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Viability of watering *Portulacaria afra* truncheons to facilitate restoration of subtropical thicket: Results from a nursery experiment and cost model

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ABSTRACT

Intensive goat farming has transformed more than a million hectares of subtropical thicket in South Africa from a dense closed-canopy shrubland into an open savanna-like system. Restoration of the degraded thicket landscapes can be achieved by planting truncheons of spekboom (*Portulacaria afra*). The sale of carbon sequestered by spekboom can potentially fund restoration projects. Maximising the rate of spekboom growth at the outset of such projects will be critical for covering upfront costs. To investigate the potential effects of watering on restoration projects, we applied 16 different watering treatments to 320 spekboom truncheons in a nursery environment over eight months. The application of 4 L of water over eight watering events per month achieved the maximal mean increase in basal stem diameter for unrooted truncheons, namely 5.6 $\pm$ 1.8 mm. By comparison, application of 6 L of water over four watering events per month resulted in a maximal mean increase of 5.0 $\pm$ 3.7 mm for rooted truncheons. The estimated total cost of manually watering truncheons in the field ranged from ZAR560 to ZAR4840 per month for truncheons planted 2 m apart (i.e. 2500 truncheons per hectare), and was ZAR59 per month for truncheons planted in micro-basins 20 m apart (i.e. 25 micro-basins per hectare). The former costs would not be affordable for restoration projects financed through sale of sequestered carbon, but the latter costs would be. Dense planting of truncheons in shallow trenches and/or micro-basins – which would collect rainwater – is a promising new protocol for increasing the rate of carbon sequestration at the start of restoration projects.

1. Introduction

Subtropical thicket – characterised by a dense canopy of tall shrubs and the succulent shrub known as spekboom (*Portulacaria afra* Jacq.) – covers ~1.7 million ha in the Eastern Cape, South Africa (Lloyd et al., 2002). Despite a long association with a diverse assemblage of large and medium-sized indigenous herbivores (Midgley, 1991; Kerley et al., 1995), this vegetation is surprisingly sensitive to being degraded through intensive browsing by goats (Stuart-Hill and Danckwerts, 1988; Stuart-Hill, 1992; Mills et al., 2005). The degradation results in the dense closed-canopy shrubland being transformed into an open savanna-like system with a cover of ephemeral grasses and forbs (Hoffman and Cowling, 1990; Kerley et al., 1995; Lechmere-Oertel et al., 2005). Approximately 1.4 million ha has been or is undergoing such degradation (Mills et al., 2007). Restoration to reverse the negative ecological and socio-economic effects of the degradation is a major priority in the region (Mills and Fey, 2004; Mills et al., 2015).

While there is considerable evidence showing that thicket restoration can be achieved by planting spekboom truncheons (Van der Vyver et al., 2013), the costs associated with this approach – largely labour and equipment – can be prohibitive (Mills et al., 2015). In addition, the costs of restoration increase in unfavourable environmental conditions such as hard soils (which increases labour costs and damages equipment) and frost (which increases cutting mortality, Duker et al., 2015). Several financing mechanisms for the restoration of thicket have been proposed and explored (Mills et al., 2015). These include the sale of carbon credits on the voluntary carbon market using accreditation organisations such as the Verified Carbon Standard (VCS) and the Climate, Community and Biodiversity Alliance (CBS) (Bekessy and Wintle, 2008; Galatowitsch, 2009). The financial viability of this funding option is underpinned by restored thicket sequestering carbon at an average rate of approximately 10 t of CO_2 per hectare per year (Mills and Cowling, 2006) over many decades.

A factor that in particular constrains the financing of spekboom planting through carbon credits is that most of the funding for a restoration project is required in the first few years of the project (for labour and equipment during the initial and supplementary planting operations), yet the majority of carbon credits generated by growing spekboom is

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only likely to accrue after a 10- to 20-year period. This delayed accrual is a result of the sigmoidal growth curve which spekboom – as with other plants – is likely to follow (Mills et al., 2007).

Investors wanting to fund spekboom restoration through the sale of carbon credits need to address the time lag between capital input and return on investment. A time lag of 10 to 20 years is likely to discourage most investors, who will also invariably be concerned by risks posed by the volatility of the carbon market or environmental factors – such as frost and severe drought – that limit the growth of spekboom truncheons. Management interventions that increase the rate at which spekboom accumulates carbon could therefore potentially greatly increase the financial viability of thicket restoration for investors. Laboratory studies on spekboom physiology by Guralnick and Ting (1986) and Guralnick et al. (1984) found that the plant's photosynthetic rate increases markedly in response to watering. Corroborating this work, Smart (2016) found that spekboom growth in the field is considerably faster in wet years (ca. 500 mm) than dry years (ca. 250 mm) years. We consequently hypothesised that watering spekboom manually or through rainwater harvesting would greatly increase the rate of carbon sequestration from spekboom truncheons. Apart from water availability, the establishment success and rate of growth of spekboom truncheons might be influenced by the presence or absence of roots and the freshness of propagation material (i.e. freshly imbibed versus severely wilted). In a garden situation, spekboom is usually established using either unrooted truncheons or rooted suckers, although in most restoration trials only unrooted material has been used (Van der Vyver et al., 2013).

Given this background, and to assist decision-making within thicket restoration projects using spekboom truncheons, a preliminary investigation was undertaken into: i) growth of truncheons under different watering regimes; ii) growth of unrooted versus rooted truncheons; iii) growth of wilted versus fresh truncheons and iv) labour costs of watering truncheons in the field.

2. Methods

2.1. Location and materials

A pot trial consisting of two experiments was undertaken at Renu-Karoo Nursery, ~1.5 km north of Prince Albert and within 3 km of naturally-occurring spekboom. Mean annual rainfall at the nursery is 177 mm and the surrounding natural vegetation is Prince Albert Succulent Karoo (Milton et al., 1997), with spekboom-dominated thicket occurring predominantly on north-facing hillsides. The pot trial was undertaken from 1 September 2014 to 30 April 2015, a period in which ambient temperatures ranged between 7 and 42 °C. Winter months (May–August) were excluded to minimise the risk of frost damage (Duker et al., 2015). During the 8-month trial period, drought conditions prevailed and only eight rain events occurred, totalling 47.5 mm.

Unrooted and rooted truncheons – approximately 1 m in length and 20–30 mm in basal stem diameter, and unbranched – were collected from a single, non-irrigated hedge on Margrieta Prinsloo Street in Prince Albert. Rooted truncheons were suckers that were severed and dug out using a spade. A total of 70 mm of rain had fallen in Prince Albert in the three months (1 June to 31 August 2015) preceding the collection of the material. The truncheon stems and leaves were not wilted when collected. With the exception of the wilting experiment (see below), all freshly harvested truncheons were weighed and measured on the day of harvesting. Weight was recorded with a “Pesola” spring balance, accurate to ±0.3% of the load.

For both experiments (details presented below), truncheons were planted in 200-μm UV-resistant plastic bags with volumes of 20 L and diameters of 250 mm. One spekboom truncheon was planted per bag to a depth of 200 mm. Each bag contained a soil mixture comprising six parts coarse river sand, three parts clay-loam and one part compost. This soil composition was chosen to allow for adequate drainage while minimising leaching of nutrients. Prior to planting, 4 L of water were added to each planting bag so that all truncheons were planted in moist soil. For the duration of both experiments, bags containing truncheons were placed in the open with no protection from sun or wind. Watering treatments and unrooted and rooted truncheons were randomly allocated to bags so that all effects were interspersed across the experiment.

Stem diameter measurements were used as an estimation of growth response to watering. Diameter measurements have previously been used to estimate growth and biomass production in spekboom (Smart, 2016). The potential for using height increment to estimate growth is poor in a shrubby succulent such as spekboom, where much of the biomass is produced as lateral shoots. Leaf counts are also likely to be problematic as a proxy for growth because both over-watered and drought-stressed spekboom sheds leaves (SJM personal observation and various gardening blogs e.g. SFGate, 2012, 2013). Measurements of stem diameter were taken 200 mm from each truncheon's base using vernier callipers. Measuring stem diameter at this position on each truncheon allowed for repeated measurements to be taken in situ, i.e. at soil level.

2.1.1. Experiment 1: watering frequency and quantity combinations

To assess the effect of watering quantity and frequency, 16 treatments of varying watering frequency and quantity were applied to groups of 10 unrooted and 10 rooted truncheons (see Table 2 and Table S2). Twelve of the treatments combined three watering quantities (0.5 L, 1.0 L and 1.5 L), with four application frequencies (1, 4, 8 or 12 times per month). Three treatments consisting of the same quantity of water (4 L) were applied either once, twice or three times in an eight-month period. One treatment consisted of no water. The basal stem diameter and mass of each truncheon was measured and recorded on the day of planting, after five months, and at the end of experiment (i.e. 8 months). Mean change in basal stem diameter after five and eight months for unrooted and rooted truncheons under each of the 16 treatments was tested using an ANOVA and plotted in R (R Core Team, 2016). Second-order polynomial regressions, tested and plotted in R, were used to compare the basal stem diameter growth of unrooted versus rooted truncheons over a period of five and eight months in response to watering frequency and number of watering events per month. In addition, the relationship between basal stem diameter and wet biomass was plotted in Excel, and an exponential curve fitted. Predicted values of wet biomass based on basal stem diameter, as calculated from equations set by Powell (2009), were plotted as a comparison, and a second-order polynomial fit was assigned. These relationships are shown in Supplementary Materials S3.

2.1.2. Experiment 2: growth of fresh versus wilted truncheons

To determine the effect of desiccation (wilting) on survival and growth rate of spekboom, a comparison was undertaken using truncheons harvested immediately prior (i.e. one day before) to planting and truncheons wilted for one month before being planted (see Table S1). Specifically, 20 freshly harvested truncheons (10 unrooted and 10 rooted, 20–30 mm basal stem diameter) and 20 truncheons (10 unrooted and 10 rooted) that had been wilted for one month (1 September 2014 to 1 October 2014) were planted individually into 20-L bags. From October 2014 to April 2015, each truncheon received 4 L of water (equivalent to 81 mm of rain) either once, twice or three times during the eight-month period. The basal stem diameter and mass of each truncheon was measured and recorded on the day of planting, after five months and at the end of the experiment (i.e. eight months). A two-sample t test, assuming unequal variances and carried out in Microsoft Excel (2010), was used to compare the basal stem diameter growth of wilted versus freshly harvested truncheons after five and eight months. Measurements from truncheons which died