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Estimation of Water Use by Vegetation Barriers Based on Climatological Factors and Soil Moisture Levels

Wim Spaan, J. Ringersma, L. Stroosnijder, A. Sikking

Department of Environmental Sciences

Wageningen University

Nieuwe Kanaal 11

6709 PA Wageningen, The Netherlands

Fax: 0031 317484759

E-mail: Wim.Spaan@users.tct.wau.nl

Abstract

Runoff management is one of the tools to increase the available water for agricultural production in areas where rainfall is erratic. Vegetation barriers have shown to increase the amount of water in the soil by slowing down runoff and thus allowing more time for infiltration. They do not cause upstream water logging problems due to the semi-permeable character of the barrier. However little is known about the water use of the vegetation barrier and thus whether its conservation effect is not being minimised by its own water use. This paper presents the results of a study conducted in Burkina Faso in 1996 in which a method has been developed to assess the water use of a vegetation barrier. Transpiration (sapflow) was measured on 3 barrier species (*Andropogon gayanus*, *Piliostigma reticulatum* and *Ziziphus mauritiana*). Transpiration was related to meteorological factors and soil moisture availability. The method used was found to be simple and reliable. The results can be used in other experiments focusing on the water use of (natural) vegetation and its competition with agricultural crop water use.

Introduction

The aim of runoff management in the Sahel is to enhance the amount of available water in the soil for plant growth and crop production. Improved local infiltration can be achieved by water conservation measures along contour lines. Hien (1995) gives an overview of these measures and their efficacy. Non permeable measures minimise runoff but can also cause waterlogging problems upstream. Semi-permeable stone and dead wood barriers result in an improved water balance and avoid waterlogging.

Vegetation barriers slow runoff and retain sediment and organic debris and still allow drainage of excess water due to their semi-permeable nature, thus positively affecting the upstream and downstream soil water availability. A vegetation barrier, using locally available species is often cheap and easy to establish. As both the crop and the vegetation barrier use water, competition for water may reduce yields of nearby crops as the extraction of water from the soil by the roots of the vegetation barrier (Smith et al., 1994). Since vegetation barriers present an appropriate measure in runoff management a method to assess the water use of vegetation barriers becomes necessary in order to optimise the design of this conservation practice.

For most agricultural crops a relation has been established between climate and potential evapotranspiration by the introduction of crop coefficients (Doorenbos and Pruitt, 1977) and the use of reference evapotranspiration. The method, recommended by the FAO (1992) requires crop factors, which are not available for non-agricultural crops used in vegetation barriers, as well as extended climatological data. The reduction of the potential evapotranspiration as a result of non-optimal soil moisture conditions (Doorenbos and Kassam, 1979) is another unknown factor for vegetation barriers.

This paper presents results of a study conducted in Burkina Faso in which a method has been developed to assess water use by vegetation barriers based on easily measured variables. Various options are presented with increasing complexity and accuracy ranging from the use of a single climatological factor, a multi-climatological factor and a combination of climate and available soil moisture under the vegetation barrier.

Materials and methods

The study took place in Gampela, Burkina Faso, in 1996. Twenty-one plots of 20 x 20 m were laid out within a 3 ha experimental site in 1994. Plots were laid in the direction of the slope, which varied between 1.5 and 2%. At 5 m from the downstream side of each plot a 1 m wide vegetation barrier was planted. Seven plant species were planted in three replications. The choice of species was influenced by local availability, anticipated growth and soil and water conservation properties.

For the development of the water use assessment method three species were selected *Andropogon gayanus* (a perennial grass), *Piliostigma reticulatum* (a tree), and *Ziziphus mauritiana* (a shrub). Transpiration was monitored for two periods of approximately 5 days. Soil moisture content and climatological factors were measured throughout the whole period. Transpiration measurements started when the barriers were in the mid-season stage and since the vegetation barriers were maintained, the biomass of the barriers remained the same over the mid-season, thus a seasonal variation of the transpiration has not been studied.

For the measurement of transpiration use was made of the stem heat balance method (Baker and van Bavel, 1987). The 20 m vegetation strips were divided in 4 sections according to plant size based on visual observations. In each section the sapflow of a representative plant was monitored continuously for 5 days and averaged every 30 minutes. Since transpiration was directly related to the biomass of the vegetation barriers through the number of leaves on the sampled stem, correlations found were between 0.86 and 0.99 for all observations (Fig. 1), the transpiration of each section could be calculated from the area of the section and the total number of leaves in the section. The transpiration of the whole barrier was calculated from the weighted average of each section.

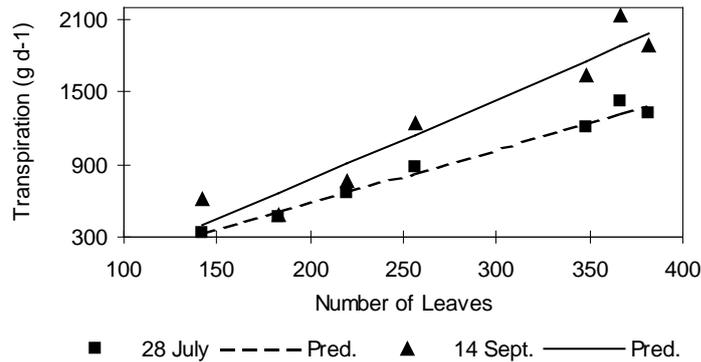


Figure 1: Relation between the number of leaves and transpiration for 28 July ($R^2=0.98$) and 14 September ($R^2=0.92$) of *piliostigma*. Gampala, Burkina Faso, 1996.

Soil moisture was measured using a TDR tube probe. Three access tubes were placed in the vegetation barrier and measurements were taken daily every 0.20 m to 1.0 m depth. The measurement depth was limited to 1 m because of a restricting soil layer at this depth. Total soil moisture in the profile was calculated by summing the depth of water in each layer of 0.20 m. In order to be able to detect stress conditions for plant growth soil moisture retention curves were made in the laboratory.

Continuous measurements of air temperature, wind speed and direction, humidity and incoming solar radiation at the experimental site were made using an agro-meteorological station and averaged for 30 minute periods. Rainfall was measured using a tipping bucket rain gauge. Reference evapotranspiration was calculated for 24 h periods using the Penman-Monteith method (FAO, 1992).

Relations of single or multi-climatological factors and transpiration were made based on 30 min. averages. The relation between transpiration and reference evapotranspiration was made on the basis of 24 h. period data. This also counts for the relation between transpiration and available soil moisture and the combination of available soil moisture with climatological factors.

A validation of the relations was made by calculating the transpiration over short periods without rainfall and fitting it into the water balance.

Results

The relation between the transpiration and single meteorological factors is presented in Fig. 2 and Table 1. All relations are linear with high correlation coefficients.

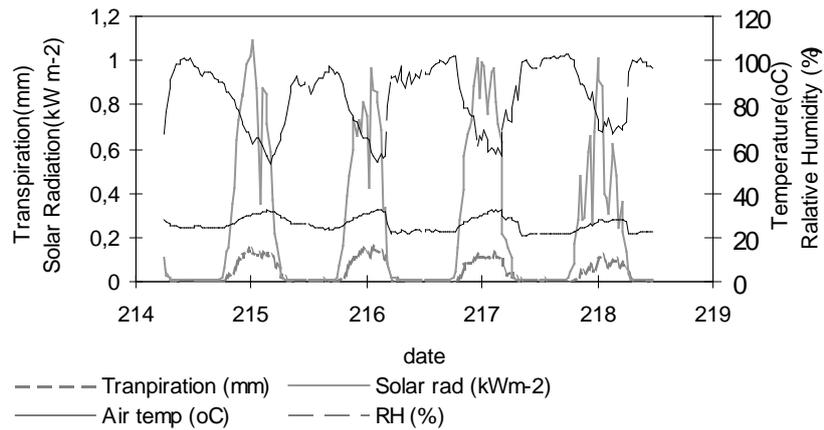


Figure 2: Relation between the transpiration of the ziziphus barrier and climatological factors, Gampala, Burkina Faso, 31 July - 5 August 1996

Table 1: Relation between transpiration ($\text{mm } 30 \text{ min}^{-1}$) of vegetation barriers and single climatological factors, Gampala, Burkina Faso, 1996

	Andropogon	Piliostigma	Ziziphus
Solar Radiation R_s (kW m^{-2})	$\text{Tr} = 0.46R_s + 0.008$ $R^2 = 0.88$	$\text{Tr} = 0.19R_s + 0.003$ $R^2 = 0.91$	$\text{Tr} = 0.14R_s + 0.007$ $R^2 = 0.89$
Temperature T ($^{\circ}\text{C}$)	$\text{Tr} = 0.04T - 0.8$ $R^2 = 0.82$	$\text{Tr} = 0.02T - 0.46$ $R^2 = 0.78$	$\text{Tr} = 0.01T - 0.3$ $R^2 = 0.73$
Relative Humidity RH (%)	$\text{Tr} = 0.008\text{RH} + 0.8$ $R^2 = 0.83$	$\text{Tr} = 0.008\text{RH} + 0.8$ $R^2 = 0.83$	$\text{Tr} = -0.008\text{RH} + 0.8$ $R^2 = 0.83$

Over a period of 10 days in July the change in the soil moisture content under the piliostigma barrier was found to be 21.2 mm. The period was without rain. An estimation of the transpiration over the same period based on the relation of transpiration and solar radiation results in 23 mm. The difference between the estimated transpiration and the change in soil moisture content is only 1.8 mm. A possible explanation could be that the vegetation barrier distracts its water from the layers deeper than the measured 1 m. Although this layer was observed to be restricting it is possible that some roots entered. Soil evaporation over the period can be neglected since the vegetation fully covers the soil surface. Percolation over the period can also be neglected since the soil moisture potential was between -1000 and -3100 cm.

Linear regression of the transpiration of the vegetation barriers and a combination of two climatological factors resulted in relations with regression coefficients of 0.78 to 0.85 for a combination of temperature and relative humidity. Combining either temperature or relative humidity with solar radiation results in relations with regression coefficients of 0.93 to 0.95. The results of the linear regression of a combination of all 3 factors are presented in Table 2.

Table 2: Regression coefficients for the relation $\text{Transpiration} = aR_s + bT + cRH + d$ of vegetation barriers, Gampala, Burkina Faso, 1996

Factor	Solar radiation (kW m ⁻²)	Temperature (C°)	Relative Humidity (%)	Constant	Regression coefficient
Coefficient	a	B	C	D	
Andropogon	0.27	0.01	-0.002	-0.05	0.96
Piliostigma	0.14	0.004	-0.0006	-0.04	0.95
Ziziphus	0.10	-0.00021	-0.00135	+0.14	0.94

Over a period of 4 days in August without rain the change in the soil moisture content under the piliostigma barrier was found to be 12.9 mm. An estimation of the transpiration over the same period based on the relation $\text{transpiration} = aR_s + bT + cRH + d$ resulted in 11.9 mm. Some unsaturated flow might have occurred during the period since the soil moisture potential was between -200 and -500 cm.

Since the reference evapotranspiration was calculated for 24 h periods and related to the 24 h transpiration of the barrier, the obtained relations are based on a limited data set. The obtained relations can be found in Table 3.

Table 3: Relation between transpiration and reference evapotranspiration of vegetation barriers, Gampala, Burkina Faso, 1996

	Andropogon (mm d ⁻¹)	Piliostigma (mm d ⁻¹)	Ziziphus (mm d ⁻¹)
Reference Evapotranspiration (mm d ⁻¹)	$\text{Tr} = 0.1.57\text{ET}_0 - 0.05$ $R^2 = 0.95$	$\text{Tr} = 2.1\text{ET}_0 - 7.7$ $R^2 = 0.77$	$\text{Tr} = 1.6\text{ET}_0 + 0.58$ $R^2 = 0.58$

The above mentioned relationships all relate transpiration with one or more elements of the atmospheric demand causing transpiration. Since the actual transpiration is a compromise between the demand and the supply of soil moisture, measured transpiration is also related to total soil moisture (TSM) under the barriers. For two species linear relations between transpiration and soil moisture existed. (Table 4).

Table 4: Relations between transpiration of vegetation barriers and total soil moisture, Gampala, Burkina Faso, 1996.

	Piliostigma (mm d ⁻¹)	Ziziphus (mm d ⁻¹)
Total Soil Moisture (mm m ⁻¹)	$\text{Tr} = -0.019 \text{TSM} + 6.66$ $R^2 = 0.87$	$\text{Tr} = 0.48 \text{TSM} - 10.94$ $R^2 = 0.96$

Since actual transpiration is a compromise between demand and supply it may be expected that a combination of a single climatological parameter or the full atmospheric demand (ET_0) and TSM will yield the best correlation with actual transpiration. Since the best fit of transpiration with a single climatological factor was found with solar radiation, this factor was used. The obtained relations can be found in Table 5.

Table 5: Relation between transpiration of vegetation barriers and a combination of total available moisture and solar radiation or reference evapotranspiration, Gampala, Burkina Faso, 1996.

	Piliostigma (mm d ⁻¹)	Ziziphus (mm d ⁻¹)
Total Soil Moisture (mm m ⁻¹) and ET ₀ (mm d ⁻¹)	Tr=- 0.03TSM+0.005ET ₀ +7.8 R ² = 0.66	Tr=0.49TSM+0.46-13.5 R ² = 0.97
Total Soil Moisture (mm m ⁻¹) and Solar Radiation (MJ m ⁻² d ⁻¹)	Tr= -0.01TSM + 0.07R _s + 4.9 R ² = 0.94	Tr= 0.5TSM + 0.02R _s - 11.29 R ² = 0.97

Conclusions

The aim of the study was to find a method to assess water use of vegetation barriers based on simply measurable parameters. The method consists of a brief measurement period with subsequent data analyses leading to simple predicting equations for each barrier species. Under conditions of good maintenance whereby the biomass and LAI of the vegetation barriers are kept at a more or less constant level, these equations can then be used for any other period in the growing season, except for the development stage. In a situation whereby no maintenance of the barrier takes place more than one relation over the season should be established in order to find water use over the whole season.

Results indicate that the simplest option, whereby transpiration is predicted with the use of a single meteorological factor gives acceptable results for all 3 factors used. Linear relations with high regression coefficients were found, therefore no attempt was made to search for non-linear prediction equations.

There is no significant improvement in the prediction of transpiration when instead of using temperature or relative humidity in a single factor relation these two factors are combined. The solar radiation single factor relation improves when combining solar radiation with either temperature or relative humidity.

The results suggest that transpiration prediction using the reference evapotranspiration ET₀ is not as good as the relation found between transpiration and the three climatological factors combination. Reference evapotranspiration was calculated for 24 h periods. Since the number of observation days on each species was only 10 days, this relation is based on a limited data set. The other relations are based on 30 min periods, thus on a far larger data set. In the 10 days of monitoring the ziziphus barrier 5 days with rainfall occurred, influencing the relationship.

The influence of the available soil moisture on transpiration could be established for 2 species (piliostigma and ziziphus) only. The restriction of limited data sets also counts for these relationships. A more extended data set will improve these relations and probably a relation for andropogon can be found when more data become available. The combination of solar radiation and available soil moisture results in the best prediction of the barrier transpiration.

References

Baker, J.M. and van Bavel C.H.M. (1987) Measurement of mass flow in stems of herbaceous plants. *Plant Cell and Environment* 10: 777 - 782

Doorenbos, J. and Pruitt, W.O. (1977) Guidelines for predicting crop water requirements, FAO Irrigation and Drainage Paper 24, Rome

Doorenbos, J. and Kassam, A.H. (1979) Yield response to water, FAO Irrigation and Drainage Paper 33, Rome

FAO (1992) Report on the expert consultation on the revision of the FAO methodologies for crop water requirements, Land and water development division, FAO, Rome

Hien, F.G. (1995) La régénération de l'espace sylvo-pastoral au Sahel, Tropical Resource Management Papers 7, Wageningen Agricultural University, Wageningen, The Netherlands

Smith, D.M., Jarvis, P.G. and Odongo, J.C.W. (1994) Water use by Sahelian windbreak trees, Presentation at The International Symposium on Wind Erosion in West Africa: the Problem and its Control, December 5 -7, Hohenheim University, Stuttgart, Germany