Identifying optimal soil conditions for successful *Cyclopia subternata* cultivation in the Langkloof and Kouga region, South Africa

MSc Thesis, Farming Systems Ecology

Name student: Jody Viljoen

Study: Organic Agriculture

Registration number: 951107889030

Supervisors: Carl Timler MSc (Farming Systems Ecology)

Dr. ir. Michel Riksen (Soil Physics and Land Management)

Roderick Juba MSc (Living Lands)

Examiner: ir. Kees van Veluw

Course code: FSE-80436

Date: November 2019

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Content

Abstract

Cyclopia spp., used to produce honeybush tea, grow naturally in the fynbos vegetation of the Eastern and Western Cape of South Africa. The growing demand for this herbal tea has led to the over-harvesting of natural populations and this necessitated the increased cultivation of honeybush. The main limitation for expansion is the shortage of knowledge in setting up and managing honeybush plantations. The aim of this study was to provide insight into the optimal mineral balance of soil to ensure economically viable honeybush yields. The study took place in the Langkloof Kouga region where *Cyclopia subternata* grows naturally and is one of the main species cultivated. The soil conditions at the natural setting were taken as a benchmark of desirable growing conditions. Within the natural setting, high carbon, iron and magnesium content were identified as indicators for successful *C. subternata* growth. In the cultivated fields, these elements were low, presumably due to frequent tillage leading to microbial oxidation, increased loss of organic matter and erosion. High phosphorus and potassium content led to weed growth in the cultivated fields and therefore, multi-nutrient rock fertilizers are recommended as supplement. A nature-based approach, which utilizes the resilience of the natural fynbos setting by integrating ecological processes into farming practices, is recommended for *C. subternata* cultivation. Integrating naturally co-occurring species into honeybush production, with reduced tillage, will have a positive impact on biodiversity and decrease microbial- and organic matter decomposition.

1. Introduction

Honeybush (*Cyclopia* spp.) is a traditional South African herbal tea which grows naturally in the fynbos vegetation in the Eastern and Western Cape. The demand for honeybush tea continues to rise worldwide due to its health promoting properties (Mabizela et al., 2017) and current supply cannot meet the demand (Joubert et al., 2011). The growing demand resulted in the over-harvesting of natural populations and stimulated the increased cultivation of honeybush as a commercial horticultural crop to protect the ecology of this sensitive ecosystem (Postma et al., 2016).

A major problem is the shortage of knowledge for establishing and managing honeybush plantations (Morokolo, 2011). Farmers cultivating honeybush are still learning about propagation, cultivation and processing through trial and error (Erasmus, 2012). It is possible that research has led to results over the years, however little has been published in scientific journals.

To understand the environmental requirements of honeybush in terms of soil conditions and to ensure economically viable yields, it is essential to know what the optimal soil conditions are for its cultivation. Knowledge about chemical soil properties is beneficial in identifying areas suitable for future honeybush cultivation (Joubert et al., 2011). For current honeybush farmers, this knowledge can provide insight into potential reasons why current honeybush cultivation is not yielding as well as natural areas. This knowledge can also indicate soil properties on cultivated fields that need to be improved to achieve higher yields.

The aim of this study was to analyse the mineral balance of soils on which one of the 23 *Cyclopia* species, *C. subternata*, grows. First, we had to find out what the current mineral balance was of soil on which *C. subternata* grows naturally and on which it was cultivated. Secondly, how the mineral balance of soil in a cultivated setting differed from soil on which *C. subternata* grows naturally. Finally, how different levels of various chemical elements and properties effected *C. subternata* growth.

2. Background

Plant Characteristics

Cyclopia spp. are endemic to the fynbos biome and can be found on the coastal plains and mountainous regions of South Africa (Joubert et al., 2011). 23 species of *Cyclopia* have been described and they can be divided into reseeders or resprouters according to their fire-survival strategy (Joubert et al., 2008). *C. subternata* is a reseeder but can also be propagated vegetatively by stem cuttings (Mabizela et al., 2017), however the farmers involved in this study have been unsuccessful in getting cuttings to root and survive. *C. subternata* plants usually have one to three long branches and can grow up to two meters tall (Joubert et al., 2011). Farmers in the Langkloof encourage horizontal growth by cutting tips off young plants. *C. subternata* is a relatively fast grower and the plants can be harvested within a year of planting under ideal conditions (Joubert et al., 2011). The whole plant; leaves, stems and flowers, is used for the manufacturing of tea (Du Toit et al., 1998). *C. subternata* can be harvested yearly and has an estimated lifespan of seven to eight years (Joubert et al., 2011). The plants should not be cut back shorter than 30 cm above the ground as too severe pruning leads to dieback (Joubert et al., 2011). According to North et al. (2016), the optimum harvest date is in September as *C. subternata* recovers fastest during the warmer and wetter spring months. The farmers in this study also harvest in September before the honeybush flowers and produces seed. Honeybush cultivation is specialized, focussing only on one crop, which makes the farms more susceptible to diseases and pests (Erisman et al., 2017). It appeared that the farms in the Langkloof were indeed vulnerable, as they mentioned their struggle with pests such as mealybugs, thrips, ants and lice.

Soil Conditions

Naturally growing honeybush is a remarkable plant resource as it grows on lands which are generally unsuitable for other agricultural production (McGregor, 2018). *Cyclopia* spp. are perennials which are adapted to well-drained, sandy to loamy soils with a low pH (< 5.3) characterized by low concentrations of phosphorus (< 20 mg kg^{-1}) (Joubert et al., 2015). Symbiotic interaction with bacteria is necessary to obtain nutrients (Postma et al., 2016). *Cyclopia* spp. form a symbiosis with rhizobium bacteria for the fixation of nitrogen by the development of root nodules which bind atmospheric nitrogen (Joubert et al., 2011). Therefore, *C. subternata* can grow on nitrogen and phosphorus poor soils and on soils with a low pH which in return facilitates nitrogen fixation by increasing nodule production of rhizobia (Brink et al., 2017). Rhizobia might not be present where new honeybush plantations are established and therefore the seeds are inoculated with a rhizobium strain (Joubert et al., 2011). Furthermore, Joubert et al. (2011) concluded that soil preparation was essential for good root development and stated that the soil should be worked to a minimum depth of 50 cm. However, such intensive turning of the soil encourages the decomposition of organic matter (Erisman et al., 2017) which is the most critical to soil health (Havlin et al., 2016).

The Langkloof

C. subternata grows naturally in the Langkloof and is one of the main species to be cultivated there (Joubert, n.d). The Langkloof is one of the most prosperous areas for deciduous fruit cultivation in South Africa, but unfortunately suffers from environmental shocks and social stress (De Kock, 2015). The Langkloof consists of the Kouga and Kromme catchments which are part of the most important water sources in the area (Living Lands, 2018). The catchments are threatened by commercial apple farming, using large volumes of water and high levels of pesticides leading to water pollution (Grounded, n.d.). Unpredictable temperature changes, wildfires, hail storms, droughts and floods are additionally of great concern (Living Lands, 2018). The Langkloof has been facing water shortages and droughts over the past 20 years; therefore, farmers are seeking ways to diversify their farms, moving away from apple farming and cultivating crops which are less sensitive to environmental risks (Grounded, n.d.). The cultivation of indigenous plant species such as honeybush are being explored to build resilience within the agricultural sector of the Langkloof (Living Lands, 2018).

3. Materials and methods

3.1 Study Location

This study was conducted in the Langkloof and Langkloof-Kouga area in the Eastern and Western Cape. *C. subternata* can be found on the wetter, cooler southern slopes along the Tsitsikamma, Outeniqua and Langeberg mountain ranges, at elevations from 160 – 1000 meters (McGregor, 2018). Soil on which *C. subternata* grows naturally was taken as a benchmark of which mineral balance is desirable. Soils of farmers who were *C. subternata* were analysed and compared to the benchmark. Sampling took place at three farms (farm 1, 2 and 3) in the Eastern Cape where *C. subternata* was cultivated and at one farm (farm 4) in the Western Cape where *C. subternata* grows naturally (Figure 1). Samples were obtained in June and July, 2019.

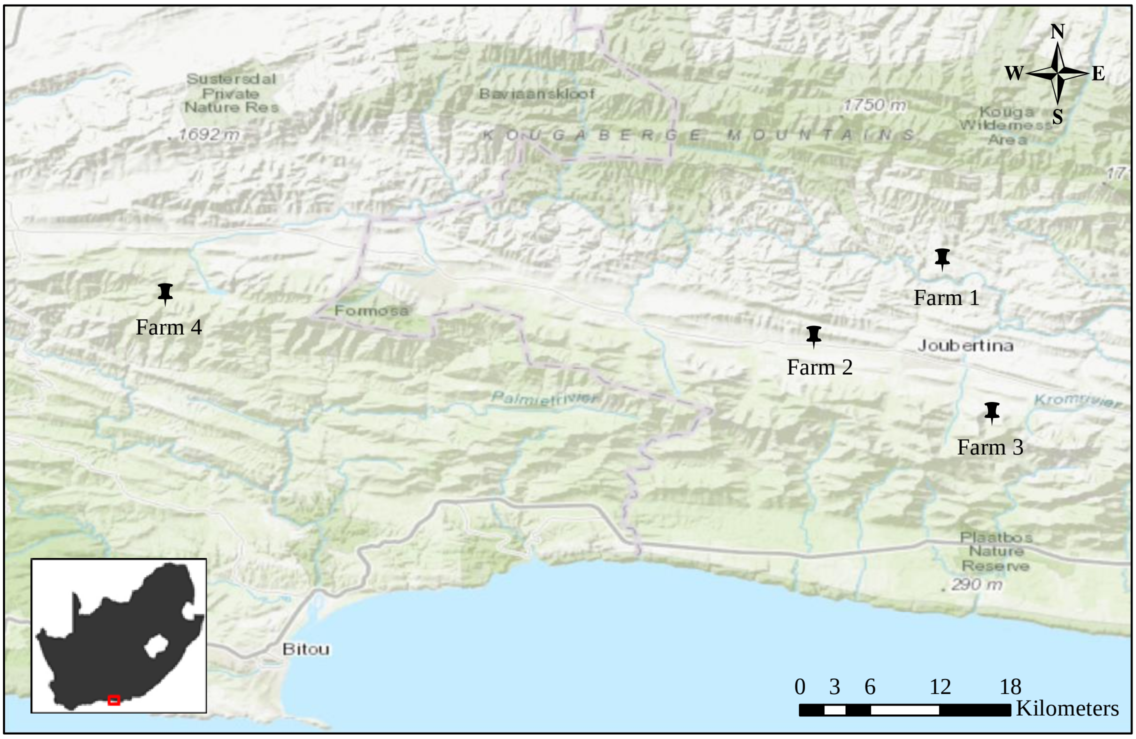

Figure 1. *Map of the Langkloof including farms with* C. subternata *cultivation (farms 1-3) and natural growth (farm 4), South Africa.*

The South African Environmental Network (SAEON) has measuring stations throughout the Langkloof where precipitation data is collected. Stations nearby the farms were identified and the data is presented in Figure 2, with graphs of the average monthly rainfall in the past (1990-2010) and from the approximate time period that the farmers from this study have been on their farms (2010-2018). Over the last few years, all farms experienced increased precipitation in the winter period (June – Augustus). Farms 1, 3 and 4 were also confronted with a great decrease in precipitation in December, the beginning of summer. For farmers with limited access to water, this formed a problem for their current fields and impeded expansion plans. Farmers are dependent on the capacity of dams to collect enough water during the rainy season for irrigation during the dry season (De Kock, 2015). Farm 3 was near to a river which does not dry up, but for the other farmers, periods of drought are an increasing problem.

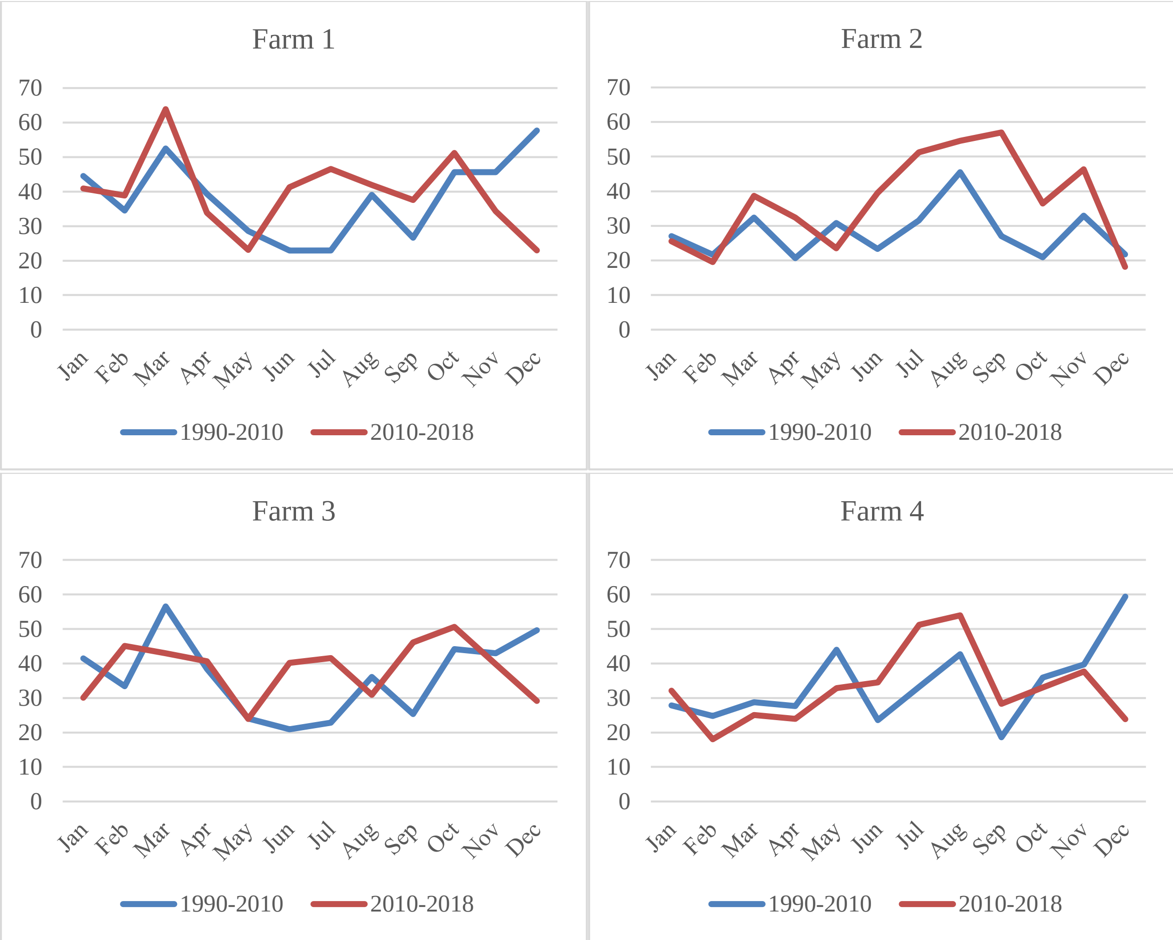

Figure 2. *Average rainfall in mm per month for measuring stations near to farms 1-4 in the Langkloof, data provided by SAEON.*

3.2 Experimental Sites

Table 1 summarizes the characteristics of the honeybush fields at farms 1, 2 and 3 where *C. subternata* is cultivated and farm 4 where *C. subternata* grows naturally.

Table 1. C. subternata *field characteristics of farms 1-4 in the cultivated and natural setting, South Africa.*

	Farm 1. Langkloof-Kouga	*Farm 2. Langkloof*		*Farm 3. Langkloof*	*Farm 4. Haarlem*
Age field	18 months	5 years	3 years	3 years	16 months
Nr. of harvests	One	Twice	Left side once and right side twice.	One	None
Area (ha)	0,5	0,4	0,1	0,5	3
Elevation (m)	538-545	527-568	591-595	588-613	909-931
Previous land use	Virgin soil, then shortly squash.	Vegetable garden.	Possibly grazing and fruit cultivation.	Possibly grazing and fruit cultivation.	Virgin soil.
Planting density (plants ha^{-1})	20 000	10 000	10 000	12 500	The north-west side of the strip was not

Slope	East	Upper side: east, bottom side: north-west	South-east	North	elevated and some areas were dense with up to 30 000 plants per hectare. The south-east side was on a slope with a lower density and increased growth of other vegetation.
Soil	Loamy sand with little organic matter which was porous and unaggregated.	Loamy sand with some organic matter and rounded aggregates.	Loamy sand with some organic matter and rounded aggregates.	Greyish, loamy sand with a lot of organic matter and some rounded aggregates.	Extremely dark, silty loam soil with a high organic matter content.
Vegetation cover	Bare topsoil and weeds were controlled by hoeing as soon as possible.	No weeding, grass cover.	No weeding, grass and weed cover.	Weeds and high grasses despite previous removal and application of hay.	Bare soil and other fynbos vegetation.
Supplements	Seagro, an organic fish emulsion by Efekto.	None	None	Worm tea against pests.	None

3.3 Sampling Strategy

A total of 40 bulked soil samples were extracted using an auger; 30 at cultivated sites and 10 where *C. subternata* grows naturally. Each bulked sample consisted of five samples excavated to a depth of 30 cm as a shallow rooting depth was expected due to the setup of drip irrigation. Each set of five samples was collected in a similar layout from a surface of approximately four m^2. The sampling location was mapped by GPS for future reference. Each bulked sample was thoroughly mixed and about six cups of soil were divided over two plastic packets, one for the laboratory and one for own measurements.

The method of arbitrary sampling was used to select sampling points (Brus, 2019). Each field had a clear distinction in areas that were growing well and areas that were growing less well. Due to these differences within the fields, three states were determined; "Good", "Bad" and "Weedy". When the state "Good" was determined, plant height and width were satisfactory and the leaves looked healthy, no dead plants were visible and there was little weed growth. For "Bad", the growth was lagging behind from the other plants, the leaves were discoloured or there were dead bushes. "Weedy" was determined when the honeybush had substantial competition with high grasses or weeds such as *Argemone mexicana* (Mexican prickly poppy) and *Urtica dioica* (stinging nettle). Three samples were taken for each of the states "Good" and "Bad" per farm. "Weedy" was not present in farms 2 and 4. All samples per farm can be found in the Appendix.

3.4 Chemical Element and Property Analyses

The samples were analysed by Elsenburg laboratory in Cape Town. The Inductively Coupled Plasma (ICP) method (Montaser & Golightly, 1987) was used to determine the stocks of all elements. It was decided to measure the stocks of nutrients as most fields had not been fertilized and the nutrient stocks might be depleted. If nutrient stocks are indeed low, the plants will be more responsive to input which could improve the productivity (Kamau et al., 2008). The major elements (phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na)) were tested using the citric acid (1%) method, the trace elements (copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe)) with ammonium EDTA extract and boron (B) with a calcium chloride extract. Soil organic carbon (C) was tested with the Walkely Black method. All methods were adopted from the South African handbook of soil testing methods (The Non-Affiliated Soil Analysis Work Committee, 1990).

Electrical conductivity was tested using a Horiba LAQUAtwin meter and pH was tested with a Hanna HI98103 pH meter. The values of all chemical elements and properties per sample can be found in the Appendix.

3.5 Statistical Analyses

T-tests were carried out with SPSS software (version 25.0) in order to identify significant soil properties per farm, per state. Least significant difference values were calculated at the 5% probability level to facilitate comparison between states. Means which differed at the 5% level of probability were considered to be significantly different.

The Principal Component Analysis (PCA) was conducted in Canoco version 5.12 (Ter Braak, 1985) to summarize relationships between soil composition and state of the honeybush for the farms individually. The variables were standardized to zero mean and unit to remove arbitrariness, as the soil properties were measured in different units (Ter Braak, 1986). The value of each property was weighed by its variance, which caused those with high variance to dominate the results. The main pattern of variation in soil composition, as accounted for by the chemical soil properties, is shown, as well as the distribution of the samples along each property.

4. Results

4.1 Mineral Balance in General

An average of the chemical soil properties per state in a cultivated and natural setting, from all farms, can be found in Table 2. The individual results from all samples can be found in the Appendix. First of all, comparing all samples from the two settings to each other, all properties are significantly different except for Ca. In the natural setting, a lower range of values was found for EC, K, Cu, Zn, Mn in comparison to the cultivated setting, while Mg, Na, Fe, B and C had a higher range. Comparing “Good” to “Bad” growth within the natural setting, “Good” growth had higher EC, Ca, Mg, Na, P, Mn, Fe and C content of which Mg, Fe and C were significant. Similar results were found when comparing “Good” to “Bad” in the cultivated setting; EC, Ca, Mg, Na, Mn and C content were higher for “Good”. Within the cultivated setting, only Na “Weedy” was significantly different from both “Good” and “Bad” growth.

Table 2. *Mean values of soil analyses for different states (“Good”, “Bad” & “Weedy”) of* C. subternata *cultivation from three farms and two states (“Good” & “Bad”) in a natural setting in the Langkloof, South Africa. Values in the same row, which are followed by the same letter, do not differ at P = 0.05.*

	State	**“Good”**	**"Bad"**	**“Weedy”**	**“Good”**	**"Bad"**
	Setting	Cultivated	Cultivated	Cultivated	Natural	Natural
	Sample Size	12	12	6	7	3
pH		5.46	5.54	5.87	4.84	5.00
EC	(mS/cm)	264.67[a]	140.00[a]	145.00[a]	89.14[b]	73.67[b]
Ca	(cmol/kg)	2.37[a]	1.71[a]	1.40[a]	2.28[a]	1.51[a]
Mg	(cmol/kg)	0.80[a]	0.65[a]	0.48[a]	1.52[b]	1.00[c]
Na	(mg/kg)	67.92[a]	50.50[a]	24.17[c]	91.86[b]	69.67[b]

K	(mg/kg)	101.17^{a}	95.25^{a}	139.67^{a}	54.86^{b}	57.00^{b}
P	(mg/kg)	19.4^{a}	22.08^{a}	34.33^{a}	41.14^{b}	26.00^{b}
Cu	(mg/kg)	0.89^{a}	0.86^{a}	0.59^{a}	0.16^{b}	0.19^{b}
Zn	(mg/kg)	2.25^{a}	2.73^{a}	1.62^{a}	0.51^{b}	0.50^{b}
Mn	(mg/kg)	101.37^{a}	83.40^{a}	60.91 ^{a}	2.68^{b}	2.21^{b}
Fe	(mg/kg)	81.97^{a}	90.89^{a}	65.53^{a}	537.84^{b}	284.20^{c}
B	(mg/kg)	0.17^{a}	0.17^{a}	0.14^{a}	0.45^{b}	0.43^{b}
C	(%)	1.14^{a}	0.87^{a}	0.72^{a}	8.29^{b}	5.76^{c}

4.2 Results per Farm

4.2.1 Farm 1

Table 3 includes the soil properties which showed a significant difference for farm 1. EC and the major elements P and K caused a decreased growth of *C. subternata* and increased weed growth. High P content was also significant for bad growth. K, Zn and B content were significantly higher for "Weedy" than for "Bad" *C. subternata* growth.

Table 3. *Farm 1, Langkloof; significant differences per state ("Good", "Bad" & "Weedy"). Values in the same row, which are followed by the same letter, do not differ at P = 0.05.*

	"Good" mean (STD)	***"Bad" mean (STD)***	***"Weedy" mean (STD)***
EC	94.0^{a} (21.0)	122.7^{ab} (48.2)	162.7^{b} (28.1)
K	88.3^{a} (3.2)	123.0^{a} (23.3)	201.7^{b} (40.5)
P	22.0^{a} (1.7)	35.3^{b} (6.7)	46.7^{b} (11.6)
Zn	1.65^{ab} (1.0)	1.03 ^{b} (0.12)	2.04 ^{a} (0.54)
B	0.13^{ab} (0.1)	0.12 ^{b} (0.02)	0.17 ^{a} (0.02)

4.2.2 Farm 2

Table 4 includes the significant results from the analysis of farm 2. The only significant difference found here, was for the chemical soil property EC which was higher for good *C. subternata* growth.

Table 4. *Farm 2, Langkloof; significantly different chemical property for the states "Good" and "Bad". Values in the same row, which are followed by the same letter, do not differ at P = 0.05.*

	"Good" mean (STD)	***"Bad" mean (STD)***
EC	417.7^{a} (167.6)	160.3^{b} (29.9)

4.2.3 Farm 3

No soil properties were found to be significant indicators for different states in farm 3.

4.2.4 Farm 4

Table 5 shows the significant results from the SPSS analysis for farm 4 where *C. subternata* grows naturally. The elements Mg, Fe and C had significantly higher values for good natural *C. subternata* growth.

Table 5. *Farm 4; significantly different chemical elements for "Good" and "Bad" production of naturally growing* C. subternata *in the Langkloof. Values in the same row, which are followed by the same letter, do not differ at P = 0.05.*

	"Good" mean (STD)	***"Bad" mean (STD)***
Mg	1.5^{a} (0.2)	1.0^{b} (0.2)
Fe	537.8^{a} (148.2)	284.2^{b} (8.6)
C	8.3^{a} (1.6)	5.8^{b} (1.0)

4.3 Principal Component Analysis (PCA)

A PCA was performed for a visualization of the states within the farms separately (Figure 3). The solid arrows represent the soil properties and the circles, squares and triangles represent the samples per state, for each farm. Each of these arrows represent an axis, obtained by extending the arrow in both directions and from each sample point a perpendicular line can be drawn to this axis (Ter Braak, 1986). Figure 3 shows an example for B as an axis, see the dotted line extending the arrow and the perpendicular dotted lines drawn from the axis to the samples. Samples perpendicular to, or beyond the tip of the arrow, are strongly correlated to, and influenced by the arrow and those at the opposite end are less strongly affected (Jabeen & Ahmad, 2009). For example, the samples from farm 4 were most correlated with B and those from farm 1 the least. The length of an arrow indicates the relative importance and the angle between arrows represents the correlation to each other (Ter Braak, 1986). Taking B as example again, there was a strong correlation with Mg, C and Fe, there was probably no correlation with EC, and there was a negative correlation with pH.

Principal components (PC) 1 and 2, explained 42.4% and 26.5% of the total variance respectively. All arrows, except for P, had approximately the same length indicating that the samples were equally sensitive to these soil properties. P was the shortest, which means it was least influential to different states of honeybush.

On the horizontal axis, the ordination results showed that all arrows had an upward trend, except for P. The direction of pH, Mn and Cu were consistent with that of the first axis (PC 1) while P was opposite to this. This reflected that, for example, Mn increased with increasing pH and Cu, whereas P gradually decreased. Furthermore, a difference can be observed between the natural growing honeybush and the cultivated along PC 1. Within the natural setting, the element mainly responsible for bad growth was low P, while C, Fe and B were indicators for good growth.

PC 2, on the vertical axis, shows the differences among the farms in the cultivated setting. Good growth in farm 2 was correlated to EC and Ca. Farm 1 and 3 however, did not show much variance between the different states. The samples from farm 2 are more spread out because they were taken in two separate fields on the farm and therefore have a larger sample size.

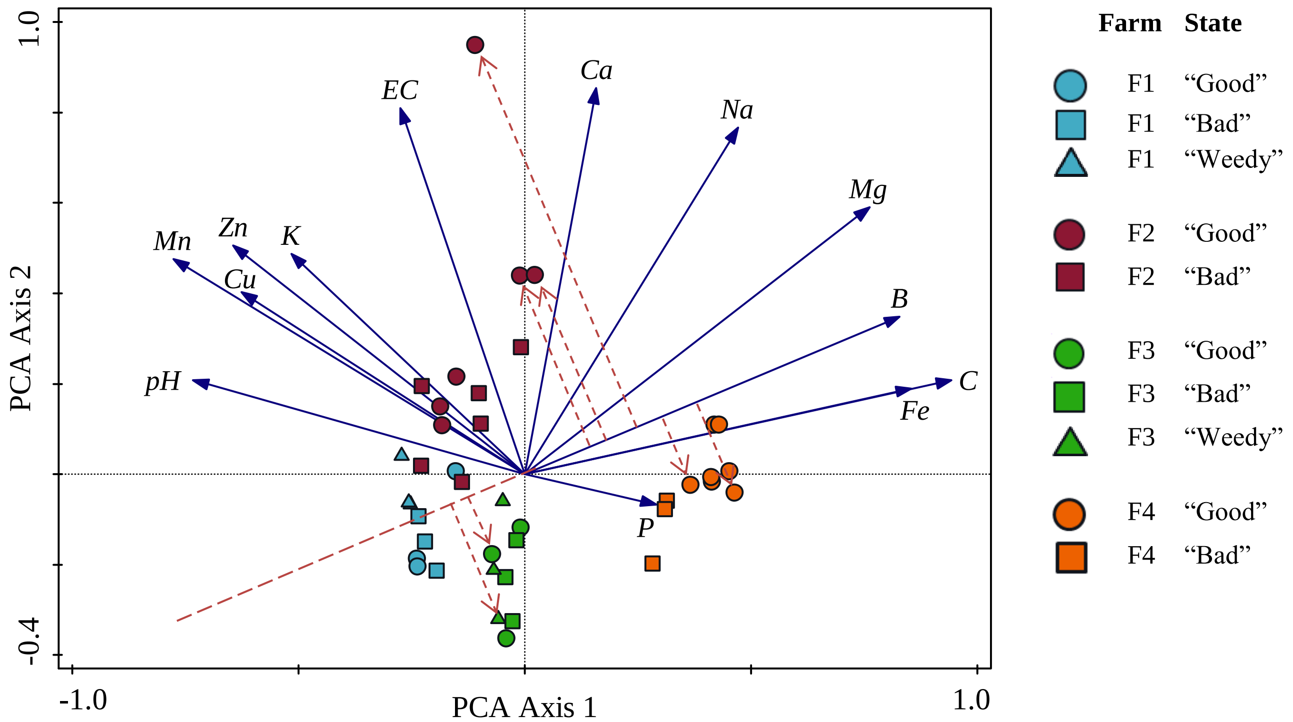

Figure 3*. Principal Component Analysis (PCA) to explore the correlation between the soil properties and states of* C. subternata *("Good", "Bad" & "Weedy").* C. subternata *is cultivated on farms 1-3 and grows naturally on farm 4, in the Langkloof, South Africa.*

5. Discussion

Indicators for Good Growth

The honeybush tea industry is one of the youngest agricultural industries in South Africa and farmers cultivating honeybush are still learning about propagation, cultivation and processing through trial and error (Erasmus, 2012). To understand the environmental requirements of *C. subternata* in terms of soil conditions and to ensure economically viable yields, it is important to know what the optimal soil conditions are for its cultivation. This knowledge provides insight into potential reasons why conventional honeybush cultivation is not yielding as well as in natural areas.

Values for the mineral balance of soil on which *C. subternata* grows naturally and for soil on which it is cultivated, can be found summarized in Table 2 or fully in the Appendix. The mineral balance in different states of production, provided insight into indicators for good *C. subternata* growth. Taking the results from soil on which *C. subternata* grows naturally as a benchmark, an important factor for successful growth was related to a high C content, preferably above 8 mg kg^{-1}. Carbon, the measurable component of organic matter, is a key parameter for soil health and plant productivity (Panpatte & Jhala, 2019). Soil C increases aggregate stability which increases infiltration, improves root expansion and improves resistance to water and wind erosion (Havlin et al., 2016). C was significantly low in the cultivated fields, presumably due to frequent tillage at planting and the periodic clearing of weeds leading to microbial oxidation and increased decomposition of organic matter (Havlin et al., 2016).

Also, high Fe content led to significant better growth in the natural setting with values above approximately 500 mg kg^{-1}. Fe is an essential plant nutrient and is often abundant in soil, however due to its low solubility it can be inaccessible to plants (Zhang et al., 2019). Soils with a low organic matter content are often also low in Fe due to erosion (Havlin et al., 2016). Fe deficiency is one of the most important factors limiting yield and reducing the quality of crops worldwide (Zhang et al., 2019).

Lastly, a high Mg content around 1.5 mg kg^{-1} led to better natural *C. subternata* growth. Mg tends to be low in acid, sandy soils (Havlin et al., 2016). Mg is an essential element for plant growth and deficiency negatively affects the yield of crops, however research is limited as Mg deficiency is difficult to recognize (Gransee & Führs, 2013).

The mineral balance of the natural setting is presumed to be the most desirable to honeybush production, but the condition of the soil is also influenced by other environmental factors. The fynbos biome has an impressive floral diversity with species that appear nowhere else in the world which coexist together in the Cape Floristic Region of South Africa (Rebelo et al., 2006). Due to this unique co-occurrence of species, a nature-based approach is suggested for honeybush cultivation. Nature-based agriculture makes optimal use of ecological processes and integrates them into farming practice, contributes to the natural environment and has a positive impact on biodiversity (Erisman et al., 2017). Not taking the conventional approach of clearing the field of its original vegetation, but integrating naturally co-occurring species into honeybush production, could be beneficial to its successful cultivation. These natural landscape elements could provide a habitat for natural enemies of pest insects (Erisman et al., 2017). This approach also includes reduced tillage whereby the ploughing of soil is kept to a minimum and organic matter is preserved (Erisman et. al., 2017). A nature-based approach will decrease microbial- and organic matter decomposition, the soil temperature will decrease, evaporation is reduced and infiltration is increased (Havlin et al., 2016). The goal is to ultimately increase soil organic matter which could additionally improve Fe availability due to decreased erosion (Havlin et al., 2016). Increasing diversity on the field could reduce vulnerability of the honeybush yield and increase biodiversity (Benayas & Bullock, 2012). A more resilient soil, achieved by improving the soil quality and soil life, is less susceptible to extreme weather and pests (Erisman et al., 2017) and can adapt to the unpredictable climate of the Langkloof.

Mineral Rocks for Micronutrients

Honeybush cultivation should strive to maintain the health of soil with low-cost, practical solutions, taking long-term, ecological sustainability into account. As fynbos soils are easily depleted in nutrients, a five-year field survey was carried out by Joubert et al. (2010) to determine the rate at which minerals should be replaced to counter losses through harvesting. For *C. subternata*, Joubert et al. (2010) found that 28% to 45% of the total mass of N, P, K, Ca and Mg was removed with harvesting. Previously, Joubert et al. (2007a) found that *C. subternata* benefit from the addition of P at doses between 5 and 20 mg kg^{-1}. However, the results from farm 1 showed that high P content (47 mg kg^{-1}), as well as K (202 mg kg^{-1}), led to significant weed growth. It is likely that weeds utilize these macronutrients better and gain a competitive advantage.

The commercial fertilizer industry focusses on fertilizers containing macronutrients (N, P and K) and not secondary nutrients and micronutrients (Van Straaten, 2006). This was probably why the farmers from this study expressed an interest in using a 1:2:7 NPK fertilizer to improve the growth of plants that were underperforming. As results showed that the macronutrients P and K caused increased weed growth and did not stimulate *C. subternata* growth, the use of multi-nutrient rock fertilizers are recommended. This agro-geological approach aims at a slow release of a multitude of nutrients, including micronutrients, from rich minerals and rocks (Van Straaten, 2006). This natural approach could be a feasible solution for the honeybush industry and is additionally in line with its organic principles.

Element Abundance

The range of many soil properties differed between the cultivated setting and the natural setting, with Fe and Mn being the most notable. Fe had values up to 700 mg kg^{-1} in the natural setting and an average of 90 mg kg^{-1} in the cultivated setting. Mn was between 1 and 5 mg kg^{-1} in the natural setting and 90 to 200 mg kg^{-1} for farm 1 and 2. Mn may have negative effects on honeybush; Joubert et al. (2007b) observed poor growth where the only measured abnormal feature was an above ambient soil Mn concentration. Joubert et al. (2007b) also conducted a short pot trial, whereby Mn addition to soil with a low Mn content (1.3 mg kg^{-1}) did not give a positive response. Manganese toxicity is a critical factor limiting plant growth on acid soil (Horst, 1988) and is a concern for farms 1 and 2. As Mn is readily taken up and transported to the shoots (Horst, 1988), future research should include leaf analysis to examine the mineral uptake of the plants.

Limitations and Future Research

This study provides a basis for further research about the effects of the soil's mineral balance on *C. subternata* growth. This research improves the state of the art knowledge and provides a good starting point towards a full understanding of the soil requirements for honeybush cultivation. Future research about honeybush cultivation needs to explore more nature-based approaches and explore the benefits of reduced tillage. The focus on the addition of macronutrients needs to shift towards micronutrients and the effects of abundant elements in the soil need to be investigated.

Future research should include a larger sample size from both the cultivated and natural setting for a more reliable generalization of the results. In this study, the sample size of the state "Weedy" was particularly small and not studied for each farm. Also, with no significant differences between the states in farm 3, few samples were left for the generated results.

Another limitation to this research is related to the classification of the three different states. These were determined objectively and once-off, and it is important to see if these states continue in the fields over time. Other, more representative factors for the state, such as yield, could be determined in future research.

At last, other factors besides the mineral balance of soil may influence the growth of *C. subternata*. For example in farm 1, the growth of a whole row of honeybush was lagging behind from the rest. It was not likely that this was related to the mineral balance of the soil but possibly due to a block in the irrigation system or bad planting of the seedlings resulting in hampered root development. More environmental variables should be taken into consideration when determining optimal soil conditions for *C. subternata* growth.

6. Conclusions

The aim of this study was to analyse the mineral balance of soil on which *C. subternata* grows naturally and on which it is cultivated to identify indicators for good growth. Results concluded that in the natural setting, high carbon, iron and magnesium content were important elements for successful growth. These elements were low in the cultivated fields, presumably due to farming techniques such as tillage at planting and the periodic clearing of weeds leading to microbial oxidation and increased loss of organic matter (Havlin et al., 2016). In cultivated fields, high phosphorus and potassium content led to increased weed growth, questioning the benefit of conventional fertilizer. Furthermore, for two farms cultivating *C. subternata*, manganese toxicity is of concern.

These findings suggest stepping away from the conventional approach of tilling the soil and clearing the original vegetation and taking a more nature-based approach instead. This approach reduces pressure on the environment by creating landscape elements and provides a habitat for natural enemies of pest insects (Erisman et al., 2017). Not clearing all vegetation before planting, but planting honeybush into its natural setting will decrease microbial- and organic matter decomposition (Havlin et al., 2016) and increase biodiversity (Benayas & Bullock, 2012). As fynbos soils are easily depleted in nutrients, the agro-geological approach is recommended which aims at a slow release of a multitude of nutrients, including micronutrients, from rich minerals and rocks (Van Straaten, 2006). A more natural cultivation setting for honeybush will improve resilience within the agricultural sector of the Langkloof by improving soil quality and soil life and enabling honeybush to become the cornerstone of a sustainable industry.

Acknowledgements

I would like to thank my two supervisors from Wageningen University Carl Timler and Michel Riksen for all their support and guidance. I would like to thank the whole Living Lands team in Twee Riviere for an unforgettable experience and especially Roderick Juba for sharing his knowledge and directly supporting the research. Also, the involved honeybush farmers in the Langkloof for their time and cooperation. Lastly, I would like to thank Cajo ter Braak for his help with the statistical analysis in Canoco and Julia Glenday from SAEON for extensive hydrology data.

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Appendix

Results of the analyses of all samples per farm with 'A' being the state "Good", 'B' "Bad" and 'W' "Weedy".

Sample	pH	EC	Ca	Mg	Na	K	P	Cu	Zn	Mn	Fe	B	C
		(mS/cm)	(cmol/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(%)
Farm 1 A1	5.7	118	2.57	0.65	30	87	21	0.64	2.78	130.5	65.13	0.18	1.24
Farm 1 A2	5.6	85	1.04	0.38	27	92	21	0.73	1.26	94.27	36.47	0.11	0.33
Farm 1 A3	5.8	79	0.92	0.35	22	86	24	0.80	0.91	133.80	87.55	0.09	0.20
Farm 1 B1	5.8	85	0.90	0.31	24	98	41	0.57	0.91	93.30	97.3	0.10	0.25
Farm 1 B2	5.9	177	1.05	0.41	22	144	28	0.71	1.04	127	89.98	0.12	0.40
Farm 1 B3	5.7	106	1.11	0.34	23	127	37	0.71	1.14	119.8	77.23	0.13	0.29
Farm 1 W1	5.8	192	1.34	0.48	22	247	60	0.83	2.55	121.7	86.63	0.17	0.33
Farm 1 W2	6.0	136	1.03	0.32	24	169	39	0.63	2.11	122.3	83.97	0.18	0.39
Farm 1 W3	5.8	160	1.13	0.42	18	189	41	0.79	1.47	103.4	68.48	0.15	0.36
Farm 2 F1 A1	5.4	307	1.51	0.68	81	105	18	1.71	2.01	94.03	86.99	0.18	0.70
Farm 2 F1 A2	5.5	273	2.28	0.95	80	105	23	1.14	4.68	133.8	74.98	0.19	1.19
Farm 2 F1 A3	4.6	310	3.21	1.49	133	119	35	1.71	6.25	149.7	146.8	0.19	1.79
Farm 2 F1 B1	5.6	140	1.21	0.54	57	63	19	2.35	1.61	127.6	59.87	0.14	1.24
Farm 2 F1 B2	5.7	154	3.39	1.28	99	148	10	0.68	1.39	165.7	104.9	0.35	1.89
Farm 2 F1 B3	5.5	173	2.62	1.01	49	134	35	0.87	2.12	63.10	59.49	0.26	0.98
Farm 2 F2 A1	4.9	558	2.47	1.08	173	126	11	0.71	1.22	194.6	98.45	0.28	2.11
Farm 2 F2 A2	6.6	689	7.74	1.63	136	237	17	0.83	2.68	175.8	108.5	0.36	2.05
Farm 2 F2 A3	5.4	369	2.00	0.71	45	75	24	1.17	2.74	96.86	73.80	0.14	0.78
Farm 2 F2 B1	5.6	135	1.39	0.62	72	59	6	0.71	2.75	94.20	152.8	0.14	0.49
Farm 2 F2 B2	5.5	215	2.00	0.81	99	76	12	1.01	5.39	95.18	170.3	0.22	0.91
Farm 2 F2 B3	5.9	145	2.56	0.73	76	67	26	1.59	13.65	103.4	122.3	0.17	0.61
Farm 3 A1	5.9	117	1.75	0.71	28	86	11	0.28	0.65	4.57	44.40	0.15	1.21
Farm 3 A2	4.8	182	1.88	0.61	41	65	11	0.65	1.38	5.17	88.47	0.13	1.37
Farm 3 A3	5.3	89	1.02	0.35	19	31	17	0.33	0.46	3.36	72.12	0.06	0.69
Farm 3 B1	5.1	128	1.78	0.71	38	74	19	0.42	1.44	4.87	61.02	0.14	1.37
Farm 3 B2	5.1	84	1.09	0.43	21	80	20	0.31	0.48	2.54	50.03	0.10	0.94
Farm 3 B3	5.1	138	1.43	0.55	26	73	12	0.38	0.79	4.15	45.49	0.14	1.03

Sample		EC	Ca	Mg	Na	K	P	Cu	Zn	Mn	Fe	B	C
		(mS/cm)	(cmol/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(%)
Farm 3 W1	5.0	165	2.33	0.82	33	105	22	0.60	1.48	10.44	59.69	0.13	1.27
Farm 3 W2	5.4	117	1.44	0.53	29	71	13	0.40	1.04	4.50	55.03	0.12	1.04
Farm 3 W3	5.0	100	1.13	0.32	19	57	31	0.30	1.09	3.10	39.38	0.08	0.91
Farm 4 A1	4.7	132	1.39	1.12	126	40	33	0.12	0.48	2.16	491.2	0.45	7.72
Farm 4 A2	4.9	82	2.36	1.62	86	48	47	0.11	0.57	1.7	519.3	0.32	9.83
Farm 4 A3	4.7	99	2.26	1.57	83	59	54	0.20	0.47	2.21	705.9	0.40	10.37
Farm 4 A4	4.8	108	1.78	1.46	97	49	72	0.17	0.44	1.1	782.2	0.34	9.28
Farm 4 A5	4.8	68	2.87	1.73	87	64	30	0.21	0.72	5.16	397	0.58	7.33
Farm 4 A6	5.0	77	2.98	1.72	89	67	28	0.21	0.47	3.69	440.9	0.58	7.72
Farm 4 A7	5.0	58	2.35	1.41	75	57	24	0.11	0.45	2.72	428.4	0.45	5.81
Farm 4 B1	5.0	99	1.56	1.08	91	47	28	0.19	0.59	2.74	298.8	0.40	6.86
Farm 4 B2	5.1	62	0.90	0.74	59	42	24	0.20	0.43	1.88	302.5	0.45	5.15
Farm 4 B3	4.9	60	2.06	1.18	59	82	26	0.17	0.48	2.00	251.3	0.45	5.27