
Growth of Quercus Macrocarpa in Response to Radiation Levels in an Oak Savanna Remnant

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Abstract: I tested whether radiation levels differed between the periphery and interior of a small oak savanna remnant in Northfield, MN. I also tested all Quercus macrocarpa within the remnant to determine whether the height of each lowest living branch and the number of dead limbs below it differed between the interior and the periphery of the forest. The test sight was a 71.6m X 80.3m oak savanna remnant. It was divided into periphery and interior according to the size of surrounding, shade-tolerant saplings. Radiation levels in both areas were measured over three days. The height of each oak's lowest living lateral branch was recorded along with the number of dead branches below it. Radiation levels within the periphery were significantly higher than radiation levels within the interior. The interior oaks' lowest living lateral branches were significantly higher above the ground than the periphery oaks' lowest branches. The interior oaks had a significantly greater number of dead limbs below the lowest living branch than the periphery oaks. This indicates that each shade-intolerant Quercus macrocarpa is being overtaken from its base up, as growing invasive species cut out its light. While a few midwest oak savanna remnants still exist, they are slowly dying out.

Introduction:

Settlement has greatly reduced the amount of oak savanna existing today in the U. S. Marschner's map of Minnesota (1974) indicates that around 1,829,750 hectares of oak savanna existed prior to settlement. Oak savannas once covered 11 to 13 million hectares of the midwest (Abrams, 1992). Within twenty to forty years of settlement, oak savanna virtually disappeared. In 1985, an investigation found only 113 sites totaling 2,067 hectares of relatively high-quality oak savanna remaining in the midwest

(Nuzzo, 1986). This is approximatély 0.02% of the original extent. All but 40 acres of these savannas were found on sandy, rocky, or similarly dry substrates. None of the eight states studied indicated any intact, high-quality deep soil mesic savanna areas.

Savanna has become the general name in many European languages for any similar plant community of which trees are a sparsely dispersed component but where their density is so low that grasses and other herbaceous vegetation are allowed to become the actual dominants of the community. It is an intermediate ecosystem between forest and prairie. Although tropical savannas are largely independent of climate, temperate savannas are best developed in the climatic belt separating forests from grasslands. The intermediate structure between forests and grasslands parallels the intermediate climate.

Oak savannas with an intact ground layer are thought to be the rarest plant communities in Minnesota and Wisconsin (Curtis, 1959). Almost all of them have been converted to farm land or forests. An early study of oak savannas was done by Bray, which examined 59 stands in southwestern Wisconsin (Bray, 1955). One of Bray's major difficulties was the great scarcity of stands remaining in their original condition. The oak openings changed quickly to closed oak forest in the absence of fire. The oak forest is then an intermediate community as more shade tolerant trees invade to choke out each large oak and the next generation.

Remembering his boyhood in Columbia County Wisconsin, John Muir described the encroachment process. "As soon as the oak openings in our neighborhood were settled, and the farmers had prevented running grassfires, the grubs grew up into trees, and formed tall thickets so dense that it was difficult to walk through them and every trace of the sunny 'opening' had vanished" (Curtis, 1959). For restoration of these lost ecosystems to be successful, we must first understand the unique conditions which maintain a savanna. Some major factors include the rate and intensity of fire (to control outside competition), climate, number of oaks in an area, and the amount of light they need.

Two of the most important factors influencing oak savannas are fire and radiation. These two aspects are highly interrelated. As settlement stopped fires, radiation levels within the oak savannas were greatly decreased as fire-intolerant species were able to invade. Although such invading species (such as sugar maple and basswood) were fire-intolerant, they were shade-tolerant. This allowed them to outcompete the shade-intolerant oaks for radiation. If we are to attempt to restore these rare ecosystems, we must learn exactly how these two aspects create and maintain the oak savanna. What levels of radiation and fire (frequency and intensity) are needed first to create the environment and then to maintain it? Are the levels required to maintain a savanna different than those required to create it?

The "Big Woods" section of the Maple-Basswood Forest region in Minnesota is surrounded by oak forest and oak savanna. The savanna extends from this southeastern corner of the state northwestwardly to the opposite corner (Figure 1). The very narrow savanna band separates the conifer and hardwood forests of the northeast from the tallgrass prairies of the southwest. The band encircling the Big Woods and the interrupted forest belt west of the Big Woods are both bur oak (*Quercus macrocarpa*) savanna (Figure 1).

This study looks into the degradation of bur oak (Quercus macrocarpa) within a small oak savanna remnant near Northfield, MN, as invading, shade-tolerant species effect its radiation levels. I tested whether radiation levels differed between the periphery and interior of the remnant. I also tested all Quercus macrocarpa within the remnant to determine whether the height of each lowest living branch and the number of dead limbs below it differed between the interior and the periphery of the forest. Lack of lower branches and existing dead lower branches were an indication of decay.

Methods:

A small remnant containing twenty four old growth bur oaks was located across from the Secclar Park entrance in Northfield, Minnesota. The plot was approximately 71.6m X 80.3m. I walked the area to determine which oaks were in the periphery of the forest and which made up the center of the canopy. While this process was partly subjective without exact parameters to separate interior from periphery, there was a definite difference between the two portions of the forest (Figure 2). The periphery oaks were those that had only young saplings surrounding them which reached no higher than the oak's lowest branch (Figure 2A). The interior oaks were completely surrounded by much larger saplings (Figure 2B). I also took ten circumference measurements of the ten largest periphery saplings and averaged them (15.5 cm) as another guideline for oaks on the periphery. These young invading saplings on the periphery had not yet begun to directly out compete the oak for radiation, leaving a large portion of it open to the sun.

In September, two LI-COR L1-1000 data loggers were then used to record photosynthetically active radiation (400-700 nm) every hour over a three day period. One data logger was placed in the very center of the forest, and the other was placed under an oak at the edge of the forest in an area which was representative of the periphery coverage. In addition, a hand held LI-COR L1-189 photometer was used during the three days to record ambient radiation at two or three points during each of the three days. This measurement was used to model the amount of radiation each oak would have received during the three days if fire had kept the larger invasive trees out of the area.

Each of the old bur oaks were then measured for decay of lower branches. I took a measurement from the ground to the lowest living branch of each oak. I also recorded the number of dead branches below the lowest living branch.

An analysis of variance was then performed (using Statview 4.5) to analyze the mean height of the lowest living lateral branch, the mean number of dead branches below that branch, and the mean level of radiation for the two different locations (interior forest and periphery forest--Tables 1-3). Light measurements in the periphery and central forests were graphed over each of the three days (Figures 3-5). Each recorded ambient light measurement taken by the hand held sensor was also added to the radiation graphs for a third level of comparison.

Results:

An Anova test revealed a significant difference between radiation in the interior of the forest and in the periphery (Table 1). Radiation levels were much higher within the periphery of the forest. The mean radiation within the periphery was 125 um greater than the mean radiation within the interior. The P-value was .0003.

When graphed, I found that all the daytime radiation readings over all three days varied according to location about the forest plot (Figures 3-5). During daytime hours, the ambient radiation recordings were consistently higher than the periphery and the interior readings. The periphery daytime readings were consistently higher than the interior readings. The readings for ambient, periphery and interior radiation during the second and third day were similar in shape and degree of variation. The peak radiation readings for all three location over all three days was just after 1:00 p.m.

Anova tests also revealed significant differences for lowest living, lateral branch height and the number of dead branches below it in relation to the oak's location within the forest. The interior oaks had higher lowest lateral branches at their bases and had a greater number of dead branches below the lowest living branch. On average, the lowest living, lateral branches within the interior were 1.183 m higher than those within the periphery (Table 2). This test revealed a P-value of .0023. The average number of dead branches below the lowest lateral branch within the interior was 1.909 greater than those within the periphery (Table 3). This test revealed a P-value of .0317.

Discussion:

Three basic relationships were revealed by this study. First, the amount of radiation in the periphery was significantly greater than in the interior of the remnant savanna. Second, the interior oaks' lowest living, lateral branches were significantly higher above the ground than the periphery oaks' lowest branches. Third, the number of dead oak branches below the lowest living branch was significantly greater within the interior than within the periphery. These data suggest that a relationship exists between the levels of radiation recorded in the periphery and interior of the remnant and the height of the lowest lateral bur oak branches, along with the number of dead branches below it.

The radiation readings in the representative periphery area were much higher than in the interior of the canopy (Figures 3-5). My results reveal this difference to be significant (Table 1). The periphery readings were not once below or even equal to the interior readings for the daytime hours over all three days. The similar variation between the graphs of the second (Figure 4) and third day (Figure 5) reflect the similar weather patterns over those two days. While September 27 was mostly cloudy (Figure 3), September 28 (Figure 4) and 29 (Figure 5) were mostly sunny. It is usual for the sun's radiation to peak at around 1:00 p.m. this time of year, which is what I found.

Oak species have low or intermediate tolerance to shade (Abrams, 1992). A recent study by M. K. Owens (juniper vs. oak in a semiarid savanna) demonstrated the competitive edge of one of the many shade tolerant invaders (Owens, 1996). A reduced leaf area and a different leaf area distribution coupled with lower leaf gas exchange rates explained the lower overall competitive potential of the oak.

The lower branches of the oaks are dying off as radiation within the understorey decreases with the continued growth of shade-tolerant saplings. As the larger invading species (basswood, black cherry, ash, elm, and buckthorn) cut out more light in the interior of the remnant savanna, it is logical that the height from the ground to the lowest living branch should increase as indicated by my results (Table 2). Degradation is further represented by the significantly higher number of dead lower branches of the interior oaks in comparison to the periphery oaks (Table 3). The lower interior radiation readings also reflect this process, as invading species cutting out more light within the interior of the forest.

With much greater radiation in the periphery of the savanna remnant, the lowest lateral branches of the bur oaks on the edge of the forest did not die off. The measurements from the ground to the lowest living branch were, therefore, shorter than for the periphery oaks (Table 2). The young invading species on the periphery had not yet gotten large enough to take away the oaks' required amount of radiation at their bases.

These results give evidence that although a few oak savanna remnants do exist, they are not permanent structures. The massive oaks are slowly dying from the ground up as settlement deprives them of the previous conditions which allowed them to thrive. Any new oak seedlings will not have a chance to grow with the shade-tolerant competitors entering the area uninhibited. On the other hand, such results also reveal the possibility of saving these beautiful specimens before they are taken over.

There are many aspects, other than radiation, of oak savannas which need to be researched to better apply restoration techniques. For example, soil and climate studies of existing remnants will help determine whether an area was once a savanna or, if not, whether one could exist under the area's current conditions. Different canopy densities could be studied to determine the number of large oaks which allow prairie to thrive below.

Fire and radiation are intimately related aspects of the oak savanna ecosystem. Fire is a dominant factor in the survival of both prairie and oak species. Periodic fires prohibit fire-intolerant tree species from growing to sapling height. They, therefore, maintain the levels of photosynthetic radiation required by the large, shade-intolerant oaks in the savanna. Relative to other hardwoods, oaks are favored by fire due to their sprouting ability, thick bark, resistance to rotting after scarring, and the suitability of fire-created seedbeds for acorn germination (Abrams, 1992).

Different size burning areas and burn intensities could be studied to learn how to most effectively manage a restored area with the loss of free ranging fires. In 1989 a study conducted on nine portions of oak savanna in east central Minnesota showed that prescribed burning not only aids in oak survival but increases the cover of true prairie grasses and true prairie forbs (Tester, 1989). White (1986) studied seven prescribed burn blocks of oak savanna and one control near St. Paul, Minnesota. He found that all grasses and forbs showing a significant relationship to each block had maximum average values in the burned blocks. The shrub layer was virtually absent in burned blocks but covered fourteen percent of the control block. He also found that burning reduced the oak overstorey by killing mainly the smaller diameter oaks. More intense burns killed the larger oaks. With these data, he suggests that pretreatment community structure and composition most likely influenced the burns he studied. One may predict the effects of fire by knowing what plant species are present and how each reacts to fire.

White's study also suggested that the type of fire needed for oak savanna restoration may be very different from the type of fire required to maintain an oak savanna. Another study investigated how fire frequency shaped the structure of a Quercus velutina savanna (Nuzzo, 1985). Frequent, low intensity fires rarely killed overstorey trees, while high intensity, infrequent fires killed large trees but stimulated dense sprouting, resembling more of a thicket. More frequent, high intensity fires would most likely avoid the thicket growth. White's and Nuzzo's studies together suggest that frequent fires of high intensity are required for restoration of an oak savanna, while frequent, low intensity fires should follow for maintenance.

The results of my study reveal that, without such fire regimes, the oaks do not have enough radiation within the interior of a shade-tolerant forest to survive. Radiation levels are much lower in the interior than in the periphery of the forest. The oaks of the interior are, therefore, slowly losing their lower branches as the new shade-tolerant species get larger and cut out more light. The lowest living branch of each oak is higher above the ground in the interior. Also, within the interior, there are more dead branches below the lowest living one.

Although the large bur oaks still remain in oak forests as savanna remnants, they are dying out. While valuable maple/basswood species may move in (basswood, black cherry, maples, etc.), they are not as valuable as the last remains of the prairie-forest ecotone that previously dominated the midwest (White, 1987). This places much ecological concern on such areas due to the limited time frame we have to restore them. While many of Minnesota's native ecosystems have been leveled due to farming and industry, the remaining oak savanna remnants still retain part of their infrastructure--the massive bur oaks. There is still time to save these old growth trees, and regenerate what's left of a now rare ecosystem.

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Table 1: A Comparison of Mean Radiation Between the Interior and Periphery of an Oak Savanna Remnant

Location	No. Samples	Mean Radiation (um)	Std. Dev.
Interior	68	6.846	11.097
Periphery	67	131.846	273.649

P-value: 0.0003

Table 2: A Mean Height Comparison of Lowest Oak Branches Between the Interior and Periphery of an Oak Savanna Remnant

Location	No. Sampled	Mean Height of Lowest Branch (m)	Std. Dev.
Interior	13	3.986	1.075
Periphery	11	2.803	0.404

P-value: 0.0023

Table 3: A Mean Comparison of the # of Dead Oak Branches Between the Interior and Periphery of an Oak Savanna Remnant

Location	No. Sampled	Mean Number of Dead Branches (per oak)	Std. Dev.
Interior	13	3	2.132
Periphery	11	1.091	1.814

P-value: 0.0317

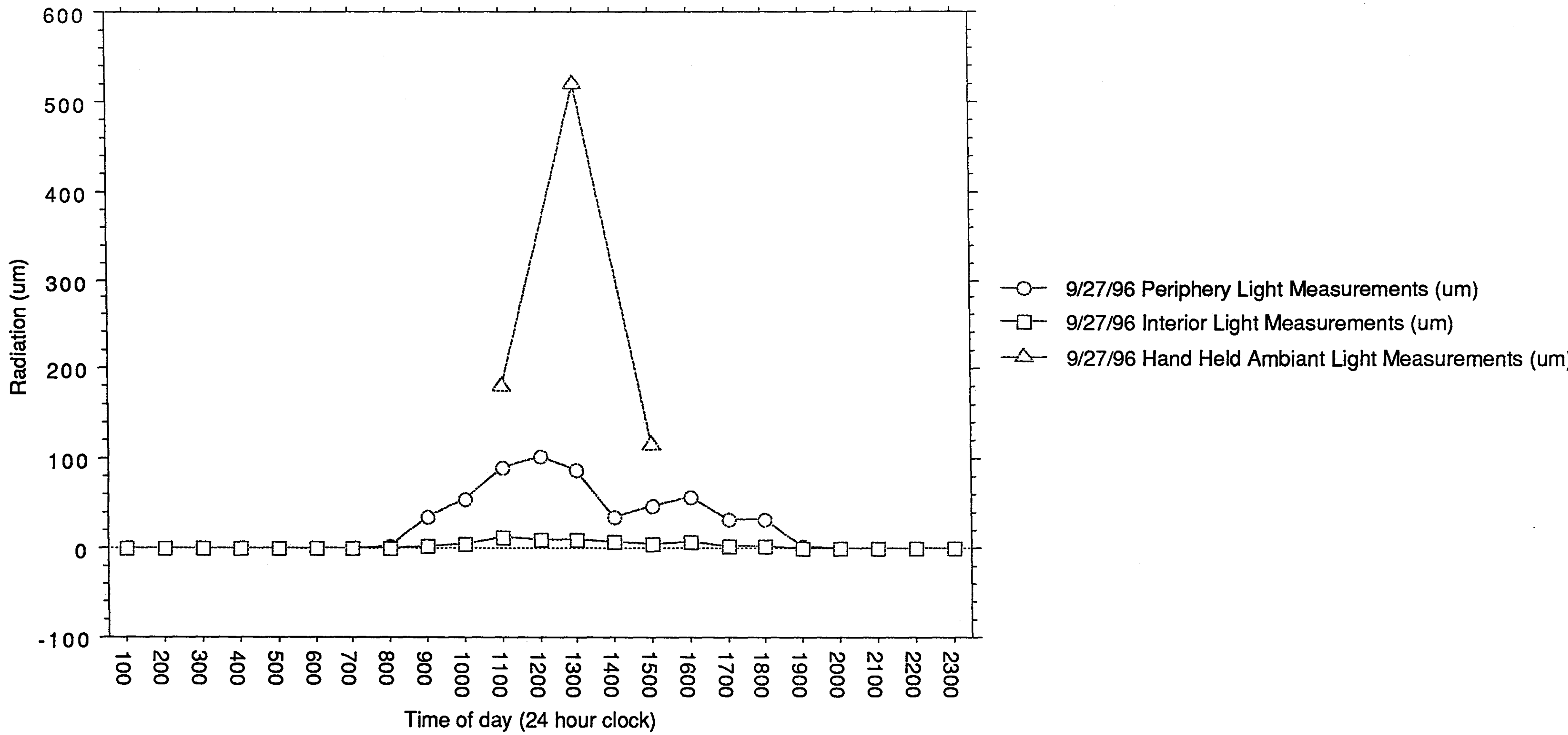

Figure 3: A Comparison of Ambiant, Periphery, and Interior Radiation Measurements of the Oak Savanna

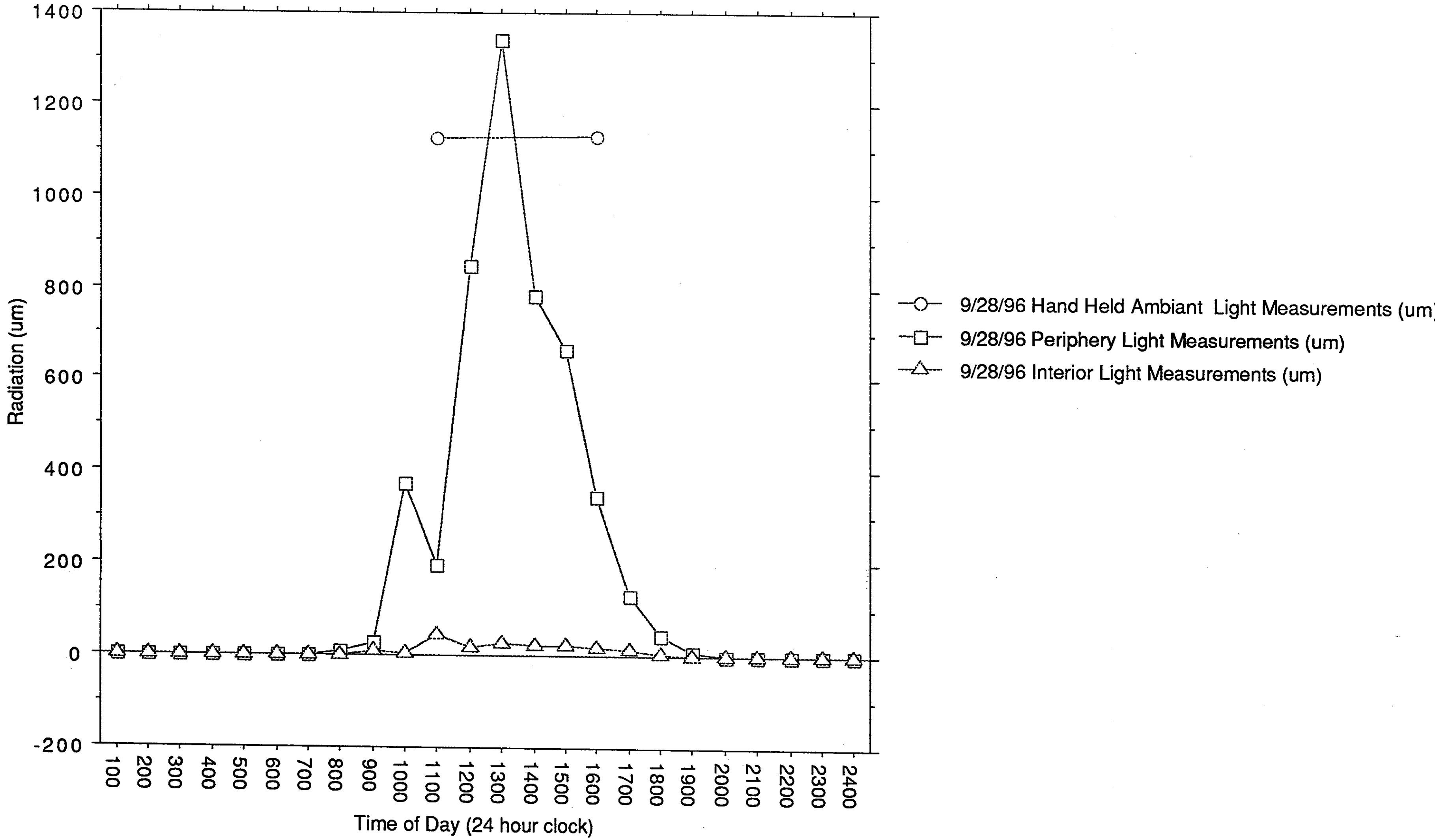

Figure 4: A Comparison of Ambiant, Periphery, and Interior Radiation Measurments of the Oak Savanna

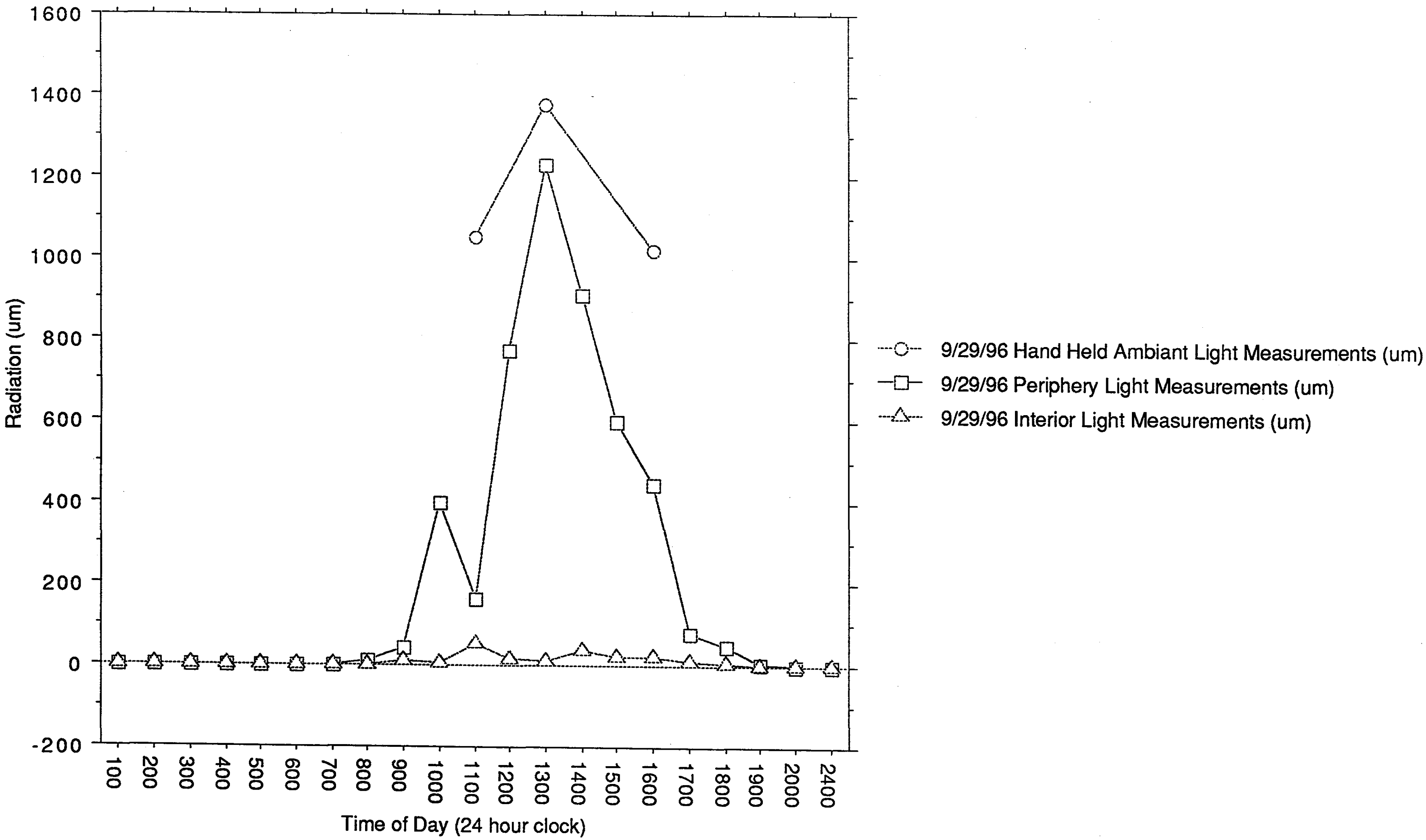

Figure 5: A Comparison of Ambiant, Periphery, and Interior Radiation Measurements of the Oak Savanna