SOIL MOISTURE REGIMES UNDER ANNUAL AND PERENNIAL CROPS AS COMPONENTS OF AGROFORESTRY SYSTEMS

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ABSTRACT

The potential for agroforestry and other perennial crops to provide hydrologic benefits is of interest in the Minnesota River Basin, where the landscape is dominated by annual row crops and the river is plagued by water quality and quantity issues. Perennial herbaceous and woody crops are thought to have higher annual consumptive use of water, which influences antecedent water status, creating more water storage, potentially decreasing discharge, and reducing the prevalence of concrete soil frost in the early spring. Quantification of potential hydrologic benefits is needed to provide support for more sustainable agroforestry and other alternative cropping practices in the basin. To this end, from May to September of 2004, biweekly measurements of soil moisture under one annual crop (corn/soybean rotation in soybeans), two perennial herbaceous crops (perennial flax and Illinois bundleflower) and two woody crops (hybrid hazel nuts and hybrid willow) were taken on replicated experimental plots at the University of Minnesota's Southern Research and Outreach Center in Waseca, Minnesota. Similar measurements were taken in a stand of mature hybrid poplar and a corn field. Analysis of preliminary data showed no significant differences in soil moisture between the various crop types on the experimental plots, perhaps because the perennial and agroforestry crops are still in the establishment phase. However, the mature poplar stand had consistently drier soils than the corn field. Agroforestry and other perennial crops appear to provide little hydrologic benefit during the first year of establishment, but when mature, could have the potential to provide such benefits.

Keywords: agroforestry, annual crops, perennial crops, soil moisture

INTRODUCTION

Soil moisture utilization differences among annual and perennial crops are of interest in establishing and managing agroforestry systems. In the Minnesota River Basin (MRB), this interest arises from the potential hydrologic benefits of converting corn-soybean farming to agroforestry and other perennial cropping systems. Current farming practices that require extensive drainage over much of the basin are considered to be unsustainable and have led to excessive streamflow (Magner et al. 1993) and high rates of sediment and nutrient export (MPCA 1994).

Woody and herbaceous perennial crops have been shown to use more water than annual crops (Jose et al. 2000; Heng et al. 2001). Hydrologic benefits are thought to arise from this higher consumptive use of water because it influences antecedent water status, creating more water storage (Ward et al. 2002), and potentially reducing discharge. Furthermore, lower levels of soil moisture in the fall of the year can result in lower levels of concrete soil frost in the spring, resulting in higher infiltration and less surface runoff from snowmelt and rainfall (Christopherson 2001).

There is growing interest in using agroforestry crops for biomass energy production in the region (Willette, 2004). The development of potential markets for agroforestry crops in the MRB also provides increasing opportunity to improve the hydrologic conditions and water quality of the basin through increased adoption of agroforestry systems in agriculture. This, in turn, could mitigate nonpoint pollution and help meet impending TMDL standards.

Differences in water use among crop types can be estimated using soil moisture depletion measurements (Izaurralde et al. 1994), and soil moisture measurements can provide direct insight into differences in available water storage. This study focuses on quantifying the effects of woody and perennial herbaceous crops on soil moisture from early spring through late fall. To this end, between May and September of 2004, biweekly gravimetric measurements of soil moisture under one annual crop (corn/soybean rotation in soybeans), two perennial herbaceous crops (perennial flax and Illinois bundleflower [IBF]) and two woody crops (hybrid hazel nuts and hybrid willow, both in the early stages of establishment) were taken on two sets of experimental plots at the University of Minnesota's Southern Research and Outreach Center in Waseca, Minnesota. Similar measurements were taken under a nearby stand of mature hybrid poplar and in a corn field. This paper presents soil moisture results for the first season in which perennial crops were established. Data on seasonal water use of crops will eventually help us calibrate and apply models that can be used to predict the hydrologic consequences of converting croplands to agroforestry and other perennial cropping systems.

METHODS

Field Site

The University of Minnesota's Southern Research and Outreach Center (SROC) in Waseca, Minnesota is in the south central part of the state (Figure 1). Most of the SROC is in the Le Sueur River Watershed, which drains to the Minnesota River, although a portion is in the Cannon River Watershed, which drains into the Mississippi. Measurements were taken in four locations at the Center (Figure 1). The study sites are underlain by soils from the Webster, Nicollet, Glencoe, and (to a lesser extent) Canisteo series, all of which are poorly drained clay-loam soils formed from glacial till (USDA 2004).

The climate in Waseca is temperate, with an average annual temperature of 6.3° C (43.3° F) and 82.2 cm (32.37 in) of average annual precipitation, of which 49.9 cm (19.65 in) typically falls in May through September (USDA). Conditions from May to September of 2004 were, on average, slightly cooler and much wetter than normal, with 80.7 cm (31.76 in) of rainfall during the period (Figure 2).

Run-off Plots

The run-off plots consist of a series of seven crops on 21 plots (Figure 1, Table 1), located in two rows on a gentle southeast-facing backslope. Two repetitions of five of the crops in the upper row are outfitted as run-off plots, with plastic barriers extending 61 cm (2 ft) into the ground along the top and bottom and 30 cm (1 ft) along the sides. Measurements were taken in those ten plots, plus the corresponding (uninstrumented) plots in the lower repetition.

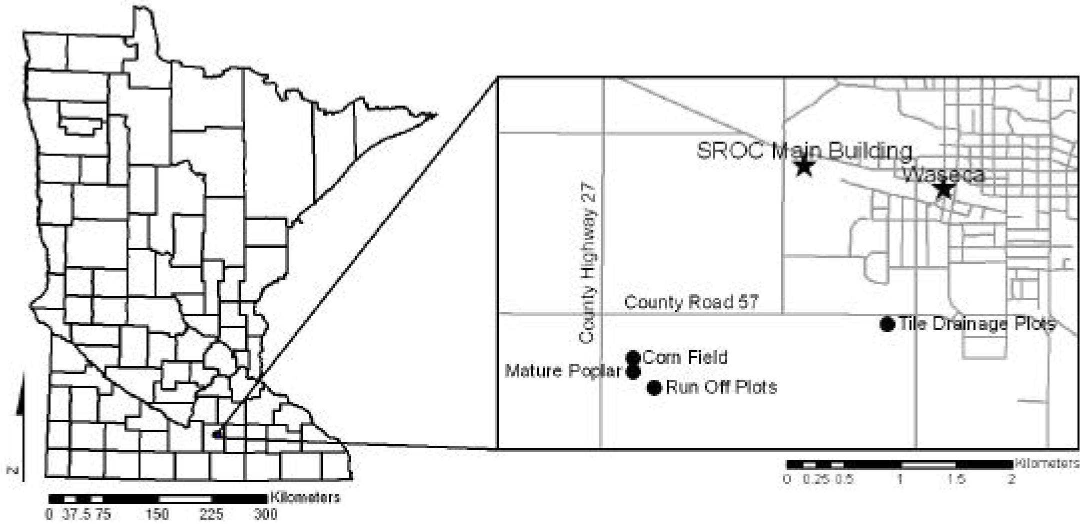

Figure 1. Location of Waseca, Minnesota field sites.

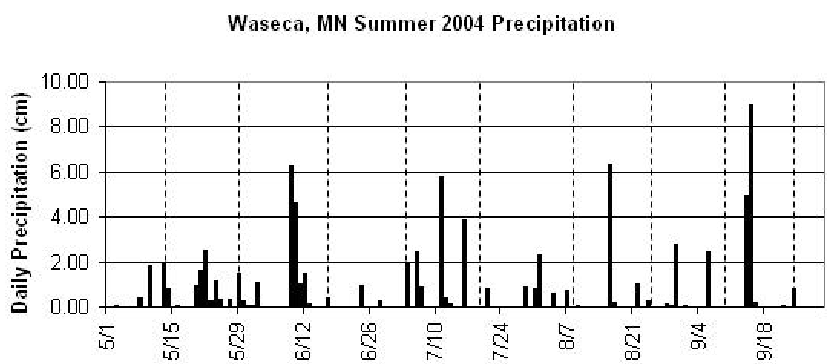

Figure 2. Rainfall distribution during sampling season. Sampling dates are indicated by dashed lines.

Tile Drainage Plots
A series of tile drainage plots are located about 2 km (1.25 mi) east of the run-off plots on a wide, flat toe slope. Although other crops are planted there as well, measurements were taken only in plots with crops corresponding to those monitored on the runoff plots.

Mature Poplar and Corn
An agroforestry stand of mature poplar extends east-west over a hillslope 0.25 km (0.16 mi) northwest of the runoff plots. Roughly 100 m (330 ft) to the north of the poplars, there is a large field of corn. Measurements were taken from similar landscape positions in the cornfield mature poplar stand.

Table 1. Description of sampling locations.

Area	Crop	Planting Date	No. of Samples	Sampling Dates	Description of Area
Run-off plots	Willow (no cover crop)	(replanted) June 2, 2004	2 (5/19, 6/3, 6/21); 3 (all other dates)	5/19 (upper plots only), 6/3 (upper plots only), 6/21 (upper plots only), 7/7, 7/22, 8/10, 8/26, 9/10, 9/24	Three 75 foot-long repetitions of seven crops, arranged two in an upper row and one along the lower. Hybrid hazel and willow plots are 30 feet wide; all the others are 15 feet wide.
	Illinois bundleflower	June 2003	2 (5/19, 6/3, 6/21); 3 (all other dates)		
	Corn/soybean rotation in soybeans	May 10, 2004	2 (5/19, 6/3, 6/21); 3 (all other dates)		
	Hybrid hazelnut (with turf grass)	(replanted) early July 2004	2 (5/19, 6/3, 6/21); 3 (all other dates)		
	Perennial flax	June 2003	2 (5/19, 6/3, 6/21); 3 (all other dates)		
Tile drain plots	Willow (no cover crop)	May 10, 2004	3	7/22, 8/10, 8/26, 9/10 (soy only), 9/24 (soy and flax only)	75 foot by 90 foot plots. Tile drains installed about 4 feet below the surface.
	Corn/soybean rotation in soybeans	May 10, 2004	3		
	Hybrid hazelnut (with turf grass)	May 29, 2004	3		
	Perennial flax	May 29, 2004	3		
Hillslope	Poplar	May 2000	8	7/22, 8/10, 8/26, 9/10, 9/26	Poplar stand is about 720 feet by 160 feet.
	Corn/soybean rotation in soybeans	May 1, 2004	8		

Measurements

Gravimetric soil moisture measurements were taken on an approximately bi-weekly basis from randomly selected positions within the respective plots, although measurements from the run-off plots were taken earlier in the year than at the other two sites (Table 1).

At each sample location, a soil auger was used to collect four soil samples, one each at the surface, 30 cm (12 in), 75 cm (30 in), and 120 cm (47 in) of depth. The approximate level of the water table was also recorded, if observed. The soil samples were taken to the lab and analyzed for gravimetric moisture content following standard procedures.

Bulk density data was taken from data collected at the SROC in 1983 (G. Johnson, pers. comm. 2004), and used to convert the gravimetric moisture content to volumetric moisture content, which was, in turn, extrapolated to estimate total water content in a 130 cm (51 in) soil column. Weather data was taken from the climatological observatory near the SROC main building (Station MN8692).

RESULTS

In the runoff plots, soil moisture measurements were remarkably consistent between crops and throughout the season, as were measurements in the tile drain plots. In fact, in the runoff plots, all soil measurements from all crops fell well within the 95% confidence intervals for soil moisture under the soybean crop (Figure 3), and no crop had consistently drier soil than any other. In the tile drainage plots, the soybean plots actually had the driest soil on two of the three sampling dates. However, overlap between confidence intervals for these measurements means that these results are also statistically insignificant.

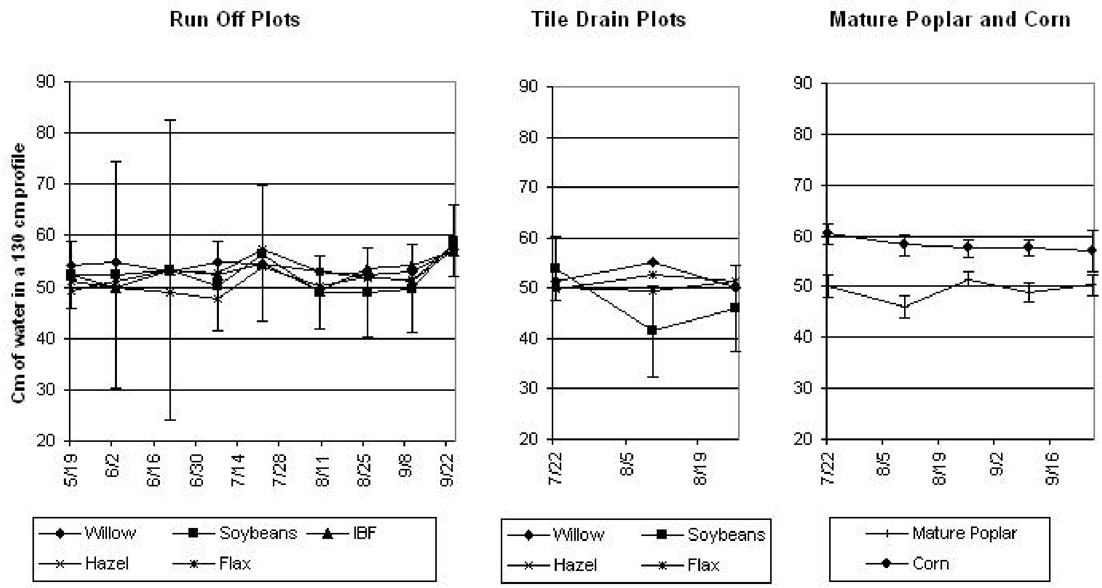

Figure 3. Total average water content in a 130 cm profile for each crop type and location over the season. Error bars represent 95% confidence intervals. Confidence intervals are shown for soybeans only in the run-off and tile drain plot charts.

A statistically significant difference in soil moisture was seen, however, between the mature poplar and nearby corn field, with the soil under the poplar having between 6.1 and 12.1 cm (2.4 and 4.8 in) less moisture content on each sampling date.

DISCUSSION

As shown above, there was very little difference between the soil moisture regimes beneath the annual, perennial and agroforestry crops in the tile drain plots and run-off plots. This might be partly attributed to the relatively rainy season. In an average summer, the area receives 49.9 cm of rain between May and September. During the same period of 2004, 80.7 cm of rain fell. There was no period between sampling dates in which rain did not fall, and most periods experienced at least one reasonably sized storm (Figure 2). This frequent rainfall may have prevented the effects of differing water use to become manifested in soil moisture by keeping the soil continuously wet, as a longer dry period might be necessary for the effects of consumptive differences to become apparent.

It is also possible that the spatially variable nature of soil moisture combined with the small sample size meant that the measurements taken were simply not refined enough to pick up differences. This idea is once again supported by the corn/poplar data, where larger sample sizes resulted in smaller margins of error, although it might be argued that even if additional measurements proved any observed differences to be statistically significant, differences of that size might be of little practical importance.

Soil moisture differences among crops would not be expected the first year of establishment because of limited aboveground biomass and shallow rooting depth of the new woody and perennial herbaceous crops. All of the plots in early spring had the appearance of annual cultivated croplands, with the exception of perennial flax, which exhibited the earliest growth, although plots were not fully covered. The lack of distinct differences in soil moisture content among newly established crops in both locations was apparent throughout the year (Figure 3). As these perennial crops become better established and mature, we would expect to see earlier soil moisture depletion in the spring and sustained soil moisture utilization throughout the year that could differentiate them from annual crops. Data from the mature poplar stand and nearby corn field support this idea, as the soil under the mature poplar was consistently drier than that in the corn field. Additional measurements taken in 2005 and 2006 should help determine if seasonal differences in soil moisture regimes exist between annual and established perennial crops.

CONCLUSIONS

The data presented here implies that agroforestry and other perennial crops are likely to provide little hydrologic benefit during the establishment phase, although there is also no evidence that establishment-phase perennial and agroforestry crops would be any more detrimental than annual row crops. However, it seems probable that agroforestry crops with mature woody components do have the potential to provide such benefits.

ACKNOWLEDGEMENTS

Support for this research was provided by the Legislative Commission for Minnesota Resources (LCMR), The University of Minnesota Department of Forest Resources, and the University of Minnesota’s Southern Research and Outreach Center (SROC) in Waseca, Minnesota. The senior author also acknowledges the financial support provided by the Peter F. Ffolliott Fellowship.

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