Growth and Water Resource Utilization of Acacia Crassicarpa, Senna Siamea and Leucaena Pallida Tree Species Established in Rotational Woodlots Agroforestry System in Western Tanzania

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Abstract: We studied growth and water use by *Acacia crassicarpa*, *Leucaena pallida* and *Senna siamea* that were established and managed together with field crops for three consecutive years. At the end of the third year the fields were left fallow to allow trees to grow and build up soil fertility. Tree growth parameters and survival were monitored at different period of the study. The amount of water transpired by trees was measured by using heat pulse system on three-year-old trees. The studied species established effective woodlots with good stands and *A. crassicarpa* had the fastest growth rate. Results on water use showed that the mean daily transpiration by *A. crassicarpa*, *L. pallida* and *S. siamea* ranged from 350 to 1,700 grams and was largely determined by the stem diameters, the size of the tree canopy and the soil moisture availability. *Acacia crassicarpa* showed better performance in terms of growth height and root collar diameter while *L. pallida* showed better water utilisation. The results have implications on the benefits of the rotational woodlots technology in providing products and services while conserving soil and water resources for sustainable development.

Keywords: *Acacia*, Heat pulse system, *Leucaena*, *Senna*, Tabora, Transpiration rate

1 Introduction

The aim of tropical agroforestry systems is to increase economic empowerment in rural areas with minimisation of environmental degradation impacts (ICRAF, 2000). Agroforestry systems, which efficiently integrate trees into the existing land use systems, can play a significant role in providing needed products and services to rural communities. One of such agroforestry technologies with great potential in the Miombo ecosystem of Southern Africa, where rapid land degradation due to excessive deforestation is a major problem, is the ‘rotational woodlot’. The rotational woodlot system involves intercropping of annual crops for two to three years in the early stage of tree growth and again after the harvest of trees for two to three years later, keeping the stumps very low depending on the tree species (Otsyina *et al*., 1996). When yields decline to an uneconomical level, the stumps can be allowed to regrow into a woodlot again.

Rotational woodlots presents excellent example of a sequential and/or intermediate tropical agroforestry system with great promise of reducing deforestation as well as increasing crop production in a sustainable manner. However, the use of some tree species such as eucalyptus as plantation trees has been criticised on the grounds that they consume water in excessive amounts (Calder *et al*., 1992; Kallarackal and Somen, 1997) and can compete strongly with crops for water (Ong *et al*., 1990). There have been several studies on the water relations and water use of trees in the humid tropics (Kallarackal and Somen, 1997). *Acacia*, *Leucaena* and *Senna* species used in rotational woodlots may as well have some serious problems on the long-term environmental impacts as there is no information on water use by most agroforestry trees planted in subtropics with low annual rainfall. The objectives of this study were to determine the growth patterns of trees and to quantify the transpired water by trees planted in the rotational woodlot agroforestry system.

2 Materials and methods

The research was conducted at Tumbi Agricultural Research Institute farm in Tabora located within the miombo woodlands of western Tanzania where the rainfall distribution is mono-modal. The long term mean annual rainfall is 880 mm, 93% of which falls between November and April. The trial contained three tree species (*Acacia crassicarpa* A. Cunn. ex Benth., *Leucaena pallida* Britton & Rose and *Senna siamea* (Lamarck) Irwin et Barneby). Treatments were arranged in a randomised complete block design and replicated three times. Tree spacing was 4 m× 4 m and they were 20 trees per plot and the plots were spaced two meters apart. Trees were grown together with maize in the first three years (1996 to 1999) and from 1999/2000 cropping season all plots were left fallow during which measurements for water and transpiration were made. Tree height, root collar diameter, stem diameter at breast height, canopy cover and branching patterns were monitored throughout the growth period to compare growth rates of trees while tree survival counts were conducted at year 2.5 and 4, respectively.

The method described by Khan and Ong (1996) was used to measure transpiration by trees using sapflow gauges. The sensors were inserted into the stem of three-year-old trees species. Continuous sapflow measurements on the same plants were made for 25 days in *A. crassicarpa*, 12 days in *S. siamea* and 10 days in *L. pallida*. Due to the predominantly diurnal pattern of sapflow (Zang *et al*., 1996), only daytime observations, that is, 6.00 am and 19.00 pm (East African Time) were considered for sapflow analysis. Heat pulse velocity or simply sapflow velocity ($cm \cdot h^{-1}$) was converted into sap flux density (the volume of sap moving in the stream per unit cross sectional area per second) by multiplying sapflow velocity by stem cross-sectional area for each tree.

3 Results and discussion

Growth performance and survival of trees in woodlots

There was no evidence ($P > 0.05$) in tree growth height differences (Table 1a) and the number of branches (Table 1b) in the first 27 months after transplanting (MAP) among tree species studied. Significant ($P < 0.05$) differences in root collar diameter was observed between the species and *S. siamea* and *L. pallida* were leading at up to 27 MAP. Strong evidence ($P = 0.010$) on monthly growth rates for height was observed when determined at 36 MAP and *A. crassicarpa* had the highest growth rates in height (Table 1a). However, strong evidence on the monthly increment rates for root collar diameter existed at both ages ($P = 0.002$ at 18 and $P < 0.001$ at 36 MAP). Considerable variation ($P = 0.003$) in the number of individual branches was noted at 36 MAP (Table 1b) and all tree species had multiple stems, some emerging from the ground level and the number increased with age. *Senna siamea* had the highest and constant survival percent while the survival of *A. crassicarpa* decreased with age (Table 1b). Canopy cover (crown diameter) determines the potential shading effects of a tree species. *Senna siamea* was able to develop a large crown (303 cm) at early stages (15 MAP) of growth and their branches completely overlapped and covered the alley of four meters at 27 MAP.

The canopy closure at 27 MAP indicates that these species completely eliminate the possibilities of intercropping after that except when pruning is applied. Generally, all tree species established effective woodlots with good stands due to high growth rates and survival percentages implying the adaptation of these tree species prior to the fallow phase of woodlot.

Sapflow velocity and sap flux density

Estimation of water flux through the stem of a plant by point estimates based on the heat pulse technique requires integration of the velocity profile (Hatton *et al*., 1992). At all measurement time the sap flow velocities were fastest at 0.5 cm depth from the cambium and slowest at 1.5 and 2.5 cm (Fig.1). At 2.5 cm depth sap flow velocity was lowest and least sensitive to soil and atmospheric changes. This probably implies that sap flow velocity in the middle and inner annuli were more sensitive to reductions

Table 1a **Mean height and root collar diameter (cm) of *Acacia*, *Leucaena* and *Senna* species at 6, 15, 27, 36 and 48 months after transplanting and the growth rates (cm· months^{-1}) at 18 and 36 months at Tabora Tanzania**

Tree species	Height (cm)					Root collar diameter (cm)					Height growth rates		Collar diameter growth rates	
	6	15	27	36	48	6	15	27	36	48	18	36	18	36
A. crassicarpa	94	325	496	623	768	1.46	4.93	9.22	15.37	18.64	18.0	17.3	0.27	0.43
L. pallida	141	311	425	427	489	1.59	3.17	4.82	6.27	6.80	14.7	11.9	0.18	0.17
S. siamea	123	360	453	505	588	2.43	7.04	10.42	13.99	14.76	20.0	14.0	0.39	0.36
S.e.d	25.4	25.2	48.2	32.7	25.3	0.26	0.43	0.85	0.82	0.85	3.32	0.91	0.02	0.02
P values	0.29	0.247	0.415	0.010	<0.001	0.039	0.002	0.006	<0.001	<0.001	0.370	0.010	0.002	<0.001
CV %	26.0	9.3	12.9	7.7	5.0	17.6	10.4	12.7	8.7	7.8	23.1	7.7	10.4	8.7

Table 1b **Number of individual branches, canopy cover, survival and diameter at breast height (DBH) at different growth ages (months) in Acacia, Leucaena and Senna species in Tabora Tanzania**

Tree species	Number of branches		Canopy cover (cm)			Survival %		DBH (cm)		
	27	36	15	27	36	27	30	48	36	48
A. crassicarpa	124	182	214	350	430	96.7	93.3	60.0	7.85	10.16
L. pallida	81	58	184	367	353	95.0	91.7	90.0	3.95	4.25
S. siamea	144	253	303	427	431	98.3	98.3	98.3	5.40	6.00
S.e.d	50.6	23.8	31.5	44.0	41.0	4.71	4.83	6.8	0.56	0.49
P values	0.500	0.003	0.042	0.293	0.211	0.790	0.015	0.010	0.006	<0.001
CV %	53.3	17.8	16.5	14.1	12.4	6.0	6.6	10.1	12.0	8.8

in transpiration rates either caused by limited soil moisture content or reduced atmospheric demand (the amount of solar radiation) at the end of each day.

The daily transpiration is indicated on Fig. 2. Results showed that each *A. crassicarpa* tree transpired at an average rate of 540—1,680 grams per day, compared to 620—1,090 grams for *S. siamea* and 360—470 grams for *L. pallida*. Generally, the stem diameters, the size of the tree canopy and soil moisture availability largely determined the daily transpiration of the studied tree species and the range was from 350 to 1700 grams. The high variation in transpiration implies that stem diameters determined the actual quantity of water taken up by trees as the transpiration flux and diameter are normally closely related to conducting wood area (Hatton *et al*., 1995). Therefore, *L. pallida* showed better water utilisation due to low stem diameter and crown diameter.

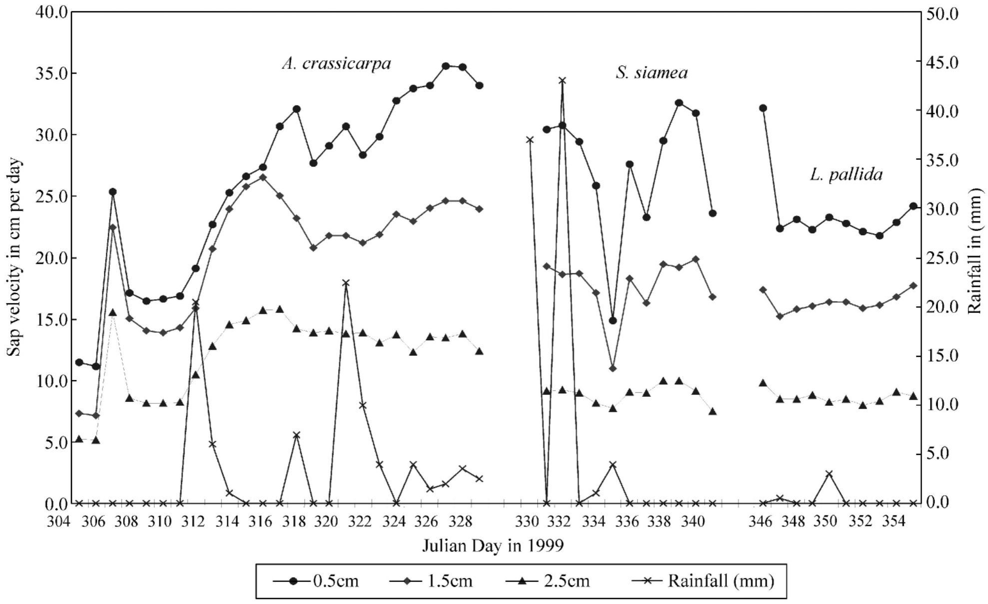

Fig. 1 Daily sap flow velocities of three year-old tree species planted in rotational woodlots agroforestry system in Tabora, Tanzania

4 Conclusion

Trees in croplands bring about microclimate changes under their canopies by reducing soil and air temperature, irradiance and wind speed. These changes will have direct influence on transpiration, soil water evaporation and humidity, which in turn may significantly affect water resource conservation and crop growth, depending on the climate. Tree growth parameters and the heat pulse method can be used to estimate stand transpiration and their consequences on water resource conservation particularly in semi arid environment.

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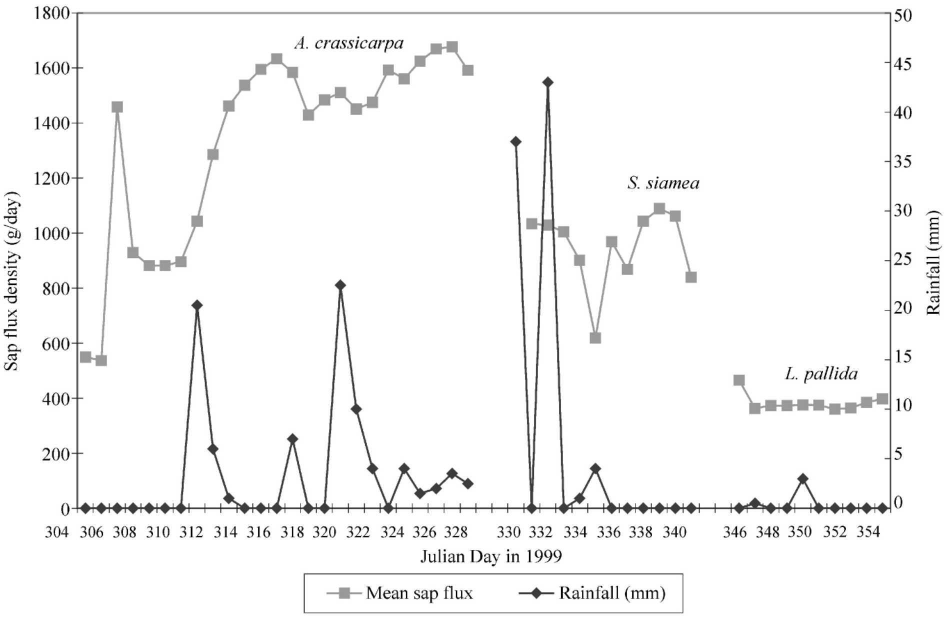

Fig. 2 Mean daily sap flux densities of three year-old trees planted in the rotational woodlots agroforestry system in Tabora, Tanzania

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