PHOTOSYNTHETICALLY ACTIVE RADIATION USE EFFICIENCY OF *DACTYLIS GLOMERATA* IN A HARDWOOD SILVOPASTURE.

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ABSTRACT

Optimal management strategies for conversion of hardwood forests in Appalachia to productive silvopastures are not available. The relationship between available understory photosynthetically active radiation (PAR) and forage productivity is not well understood for thinned mature hardwood forests. An experiment using container-grown plants was conducted under field conditions to determine how open (O), shaded woodland (W), and open-to-shaded woodland transition zones (Eo,Ew) influenced productivity and PAR-use-efficiency in *Dactylis glomerata* L. (cv. Benchmark). Plants harvested during the summer were established in both early spring and the autumn to allow vernalization for harvesting the second year. Pots were clipped whenever the forage in a treatment reached a 20 cm height, leaving a 5 cm residue to simulate grazing. Plants established in the autumn had fewer but larger tillers. Due to cloudiness, the O treatment received 67 and 45% of maximum possible mid-summer PAR for 2001 and 2002 respectively. The Eo, Ew and W treatments received 44, 25, and 13 % of O treatment levels. Total yield increased with daily PAR, however, maximum PAR-use-efficiency was achieved under the Ew (25% PAR) treatment. Orchardgrass in the W treatment retained juvenile characteristics even after a winter vernalization, unlike the other three treatments. The differences in physiological and morphological response to PAR suggest that management needs to be flexible and vary between radiation zones to optimize production. Orchardgrass response to various PAR levels suggests a high degree of plasticity in terms of productivity and resource allocation even though the cultivar used, Benchmark, was developed for high productivity in open field sites. Selecting or breeding forages for minimal nitrate accumulation and maximum total nonstructural carbohydrate accumulation under shade may be key to increasing temperate silvopastoral productivity.

Keywords: Cloudiness, growth, red far-red ratio, seasonal radiation, shade, solar angle

INTRODUCTION

The economic success of silvopastoral systems requires proper management of the solar radiation resource. Perhaps the most critical management requirement is that a well adapted forage species, such as orchardgrass (*Dactylis glomerata* L.), is used as an understory crop (Lee 1991; Devkota et al. 1998). Tree shade induces changes in light intensity and quality that can cause morphological changes in forage grasses such as increased leaf elongation, reduced specific leaf weight and reduced tillering (Devkota and Kemp 1999; Monaco and Briske 2000; Belesky 2005). Adaptation to shade does not significantly change leaf radiation adsorption efficiency in tree species (Baltzer and Thomas 2005). However, since plants convert only a small percentage of absorbed radiation into photosynthate facilitating growth, absorption efficiency may not be a relevant measure of adaptation benefits.

Our objective is to identify attributes of biomass production efficiency of orchardgrass in different photosynthetically active radiation environments under deciduous trees.

MATERIALS AND METHODS

The research was done adjacent to and within the north edge of a 400 by 30 m group selection clearcut of a second growth hardwood forest (*Quercus* spp.), made four years prior to the experiment. The long axis of the clearing was oriented east-west and was wide enough such that the base of the region near and within the north edge received no shading from the south side throughout the growing season. The remaining forested area had achieved a closed canopy of more than 25 m in height. Mowing had allowed the site to develop a low canopy within the clearing and forest edge of mixed low forbs and grasses with some bare ground patches which increased in area with distance into the forest. The site was in southern West Virginia (81^{o} 7’ W. 37^{o} 45’ N, 760 m elev.) in an area that averages 1.1 m of precipitation annually.

We used a grazing tolerant orchardgrass, cv. Benchmark, (early flowering) for this experiment. Plants were established in 2.5 L containers containing a mixture of four parts soil (lily, fine-loamy, siliceous, semi-active, mesic, Typic Hapludult) and three parts sand and sown with 100 seeds per pot. During establishment, plants were allowed to develop uniform full canopies in an unshaded area. Container grown plants eliminate or minimize site and soil related effects on establishment, growth and nutrient availability (Monaco and Griske 2000). Bottoms were removed from the containers before placing in the ground.

The plants were placed into four shading treatments. An open (O) treatment in the clearing with no direct beam solar shading, a wooded (W) treatment 25 m within the forest that received no direct beam solar radiation except from sun flecks, and two intermediate edge treatments (Eo and Ew) under trees but varying in distance from the forest edge and in amount of direct beam solar radiation received. Two herbage treatments were analyzed for their response to these shade treatments. One set of containers were prepared for planting in early May 2001 (SP) to analyze the response of juvenile plants. Another set was prepared for planting in late August of 2001 (LS) and allowed to vernalize to evaluate the response of more mature plants in the following growing season.

Baseline data on plant size were collected from nine replicates immediately prior to field placement, at which time all plants were clipped to a 5-cm residual plant height. Three replicates (initial total of 24 replicated in each shade treatment) were collected and destructive sampling made each time mean plant height reached 20 cm. Remaining plants were clipped to 5 cm and allowed to regrow to 20 cm. Plants (grasses and forbs) surrounding orchardgrass pots at each microsite were clipped to 5 cm height each time experimental plants were clipped. Discussion of all plant component mass and nutritive value analysis can be found in Belesky (2005).

In order to determine PAR for each of the 4 light treatment zones, a system of 8 LI-COR LI-191-SB 1 m line quantum sensors (LI-COR Lincoln, NE) were periodically installed with data recorded using a Campbell Scientific 21X data logger (Campbell Scientific Inc., Logan, UT). One sensor was placed at the O site, two at both Eo and Ew, and three at W. Data collection was timed to capture values during leaf extension, early, mid and late summer, and post leaf drop. Using this data, values were extrapolated for all periods using PAR data from an automated weather station in the clearing equipped with a LI-190SZ quantum sensor. Maximum Potential PAR above the tree canopy level throughout the year was calculated for the specific longitude and latitude using WinSCANOPY software (Instruments Regent Inc., Quebec, Canada).

The efficiency with which plants converted PAR into dry matter was calculated by dividing dry weight by the total PAR for a given clipping interval. For the first harvest of 2002, the PAR was summed from day-of-year 100 (April 10), which approximates when forages begin sustained spring growth.

RESULTS AND DISCUSSION

At this location oaks generally begin leaf extension around DOY 120. By DOY 130 tree canopy approaches half extended and is fully extended by DOY 150 at which time PAR at the three shaded sites no longer decreased relative to values at O (Figure 1a). By DOY 220 (early August in northern latitudes) solar angle decreased enough to allow a substantial increase in PAR at site Eo, and by mid September site Ew also experienced a substantial increase in PAR for the same reason. Site W had low PAR levels until leaf fall, which begins early to mid October. By DOY 305 leaf fall was complete and site W PAR increased to about 60% of site O levels. During periods where the trees were leafless sites Eo and Ew received similar PAR levels as site O (Figure 1a).

Seasonal PAR is restricted by cloudiness relative to maximum potential PAR at site O (Figure 1b). At the other three sites PAR impinging on the forage canopy was limited by both cloudiness and to different degrees, tree leaves. Sites Eo and Ew converge with site O in the spring prior to tree leaf extension and also at different times in late summer as solar angle decreases. Because of shading caused by tree leaves and stems, site W never did converge with site O although there were spring and autumn increases over mid-summer levels. Forages growing in deciduous silvopastures experience fluctuating PAR caused by the net effects of solar angle, cloudiness, and location relative to trees. There are also variations in PAR from year to year as a result of variability in large scale climate patterns (Table 1). The mid summer PAR at site O was 67 and 45% of maximum direct beam possible for 2001 and 2002, respectively, which resulted in relative differences in PAR at the other sites.

Leaf mass and total plant mass was directly proportional to the amount of PAR sites received for both years (Figures 2a and 2b). The juvenile plants (spring established) generally had higher leaf mass while the more mature plants (late summer established) had generally higher total plant mass. The result was that at all sites except W, the leaf ratio was higher for juvenile plants than for mature plants (Figure 2c). The fact that only at the W site the leaf ratio did not decrease the second year supports the conclusion of Belesky (2005) that the plants at the W site behaved much like juvenile plants even after a winter vernalization.

Table 1. Summer solstice (7-week average) actual and relative PAR.

Measurement Site	**O**	**Eo**	**Ew**	**W**	**Max**
PAR (Mol d^{-1})					
2001	39.7	18.7	9.7	4.9	59.3
2002	26.8	10.7	6.9	3.7	59.3
% of Open (100-Shade)					
2001	100	47	24	12	
2002	100	40	26	14	
% of Max					
2001	67	32	16	8	
2002	45	18	12	6	

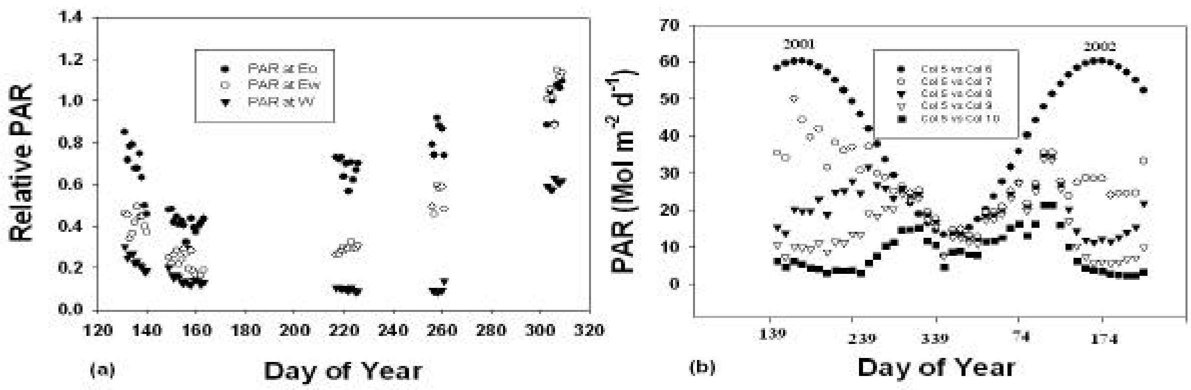

Figure 1. Values of PAR for three shaded sites relative to the open site (O) as influenced by forest leaf status and changes in solar angle with time (a), and actual PAR during the experiment compared to modeled maximum direct beam possible (b).

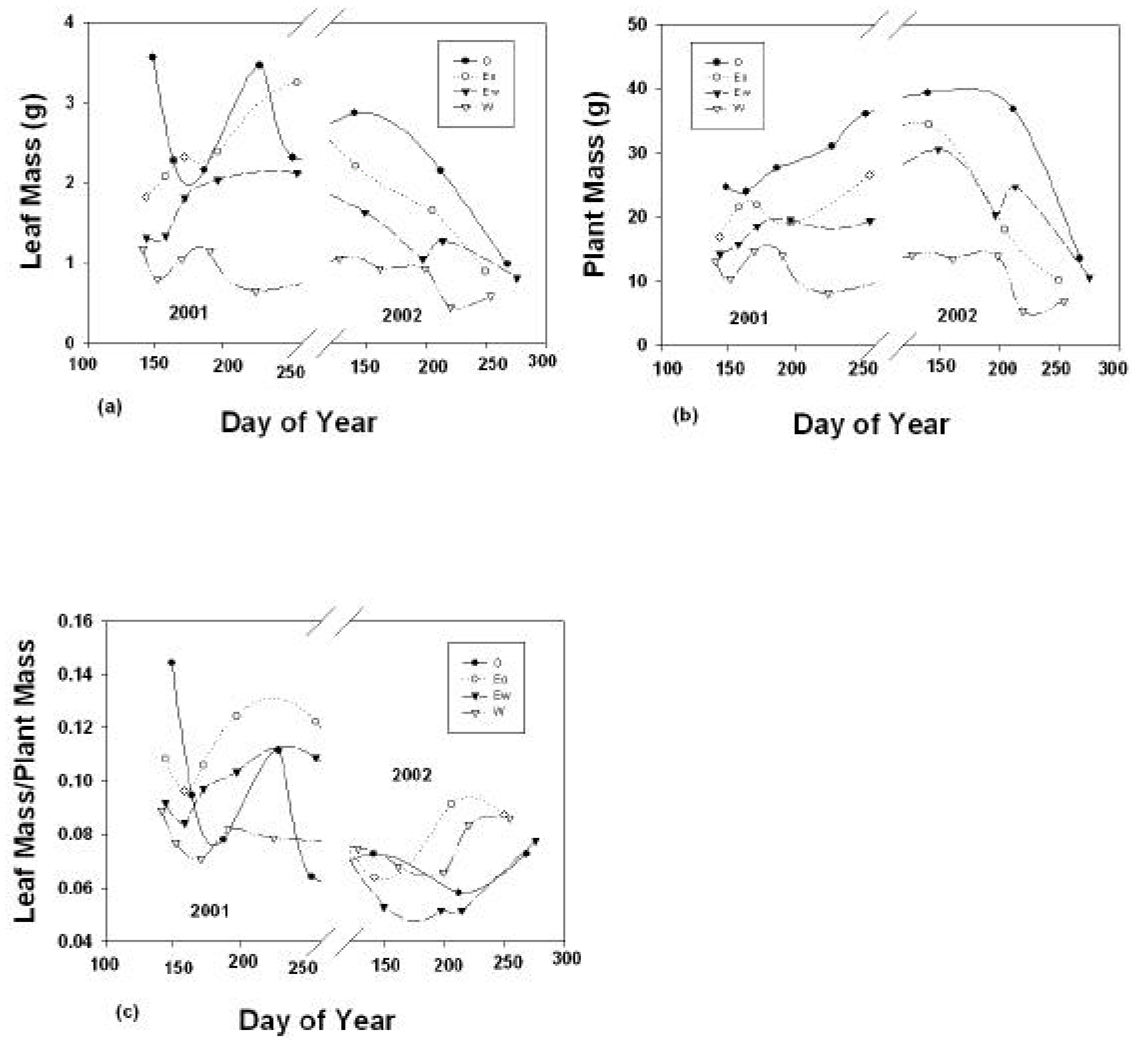

Figure 2. Leaf mass (a), total plant mass (b) and leaf ratio (c) as a function of harvest date.

There was a general inverse relationship between PAR use efficiency relative to leaf growth and PAR (Figure 3a). Very low PAR use efficiency occurred at the O site for both years. In 2001, the Eo site had high PAR use efficiency at the second harvest which was the first growth period with complete shade but PAR use efficiency decreased to O site levels as the solar angle decreased and PAR increased. The highest PAR use efficiency values were achieved for the Ew site in mid to late July (DOY 195 to 210). This corresponds to the period when decreasing solar angle is just starting to increase direct beam radiation at that site. The PAR use efficiency on a leaf mass basis was greater for juvenile than mature plants at all sites. Based on total plant mass, PAR use efficiency was similar to leaf mass efficiency values on a relative basis (Figure 3b).

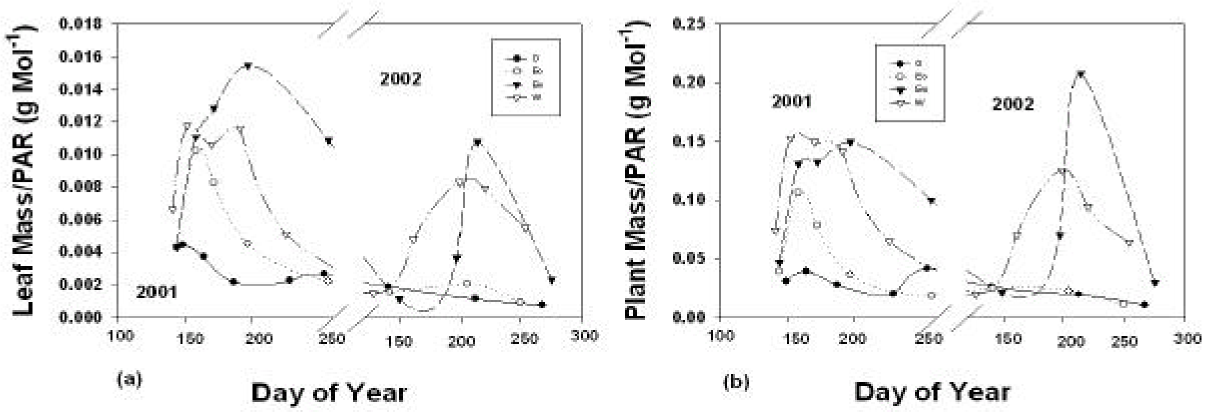

Figure 3. Leaf mass (a) and total plant mass (b) relative to incident PAR since the previous harvest as a function of harvest date.

Orchardgrass was able to continue growing during midsummer with PAR levels less than 10% of potential. However, productivity was reduced along with forage quality (Belesky 2005). Total nonstructural carbohydrates (energy) were very low and nitrate levels were in the toxic range relative to the nutritional needs of grazing livestock. As a result of changes in the tree canopy and seasonal solar angle, deciduous silvopastures do allow periods of higher PAR for forages grown in heavily shaded sites, which may aid in persistence. Deciduous silvopastures also exert a greater impact on red/far-red ratio than either pine silvopastures or shade cloth at low PAR levels (Figure 4). Further study is needed to assess the management implications of changes in light quality.

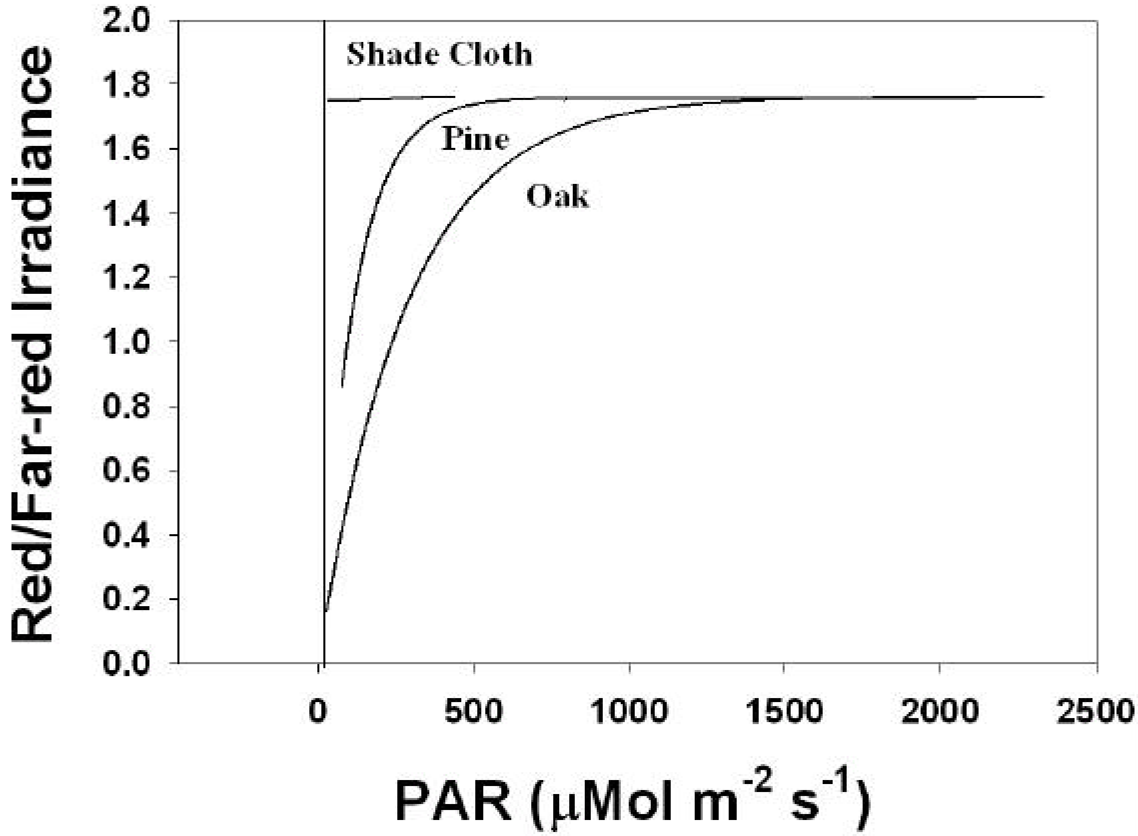

Figure 4. Red/far-red irradiance under an oak tree canopy, pine tree canopy, and estimated shade cloth as a function of PAR intensity.

Orchardgrass response to various PAR levels suggests a high degree of plasticity in terms of productivity and resource allocation. There are genetic limits to plant size that may minimize the ability or need to utilize PAR efficiently at high levels. There is an obvious need to utilize PAR efficiently at low levels to acquire photosynthate to sustain growth. During mid-summer in this study, PAR varied by a factor of about eight between the O and W extremes while dry matter varied by a factor of only about three. Orchardgrass was most efficient at producing dry matter at PAR levels of about 25% of O site levels which was only about 15% of maximum PAR possible had there been no cloudiness. Baltzer and Thomas (2005) and others have found no difference in light use efficiency between sun exposed and shaded trees. However, they defined light use efficiency on the basis of absorbance efficiency rather than on growth.

Orchardgrass cultivars such as Benchmark have been selected for productivity in open field sites with high PAR. In order to maximize the productivity of silvopastoral systems forages need to be selected for persistence and productivity under low PAR conditions. There is especially a need for cultivars that do not accumulate nitrate but do accumulate total nonstructural carbohydrates. Plant breeders will be key contributors to future advances in temperate silvopastoral productivity.

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