

A STUDY OF THE EFFECTS OF CLIMATIC FACTORS ON TREE SAPFLOW IN AN AGROSILVOPASTORAL SYSTEM

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Abstract: Effects of climatic factors such as solar radiation, air temperature and relative humidity on the rate of tree sapflow were studied in a agrosilvopastoral system of agroforestry using the Thermal Dissipation Probe (TDP). Sapflow was found to be positively correlated with solar radiation and air temperature and negatively correlated with relative humidity. Sapflow revealed to be closely dependent on air temperature, solar radiation and related humidity at high stem densities (2500 stems/ha.) and less correlated at low stem densities (400 stems/ha.).

Key words: Agroforestry; Water balance; Sapflow; Climatic factors

Introduction

A sound understanding of the processes and mechanisms involved in resource capture and use by the production components (perennial trees, annual crops and livestock) and their interactions with the environment are essential for the development of more reliable and productive agroforestry systems. Water is an essential plant component and a major constituent of plant cells. The amount of water present in a system is a useful measure of plant and soil water status. The water status in plant systems is measured in terms of water potential, which is a measure of free energy available to do work. Water potential is defined in terms of the chemical potential of water, which in turn is the amount of water by which the Gibbs free energy (G) in the system changes as water is added or removed while temperature, pressure and other constituents remain constant (Jones, 1992). For transpiration to take place there must be continuous supply of water. Transpiration is a dominant factor in plant water relation because it produces the energy gradient which causes the movement of water into and throughout plants (Bhatt, 1990). The quantity of dry matter production is directly proportional to the volume of water transpired and thought to be linearly related to the quantity of water transpired (Monteith, 1981). The influence and regulatory role that trees play in water movement is very important in agroforestry systems (Dawson, 1996).

Conservation of surface water is of paramount importance for crop growth in agroforestry systems. If a plant transpires more the canopy temperature would be lower and therefore the loss of water from the soil surface due to surface evaporation will also

be lower and it will allow better crop growth beneath and adjacent to it (Bhatt, 1990). Current cropping systems in tropical semi-arid regions often use less than half the rainfall input since there can be substantial loss of water via soil evaporation, runoff and drainage (Cooper *et al.*, 1983). Thus any reduction in soil evaporation, runoff or deep drainage resulting respectively from increased shading and reduced soil surface temperature, the physical barriers presented by the tree component or increased abstraction during the rainy season would increase the proportion of the annual rainfall retained for transpiration and hence biomass accumulation. Agroforestry has been proved to be more effective in utilizing available moisture than annual crops and improves productivity by using a larger proportion of the annual rainfall.

In order to get benefit from the agroforestry systems in terms of water balance, the component of the system need to be managed in a way so that soil evaporation, runoff and drainage are minimized (Ong *et al.*, 1996). Actively growing crops that provide full ground cover and are well supplied with water exert minimal control over transpiration, and transpire at rates determined by the evaporative demand of the atmosphere. The balance between transpiration and absorption of water depends on both atmospheric and soil moisture conditions (Gregory and Reddy, 1982). Although atmospheric conditions predominantly determine potential evaporation, it is the attributes of the vegetation that limit transpiration and determine actual evapo-transpiration in water-limiting environments (Ong *et al.*, 1996). 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 (Rakkibu, 1999). 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).

Sap flow measurements can provide an accurate method for determining the transpiration at the individual tree scale (Steinberg *et al.*, 1990; Grime *et al.*, 1995) and sap flow can be monitored continuously over long periods (Allen and Grime, 1995). Estimates of stand sap flow are directly dependent on local conditions which may vary over a short distance. Techniques for measuring sap flow have also been used in studies of plant water relations (Breda *et al.*, 1995) and to study the energy budgets of trees (Green, 1993) and the effects of atmospheric turbulence on transpiration by trees (Hollinger *et al.*, 1994). Thus, the use of sap flow methods in studies of plant water use is becoming increasingly widespread, so that they are likely to play a prominent role in future efforts to devise solutions to hydrological problems encountered by farmers, foresters and conservationists.

The present study was carried out to assess the effects of relative humidity, air temperature and solar radiation on tree sapflow in agroforestry situation and to find out the correlation, if any, between sapflow and climatic factors.

Materials and Methods

The study was carried out in a agrosilvopastoral agroforestry experimental site at Bangor, UK in 1998. The experiment involved seven treatments which were replicated three times in a randomised complete block design. The treatments are summarised below:

- Three different densities of sycamore trees planted on a square grid pattern; at 100 stems ha^{-1} and 400 stems ha^{-1} in grazed pasture with regular application of 160 kg of N ha^{-1} and a farm woodland control at 2500 stems ha^{-1} .
- A nitrogen fixing tree species, red alder, planted on a square grid pattern; at 400 stems ha^{-1} in grazed pasture without application of N fertiliser, and as a farm woodland control at 2500 stems ha^{-1} .
- An alternative planting arrangement of sycamore at 400 stems ha^{-1} in grazed pasture with trees planted in clumps with closer spacing of trees within clumps (1.5 m) than between them (20 m between clump centres). Thirteen trees are planted within each clump in a diamond pattern which together with the stock-proof fence surrounding the clump, occupies 36m^2 . There are thirteen clumps per plot.
- A grazed pasture control with no trees.

The present study was concentrated on the nitrogen fixing tree species red alder (*Alnus rubra*) in two treatments in three blocks (1) planted on a square grid pattern at 400 stems per ha^{-1} in grazed pasture without regular application of N fertilizer and (2) a farm woodland control at 2500 stems ha^{-1} with no grazing. Field studies on sapflow measurement were conducted over a period of six weeks and sapflow rate was measured using the Thermal Dissipation Probe (TDP) and the connecting data logger was programmed to take readings at sixty seconds intervals.

The Thermal Dissipation Probe heated needle is an improved heat dissipation sensor (Granier, 1985) which measures the temperature on a line heat source implanted in the sapwood of a tree, referenced to the sap wood temperature at a location well below the heated needle. The probe measures the sap wood heat dissipation which increases with sap flow and the resultant cooling of the heat source, as the apparent thermal conductance of sapwood increases with sap velocity. When the sap flow velocity is zero or minimal, the temperature difference (dT) between the two sensors is maximal. When the flow increases, this temperature difference decreases. This approach enables the measurement of sap flow velocity with inexpensive equipment from a known relation between dT and the sap velocity. An important feature of the TDP is that a constant heat method is used, that is, the heating element of the probe stays on and permits continuous and frequent measurements.

Climatic factors of the site including solar radiation, air temperature and relative humidity were obtained from an automatic weather station located on the southern side of the experimental site.

Results and Discussion

Relationship between sapflow and solar radiation: Tree sapflow was found positively correlated and closely dependent on solar radiation. Stronger correlation between sapflow and solar radiation was found in all the experimental plots but very strong correlation ($r = 0.93$) was found in block 3, in Alder 2500 (pure forestry control of 2500 trees per hectare) and lowest but still strong ($r = 0.76$) correlation was found in block 1, in Alder 400 (a grazed pasture land of 400 trees per hectare with livestock) (Table 1). In all the three blocks radiation correlation was stronger in forestry control (Alder 2500) than in agroforestry plots (Alder 400). Sapflow rates in all the six experimental plots showed a very close trend which increased with an increase in solar radiation. Similar trend in relationship has been reported by Morikawa *et al.* (1986).

Table 1. Pearson's correlation coefficients.

	SAPFLOW					
	Alder 400 stems ha ⁻¹	Alder 2500 stems ha ⁻¹	Alder 400 stems ha ⁻¹	Alder 2500 stems ha ⁻¹	Alder 400 stems ha ⁻¹	Alder 2500 stems ha ⁻¹
	Block 1	Block 1	Block 2	Block 2	Block 3	Block 3
Solar radiation	0.76	0.79	0.80	0.82	0.86	0.93
Air temperature	0.56	0.66	0.50	0.87	0.91	0.87
Relative humidity	-0.56	-0.79	-0.60	-0.80	-0.80	-0.90

Higher leaf irradiance causes higher stomatal conductance hence more sapflow and stomatal conductance is affected by solar radiation, vapour pressure deficit and soil moisture (Mcnaughton and Jarvis, 1993). Stronger correlation between sapflow and solar radiation in block 3 than in block 2 and block 1 may be explained in terms of the decrease in stomatal conductance in block 3 due to deep water table (>6m) and less soil moisture. Similar relationships have been reported by Zhang *et al.*, (1997) between sapflow, stomatal conductance and solar radiation.

Relationship between sapflow and air temperature: With the increases in air temperature tree sapflow increased in all the treatments. Similar relationship between air temperature and sapflow has been reported by Bhatt (1990). Increase in air temperature causes decrease in relative humidity of air hence decrease in air vapour pressure but vapour pressure within the internal leaf surface increases leading to increase in vapour pressure deficit which causes increase in transpiration. Air temperature was found modestly correlated ($r = 0.56$; $r = 0.66$) with tree sap flow in both the treatments of block 1 and in the Alder 400 ($r = 0.50$) of block 2. But stronger correlation ($r = 0.87$) was found in Alder 2500 of block 2 and in both the treatments of block 3 ($r = 0.91$; $r = 0.87$). In block 1 sapflow was less dependent on air temperature which may be due to presence of adequate soil moisture in the rooting zone that allowed continuous flow of transpiration stream and therefore internal leaf surface was well saturated with water and would have transpired more even at low vapour pressure deficit. In block 1 and block 2, sapflow in Alder 2500 was found more strongly ($r = 0.66$; $r = 0.87$) correlated than in Alder 400 ($r = 0.56$; $r = 0.50$). This was may be because in Alder 2500 the tree canopy was closed and the surrounding air temperature just above the canopy would have been cooler which increased slowly with the increase in air temperature than in Alder 400. But in block 3, the reverse relationship between sapflow and air temperature was found where stronger correlation ($r = 0.91$) was observed in Alder 400 than in Alder 2500 ($r =$

0.87). This may be due to soil water stress in Alder-2500 which enforces stomatal closure. Similar influence on sapflow has been reported by Ong *et al.*, (1992).

Relationship between sapflow and relative humidity: Relative humidity was found negatively correlated ($r = -0.56, -0.79, -0.60, -0.80, -0.80, -0.90$) with sapflow in both the treatments of three blocks. Tree sapflow increased with the decrease in relative humidity in all the treatments of three blocks. A decrease in relative humidity causes a decrease in air vapour pressure and vapour pressure deficit (VPD) between leaf and air increases leading more transpiration. In block 1 and block 2, relative humidity was found weakly correlated with sapflow and even weaker in Alder 400 ($r = -0.56, -0.60$) than Alder 2500 ($r = -0.79, -0.80$). This may be because of greater sapflow per tree in block 1 and block 2 and within the blocks even more in Alder 400 than in Alder 2500 as a result of more soil water in the rooting zone. Due to more sapflow, relative humidity of the adjacent air just above the canopy in block 1 and block 2 would be higher than that of in block 3 at the same temperature. In block 3, strong negative correlation between sapflow and relative humidity was found and it was stronger in Alder 2500 than in alder 400. This may be related to decrease in canopy conductance with the increase in VPD. Similar results have been shown by Stewart (1988). As the rate of sapflow per tree in block 3 is much lower than that of the block 1 and block 2, the relative humidity above the canopy of block 3 would be much lower resulting greater vapour pressure deficit and stomata may close at higher VPD resulting in decreased sapflow (Jones, 1992).

Conclusion

Effects of climatic factors on trees in relation to water use and transpiration were found to be modified depending on stem densities in agroforestry system. In agroforestry, soil water is a very important and limiting resource for the shallow rooted annual crops. The amount of water would be left available for the utilization of annual crops in an agroforestry system would depend on the amount of transpiration by the perennial tree components. So, under certain climatic factors, for an agroforestry system to be optimum productive and sustainable, tree densities should be maintained in such a manner that component species could capture required amount of soil water.

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