>
- Matchaya, G., Nhamo, L., Nhlengethwa, S., & Nhemachena, C. (2019). An overview of water markets in Southern Africa: An option for water management in times of scarcity. *Water*, 11:1006. <https://doi.org/10.3390/w11051006>
- Mbanjwa, V.E., Hughes, J.C. & Muchaonyerwa, P. (2022). Organic carbon and aggregate stability of three contrasting soils as affected by arable agriculture and improved pasture in northern KwaZulu-Natal, South Africa. *Journal of Soil Science and Plant Nutrition*, (22):2378–2391. <https://doi.org/10.1007/s42729-022-00815-x>
- Meldal-Johnsen, A. (2011). Soil Survey Outeniqua Research Farm, George, Western Cape Province. Internal publication, available from Outeniqua Research Farm, George.
- Moncada, M.P., Gabriels, D., Cornelis, W. & Lobo, D. (2015). Comparing aggregate stability tests for soil physical quality indicators. *Land Degradation and Development*, 26(8):843-852. <https://doi.org/10.1002/ldr.2225>
- Ott, R.L. (1998). An introduction to statistical methods and data analysis. Belmont, California, Duxbury Press; pp 807-837 (pp 1-1051).
- Pati, S., Padhan, D., Saha, A.K., Pal, B., Chaitanya, A. K., Dasgupta, S., Dey, A. & Hazra GC. (2016). Land use pattern influences the aggregate stability of soil. *International Journal of Environmental Science*; 42(1):63-70.
- Patle, P., Navnage, N.P. & Barange, P.K. (2018). Fluorescein diacetate (FDA): measure of total microbial activity and as indicator of soil quality. *International Journal of Current Microbiology and Applied Sciences*, 7:2103-2107. <https://doi.org/10.20546/ijcmas.2018.706.249>
- Poeplau, C., Riefling, T., Schiedung, M. & Anlauf, R. (2024). Land use and soil property effects on aggregate stability assessed by three different slaking methods. *European Journal of Soil Science*, (75)4: e13549. <https://doi.org/10.1111/ejss.13549>
- Royal Eijkelpamp Wet sieving apparatus manual (n.d.). <https://www.royaleijkelpamp.com/products/lab-testing-equipment/soil-physical-research/aggregate-stability/wet-sieving-apparatus/>
- Sinclair, R., Nodi, S. & Kabir, M.A. (2024). Evaluating mobile applications for estimating soil properties: Quality of current apps, limitations and future directions. *Computers and Electronics in Agriculture*, 216:1 <https://doi:10.1016/j.compag.2023.108527>

- Six, J., Elliott, E.T. & Paustian, K. (2000). Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology and Biochemistry*, 32(14):2099-2103. [https://doi.org/10.1016/S0038-0717\(00\)00179-6](https://doi.org/10.1016/S0038-0717(00)00179-6)
- Smith, H.J., Trytsman, G., Nel, A.A., Strauss, J.A., Kruger, E., Mampholo, R.K., van Coller, J.N., Otto, H., Steyn, J.G., Dreyer, I.D., Slabbert, D., Findlay, R., Zunckel, E. & Visser, L. (2022). From theory to practice – key lessons in the adoption of Conservation Agriculture in South Africa. In A. Kassam, (Ed.), *Advances in Conservation Agriculture Volume 3: Adoption and Spread*; Burleigh Dodds Science Publishing, Cambridge, UK
- Smith, J.D.V. (2014). The effect of long-term no-till and crop rotation practices on the soil organic matter functional pools. [MSc (Agric) thesis]. Stellenbosch. University of Stellenbosch, South Africa.
- Soil Classification Workgroup. (1991). Soil Classification, a taxonomic system for South Africa. Memoirs on the Natural Agricultural Resources of South Africa. (15). Department of Agricultural Development, Pretoria.
- Tetegan, M., Korboulewsky, N., Bouthier, A., Samouëlian, A. & Cousin, I. (2015). The role of pebbles in the water dynamics of a stony soil cultivated with young poplars. *Plant and Soil*, 391:307–320. <https://doi.org/10.1007/s11104-015-2429-1>
- The Non-affiliated Soil Analysis Work Committee. (1990). Handbook of Standard Soil Testing Methods for Advisory Purposes. Pretoria: Soil Science Society of South Africa.
- Western Cape Department of Agriculture research farms. (n.d.). [document on the internet]; [cited on 23 October 2025] Available from: <https://www.elsenburg.com/research-farms/>
- Wiese, J.D., Labuschagne, J. & Agenbag, G.A. (2015). Soil water and mineral nitrogen content as influenced by crop rotation and tillage practice in the Swartland subregion of the Western Cape. *South African Journal of Plant and Soil*, 33(1):33–42. <https://doi.org/10.1080/02571862.2015.1057772>
- Xiao, L., Zhang, W., Hu, P., Xiao, D., Yang, R., Ye, Y. & Wang, K. (2021). The formation of large macroaggregates induces soil organic carbon sequestration in short-term cropland restoration in a typical karst area. *Science of the Total Environment*, 801. <https://doi.org/10.1016/j.scitotenv.2021.149588>
- Zhang, S., Wang, R., Yang, X., Sun, B. & Li Q. (2016). Soil aggregation and aggregating agents as affected by long term contrasting management of an Anthroisol. *Scientific Reports*, 6:39107. <https://doi.org/10.1038/srep39107>