

Photosynthetically Active Radiation relationship to forage yield in Central Appalachian Silvopastures

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Introduction

The Appalachian Region is 23% larger than the state of California and encompasses parts of 11 states including all of West Virginia. While there are some highly productive agricultural regions within Appalachia, most of it is marginally productive, hilly and difficult to farm (Barnes, 1938; Proctor and White, 1962). Agricultural production is mainly from small farms averaging 60 ha with 40% of that land area occupied by woodlands (USDA 1999). . The dominant form of agriculture, on an area basis, is the production of perennial forage grazed by beef cattle. This form of agriculture does not generate enough income to support a family on an average farm, thus off-farm jobs are the norm.

Conversion of pasture and woodlands to silvopasture production systems has the potential to increase farm income in an ecologically sustainable manner. Silvopastures diversify farm income by growing trees for wood or other useful products and forage for animal production within the understory. Silvopastoral systems provide forages with an environment where both solar radiation and temperature vary spatially on a daily and seasonal time scale. The economic success of silvopastoral systems requires proper management of the solar radiation resource.

Forage growth does not have a simple relationship to light environment. Some C3 plants appear to use diffuse radiation more efficiently than direct beam radiation (Sinclair et al., 1992; Healey et al., 1998) so that in a humid, cloudy environment the amount of field-of-view open to reflective clouds is more critical than in sunny, arid regions. 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 which in turn affects forage quality (Devkota and Kemp, 1999; Monaco and Briske, 2000; Burner, 2003; Belesky 2005). Timing of daily exposure to solar radiation is also important since it affects plant carbohydrate content, thus energy value as animal feed (Ciavarella et al., 2000; Mayland et al., 2000).

This paper reports how forage performance was related to Photosynthetically Active Radiation (PAR) spatially and temporally for several silvopasture research projects at the USDA-ARS Appalachian Farming Systems Research Lab, Beaver, WV and in cooperation with Virginia Tech, Blacksburg, VA.

Materials and Methods

PAR

Photosynthetically active radiation (PAR) was measured for all experiments using 1 m long LI-COR LI-191-SB line quantum sensors (LI-COR inc., Lincoln, NE). Sensors were mounted horizontally about 25 cm above the ground to prevent shading by forages. Data from the sensors were collected using Campbell Scientific 21X data loggers (Campbell Scientific, Logan, UT) with measurements made every 10 seconds and averaged hourly. Sensors were moved between sites throughout the growing season for 7-10 day measurement periods with up to 16 sensors used at any given time depending on spatial requirements. Sensors were placed close together in an open field once early and late each summer for calibration. Automated weather stations were used to measure open-site PAR continuously throughout the growing season for estimation of silvopasture PAR during periods without quantum sensors at a given site.

Yield

Forage yield was measured for 5 different silvopasture experiments.

- 1). Black locust (*Robinia pseudoacacia* L.) rows planted in a steep pasture watershed
Plots, .7 X 4 m were clipped in 3 or 6 week intervals during 2001,2002 and 2003. Trees were in row 12 m apart oriented SE to NW. Plots were parallel to tree rows at varying distance from trees. Pasture was dominated by tall fescue (*Festuca arundinacea* Schreb.) and white clover (*Trifolium repens* L.).
- 2) Black walnut (*Juglans nigra* L.) and honey locust (*Gleditsia triacanthos* L.) rows planted on a hillside pasture
Plots with each tree species contained rows oriented SE to NW that varied in tree density with harvest strips placed to give three treatments, closed overstory, afternoon shade, and no shade most of the day. Strips were .53 X 2.44 m and harvested every 5 weeks during 2002 and 2003. Pasture was dominated by tall fescue.
- 3) Forage planted in a mixed density northern conifer stand composed of mostly white pine (*Pinus strobus* L.) and red spruce (*Picea rubens* Sarg.).
Twelve plots with varying shade were identified and 4, 0.1 m² samples were harvested from each every time the forage reached 20 cm during 2000, 2001 and 2002. The area was grazed by sheep after each clipping. Pasture was dominated by orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.) and white clover.
- 4) Forage planted in a thinned mixed hardwood forest.
Grazing paddocks for sheep were established in a thinned second growth mature hardwood forest dominated by oak (*Quercus* spp). Paddocks were planted with perennial ryegrass and white clover. Open pasture paddocks for comparison were dominated by orchardgrass and white clover. Pastures were grazed in a 6 week rotation with yield samples taken before grazing. This work started in 2002 and is ongoing as new paddocks are still being created.

- 5) Forage-containing pots placed in-ground within a forest clearing and on a gradient within a north side forest edge.

The research was done adjacent to and within the north edge of a 400 by 30 m group selection clear-cut 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 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 over 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. Pots with orchardgrass, 15 cm in diameter with bottoms removed were placed into the ground within a shade gradient going from forest edge to 10 m into the forest along the north edge. Pots in the cleared area were designated as “O”, 2 m within the forest as “Eo”, 10 m within the forest as “Ew” and 35 m within the forest “W” for a deep forest comparison. Selected pots were harvested and all others clipped whenever grass reached 20 cm.

Results

- 1) Forage yield was not statistically different between harvest strips relative to distance from black locust tree rows. This is in spite of a nearly 5 fold difference in total daily PAR on sunny days between the sites under tree canopies compared to mid alley. The major difference in forage across the site was more clover in the mid alley compared to under black locust. Because of row orientation the forage under the black locust received sunlight early and late in the day when the mid alley was shaded, thus coupled with diffuse radiation and sun flecks, the forage under the trees effectively experienced a longer growing day than other harvest strip sites.

- 2) In the black walnut and honey locust silvopasture the sites receiving shading in the afternoon yielded higher than sites with full sun or mottled shade most of the day. A similar trend was evident both in 2002 and 2003 even though 2002 was a very dry summer and 2003 was a very wet one. Under closed tree canopies black walnut restricted PAR about 15 % more than honey locust. During the dry summer of 2002 forage yield was higher in association with black walnut compared to honey locust but yields during the wet 2003 summer were similar under the two tree species.

- 3) Within the conifer silvopasture yield decreased with PAR although there were plot site limitations such as shallow rocky soil that complicated the relationship. At the best yielding sites 20-30% of maximum PAR produced over 60% of a largely unshaded site's yield. One factor limiting yield in a conifer silvopasture is that forage does not receive as much PAR in spring and autumn compared to a deciduous tree silvopasture thus PAR is more restricted during what is usually optimal growth periods for C3 forages. Also, since at this site the trees were not in north-south rows, the forage had a shortened day in which high PAR levels could be incident since the horizon was blocked and eliminated 2 hours of direct beam radiation both in the morning and evening.

- 4) Forage yield in the grazed hardwood silvopasture was about half the yield

from the open pasture. While PAR was also about half, the yield difference cannot be attributed primarily to the reduction in PAR. The open pasture had been managed as pasture for many decades with additions of lime and fertilizer. The silvopasture site had shallower, rocky soils that had been established in forage in 2001 so these forest soils were not optimal for forage production. Lambs did perform as well in the silvopasture as the open pasture, however, larger paddocks were required in the silvopasture for replication of animal units.

5) In the forests edge pot study, forage yield increased with PAR. By late summer the O treatment and Eo received essentially the same amount of daily PAR since the changing solar angle allowed direct beam radiation to penetrate under the tree foliage canopy (Figure 1). Maximum differences in PAR between treatments happened about 3.5 weeks before and after summer solstice. This was the period when trees were fully leafed out and the sun angle was most vertical. The two years were very different during summer with 2003 being much cloudier (Table 1). The comparison of PAR data from the two years demonstrates the importance of expressing PAR as true values rather than percent since percent of maximum received in the open is very different than percent of maximum possible with no cloud cover (Table 1).

Summary

Levels of unobstructed PAR vary widely between regions of the country, time of year and between years with different prevailing weather patterns. For this reason comparisons between silvopasture systems, which are complex by nature and often limited in PAR interception, need evaluation relative to absolute PAR and not relative indices such a percent shade. The relationship between PAR and forage productivity will differ between thinned forests with a newly established forage on a forest soil and long-established pasture with planted trees. Forages respond differently within confer silvopastures where spring and autumn have lower levels of PAR compared to summer due to larger tree shadows cast by a low sun angle compared to deciduous-tree silvopastures where spring and autumn PAR levels are higher than during summer since the trees have no leaves and produce little shade. The spatial growth patterns for forages are affected also by tree spacing since in thinned forests environments, high PAR day length is limited by horizon obstruction by trees but in north-south tree row silvopastures forage under trees may have a longer day length than at mid-alley locations. What is evident from a variety of experiments at our location and others is that it is possible to produce high quality forages within a variety of silvopasture configurations and the factors determining design characteristics will depend on soils, long-term site weather and economics.

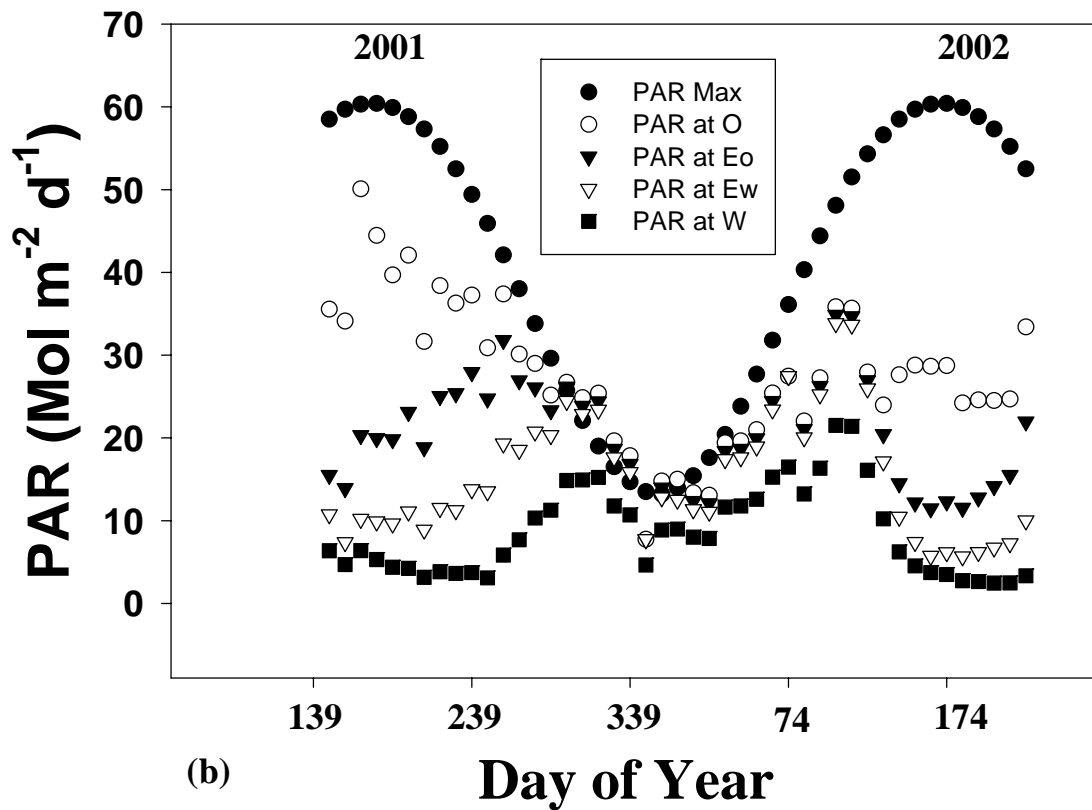


Figure 1. Modeled maximum PAR and measured PAR for the open (O), within forest edge near the open (Eo), 8-10 m within the forest (Ew), and 35 m within the forest (W). Each point represents the average of 10 days.

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

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

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