Effect of organic cultivation of rooibos tea plants (Aspalathus linearis) on soil nutrient status in Nieuwoudtville, South Africa

Samson BM Chimphango*1, Dawood Hattas1 and Noel Oettlé2

1 Department of Biological Sciences, University of Cape Town, Cape Town, South Africa
2 Rural Programme, Environmental Monitoring Group, Cape Town, South Africa
* Corresponding author, email: samson.chimphango@uct.ac.za

The shoots of rooibos (Aspalathus linearis (Burm.f.) R.Dahlgren) plants, cultivated organically by small-scale farmers in Nieuwoudtville, are harvested for the production of tea. These practices could lead to decreasing soil fertility. It was hypothesised that soil from cultivated rooibos plots will have lower nutrient concentrations than soil from adjacent uncultivated plots. Soil and shoot samples were collected in December 2005, 2006 and 2009 from cultivated fields of increasing plot age and from adjacent uncultivated plots on three farms, and analysed for nutrient concentration. Compared with the uncultivated plots, no measured soil nutrients including concentrations of phosphorus (P), exchangeable potassium (K), magnesium (Mg) and calcium (Ca), and soil carbon (C) decreased in cultivated plots over the five-year period of assessment. Soil C correlated positively with concentrations of soil exchangeable K, Mg and Ca, and sodium (P < 0.001), indicating that soil C is an important indicator of soil fertility. Folliar P increased, and consequently the nitrogen:P ratio decreased in cultivated relative to uncultivated plants, implying higher P-uptake by cultivated plants. Overall, organic rooibos cultivation in Nieuwoudtville appears to be sustainable in terms of maintaining soil nutrition because soil nutrient status did not decrease over the five-year period.

Keywords: Aspalathus, fynbos, legume, rooibos, soil fertility)

Introduction

The shrub legume Aspalathus linearis (Burm.f.) R.Dahlgren (Fabaceae, tribe Crotalarieae) is endemic to the Western and Northern Cape provinces of South Africa. The plant is commonly called ‘rooibos’, which literally means ‘red bush’ because the shoots (green leaves and twigs) turn reddish-brown when dried. The shoots of A. linearis are used to make a mild-tasting tea that contains no caffeine, very little tannin and large amounts of polyphenol antioxidants, attributes that are associated with important health benefits and medicinal value (van Heerden et al. 2003; Joubert and de Beer 2011). Rooibos was first cultivated early in the twentieth century to meet growing demand locally. To meet the increasing world demand, cultivation expanded from 14 000 ha of rooibos in 1991 to 36 000 ha in 2007, but with a footprint of up to 60 000 ha due to fallow areas (Pretorius 2008). The majority of rooibos is produced in the Greater Cederberg Biodiversity Corridor (Hansen 2006), mainly in three sandstone fynbos areas: Cederberg, Olifants River Valley and Bokkeveld (Hawkins et al. 2011).

Rooibos evolved to grow in the coarse-grained, nutrient-poor, acidic soil and hot dry summers of the Cape Floristic Region, recently renamed the Core Cape Subregion (Manning and Goldblatt 2012). The plant is known to use three specialised mechanisms for uptake of nutrients, namely cluster roots (Hawkins et al. 2011; Maistry et al. 2013) and mycorrhizal roots (Lambers et al. 2006) for enhanced acquisition of phosphorus (P), and formation of root nodules in symbiosis with rhizobia that fix atmospheric nitrogen (N) of c. 105–128 kg N ha−1 (Muofhe and Dakora 1999). The ‘Nortier’ form of rooibos that is commonly cultivated is a reseeder shrub selected for its growth form and prolific production of seeds (Morton 1983). The wild rooibos ecotype consists of both reseeders and resprouters (Malgas et al. 2010; Hawkins et al. 2011), with the latter producing far smaller quantities of seed, but able to survive fire events and resprout from the crown or stems.

In the Nieuwoudtville district, Northern Cape province, South Africa, the primary agricultural activities are sheep farming and production of wheat and rooibos. Small-scale farmers in this area formed the Heiveld Co-operative as a community-based enterprise that is internationally certified as a producer of organic rooibos tea according to European Union Standards, and export their tea worldwide (Oettlé et al. 2004). Organic production of rooibos by these farmers refers to planting and harvesting shoot biomass for processing into tea without using inorganic nutrient fertiliser, pesticides or insecticides. Land intended for planting is prepared by means of deep ploughing at the beginning of the winter rains (April–May). At planting (June–July), seedlings that have reached a height of 10–20 cm are transplanted into plantations in rows, approximately 1 m apart, but spacing between plants varies among farmers. Fourteen months after planting, the rooibos plant is pruned for the first time to a height of 30 cm, and thereafter harvested annually during summer (January–March) by cutting shoots at 30–50 cm above the ground. The rooibos
plant has an average lifespan of six years, which equates to four harvestable yields in its lifetime, and an average yield of 375 kg ha\(^{-1}\) y\(^{-1}\) is reported from this area (Pretorius 2008).

Declining fertility of soils is known to be a major factor in limiting per capita food production in the majority of small farms in Africa (Sanchez et al. 2001). Soil fertility decline refers to the net loss of plant nutrients from the soil due to higher nutrient outputs such as harvest, erosion or leaching compared with inputs including inorganic fertilisers, manure, rainfall or fallow (Drechsle et al. 2001). Although agricultural production and related activities in Nieuwoudtville are controlled by a wide range of local legislations (Hansen 2006; Pretorius 2008) aimed at ensuring the maintenance of ecological integrity through sustainable production, annual harvesting of rooibos shoot biomass for rooibos tea without any inorganic nutrient addition would more than likely lead to nutrient mining and reduced soil nutrients. Similarly, deep ploughing during land preparation may enhance organic matter decomposition, nutrient leaching and soil erosion. Consequently, soil organic matter or soil carbon (C) may decline, resulting in decreased capacity to retain water compared to uncultivated areas. Since plants rely on both macro- and micronutrients from the soil for growth, productivity of most ecosystems is influenced by the availability of macronutrients including N (LeBauer and Treseder 2008), P (Vitousek et al. 2010; Barbiault et al. 2012), and base cations (K, Mg and Ca) (Andersen et al. 2010; Barbiault et al. 2012). Soil pH is a good indicator of nutrient availability in the soil, and cultivation was reported to increase (Mäder et al. 2002; De Moraes Sá et al. 2009) or decrease pH (Berner et al. 2008) depending on soil type and organic residues. Furthermore, Mäder et al. (2002) showed that organic farming systems, relative to conventional farming, offers many benefits to the environment such as reduced pollution, enhanced soil fertility and conservation of biodiversity. Organic matter improves soil nutrients by acting as a source of C and nutrients to the soil, contributing to cation exchange sites or substituting previously adsorbed nutrients from clay particles (Bauer and Black 1994; Asadu et al. 1997).

In general, a decline in soil nutrient concentration will most likely decrease tissue concentration of nutrients and affect their ratios because of the plants’ reliance on soil for its nutrient supply. This view is supported by several studies that reported correlations between soil and foliar chemical elements (Pärtel 2002; Ordoñez et al. 2009; Han et al. 2011). Furthermore, the critical N:P ratio has been used to determine whether soil N or P is limiting plant growth in an area, with foliar N:P ratios of 10–20 indicating co-limitation by both N and P, <10 indicating limitation by N and >20 showing limitation of growth by P (Güsewell 2004). In a study involving terrestrial ecosystems and European wetlands, plant growth was reported to be N-limited at N:P ratios of <14 and P-limited at N:P ratios >16 (Koerselman and Meuleman 1996; Tessier and Raynal 2003). However, the use of critical N:P ratios to identify limitation by N or P has been challenged (Craine et al. 2008; Townsend et al. 2007) due to lack of empirical support from fertilisation experiments and variation of N:P ratio thresholds among species at a given site (Zhang et al. 2004). The aim of this study was to assess the effects of rooibos cultivation on soil C and macronutrient concentrations, and foliar concentration of N and P. This was achieved by measuring soil C and macronutrient concentrations, as well as rooibos foliar N and P in cultivated and uncultivated rooibos plots over a five-year period. It was hypothesised that soil C and macronutrient concentrations of cultivated plots will decrease with increasing plot age, and that rooibos foliar N:P ratio will increase in older cultivated plants due to the expected decline in soil P.

Materials and methods

Selection of farms, and collection and analysis of soil and shoot samples

The study was conducted in the Nieuwoudtville district, part of the Bokkeveld sandstone fynbos, Northern Cape Province, South Africa, which receives its rain mostly in winter with an average annual rainfall of 375 mm. The average for the study period (2004–2009) was however c. 475 mm, and maximum monthly temperatures ranged between 18.0 and 31.9 °C (Figure 1). Three farms were purposely selected to include farms at least 10 km apart, with potential differences in soil fertility, presence of at least four age groups of cultivated rooibos plots per sampling time, and locations most representatives of rooibos farms in the area. The selected farms were Blomfontein, Dobbelaarskop and Landskloof, located between longitudes 19°07.30’ and 19°13.54’ E, and latitudes 31°3.04’ and 31°73.24’ S, and the farmers grow rooibos organically. At each farm, the total area under rooibos cultivation in 2005 was c. 5, 14 and 36 ha for Blomfontein, Dobbelaarskop and Landskloof, respectively, with plots of rooibos of different ages and sizes ranging from 0.07 to 6.8 ha.

Soil and shoot samples were collected in December of 2005, 2006 and 2009, to cover an average six-year lifespan of rooibos plants, from cultivated plots and adjacent vegetation with rooibos plants growing naturally in the veld hereby called ‘uncultivated plot’. The soils were collected using an auger (10 cm diameter) or garden trowel where soil was too dry, taking a uniform sample at a depth of 15–20 cm from the newly planted plot (Year 1), and plots containing two-, three- and four-year-old cultivated rooibos, hereby designated as Year 2, Year 3 and Year 4, respectively. In the subsequent years, samples were collected from the same plots and therefore, the plot designated as Year 1 became the two- and five-year old cultivated rooibos plots in 2006 and 2009, respectively. Similarly, Year 4 plot was five and eight years old in 2006 and 2009, respectively. None of the plots had been reploughed at the time of soil sample collection in both 2006 and 2009. At each plot, five replicate soil samples of c. 300 g were collected randomly across the diagonal of the plot. Samples were air dried, passed through a 2 mm sieve, and subsamples were analysed by BemLab Private Laboratory (Somerset West, South Africa) for pH, total N, ammonia (NH\(_4^+\)), nitrate (NO\(_3^-\)), available P (Bray II P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), copper (Cu), boron (B) and soil C. Soil pH was determined by shaking 2 g of soil in 20 mL 1 M KCl at 180 rpm for 60 min, filtering the mixture through Whatman No. 2 filter paper and measuring the pH of the supernatant. Total soil C and N...
Concentration of NH$_4^+$ in the soil was determined by a thermal conductivity cell against a He background (Yeomans and Bremner 1991). Concentration of NO$_3^-$ was determined by means of the salicylate method and NO$_3^-$ was extracted in hot water (The Non-affiliated Soil Analyses Work Committee 1990). The P in the solution was determined by ashing ground shoot material at 480 °C for 8 h and dissolving in 16% HCl (Kalra 1998). The P in the solution was determined using ICP-OES. For the plant nutrient section, only concentrations of N and P, and calculated N:P ratio are reported because foliar N:P ratio is commonly used as an indicator of soil N and P fertility status for an area (Koerselman and Meuleman 1996; Güsewell 2004).

**Statistical analysis**

All measurements except soil pH were log transformed where necessary before statistical analysis. Canonical discriminant analysis (CDA) examined the multivariate nutritional differences between soils of the three farms. The CDA generates linear combinations of variables, i.e. canonical variates (CV), such that the statistical algorithm derives an optimal separation between groups established a priori (i.e. farms) by maximising between-group variance (Raamsdonk et al. 2001). The CV’s standardised coefficients allow identification of the variables that contributed the most in the separation of the groups. To assess the differences in soil and foliar nutrient concentrations among cultivated plots of different ages and years, a repeated-measures analysis of variance (ANOVA) was performed separately for each farm. Pearson’s correlation coefficient and Student’s t-test were used to test statistical relationships between soil C and concentration of other soil nutrients. All statistical analyses were performed with Statistica 12 (StatSoft, Inc., Tulsa, OK, USA).

**Results**

**Concentration of nutrients in the soil**

The scatterplot of canonical scores of soil characteristics showed that the three farms (Figure 2) were nutritionally different. Squared Mahalanobis distance (Table 1) of the soil characteristics among the farms indicated that the separation between farms was significant ($P < 0.001$). Both CV1 and CV2 (Table 2) contributed significantly ($P < 0.001$) in the separation of the farms with P contributing most, as it recorded the most extreme standardised coefficient within CV1. Soil K and pH were the other parameters with extreme standardised coefficients under CV1. Within CV2, Cu and soil C were the nutrients with high standardised coefficients and therefore also contributed highly in the
separation of the farms. The separation of the farms based on soil nutrients necessitated that a repeated-measures ANOVA be performed separately for each farm. However, nutrients (i.e. Na, Cu, Mn and B) that showed random and inconsistent response patterns after the repeated-measures ANOVA were not reported.

All three farms showed a decrease in concentration of soil C (Figure 3d–f) in 2006 relative to 2005 and 2009, which varied with cultivation age of the rooibos plot. Similarly, the concentration of soil P was lower in 2006 relative to 2009 (Figure 3b and c) in Dobbelaarskop and Landskloof, but the differences also varied with cultivation age of the rooibos plot. The interaction between cultivation age of the rooibos plot and year of sample collection showed that P in cultivated plots of up to three years old was either similar to or greater than soil from uncultivated plots across the three farms (Figure 3a–c), but decreased in Year 4 plots at Blomfontein and Dobbelaarskop. A slightly different pattern was observed for C where, compared with uncultivated plots, concentration in cultivated plots was either similar or decreased in the early years of cultivation but recovered to be either similar or higher than the uncultivated levels by Year 4, with the exception of 2009 results at Dobbelaarskop. However, the soil C uniquely increased in Year 4 plots at Blomfontein (Figure 3d). The pattern of results for concentrations of soil K, Ca and Mg, and pH (Supplementary Table S1) was similar to those recorded for C (Figure 3).

**Correlation between soil C and other nutrients**

Concentration of soil C was positively correlated with that of soil exchangeable K, Ca, Mg and Na ($P < 0.001$, Figure 4c–f). There was however no relationship between soil C and pH or P ($P > 0.05$, Figure 4a and b).

**Foliar concentration of N and P, and N:P ratio**

Similar to the findings in soil, concentration of foliar N and P, and the N:P ratio varied with farm, year of data collection and cultivation age of each rooibos plot. For instance, decreased foliar N and P were recorded in 2006 and 2009 compared with 2005 at Dobbelaarskop farm, but not at Blomfontein (Figure 5). Relative to the uncultivated rooibos, foliar P increased in cultivated plots at both Blomfontein and Dobbelaarskop farms, but the increase in foliar N was apparent only in 2005 and 2009 at Blomfontein. Consequently, N:P ratio generally decreased ($P < 0.001$) in cultivated rooibos plants relative to their uncultivated counterparts (Figure 5c and f).

**Discussion and conclusion**

Organic cultivation of rooibos at Nieuwoudtville maintained soil nutrition and was sustainable, contrary to our hypothesis, because there was generally no pattern of decreasing concentration of soil nutrients with increasing age of cultivated plots relative to uncultivated plots over a five-year period. In cultivated plots, where soil nutrient concentration declined in the early years of cultivation, e.g. soil C in 2006 at Dobbelaarskop (Figure 3e), and in 2009 at Landskloof (Figure 3f), the levels of nutrients recovered to that of uncultivated plots by Year 4, and in some instances the cultivated plots had greater...
The maintenance of soil nutrient status over five years of rooibos production may be due to good soil management practices by the farmers associated with the recommended best practice methods for sustainable rooibos production (Oettle et al. 2004; Pretorius 2008). These methods include orienting the rooibos plots in such a way that the surface movement of soil particles through the action of wind is restricted, creating vegetative barriers by establishing hedge-rows between rooibos plots to slow down wind velocity, and mulching or growing cover crops such as oats. These practices are recommended for rooibos growing areas because the sandy soil of the areas is highly susceptible to wind erosion as the top layer does not compact easily (Pretorius 2008). Field observations showed that the surface of most plots was covered by a winter oat crop, annual weed residues or grass. Cover cropping or mulching is an effective soil conservation strategy for maintaining or building up soil organic matter and nutrients, while also preventing soil erosion (Tonitto et al. 2006; Manlay et al. 2007; Berner et al. 2008). Similarly, in an experiment where tillage and mulching treatments were assessed in maize (Zea mays L.) fields for two years, soil total N and P were maintained in the tilled and mulched treatments (Zhou et al. 2012). Furthermore, nutrient input through deposition may have contributed to the maintenance of nutrients in the soil because N deposition ranging from 2 to 13 kg N ha\(^{-1}\) y\(^{-1}\) has been recorded in the fynbos biome (Stock and Lewis 1986; Wilson et al. 2009). The increase in soil C with cultivation in the Year 4 plot at Blomfontein relative to cultivated or other uncultivated plots (\(P < 0.001\) in all cases), coupled with an increase in soil K, Ca and Mg (Supplementary Table S1), and the consistently decreased soil P in the three years was unique for this farm and therefore suggests that other unknown factors, such as inherent soil characteristics or cropping history (Neff et al. 2006, Ding et al. 2012), other than cultivation effect, may have influenced these changes.

The use of foliar N:P ratio to indicate soil nutrient limitation by either N or P, and as a management tool in fertiliser planning, was proposed and used in some studies (Koerselman and Meuleman 1996; Tessier and Raynal 2003; Güsewell 2004). In this study, the increased foliar P and the decreased N:P ratios, despite the generally similar foliar N in cultivated plants relative to the uncultivated rooibos plants, suggest that plants in the cultivated plots accessed more P than their uncultivated counterparts. Since soil P in the cultivated plots was generally either similar to or lower than that in the uncultivated plots, increased P uptake by the cultivated plants can be attributed to their mechanisms for enhanced acquisition of P. Deep ploughing during land preparation followed by soil conservation practices such as no-tillage for up to eight years, and mulching, may have promoted proliferation of roots with greater formation of cluster roots or root biomass or both, leading to the increased foliar P. Although

![Figure 3: Soil P and C concentration (mean ± SE) of uncultivated and cultivated rooibos plots of different ages of cultivation at Blomfontein (a, d), Dobbeelaarskop (b, e) and Landskloof (c, f) farms in Nieuwoudtville. Within a farm, bars with different lower case or primed letters are significantly different at \(P < 0.05\). Upper-case letters indicate significant differences between year of sample collection at \(P < 0.05\). For (a) primed letters indicate main effect differences of year of sample collection and age of rooibos plots without interaction.](image-url)
formation of cluster roots was not quantified in this study, cluster roots were observed in the field rooibos plants as previously reported (Lambers et al. 2006). However, similar concentrations of tissue N between cultivated and uncultivated rooibos, and among years of sample collection, suggest that uptake of soil N or biological N fixation or both were not affected by cultivation practices.

Soil organic matter content is an important indicator of soil fertility and sustainability through influencing decomposition processes and cycling bioavailable nutrients (Palm et al. 2001; Berner et al. 2008). The positive correlation \( (P < 0.001) \) observed between soil C and soil cations, including K, Ca, Mg and Na (Figure 4c–f), was consistent with previous reports (de Moraes Sá et al. 2009; Qin et al. 2010), and supports the view that soil organic matter as measured by soil C is a major source of plant nutrients (Bauer and Black 1994; Manlay et al. 2007). There was no relationship, however, between soil C and available P, similar to observations in Lajtha and Schlesinger (1988), suggesting that soil P in some areas is influenced mainly by geology and not by nutrient cycling. In conditions where soil P is largely influenced by nutrient cycling, soil organic matter usually correlates positively with available soil P (de Moraes Sá et al. 2009; Qin et al. 2010). This is because an increase in soil C is associated with increased supply of organic P and negative charges on the soil particles, resulting in decreased contact of P with Fe and Al oxides, which reduces P fixation (Negassa et al. 2008; de Moraes Sá et al. 2009), thereby increasing availability of P in the soil for plant uptake.

In this study, there was evidence that cultivation can change the pH of the soil (Supplementary Table S1), but the results varied with year of sample collection and farm such that there was no consistent trend or any correlation with available P. Similar variable results were reported in the literature where, relative to conventional tillage,
no-till increased pH. This increased pH was associated with increased concentration of soil organic carbon that ultimately increased negative charges, cation exchange capacity and base saturation (Mäder et al. 2002; De Moraes Sá et al. 2009). Conversely, soil pH decreased in a no-till system and was linked to accumulation of organic acids and leaching of basic cations into deeper soil layers (Berner et al. 2008).

Overall, the results showed that, from a nutritional perspective, organic cultivation of rooibos at Nieuwoudtville appears to be sustainable in terms of maintaining soil nutrition because soil nutrient concentration was generally unaffected over a five-year period.

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**Figure 5:** Foliar concentration of N and P, and N:P ratio (mean ± SE) in rooibos plants harvested from uncultivated and cultivated plots of different ages of cultivation at Blomfontein (a–c) and Dobbelaarskop (d–f) farms. Within a farm, bars with different lower-case letters are significantly different at $P < 0.05$. Uppercase letters indicate significant differences between year of sample collection at $P < 0.05$.
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