

## Variation in Drought Tolerance and Survival among Three Provenances of *Acacia tortilis* Subspecies *Raddiana* and Subspecies *Spirocarpa* Seedlings

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**Abstract:** The aim of this study was to investigate inter-specific variation in drought tolerance and survival among three provenances of *Acacia tortilis* subspecies *Raddiana* and subspecies *Spirocarpa* under water stress. The seeds were collected from White Nile (Elgetiana), Kassala (Halfa Elgadida) and River Nile (Shandi) states, where the association of the two subspecies occurs in their natural habitats. The seeds of each subspecies per each provenance were sown under three irrigation frequencies. Relative growth rate, relative water contents, biomass production and mortality rates were measured. At the end of growth measurements water was totally withheld from all the seedlings and mortality was counted at one week interval. The results revealed significant irrigation treatment and subspecies effects in relative growth rate, leaf relative water content and seedlings mortality, where no significant differences exist between the provenances. Water stress increased relative water content and decreased relative growth rate and mortality. Drought preconditioning increased seedlings survival during the final dry-down compared to well-watered. Seedlings that had been preconditioned to drought survived 14 days longer than those had been well watered. The high similarity between provenances might reflect adaptation to near similar environmental conditions, whereas the variation within subspecies could be due to genetic differentiation resulting from minor environmental differences or to individual tree differences within provenances.

**Key words:** *Acacia tortilis*, mortality, provenances, *Raddiana*, relative growth rate, relative water content, subspecies, *Spirocarpa*

### INTRODUCTION

The ability of plants to function under conditions of low soil moisture depends on their capacity to adjust form and function to offset the damaging impact of negative water potentials in soil and atmosphere (Khalil and Grace, 1992). In dry lands, water availability is the main environmental factor controlling plant growth and survival, depending on the different manifestation of ecological selection pressure towards morphological characters and physiological behaviour that enable plant to survive and grow (Kondoh *et al.*, 2006). Plant response to water deficit vary temporally and spatially over long time scale (Li, 1998). Plant capacity to resist drought results from the integration of variety of adaptive characteristics and mechanisms (Jones, 1980; Turner, 1986). Drought avoidance which is generally found in higher plants, is achieved primarily through adaptation that retard water losses or increase water absorption (Bewley and Krochko, 1982).

Water deficit increase the amount of bound water and dry weight/turgid weight ratio. Water stress treatment

caused large difference in relative growth rate leading to significant differences in dry matters accumulated of five months seedling of *Acacia tortilis* from different habitats in Kenya (Otieno *et al.*, 2001). Relative growth rate (RGR) is defined as the increase in dry weight by unit biomass per unit time (Cervantes *et al.*, 1998). Relative growth rate for nine Mexico native species studies was varied among genera as well as among species within the same genus, (Cervantes *et al.*, 1998). Plant with conservative strategy are adapted to conditions where individuals are isolated with drought periods are supposed to be long. The conservative strategy is usually associated with drought resistances of species and with high water use efficiency and slow intrinsic growth rate (Kramer, 1983; Dickmann *et al.*, 1992; Li, 1999). Recent studies, indicate significant genotypic variation in physiological and morphological adaptation to stress, particularly drought, in tree species provenances, families and clones (Abrams, 1988; Cregg, 1993). The effectiveness of any combination of traits in conferring drought resistance will depend on the specific environment, (Ranney *et al.*, 1990).

Plant growth analysis has been successfully used in both study of wild plant population dynamics and in studies with more applied orientation, particularly those aimed at increase useful. Due to selective pressure in dry land species to conserve water and thus optimize water use may be an important factor contributing to plant survival in extreme condition (Tuomela, 1997). Leaf water relations provide useful tool to improve the understanding of intra-specific adaptation mechanisms, (Tuomela and Kanninen, 1995). This study is attempted to improve the understanding of the growth performance of *Acacia tortilis* population on the basis of their physiological and morphological behaviour and of the climatic conditions in their natural habitats.

The aim of the present study was to investigate inter-specific variation in relative growth rate, leaf relative water content and survival of *Acacia tortilis* subspecies *Raddiana* and *spirocarpa* among provenances under three irrigation regimes.

## MATERIALS AND METHODS

**Seed sources:** Seeds of *A. tortilis* subspecies *raddianna* and *A. tortilis* subspecies *Spirocarpa* were collected from three sources where the association of the two subspecies occurs in their natural habitats. The sources are White Nile (Elgetiana), Kassala (Halfa Elgadida) and River Nile (Shandi). The seed were collected from +25 trees in each area and pooled together as one lot. The description of the sources is shown in Table 1.

**Experimental design:** The study was conducted in the Forestry research Centre Nursery at Soba in 2005. Viable seeds from the three origins were directly sown in polythene bags (30×25 cm size) with one seed sown per bag. The bags were filled with clay soil as plant medium. The seeds were treated with sulphuric acid to break the dormancy and enhance the germination. A complete randomize design with three factors i.e., 3 provenances×2 subspecies×3 irrigation levels×3 replicates×8 seedlings per replicate resulted in total of 432 experimental units. The seedlings were raised in nursery under direct heat and light from the sun. The seedlings were grown for 45 days, with regular watering before subjected to irrigation treatments. Then three irrigation levels 3, 7 and 11 days, respectively interval were applied to the experiment for 3 months.

**Relative Growth Rate (RGR):** Relative growth rate was derived from the data measurement (water stress experiment) and calculated by the general growth equation,  $RGR = (W_2 - W_1)/(t_2 - t_1)$ . Where  $W_1$  and  $W_2$  are seedling total dry weights at times  $t_1$  and  $t_2$  (Hoffmann and Poorter, 2002; Khurana and Singh, 2004a).

Table 1: Seed sources of three provenances of *Acacia tortilis* subspecies *Raddiana* and *Spirocarpa* used in study

Provenances	Latitude	Longitude (m)	Attitude		Max (°C)	Min (°C)
			(m)	(mm)		
White Nile	13° 30'N	32° 33'E	185	180	37.3	23.3
Kassala	15° 30'N	35° 58'E	458	318.6	37.9	21.7
River Nile	16° 20'N	32° 36'E	178	62.6	37.5	22

Modified from Ministry of Sciences and Technology, Meteorological Authority, Khartoum Airport station and Heavens-above.com. 2008

**Leaf relative water content (RWC):** This was measured by random selection of 6 leaves for each subspecies for each provenance for each irrigation regime from mortality experiment. The leaves were placed in air tight vial and immediately taken to the laboratory where they were weighed using sensitive balance three decimal. Then the leaves were hydrated to full turgidity by floating the leaves on distilled water in close Petri dish for 6 h. Leaves were removed from the water and weighed with the same balance, then turgid weight was obtained. Afterwards the leaves were dried in the oven at 80°C for 48 h and dry weights were determined. RWC was calculated using the equation:

$$RWC\% = (W_f - W_d) \times 100 / (W_t - W_d)$$

Beadle *et al.*, 1993:

where  $W_f$  is the fresh weight,  $W_d$  is dry weight and  $W_t$  is turgid weight.

**Seedling survival (seedling mortality):** Seedlings in all irrigation levels were subjected to final dry-down totally withheld water to determine the length of survival and mortality without water. Then mortality percent was assessed by counting the dead seedlings every week (seedling with dead leaves were count as dead).

Mortality percent was calculated as follows = (dead seedling×100)/total seedlings

**Analysis of the data:** The data were subjected to analysis of variance (ANOVA) to confirm the differences between the provenances, subspecies and irrigation frequency. Duncan multiple range test was used to separate the means. Statistical Analysis System (SAS, 1996) was used for data analysis.

## RESULTS

**Variation in relative growth rate:** The results of this study showed high significant differences between irrigations levels in relative growth rate, but there was no significant differences existed between the provenances, subspecies, irrigation\* subspecies and provenance \*subspecies interactions Table 2. Subspecies *Raddiana* from Kassala attained the greatest relative growth rate followed by White Nile at 3 days irrigation level, but at 7 and 11 days the three provenances had more or less similar relative growth rates Table 3.

Table 2: ANOVA results of the effects of irrigation, provenance, subspecies and interactions on leaf relative water content and mortality

	Source of variation	df	F-value
Relative water content	Irrigation frequency	2	30.58***
	Provenance		22.62ns
	Subspecies	1	10.30***
	Irrigation×subspecies	2	0.39ns
	provenance×subspecies	2	0.39ns
	Irrigation×provenance×subspecies	8	2.27*
Mortality percent	Irrigation	2	3.04*
	Provenance	2	0.09ns
	Subspecies	1	2.14ns
	Irrigation×subspecies	2	0.57ns
	provenance×subspecies	2	0.19ns

\*\*\*: Significantly different at  $p < 0.001$ ; \*: Significantly different at  $p < 0.05$ ; \*\*: Significantly different at  $p < 0.01$ ; ns: not significantly different at  $p < 0.05$

Table 3: Variation in relative growth rate between *Acacia tortilis* subspecies *Raddiana* and *Spirocarpa* under three irrigation regimes

Irrigation frequency	Subspecies <i>Raddiana</i>			Subspecies <i>Spirocarpa</i>		
	White Nile	Kassala	River Nile	White Nile	Kassala	River Nile
Twice a week	0.48 <sup>a</sup>	0.50 <sup>a</sup>	0.45 <sup>a</sup>	0.37 <sup>a</sup>	0.38 <sup>a</sup>	0.42 <sup>a</sup>
Once a week	0.24 <sup>a</sup>	0.24 <sup>a</sup>	0.25 <sup>a</sup>	0.20 <sup>a</sup>	0.21 <sup>a</sup>	0.21 <sup>a</sup>
Fortnight	0.10 <sup>a</sup>	0.11 <sup>a</sup>	0.10 <sup>a</sup>	0.10 <sup>a</sup>	0.58 <sup>a</sup>	0.10 <sup>a</sup>

\*: Mean with same letters for same subspecies for same irrigation in same row are not significantly different at  $p = 0.05$  using Duncan Multiple Range Test

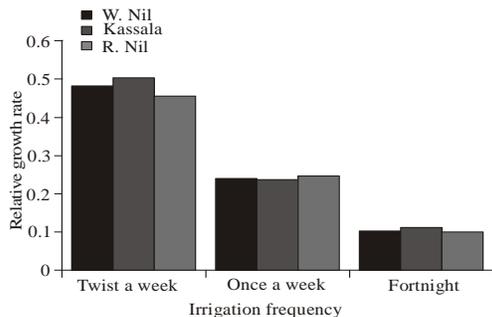


Fig. 1: *Acacia tortilis* subspecies *Raddiana* relative growth rate among provenances

Figure 1 and 2 showed that for the subspecies *Raddiana* the seeds collected from Kassala provenances had better RGR performance, whereas for subspecies *Spirocarpa* River Nile had better performance.

**Variation in leaf relative water content:** Statistically highly significant differences were found among the irrigation levels in leaf relative water content ( $p \leq 0.0001$ ), but, no significant differences were found between the provenances. Statistically significant differences were found between the subspecies in leaf relative water content ( $p \leq 0.001$ ). Also the irrigation \* provenance \*

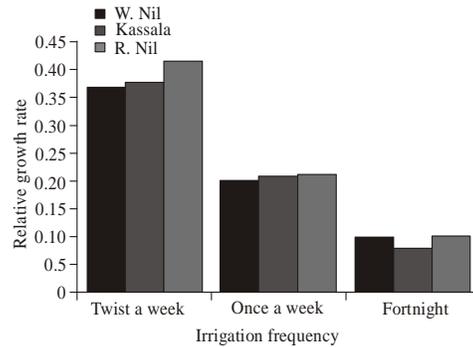


Fig. 2: *Acacia tortilis* subspecies *Spirocarpa* relative growth rate among provenances

Table 4: Provenances variation in leaf relative water content of *Acacia tortilis* subspecies *Raddiana* and *Spirocarpa* under the effect of irrigation regimes

Irrigation frequency	<i>Raddiana</i>			<i>Spirocarpa</i>		
	White Nile	Kassala	River Nile	White Nile	Kassala	River Nile
3 days	67.70 <sup>a</sup>	73.35 <sup>a</sup>	68.27 <sup>a</sup>	65.80 <sup>a</sup>	70.75 <sup>a</sup>	64.15 <sup>a</sup>
7 days	82.37 <sup>a</sup>	76.19 <sup>a</sup>	81.78 <sup>a</sup>	69.90 <sup>a</sup>	72.82 <sup>a</sup>	80.43 <sup>a</sup>
11 days	79.41 <sup>a</sup>	87.11 <sup>a</sup>	80.59 <sup>a</sup>	76.47 <sup>b</sup>	82.31 <sup>a</sup>	77.82 <sup>b</sup>

\*: means with letters for the same subspecies for same irrigation in same row are not significantly different at  $p = 0.05$  using Duncan multiple range test

subspecies interaction showed significant differences ( $p \leq 0.02$ ), but irrigation\* provenance and provenance×subspecies interaction did not show significant differences in leaf water relative content Table 2.

Subspecies *Raddiana* from Kassala exhibited the greatest leaf relative water content at 3 and 11 days irrigation level but, White Nile at 7 days irrigation level, Table 4. However for subspecies *Spirocarpa*, Kassala exhibited the greatest leaf relative water content at 3 and 11 days irrigation level but, River Nile at 7 days irrigation level Table 4. The leaf relative water content was increased in both subspecies in the three provenances when water deficit periodicity was increased.

**Variation in mortality percent:** In week one, there was no mortality for the three irrigation levels for both subspecies in the three provenances. While at week two and three, water stress treatments cause large differences in mortality leading to significant differences ( $p \leq 0.0001$ ) and ( $p \leq 0.05$ ) respectively. While the provenance and subspecies did not show significant variation in mortality. Also the irrigation\* subspecies and provenance\* subspecies interaction did not show significant variation in mortality Table 2.

In subspecies *Raddiana* at 3 days irrigation frequency more than 95% of the seedlings from all the provenances were died and total mortality was reached in the third

Table 5: Variation in mortality percent between provenances of *Acacia tortilis* subspecies *Raddiana* under the effect of three irrigation regimes

Irrigation frequency provenance	3 days			7 days			11 days		
	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
White Nile	0 <sup>a</sup>	99.4 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	11.11 <sup>a</sup>	94.44 <sup>a</sup>	0 <sup>a</sup>	0 <sup>a</sup>	88.89 <sup>a</sup>
Kassala	0 <sup>a</sup>	100 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	11.11 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	0 <sup>a</sup>	72.22 <sup>a</sup>
River Nile	0 <sup>a</sup>	94.4 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	33.33 <sup>a</sup>	88.88 <sup>a</sup>	0 <sup>a</sup>	0 <sup>a</sup>	83.53 <sup>a</sup>

\*: Means with same letters in same column for same irrigation for same week are not significantly different at p=0.05 using Duncan Multiple Rang Test

Table 6: Variation in mortality percent between provenances of *Acacia tortilis* Subspecies *Spirocarpa* under the effect of three irrigation regimes

Irrigation frequency provenance	3 days			7 days			11 days		
	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
White Nile	0 <sup>a</sup>	100 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	11.11 <sup>a</sup>	94.44 <sup>a</sup>	0 <sup>a</sup>	0 <sup>a</sup>	94.44 <sup>a</sup>
Kassala	0 <sup>a</sup>	100 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	16.68 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	0 <sup>a</sup>	88.88 <sup>a</sup>
River Nile	0 <sup>a</sup>	100 <sup>a</sup>	100 <sup>a</sup>	0 <sup>a</sup>	22.22 <sup>a</sup>	89.22 <sup>a</sup>	0 <sup>a</sup>	0 <sup>a</sup>	94.44 <sup>a</sup>

\*: Means with same letters in same column for same irrigation for same week are not significantly different at p = 0.05 using Duncan Multiple Rang Test

week. For 7 and 11 days frequencies even at the third week not all the seedlings were died Table 5.

For subspecies *Spirocarpa* in first week, no mortality was observed in the three provenances in both irrigation levels. While in second week the three provenances exhibited 100% mortality at 3 day irrigation regime. However in both subspecies in three provenances when the water periodicity increased the mortality decreased Table 6.

## DISCUSSION

Water stress treatments caused large differences in relative growth rate leading to significant differences in dry matter accumulated after six months for both subspecies seedlings in the three provenances. When the water deficit duration increased the relative growth rate decreased, so the water deficit has great effects on *Acacia tortilis* relative growth rate. The non significant differences among the subspecies suggest that the subspecies respond similarly to water stress. While the non significant differences occurred between the provenances, may indicate that the provenance does not appear to play a great role in species comparison, because the species seem to occupy the same ecological niches (micro-sites).

Relative growth rate differ widely among plant species, and these differences can be related, to environmental conditions and to inherent characteristics (Poorter and Remkes, 1996). In this study, the provenances showed no significant variation in the RGR. This study consistent with Raddad (2007), who studied *Acacia senegal* from different provenances in Sudan and found no significant differences in relative growth rate. The study is in contrast with Atkin *et al.* (1998), who reported that Relative Growth Rate (RGR) from contrasting habitat environment is highly variable. General responses of seedlings relative growth rate as the

result water stress, as observed in this study, demonstrate the ability of species to tolerate and acclimate to broad ranges of water levels by morphological and plastics response. Relative growth rate was reduced by water stress in both subspecies in the three provenances. Similar results were reported by Otieno *et al.* (2001), where water stress treatment, caused large differences in *Acacia tortilis* relative growth rate. The variation in this study is quite small indicating high similarity between the populations. Diverse environmental conditions in the native habitats of the populations, such as seasonal changes in water availability, may result in large inter-specific variation in morphological and physiological traits (Tuomela, 1997; Li, 1999).

Water stress induced increases in leaf dry weight to turgid weight ratio indicates that leaves represent a real change in the elastic rigidity of the cell walls and this might have been expected to increase relative water content at zero turgidity (Khalil and Grace, 1992). In this study the leaf relative water content increased when the water is deficit or moderate than in well-watered seedlings. A plant capacity to resist drought results from the integration of a variety of adaptive characteristics and mechanism (Jones, 1980; Ranney *et al.*, 1990). Water deficit led to change in dry weight/turgid weight. Higher dry weight/turgid weight ratio may indicate that drought induces the growth of cell wall in leaves (Tuomela, 1997; Li, 1999). The high relative water content in water stressed seedlings over well watered seedlings in both subspecies in the three provenances, inferring that the plant may respond to water deficit by creating a water reserve in cell walls. Water deficit modified the leaf structure by increasing the amount of bound water, the dry weight-turgid weight and dry leaf area as well as osmotic effects (Lediges, 1979; Tuomela, 1997).

The significant variation in *Acacia tortilis* seedlings, within subspecies in same provenances in leaf water relative content, could be due to genetic differentiation

resulting from minor environmental differences among the habitats occupied by these subspecies, or it might be attributed to individual tree differences within provenances from the seeds were collected, or the two subspecies may be differed in their ecological requirements.

Water stress significantly reduced mortality of *Acacia tortilis* seedlings in the three provenances. When water stress periodicity increased seedlings start dying one to two week later than well watered seedlings. This indicate that seedlings of the two subspecies when exposed to drought conditioning exhibited prolonged stress resistance and enhanced survival. This suggests that the species is well adapted to drought condition. Overall, drought preconditioning increased seedling survival during the final dry-down by about 14 days compared to the well-watered, which had been kept well watered before the final dry-down in the three provenances for both subspecies.

Soil drought reduced growth and total dry weight accumulation in seedlings of both subspecies, but, increased leaf relative water content and survival rate in both subspecies in the three provenances. The variation in this study is quite small indicating high similarity between the subspecies and between the provenances. The similarity between the provenances in relative growth rate, leaf relative content and mortality in seedling traits might reflect adaptation to near similar environmental conditions. The wide ability of seedlings from the three sources examined to survive imposed drought suggests that selection to improved drought tolerance of *Acacia tortilis* for conservation forestry is possible.

The efficiency of selection for drought tolerance may be increased by identifying site factors or morpho-physiological traits that are closely associated with increased survival and growth under drought (Cregg, 1993). Findings indicate that drought adaptation mechanisms in the different *Acacia tortilis* population that allow a reasonable production under water stress. They are more productive under both sufficient and moderate water stress than severe water stress. Apparently, the reasonable productivity of both subspecies in the three provenances may depend on physiological and morphological adaptation mechanism that enables them to use the available water effectively under varying conditions of water supply.

## CONCLUSION

The high similarity between the *Acacia tortilis* provenances in relative growth rate, leaf relative water content and mortality in seedlings traits, might reflect adaptation to near similar environmental conditions. The variation within subspecies in seedlings relative growth

rate could be due to genetic differentiation resulting from minor environmental differences among the habitat occupied by the subspecies, or it might be attributed to individual tree differences within provenances from which the seeds were collected, or may be due to different ecological requirements.

Water stress treatment caused significant variation in seedlings relative growth rate, leaf relative content and mortality. When water stress increased, relative growth and mortality rate decreased, but the leaf relative water increased. Drought preconditioning increased seedlings survival during the final dry-down by about 14 days compared to well-watered seedlings.

## REFERENCES

- Abrams, M.D., 1988. Comparative water relation of three successional hardwood species in Central Wisconsin. *Tree Physiol.*, 4: 263-273.
- Atkin, O.K., M. Schortemeyer, McFarlane and J.R. Evans, 1998. Variation in the components of relative growth rate in ten *Acacia* species from Contrasting environments. *Plants Cell Environ.*, 21: 1007-1017.
- Beadle, C.L., M.M. Ludlow and J.L. Honeysett, 1993. Water relations In: (Hall, D.O., J.M.O. Scurlock, H.R. Bolhar-Nordencampf, R.C. Leegood and S.P. Long, (Eds.), *Photosynthesis and Production in a Changing Environment: A Field and Laboratory Manual*, 1<sup>st</sup> Ed. Chapman and Hall, London, pp: 464.
- Bewley, J.D. and J.E. Krochko, 1982. Desiccation Tolerance. Lange, O.I.N., *Physiological Plant Ecology Water Relation and Carbon Assimilation*. *Encyclopedia of Plant Physiological*, New series, Vol. 12.
- Cervantes, V., V. Arriaga, J. Meave and J. Carabias, 1998. Growth analysis of nine multipurpose woody legumes native from southern Mexico. *Forest Ecol. Manag.*, 110: 329-341.
- Cregg, B.M., 1993. Carbon allocation, gas exchange, and needle morphology of *Pinus ponderosa* genotype, known to differ in growth and survival under imposed drought. *Tree Physiol.*, 14: 883-898.
- Dickmann, D.I, Z. Liu, P.V. Nguyen and K.S. Pregitez, 1992. Photosynthesis, water relations, and growth of two hybrid populus genotypes during a severe drought. *Can. T. Res.*, 22: 1094-1106.
- Hoffmann, W.A. and I.I. Pooter, 2002. Avoiding bias in calculation of relative growth rate. *Ann. Bot.*, 80: 37-42.
- Jones, H.G., 1980. Interaction and integration of adaptive responses to water stress. The implications of unpredictable environment. In: Turner, N.C. and P.J. Kramer, (Eds.), *Adaptation of plants to water and high temperature stress*. Wiley, New York, pp: 353-365.

- Khalil, A.M. and J. Grace, 1992. Acclimation to Drought in *Acer pseudoplatanus* L. (sylamore) seedlings. J. Experim. Bot., 43(257): 1591-1602.
- Khurana, E. and J.S. Singh, 2004a. Response of tropical tree seedlings to evaluate CO<sub>2</sub> of seed size and successional status. N. Forest, 27: 139-157.
- Kondoh, S., H. Yahata, T. Nakashizuka and M. Kondoh, 2006. Site-specific variation in Vesselsize, growth and drought tolerance of broad-leaved trees in semi-arid regions of Kenya. Tree Physiol., 26: 899-904.
- Kramer, P.J., 1983. Water relations of plants. Academic Press, New York.
- Lediges, P.Y., 1979. Some aspects of tissue water relations in the three populations of *Eucalyptus viminalis* Labill. N. Phytol., 75: 53-62.
- Li, C., 1998. Variation of seedling traits of *Eucalyptus microtheca* origins in Different watering regimes. Silvae Genetica, 47: 2-3.
- Li, C., 1999. Drought adaptation and genetic diversity in *Eucalyptus microtheca*. Doctoral Thesis, University of Helsinki, Department Forest Ecology, Tropical Forest Report, 18.
- Otieno, D.O., J.I. Kinyamario and T.O. Omenda, 2001. Growth features of *Acacia tortilis* and *Acacia xanthophoea* seedling and their response to cyclic soil drought stress. Afri. J. Ecol., 39(21): 126-132.
- Poorter, H. and C. Remkes, 1996. Leaf area ratio and assimilation rate of 24 wild species differing in relative growth rate. Oecologia, 83: 553-559.
- Raddad, A.Y., 2007. Ecophysiological and genetic variation in seedling traits and in first-year field performance of eight *Acacia Senegal* provenances in Blue Nile, Sudan, Springer /New Forest.do, 11056-007- 9049-4.
- Ranney, T.G., T.H. Whitlow and N.L. Bassuk, 1990. Response of five temperate deciduous tree species to water stress. Tree Physiol., 6: 439-488.
- SAS, 1996. SAS statistical analysis. Version 6.12, SAS institute Inc., Cary.
- Tuomela, K. and M. Kanninen, 1995. Effects of water vapour pressure deficit and soil water content on leaf water potential between selected provenances of *Eucalyptus microtheca* in an irrigated plantation. Eastern Kenya-Silva Fennica, 29(3): 217-223.
- Tuomela, K., 1997. Physiological and morphological response of *Eucalyptus microtheca* provenances to water availability in tropical dry lands. Ph.D. Thesis, Tropical Forestry reports (13). University of Helsinki, Department of Forest Ecology.
- Turner, N.C., 1986. Adaptations to water deficits. A changing perspective. Plants Physiol., 13: 175-190.