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Evapotranspiration differences between agroforestry and grass buffer systems

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ABSTRACT

Improved soil and water quality, and carbon sequestration are notable benefits of agroforestry practices compared to row-crop agriculture. Over an agricultural watershed with two buffer cropping systems (agroforestry buffers and grass buffers) soybean crop evapotranspiration was calculated from the Penman-Monteith equation using 10-min averages of meteorological measurements within crop alleys for 54 days in summer 2007. Wind speeds were consistently lower over the agroforestry buffer portion of the watershed by an average of 0.42 m s^{-1}. For calculated evapotranspiration assuming water-stressed conditions, this decrease in wind speed from the presence of agroforestry buffers was offset almost entirely by an increase in net radiation. Net radiation differences between the two systems were highest during the morning ($\sim$40 W m^{-2}) and were likely the result of solar radiation scattered from the agroforestry buffers. Wind speed reduction over the crop portion surrounded by agroforestry buffers varied by wind direction with daytime winds $\geq$0.6 m s^{-1} greater over the grass buffer portion of the crop for northerly and southerly winds (nearly perpendicular to the agroforestry buffers). Therefore, buffer orientation relative to the prevailing wind is important for reducing evapotranspiration. Changes in crop alley width would be expected to impact the portion of the crop within wind-sheltered zones and the portion receiving scattered radiation from trees. The sensitivity of evapotranspiration to agroforestry buffer orientation and crop alley width should be a focus of future investigations.

1. Introduction

Carbon sequestration and improvements in soil and water quality are among the potential benefits of agroforestry practices compared to row-crop agriculture (Quinkenstein et al., 2009; Udawatta et al., 2011; Udawatta and Jose, 2012). Agroforestry and grass buffers have been found to reduce non-point source pollution in runoff while improving soil properties (Seobi et al., 2005; Udawatta et al., 2006; Kumar et al., 2008). Such improvements have been attributed to the addition of organic matter, roots of the permanent vegetation, nutrient uptake, and water use (Kumar et al., 2011; Udawatta et al., 2014; Chendev et al., 2015).

Changes in microclimate from the permanent vegetation in buffers may influence evapotranspiration, soil water dynamics, carbon sequestration, nutrient dynamics, and soil enzyme activities. Larger trees act as a barrier to wind speed, reducing crop damage (Brandle et al., 2004) and influencing evapotranspiration and other energy fluxes in the adjacent areas (Campi et al., 2009; Tamang et al., 2010). Reduced energy levels under buffers and adjacent areas should promote less evapotranspiration and greater soil moisture storage. Increased crop quality and yields have been found on the leeward side of windbreaks (Huth et al., 2002; Campi et al., 2009). The potential for increased frost damage in the leeside of windbreaks has also been noted (Tamang et al., 2010). The wind break effect varies by crop, windbreak type, geographic location, moisture condition, and soil properties (Brandle et al., 2004). For example, in the drier regions of Australia, long-term benefits of forest buffers to improve soil quality may be offset by competition from the trees for soil moisture (Cleugh et al., 2002; Huth et al., 2002). Lopez-Bravo et al. (2012) found reductions in coffee yields near shade trees in Costa Rica.

Turbulence generated by windbreaks increases vertical mixing of heat and moisture downwind of the break (Cleugh, 1998). Less vertical mixing would be expected in the 'quiet zone,' resulting in warmer and moister daytime conditions compared to those in the 'wake zone.' One would expect the 'wake zone' to experience greater evapotranspiration in response (Cleugh, 1998). Campi et al. (2009) show a peak in evapotranspiration 10 tree heights down-

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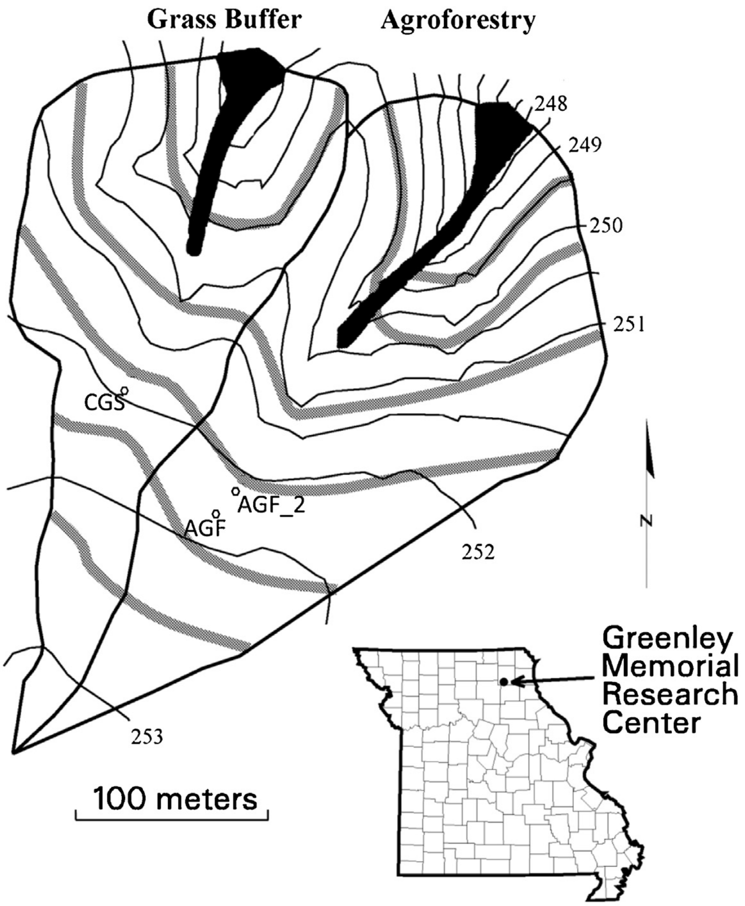

Fig. 1. Contour grass strip (grass only; CGS) buffer and agroforestry (grass and trees; AGF) buffer watersheds at the Greenley Memorial Research Center, Knox County, Missouri. Elevation contour intervals are 0.5 m (black). Buffers (gray), grass waterways (wide black) and microclimate station locations (circles) are also displayed.

wind of a windbreak. The repeated linear structure of the forest buffers in alley cropping systems adds complexity. For example, a greater proportion of the crop in the sheltered 'quiet zone', compared to that in the turbulent 'wake zone', is to be expected for alley cropping systems compared to a single extended windbreak. Exact extents of the quiet zone and wake zones are sensitive to the turbulent structure of the incident wind, related to the site's upwind surface roughness, as well as the porosity of the windbreak and wind direction. The radiation budget in crop alleys may also be influenced by the tree buffers through emitted longwave and scattered shortwave radiation (Brandle et al., 2004).

In this investigation, differences in microclimate and calculated evapotranspiration between agroforestry and grass buffered areas of a soybean [Glycine max (L.) Merr.] crop are examined. Although dependent on the permeability of the buffer, the 'quiet zone' will generally extend downwind of the windbreak for a distance equal to a number of tree height multiples (H). In this investigation, the distance between agroforestry buffer strips is approximately 10H, therefore, we expect a clear effect of agroforestry buffers on the microclimate within crop alleys.

2. Materials and methods

2.1. Experimental site and management

The study site is a north aspect watershed located at the University of Missouri, Greenley Memorial Research Center near Novelty, Missouri (40° 01′ N, 92° 11′ W; Fig. 1). A corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] rotation, with contour planting and no-till land preparation has been implemented on the watershed since 1991 (Udawatta et al., 2002). The contour grass strip (CGS) buffer portion of the watershed is 3.16 ha with grass only buffers and the agroforestry buffer portion (AGF) is 4.44 ha with grass and tree buffers. The buffer strips (Fig. 1) are 4.5 m wide and spaced 36.5 m apart (22.8 m at lower slope positions). A grass and legume combination was established in 1997 in the buffer strips and included brome grass (*Bromus* spp.), birdsfoot trefoil (*Lotus corniculatus* L.) and redtop (*Agrostis gigantea* Roth). The agroforestry buffers consisted of Pin oak trees (*Quercus palustris* Muenchh.) planted in the center of the buffer strips at 3-m spacing. Average tree heights in the AGF area were 3.9 m in 2007. In both areas, grass waterways consisted of Kentucky 31 fescue [*Schedonorus phoenix* (Scop.) Holub]. Further details on watershed management and general experimental design, as well as parent material, soils, and climatic data can be found elsewhere (Udawatta et al., 2002, 2006).

In 2006, corn was planted and harvested over both the AGF and CGS areas on 14 April and 27 September respectively, with a mean yield of 11.06 Mg ha^{-1}. In 2007, soybeans were seeded on both the AGF and CGS areas at 444,600 seeds ha^{-1} on 8 June and harvested on 26 October with a mean yield of 3.4 Mg ha^{-1} (Senaviratne et al., 2012).

2.2. Microclimate stations and data collection

Net radiometers, anemometers, humidity and temperature sensors were installed on masts above the crops at 3 m above ground level. Data were recorded at 10 min intervals with a CR23X data logger. The microclimate stations are 12 m south of the third buffers in