Journal of Hydrology 396 (2011) 321–326

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Influence of *Eucalyptus globulus* plantation growth on water table levels and low flows in a small catchment

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ARTICLE INFO

Article history:
Received 12 April 2010
Received in revised form 23 November 2010
Accepted 24 November 2010

This manuscript was handled by Geoff Syme, Editor-in-Chief

Keywords:
Afforestation
Foliage biomass
Eucalyptus globulus
3-PG model
Galicia

SUMMARY

In a catchment with a shallow water table, switching land use from fodder maize and pasture to *Eucalyptus globulus* plantation altered dry season hydrology: the water table fell more rapidly each year, and the concomitant decrease in discharge soon led to the stream drying up every year. During the first 3 years of growth, the rate of fall of the water table, *S*, remained stable in spite of rapid stand growth, which is attributed to transpiration in the catchment being dominated by the background vegetation during this period. Between the third and sixth years, *S* increased linearly with foliage biomass W_s (calculated with the 3-PG model as a proxy for the transpiration capacity of the stand). Subsequently, the levelling off of W_s as the result of canopy cover reaching 100% was reflected by similar behaviour of *S*. The final values of *S*, in the range 4.5–4.9 mm day^{-1}, were just over double the initial values of around 2.2 mm day^{-1}. The influence of plantation with *E. globulus* on water reserves and discharge needs to be taken into account by catchment management.

1. Introduction

Whether driven by the needs of the paper and timber industries or by incentives of carbon sequestration, recent decades have seen a marked increase in the afforestation, the planting of forests in previously unforested areas, over large areas that were formerly occupied by pasture and other short-term crops (Calder et al., 2002; Farley et al., 2005; Sun et al., 2006).

Together with such unquestionably beneficial effects as increased water quality and reduced peak runoff flow and erosion, afforestation can also have the less desirable effect of reducing water yield (Andréassian, 2004; Calder et al., 2002; Iroumé et al., 2005; Lane et al., 2003, 2005; Scott and Lesch, 1997; Scott and Smith, 1997; Sikka et al., 2003; Sun et al., 2006; Zhou et al., 2002). The extent of this reduction in yield essentially depends on local climate, soils, and vegetation cover: in China, for example, reported reductions have ranged from 50 mm/year on the semi-arid loess plateau to 300 mm/year in tropical southern regions (Sun et al., 2006). Percentage wise, these figures amount to reductions of 50% and 30% respectively (Sun et al., 2006), while a reduction in average monthly streamflow of 51% over 6 years has been reported in a South African basin following afforestation with *Eucalyptus grandis* (Scott and Lesch, 1997). In their classical review of experiments in 94 catchments, Bosch and Hewlett (1982) estimated that water yield fell by 40 mm for each 10% of a catchment area afforested with *Pinus* or *Eucalyptus*.

In many contexts, the effect of afforestation on the duration or intensity of drought during rainless periods is of greater social and environmental concern than a reduction in total annual yield (Iroumé et al., 2005; Johnson, 1998; Sikka et al., 2003). However, most of our knowledge of this influence comes from cross-sectional studies that have compared short-term flow parameters in catchments with differing woodland coverage (with or without matching levels of rainfall); there have been few longitudinal studies of the dynamics of afforestation-induced changes in dry-period groundwater reserves.

In this study we analyze, at a catchment scale, the effects of the growth of plantation trees on water availability during the summer dry period. Specifically, we measured the rate at which the water table fell during the summer dry period and the effect this had on flow rates, in a small catchment afforested with *Eucalyptus globulus*. We also related year-to-year changes in this rate of fall to the growth of the stand between the second and ninth years following its plantation, a period that covers virtually the entire growth cycle of *E. globulus* prior to felling.

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doi:10.1016/j.jhydrol.2010.11.027

2. Material and methods

The study area comprises a 400 Ha site in the municipality of Abegondo (Galicia, N.W. Spain, Fig. 1), where eucalyptus were planted in 1998 on land formerly used for pasture and the cultivation of maize as a fodder crop., The site is at an altitude of 375–450 m above sea level, with a mean annual rainfall of 1490 mm and annual mean temperature of 12.3 °C.

Geologically the area is characterised by a rocky substrate, dominated by metamorphic schist of the Ordes series, in which permeability is associated with fissuring and surface alteration. The low permeability of these rock formations means that the piezometric level tends to follow the shape of the topography (Samper, 2003). Recharging occurs via fractures and zones of alteration within the rocks, and as a result the piezometric level tends to show a fairly rapid response to recharging, particularly when fractures reach ground surface level. (Enresa, 1987; Lerner et al., 1990). Lying over these schists, its soils – Ferralic and Haplic Umbrisols according to the World Reference Base classification (FAO, 1998) – are loams or silt loams (average composition 30% sand, 50% silt, 20% clay) with depths of 45–125 cm and organic matter contents of around 9.5%.

Within the plantation a 10.7 ha catchment was selected, located at 8°20′39″N, 43°9′2″ W and with a mean altitude of 417 m. *E.* globulus was planted in 85% of the area of this catchment, leaving only two narrow strips of pasture (11% of the area) and a small area of riparian woodland (4% of the area) (Fig. 1). The trees were planted at a density of 1270/ha with 2.25 × 3.5 m spacing. Since the time of plantation, growth has been monitored in three plots by measuring the height *H*, breast-height trunk diameter D_{BH} and crown diameter DC of each of the nine trees in each plot. Measurements were taken every 15–30 days during the first 3 years, and every 2–3 months thereafter.

Since November 1997, when a 60° V-notch weir was constructed at the outlet of the catchment, streamflow has been measured every 5 min using a capacitive depth probe linked to a Unidata® Starlog datalogger, and meteorological data have been recorded at the same frequency in a Unidata® Starlog datalogger by an automatic weather station that was installed at the centre of one of the pasture strips (Fig. 1) and is equipped with a Vaisala® HMP45A relative humidity and temperature sensor, a Kipp & Zonen® CMP-11 pyranometer, an Ornytion® 107H anemometer, and a Campbell Scientific® ARG100 tipping bucket rain gauge (0.2 mm per tip).

A well, of 120 mm diameter and 15 m depth, has also been sunk within the study catchment in order to determine variations in the water table level. Between June 1999 and February 2000, water table depth was measured manually every 7–14 days in a well located in the vicinity of the outlet (Fig. 1) since February 2000, these measurements were performed and recorded automatically every 5 min using a Unidata® 6541 float-driven digital level recorder. In this study we consider results for the period 1999–2007.

The data acquired were used to calculate reference crop evapotranspiration ET_0 by means of the FAO Penman–Monteith equation (Allen et al., 2006), and to simulate stand growth (*H*, D_{BH}, stem volume, leaf area index, and stem, root and foliage biomasses) using the physiological-process-based 3-PG model "Physiological Principles for Predicting Growth" (Landsberg and Waring, 1997), which has been applied to *E. globulus* stands on numerous occasions (Coops and Waring, 2001; Esprey et al., 2004; Landsberg et al., 2003; Sands and Landsberg, 2002). 3-PG predictions were tested by comparison with measured values of *H*, D_{BH} and canopy cover (*CC*, defined as the proportion of soil area occupied by the vertical projection of crowns) (Rodriguez-Suarez et al., 2010).

As a measure of the rate of depletion of groundwater reserves in the catchment during the annual summer dry period (defined as June 1st–September 15th), we determined the rate at which the water table fell during defined subperiods. The influence of year-to-year differences in loss of groundwater to streamflow, which is determined by the level of the water table (Mishra et al., 2004), is minimized when defining these subperiods. This is accomplished by starting a subperiod when the table attains a depth of 250–255 cm and terminating on September 15th or upon the onset of significant rainfall (whichever occurred first). The rate of fall was determined by regressing 5-day mean water table depths against time. In what follows, these subperiods are referred to as "MRF periods" ("MRF" for "measurement of rate of fall").

3. Results and discussion

Annual rainfall in the catchment during the study period was on average 1750 mm, 260 mm above the long-term average for the area, 1490 mm. As Table 1 shows, variation was considerable (1123–2231 mm; relative standard deviation RSD = 21.5%, with a statistically significant decline throughout the study period ($p < 0.05$). Rainfall during the dry period was likewise variable (123–257 mm; RSD 20.6%), but the mean itself, 192 mm, are close

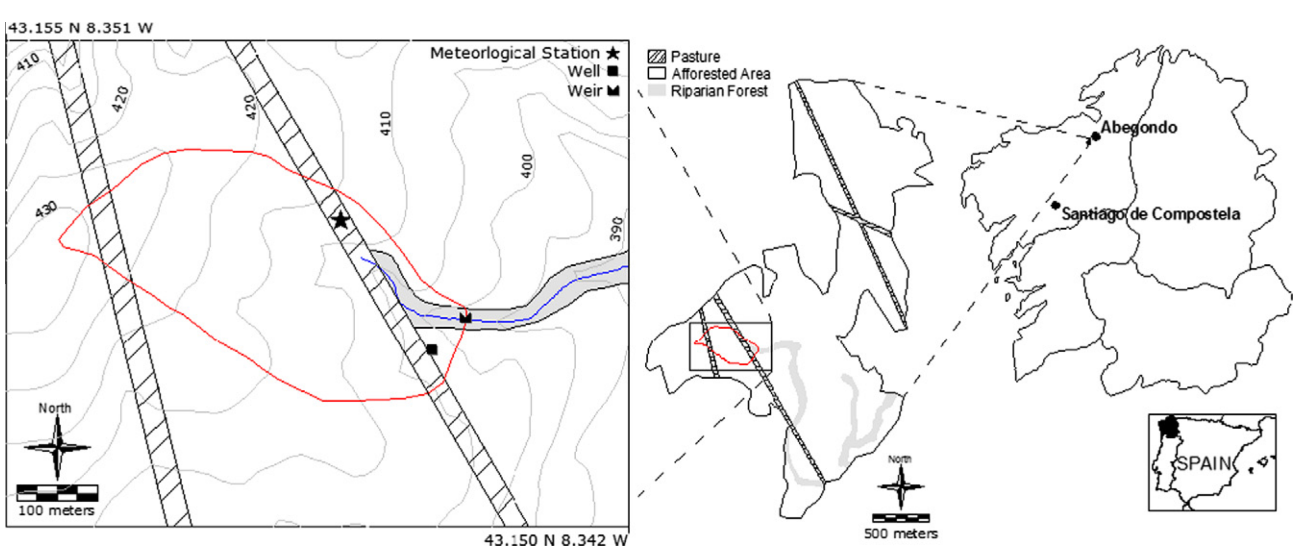

Fig. 1. Location of the study area and distribution of land uses (red line is the limit of the catchment).