An assessment of morphological and physiological traits that correlate with faster growth rate and high biomass production in *Acacia tortilis* (Forsk.) Hayne seedlings

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Abstract

Presently, there are no procedures for selecting superior genotypes at seedling stage. We do not know which morphological or physiological characteristics can be used to predict superior growth in trees. Field testing of genotypes requires a substantial amount of time and money before a genotype shows significant promise in the field. For this reason, morphological and physiological parameters that correlate with growth rate were sought as early indicators of field performance. Six seed provenances of *Acacia tortilis* (Forsk.) Hayne collected from areas of varying aridity where compared in biomass productivity and gas exchange traits. After 3.5 months of growth, biomass ranged from 1-2 g. Significant provenance variation was observed in total biomass productivity, root dry weight, leaf area, net photosynthetic rates per unit leaf area, stomatal conductance ($P<0.001$) and leaf transpiration rate ($P<0.05$). More xeric provenances exhibited lower biomass productivity compared to mesic ones. They also showed lower photosynthetic rates, stomatal conductance's and low photosynthetic capacity. Larger leaf areas, high stomatal conductances and photosynthetic rates appeared to be positively correlated with total biomass productivity since faster growing provenances had a greater leaf area, higher stomatal conductance and photosynthetic rates. Taken together, the results suggest that differences in leaf area, stomatal conductance and photosynthetic rates (photosynthetic capacity) among provenances may be responsible for the variation in biomass productivity in *Acacia tortilis* provenances. The probable premise and sequence of physiological events responsible for the variability depends on photosynthetic rate, total leaf area and leaf longevity.

Keywords: Acacia tortilis, morphological traits, physiological traits, growth rate, biomass production, stomatal conductance, photosynthetic rate

Introduction

Acacias tortilis (Forsk. Hayne) (Leguminosae:Mimosoideae) is a drought tolerant, slow-growing species found in the Arid and Semi-Arid Lands (ASALs)of Africa and the Middle East where it is sought after because of its many uses. Genetic selection and breeding can increase the productivity of the species, however, conventional field selection techniques are time-consuming and expensive (Quinsberry *et al*., 1982,Thakur, *et al*., (2014). Early selection of faster growing genotypes varieties based on physiological or morphological criteria may provide a rapid and cheap option as has been shown in crop species. However this requires an understanding of morphological and physiological mechanisms in tree species which is poorly understood (Blum, 1988).In particular very little is known about the physiological and morphological features of faster growth and high biomass production in Acacia *tortilis*.

The study was undertaken to improve the understanding of physiological and morphological variations among provenances of *Acacias tortilis* and their relationship with fast growth and high biomass production. Comparative studies of this kind assists in providing physiological and or morphological criteria for selecting fast-growing, provenances of *Acacia tortilis.*

Objectives of the study

The objectives of this study were:
1. To examine provenance variations in physiological and morphological traits in *Acacia tortilis*;
2. To determine the relationship between these characteristics and biomass productivity.
3. To determine physiological and morphological 'markers' in seedlings that can be selected for in early selection of faster-growing provenances.

Materials and methods

Seedling culture

The experiment was conducted using potted *A.tortilis* seedlings grown from seeds. Seeds of different provenances were collected from areas of varying climatic conditions in Kenya, namely, Makueni, Kitui, Wamba ,Lodwar, Marigat and Loboi. Germinated and grown in a growth chamber.

Gas exchange measurements

After 3.5 months growth in a growth chamber, gas exchange characteristics including net photosynthesis and transpiration were measured on leaf surfaces of fully expanded leaves using a Li-6200 portable photosynthesis system, as described by Bellasio, *et al*.,2014)..Water use efficiency (WUE) was calculated from as the ratio of photosynthesis (P_n) to transpiration (T_l), while photosynthetic capacity was calculated from photosynthetic rates and leaf area following the procedures of Busch, *et al*., 2013.

Morphological measurements

Five seedlings were sampled for dry weight measurements after 3.5 month-growth period in a growth chamber. Leaf area was determined using a portable leaf area meter. The seedlings were partitioned into stem, leaf and root components, oven dried at 70^0C for 48 hours, and weighed to determine dry weights.

Data analysis

The analysis of variance and students T test was used to calculate the least significant differences between the means. The ANOVA Procedure using SAS\ PC was used in all analysis

Results

Physiological characteristics

Significant differences ($P<0.001$) were observed among provenances with respect to their gas exchange characteristics (Table 1). Relative to other provenances, net photosynthetic rates (P_n) and stomatal conductance (C_s) and water use efficiency (WUE) were higher in Makueni than all other provenances. It however had intermediate transpiration rates (T_l). The order of provenances in terms of highest P_n and C_s to lowest was Makueni, Lodwar, Marigat, Loboi, Wamba and Kitui

Table 1: Leaf gas exchange characteristics of *Acacia tortilis* provenances measured after 3.5 months of growth. Provenances listed in order of dry matter production (high to low). P_n- net photosynthetic rate (μmol CO_2 m-^{2} s-^{1}), T_l- transpiration rate(mol m-^{2} s-^{1}), C_s- stomatal conductance (cm-^{3} s-^{1}), WUE-water use efficiency (μmol co_2/mol H_2O), P_C- photosynthetic capacity (μmol Co_2 m-^{2} s-^{1}) ×LA, [1]column followed by the same letter are not significantly different ($P<0.05$)(ANOVA, T test).

Provenance	**P_n**	**T_l**	**C_s ($\times 10^{-2}$)**	**WUE($\times 10^{-4}$)**	**P_c**
Makueni	6.536**a**[1]	1994.4**bc**	19.8**a**	32.97**a**	1196.7**a**
Marigat	6.002**a**	2123.4**ab**	14.5**bc**	30.32**ab**	689.6**c**
Wamba	4.272**b**	1623.5**bc**	8.8**d**	27.10**ab**	508.3**cd**
Lodwar	6.225**a**	2573.6**a**	15.7**ab**	24.05**b**	795.5**b**
Kitui	3.759**b**	1604.8**c**	7.0**d**	31.10**ab**	286.1**e**
Loboi	4.451**b**	2078.0**abc**	10.5**cd**	23.19**b**	451.3**d**

Biomass components and morphological characteristics

The provenances can be ranged according to biomass production as follows: High (Makueni), Intermediate (Marigat, Wamba and Lodwar) and Low yielding (Kitui and Loboi). ANOVA followed by T test showed that there was significant differences in total biomass productivity ($P < 0.001$) and root dry weight, leaf area and leaf area ratio (LAR) (i.e leaf area: total biomass ratio).

Table 2: A comparison of mean total dry weight, shoot dry weight and root dry weight (g) of 3.5 month-old *Acacia tortilis* seedling provenances. [1]column followed by the same letter are not significantly different ($P<0.05$)(ANOVA, students T test).

Provenance	**Root**	**Shoot**	**Total**
Makueni	0.30**a**[1]	2.16**a**	2.46**a**
Marigat	0.25**b**	1.80**b**	2.05**ab**
Wamba	0.18**bc**	1.64**bc**	1.82**c**
Lodwar	0.14**c**	1.52**c**	1.66**d**
Kitui	0.12**d**	1.44**c**	1.56**d**
Loboi	0.22**b**	1.28**d**	1.50**d**

Table 3: A comparison of leaf area (LA) (cm^2) and leaf area ratio (LAR) (cm^2/g) of *Acacia tortilis* seedling provenances grown under irrigation. [1]column followed by the same letter are not significantly different ($P<0.05$)(ANOVA, students T test).

Provenance	LA	LAR
Makueni	185**a**[1]	75.22**a**
Marigat	130**b**	63.4**b**
Wamba	117.5**bc**	64.6**b**
Lodwar	102.5**c**	61.7**b**
Kitui	106**c**	67.9**ab**
Loboi	77.5**d**	51.7**c**

Correlation between morphological/physiogical traits and biomass production

Correlation analysis revealed that relationships and total biomass productivity existed. Highly significant ($P<0.0001$) correlations were found between total biomass production and net photosynthetic rates (P_n), root/shoot ratio (R/S), leaf area (LA) and stomata conductance (C_s). High leaf area ratio (LAR) and leaf area root dry weight ratio (LA/RDW) where negatively correlated with biomass production

Table 4: Summary of morphological characteristics that correlate with biomass production in *Acacia tortilis* provenances. Spearman correlation coefficients are indicated and their statistical significance. P_n- net photosynthetic rate (µmol CO_2 m^{-2} s^{-1}), T_l- transpiration rate(mol m^{-2} s^{-1}), C_s- stomatal conductance (cm^{-3} s^{-1}), WUE-water use efficiency (µmol co_2/mol H_2O), LA-leaf area (cm^2), LAR –Leaf area ratio (cm^2/g), RDW –root dry weight (g), LA/RDW- Leaf area/Root dry weight ratio (cm^2/g), R/S-Root/Shoot ratio.
***** Significant at $P<0.001$ level**
**** Significant at $P<0.05$ level**

Variables	R	Pr>R
P_n	0.74	***
T_l	0.52	***
C_s	0.57	***
WUE	0.28	**
LA	0.64	***
LAR	-0.79	***
RDW	0.52	***
LA/RDW	-0.72	***
R/S	0.67	***

Discussion

Acacia tortilis is generally regarded as drought tolerant and performs well in moisture limited environments. Total dry matter production varied among different provenances and seedlings from less arid site. Makueni provenance produced more dry matter than provenances from intermediate or more arid sites (Lodwar ,Kitui and Loboi).

The rapid growth of the Makueni provenance may be related to its generous allocation of carbon to the leaf (high leaf area ratio (LAR)), and the slow growth of the Loboi provenance to its meagre leaf allocation. Under adequate moisture conditions, seedlings which distribute its photosynthate towards leaf growth increases its photosynthesizing leaf surface, and increase its photosynthetic capacity and total dry matter production under moist soil conditions. Makueni provenance also had the highest stomatal conductance and photosynthetic rate, while Kitui provenance, which was the least productive in terms of dry weight, had low stomatal conductance and net photosynthesis. The productivity of a plant depends on photosynthetic rate, total leaf area and the retention (leaf longevity). Differences among the provenances in leaf longevity did not influence productivity in this study as none of the provenances lost any leaves. Therefore the relationship between growth traits and Pn*total leaf area (photosynthetic capacity) computed at the time of measurement indicated a strong correlation between growth traits and net photosynthetic rate per unit leaf area, which is in agreement with the study of black locust clones (Mebrahtu & Hanover 1989b, Nicolas *et al.*, 2006). Despite significant variation among provenances in root/shoot ratio and differences in root dry weight among the provenances, there was no consistent relationship between root/shoot ratio and biomass productivity or aridity of seed origin. The wet soil conditions under which the seedlings were grown may have altered carbon partitioning. Dry matter allocation to photosynthesizing leaf area may be one of the other factors responsible for more vigorous growth of Makueni provenance as observed in black spruce (Tan *et al.*, 1992, Taylor *et al.*, 2003). This agrees with the findings of Tschaplinski and Blake (1989), and Nicolas *et al*, 2007), for Poplar clones but contrasts with findings of Ni and Pallardy (1991) who reported that when soil moisture was abundant, photosynthetic rates and stomatal conductance were highest in the more xeric white oak and post oak compared sugar maple and black walnut which were mesic species. This suggests that the maintenance of wide stomatal apertures and hence high net photosynthetic rates are required for high dry matter production as observed previously by Blake and Sutton (1988) in *Jack pine* and *Black spruce,* and Rae *et al*., *(*2004) in poplar. Stomatal opening to lower water potentials during moderate water stress allows photosynthesis and carbon assimilation to continue, providing more carbon for repair processes and growth, (Lloyd *et al*., 2013).

Conclusion

Selection techniques have tended to emphasize drought tolerance or high dry matter productivity in isolation, (Jones, 2013). This can prove disappointing when growing conditions change. The reason for this discrepancy has been due to the notion that drought tolerance and high productivity are competing attributes, (Westoby, *et al*., 2013). Although high drought tolerance does not necessarily ensure high productivity under drought conditions, it may ensure survival (Tschaplinski & Blake, 1989). Lodwar and Marigat provenances combine relatively high dry matter productivity and drought tolerance since they originate from arid sites. Selection in this species should therefore consider provenances that combine both drought tolerance and high productivity, (Appiah, 2013; Nicholas, 2007). This two provenances would be the most appropriate for afforestation in drier sites. Makueni provenance being the highest biomass producer but less drought tolerant can be introduced in sites with less severe drought. The primary objective should be to match genotypes with sites. Genotypes that balance high productivity under favourable moisture conditions with drought tolerance under adverse conditions may be able to continue growing when environmental conditions change over time.

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