The Competitiveness of Autumn Olive (*Elaeagnus umbellata)* Associated with Nitrogen Fixation

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Abstract

Nonnative and invasive species are an increasing concern as native species are out-competed and relationships between species are altered. Autumn Olive, *Elaeagnus umbellata,* is a particularly invasive shrub that has invaded meadows, the forest understory, and was actively promoted to be used in mine spoils and roadsides through the 1980s. Pierce Cedar Creek Institute (PCCI) in Hastings, MI has been attempting to eliminate Autumn Olive from its property, which has proven difficult. In order to further the understanding of Autumn Olive and its effects on native populations our study focuses upon Autumn Olive's purported ability to fix atmospheric nitrogen. We counted and measured the root nodules, which likely convert atmospheric nitrogen to a form usable by the plant, and measured the leaf chlorophyll content of 1-2 year, 3-4 year, and 5-7 year Autumn Olive plants growing in five different soil types. We found that Autumn Olive plants with more, but not larger, nodules have higher leaf chlorophyll content. Older Autumn Olive plants growing in meadow soils produce more root nodules, leaves with higher chlorophyll content, and faster photosynthesis rates than Autumn Olive in forest soils. Previous studies have reported that Black Walnut trees with Autumn Olive planted within the drip line grew significantly taller and had higher leaf chlorophyll content than control Black Walnut trees over a nine year period. To further test the possible positive effect Autumn Olive may have on a variety of neighboring species, we planted an Autumn Olive seedling with a Gray Dogwood, Black Cherry, Black Walnut, or a Hawthorn seedling in gallon pots. After just six weeks, most native shrubs of comparable size exhibited significantly more leaves and

significantly higher leaf chlorophyll content when grown in the same pot as an Autumn Olive plant as opposed to another plant of the same species. These results suggest that Autumn Olive gains competitive advantage in photosynthesis rates as reported by previous researchers, possibly due to the additional fixed nitrogen, particularly in plants from well-drained soils, promoting higher chlorophyll content. Further, excess nitrogen from Autumn Olive plants is released, possibly by root death and decomposition, to the soil environment and is later absorbed and utilized by competing native plants incapable of fixing nitrogen. Even though native plants may gain some temporary aid from Autumn Olive, the faster growth of Autumn Olive likely enables it to out-compete the nearby native plants.

Introduction

Approximately 50,000 non-native species have been introduced into the United States, which have been estimated to cost nearly $120 billion per year in environmental damages and directly contributing to the pressures threatening approximately 42% of the species on Endangered Species Lists (Pimentel et al., 2004). Only a small portion of non-native species become invasive, but those that do can be devastating (U.S. Congress Office of Technology Assessment 1993; Mack et al. 2000). Invasive species are typically characterized as being outside of their historical range, spreading rapidly after becoming established and displacing native species (Alpert et al., 2000). Invasive plant species often have high growth rates relative to native plant species which seems to provide the competitive advantage of invasive species (eg., Knapp & Canhan, 2000). Nevertheless, the ways in which invasive species gain this advantage is not well understood (Orr et al., 2005).

Autumn Olive, *Elaeagnus umbellata*, is an invasive species from Asia that purportedly fixes atmospheric nitrogen through a mutualism with *Frankia sp.* Autumn Olive was actively promoted and planted throughout the 1970s and the 1980s to reduce soil erosion along roads, to re-foliate mine spoils, and as a nurse plant in Black Walnut plantations. Autumn Olive is now common throughout Michigan along roadways and in many other areas. At Pierce Cedar Creek Institute (PCCI) in Hastings, Michigan Autumn Olive is found in a variety of areas including unmaintained meadows and even in the forest understory. In 2007, a survey of Autumn Olive infestation of 76 acres north of Cloverdale Road demonstrated the high Autumn Olive density found in many portions of the property. When wetland plots were removed from consideration, over 52% of plots had at least some Autumn Olive (Travis and Wilterding, 2007). Based on anecdotal evidence, the percentage of the PCCI property affected by Autumn Olive has increased since this survey was completed. Additionally, based upon observation, Autumn Olive is also quite dense in many areas south of Cloverdale Road as well. Previous studies at PCCI have shown that Autumn Olive exhibits higher rates of photosynthesis as well as greater leaf chlorophyll content than comparable native species (Hesselink and Dornbos, 2008; Edwards and Dornbos, 2007). If Autumn Olive is a nitrogen fixer, as it is purported to be, it could explain these higher values and root nodules should be present.

Before a study could be carried out to make claims on the effects of Autumn Olive on the environment due to root nodules, it had to be confirmed that the root nodules were actually there. Some smaller plants were found to have root nodules so a larger more comprehensive survey was conducted. This larger survey served as a means to quantify the amount of root nodules based on the location of plant growth. Observations could then be made regarding the number and size of root nodules based on the age of the plant as well as the soil type the plants were growing in. If observations were made that there were more or larger root nodules, the logical projection is that there may be more nitrogen being fixed. On top of this survey, a study was performed in which small Autumn Olive plants (which, based on observations of other plants of similar size, were confirmed to have root nodules) were planted with native seedlings to see if there was a promotion of growth due to Autumn Olive providing nutrients to the other plants which are in close proximity to it.

Methods

1) Survey of Autumn Olive Plants for Root Nodules

To quantify the presence of root nodules on Autumn Olive plants, a survey was taken of Autumn Olive plants from around the property. When doing the survey, the plants were observed for the number of root nodules present as well as the size of the nodules. Five different soil types found at PCCI, Perrington, Tekenink, Marlette, Coloma and Oshtemo, were selected for the survey based upon the high frequency of Autumn Olive found in each location. From each location, young plants between one and two years old, medium plants between three and four years old and older plants between the ages of five and seven were selected. Age was determined by counting terminal bud scars.

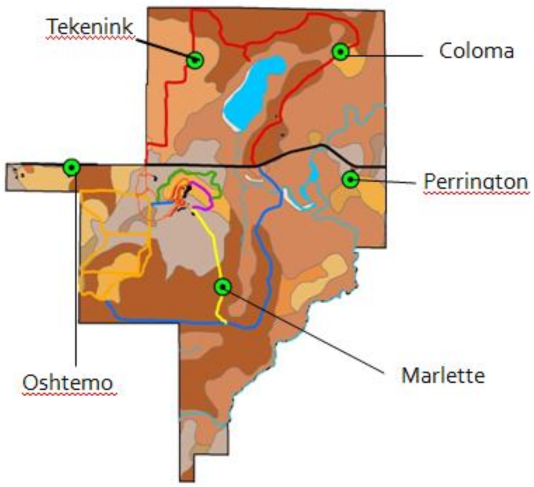


Image 1: Locations of Autumn Olive root nodule sites.

The root systems were dug up as carefully as possible at a half meter radius. This allowed for the root systems to remain intact. Once the root systems were dug up, the soil was carefully removed from the root system by hand to expose the root nodules. The soil was more difficult to remove from some root systems, and so water was run over the root systems to remove the soil and preserve the root nodules. Once the soil was completely removed from the root system, the root nodules were counted. The three largest root nodules were identified and the length, width, and height were measured in centimeters to the nearest millimeter. Length was defined as the longest measurement, height was the measurement from the base of the nodule to the top of the nodule, and the width was defined as the measurement perpendicular to the measurement of length within the same plane.

2) Potted Plant Cohort Study

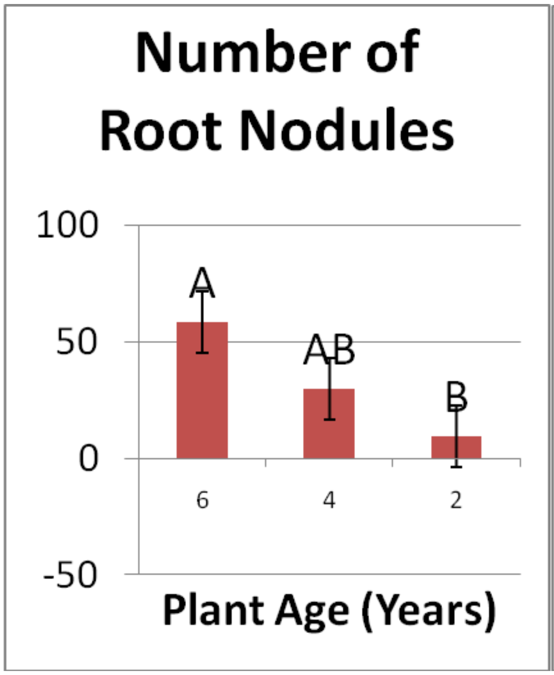
In order to elaborate on previous studies done with Autumn Olive as well as build up more evidence for the fixation of nitrogen by Autumn Olive, a potting cohort study was done. These were planted together in pots and the growth and changes in the plants were recorded. A total of ninety saplings of four native tree and shrub species (Hawthorne, Gray Dogwood, Black Cherry, and Black Walnut) and one invasive species (Autumn Olive) were collected from the property of Pierce Cedar Creek Institute (PCCI) during the last two weeks of June 2010. The saplings obtained were greater than 20 centimeters and less than 40 centimeters tall. Thirty two-three year old plants each of Hawthorn were collected from the woods by the yellow trail. Grey Dogwood seedlings were collected from the edge of the prairie on the orange trail. Black Cherry seedlings were collected from the prairie next to the beginning of the loop trail. Black Walnut seedlings were collected from both the prairie next to the beginning of the loop trail and behind the wet lab. Ten Autumn Olive seedlings were collected from each of the areas in which the native species seedlings were found and the remaining twenty Autumn Olive plants were obtained along the red trail in a wooded area. A control was set up for each of the four native species and also for Autumn Olive, with ten replicates for each species in one gallon pots each containing two of the same species. The experimental pots contained one Autumn Olive seedling and one native plant seedling with ten replicates of each combination. These plants were put under shade tents for the first week and a half to prevent damage from the sun during the recovery period, and were watered and monitored daily. Plants that died during the recovery period were replaced.

The pots were arranged in a randomized complete block design with replicates forming a north-south oriented gradient and laid out in a ten pot by nine pot grid. The pots were watered and monitored daily. Each week, height, number of new leaves, and chlorophyll content were measured for each plant. Height was measured using a meter stick and measuring to the nearest millimeter. Chlorophyll content was measured using the Minolta SPAD 502 Chlorophyll Meter. For each plant, chlorophyll content of three different leaves was measured and averaged. During the first week of measurements all of the leaves of each plant were counted and a string was tied to the third leaf down from the top-most leaf. The numbers of new leaves above the string were counted each week.

Results

Root nodule number increased with Autumn Olive plant age (Figure 1a). The 6 year and older plants had the largest number of nodules, the 2-4 year old plants had the second highest amount and the 1-2 year old plants had the least amount. The 6 year and older plants had an average of 58.3 nodules per plant. The 2-4 year old plants had an average of 29.9 nodules per plant. The 1-2 year old plants had an average of 9.4 nodules per plant. 6 year and older Autumn Olive plants had significantly more root nodules than both the 2-4 year plants and the 1-2 year old plants and the .05 level with a p-value of .0158.

Similarly, the size of the root nodules increased with plant age (Figure 1b). The plants were estimated to be 1-2 years old, 2-4 years old and 6 years old or older. The 6 year and older plants had the largest height, the 2-4 year old plants had the second largest height and the 1-2 year old plants had the smallest. The 6 year and older plants had an average height of 221 m. The 2-4 year old plants had an average height of 94.6 m. The 1-2 year old plants had an average height of 39.4 m. The oldest plants had significantly larger root nodules than the other two age groups at the .01 level with a p-value of $<.001$.



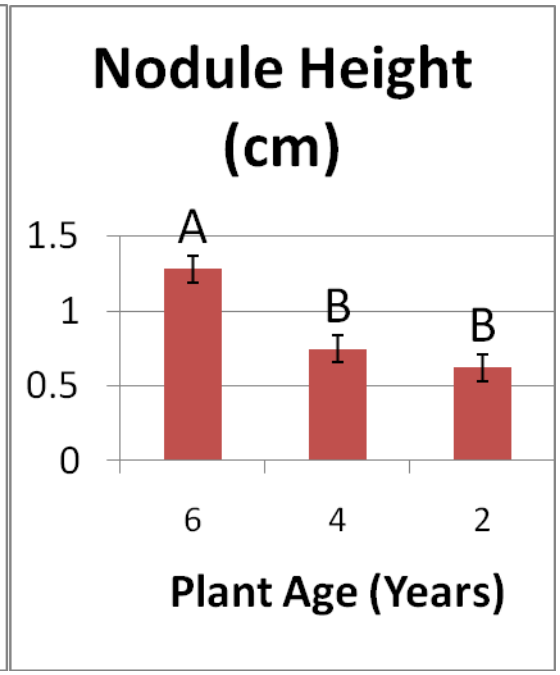


Figure 1a. The relationship between the age of Autumn Olive and the number of Root Nodules.

Figure 1b. The relationship between the age of Autumn Olive and the nodule size.

The oldest Autumn Olive plants have the highest chlorophyll content. Figure 2 shows the chlorophyll content of the leaves of Autumn Olive in relationship to the age of the plants. The Autumn Olive plants 6 years and older had the highest chlorophyll content. The 2-4 year old plant had the next highest chlorophyll content. The youngest plants had the lowest chlorophyll content. The plants ages 6 years and above had an average chlorophyll content of 58.43. The plants ages 2-4 years old had an average chlorophyll content of 48.00. The plants ages 1-2 years old had an average chlorophyll content of 47.33. The oldest plants had significantly higher chlorophyll levels than the other two age groups at the .05 level with a p-value of .0211.

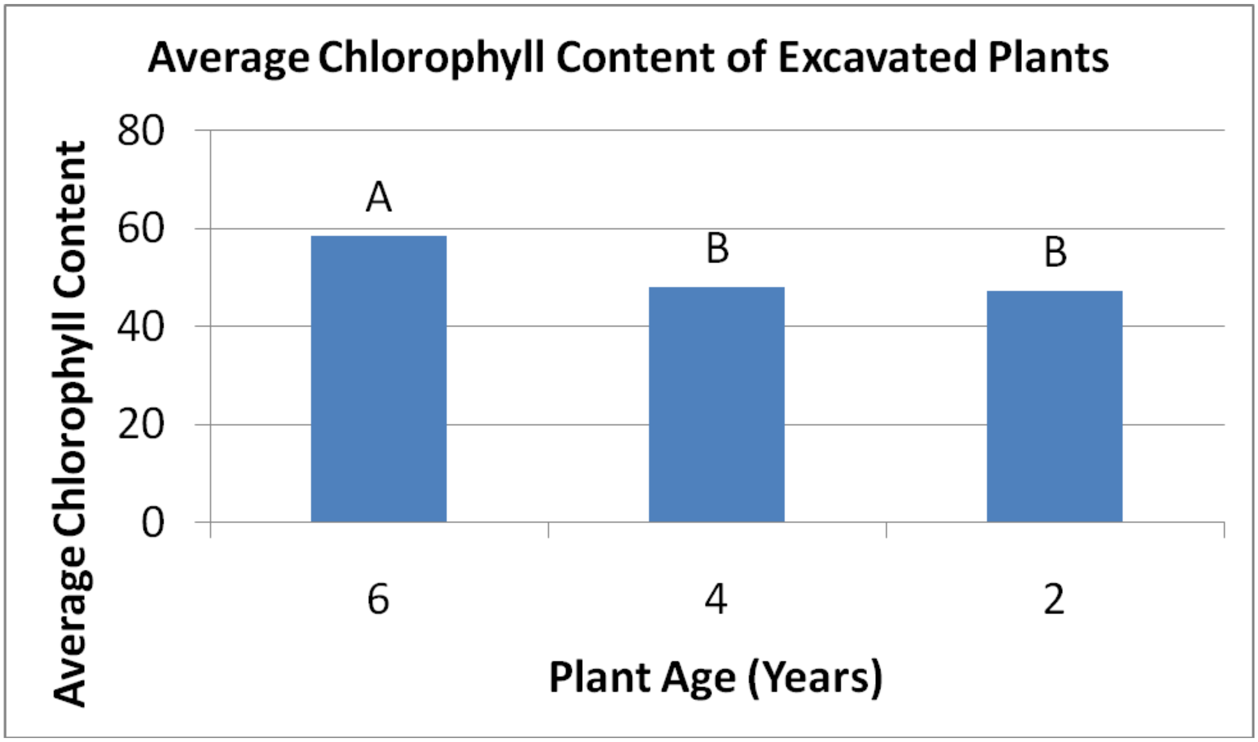
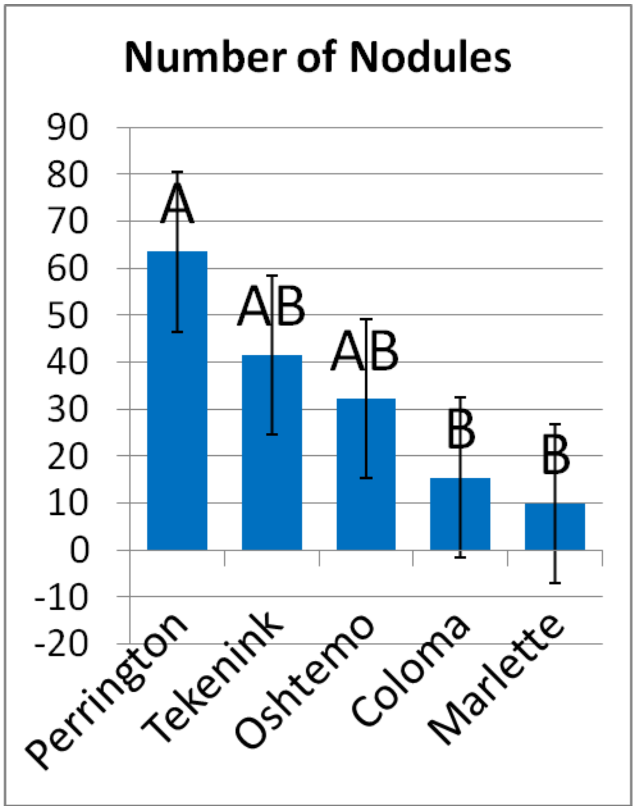


Figure 2. The relationship between the age of the plant and the average chlorophyll content.

Figure 3a shows the relationship between the number of root nodules and the type of soil that the plants were growing in. The plants growing in the Perrington soil had the highest amount of root nodules with an average of 64 nodules per plant, the plants growing in the Tekenink soil had the second highest with 42 nodules per plant, the plants growing in the Oshtemo soil had the third highest with an average of 32 nodules per plant, the plants growing in the Coloma soil had the fourth highest with 15 nodules per plant, and the plants growing in the Marlette soil had the least with an average of 10 nodules per plant. The number of root nodules found in the Perrington soil are in a completely different statistical group than the Marlette or Coloma soils.



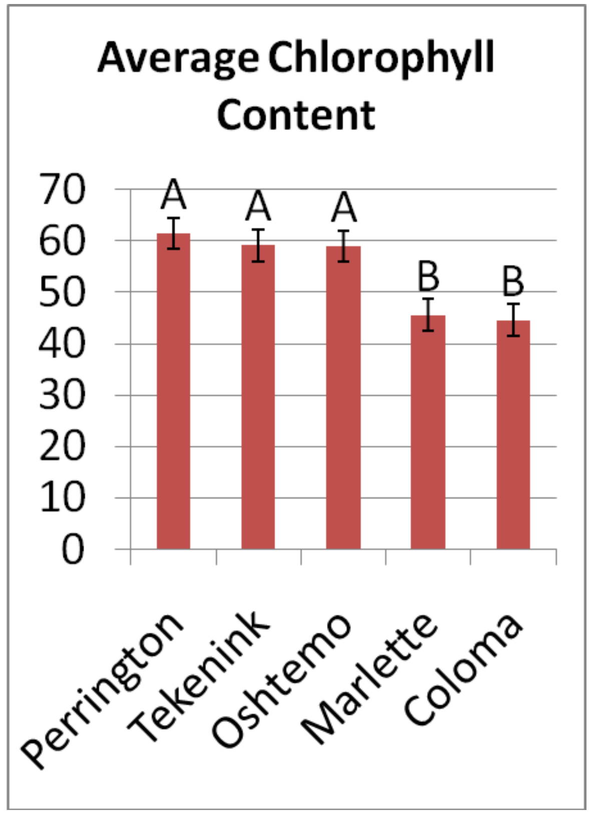


Figure 3a. The relationship between soil type and the average number of root nodules for all ages of Autumn Olive plants in the area.

3b. The relationship between soil type and the average chlorophyll content of all ages of Autumn Olive plants in the area.

Figure 4a shows the chlorophyll content of Hawthorne, Gray Dogwood, Black Cherry, and Black Walnut growing in pots by themselves and with Autumn Olive. The Autumn Olive, both by itself and with other plants, had the highest chlorophyll content of 44.03, confirming the previous research stating that Autumn Olive has the highest chlorophyll data. The Autumn Olive was grouped together as a whole because it should all provide the same data output because they were all similar in age. Grouping them separately would only complicate calculations. The next highest is Black Walnut by itself at 36.981, then Gray Dogwood with Autumn Olive at 36.7, then Black Walnut with Autumn Olive at 35.4, then Hawthorne with Autumn Olive at 29.97, then Black Cherry with Autumn Olive at 28.891. The native species growing with Autumn Olive (except for Black Walnut) are in different statistical groupings than their counterparts growing with only another native tree sapling.

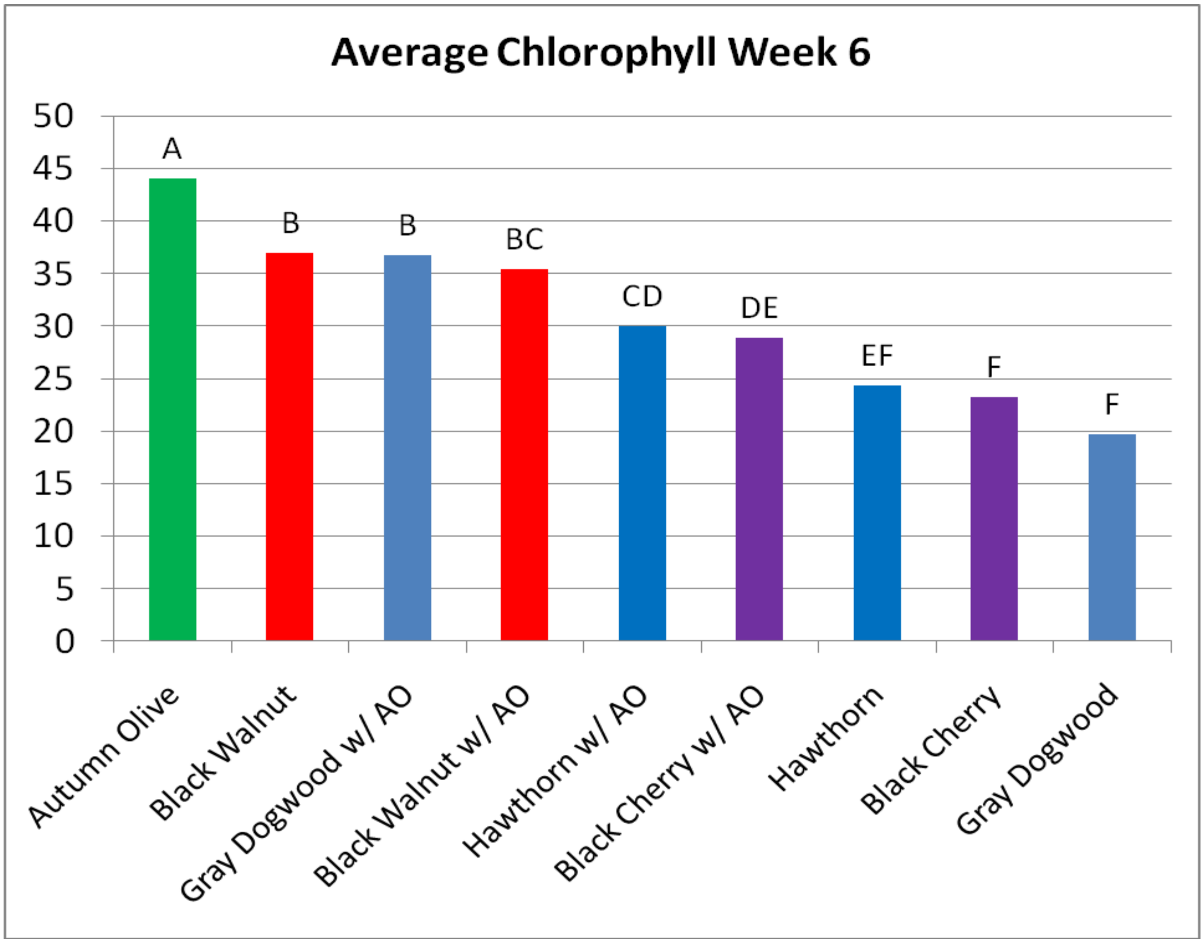


Figure 4a. The relationship in chlorophyll content between AO and native trees growing in pots.

Discussion

1) Root Nodules and Age

The data collected supports the hypothesis that older Autumn Olive plants have higher numbers and larger sizes of root nodules. In all five locations where Autumn Olive was collected, the older plants had more root nodules. The different locations had varying amounts of root nodules but all of them followed the same pattern with the oldest plants having the highest number and largest root nodules shown by figures 1a and 1b.

The fact that both the number and size of root nodules increases with age may suggest that Autumn Olive is fixing more nitrogen as it gets older, supporting a larger plant and possibly putting more nitrogen into the soil. Increased chlorophyll content in the older plants supports previously reported data that Autumn Olive plants exhibit very high photosynthesis rates, but not higher water use efficiency. By producing more chlorophyll, and likely more photosynthetic enzymes involved in the photosynthetic process, Autumn Olive likely gains this competitive advantage by capturing and utilizing light more efficiently than its neighboring plants. In order to produce more chlorophyll, the plant needs to attain nutrients (in the form of nitrogen in this case) from somewhere.

The data that was collected suggests that the Autumn Olive shrubs are fixing more nitrogen through producing more and larger root nodules, thereby giving in more usable nitrogen in the soil. Nitrogen being a key component in the synthesis of many functional molecular groups, the plants can produce more chlorophyll. This allows it to compete better and grow faster by producing more nutrients for itself. This is a major problem because when this happens, Autumn Olive can out-compete the native plants and displace or eliminate them from the area. This could also possibly lead to detrimental effects in the natural ecosystems if the shrub is allowed to continue growth without being stopped because it can leak excess nitrogen into the ecosystem and possibly have detrimental effects. Invasive plant infestation has been shown to be a key factor driving higher extinction rates and by altering ecosystem services.

2) Root Nodules and location

The hypothesis that Autumn Olive contains different numbers of root nodules based on location is also supported. Autumn Olive is competitive in all environments in which it is found, but more so in some than others. The original hypothesis was that Autumn Olive would produce different numbers of root nodules based on soil type. Figure 3a shows the average number of root nodules of plants that were found in different soil types. The soil type Perrington was found to have the most root nodules and was overlapping with the soil types Tekenink and Oshtemo in statistical groupings. The soil types Coloma and Marlette were in completely different statistical groupings than Perrington. Along with that, Figure 3b shows that the soil types of Perrington, Tekenink and Oshtemo have significantly higher chlorophyll contents than Coloma and Marlette.

Plant communities vary with soil type. The plants found in soil types of Perrington, Tekenink and Oshtemo were all found in open environments that had lots of light available to them. The plants that were found in the soil types Coloma and Marlette were in shaded areas that were either in the forest or on the edge of a forest. This is crucial in understanding that Autumn Olive is especially competitive in an open field environment.

It should be noted that Autumn Olive still outcompetes most plant species in the forest understory as well, even though the chlorophyll content of Autumn Olive in the forest was lower than that in the meadow. While nodule numbers are not as high in forest understory soils, possibly because these plants had much lower light levels available for photosynthesis, they exhibited a greater competitive advantage relative to their native plant co-inhabitants. Chlorophyll content of Autumn Olive plants was significantly higher than the native plants, likely contributing to the two- to three-fold advantage in photosynthesis rate it enjoys.

3) Potting Study

The potting study was set up to see if there were any effects on native plant species by Autumn Olive. The final data collected was after allowing the plants to grow for six weeks together in pots. This time should have allowed the roots of the plants to grow together and have the Autumn Olive's root nodules growing in close proximity to the root systems of the other plants. After only six weeks the native plants exhibited both higher leaf chlorophyll content and greater leaf numbers when growing with Autumn Olive. This suggests that the native plants may be gaining nitrogen nutrition from Autumn Olive through nitrogen fixing root nodules. Even so, in light of previous observations and infestations by Autumn Olive, the rapidity of Autumn Olive growth in comparison to the native plants will likely overshadow the temporary benefit provided by greater nitrogen availability.

Further research is being planned for the future. One more year of root nodule data would confirm the findings of this study. By collecting two years of data that report the same thing, factors such as weather can be overlooked more easily. Furthermore, the potting study was moved to Calvin College at the end of the summer. As with the root nodule survey, another year of data collection will be done next year using the same pots. This second set of data collection will also strengthen the data already collected.

References

Alpert, P., Bone, E., & Holzapfel, C. (2000). Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology*, *3*(1), 52-66.

Edwards, K., & Dornbos, D. (2007). Characterization of the competitiveness of autumn olive in a mature forest. In *Pierce Cedar Creek Institute*. Retrieved August 20, 2010, http://www.cedarcreekinstitute.org/media/downloads/pdf/research_findings/calvin-edwards-dornbos.pdf.

Hesselink, R., & Dornbos, D. (2008). Characterization of the physiological competitiveness of autumn olive in meadow and forest environments. In*Pierce Cedar Creek Institute*. Retrieved August 20, 2010, http://www.cedarcreekinstitute.org/media/downloads/pdf/research_findings/Hesselink-Dornbos-Autumn-Olive.pdf.

Knapp, L. B., & Canham, C. D. (2000). Invasion of an old-growth forest in New York by *Ailanthus altissima*: Sapling Growth and Recruitment in Canopy Gaps. *Journal of the Torrey Botanical Society*, *127*(4), 307-315.

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz F. 2000. Biotic invasions: causes, epidemiology, global consequences and control. Issues in Ecology 5:1-20.

Orr, S. P., Rudgers, J. A., & Clay, K. (2005). Invasive Plants can Inhibit Native Tree Seedlings: Testing Potential Allelopathic Mechanisms. *Plant Ecology*, *181*(2), 153-165. doi:10.1007/s11258-005-5698-6.

Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, *52*, 273-288.

Travis, J., & Wilterding, J. (2005). *Assessment of Autumn Olive (Elaeagnus umbellata) Population at Pierce Cedar Creek*.

US Congress Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. Washington: US Government Printing Office Report nr OTA-F-565.