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EFFECT OF TREE DENSITY ON SOIL WATER USE EFFICIENCY IN AGROFORESTRY SYSTEM

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Abstract: Sapflow of individual trees of red alder (*Alnus rubra*) was measured at two stem densities over three blocks in a silvopastoral agroforestry experiment at Bangor, UK in 1998 where trees were planted at densities of 400 stems/ha (agroforestry) and 2500 stems/ha (forestry control). Sapflow rate was measured using the Thermal Dissipation Probe (TDP) in two trees in each treatment. Tree sapflow were related to the stand density (stems/ha). Planting density was found to modify individual tree sapflow. During the experiment, mean sapflow per tree was found to be lower at high tree densities being 0.29 dm^{-2} h^{-1} compared to 0.44 dm^{-2} h^{-1} at low densities and the difference was highly significant ($p = 0.001$). The higher sapflow in agroforestry was related to a high rate of crown transpiration caused by greater canopy exposure.

Keywords: Agroforestry; Soil water; Tree density; Transpiration

Introduction

In a forest ecosystem, transpiration is one of the major water fluxes and therefore its measurement or estimation is of great importance. According to Jarvis and McNaughton (1986) transpiration is mainly controlled by vapour pressure deficit and stomatal conductance. Transpiration from a forest canopy is also dependent on the energy balance and leaf area index of the canopy, on the availability of water in the soil and on the supply of water through the conducting tissues of stem (Whitehead and Jarvis, 1981). Transpiration may increase with an increase in leaf area index (Greenwood *et al.*, 1985), evaporative demand (Jarvis, 1981), stomatal conductance (Schulze and Hall, 1982) and soil water availability (Whitehead and Jarvis, 1981). Thus different transpiration rates may be expected from forests which differ markedly in leaf area, stomatal function, microenvironment and water availability.

There must be a continuous supply of water for transpiration to take place. If water supply is inadequate, plants become water stressed. Water stress has been shown to reduce plant growth (Acevedo *et al.*, 1971), so quantitative studies of water loss from vegetation are important. Water

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use efficiency, defined as the ratio of biomass produced per unit volume of water evaporated, is also important under water-limiting conditions. Dry matter production is thought to be directly proportional to the volume of water transpired (Monteith, 1981).

As tree density in a agroforestry system decreases, there is likely to be less competition for water by root overlap between trees, mutual shading will be reduced and canopy boundary layer conductance will be increased. In an agroforestry system, tree density will also affect transpiration of the associated crop or pasture species by modifying microclimate, and trees may also compete with the associated species for water, both by canopy interception of rainfall, and by root uptake of soil water. Modification of the environment by varying tree density is therefore likely to have a complex effect on biomass production and water use efficiency of components of agroforestry systems, through effects on both photosynthesis and water use (Eastham *et al*., 1990).

Adequate evaluation of competition interfaces between trees and intercrops is an important consideration in the assessment of agroforestry systems (Samra *et al*., 1993). A sound understanding of the processes and mechanisms involved in resource capture and use and their interactions with the environment are essential for the development of more reliable and productive agroforestry systems. Widely spaced trees in agroforestry are best considered isolated trees or rows of trees. It is of practical and theoretical interest to understand the controls on the transpiration rate of single trees.

Different techniques of xylem sap flow measurement have been used in agroforestry. The Granier method which is an empirical alternative to the heat balance and heat-pulse methods have been used in pure forestry conditions but never been applied in agroforestry conditions. In general, there have been several studies on sap flow and transpiration in forest conditions but very few in agroforestry situation. The present transpiration study was carried out in agroforestry situation using the Granier method to asses the effect of tree density on sap flow.

Materials and Methods

The study was carried out at Bangor, UK in 1998 in the two treatments in three blocks: (1) red alder *(Alnus rubra*), planted on a square grid pattern at 400 stems ha^{-1} in grazed pasture without regular application on N fertiliser and (2) a farm woodland control at 2500 stems ha^{-1} with no grazing. Field studies on sapflow measurement were conducted over 6-weeks periods and sapflow rate was measured using the Thermal Dissipation Probe (TDP) in two trees in each treatment and the connecting data logger was programmed to take readings at sixty seconds intervals.

Xylem sap flow techniques have been used in recent years to estimate transpiration of herbaceous plants and in trees by determining the rate at which sap ascends stem. Sap flow measurements can provide an accurate method for determining the transpiration at the individual tree scale (Grime *et al*., 1995). Techniques for measuring sap flow have been used in studies of plant water relations (Breda *et al*., 1995), the energy budgets of trees (Green, 1993), the effects of atmospheric turbulence on transpiration by trees (Hollinger *et al*., 1994) and can be monitored continuously over long periods (Allen and Grime, 1995).

Several methods of sap flow measurement have been developed for measuring rates of sap flow in stems and all utilise heat as a tracer for sap movement, but there are fundamental differences in the principles by which each operates. In the heat balance methods, a stem is heated continuously and the heat balance of the stem is then solved to obtain the rate of sap flow from the amount of heat dissipated by convection in the moving sap stream. In the heat-pulse technique, rather than continuously heating the stem, short pulses of heat are applied and the sap flow rate determined from a measurement of the velocity of the heat pulse as it moves along the stem. An empirical alternative to the heat balance and heat-pulse method was developed by Granier (1985). In this method, two cylindrical probes of 2mm diameter are inserted radially into woody stems, with one probe placed approximately 100 mm above the other. The upper probe contains a heater element and a thermocouple junction that is referenced to a thermocouple junction in the lower probe (Granier, 1987). Constant power is applied to the upper probe and the difference in temperature between the two probes is then dependent on the rate of sap flow around the probes; as sap flow rates increase, the temperature difference between the probes decreases. Together with biometric information about tree size and distribution in the stand xylem sap flow are measured which allows the estimation of total forest transpiration (Granier *et al*., 1996).

Results and Discussion

Mean sapflow per tree was found to be highest (0.42 dm^{-2} h^{-1}) in block 1 and lowest in block 3 (0.27 dm^{-2} h^{-1}) (Table- 1). Analysis of variance of mean sapflow per tree showed highly significant (P = 0.003) difference in tree sapflow between the three blocks (Table- 2). This significant difference could be attributed firstly to the difference in water table between the three blocks. Water table is very shallow in block 1 (1 m) and fairly deep (7 m) in block 3. Thus proximity of trees to soil water is much greater in block 1 than in block 3 and as a result trees in block 1 are likely to transpire more water. Similar results have been shown by Lu *et al*. (1995) where significant differences in transpiration were observed between dry and wet plots. Secondly, due to abundance of soil water, trees in block 1 and block 2 were able to grow more than trees in block 3. Alder is known to prefer wet sites (Dilly and Munch, 1995). Thus, sapflow in trees with larger diameter and crown areas are likely to be larger due to larger sapwood and bigger crown areas. Similar influence of DBH and crown status on sapflow have been reported by Granier *et al*. (1996).

Table- 1. Mean sapflow (l dm^{-2} h^{-1}±SE) in red alder (*Alnus rubra*) at tow plant densities in Bangor.

	Block 1	Block 2	Block 3	Mean
Alder 400*	0.44±0.04	0.58±0.10	0.29±0.03	0.44±0.04
Alder 2500**	0.39±0.03	0.25±0.03	0.24±0.03	0.29±0.02
Mean	0.42±0.03	0.41±0.05	0.27±0.02	

Note: * Alder 400 refers to 400 stems/ha in agroforestry. ** Alder 2500 refers to 2500 stems/ha in a forestry control.

Table- 2. Analysis of variance on sapflow between blocks and treatments and interactions between blocks and treatments.

Source	DF	Seq SS	Adj SS	Adj MS	F	P

Block	2	1.3999	1.3999	0.7	5.93	0.003
Treatment	1	1.4726	1.4726	1.4726	12.47	0.001
Block*Treatment	2	1.1904	1.1904	0.5952	5.04	0.007
Error	282	33.2897	33.2897	0.118		
Total	287	37.3526				

Differences in mean sapflow per tree between the two treatments was also found highly significant (P = 0.001). Mean sapflow per tree in alder 2500 was much lower (0.29 $dm^{-2} h^{-1}$) than that of alder 400 (0.44 $dm^{-2} h^{-1}$). That was probably due to the low stem density in Alder 400, which made each tree to be more exposed to sun and wind than in alder 2500. Similar results have been reported by Morikawa *et al*. (1986) where the rate of sapflow per tree was higher in a thinned plot at a given level of solar radiation and the difference between sapflow before and after thinning increased with solar radiation. Lower sap flow per tree in alder 2500 may be due to mutual shading of neighbouring trees as reported by Granier *et al*. (1996).

Conclusion

The conclusion that can be drawn from the results of the present study is that water use and sapflow per tree in the agroforestry experiment were modified by tree density. Sapflow rate was much higher in trees planted at low densities. Stem density induced a significant difference in individual tree transpiration as a consequence of differences in water and energy availability.

It may be possible that sapflow rate of individual trees may increase with the decrease in tree density up to a certain level of tree density after which tree sapflow may decrease at much lower densities because of high competition for water with agricultural crops (Eastham *et al*., 1990). Thus, further study is required to establish the relationship between tree density and sapflow by including several density treatments for determining a optimum density.

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