AERODYNAMIC AND CANOPY RESISTANCE OF SHORT-ROTATION FOREST IN RELATION TO LEAF AREA INDEX AND CLIMATE

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Abstract. The aerodynamic and canopy resistances of a willow short-rotation stand were estimated during the course of a growing season on the basis of micrometeorological measurements. The normalized roughness length \((z_0/h)\) decreased from about 0.10 at a leaf area index of one to 0.05 at a leaf area index of seven. This implies that the aerodynamic resistance at peak leaf area index is more than twice the value at zero leaf area index, all other variables unchanged. The canopy resistance depended strongly on air water concentration deficit and on leaf area index. The Lohammar equation showed good agreement between estimated and "measured" canopy resistances over the whole course of leaf development. The stand was well-coupled to the atmosphere only for very small values of leaf area indices, less than one, and it was practically de-coupled for leaf area indices above two. From the point of view of factors controlling evaporation, this type of stand acts as a traditional forest at the beginning and end of the season and as an agricultural crop in the middle of the season.

1. Introduction

Many of today's models dealing with estimation of fluxes of heat, water or other gases from vegetated surfaces require quantitative information about stomatal and boundary-layer resistances. The so-called Penman–Monteith big leaf model has been shown to give good results provided that the bulk resistances for the whole canopy are known (e.g., Stewart, 1984). The bulk resistances, here denoted canopy and aerodynamic resistance, depend on stand characteristics like size, shape and distribution of leaves, on climatic variables and on other specific plant factors.

It is today generally recognized that the canopy resistance, which is assumed to equal the total resistance per unit of ground area of all stomata acting in parallel, depends primarily on solar radiation, vapour concentration deficit and soil moisture deficit. It depends also, by definition, on the leaf area index of the vegetation. For a deciduous forest, the latter dependence might prove to be equally important for successful modeling of the seasonal course of evaporation as does the knowledge about the functional relationships between climatic factors and canopy resistance.

The bulk aerodynamic resistance, \(r_a\), for transfer of heat and water from a horizontally homogeneous vegetated surface to a reference level, \(z\), above the canopy can, in adiabatic conditions, be expressed as (Thom, 1976):

\[ r_a = \frac{\ln^2((z - d)/z_0)}{k^2u(z)} \]

where \( d \) is displacement height and \( z_0 \) is roughness length for heat and water, \( k \) is von Karman's constant and \( u(z) \) is the wind speed at level \( z \). This type of parameterization of the aerodynamic resistance is used in many models (e.g., Johnsson and Jansson, 1991). The displacement height and the roughness length are commonly assumed to be a constant fraction of stand height. This is, however, not a very realistic assumption and it has been shown by numerical model experiments that these parameters depend quite strongly on both height and density of the vegetation (e.g., Shaw and Pereira, 1982). Since the aerodynamic resistance is sensitive to these parameters, it would be important to incorporate such dependencies in models aiming at describing the seasonal course of evaporation. There is, however, to my knowledge, no experimental verification of such dependencies.

The aim of this paper is to estimate the aerodynamic and canopy resistances of a willow short-rotation stand during the course of the season in order to find out how the development of the stand, here expressed as leaf area index, will affect these resistances. The coupling between the atmosphere and the stand in terms of the omega factor (McNaughton and Jarvis, 1983) is also discussed. The results are based on micrometeorological measurements of fluxes.

2. Material and Methods

2.1. Site and Stand

The short-rotation stand, situated at Ultuna (Lat. 59.3°N, Long. 17.4°E, Alt. 5 m), southern Uppsala, Sweden, was planted in 1984 with 2 plants (cuttings) per square metre on a clay soil which had earlier been used for agricultural crops. The planting material consisted of at least two different clones of *Salix viminalis* L. (Verwijst, 1990). The plot was approximately rectangular in shape and it had a length of 225 m in the north-south direction and a width of 125 m in the east-west direction. The plot had a gentle slope from northwest to southeast of about 3%. The stand was irrigated and fertilized daily from June to September with a drip irrigation system. Total irrigation was 245 mm in 1988. The stand was cut down for the first time in January 1987 and accordingly, the shoots were two years old at the end of the 1988 season.

The growing season (threshold of 5 °C at Ultuna normally starts in mid-April and ends in late October. The mean (1931–1960) annual air temperature is 5.8 °C and the mean annual precipitation (non-corrected) is 554 mm.

2.2. Stand Leaf Area and Height

Estimation of leaf area was based on diameter measurements which were taken repeatedly on the same shoots during the season, and on allometric equations derived from destructive samples, taken on 10 occasions. Using these allometric