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RESEARCH ARTICLE

Responses and recovery among seedlings of some arid land woody legumes under combined effects of sudden drought and nutrient stress

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Abstract: The present study investigated the combined effects of sudden drought and low soil nutrients on drought responses and recovery among seedlings of some leguminous species. Nutrient stress has negative effects on drought resistance of the plants. Further, drought responses and recovery capacity from sudden drought and nutrient stress differ among seedlings of different plant species. *Bauhinia Rufescens* and *Acacia nilotica* had the highest percentage (p=0.001) of re-sprouted leaves (mean: 92.6 and 136.0, respectively), and the least were found in *Faidherbia albida* and *Piliostigma thoningii* (27.1 and 47.5, respectively). *A. nilotica* and *B. rufescens* had significantly (p=0.001) lowest recorded number of dead seedlings with a total number of 2 and 0, respectively. The highest number of dead plants was recorded for *F. albida* (22) and *P. thoningii* (13). *B. rufescens, A. nilotica* and *P. reticulatum* are therefore recommended for rehabilitation purposes in the arid zones.

Keywords: *Acacia*, arid, bauhinia, drought, piliostigma, rehabilitation, re-sprouting.

INTRODUCTION

Arid zone ecosystems in the world cover about 40% of the Earth's land surface, and provide the major critical supports for human livelihood by provision of goods and services to over 2 billion people living in arid lands (James *et al*., 2013). The arid zone ecosystems also supports 50% of the world's livestock, harbour over a third of the global biodiversity hotspots, and is responsible for more than 45% of the global terrestrial carbon storage (James *et al*., 2013). However, the arid zone which is a dry land, is characterised by very high moisture deficits as a result of low and unpredictable rainfall, low soil nutrient availability and poor soil structure (Mganga *et al*., 2010). These abiotic factors make dry land ecosystems highly fragile and one of the most vulnerable to degradation and climate change. As a result, the arid lands (especially, in the developing countries) are currently facing a serious environmental crisis. Depletion and impoverishment of the arid land vegetation cover, coupled with land degradation and loss of soil fertility lead to decline of the ecosystem's primary productivity, loss of biodiversity and agricultural production (Mganga *et al*., 2010; Yirdaw *et al*., 2017). About 10–20% of the global dry lands are already estimated to be degraded with an additional annual rate of millions of hectares being degraded by climate change (James *et al*., 2013). Moreover, scientific forecasts have revealed that the menace of climate change will continue to be in the increase with greater occurrence of droughts and increasing aridity in the arid lands (He and Dijkstra, 2014). By implication, it is expected that the arid zone will continue to suffer from loss of vegetation, soil integrity, biodiversity, and other natural resources, which in turn will exacerbate the decline of agro-sylvo-pastoral productivity (Merine *et al*., 2015). Therefore, millions of people in arid lands are currently at a greater risk of loss of income, and shortage of food and water supplies (Bayen *et al*., 2016). These will undoubtedly increase the escalation of resource

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conflicts; human migration and environmental refuges; and thereby off-setting social order locally, nationally, regionally, and even globally (Gardner & Nicklas, 2007).

Afforestation, which is usually focused on the recovery of functional plant communities, is one of the major strategies for ecological restoration of degraded arid lands. Trees are known to have numerous positive impacts on their environment, which include hydrological balance, soil stability and nutrient enrichment, increased understory biodiversity, and, thereby regaining self-sustaining ecosystem with the provision of essential goods and services for human wellbeing (James *et al*., 2013). However, the arid land condition poses serious challenges to plantation programmes. Firstly, arid land is an environment of low moisture availability, and this is believed to be the master limiting factor that is responsible for low productivity in the arid zone. Further, the soils are usually low in nutrient and organic matter. These limit seedling growth, and in severe cases lead to seedling mortality (Hailemariam *et al*., 2017).

For these reasons the costs of establishing tree plantations in the arid lands are very high, making most countries in the arid zone reluctant to engage in afforestation programmes. Additionally, natural tree recruitment is nearly impossible due to the high seedling mortality owing to the arid land environmental cues (Simon, 2007). Scientists should therefore find a way to improve the success of afforestation programmes in dry lands especially by finding trees that can thrive in drier and low fertility soils, so as to minimise the cost of raising seedlings. For a tree species to be a candidate for restoration of degraded arid land, it should be drought resistant, able to survive and grow well on impoverished soils, produce greater vegetation cover in a relatively shorter period of time, and improve soil structure, fertility, organic matter content and microbial biomass (Bayen *et al*., 2016). For these reasons, the use of tree species that are native to dry land are becoming more attractive, because they proved to be more suitable for rehabilitation of degraded arid lands (Carpentera *et al*., 2004).

Although there are many studies on drought resistance of tree seedlings, comparative studies on the survival of seedlings of different tree species native to arid land, especially with regard to their responses to combine effects of sudden drought and low nutrients is still rarely investigated. Moreover, previous studies mainly used different water regimes to study drought resistance in plant. This may be far from the reality in nature, and may render the practical application of such results difficult. Therefore, the main aim of this study is to compare responses and recovery variations from sudden drought and nutrient stress among seedlings of different tree and shrub species that are native to the arid zone of Bauchi State of Nigeria. The study specifically focused on to find out how low soil nutrient level affects drought responses of seedlings by avoidance of leaf desiccation, and to investigate recovery from sudden drought through re-sprouting and avoidance of death. It was hypothesised that the nutrient stress will have negative effects on drought resistance of seedlings of woody plant species, and that responses and recovery from sudden drought and nutrient stress will differ among seedlings of different woody plants. The results will help in selecting more suitable tree species that are native to arid land to be used in restoration of degraded lands in the arid zones, which will help to reduce the cost implications of restoration programmes.

METHODOLOGY

Preparation of experimental soil

The top soil (about 15-20 cm deep) was collected from a farm that was continuously cultivated for more than 15 years and has become impoverished as indicated by poor crop yield. This soil was called degraded soil in this study. The second soil sample was also degraded soil but was amended with domestic waste dump soil at a ratio of 1:3 waste dump soil:degraded soil, and was called fertile soil in this study. The degraded soil was collected from a farm land in the Yelwa Campus of Abubakar Tafawa Balewa University (ATBU), Bauchi, Nigeria while the domestic waste dump soil was collected from Yelwa area of Bauchi town metropolis. Both soil samples were heated in boiling water (100 ^{o}C) for 1 hour and cooled before the experiment. About 1.2 kg of each soil was placed in 1.5 L plastic cups that were perforated at the bottom to avoid water logging. Each of the cups contained either the degraded soil or the fertile soil. The soils were analysed for their physico-chemical properties, which was conducted in Soil Science Laboratory of Faculty of Agriculture of the ATBU. The results of this soil analyses is presented in Table 1. The soil textural class was described following Groenendyk *et al*., (2015).

Table 1: Physico-chemical properties of the experimental soils used in this study

Soil type	K mg/L	N mg/L	P mg/L	Mg mg/L	Ca mg/L	OM %	pH	Soil texture			
								Sand	Silt	Clay	Class
Degraded soil	60	0.354	0.00	46.2	0.5	0.36	5.48	76.24	12.80	10.96	Loamy sand
Amended (fertile) soil	160	1.035	0.00	193.33	242	0.54	5.74	72.24	14.80	12.96	Sandy Loam
Waste dump soil	280	8.451	0.00	353	816.66	1.09	6.13	68.24	15.85	15.96	Sandy Loam

Table 2: Tree and shrub species to be used in the study

Scientific name	Authority	Family	Common name	Hausa name
Trees				
Acacia nilotica	(L.) Willd. ex Del	Leguminosae	Egyptian mimosa	Bagaruwa
Acacia senegal	(L) Willd	Mimosoideae	Gum arabic	Dakwara
Faidherbia albida	(Del.) A. Chev.	Fabaceae	Ana tree	Gao
Shrubs				
Bauhinia rufescens	Lam.	Caesalpinioideae	Silver butterfly tree	Dirga
Piliostigmareticulatum	(DC.) Hochst.	Caesalpiniaceae	Camel's foot	Kalgo
Piliostigmathoningii	(Schum.) Milne-Redh.	Caesalpiniaceae	Camel's foot	Kalgo

Preparation of seeds and planting

The plants used in this study include three tree species (*Acacia nilotica, Acacia senegal* and *Faidherbia albida*) and three different shrubs (*Bauhinia rufescens, Piliostigma reticulatum* and *Piliostigma thoningii*) (Table 2). Seeds of *A. senegal, F. albida* and *P. reticulatum* were collected near Maiduguri Town, which is situated in a semi-arid zone while the seeds of *A. nilotica, B. rufescens* and *P. thoningii* were collected near Bauchi Town in the northern guinea savanna, all in northeast Nigeria. The seeds were collected at the end of rainy season when they were matured, dried and abundant. Seeds were gently crushed and separated from the pod. Bigger seeds without any sign of wrinkle, damage or insect attack were selected for the study. To obtain a large number of simultaneously germinating seeds, seed dormancy was broken by scarification using concentrated H_2SO_4 for 30 - 50 min. The seeds were pre-germinated to the point of just the emergence of radicle. This was carried out inside plastic dishes containing clinical cotton wool that was soaked in tap water (Osonubi *et al*., 1992). The pre-germinated seeds were planted in the soils inside 1L plastic cups (11 cm wide and 11 cm deep) at a depth of about 2 cm. Initially, each cup contained four of the pre-germinated seeds but later reduced to two after successful germination with full emergence of shoots.

Experimental design and data collection

Seedlings of each of the six plant species were replicated in 24 perforated-bottom cups for both the degraded soil and the fertile soil. The cups were arranged in randomized complete block design (RCBD) in a screen house the ATBU. Each individual cup was tagged with letters and numbers using a permanent marker. The cups were arranged in such a way that the seedling inside would be described as either left or right side, such that individual seedlings could be identified. The plants were regularly watered at two-day intervals with about 500 mL of tap water. After 8 wk of growth, the number of leaves in each seedling was counted and recorded appropriately for individual plants as they were tagged. Watering was then withdrawn on the same day and the plants were subjected to drought for 7 d. At the end of the 7 d, the soil water content of each cup was measured using PMS 710 soil moisture meter and the values were recorded. Further, the number of dried (complete or partial) leaves were counted and appropriately recorded for individual plants as they were tagged. The plants were then watered again regularly for two more weeks. Number of newly sprouted leaves (including buds) at the nodes were counted and appropriately recorded for individual plants as they were tagged. Number of dead plants was also recorded. The dead plants were those with dry stem with no newly sprouted leaf or a bud.

Data analyses

The number of dried and newly sprouted leaves were converted to the percentages of the original number of leaves of their corresponding seedlings so as to validate comparisons among the different plant species. This is because number of leaves on the seedlings may naturally differ at the same age, e.g. *Piliostigma* spp. naturally have fewer leaves than *Acacia* spp. The data obtained were analysed using Minitab®18.1. Analysis of variance (ANOVA) was conducted followed by Tukey multiple comparison of means of dry leaves, re-sprouting (new budding leaves), and dead plants among different tree species of the same treatment (soil type) and among the same tree species in different treatments.

RESULTS AND DISCUSSION

In this study, responses and recovery variations from combined effects of sudden drought and low soil nutrients by analysing dry leaves, recovery by re-sprouting and death of plants was investigated among seedlings of different tree and shrub species that are native to arid zone. The plants include *Acacia nilotica, A. senegal*, *Faidherbia albida*, *Bauhinia rufescens, Piliostigma reticulatum* and *P. thoningii*. The results revealed that the degree of drought resistance by avoidance of leaf desiccation and the recovery ability differs among the different tree and shrub species and among the different soil types.

Leaf desiccation avoidance

In fertile soil *A. nilotica* and *A. senegal* had significantly (p = 0.001) higher percentages of dry leaves with the means 31.7 and 22.83, respectively (Table 3). *Bauhinia rufescens* had the significantly lowest percentage of dry leaves (6.90), followed by *F. albida* and *P. reticulatum* (6.5 and 6.74, respectively), which were not significantly different. The degree of drought resistance among the different tree and shrub species with regard to avoidance of leaf desiccation was in the order: *B. rufescens* > *F. albida* = *P. reticulatum* > *P. thoningii* > *A. nilotica* = *A. senegal.*

Table 3: One way analyses of variance for dry leaves at the end of drought period among different species of trees and shrubs grown in degraded soil and fertile soil. Significance level α = 0.05

Trees**	N	Mean*	SD	95% CI	p value
A. nilotica Fs	48	15.05 d	3.509	(13.68, 16.42)	0.001
A. nilotica Ds	48	14.13 d	5.033	(12.75, 15.52)	
B. rufescens Fs	48	16.92 bcd	3.170	(15.55, 18.29)	
B. rufescens Ds	48	21.39 a	6.520	(19.60, 23.19)	
F. albida Fs	48	15.35 cd	4.034	(13.98, 16.72)	
F. albida Ds	48	19.31 ab	6.910	(17.91, 20.71)	
A. senegal Fs	48	17.12 bcd	6.261	(15.74, 18.48)	
A. senegal Ds	48	13.96 d	4.775	(12.59, 15.33)	
P. reticulatum Fs	48	16.63 bcd	3.297	(15.26, 18.00)	
P. reticulatum Ds	48	18.71 abc	5.321	(17.034, 20.39)	
P. thoningii Fs	48	15.35 cd	3.036	(13.98, 16.72)	
P. thoningii Ds	48	17.253 abcd	5.319	(15.520, 18.99)	

* Within a column, the means followed by the same letter are not significantly different at p = 0.05.

** Fs = fertile soil; Ds = degraded soil

In degraded soil, *B. rufescens* had the significantly (p = 0.001) lowest percentage of dry leaves (16.01) followed by *A. senegal* (65.65), while *A. nilotica* had the highest (88.06). The degree of drought resistance among the plants in degraded soil was in the order: *B. rufescens* > *A. senegal* > *F. albida* = *P. reticulatum* = *P. thoningii* > *A. nilotica.*

Results of the two-sample t-test analyses of dry leaves of plants of the same species that were grown in different soil types (fertile and degraded soils) show that there was no significant difference (p = 0.160) between the seedlings of *B. rufescens* that were grown in fertile soil and degraded soil (Table 4). However, there were significant (p = 0.001) differences between seedlings of the rest of the 5 trees and shrubs (*A. nilotica, F. albida, A. senegal, P. reticulatum, P. thoningii*) grown in fertile soil and degraded soil. These indicate that *B. rufescens* was the only plant whose drought tolerance, in terms of drying leaves, was not affected by low soil fertility.

Table 4: Two-sample t-test for dry leaves among different species grown in degraded soil. Significance level α = 0.05

Factor	*Mean (dry leaves)	SD	95% CI	p value
A. nilotica				
Degraded soil	88.1	27.5	(44.46, 68.27)	0.001
Fertile soil	31.7	30.8		
B. rufescens				
Degraded soil	15.0	31.8	(-3.29, 19.44)	0.160
Fertile soil	6.9	12.3		
F. albida				
Degraded soil	75.6	39.1	(57.23, 80.90)	0.001
Fertile soil	6.6	11.8		
A. senegal				
Degraded soil	65.7	39.7	(29.56, 56.10)	0.001
Fertile soil	22.8	23.6		
P. reticulatum				
Degraded soil	79.8	36.9	(61.45, 84.72)	0.001
Fertile soil	6.7	13.4		
P. thoningii				
Degraded soil	68.4	43.4	(29.06, 61.36)	0.001
Fertile soil	23.2	29.2		

In this study, it was assumed that the higher the percentage of dry leaves of a particular species, the lower its drought resistance. For plants grown in fertile soil, *A. nilotica* and *A. senegal* showed the least drought resistance, and the highest drought resistance was observed in *B. rufescens* followed by *F. albida,* while *P. reticulatum* and *P. thoningii* were moderate in terms of the percentage of dry leaves. The degree of drought resistance with regard to dry leaves among these plants was also found to be in the same order for the plants grown in degraded soil, except for the *A. senegal*. In fertile soil *A. senegal* was one of the least drought resistant plants but it turned out to be higher than the rest of the plants (except *B. rufescens*) in degraded soil. Results of this study also revealed that low soil fertility did not affect drought resistance of *B. rufescens* but the rest of the five species (*A. nilotica, F. albida, A. senegal, P. reticulatum, P. thoningii*) were negatively affected with regard to their drought resistance. Therefore, *B. rufescens* emerged as the highest drought resistant plant among the species for having the least percentage of dry leaves at the end of the drought exposure in both fertile and degraded soils. Studies revealed that there is a strong connection between water stress, soil nutrients and plant growth. Plants under water stress have less access to soil nutrients, which leads to significant decline in growth rates (Merine *et al*., 2015). When the soil is rich in nutrients, plants do not expend much carbon and energy on root development (Daldoum & Hakim, 2013). This can have negative effects on their drought resistance when exposed to sudden water stress. It was also found that high soil nutrients, particularly nitrogen, can decrease the drought resistance of plants (Nilsen, 1995). Although it is difficult to explain with certainty why higher soil nutrient levels lower drought resistance, it is possible that plants growing in nutrient rich soil have faster growth rates (Merine *et al*., 2015), which means they have higher number of dividing (meristematic) cells. The meristematic cells are the youngest plant cells and should be expected to be more vulnerable to sudden drought stress. Low soil nutrient, especially nitrogen, is known to speed up ageing of cells. Older plants are seemed to be more resistant to environmental stress. However, it was also found that nutrient-rich soil produces more healthy plants, which have greater resources and the ability to produce features that are required to cope with water stress (Fischer, 2004). Nilsen (1995) stressed that there is an optimal level of soil nutrients for positive effects on drought resistance, and this level may be species-specific. But knowledge of generalised optimal levels of soil nutrient that give positive effects on drought resistance of different plants is still at large (Merine *et al*., 2015). This is as a result of methodological differences in drought stress experiments, which lead to inconsistent results with unclear relationships (He & Dijkstra, 2014).

The assumption that higher number of dry leaves at the end of the drought stress period is an indication of lesser drought resistance may not be true with all species. It should be noted that strategies employed by plants to cope with drought shocks differ among different plant species and therefore their responses can also differ. The sequence of responses by plants to cope with drought stress usually start with stomatal closure (Basu *et al*., 2016). This brings about a reduction of the stomatal carbon conductance and therefore, reduction of photosynthesis, which lead to drying or even death of leaves (Avramova *et al*., 2015). In some species drought stress conditions trigger early leaf senescence (Lyon *et al*., 2016) and subsequently leaf shedding so as to achieve water conservation by reduction in transpiration (drought deciduous species). In other species, plants form hard leaves (sclerophylly) as counter-drought stress adaptation to avoid permanent leaf damage as a result of the reduction in cells, turgor pressure but restore their complete functionality on the resumption of water availability (Basu *et al*., 2016). Sclerophyllous plants maintain their cells' turgor pressure during drought stress through osmotic adjustment, i.e., by accumulating solutes in their dividing cells which maintains their stomatal conductance and subsequently, photosynthesis and growth (Basu *et al*., 2016). In this study seedlings of *B. rufescens*, *P. reticulatum* and *P. thoningii* appeared to be or remained sclerophyllous in response to drought stress. However, but there is no certainty whether the drying and subsequent heavy leaf shedding in *A. nilotica, F. albida* and *A. senegal* is a strategy to withstand drought stress or whether it is just the process of dying. Hélène and Dreyer (1998) also observed rapid stomatal closure and leaf shedding on potted seedlings of *A. albida* under drought stress. To confirm whether or not the leaf shedding is an indication of drought resistance the recovery of the plants affected by drought was analysed by observing budding or re-sprouting of new leaves after the drought stress.

Recovery by re-sprouting and death avoidance in degraded soil

The result of new re-sprouted leaves (and buds) after drought period in degraded soil show that *A. nilotica* and *B. rufescens* have the highest percentage of new leaves with the mean of 92.6 and 136.0, respectively (Table 5). Lowest number of new leaves was recorded in *F. albida* (27.1) and *P. thoningii* (47.5). The ability to recover from drought shock through re-sprouting among the different plant species was in the order: *A. nilotica = B. rufescens > P. reticulatum > A. senegal > P. thoningii > F. albida.* Dead plants were those seedlings that failed to show any sign of recovery through production of new buds and their stems were completely dry after two week of regular watering at the end of the drought period. Dead plant analysis revealed that *A. nilotica* and *B. rufescens* have the lowest recorded number of dead seedlings with a total number of 2 and 0, respectively. The highest number of dead plants was recorded for *F. albida* (22) and *P. thoningii* (13). The recovery ability of the plants from drought with regard to dead plants among the different species of trees and shrubs was in the order: *B. rufescens > A. nilotica > P. reticulatum > A. senegal = P. thoningii > F. albida.*

Table 5: Mean number of dead plants and re-sprouting among different plant species grown in degraded soil

Trees	N	Dead plants	Mean	StDev
Re-sprouting analyses				
A. nilotica	39		92.6	72.10
B. rufescens	4		136.0	37.20
F. albida	34		27.1	43.31
A. senegal	24		59.1	61.20
P. reticulatum	35		68.1	52.28
P. thoningii	30		47.5	50.02
Dead plant analyses				
A. nilotica	39	2	0.05	0.22
B. rufescens	4	0	0.00	0.00
F. albida	34	22	0.65	0.49
A. senegal	24	11	0.46	0.51
P. reticulatum	35	9	0.26	0.44
P. thoningii	30	13	0.43	0.50

The analysis of recovery ability of these plants through budding (or sprouting of new leaves) following re-watering after the drought period in degraded soil showed the levels of drought resistance exhibited by the plants. Re-sprouting occurs by the production of new buds following activation of apical, basal or below-ground meristematic tissues (Zeppel *et al*., 2014). It is assumed that higher percentage of newly sprouted leaves (including buds) upon resumption of watering after the drought period indicates higher drought resistance. *B. rufescens* retained its position as the highest drought resistant species among the plants. But *A. nilotica*, which was regarded as the least drought resistant in terms of number of dry leaves, turned out to be more drought resistant than the rest of the four species (*F. albida, A. senegal, P. reticulatum P. thoningii*), and it was statistically similar *B. rufescens* in terms of recovery by re-sproutung. This is a confirmation that drying (or death) of leaves in *A. nilotica* was an adaptation for drought resistance to reduce transpiration rate and conserve water (Lyon *et al*., 2016). Further, *F. albida,* which performed relatively better than the other four species in terms of avoidance of leaf desiccation, turned out to be least drought resistant among all the plants in terms of production of new buds after drying of leaves. This also confirmed that the heavy drying and shedding of leaves in *F. albida* was an expression of drought susceptibility and a dying process (Avramova *et al*., 2015). The ability of these plants to recover from drought shock through re-sprouting is in the order: *B. rufescens* = *A. nilotica* > *P. reticulatum* > *A. senegal* > *P. thoningii* > *F. albida.* The extent and magnitude of recovery may be partial, full or over-compensatory (Xu *et al*., 2010). These were observed among the individuals of all the species, where the percentage of re-sprouting was less, equal to or more than 100 % of the original number of the dead leaves.

Analysis of the number of dead plants also exhibited the degree of drought resistance among these plants. Dead plants were those seedlings that failed to show any sign of recovery through production of new buds and their stems was completely dry after two week of resumption regular watering at the end of the drought period. Greater severity and/or duration of drought stress can irreversibly damage plant tissue apparatus, which can lead to the death of the plant in severe cases (Xu *et al*., 2010). Here it is also assumed that the higher the number of dead plants among seedlings of a species, the lesser the drought resistance of that particular species. There were no deaths recorded among the 48 seedlings of *B. rufescens* involved in this study. Among the rest of the five species, *A. nilotica* had the lowest recorded number of dead seedlings which was two. *F. albida* proved to be the least drought resistant among all the species with the highest number of dead plants, which was 22 out of 48 seedlings. It was followed by *P. thoningii* while *P. reticulatum* and *A. senegal* showed the moderate resistance, with *P. reticulatum* being more drought resistance than *A. senegal.* The drought resistance among the six species of trees and shrubs as revealed by considering the number of dead plants can be summarised as follows: *B. rufescens* > *A. nilotica* > *P. reticulatum* > *A. Senegal* = *P. thoningii* > *F. albida.* This is similar to their recovery ability from drought shock through re-sprouting. Simon (2007), who studied the effects of different water regimes on the growth of *A. nilotica, A. senegal* and *A. albida,* found that seedlings of *A. nilotica* produced greater biomass and utilised more water than *A. senegal* and *A. albida* in non-droughted and moderately-drought stressed conditions. It was also found that *A. albida* was more severely affected by drought stress than the other species. This is in line with the results of the present study. *A. senegal* was also found to tolerate high water stress (Merine *et al*., 2015), but it was less water resistant compared with some species in this study. Xu *et al*. (2010) stressed that the recovery capacity of plants after stress varies with species. The recovery potential of a plant after stress depends on the intensity and/or duration of the stress, which affects the plant's capacity to repair damaged cells (Ruehr *et al*., 2019). In general, more intensity and/or duration of water stress result in a less or slower recovery process and the rate of this recovery again depends on species. Additionally, the plant's health condition before the drought stress also effects its capacity to recover after re-watering (Xu *et al*., 2010). Ruehr *et al*. (2019) further explained that repair of damaged tissues or production of new ones after drought-induced senescence places demands on stored non-structural carbon and other compounds. However, if these compounds failed to provide sufficient energy and carbon for the recovery process, the plant will die.

Soil water consumption

To assess the pattern of soil water consumption among the plants with regard to soil type, analysis of soil water content of fertile and degraded soils at the end of the drought period was conducted. The results revealed that the soil water content depends on soil type and the plant species growing in it. Fertile soil, which contains higher organic matter and in which there was no any dead seedlings, have significantly ($p = 0.001$) lower water content than degraded soil for all the plant species except for *A. senegal* where the fertile soil had significantly more water content (mean = 17.12) than degraded soil (13.96) (Table 6). Also, both the fertile and degraded soils with *A. nilotica* have statistically the same water content (15.05 and 14.13, respectively). In fertile soil, *A. nilotica* has the significantly lowest soil water content among the species with the mean value of 15.05, followed by *F. albida* and *P. thoningii,* which had the same water content (15.35). Highest water content was recorded for *A. Senegal* (17.12) *B. rufescens* (16.92) and *P. reticulatum* (16.63), which were not statistically different. The significant difference in soil water content among the different species in fertile soil was in the order: *A. senegal* = *B. rufescens* = *P. reticulatum* > *F. albida* = *P. thoningii* > *A. nilotica.* In degraded soil, a significantly higher water content was recorded for *B. rufescens* (21.39) followed by *F. albida* (19.31) while the lowest were recorded for *A. senegal* (13.96) and *A. nilotica* (14.13), which were not statistically different. The significant difference in soil water content among the different species in degraded soil was in the order: *B. rufescens* > *F. albida* > *P. reticulatum* > *P. thoningii* > *A. senegal* = *A. nilotica.*

Table 6: One way analyses of variance for soil water content of fertile and degraded soils at the end of the drought period. Significance level α = 0.05.

Trees	Mean*	SD	95 % CI	p-value
Fertile soil				
A. nilotica	31.70 a	30.76	(25.32, 38.08)	0.001
B. rufescens	6.90 bc	12.33	(-1.37, 15.17)	
F. albida	6.57 c	11.80	(0.12, 13.03)	
A. senegal	22.83 a	23.61	(16.51, 29.14)	
P. reticulatum	6.74 c	13.39	(-0.99, 14.48)	
P. thoningii	23.17 ab	29.16	(15.44, 30.91)	
Degraded soil				
A. nilotica	88.06 a	27.53	(77.60, 98.53)	0.001
B. rufescens	16.01 c	32.30	(5.54, 26.47)	
F. albida	75.64 ab	39.09	(65.17, 86.11)	
A. senegal	65.65 b	39.66	(55.19, 76.12)	
P. reticulatum	79.83 ab	36.86	(69.36, 90.29)	
P. thoningii	68.39 ab	43.38	(57.92, 78.85)	

* Within a column, the means followed by the same letter are not significantly different at p = 0.05.

Furthermore, analysis of soil water content of fertile and degraded soils at the end of the drought period can also assist the interpretation of pattern of drought resistance manifested among the plant species. One of the main functions of organic matter in soil is to maintain higher holding capacity (Daldoum & Hakim, 2013). Despite having higher organic matter content, the fertile soil in this study has lower water content than the degraded soil. This is consistent with all the plant species, except for *A. senegal* where the fertile soil had significantly more water content than degraded soil. The differences in water content among the soils of different plant species at the end of the drought period suggest that loss of soil water was significantly through transpiration than by direct evaporation from the soil. A healthy plant is expected to have a large number of leaves and leaf area, root density and more active physiological activities. Hence, there will be greater water demands and transpiration rate (Daldoum & Hakim, 2013). Higher water consumption is therefore expected to be by the plants growing in fertile soil, which leads to lower water content in that soil. In *A. nilotica* both fertile and degraded soils have the same water content. In fertile soil, *A. nilotica* has significantly the lowest soil water content among the species, followed by *F. albida* and then *P. thoningii*, while the highest water contents were recorded for *A. senegal, B. rufescens* and *P. reticulatum*, which were not statistically different. The significant difference in soil water content among the different species in fertile soil was in the order: *A. senegal* = *B. rufescens* = *P. reticulatum* > *F. albida* = *P. thoningii* > *A. nilotica.* In a degraded soil, a significantly higher water content was recorded in *B. rufescens* followed *F. albida*, while the lowest were recorded for *A. senegal* and *A. nilotica*, with the mean of 13.96 and 14.13, respectively, which were statistically similar. The significant difference in soil water content among the different species in degraded soil was in the order: *B. rufescens* > *F. albida* > *P. reticulatum* > *P. thoningii* > *A. senegal* = *A. nilotica*. Considering the soil water status in both fertile and degraded soils, it can be concluded that *B. rufescens* is generally a low water consuming plant, and *A. nilotica* is a high-water consuming species in relation to the other species, while *P. reticulatum* is moderate. Water consumption of *F. albida* and *A. senegal* depends on the soil nutrient status. It appeared that *A. senegal* produced higher biomass in fertile soil and therefore consumed more water than in degraded soil. Water requirement for growth generally differs among plants of different species, growth stage and prevailing weather conditions (Daba & Tadese, 2017), but it is possible that it also depends on the health status of a plant.

CONCLUSION

In conclusion, the degree of drought resistance and recovery ability differ among the different woody species and nutrient stress has negative effects on drought resistance of the plants. By avoidance of leaf desiccation, highest drought resistance was observed in *B. rufescens* followed by *F. albida.* Further, *B. rufescens* and *A. nilotica* have the highest re-sprouting ability. However, the heavy shedding of leaves in *A. nilotica* in response to drought was found to be a mechanism of adaptation for drought resistance to reduce transpiration rate and conserve water. These results have implications for rehabilitation of degraded arid land, and *B. rufescens, A. nilotica* and *P. reticulatum* are recommended for this purpose.

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