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Diurnal Photosystem II Photochemical Efficiency and Biomass Partitioning in *Acacia mellifera* and *Acacia laeta* Seedlings Under Drying Soil

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Abstract

Aim of study: The study aimed to assess the impact of drying soil on diurnal photochemical efficiency of photosystem II and biomass partitioning of the seedlings of *Acaia mellifera* (Mf) and *Acacia laeta* (Lt).

Study area: The study was conducted at the nursery of Department of Forestry & Range Sciences, Faculty of Environmental Sciences and Natural Resources, University of Al Fashir, North Darfur, Sudan.

Materials and methods: Thirty-six seedlings of two-months old per each species were selected for study. A half of seedlings per species was kept well-watered and the other was exposed to five drought cycles before exposed to continuous drying.

Main results: The results of chlorophyll fluorescence study were indicated that both species are capable to maintain sound photosynthetic machinery throughout the course of measurements. Mf manifested higher biomass production compared to Lt in control seedlings. Conversely, repeated drying cycles techniques were likely improved growth and production in Lt. Strong negative relationships were established between ΔF/Fm' and incident photosynthetically active radiation (PAR), and between Fv/Fm and leaf temperature (T).

Highlights: Under the intermittent irrigation conditions during dry season in general *A. mellifera* would show better growth hence greater potentials for live fence and afforestation purposes in semi-arid environments compared to *A. laeta*.

Keywords: Chlorophyll fluorescence, dry matter allocation, water stress, *Acacia mellifera*, *Acacia laeta*

Acacia mellifera ve *Acacia laeta* Fidanlarinda Kurak Toprakta Diurnal Fotosistem II Fotokimyasal Verim ve Biyokütle Bölümlenmesi

Öz

Çalışmanın amacı: Çalışmada, kurak toprağın fotosistem II'nin diürnal fotokimyasal etkinliği üzerindeki etkisi ve *Acaia mellifera* (Mf) ve *Acacia laeta* (Lt) fidanlarının biyokütle bölümlenmesinin değerlendirilmesi amaçlanmıştır.

Çalışma alanı: Araştırma, Sudan'ın Kuzey Darfur Eyaletinde, Al Fashir Üniversitesi Orman ve Çevre Bilimleri Fakültesi, Çevre Bilimleri ve Doğal Kaynaklar Fakültesinde yürütülmüştür.

Materyal ve yöntemler: Her bir tür için iki aylık 30 adet fidan çalışma için seçildi. Tür başına fidanların yarısı iyice sulandı, ve diğer yarısı tam kuraklığa maruz kalmadan önce beş farklı kuraklık derecesine maruz bırakılmıştır.

Sonuçlar: Klorofil flüoresans çalışmasının sonuçları, her iki türün ölçümler boyunca fotosentez mekanizmalarını koruyabildiğini göstermiştir. Mf, kontrol fidelerinde Lt'ye kıyasla daha yüksek biyokütle üretimi gösterdi. Diğer taraftan, tekrarlanan kuraklık döngü teknikleri muhtemelen Lt'nin büyüme ve gelişmesini arttırmıştır. ΔF/Fm ve photosynthetically aktif radyasyon (PAR) arasında, ve Fv/Fm ve yaprak sıcaklığı (T) arasında kuvvetli negatif ilişki tespit edilmiştir.

Önemli vurgular: Kurak mevsimde genel olarak aralıklı sulama koşullarında A. mellifera, daha iyi bir büyüme gösterecektir, ve bu nedenle, A. laeta'ya göre yarı kurak ortamlarda canlı çit ve ağaçlandırma amacı için daha uygun olduğunu göstermiştir.

Anahtar Kelimeler: Klorofil flüoresan, kuru madde dağılımı, Su stresi, *Acacia mellifera, Acacia laeta*

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Introduction

The growth and conservation of acacia trees in arid and semi-arid areas is essential for agricultural lands amelioration and animal survival. During periods of drought when cereal crops and grass may fail to grow, acacia trees can be relied on to provide fodder for livestock and various products for mankind and environmental services in sub-Sahara Africa (Hayward, 2004; Hussein, 2006). Therefore, sustainable management of acacia woodland is a priority task in some African countries (Eshete and Stahl, 1998). *Acacia mellifera* (Vahl) and *Acacia laeta* (R.Br. ex) Benth are wide-spread in dry African savanna; tend to be suitable trees or shrubs for agroforestry and establishment of live fences and hedges and serve as boundary demarcation between farms (Vogt, 1995; Hussein, 2006; Orwa, Mutua, Kindt, Jamnadass & Simons, 2009). In Sudan their occurrence extends on clay or sandy loam soil from eastern parts at the border with Ethiopia to westwards up to border with Chad. *Acacia mellifera* and *Acacia laeta* often coexist and being confused to differentiate between them. *A. mellifera* flourishes where the mean annual rainfall exceeds 300mm growing up to 6 m, and *Acacia laeta* grows under mean annual rainfall 250-750 mm up to 4-10 m.

During last decades the recurrent drought and misuse of land have caused degradation in natural vegetations in semi-arid Sudano-Sahelian zone (Karlson and Ostwald, 2016) including acacia tree species (Eltayb and Mohamed, 2013). Dryland forests which encompass vast area of Africa (Tesfaye and Negash, 2018), became the most threatened ecosystems and the climatic forecasts suggest that drought occurrence could threaten further the livelihood of millions of people (UNEP, 2007; Chen and Cheng, 2009; FAO, 2012; Lina and Eloisa, 2018). In order to restore degrading tree species, their physiological and morphological traits such as photosynthetic performance and photosynthate partitioning under drying conditions must be understood. Gas exchange and chlorophyll fluorescence are particularly sensitive to the effects of water deficiency and other stresses and can be used in elucidating plant adaptation mechanisms to harsh conditions (Liu et al., 2003; Siam, Radoglou, Noitsakis & Smiris, 2008; Hopkins and Huner, 2009). Vegetation structure, productivity and survival controlled by various processes that influence photosynthetic capacity to regulate functional activities (Jones, 1979; Vilagrosa, Bellot, Vallejo & Gill-Pelegrin, 2003; Tikkanen and Aro, 2012; Mathur and Jajoo, 2014; Axelsson and Hanan, 2017; Nolan et al., 2018). Photosystem II adjustment has been used as important indicator of environmental stresses and demonstrates at any time the stability or state of photosynthetic machinery (Tenhunen, Beyschlag, Lange & Harley, 1987; Taiz and Zeiger, 2002; Liu et al., 2003; Balaguer et al., 2002; Shirke and Pathre, 2003; Martinazzo, Ramm & Bacarin, 2012). Chlorophyll fluorescence provides potentials to estimate photosynthetic machinery state under conditions in which other methods would fail (Maxwell and Johnson, 2000; Li, Pezeshki & Goodwin, 2004).

Plant growth and productivity particularly young seedlings are determined by water deficit in arid and semi-arid environments (Kramer and Boyer, 1995). Therefore, drought tolerance should be evaluated at seedling stage to screen out the hardy species (Johnson, 1980). Plant that produces more biomass than the other species would show greater potentials for use as multipurpose tree in semi-arid area of Senegal (Deans et al., 2003). Understanding how the growth of *A. mellifera* and *A. laeta* seedlings respond to episodic soil drying conditions perhaps help us to manage the plantation activities in water-stressed environments. This study would provide information on growth performance and endurance of young seedlings of two acacias to water stress during early life stage. Thus, it addresses wide range of plant scientists particularly eco-physiologists as well as policy makers and other stakeholders to be aware of tree seedling physiological patterns in sahelian Africa and other similar environments for further researches and informed exploitation. As we know, no studies have been done on the comparative study of seedling photosystem II photochemical efficiency between *Acacia* *mellifera* and *Acacia laeta* in dry environment of Sudan.

The study aimed to test photosynthetic machinery capacity and growth patterns of the *A. mellifera* and *A. leata* seedlings under water deficit conditions and the specific objectives were: (1) to assess the impact of drying soil on diurnal photochemical efficiency of phtosystem II, and (2) to evaluate the effect of repeated soil drying on biomass production of seedlings of *A.mellifera* and *A.leata*.

Materials and methods

Location and environmental condition of the study area

The study conducted at the nursery of Department of Forestry & Range Sciences, Faculty of Environmental Sciences and Natural Resources, University of Al Fashir, North Darfur State – Sudan. El Fasher lies at latitude 13° 38' N, longitude 25° 20' E, and altitude 740 m above sea level (Fig.1). The climate of North Darfur is arid in the north and semi- arid in the south parts. Magnitudes of rainfall range from zero in the north to 500 mm/year in the south parts and the mean temperature of area is 36.6˚C. Soil type is mainly sandy found either in stabilized or moving dunes. The main feature of vegetation is desert and dry savanna annual grasses and perennial woody stunted trees and shrubs with few broadleaved tree species around water courses.

Assessment of chlorophyll fluorescence and biomass of seedlings

Thirty six seedlings of two-months old per each species of *Acacia mellifera* (Mf) and *Acacia laeta* (Lt) grown in large polythene bags (20 cm in diameter and 40 cm in height) were selected for the experiment. Polythene bags were filled with a mixture of clay and sand (2:1) soil by volume respectively as planting medium. Bags were placed under partial shade then transferred to full sun light on open yard. A randomized complete block design with three blocks and six replicates was applied. A half of seedlings per species was kept well watered (control, W+) and the other was subjected to water stress (W). The control seedlings were irrigated every day, while the water stress seedlings were exposed to five drought cycles (3days, 5days, 7days, 3days, and 4days). Re-watering of seedlings depends on the first appearance of visible wilting sings during the day compared to control seedlings. After the last drought cycle both control and stressed seedlings were subjected to continuous drying for eighteen days starting from 30/7/2016. Diurnal photochemical efficiency of photosystem II was measured on 30/7/2016, 7/8/2016, and 16/8/2016 as described below. Thereafter the dry biomass assessment was performed.

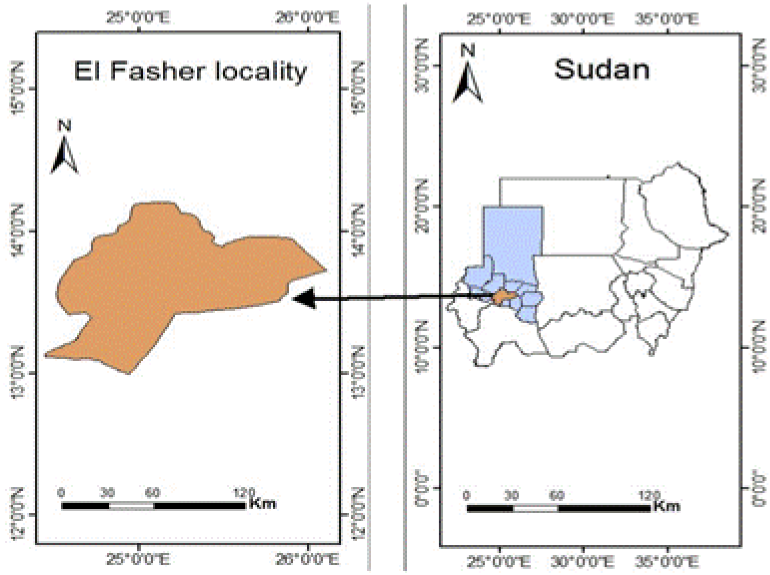

Figure 1. Map shows country, state and locality of study area

Photochemical Efficiency of photosystem II

Three seedlings / species / replicate / treatment were selected randomly to assess photochemical Efficiency of photosystem II (Chlorophyll fluorescence) using Portable Chlorophyll Fluorometer (Mini-Pam, Walz GmbH, Effeltrich, Germany). Three hours interval was taken between consecutive measurements (7:00, 10:00, 13:00, 16:00, 19:00). Both; Effective quantum Yield of photosystem II ($\Delta F/Fm'$) and Maximum quantum Yield of photosystem II (Fv/Fm) were measured.

To measure diurnal effective quantum yield of photosystem II ($\Delta F/Fm'$), light-exposed leaves were placed in leaf clip holder 2030-B. Twelve millimeters distance was taken between sample leaf surface and fiber optics. The fiber optics axis formed 60 degree angle with the leaf plane. A high care was taken to avoid the shading of leaf during measurement. The $\Delta F/Fm'$, minimum chlorophyll fluorescence (F), maximum chlorophyll fluorescence (Fm'), and photosynthetically active radiation (PAR) incident to leaf were determined concurrently by pressing START Key.

For determination of diurnal maximum photochemical efficiency of photosystem II (Fv/Fm), dark leaf clips DLC-8 weighing about 4grams were attached to sample leaves at least for 20 minutes as dark adaptation period. With the dark leaf clips, the fiber optics were positioned at 90 degree angle with respect to the leaf surface at distance of 7 millimeters. The minimal (Fo), maximal (Fm) chlorophyll fluorescence, maximum quantum yield (Fv/Fm), of photosystem II, and abaxial leaf temperature (T) were assessed instantaneously.

Assessment of seedlings Biomass

Four seedlings / species / treatment / replicate were selected randomly and destructively harvested on 21\8\20. Shoots and roots for each seedling were separated and oven dried at 70˚C for 72 hours, then dry biomass of each part weighed by sensitive balance (A&D Company, Limited, Tokyo, Japan).

Statistical analysis

Variable differences among species and within species were assessed by Analysis of Variance (ANOVA) using Statistical Package for Social Sciences (SPSS). Significant differences of means at 95 % level were determined by Ducan’s Multiple Range Test. Relationships between means of different variables were established by Regression Analysis using Excel Microsoft

Office Program. The significance of relationships was determined at P = 0.05.

Results

Photochemical efficiency of photosystem II

Effective quantum yield of photosystem II (ΔF/Fm')

The results revealed that both stressed and control seedlings in both species were displayed midday and afternoon depression ΔF/Fm' compared to morning values (Fig.2). Stressed seedlings of Mf were significantly reduced at midday compared to control seedlings throughout the measurement course. While stressed seedlings of Lt were exhibited significant decline of ΔF/Fm' compared to watered seedlings only on first day after sunrise (10:00) and afternoon (16:00). On the other hand, water stressed seedlings of *A. mellifera* depressions at midday (13:00) on first and third day and at afternoon (16:00) on second and third day of measurement were significant compared to that of *A.laeta*. All seedlings in both species were able to recover their ΔF/Fm' in the evening to values similar to early morning levels (0.8) till the second measurement. After eighteen days of continuous soil drying seedlings failed to recover optimum morning values, nevertheless they maintained ΔF/Fm' values above 0.73. The ΔF/Fm' displayed strong positive relationships with maximum chlorophyll fluorescence (Fm') of seedlings of both water treatments and tree species (Fig. 3). Contrastingly, ΔF/Fm' established strong negative relationship with minimum chlorophyll fluorescence (F) and incident photosynthetically active radiation (PAR).

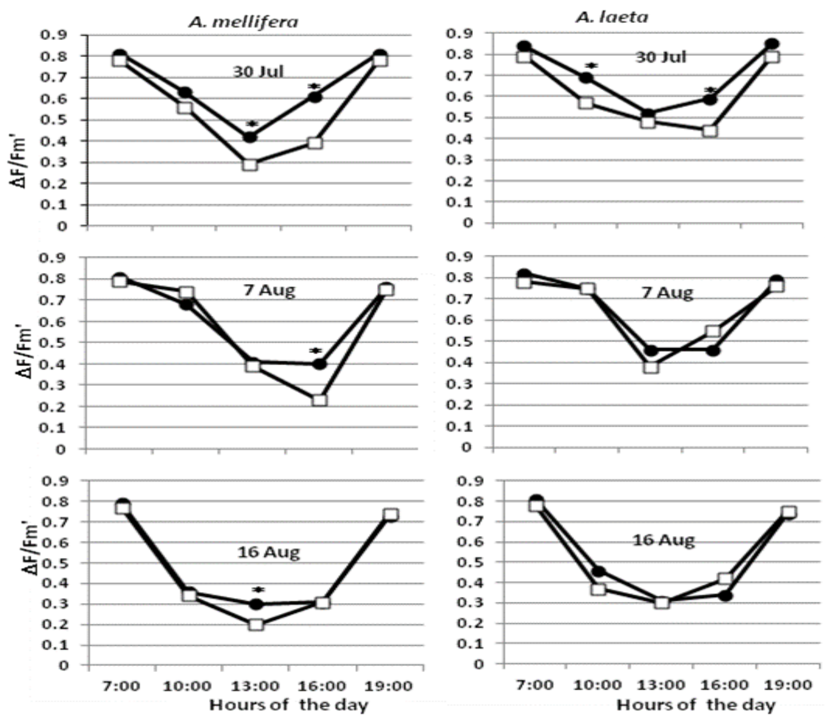

Figure 2. Quantum Yield of photosystemII (ΔF/Fm') of seedlings of two acacia tree species. Circles and squares represent control and water-stressed seedlings respectively. Points are means of three replicates. Asterisks (*) indicate significant differences between control and stressed seedlings for a given date and hour.

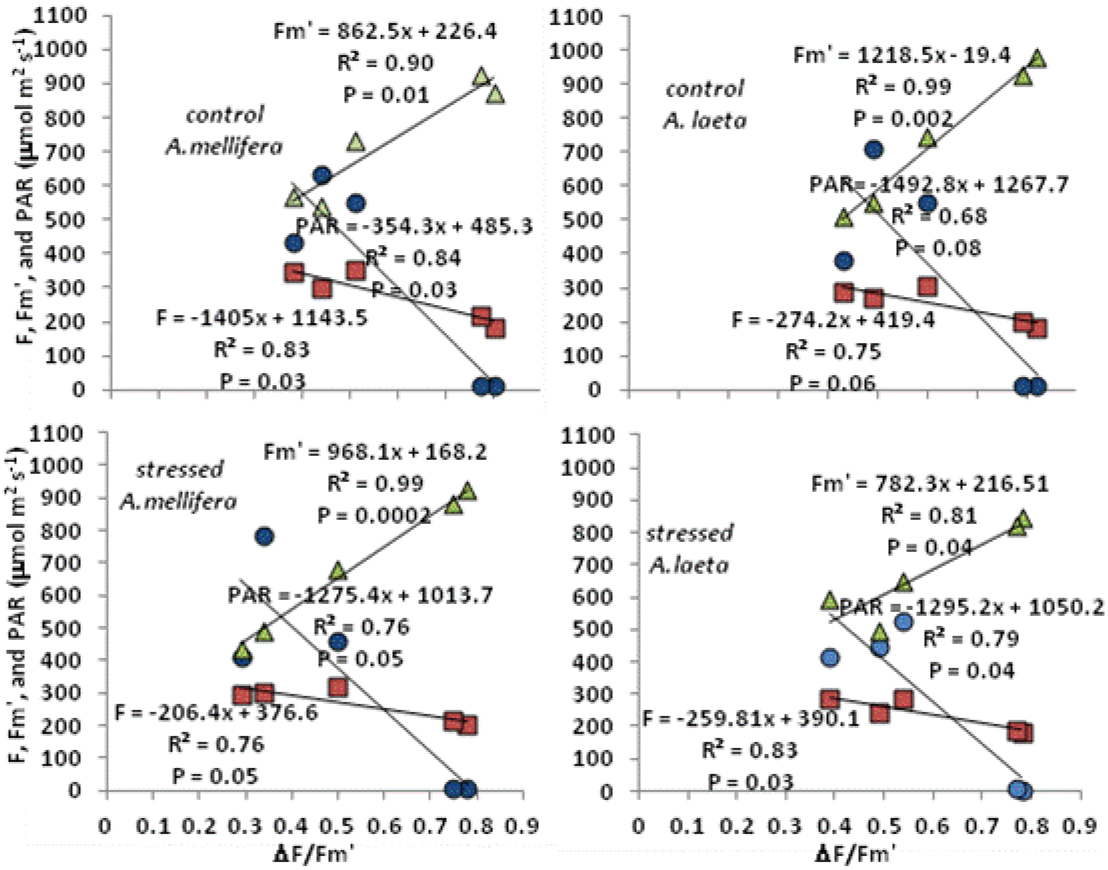

Figure 3. Relationship between quantum yield of photosystem II (ΔF/Fm') and maximum chlorophyll fluorescence (Fm'), minimum chlorophyll fluorescence (F), and incident photosyntheitically active radiation (PAR) of seedlings of two acacia tree species. Triangles, circles, and squares represent Fm', PAR, and F respectively.

Maximum quantum yield of photosystem II (Fv/Fm)

Maximum photochemical efficiency of photosystem II displayed relatively similar diurnal pattern in the seedlings of both species and water treatments (Fig. 4). The main pattern was slight depression of Fv/Fm at midday (13:00) and afternoon (16:00) with evening recovery. Highest values of Fv/Fm (0.85) were recorded in the early morning (7:00) and evening (19:00). The average of seedlings' Fv/Fm depression was 20%, 19%, 16%, and 17% of the highest values of control Mf, control Lt, stressed Mf, and stressed Lt respectively. The largest depression was 25% and displayed by control Mf at afternoon on the third day of measurements. Stressed seedlings of Mf exhibited significant decline of Fv/Fm compared to control ones in the morning hours of the third measurement day. Fv/Fm established strong opposite relationship with leaf temperature (T) in all seedlings of both species (Fig. 5).

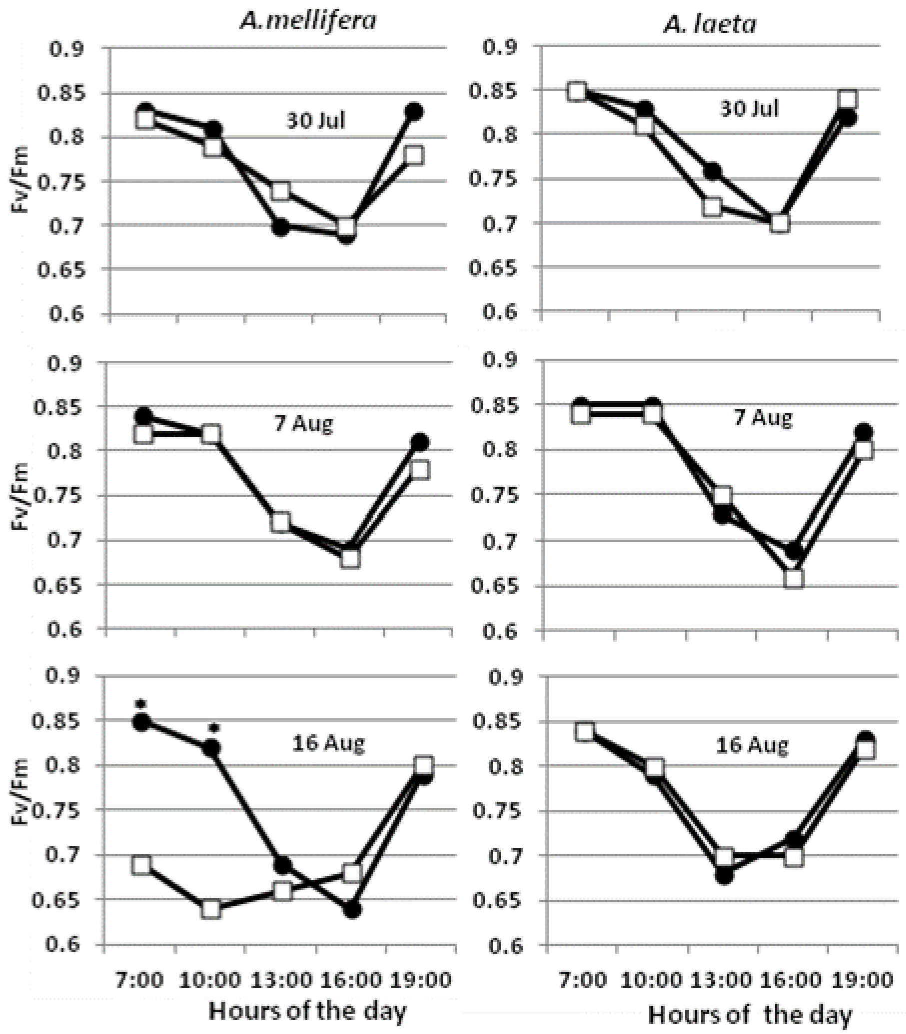

Figure 4. Maximum quantum yield of photosystem II (Fv/Fm) of seedlings of two acacia tree species. Circles and squares represent control and water stressed seedlings respectively. Points are means of three replicates. Asterisks (*) indicate significant differences between control and stressed seedlings for a given date and hour.

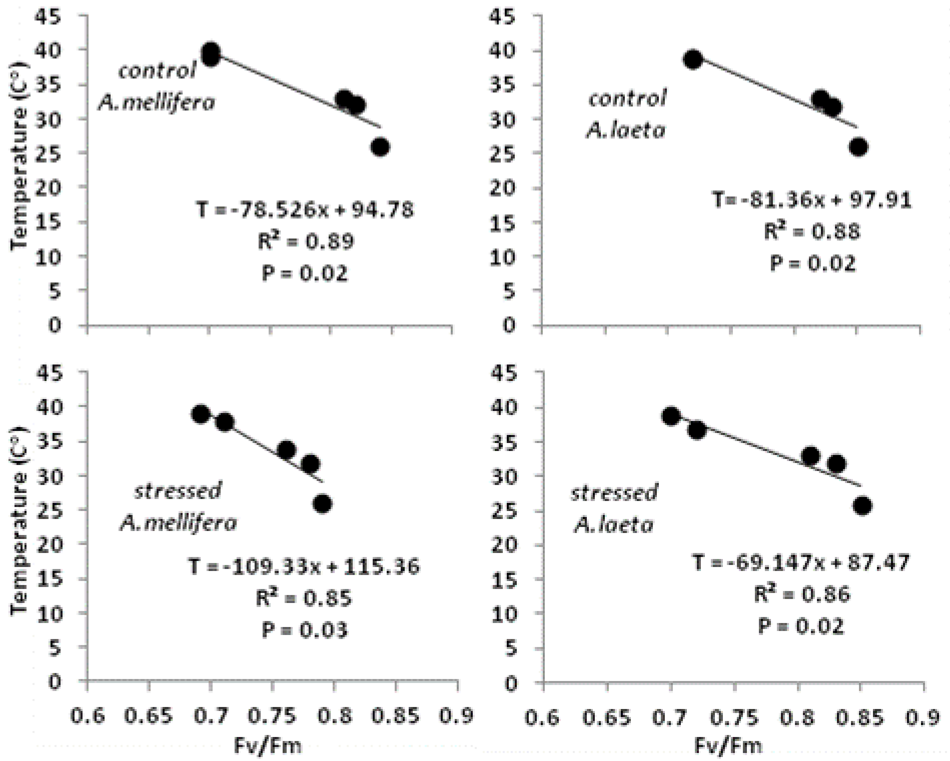

Figure 5. Relationship between photochemical efficiency of photosystem II (Fv/Fm), and leaf temperature (T) of seedlings of two acacia tree species.

Biomass

The results exhibited significant differences between the water treatments and between the studied species seedlings in dry shoot weight, root weight, root shoot ratio and total biomass. Shoot and root weight and total biomass of control seedlings of Mf were significantly greater than that of Lt seedlings (Table 1). Moreover, shoot and root weight and total biomass of control seedlings of *A. mellifera* were significantly greater than its water stressed seedlings. In contrast the root, shoot, and total biomass of control *A. laeta* displayed substantially lower weight compared to water stressed seedlings. Root:shoot ratio of control Lt manifested greater weight than stressed seedlings. On the other hand, root:shoot ratio weight of Lt was significantly higher than that of Mf seedlings in both water treatments.

Table 1. Dry weight of shoot, root, root:shoot ratio, and total biomass of control and water stressed seedlings of *A.mellifera* and *A.laeta*.

Water treatment	*A. mellifera*				*A. laeta*			
	Shoot weight	Root weight	Root:shoot ratio	Total biomass	Shoot weight	Root weight	Root:shoot ratio	Total biomass
Control	1.78± 0.29Aa	0.88± 0.09Aa	0.57± 0.31Ba	2.66± 38Aa	0.53± 0.20Bb	0.52± 0.09Bb	0.97± 0.45Aa	1.05± 0.29Bb
Stressed	1.07± 0.14Ab	0.56± 0.07Ab	0.55± 0.5Ba	1.63± 0.21Ab	0.85± 0.15Aa	0.60± 0.09Aa	0.77± 0.6Ab	1.45± 0.24Aa

Differences between species are indicated in row by letters of upper case, while between treatments are in column by letters of lower case. Values are means of four replicates ± standard error. Significant differences at $P \leq 0.05$ are indicated by different letters.

Discussion

The significantly greater effective quantum yield (ΔF/Fm') shown by stressed seedlings in both species relative to control seedlings from 10:00 to 16:00 during the first day of measurements may reflect sudden shock response to water deficit by those seedlings previously didn’t subject to drying cycles. Because, during subsequent measurements almost no substantial variations were detected between two treatments particularly in *A. laeta*. The midday and afternoon decline of (ΔF/Fm') could be attributed to adaptation mechanism to external environmental stresses by seedlings as they were able to recover the early morning values of (ΔF/Fm') in the evening hours. The decrease of ΔF/Fm’ during the midday might indicate closed or reduced photosynthetic centers (Filella, Llusia, Pinol & Penuelas, 1998). To avoid damage plants reduce ΔF/Fm' temporarily and dispose excess excitation safely providing protection against excess solar energy (Genty, Briantais & Baker, 1989; Franco et al., 1996; Murata, Takahashi, Nishiyama & Allakhverdiev, 2007; Lambers, Chapin & Pons, 2008).

The above assumptions and statements would be supported by strong inverse correlation established between ΔF/Fm' and Photosynthetically active radiation (PAR) in control Mf (R^2 = 0.98) and appreciable in stressed Mf and Lt and control Lt seedlings (R^2 = 0.69, 0.56, and 0.65) respectively. Furthermore, the relationships between ΔF/Fm' and diurnal minimum fluorescence yield (F) and maximum fluorescence yield (Fm') detected in this study are consistent with the claim that photosynthetic quantum conversion decline is usually link with a decrease Fm' and increase of F (Lichtenthaler, 1996; Wen, Qiu, Lu & Lu, 2005; Chen and Cheng, 2009).

It was obvious that, control and stress seedlings of *A. mellifera* and *A. laeta* maintained relatively optimum constant Fv/Fm (0.80 - 0.85) in the morning and evening hours throughout the measurement course (Fig. 3). Fleck, Hogan, Llorens, Abadia & Aranda (1998), reported that the optimal values range from 0.75 to 0.85 for Fv/Fm in healthy unstressed leaves of higher plants. The slight midday depression of Fv/Fm was likely caused by stresses such as air temperature and increase minimal fluorescence yield. It has been reported that, Fv/Fm of plant leaves show slight reversible midday decline that occurs synchronizely with increase of light and temperature (Faria et al., 1996; Werner, Correia & Beyschlag, 1999; Mathur and Jajoo, 2014). The claim could be supported by appreciable opposite relationship between Fv/Fm and abaxial leaf temperature (R^2 = 0.50, 0. 89, 0.31, and 0.65) for stressed Mf and Lt and watered Mf and Lt seedlings, respectively. Under stress conditions photosynthetic quantum conversion declines whereas heat emission and chlorophyll fluorescence increase (Lichtenthaler, 1996). The photochemical efficiency of photosystem II assessment of *A.mellifera* and *A. laeta* was indicated that both species are capable to maintain safe photosynthetic machinery over more than eighteen days soil drying. The recovery of Fv/Fm by *Leymus chinensis* leaves after exposure to severe drought might reflect fully maintenance of functional activity of PSII photochemistry (Xu, Zhou & Shimizu, 2010). The evening recovery to nearly optimum values shown in the present study can qualify both species to survive in drought prone, high temperature, and intensive irradiants which are typical in Sudan environment. However, still remains urgent to conduct further studies regarding *A. mellifera* and *A. laeata* water relations and ecophysiology before concrete conclusion is made.

Regarding biomass production, Mf seedlings manifested superior traits in both shoot and root parts and total biomass of control seedlings compared to Lt. The phenomena are likely attributed to genetic traits and/or detrimental impact of water stress on growth of *A. laeta* seedlings. The growth and biomass production of plants are determined by their genetic potentials and the level of environmental stresses that affect on the physiology (Otieno, Schmidt, Kinyamario & Tenhunen, 2005; Gindaba, Rozanov & Negash, 2005; Ngugi, Hunt, Doley, Ryan & Dart, 2004; Aref and El-Juhany 2001; Gupta et al., 2013). Drought cycles might triggered root and shoot growth of *A. laeta* seedlings as they exhibited significantly higher weight relative to its control seedlings and no difference between stressed seedlings of *A. mellifera*. Thus, repeated drying cycles techniques seem to be suitable for improvement of growth and production in *A. laeta*. However, greater root:shoot ratio shown by Lt relative to Mf was probably referred to poor growth of shoot rather than root extensibility as long as no higher root weight has been exhibited by *A. laeta*. Leaf growth in some plant species is one of the first processes that commence to diminish under water deficit conditions to avoid the damaging effects (Boyer, 1970; Chartzoulakis, Noitsakis & Therios, 1993). Conversely, repeated drying cycles induced negative impacts on *A. mellifera* seedlings as attested by substantial higher root, shoot, and total biomass production of control relative to stressed seedlings. It has been documented that, intermittent water limitation induced significant decrease in *Typha latifolia* plant biomass and root growth (Li et al., 2004) and in shoot dry matter of *Ligustrum japonicum* (Silva, Kane & Beeson, 2012) relative to well-watered. Furthermore, water-stressed treatment reduced significantly all the growth characteristics of eight acacia grown in Egypt (Aref and El-Juhany, 2001) and Durum wheat in Tunisia (Othmani, Rizgui, Cherif, Mouelhi & Melki, 2015). The substantial decrease in root dry weight has been reported for other acacia species such as *A. nilotica* by Pokhriyal, Chukiyal & Singh, (1997) and *A. albida* and *A. seyal* by Awodola, (1991).

Nevertheless under the conditions of intermittent irrigation during dry season *A. millifera* would show better growth hence great potential for live fence and plantation purpose in semi-arid environments compared to *A. laeta*. It has been stated that *Prosopis juliflora* produced more biomass than the other species and showed greatest potentials for use as multipurpose tree in semi-arid area of Senegal (Deans et al., 2003). The desiccation tolerance of most plant species can be expressed by their well adaptation to seasonally intermittent rainfall in Central Panama (Tyree, Vargass, Engelbrecht & Kursar, 2002).

Conclusion

The photochemical efficiency of photosystem II photochemistry in light exposed leaves ($\Delta F/Fm'$) and dark adapted leaves (Fv/Fm) of *A.mellifera* and *A. laeta* are capable to maintain safe photosynthetic machinery over more than eighteen days soil drying. The mechanism of photosystem II photochemical efficiency recovery to optimum values shown in the current study may qualify both species to survive in drought prone with high day temperature and irradiants of Sudan environment. Repeated drying cycles induced better growth for *A. laeta* seedlings relative to control seedlings, thus tend to be suitable techniques for improvement of growth and production of this species. Under the conditions of intermittent irrigation during dry season *A. mellifera* would show better growth and potential for afforestation and reforestation purposes in semi-arid environments.

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