Water Use by Rootstocks of Emory Oak Coppice

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ABSTRACT

Knowledge of water use in dryland oak ecosystems is critical for the application of intensive management strategies. Thinning prescriptions of Emory oak (*Quercus emoryi*) coppice (sprouts) to accelerate tree growth are becoming common. The effects of thinning on estimated transpiration rates of Emory oak coppice were determined by the sap-flow velocity method. Rootstocks were thinned to one, two, or three dominant sprouts, or left as untreated controls. Results showed that there were differences in transpiration rates among the rootstocks for each of the thinning treatments and control. The daily transpiration rate for all rootstocks averaged 20 liters per day and ranged from 4 liters in the winter to 52 liters in the summer. The unthinned rootstocks transpired 80% of the annual precipitation whereas the rootstocks thinned to one residual sprout transpired 34%. Seasonal variations of the transpiration rates were likely attributed to changes in precipitation and solar radiation.

INTRODUCTION

Management related research of the Emory oak woodlands in southeastern Arizona have focused primarily on the growth and yield of stump sprouts (coppice) to shorten rotation periods for fuelwood harvesting (Bennett 1990, Touchan and Ffolliott 1999, and Farah *et al.* forthcoming). The fuelwood rotation period for Emory oak trees growing from sprouts is reduced from 100 years to approximately 30 years (Touchan and Ffolliott 1999).

The question of how fuelwood harvesting through coppice management impacts the hydrologic cycle has recently been raised. Folkerts (1999) and Ffolliott and Gottfried (2000) reported differences in water use between mature and coppice tree forms to obtain a better understanding of the hydrological functioning of the Emory oak woodlands for management purposes. The change in transpiration (estimated by water use) due to tree harvesting can impact the water budget, affecting understory plant growth, wildlife habitats, or groundwater aquifer recharge in these woodlands (Ffolliott and Gottfried 2000).

Reducing transpiration losses by coppice thinning can be one way to increase available water for other uses. Folkerts (1999) and Ffolliott and Gottfried (2000) reported a daily average transpiration rate of 17.5 liters for mature trees compared to 4 liters per day for coppice sprouts. It was estimated that the unharvested Emory oak stand would transpire 47.5% of the annual precipitation compared to the harvested site which would transpire up to 79.2% of the annual precipitation. The greater volume of transpiration in the harvested stand was attributed to a larger number of actively growing, post-harvesting stump sprouts present in the stand even though transpiration of individual stems was lower.

The objective of the current study was to expand our knowledge on the hydrologic functioning of the dryland oak woodlands by analyzing the response of transpiration rates to coppice thinning treatments. The incorporation of coppice management into a silvicultural system requires a thorough knowledge of all ecosystem processes to achieve a desired management objective. This research was conducted in conjunction with a project funded by the International Arid Lands Consortium (IALC) in northern Israel to study the adaptability of dryland oak species to ecosystem processes (Ffolliott *et al.* forthcoming). Preliminary results of water use by thinned Emory oak rootstocks are presented in this paper.

STUDY AREA

The study area was located in the San Rafael Valley at the base of the Huachuca Mountains. The site is situated on a south-facing slope approximately 1,750 meters in elevation. The area receives an average of 541 ± 32 (mean ± standard error) millimeters of precipitation annually in a bi-modal distribution with short duration, intensive convectional summer monsoon storms and moderate winter rains generated by frontal storms. The soil group on the site is the Casto-Martinez-Canelo type formed from old alluvium, made up of sedimentary and igneous rock. Hendricks (1985) describes the soil association as having a clayey texture with slow permeability and containing excessive amounts of rock fragments.

The oak woodlands in southeastern Arizona are composed mainly of Emory oak, Arizona white oak (*Q. arizonica*), and Mexican blue oak (*Q. oblongofolia*). Emory oak is characterized as a broadleaf, drought-deciduous, medium-sized tree (9 to 12 meters in height). Most Emory oak regeneration results from stump or root sprouts (coppice) rather than by seedling establishment (Bennett 1990).

METHODS

The sampling site was last harvested for fuelwood in 1981. Four thinning treatments were subsequently imposed in 1984. Selected rootstocks were thinned to one sprout, thinned to two sprouts, and thinned to three sprouts. A total of 16 rootstocks representing four rootstocks of each treatment and the control were selected for the study. Sap-flow measurements were conducted on the dominant sprout of each rootstock. The measurement period was from June 2000 through September 2002.

Heat-pulse velocity measurements of the dominant sprout were taken every two weeks using a modified sap-flow instrument of the original instrument developed by Swanson (1962). Two exceptions in the measurement schedule occurred when it was not possible to visit the site. The sap-flow method allows for non-destructive and time efficient sampling of the measured stems. Sap-flow was measured at a depth just inside of the bark and within the outlying sapwood layers. A heat pulse was used as a tracer in the column of sap-flow. The placement of two thermistor probes at 0.5 cm below and 1.0 cm above the heat probe allowed the heat pulse velocity to be calculated by: $HPV(cm/hour) = {}^{900}\!/_{t_o}$

HPV represents the heat pulse velocity in centimeters per hour and t_o is the elapsed time in seconds from the initial heat pulse application until the two thermistors regain equilibrium (Swanson 1962).

Water use of an individual sprout was determined from knowledge of the cross-sectional area of sapwood and the heat pulse velocity measurements. A best-fit regression relationship using the least-squares method related sapwood area to diameter at breast height (dbh). The relationship estimated the cross-sectional sapwood area of the sprouts measured for transpiration. The resulting rate of sap-flow (cubic centimeters per hour) was then transformed to a volume (liters per day) before analyzing treatment differences.

The estimated transpiration rate per rootstock was calculated by multiplying the daily water use of the measured stem by the number of dominant sprouts per rootstock for that treatment. Transpiration data on each sample date were averaged for each of the three coppice treatments and the control. An analysis of variance at the 0.10 alpha-level was used to evaluate significant differences in the average daily water use among the treatments for the sampling period between June 2000 and September 2002. The Tukey-Kramer multiple comparison test evaluated differences between the treatment means.

Transpiration measurements during 2001 were selected to be a representative sample of an average year. Annual precipitation for 2001, 544 mm, was near to the average. Coppice rootstock and mature stem densities were obtained by sampling 0.08 hectare plots within the harvested stand. The estimated transpiration rate for each treatment in 2001 was averaged and combined with rootstock and stem density measurements to obtain annual transpiration as a depth per unit area. The density of mature stems within the study area was measured at 177 ± 28 stems per hectare and the average transpiration rate of the mature trees was assumed to be 17.5 liters per day (Folkerts 1999; Ffolliott and Gottfried 2000). The depths per unit area for each of the treatments were used to determine the percent of annual precipitation transpired by the rootstocks.

The influence of precipitation and temperature on daily average transpiration rates was interpreted qualitatively. Precipitation and maximum daily temperature measurements were obtained from the Coronado National Memorial weather station located approximately eight kilometers from the study site.

RESULTS AND DISCUSSION

Indicated by the sap-flow results, the Emory oak coppice did not lapse into complete dormancy during the period of complete leaf loss from mid-May to early August 2002. New leaves were fully developed within approximately one month following the initiation of the monsoon summer rains. The unthinned control with an average of 4.5 dominant stems per rootstock transpired the greatest volume of water of 32.88 ± 1.17 (mean ± standard error) liters per day during the 24 month study (Table 1). The treatment of thinning to one sprout transpired the least with an average of 7.33 ± 0.27 liters per day.

The three thinning treatments and the control were significantly different (Table 1). The number of sprouts from a rootstock affected the total transpiration of that particular rootstock. The trend in the estimated transpiration rates during the sampling period are presented in Figure 1. Changes in solar radiation, air temperature, relative humidity, and/or wind speeds over the course of a day might have caused variation among the daily transpiration rates. Factors, which may impact transpiration rates, include the sprout's ability to sequester water from an extensive inter-connected root system or the leaf area of individual sprouts.

Table 1. Averages and standard errors of daily rootstock transpiration rates for Emory oak coppice thinning treatments during the study period.

	Thinning Treatment			
	Control	One Sprout	Two Sprouts	Three Sprouts
Daily Average Water Use per Rootstock (liters/day) (Mean ± Standard Error)	32.88 ± 1.17	7.33 ± 0.27	17.19 ± 0.64	23.02 ± 0.97
Minimum Water Use per Rootstock (liters/day)	19.44	4.12	9.30	11.20
Maximum Water Use per Rootstock (liters/day)	52.02	12.60	29.07	36.13

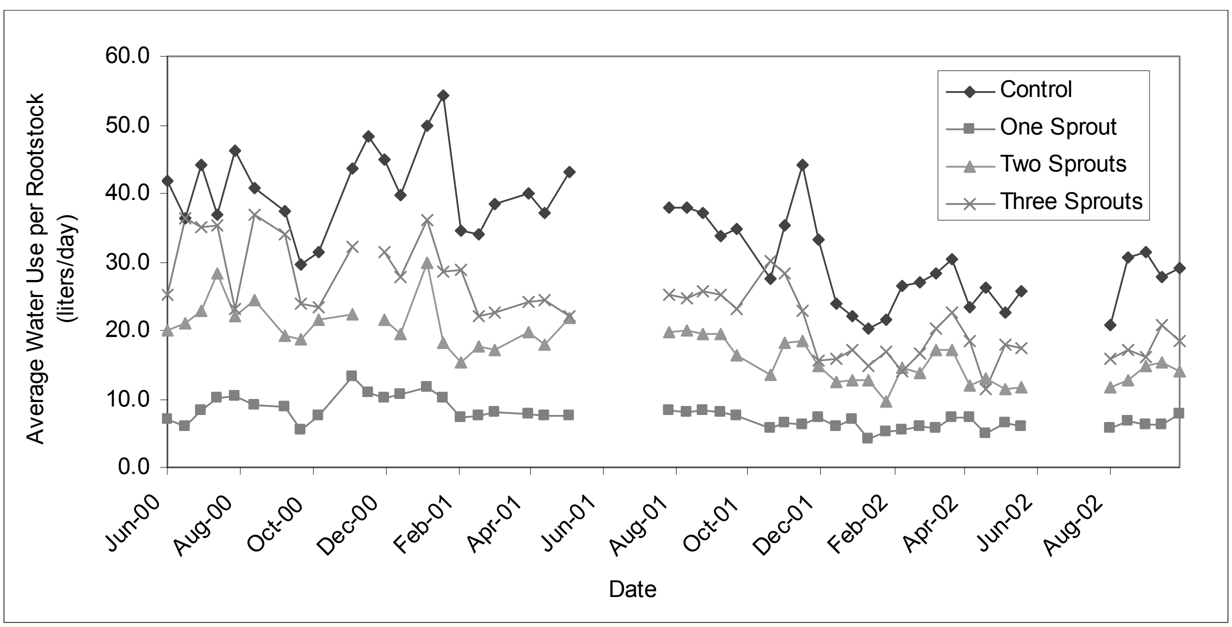

Figure 1. Average rootstock daily transpiration rates for three coppice treatments and the unthinned control from June 2000 to September 2002.

Table 2 presents each treatments significantly different average water use in 2001 as a depth per unit area and the percentage of annual rainfall transpired by the rootstocks. The unthinned control transpired approximately 80% of the annual precipitation in 2001 compared to the rootstocks thinned to one sprout at 34%. Thinning the coppice on a stand basis can have an impact on water availability for other ecosystem processes such as forage production.

Table 2. Estimated average daily transpiration rates, yearly unit area water use, and the percent of annual precipitation lost by different coppice thinning treatments during 2001.

	Thinning Treatment			
	Control	One Sprout	Two Sprout	Three Sprout
Daily Water Use (liters) (Mean ± Standard Error)	35.30 ± 1.72	7.48 ± 0.31	17.65 ± 0.86	23.72 ± 1.12
Water Use of Coppice per Unit Area (mm/yr)	320.4	67.9	160.2	215.3
Total Water Use of Coppice and Standards* (mm/yr)	433.4	181.0	273.2	328.4
Percent of Annual Rainfall Transpired in 2001**	80.2	33.5	50.5	60.7

* Estimated water use for mature stems was 17.5 liters/day (Folkerts 1999; Ffolliott and Gottfried 2000)
** Annual precipitation in 2001 was 544.3 mm.

The annual precipitation was 778 mm and 544 mm in 2000 and 2001, respectively. The mean daily transpiration rates for each treatment were averaged to present the transpiration trends with daily precipitation records and monthly averages of maximum daily temperatures (Figures 2 and 3). Daily maximum temperature appears to directly affect the rate of transpiration except during two periods. The first period followed a wet autumn that included two frontal storms in October 2000 with 188 mm and 122 mm of rainfall. The second period occurred in the summer of 2002 during a dry period with complete leaf loss of the oak trees.

Precipitation appears to influence the average daily transpiration rates (Figure 2). A delay between a precipitation event and an increase in the estimated transpiration rate could reflect the time required for water to infiltrate and percolate to soil depths accessible by tree roots. Transpiration rates following precipitation events can also remain suppressed due to higher humidity levels (especially during the summer rainfall period). Additional data on available moisture in the soil profile at periodic time intervals following precipitation are needed to clarify the relationship.

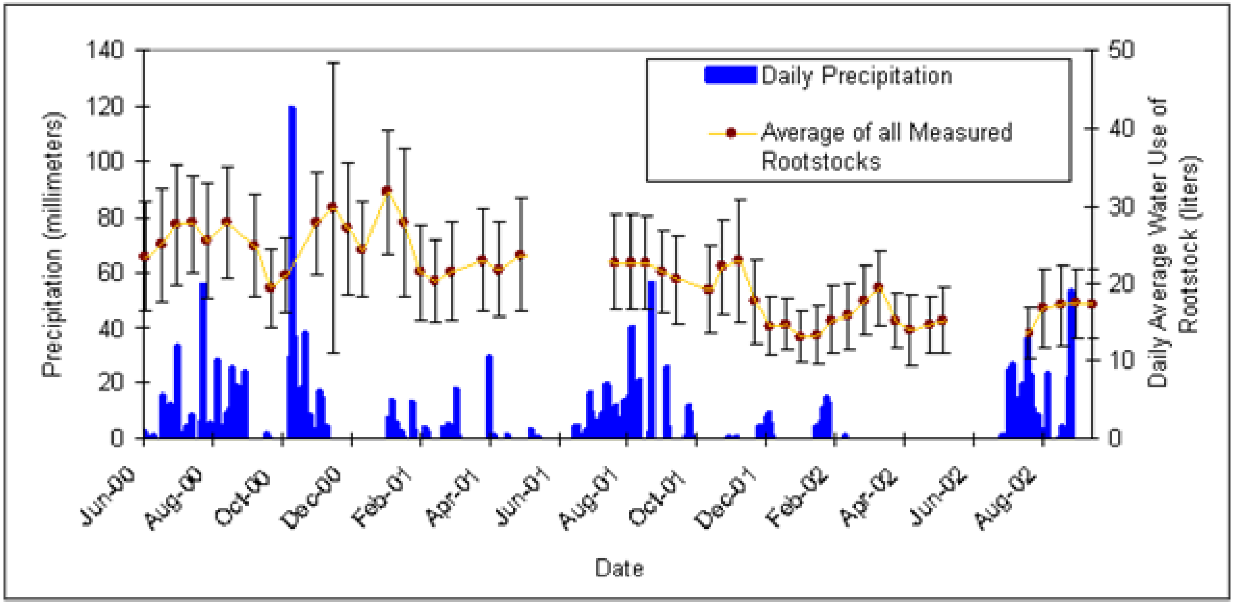

Figure 2. Average daily rootstock transpiration rates for all treatments and control in relation to daily precipitation from June 2000 to September 2002 (bars on the water use line represent standard errors).

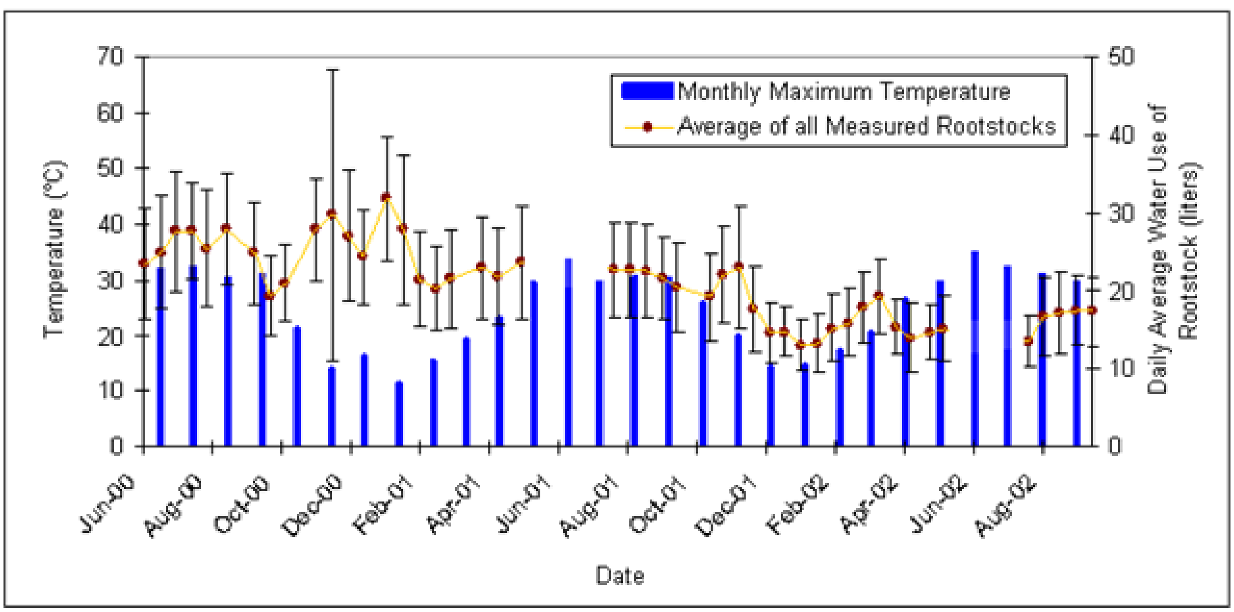

Figure 3. Average daily rootstock transpiration rates for all treatments and control in relation to average monthly maximum temperatures from June 2000 to September 2002 (bars on the water use line represent standard errors).

MANAGEMENT IMPLICATIONS

Coppice thinning following tree harvesting is an important management tool. Touchan and Ffolliott (1999) and Farah *et al.* (forthcoming) reported that average growth and yield of oak coppice is greatest when a thinning treatment leaves one residual sprout. However, the impact of tree harvesting on the water budget and the structural diversity of woodlands requires planning and management to attain a desired objective. The increased proportion of annual precipitation used for transpiration noted by Ffolliott and Gottfried (2000) could decrease available water for streamflow or on-site uses. Alternatively, a thinning treatment leaving three residual sprouts will increase available water by decreasing transpiration losses and improve wildlife habitat diversity. Therefore, it is critical that managers first determine realistic management objectives and then prescribe the appropriate silvicultural treatments.

ACKNOWLEDGMENTS

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