Tree seedling establishment among C_4 grasses

Edmund C February, Joel R Lewis

The coexistence of leguminous trees and C_4 grasses in African savanna remains poorly understood. Trees are able to establish among grasses despite grasses being competitively superior for below ground resources. Here we test the hypothesis that trees are only able to establish when grass biomass has been reduced.

We do this at four locations in Limpopo Province South Africa where we locate young seedlings of *Senegalia nigrescens*. Where we found seedlings we determine grass species composition as well as grass percentage canopy cover, height above ground, and root length. We also make determinations of grass characteristics at two locations where we found no seedlings. For seedlings we determine rooting depth, plant height and stem diameter. To confirm that these are indeed young seedlings, less than a year old, we compare root length and plant height with that of seedlings germinated and grown for 77 days in a greenhouse.

Our results show that where seedlings are present grasses are dominated by short-lived species such as *Aristida congesta* and *Enneapogan cenchroides.* These species are often found in disturbed soils and would increase with overgrazing. On those sites with no seedlings grass species composition is dominated by perennial species such as *Panicum maximum, Panicum coloratum* and *Cenchrus ciliarus* that would decrease with overgrazing and/or repeated burning. The perennial species have a 90-100% canopy cover while the short-lived species have a much lower canopy cover of less than 50%. Within 77 days of germinating tree seedlings are able to develop a root system that is deeper than the short-lived grasses but not deeper than the perennial grasses.

These results demonstrate that tree seedlings are only able to establish among grasses if there are gaps in both grass canopy and root mass resulting from increased herbivory, frequent fire or extended drought.

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2080v1 | CC-BY 4.0 Open Access | rec: 26 May 2016, publ: 26 May 2016

Tree seedling establishment among C_4 grasses

Edmund February* and Joel Lewis

Department of Biological Sciences, University of Cape Town, Private Bag, 7701, Rondebosch, South Africa.

* Corresponding author

e-mail: Edmund.February@uct.ac.za

Both authors contributed equally to this work.

Abstract

The coexistence of leguminous trees and C_4 grasses in African savanna remains poorly understood. Trees are able to establish among grasses despite grasses being competitively superior for below ground resources. Here we test the hypothesis that trees are only able to establish when grass biomass has been reduced.

We do this at four locations in Limpopo Province South Africa where we locate young seedlings of *Senegalia nigrescens*. Where we found seedlings we determine grass species composition as well as grass percentage canopy cover, height above ground, and root length. We also make determinations of grass characteristics at two locations where we found no seedlings. For seedlings we determine rooting depth, plant height and stem diameter. To confirm that these are indeed young seedlings, less than a year old, we compare root length and plant height with that of seedlings germinated and grown for 77 days in a greenhouse.

Our results show that where seedlings are present grasses are dominated by short-lived species such as *Aristida congesta* and *Enneapogan cenchroides.* These species are often found in disturbed soils and would increase with overgrazing. On those sites with no seedlings grass species composition is dominated by perennial species such as *Panicum maximum, Panicum coloratum* and *Cenchrus ciliarus* that would decrease with overgrazing and/or repeated burning. The perennial species have a 90-100% canopy cover while the short lived species have a much lower canopy cover of less than 50%. Within 77 days of germinating tree seedlings are able to develop a root system that is deeper than the weakly perennial grasses but not deeper than the perennial grasses.

These results demonstrate that tree seedlings are only able to establish among grasses if there are gaps in both grass canopy and root mass resulting from increased herbivory, frequent fire or extended drought.

Key words

Seedling establishment, savanna, below ground, above ground, resource competition.

Introduction

Savanna may be characterised as a discontinuous layer of trees set among a continuous layer of grasses (Scholes & Archer 1997). While the structure of savanna may change from lightly wooded grassland to dry woodland through changes in the relative proportions of these two life forms there is no consensus as to the primary drivers that determine the proportions of each (Sankaran et al. 2004). There is however general recognition that herbivory and fire may act as top-down control agents with the availability of nutrients and water as bottom up controls (Frost et al. 1986). Several hypotheses have been proposed explaining how these drivers may interact to set limits on tree cover in savanna (Sankaran et al. 2004). These hypotheses may be grouped into either resource based or disturbance based hypotheses both of which consider water availability as a critical determinant for savanna vegetation structure (Higgins et al. 2000; Walter 1971).

More recently it has been shown that the fine roots of both trees and grasses are primarily located in the upper layers of the soil where nitrogen concentrations are highest (February et al. 2013a; February & Higgins 2010). Several studies have also shown that grasses may outcompete juvenile trees for both nutrients and water (Bond 2008; February et al. 2013a). This superior ability for nutrient acquisition combined with high water and nitrogen use efficiency and a lack of woody tissue allow grasses to respond very rapidly at the beginning of the growing season when nitrogen and water become available (Bond 2008).

Here we make the distinction between seeds germinating and establishing as seedlings and juvenile trees establishing into adult size classes. We do this because once seedlings establish as juvenile trees these established trees may persist as juveniles for several decades caught in the grass layer through herbivory and fire (Bond & van Wilgen 1996). Even after their above ground structure has been killed by fire juvenile trees may re-sprout from the base by utilising stored reserves for growth (Schutz et al. 2011). These juvenile trees may be caught in a continuous negative feedback loop not reaching reproductive maturity even after several decades (Higgins et al. 2007). In this study we refer to seedlings that have recently germinated and established within the previous growing season.

Despite an apparent competitive advantage grasses do not prevent tree seedlings from germinating and establishing. Rather, over the past century there has been a global increase in woody vegetation cover with several studies suggesting that grasses have relatively little influence on woody seedling germination and establishment (Brown & Archer 1999; Ward 2005). More recently, however, it has been suggested that tree seedling establishment is not possible in dense grass swards and that it is only when grass biomass has been reduced through herbivory, drought or increased fire frequency and intensity that seedlings are able to establish (D'Odorico et al. 2006; February et al. 2013b; Wakeling et al. 2015).

We test this prediction in the field at four locations in Limpopo Province, South Africa, representing differing geologies, herbivory and disturbance by fire. We concentrate our study on the critical germination to establishment phase represented by young seedlings. To confirm that these were individuals around one year old that we have sampled we compare diameter, height and rooting depth to that of seedlings grown from seed for six months in the laboratory. We specifically ask: Under what circumstances are tree seedlings able to establish among grasses? We hypothesised that even at intermediate levels of grass biomass tree seedlings would not be able to establish because grasses are able to outcompete seedlings for both above and below ground resources (February et al. 2013b; Riginos 2009).

Methods

The study was comprised of two parts, the first was conducted in the field. The second was a seedling-growth experiment in the University of Cape Town's greenhouse. Field data were collected from 12 study sites in the Limpopo Province, South Africa between 12 May and 1 June, 2014 (middle of the dry season). The green house experiment was conducted between 21 July and 9 October, 2014.

Study site

Our study site is centred around and south of the town of Phalaborwa (23°56'36.07"S 31°8'27.50"E) in Limpopo Province, South Africa. The climate of the region is typified by a hot, wet, season and a cool, dry, season. Mean annual rainfall is 486 mm at Phalaborwa and 502 mm at Satara (24°23'38.00"S 31°46'37.45"E) 80 kms to the south east (Venter et al. 2003). Monthly maximum and minimum temperatures are 24°C and 18.5°C at Phalaborwa and 29.8°C and 16°C at Satara (February & Higgins 2010; Stevens et al. 2014). Rainfall is distinctly seasonal resulting in a growing season that starts at the end of October and ends in April (February et al. 2013b).

Our study was conducted at four locations, two Associated Private Nature Reserves (APNR) Grietjie Private Nature Reserve (24° 7'2.68"S, 31° 1'19.69"E), and Balule West Private Nature reserve (24°09'S, 30°59'E), the outskirts of the town of Phalaborwa (23°55'39.37"S, 31° 7'37.27"E) and in a section of the Buffalo enclosure near Satara rest camp in the Kruger National Park (24°24'22.41"S, 31°44'51.63"E). The APNR's are a group of privately owned reserves all bordering on the Kruger Park. There are no fences between the APNR's and the Kruger National Park allowing access for large herbivores such as elephant, rhino, buffalo and zebra.

The soils for Phalaborwa and the two sites immediately south of the town are derived from the underlying Phalaborwa igneous complex comprised of syanite and can be described as nutrient poor coarse sands (Barton et al. 1986). The soils at Satara are derived from the Letaba Formation basalts of the Karoo supergroup resulting in clay soils that are more nutrient rich (February & Higgins 2010; Scholes 1990).

Grietjie Private Nature Reserve is a 2, 800 hectare reserve bordering on the Kruger National Park at the Olifants River. Grietjie borders on Balule Private Reserve and as with all the APNR's has very high grazing pressure and a managed fire regime with a return interval of less than 3 years (Palmer et al. 2006; van der Waal et al. 2011). The vegetation for the area is classified as Lowveld Rugged Mopane veld by Mucina and Rutherford (2006) with *Senegalia nigrescens* and *Sclerocarya birea* subs. *caffra*, the dominant trees and *Aristida congesta, Enneapogon cenchroides* and *Sporobolus panicoides* the dominant grasses.

The town of Phalaborwa borders onto the Kruger National Park to the north of Grietjie near the confluence of the Selati and Olifants Rivers. We sampled on the edge of town where fire is suppressed and all grazing and herbivory has been excluded for several years. The vegetation for the area is also classified by Mucina and Rutherford (2006) as Lowveld Rugged Mopane veld.

Balule West Private Nature Reserve is a 40 000 hectare APNR bordering onto the Kruger National Park at the Olifants River to the south of Grietjie. The vegetation for the area is classified as Granite Lowveld by Mucina and Rutherford (2006) with *Senegalia nigrescens* and

Sclerocarya birea subs. *caffra*, the dominant trees and *Brachiaria nigropedata, Digitaria eriantha* subsp. *eriantha* and *Eragrostis rigidior* the dominant grasses.

The Buffalo enclosure is located close to Satara Rest Camp in the Kruger National Park. We sampled in a 7.7 hectare section of the enclosure that had been protected from fire and herbivory for 13 years (February et al. 2013b). The vegetation for the area is classified as Tshokwane-Hlane Basalt Lowveld by Mucina and Rutherford (2006) with *Senegalia nigrescens* and *Sclerocarya birea* subs. *caffra*, the dominant trees and *Bothriochloa radicans, Digitaria eriantha* subsp. *eriantha* and *Panicum coloratum* the dominant grasses.

Field sampling

Seedlings that are around one or two year old are extremely rare at our study site. To locate these we searched large areas of each location on foot. Where seedlings were located we set up a series of plots for measurements on both seedlings and grasses. We also set up a series of random plots for measures of grasses at two locations where we found no seedlings. This sampling technique resulted in 12 plots at our four locations, 5 at Grietjie, 4 at Phalaborwa, 2 at Balule and 1 in the Satara Buffalo enclosure.

On each plot we identified and visually estimated the percentage canopy cover of the dominant grass species in ten randomly located 1 m^2 quadrats (Mueller-Dombois & Ellenberg 1974). We then determined for a maximum of ten individuals of the dominant species on each plot height above ground, root length and stem diameter for tree seedlings and for grasses height above ground and root length. Stem diameter for seedlings was obtained, at ground level, using a steel rule. Height for both trees and grasses was determined by measuring the height of the plant from the soil surface to the highest point of the plant using a steel rule. Individual specimens of both tree seedlings and tufts of the dominant grass species were carefully excavated by hand to determine rooting depth. The length of the longest root was then measured from the base of the plant using a steel rule.

Seedling growth

We grew *Senegalia nigrescens* from seed in a greenhouse on the campus of the University of Cape Town. We did this as a calibration to ensure that our field sampled seedlings were indeed around one or two years old. For this we soaked 50 seeds overnight in warm water before placing these between layers of moist absorbent-paper. After three days all the seeds (13) that germinated were planted in pots (9 cm X 8 cm) filled with washed river sand (Consol filter sand, Cape Silica Suppliers, Cape Town) containing no organic matter. Seedlings were then left to grow for five weeks (36 days) before being transferred to larger (50 cm X 10 cm) pots filled with the same sand. At the time of this transfer, seedling height above ground, root length and stem diameter at the widest point were determined as described above. The seedlings were then left to grow for a further seven weeks (41 days) before harvesting and height above ground, root length and stem diameter determined again. During this time the seedlings were watered three times a week and received a twice weekly dose of 300 ml of fertilizer.

Statistics

We analysed the data from each site using simple regression. As our root-length data were not normally distributed a non-parametric Wilcoxon rank sum test was employed to test the means for significant difference. For age calibration the stem diameter and root length for field seedlings was used to estimate age by substituting the value into a linear model (with y-intercept = 0) created from glasshouse seedling data and solving for time (x-axis). Linear models were forced through zero to reflect germination from seed. The estimated ages of all seedlings were then used to calculate the average age of the seedlings based on stem diameter or root length found in the field. All statistical analysis were performed using R statistical software (R_Development_Core_Team 2011).

Results

The dominant tree species on all of our plots was *S. nigrescens* while the dominant grasses differed considerably between locations. At Grietjie these were *Aristida congesta subsp. Congesta, Enneapogon cenchroides* and *Tricholaena monachne.* At Phalaborwa *Panicum maximum*, *Cenchrus ciliarus*, and *Eriochloa meyeriana*. At Balule *Aristida congesta subsp. congesta, Sporobolous panicoides, Enneapogon cenchroides* and *Tricholaena monachne.* In the Buffalo exclosure at Satara *Panicum coloratum*, *Themeda triandra* and *Setaria sphacelata* (Table 1). All grass identifications follow the nomenclature of van Oudtshoorn (2002).

An increase in grass canopy cover from 36 % at Grietjie to 99 % at Phalaborwa is strongly correlated with an increase in grass sward average height from 52.9 cm at Grietjie to 92.6 cm at Satara (Fig. 1, Table 2, $R^2 = 0.66$). Our results also show that grass root length increased from 10.6 cm at Balule to 22 cm at Satara (Fig.1, Table 2, $R^2 < 0.001$).

There is a strong positive correlation between grass canopy cover and tree seedling density with the highest density of seedlings at Grietjie (50) and none at Phalaborwa and Satara (0, $R^2 = 0.92$, Fig. 1, Table 2). Where tree seedlings are able to establish these consistently root deeper than coexisting grasses (P<0.001, Table 2, Fig. 1). At Grietjie and Balule grasses root with a mean depth of 13.2 cm, while tree seedlings root with a mean depth of 27.6 cm (Fig. 1, Table 2).

The results of our greenhouse study show that stem diameters of seedlings are indistinguishable from field samples and after 60 days our greenhouse seedlings had root lengths and canopy height slightly lower than but similar to those found in the field demonstrating that our field samples are indeed less than a year old (Table 2).

Discussion

Our four sites represent different levels of fire and herbivory. The two APNR sites Grietjie and Balule have fire return intervals of less than 3 years with relatively high stocking rates (4 880 kg/km^2) when compared with our study site at Satara in the Kruger National Park and the outskirts of the town of Phalaborwa where there are no large herbivores (Palmer et al. 2006). Our results show that these differences in fire return intervals and herbivory have resulted in large differences in the dominant grass species on each of our plots. At Grietjie and Balule the dominant grasses *Aristida congesta* and *Enneapogon cenchroides* are species that increase with disturbance such as overgrazing (van Oudtshoorn 2002). At Satara and Phalaborwa where grazing is absent, the grass sward is dominated by *Panicum maximum*, *Panicum coloratum*, *Themeda triandra* and *Setaria sphacelata* which are all highly-palatable perennial grasses that grow for more than five seasons. These species also decrease with disturbance and overgrazing (Fish L. 2015; van Oudtshoorn 2002).

The perennial grasses at Satara and Phalaborwa root significantly deeper than the more ephemeral grasses at Grietjie and Balule. Our greenhouse data show that trees are able to develop a tap root averaging 15 cm long within 30 to 60 days after germination. This rooting depth is deeper than that of the annual or weakly perennial grasses at Grietjie (14.1 cm) and Balule (10.6 cm) but not deeper than the perennial grasses at Phalaborwa (16.3 cm) and Satara (21.7 cm). Not only are grasses deeper rooted at our Phalaborwa and Satara sites but the canopy cover at these sites is also close to 100% whereas, it is much lower at Grietjie (36%) and Balule (51%).

Our results demonstrate that tree seedlings are only able to establish when there has been a change in grass species composition and biomass resulting in a reduction in both above and below ground competition for resources. We demonstrate that this establishment is not possible in dense swards of perennial grasses where establishment opportunities may only be created through increased fire and herbivory or extended drought. Such disturbances may allow for a change in grass species composition resulting in gaps in both canopy and root mass (O'Connor et al. 2001; Wakeling et al. 2015).

The tree seedlings at our study site are rooting down to 28 cm which is even deeper than that of our perennial grasses. These results suggest that tree seedlings avoid competition for water by rapidly deploying roots below that of grasses. Several recent studies have demonstrated that trees do indeed use moisture from deeper soil layers than grasses and our results for rooting depth merely confirm this (Kambatuku et al. 2013; Kulmatiski & Beard 2012). A number of studies have however also shown that nitrogen is highest in the upper layers of the soil and that the competition between trees and grasses is in these upper layers of the soil for nutrients and not water (Cramer et al. 2010; February & Higgins 2010; February et al. 2013b). Tree seedlings have to establish fine roots in these upper soil layers primarily for nutrient acquisition. In African savannas, tree seedlings are able to form symbiotic relationships with bacteria to fix atmospheric nitrogen (Cramer et al. 2010). Once established however these trees no longer form this relationship (Cramer et al. 2007). Future research should focus on the role of nitrogen fixation in allowing for trees to establish roots in the upper layers of the soil where grasses are competitively superior.

Conclusion

Our results demonstrate that grass species composition is critical in allowing for seedling establishment in savanna where competitively superior C_4 grasses dominate the shallow nutrient-rich soil horizons. Tree seedling are only able to establish with a change in grass species composition allowing for gaps in grass biomass both above and below ground. They do this by very rapidly establishing a deep tap root that is able to access water below the grass root layer. Despite this seedlings have to access the upper layers of the soil for nutrients as this is where nutrients are highest (February & Higgins 2010). Future research should concentrate on understanding how this is possible with grasses dominating the upper layers of the soil (Bond

2008; February et al. 2013b). We hypothesis that many African tree seedlings are able to form symbiotic relationships with bacteria to allow for the uptake of atmospheric nitrogen (Cramer et al. 2007; Cramer et al. 2010). We speculate that once established with a deep root system for water these seedlings are able to use nitrogen fixation to avoid direct competition with grasses and establish more shallow roots primarily for nutrient acquisition.

Acknowledgments

We are grateful to Tony Swemmer of SAEON for useful discussion, advice as to where to sample and help with the grass identification. This research was made possible through permission by South African National Parks (Kruger Park Scientific Services), Liz Lewis and Peter Meyer of Grietjie and Craig Spencer, warden of Balule West Private Nature Reserve.

References

Barton JM, Bristow JW, and Venter FJ. 1986. A summary of the Precambrian granitoid rocks of the Kruger National Park *Koedoe* 29:39-44.

Bond WJ. 2008. What limits trees in C_4 grasslands and savannas? *Annual Review of Ecology Evolution and Systematics* 39:641-659.

Bond WJ, and van Wilgen BW. 1996. *Fire and Plants*. London: Chapman and Hall.

Brown JR, and Archer S. 1999. Shrub invasion of grassland: recruitment is continuous and not regulated by herbaceous biomass or density. *Ecology* 80:2385-2396.

Cramer MD, Chimphango SBM, Van-Cauter A, Waldram MS, and Bond WJ. 2007. Grass competition induces N_2 fixation in some species of African Acacia. *Journal of Ecology* 95:1123-1133.

Cramer MD, Van Cauter A, and Bond WJ. 2010. Growth of N_2-fixing African savanna Acacia species is constrained by below-ground competition with grass. *Journal of Ecology* 98:156-167.

D'Odorico P, Laio F, and Ridolfi L. 2006. A probabilistic analysis of fire-induced tree-grass coexistence in savannas. *The American Naturalist* 167:E79-E87.

February EC, Cook GD, and Richards AE. 2013a. Root dynamics influence tree–grass coexistence in an Australian savanna. *Austral Ecology* 38:66-75. 10.1111/j.1442-9993.2012.02376.x

February EC, and Higgins SI. 2010. The distribution of tree and grass roots in savannas in relation to soil nitrogen and water. *South African Journal Of Botany* 76:517-523. 10.1016/j.sajb.2010.04.001

February EC, Higgins SI, Bond WJ, and Swemmer L. 2013b. Influence of competition and rainfall manipulation on the growth responses of savanna trees and grasses. *Ecology* 94:1155-1164. 10.1890/12-0540.1

Fish L. MAC, Moecha M.J., Nembudani M.T. 2015. *Identification guide to the southern African grasses. Strelitzia 36.*: Pretoria: South African National Biodiversity Institute

Frost P, Menaut JC, Walker B, Medina E, and Solbrigo T. 1986. Responses of savannas to stress and disturbance. International Union of Biological Sciences Special Issue 10 Paris, France.

Higgins SI, Bond WJ, February EC, Bronn A, Euston-Brown DIW, Enslin B, Govender N, Rademan L, O'Regan S, Potgieter ALF, Scheiter S, Sowry R, Trollope L, and Trollope WSW. 2007. Effects of four decades of fire manipulation on woody vegetation structure in savanna. *Ecology* 88:1119-1125.

Higgins SI, Bond WJ, and Trollope WS. 2000. Fire resprouting and variability: a recipe for grass-tree coexistence in savanna. *Journal of Ecology* 88:213-229.

Kambatuku JR, Cramer MD, and Ward D. 2013. Overlap in soil water sources of savanna woody seedlings and grasses. *Ecohydrology* 6:464-473.

Kulmatiski A, and Beard K. 2012. Root niche partitioning among grasses, saplings, and trees measured using a tracer technique. *Oecologia*:1-13. 10.1007/s00442-012-2390-0

Mucina L, and Rutherford MC. 2006. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. Pretoria: South African National Biodiversity Institute

Mueller-Dombois D, and Ellenberg H. 1974. *Aims and methods of vegetation ecology*. New York: John Willey and Sons.

O'Connor T, Haines L, and Snyman H. 2001. Influence of precipitation and species composition on phytomass of a semi-arid African grassland. *Journal of Ecology* 89:850-860.

Palmer AR, Peel M, and Kerley G. 2006. Arid and semiarid rangeland production systems of Southern Africa: Wildlife. *Science et changements planétaires/Sécheresse* 17:362-370.

R_Development_Core_Team. 2011. *R: A language and environment for statistical computing*: R Foundation for Statistical Computing, Vienna, Austria.

Riginos C. 2009. Grass competition suppresses savanna tree growth across multiple demographic stages. *Ecology* 90:335-340. doi:10.1890/08-0462.1
Sankaran M, Ratnam J, and Hanan NP. 2004. Tree-grass coexistence in savannas revisited - insights from an examination of assumptions and mechanisms invoked in existing models. *Journal of Ecology* 7:480-490.
Scholes R. 1990. The influence of soil fertility on the ecology of southern African dry savannas. *Journal of Biogeography* 17:415-419.
Scholes RJ, and Archer SR. 1997. Tree-Grass Interactions in Savannas. *Annual Review of Ecology and Systematics* 28:517-544.
Schutz AE, Bond WJ, and Cramer MD. 2011. Defoliation depletes the carbohydrate reserves of resprouting Acacia saplings in an African savanna. *Plant Ecology* 212:2047-2055.
Stevens N, Seal CE, Archibald S, and Bond W. 2014. Increasing temperatures can improve seedling establishment in arid-adapted savanna trees. *Oecologia* 175:1029-1040.
van der Waal C, Kool A, Meijer SS, Kohi E, Heitkönig IM, de Boer WF, van Langevelde F, Grant RC, Peel MJ, and Slotow R. 2011. Large herbivores may alter vegetation structure of semi-arid savannas through soil nutrient mediation. *Oecologia* 165:1095-1107.
van Oudtshoorn F. 2002. *Guide to grasses of Southern Africa*. Pretoria, South Africa: Briza Publications.
Venter FJ, R.J. S, and H.C. E. 2003. The abiotic template and its associated vegetation pattern. In: DuToit JT, Rogers KH, and Biggs HC, editors. The Kruger Experience Ecology and Management of savanna heterogeneity. Washington: Island Press. p 519.
Wakeling J, Bond W, Ghaui M, and February E. 2015. Grass competition and the savanna-grassland 'treeline': A question of root gaps? *South African Journal Of Botany* 101:91-97.
Walter H. 1971. *Ecology of tropical and subtropical vegetation*. Edinburgh, UK.: Oliver and Boyd.
Ward D. 2005. Do we understand the causes of bush encroachment in African savannas? *African Journal of Range and Forage Science* 22:101-105.

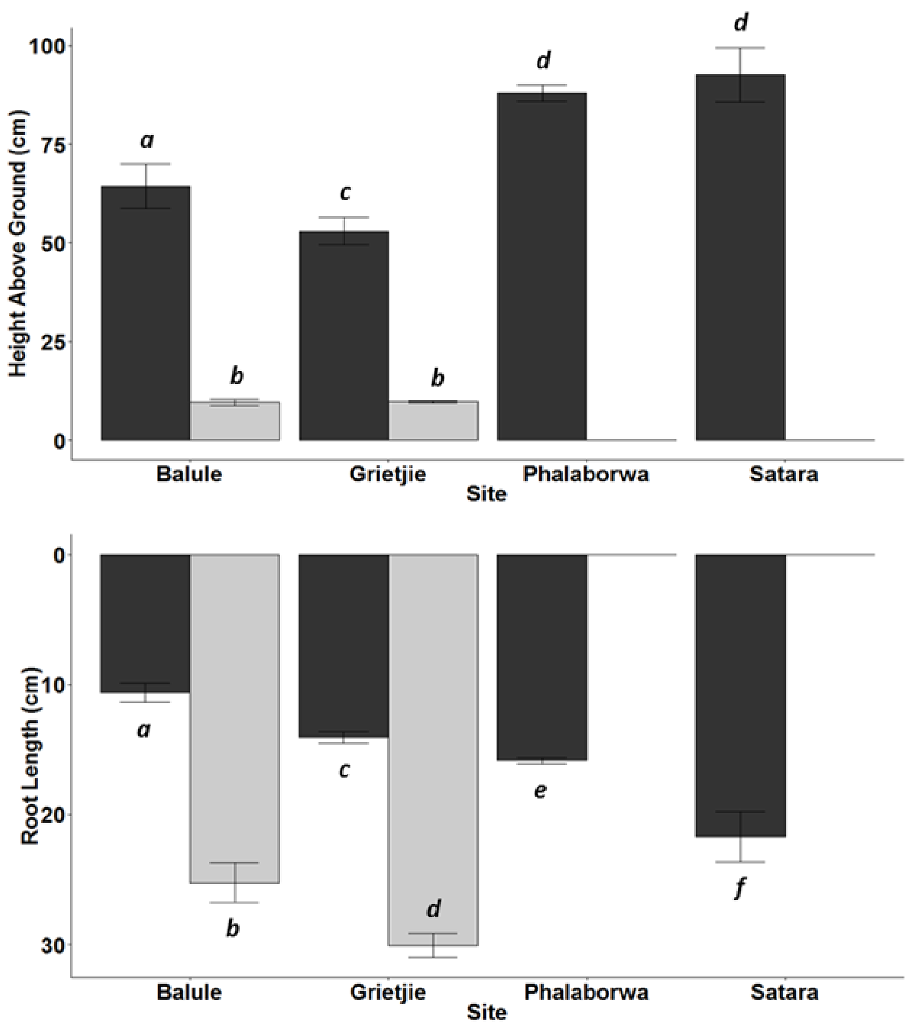

Figure 1. Plant height (top) and root length (bottom) for both trees (grey) and grasses (black) at the four locations at our study site (means ± S.E.). Values not sharing the same letters indicate significant differences (P<0.01) between means.

Table 1. Grass species composition at the four locations at our study site.

	Grietjie	**Balule**	**Phalaborwa**	**Satara**
Aristida congesta	X	X		
Enneapogon cenchroides	X	X		
Tricholaena monachne	X	X		
Sporobolous panicoides		X		
Panicum maximum			X	
Cenchrus ciliarus			X	
Eriochloa meyeriana			X	
Panicum coloratum				X
Themeda triandra				X
Setaria Sphacelata				X

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2080v1 | CC-BY 4.0 Open Access | rec: 26 May 2016, publ: 26 May 2016

Table 2. Averages and standard error for measured traits as determined on the four locations at our study site and in the green house after 60 days.

	Grietjie	**Balule**	**Phalaborwa**	**Satara**	**Greenhouse**
Number of seedlings	50	16	0	0	26
Number of grasses	50	20	40	10	0
Grass canopy cover (%)	36 ± 2.6	51 ± 6.0	99 ± 0.2	98 ± 1.0	N/A
Grass height (cm)	52.9 ± 3.5	64.4 ± 5.5	85.5 ± 2.1	92.6 ± 6.8	N/A
Grass root length (cm)	14.1 ± 0.4	10.6 ± 0.7	16.3 ± 0.2	21.7 ± 6.1	N/A
Seedling height (cm)	9.7 ± 0.3	9.6 ± 0.7	N/A	N/A	6.5 ± 0.2
Seedling root length (cm)	30.2 ± 0.9	25.3 ± 1.5	N/A	N/A	15 ± 1.2
Seedling stem diameter (mm)	2.4 ± 0.1	2.2 ± 0.1	N/A	N/A	2.5 ± 0.1

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.2080v1 | CC-BY 4.0 Open Access | rec: 26 May 2016, publ: 26 May 2016