Characterization of the Physiological Competitiveness of Autumn Olive in Meadow and Forest Environments

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Abstract

As a continuation of research done by Ritsema and Dornbos in 2006 and Edwards and Dornbos in 2007, the purpose of this research was to characterize and describe the physiological properties of Autumn Olive (*Elaeagnus umbellata)*, an invasive shrub found along roadsides and throughout meadows and forests in the Midwest. To evaluate the competitiveness of Autumn Olive in both the meadow and forest environments, data was collected throughout the summer of 2008 with the TPS-1 gas exchange meter. Photosynthesis and transpiration rate was measured for Autumn Olive and compared with that of seven co-existing native species. Chlorophyll content was determined by extraction and chlorophyll meter measurements to further evaluate the competitiveness of Autumn Olive in these two habitats. These results enable us to quantify the competitiveness of Autumn Olive in both the meadow and the forest ecosystems in comparison with native species so that we can predict the rate of spread and to inform restoration efforts designed to protect the native plants and habitats in the area.

Introduction

Today the world is experiencing more extinctions than ever before. The cause for these rapid extinctions is two-fold. Extinctions are due to habitat loss and the introduction of invasive species. Invasive species are non-native organisms that thrive and out-compete the native plants in their environment due to a lack of ecological constraints. Invasives can disrupt the natural rhythms of a community, reducing the goods and services that community can provide, often at the expense of the native species.

At Pierce Cedar Creek Institute in Hastings, MI, there are many invasive species of plants threatening the native plant communities. These include *Alliaria petiolata* (Garlic Mustard), *Lythrum salicaria* (Purple Loosestrife), *Phragmites australis* (Phragmites), and *Eleaegnus umbellata* (Autumn Olive). The focus of this research is on *Eleaegnus umbellata* because of its uncharacteristic ability to spread in both meadow and forest environments. Autumn Olive is widely recognized as a meadow invader, but it is rarely mentioned as a forest invader. At Pierce Cedar Creek Institute, though, there are dense patches of Autumn Olive in the forest understory, and these plants are producing seeds. Research by Wilterding (2005) and Ritsema and Dornbos (2007) demonstrated that Autumn olive is rapidly invading new forest areas and the density of this invasive plant is rapidly increasing within sites already invaded.

Autumn Olive is an invasive shrub from Eastern Asia. It was widely planted in the 1970's and 80's along roads and highways to stabilize marginal soils. It was also used as an ornamental shrub in landscaping. Autumn Olive has small, oval leaves with smooth margins and silvery undersides. In the spring the shrub produces a profuse number of small pale yellow flowers, which if pollinated, produces red berries in the fall. Other species of the Eleagnus family have been confirmed as having some capacity for nitrogen fixation, and thus it is believed that Autumn Olive may also have that capacity.

Autumn Olive's unusual behavior of invading both meadow and forest sites has led to research in 2006 by Ritsema and Dornbos and in 2007 by Edwards and Dornbos. In 2006, Ritsema and Dornbos found that Autumn Olive had a higher CO_2 uptake rate than the other plants studied in both the meadow and the forest at PCCI. In 2007, Edwards and Dornbos repeated the 2006 research in the forest environment and found similar results.

The purpose of this year's research was to repeat the study of 2006 in the meadow and forest by measuring the CO_2 uptake levels, transpiration rates, water use efficiency, stomatal conductance, and light use efficiency of Autumn olive and seven co-existing native species. A second goal was to quantify the chlorophyll levels and use efficiency of these same species. Chlorophyll content and function are foundational to the photosynthesis process and may serve as a quick screen of growth rate, serving as a surrogate for gas exchange measurements.

Methods

Two areas of the Pierce Cedar Creek Property were chosen as test sites for the research. One was the meadow area behind the research lab on Cloverdale Rd. The other was a section of forest off the north-east corner of the red trail. These two sites were chosen because they were the sites used in Michelle Ritsema's and Kelly Edwards' work. Both sites have been extensively degraded by Autumn Olive while yet retaining a number of competing native trees and shrubs. Four native species and Autumn Olive were chosen in each area to be the focus of the study. In the meadow plot, native species included Wild Black Cherry, Grey Dogwood, Hawthorn, and Black Walnut. In the forest, Black Oak, American Beech, Red Maple, and Wild Black Cherry were compared with Autumn olive. Four plants of each species in each area were chosen as the test subjects for the summer. In choosing which plants would be flagged and analyzed all summer, special care was taken to make sure that each of the four plants from each species was spaced evenly throughout the test site, and that Autumn olive plants of size and age were comparable with those of the native species.

TPS-1 Gas Exchange Meter:

A TPS-1 meter was used to measure the light intensity received by each leaf and the resultant photosynthesis and transpiration rate. These data were collected from two leaves of each tree for each species approximately once per week during a 10-week period in the meadow. The same process was repeated in the forest, but less often as there were already two summers' data from this environment. To collect the gas exchange data with the TPS-1 system, the cuvette was clamped onto two leaves on each plant, and two readings were recorded for each leaf. The TPS-1 meter was allowed to equilibrate 1 minute before the first reading was saved, and then it was allowed an additional minute before the second reading was taken. The data was downloaded to the computer and combined with the data from the previous two years. The results of the TPS-1 meter were analyzed to calculate photosynthesis rate, transpiration rate, and water use efficiency (CO_2 uptake/transpiration).

Chlorophyll Meter:

A Minolta Chlorophyll Meter SPAD-502 was used to estimate the chlorophyll content of Autumn olive and the seven native species. This was done by sampling 20 random leaves from each plant and calculating an average. Chlorophyll content was measured three times throughout the summer using the chlorophyll meter, once each in June, July, and August.

Chlorophyll Extraction:

Four leaves were sampled from each Autumn olive and native plant used for gas exchange and chlorophyll meter measurements for chlorophyll extraction. A 1 cm^2 area of leaf material was excised from each leaf and combined with comparable samples from each of the leaves of the same plant. The chlorophyll was extracted using a 90% methanol extraction as articulated by Arnon (1949). Chlorophyll content of the leaf extracts was determined using spectrophotometry.

Fluorometer:

An OS-30 Fluorometer was used to measure the amount of fluorescence emanating from the leaves exposed to a pulse of light to evaluate the functionality of the chlorophyll complexes in each of the species studied. For this process 7 clips were placed on the leaves of each plant for 15 minutes to condition them in darkness. Then the Fluorometer delivered a 3000µE light pulse to and resulting fluorescence was measured at each clip. The 7 fluorescence readings from each plant were averaged together and compared with the chlorophyll data.

Forest Results and Discussion

The average carbon dioxide uptake rates of Autumn olive were about two times the carbon dioxide uptake rates of all four native forest species evaluated. Autumn Olive produced photosynthesis rates of 4.5 $\mu mol/m^2/sec$, significantly faster than that of Wild Black Cherry, Black Oak, Red Maple, or American Beech (Figure 1). Photosynthesis rates among the native species were not significantly different from one another at around 2.0 µmol/m^2/sec.

The pattern of results for transpiration rate was similar to that of photosynthesis (Figure 2). Autumn Olive had an average transpiration rate of 2.3 µmol/m^2/sec and the native species were in a unique group with lower transpiration rates. In the case of transpiration, lower rates may connote an advantage in dry soils as limiting soil water would be conserved. In a competitive environment, however, it could mean that Autumn olive is better suited to extract soil water, enabling stomates to remain open allowing faster rates of CO_2 uptake at the expense of the native plants less able to access the soil moisture, closing stomates, and reducing CO_2 uptake rate. Water use efficiency, calculated by dividing CO_2 uptake by transpiration rate, of Autumn Olive was 1.81, significantly greater than the native species at approximately 1.0 (Figure 4). This suggests that not only was Autumn olive more efficient in extracting soil water, it also fixed CO_2 more efficiently as well with the soil water it was able to extract.

Chlorophyll levels in Autumn Olive leaves were also significantly higher than the native plants in the forest environment. Autumn Olive had a relative chlorophyll average of 47.8 in comparison with Wild Black Cherry and Red Maple at 35.1 and 32.4, and American Beech and Black Oak representing the lowest level at 28.3 and 28.3. Chlorophyll extraction results followed a similar pattern (Figure 3). From these data, chlorophyll use efficiency (CUE) was determined by dividing the CO_2 uptake averages by chlorophyll content. Autumn Olive and American Beech produced the highest CUE, significantly more than the remaining native species. Finally, fluorescence results indicated that the average fluorescence for Autumn Olive and Wild Black Cherry were greater than the other species (Figure 5), indicating that these plants were able to utilize incident light more effectively.

In all these physiological measures of plant performance in the forest environment, Autumn olive exhibited the highest level of performance. These data confirm that Autumn Olive is extremely competitive in the forest compared to the native species of Black Oak, Wild Black Cherry, Red Maple, and American Beech and that rapid encroachment of the understory would be expected to progress without targeted intervention. Chlorophyll results suggest that the higher photosynthesis rate of Autumn olive is due largely to its leaves having greater capacity to process incident sunlight effectively. This ability, coupled with Autumn olives ability to extract more soil water than the competing native plants, enables the leaves to keep its stomates open to a greater degree to facilitate rapid CO2 uptake. Finally, the advantage in water use efficiency suggests that not only is Autumn olive more effective in extracting soil water, it gains additional advantage by fixing a greater amount of carbon per unit of water absorbed. Even though Autumn Olive is largely recognized as a meadow invader, this summer's research suggests that it should also be considered an effective forest invader.

Meadow Results and Discussion

The two year average CO_2 uptake by Autumn Olive and Wild Black Cherry in the meadow environment is significantly higher than the other meadow species, but they are not significantly different from each other (figure 6). In 2008, Autumn Olive, Wild Black Cherry (WBC), and Hawthorn produced comparable photosynthesis rates Hawthorn may have been more competitive in 2008 because of a rust found on hawthorn leaves in 2006 that covered a significant proportion of the leaf area. In 2008 there were a few small rust spots on a few leaves, but most of the Hawthorn leaves did not have rust present. It has been reported that invasive plants often gain advantage when the natives they compete with demonstrate susceptibility to diseases that have not yet adapted to the invasive plant.

The transpiration rate of Black Walnut and Grey Dogwood were the highest while Autumn Olive was significantly lower than the other species. Translating this into water use efficiency (CO_2 Uptake/transpiration), Autumn Olive and Black Cherry have the largest WUE coefficients, Black Walnut has the smallest (figure 7). Consistent with the forest results, Autumn olive is the most efficient species in fixing carbon as a function of water loss.

The chlorophyll levels of Autumn olive in the meadow were the highest when measured using a chlorophyll meter, while each of the native species had a much lower average chlorophyll concentration. The chlorophyll extraction data was less definitive, however, as Autumn Olive is not exhibit higher chlorophyll content than all native species using this method of quantification. Even so, Autumn olive remained in the group with the highest chlorophyll content with Black Cherry and Grey Dogwood. Calculation of chlorophyll use efficiency coefficients for the meadow species indicated that Autumn Olive is not more efficient with its chlorophyll use than the other species, unlike the small difference detected in forest plants. These results are supported by the fluorescence data which also shows that Autumn olive chlorophyll use efficiency was comparable the native species evaluated with the one exception of Hawthorn, which was more efficient.

Considering the aggregate meadow results of this summer, Autumn Olive exhibited among the fastest photosynthesis rates and the highest chlorophyll concentration, but it does not exhibit the same level of dominance over native species as noted in the forest. Autumn olive is obviously a problem in the meadow given its ability to spread rapidly as a function of the ample amounts of sunlight present. These data do suggest that black cherry and hawthorn in low rust years can compete effectively with Autumn olive and might be actively used in restoration plans to slow its rate of encroachment. This is not the case when considering forest results, however, as no native species tested is able to compete with Autumn olive in the understory. These results would suggest that the creation of canopy gaps would promote the formation of canopies dominated by Autumn olive thereby significantly slowing recruitment by juvenile plants of the native overstory species.

Comments

When studying invasive species one must take into account the release from many constraints that would be present in that species' original habitat. For instance, there are no diseases or fungi known to attack Autumn olive, whereas hawthorn had to deal with the rust, wild black cherry had fungi causing leaves to shrivel, and Black Oak had another disease on some of its leaves that resulted in necrotic spots on the leaves. We also noted that deer preferentially browsed Hawthorn plants while Autumn Olive exhibited minimal deer feeding damage. Disease traits could contribute to the higher photosynthesis rates of plant leaves we measured whereas other traits simply confer an even greater advantage to Autumn olive than what we determined.

Another thing to think about, especially for future research, is that Autumn Olive is in a nitrogen fixing family, as found by John G. Torrey in 1978. This could contribute to Autumn olive's success in forest environments where soils are typically nitrogen-poor. Even the meadow location at PCCI is characterized by sandy, well-drained soils that have low nitrogen content (data not shown). In particular, chlorophyll is a nitrogenous pigment key to photosynthesis rates. Our data demonstrates a high correlation with chlorophyll content and photosynthesis rates. Much of the advantage demonstrated by Autumn olive can be attributed to its leaves containing higher chlorophyll content. If these Autumn olive plants are fixing nitrogen, it may be gaining its photosynthetic advantage simply by producing more chlorophyll in its leaves. It would be interesting to see if the native species, particularly black walnut, are benefiting from having Autumn Olive nearby if some fixed nitrogen remains in the soil.

Works Sited

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Ritsema, Michelle and David Jr. Dornbos. "Characterization of the Physiological Competitiveness of Autumn Olive." PCCI Final Report. 2006.

Sauer, Leslie Jones. The Once and Future Forest. Washington, DC: Island Press, 1998.

Torrey, John G. "Nitrogen Fixation by Actinomycete-Nodulated Angiosperms." BioScience 28.9 (1978): 586-592.

Travis, John and John Wilterding. "Assessment of Autumn Olive (Elaeagnus umbellata) Population at Pierce Cedar Creek." PCCI Final Report. 2005.

Figures and Tables

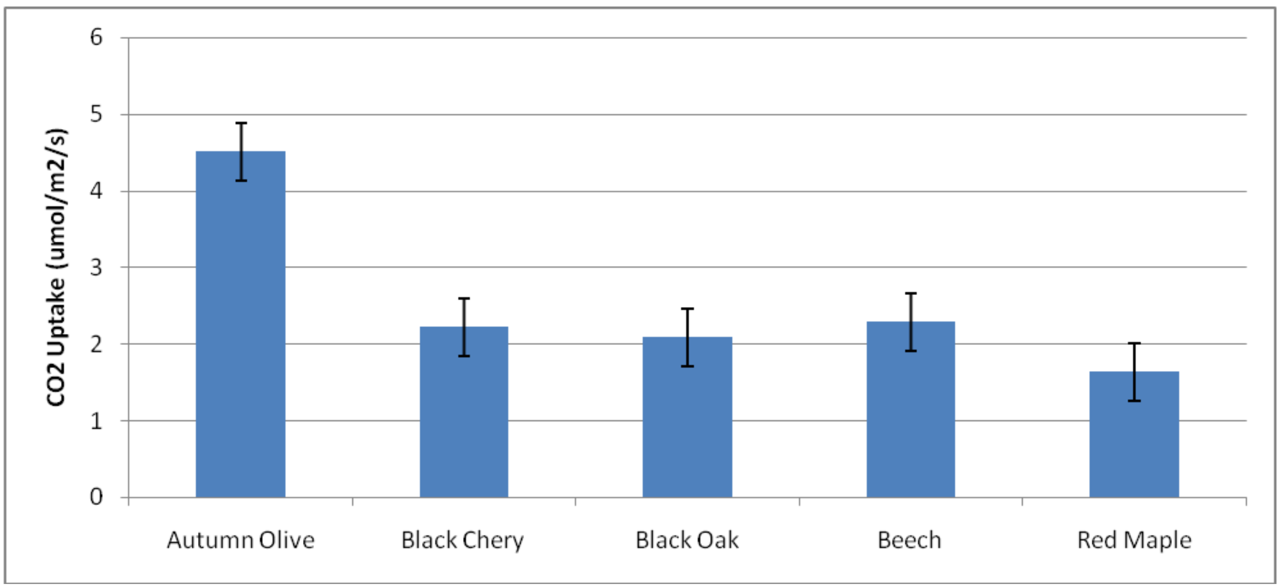

Figure 1: Average photosynthesis rates of the five forest species at PCCI, taken in the summers of 2006-08. (p=.0000)

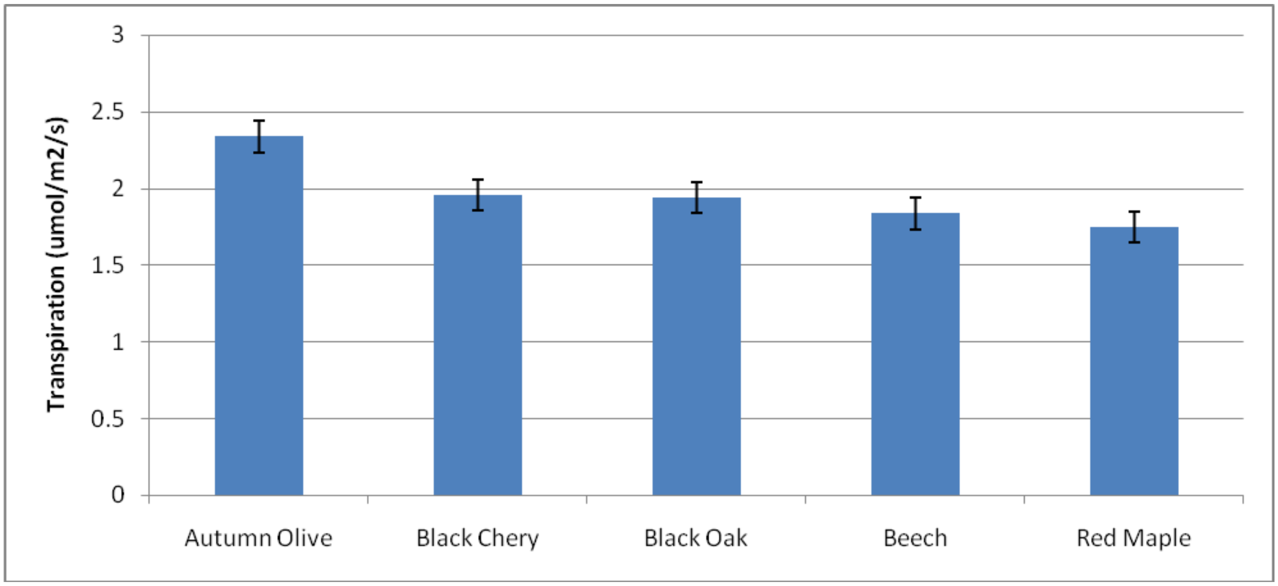

Figure 2: Transpiration rate averages in the forest for the five species, taken from 2006-2008 at PCCI. (p=.0000)

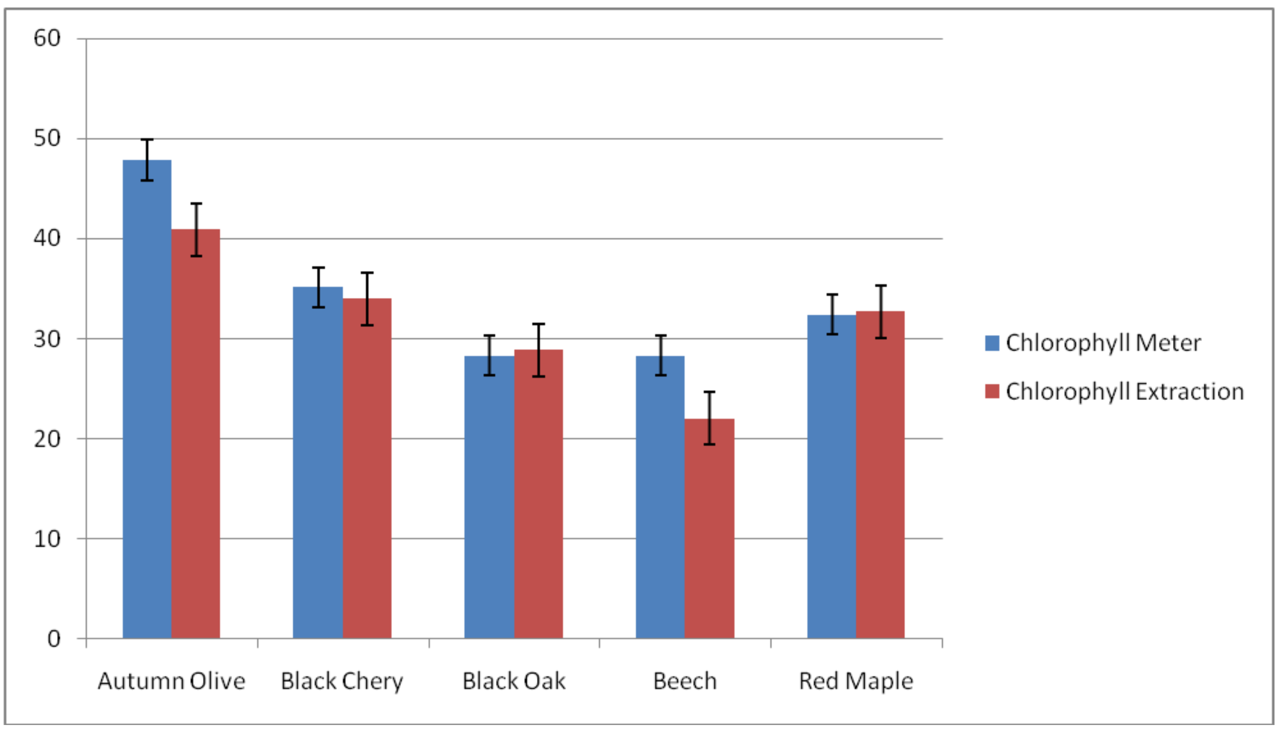

Figure 3: Average chlorophyll levels in the forest for both the chlorophyll meter and the chlorophyll extraction, the chlorophyll meter is displayed in blue, the chlorophyll extraction is in red. (p=.0000 for chlorophyll meter, p=.0000 for chlorophyll extraction)

SPECIES	MEAN	GROUP
Autumn Olive	1.8161	A
Black Cherry	1.1433	B
Black Oak	0.9386	B
Beech	1.0321	B
Red Maple	0.7715	B

Figure 4: Average water use efficiency in the forest from 2006-08, found by dividing CO2Uptake/Transpiration. (p=.0002)

SPECIES	MEAN	GROUP
Autumn Olive	0.8013	A
Black Cherry	0.7993	A
Black Oak	0.7692	B
Beech	0.757	B
Red Maple	0.775	B

Figure 5: Average fluorescence in the forest. (p=.0011)

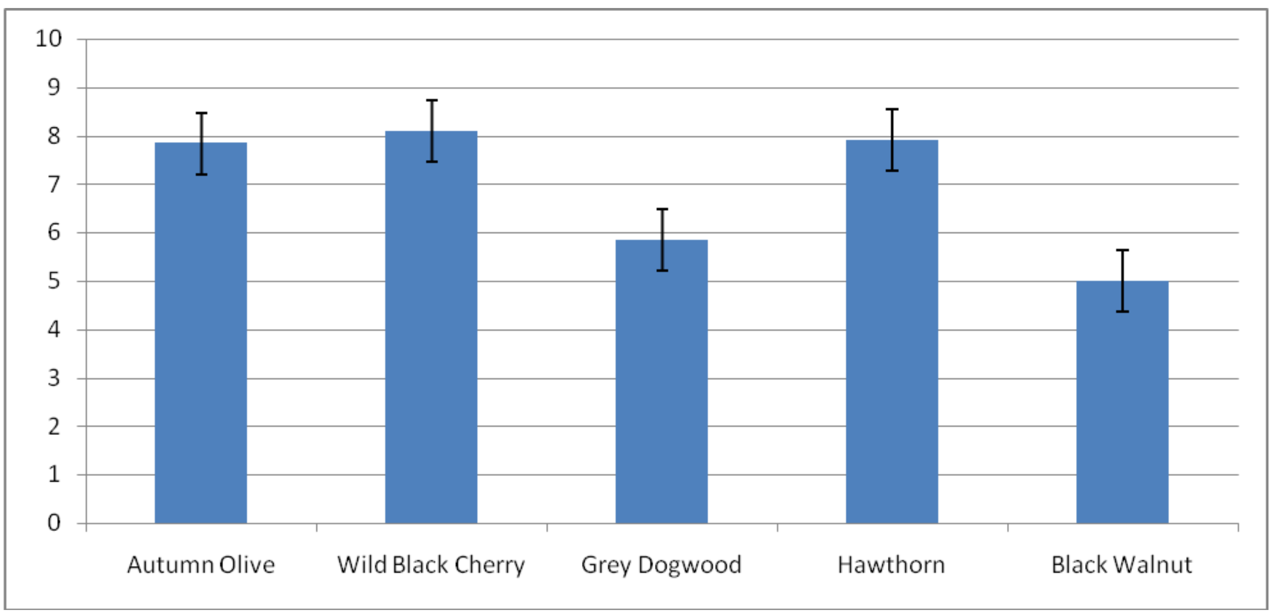

Figure 6: Average CO_2 uptake in the meadow for 2008. (p=0.0000)

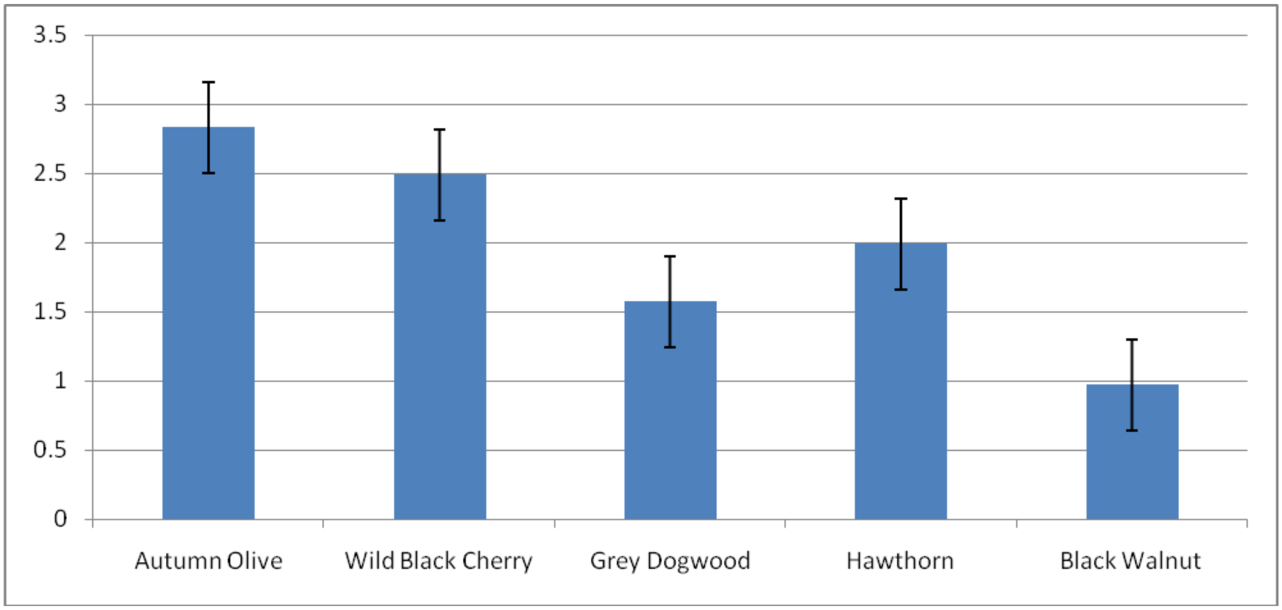

Figure 7: Average water use efficiency in the meadow. (p=.0000)

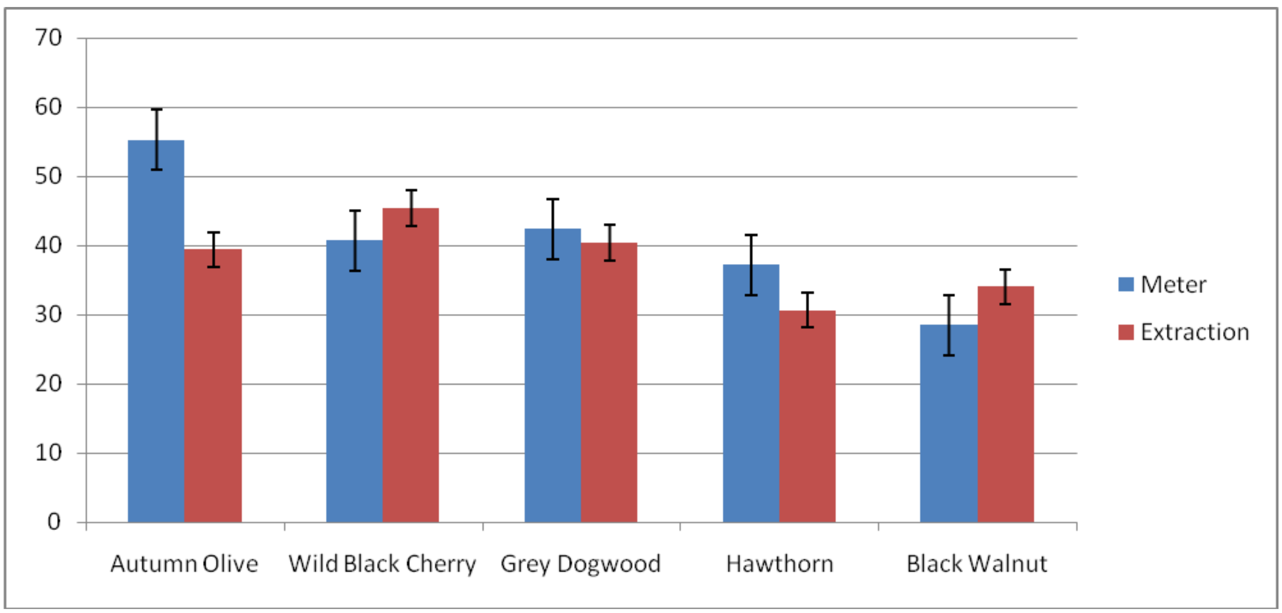

Figure 8: Average chlorophyll levels in the meadow found by using the chlorophyll meter and chlorophyll extraction. (p=0.0000 for chlorophyll meter, p=0.0024 for chlorophyll extraction.

SPECIES	MEAN	GROUP
Autumn Olive	.1915	AB
Black Cherry	.1813	B
Grey Dogwood	.1484	B
Hawthorn	0.2606	A
Black Walnut	0.1477	B

Figure 9: Average fluorescence for each species in the meadow. (p=.0331)