NITROGEN FERTILIZER EFFECTS ON BLACK CHERRY (PRUNUS SEROTINA EHRH) REGENERATION IN ALLEGHENY HARDWOOD FORESTS

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NITROGEN FERTILIZER EFFECTS ON BLACK CHERRY (*PRUNUS SEROTINA* EHRH)

REGENERATION IN ALLEGHENY HARDWOOD FORESTS

by

Nicolette A. Fruehan

A thesis
submitted in partial fulfillment
of the requirements for the
Master of Science Degree
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Abstract


Declining nitrogen inputs in the soil profile from the Clean Air Act Amendment (CAAA) may be responsible for the decrease in black cherry (Prunus serotina Ehrh) vigor in Allegheny Hardwood Forests. A low rate of 3.39N kg/ha fertilizer was applied to five treatment plots to replicate the amount of nitrogen missing in the soil profile and a high rate of N and P-fertilizer was applied to three additional plots. The treated plots were compared to control plots and pre-treatment plots in 2015 and 2016. For both fertilizer rates, new red maple seedlings significantly increased in control and fertilized plots in 2016. In the high N-fertilized sites, black cherry seedlings (0.3 to 0.9m) significantly increased and new birch seedlings significantly decreased. Sites with black cherry advanced regeneration can keep black cherry in the mix by adding relatively higher levels of fertilizer which reduces birch seedling establishment and favors other species.

KEYWORDS: Allegheny Plateau, Allegheny National Forest, nitrogen deposition, nitrogen fertilizer
Chapter 1. Literature Review

Background of Study Area: Allegheny Plateau

Geology and Climate of Allegheny Plateau

The geology and soils development of the Allegheny Plateau region are critical to understanding the ecology of black cherry (*Prunus serotina* Ehrh) dominated Allegheny hardwood forests. Black cherry is uniquely positioned for success on the plateau. Allegheny hardwood forests are primarily located in the High Plateau region of the Allegheny Plateau Province of New York, Pennsylvania, Maryland, and extending to West Virginia (Cronce and Ciolkosz, 1983; Marquis, 1983). The west and east borders of the High Plateau were glaciated by Late Wisconsin and pre-Wisconsin glaciers (Cronce and Ciolkosz, 1983). However, between these glacial borders bounded by the Allegheny River to the north, lies the unglaciated plateau region including the Allegheny National Forest (ANF) which lies about 20 to 35 kilometers south of the terminal moraine of the Wisconsin glacial advances (Bailey *et al*., 2005; Whitney, 1990). The Wisconsin Laurentide sheet was deflected by the relatively high altitude of the plateau (Hough and Forbes, 1943). Elevations of 610 to 762 meters (2000 to 2500 feet) above sea level resulted from a warping or upward doming (Hough and Forbes, 1943). Valleys are V-shaped, narrow, and winding with a relief of 122 to 244 meters (400 to 800 feet) or more and the floors are narrow and usually steep and rocky (Whitney, 1990; Hough and Forbes, 1943).

The Allegheny Plateau has a cool and humid temperate climate with an average annual daily temperature of 9.1 degrees Celsius (48.3 degrees Fahrenheit) (Whitney, 1990; Cronce and Ciolkosz, 1983; Hough and Forbes 1943). The region has a relatively cooler average summer temperature of 18.9 degrees Celsius with the growing season lasting about 100 to 130 days (Whitney, 1990). An average of 107 centimeters (42 inches) of precipitation is received annually.
(Whitney, 1990; Cronce and Ciolkosz, 1983; Hough and Forbes 1943). Elevation, slope, and aspect can influence the varying environmental conditions within the Allegheny National Forest (Cronce and Ciolkosz, 1983).

**Soils of the Allegheny Plateau**

The soils of the Allegheny Plateau are broadly categorized in the soil order of Ultisols with patches of Alfisols throughout (USDA NRCS Ultisols distribution map). Soils within the Ultisol soil order are characterized as having a clayey argillic or kandic horizons with low base saturation due to its process of formation by mineral weathering which translocates clays to accumulate in the argillic or kandic horizon and leaches base cations from the profile (Brady and Weil, 2008; Soil Survey Staff, 1999). There is typically more precipitation than evapotranspiration within these regions (Soil Survey Staff, 1999).

The soil order Ultisol is further classified into sub-orders. The soils within the Allegheny Plateau region are of the soil suborder Udults. Udults are humus-poor Ultisols that have an udic moisture regime and are more or less freely drained (Soil Survey Staff, 1999). They are typically found in humid regions with well distributed rainfall. The physical characteristics of Udults include light colored upper horizons commonly a grayish horizon above a yellowish brown to reddish argillic or kandic horizon. The Udults that have developed from basic rocks have a dark red or dusky red argillic or kandic horizon. Some contain a fragipan or plinthite or both below the argillic or kandic horizon (Soil Survey Staff, 1999).

More specifically, the soils of the Allegheny region can be classified based on how they were formed by the five forming factors: parent material, climate, topography, organisms, and time. The topography and climate are generally uniform throughout the Allegheny High Plateau. The parent materials of ANF soils are mostly from weathered bedrock or colluvial deposits and
have a major role in the soil’s physical and chemical properties. The rock types include coarse conglomerates, sandstones, shales, siltstones, limestones, and occasional coal seams (Cronce and Ciolkosz, 1983). The characteristics of soil from weathered bedrock material include high subsoil variability among soil series within short distances. This is due to the variability in depth to and degree of fracturing of the bedrock, which is highly fractured and physically weathered to depths below 150 to 180 centimeters. The bedrock is often highly contorted, faulted, or turned over on itself in the upper C or R horizons. In present day soils, the lower zones of horizons B, C, and R are derived from this physically disturbed bedrock (Cronce and Ciolkosz, 1983).

The characteristics of soils developed in colluvium in the ANF differ from those developed by weathered bedrock. The gravity transported material can be found on smooth long slopes of less than five percent. They are often stratified deposits of contrasting material indicating that these deposits are periglacial solifluxion or mud flow deposits (Cronce and Ciolkosz, 1983). The presence or absence of mottling or redoximorphic features indicates variable soil drainage classes which range from poorly drained (shallow depth to fragipan) to moderately well drained (Cronce and Ciolkosz, 1983). The soils generally have a depth to the fragipan 40 to 90 centimeters (Bailey et al., 2005).

The soil profiles within the ANF are variable depending on their parent material. The soils appear to be of similar (Wisconsin) age. Frost action and erosion generated colluvium that was remixed and homogenized removing upper parts of the soil profiles. Although the subsoils are highly variable, the upper horizons are relatively uniform in characteristics (Cronce and Ciolkosz, 1983).

Organisms also influence soil formation. Most soils within the ANF have developed under similar vegetation which could highly influence the uniform characteristics of the upper
horizons of these soils (Cronce and Ciolkosz, 1983). Upper horizons are typically comprised 51 to 76 centimeters of yellowish brown loam containing more than 50 percent silt and less than 10 percent coarse fragments (Cronce and Ciolkosz, 1983). The organic horizon, typically less than 10 centimeters thick, combined with the A horizon contain a large proportion of the base cations and plant available nitrogen (Cronce and Ciolkosz, 1983). Iron and organic matter accumulate in the E, Bhs, and Bs horizons (Cronce and Ciolkosz, 1983).

Among the many soil series within the ANF, the two most common are Cookport and Hazleton. Cookport soils are derived primarily from sandstone, but can include some materials from siltstone (USDA NRCS, 2003; Cronce and Ciolkosz, 1983). Hazleton soils are derived from acid sandstone (UDSA NRCS, 2002; Cronce and Ciolkosz, 1983). These two soil series, along with most others in the region, are associated with high exchangeable aluminum contributing to a lower pH and acidic character (Cronce and Ciolkosz, 1983). The parent material has a great influence on the acidity of the soils. As previously mentioned the underlying bedrock of Allegheny and Pottsville groups are of acidic rock types. This may be different compared to acidic soils found elsewhere where acidity can be caused by intense soil leaching (Cronce and Ciolkosz, 1983).

Another soil parent material characteristic within the Allegheny Plateau region is that kaolinite is the dominant clay mineral (Marquis, 1990). Kaolinite is 1:1 silicate clay; meaning each kaolinite layer contains one silicon tetrahedral sheet and one aluminum octahedral sheet (Brady and Weil, 2008). Because of this structure, removal or addition of hydrogen ions can produce positive or negative charges, depending on soil pH (Brady and Weil, 2008). Kaolinite can also react with and strongly bond to specific anions such as sulfate (SO₄) and nitrate (NO₃) (Brady and Weil, 2008). Adjacent layers are held tightly together by hydrogen bonding creating
a fixed structure with no expansion when kaolinite is wetted (Brady and Weil, 2008). The structure lacks significant isomorphous substitution resulting in relatively low cation exchange capacity (Brady and Weil, 2008; Bailey et al., 2005; Marquis, 1990). Also, due to its low cation exchange capacity, kaolinite clays exchange cations more readily and at a lower percentage of base saturation compared to non 1:1 silicate clays (Brady and Weil, 2008; Marquis, 1990).

Although Allegheny Plateau soils are acidic due to soil formation factors, acid deposition has also contributed to their acidity (Driscoll et al., 2001; Cole and Gessel, 1992). Nitrogen deposition changes soil solution ion composition in highly weathered unglaciated soils by increasing the concentration of protons (H+) and strong acid anions (Bailey et al., 2005; Driscoll, et al., 2001). The acidic soils and favorable moisture conditions of the Allegheny Plateau are contributing factors to the historically successful establishment and growth of black cherry within the regions (Bailey et al., 2005; Drohan and Sharpe, 1996; Thomas et al., 2009). Research indicates that black cherry grows and survives better under acidic conditions compared with more alkaline soils (Long et al., 2011; Long et al., 2009; Thomas et al., 2009).

**History of Black Cherry and Nitrogen Deposition on the Allegheny Plateau**

In the Allegheny High Plateau of northwestern Pennsylvania, black cherry is a prominent and important commercial timber species that defines the Allegheny hardwood forest type (Marquis, 1975a; Husch, 1954). Black cherry is a fast-growing, early-successional species and in addition to timber, provides soft mast, nesting material, and den sites for wildlife (Marquis, 1990). Although black cherry has been a naturally regenerating species since pre-settlement times, it has not always had the same relative abundance (Whitney, 1990; Marquis, 1975a; Hough and Forbes, 1943).
Within the Allegheny Plateau, in pre-settlement times, black cherry abundance was between 0.8 to 3.2 percent of the stems (Whitney, 1990; Marquis, 1975a). The most abundant species were American beech (*Fagus grandifolia* Ehrh.), eastern hemlock (*Tsuga canadensis* L. Carrière), and sugar maple (*Acer saccharum* Marsh.) before settlers and disturbance changed the composition (Whitney, 1990; Marquis, 1975a). By 1860, industrial development accelerated forest cutting (Marquis, 1975a). The majority of the cutting was selective for partial cutting of white pine (*Pinus strobus* L.) stands due to their high value and lightweight characteristics which facilitated transportation down the Allegheny River (Whitney, 1990; Marquis, 1975a). The development of railroads and other equipment after 1880 enhanced the logging industry by creating new opportunities to log in even the most rugged of areas, not just near streams or rivers (Marquis, 1975a). By that time, nearly every species was merchantable and eastern hemlock was highly desired for its high tannin content supporting the tanning industry (Whitney, 1990). Between 1890 and 1920, the virgin and partially cut forests were almost completely clearcut (Marquis, 1975a).

Black cherry spread throughout the forest, reproducing consistently during a period of heavy cutting from 1890 to 1920 (Whitney, 1990). As a result of how the forest was cut along with very low deer browsing pressure, black cherry became abundant in second growth stands (Whitney, 1990; Hough and Forbes, 1943). The dominant forest type of hemlock – northern hardwood in the pre-settlement period was replaced by regenerating cherry and maple (Whitney, 1990). The cherry - maple forest is known as an Allegheny hardwood forest with 25% black cherry basal area and it dominates the region (Whitney, 1990; Marquis, 1975a). The proportion of the Allegheny hardwood forest type within the Allegheny National Forest was about 53% in 1986 (Whitney, 1990).
Management practices that favor black cherry regeneration have been recommended in the region since the early 1950s (Whitney, 1990; Husch, 1954; Hough 1953). Before the 1950s, the failure of regeneration to thrive kept black cherry from being well-represented in third-growth stands (Husch, 1954; Hough, 1953). The earliest method suggested for black cherry regeneration was clearcutting of narrow strips (Husch, 1954; Hough, 1953). Later, Marquis (1979) suggested a shelterwood seed cut. The purpose of the shelterwood seed cut is to leave well-distributed seed trees, removing most of the basal area from the small size classes leaving 60% residual relative density (Marquis et al., 1992; Marquis, 1979). More recent guidelines have been created for Allegheny hardwood regeneration that prescribe silvicultural treatment based on stand characteristics, deer browsing pressure, and amounts of interfering vegetation (Marquis et al., 1992). Regeneration methods have been suggested based on the silvics and ecology of black cherry.

Black cherry seed was historically widely distributed with good seed crops every 1-5 years and some seed produced almost every year (Bjorkbom, 1979; Grisez, 1975; Husch, 1954). In the forest floor, the seeds remain viable for 3-5 years making propagule supply sufficient for successful regeneration at any time (Marquis 1975b; Hough and Forbes, 1943). The mortality rate of seedlings was relatively high except in openings, but seed germination occurred throughout the forest every year (Hough and Forbes, 1943). Seedlings could persist in moderately shaded areas, but grow relatively slowly so the species is considered shade intolerant (Hough and Forbes, 1943; Marquis, 1990).

Throughout North America, black cherry grows on a variety of soil types. Black cherry can tolerate a wide range of soil drainages; however rapid loss in productivity occurs with increasingly wetter conditions (Marquis, 1990). Black cherry is more prominent in strongly
acidic soils and studies have shown that long-term liming negatively affect black cherry growth and survival (Long et al., 2011; Marquis, 1990). However, black cherry fertilization studies have shown increases in growth as well as flower and seed production following nitrogen application in northwestern Pennsylvania (Horsley, 1988; Auchmoody 1982; Bjorkbom, 1979).

Black cherry has a high nitrogen requirement for growth and relies on nitrate – nitrogen for seed germination (Auchmoody, 1982; Auchmoody, 1979). Nitrate - nitrogen within forest soils becomes more available with the application of fertilizers and nitrogen deposition (Driscoll et al., 2001). Black cherry grew more rapidly under high nitrogen deposition likely due to the increased availability of inorganic nitrogen (Thomas et al., 2009). Nitrogen deposition has impacted forest soils within the northeastern United States and the Allegheny Plateau for decades (Bailey et al., 2005; Driscoll et al., 2001).

**History of Nitrogen Deposition**

Early records from the Hubbard Brook Experimental Forest (HBEF) in New Hampshire indicate that nitrogen deposition or acid deposition started around 1950 to 1955 in the northeastern United States (Driscoll et al., 2001; Likens et al., 1996). The National Atmospheric Deposition Program records from the Kane Experimental Forest located on the ANF documented acid deposition at high levels starting from its first complete year of data in 1979 (National Atmospheric Deposition Program, 2016a). A thirty-year study of the forest soils of the Allegheny Plateau showed that from 1967 to 1997 there was a long-term decrease in pH, exchangeable calcium (Ca) and magnesium (Mg), and an increase in exchangeable aluminum (Al) consistent with an acid deposition hypothesis altering the entire soil profile in these unglaciated soils (Bailey et al., 2005).
Acidic deposition increases the concentrations of hydrogen cation (H\(^+\)) and strong acid anions sulfate and nitrate within forest soils (Driscoll *et al.*, 2001). Forest soils are affected by the deposition of sulfate and nitrate through their activity as mobile anions and essential plant nutrients (Driscoll *et al.*, 2001; Ollinger *et al.*, 1993). Nitrates and sulfates mobilize cations that displace and decrease exchangeable cations such as calcium and magnesium from the forest soils (Driscoll *et al.*, 2001). The leaching of essential elements makes them unavailable for plant use (Driscoll *et al.*, 2001). Sugar maple has been reported to be negatively affected by decreased levels of calcium and magnesium within the Allegheny Plateau region (Long *et al.*, 2009; Bailey *et al.*, 2004; Horsley *et al.*, 2000). Black cherry has shown a positive response to nitrogen deposition most likely due to the increased availability following nitrification (Thomas *et al.*, 2009).

With long-term nitrogen deposition, a condition known as nitrogen saturation may begin to occur as high levels of nitrogen accumulated (Adams, 1999; Aber *et al.*, 1989). Inputs of inorganic nitrogen to the forest ecosystem exceed biotic demand, which leads to a series of changes that reduce ecosystem capacity to retain nitrogen (Peterjohn *et al.*, 1996; Aber *et al.*, 1989). The system is unable to retain the added nitrogen leading to acidification, aluminum mobility, leaching of nitrate, calcium, and magnesium (Adams *et al.*, 2000; Adams, 1999; Aber *et al.*, 1989). Nitrogen saturation leads to rapid nitrogen cycling and an increase in nitrate loss via leaching as mobile nitrate anions move through the soil solution and through ground water (Aber, 1992; Aber *et al.*, 1989). Nitrogen saturation also further increases aluminum mobility accelerating leaching of base cations as they are removed from the soil colloid exchange sites (Adams *et al.*, 2000). Loss of base cations negatively affects tree growth of some species and forest ecosystems.
Other consequences of nitrogen saturation include decreases in foliar lignin concentration, increases in foliar nitrogen concentration, and decrease in soil carbon/nitrogen ratios (Aber, 1992). In a review of nitrogen saturation within the United States, seven symptoms were identified: 1) high relative rates of net nitrification, 2) long-term increases in stream-water concentrations of nitrate and base cations, 3) relatively high nitrate concentrations in soil solution, 4) little seasonal variability in stream-water nitrate concentrations, 5) a high discharge of nitrate from a young aggrading forest, 6) a rapid increase in nitrate loss following fertilization of a young aggrading forest, and 7) low retention of inorganic nitrogen when compared with other forested sites (Peterjohn et al., 1996). Susceptibility to frost damage or disruptions of physiological function, increased emissions of nitrous gases such as nitrous oxide, changing rates of litter decomposition, and reduced soil fertility have also been reported with nitrogen saturation (Adams et al., 2000; Adams, 1999). However, in the northeastern United States in hardwood forests nitrogen deposition alone is a poor predictor of the onset of nitrogen saturation (Lovett et al., 2000).

Due to the lasting effects of acid deposition on ecosystems, legislative action took place in the form of the Clean Air Act (CAA) of 1970 (Driscoll et al., 2001; Likens et al., 1996). The passage of the CAA reduced emissions of sulfate resulting in slightly less acidic precipitation and a reduction of sulfates in surface waters in northeastern United States (Driscoll et al., 2001; Likens et al., 1996). The Clean Air Act Amendment (CAAA) in 1990 and the Clean Air Interstate Rule (CAIR) in 2005, further reduced emissions of sulfate and controlled nitric oxides (NOx) emissions from electric utilities and decreased acid deposition (Driscoll et al., 2001; Likens et al., 1996). Emissions in the United States have been reduced 64% compared with 1990 levels and NOx emissions reduced 67% compared with 1995 levels since the implementation of
CAAA and CAIR (Burns, 2011). Prior to the Clean Air Act Amendment (CAAA) in 1990, high levels of nitrate - nitrogen were added via acidic deposition on the Allegheny Plateau (National Atmospheric Deposition Program, 2016a).

The effects of nitrogen deposition on black cherry on the Allegheny Plateau were observed while measuring the effects of base cations on sugar maple (Horsley et al., 2000). In contrast to sugar maple, black cherry is not limited by calcium and magnesium and was negatively affected by a liming application on the Susquehannock State Forest, Potter County, PA (Long, et al., 2009; Long et al., 1997). Horsley (1988) varied the amounts of ammonium and nitrate used to water black cherry seedlings and showed that growth and vigor improved with nitrate - nitrogen.

**The Nitrogen Cycle and Deposition**

Nitrogen is one of nine essential plant macronutrients required in relatively large amounts (Cole and Gessel, 1992). Virtually all biological processes require nitrogen because it is an integral part of amino acids which are the building blocks of proteins and enzymes (Brady and Weil, 2008). Nitrogen is a component of nucleic acids, which store hereditary information, and is a component of chlorophyll, which is important for photosynthesis (Brady and Weil, 2008). Also, nitrogen is essential for carbohydrate use and stimulates root growth and development (Brady and Weil, 2008). Elemental nitrogen is a major factor in plant health, but must first be converted to a plant available form for plant uptake.

Although the element is the most abundant gas in the atmosphere, it exists in the form of N₂ which most plants and animals cannot use (National Atmospheric Deposition Program, 2016b). Organic nitrogen must be converted through the nitrogen cycle from its organic form into inorganic forms (nitrate (NO₃) or ammonium (NH₄)) to be used by most plants and animals.
Nitrogen is incorporated into biological molecules through nitrogen fixation, which is a process where certain prokaryotes (bacteria and archaea) and some eukaryotes (legumes and termites) reduce nitrogen gas from the atmosphere into ammonium in the soil (Canfield et al., 2010; Brady and Weil, 2008; Cole and Gessel, 1992). The oxidation of ammonium, called nitrification, converts ammonium to nitrite (NO₂) and then to nitrate as an end product (Canfield et al., 2010; Brady and Weil, 2008; Cole and Gessel, 1992). The process of nitrification readily transforms ammonium to nitrate, so when ammonium is released or added to the soil it is usually converted rapidly into nitrate (Brady and Weil, 2008; Cole and Gessel, 1992). Nitrate is then plant available, but can become unavailable to plants by leaching, denitrification, or immobilization. Denitrification and immobilization convert inorganic nitrogen ions, such as nitrate and ammonium, into unavailable organic and gaseous forms (Brady and Weil, 2008).

Nitrogen can also be added to the soil through decomposition of organisms. Amine groups (R-NH₂) are added to the soil and can go through the process of mineralization (Canfield et al., 2010; Brady and Weil, 2008; Cole and Gessel, 1992). Nitrogen also enters the system through atmospheric deposition, as a result of anthropogenic activity (Driscoll et al., 2001).

Processes, such as the combustion of fossil fuels create high temperatures at which atmospheric nitrogen gas is converted into reactive NOₓ (National Atmospheric Deposition Program, 2016b). In the United States, emissions from motor vehicles, electric utilities, and industrial processes are the largest sources of NOₓ (National Atmospheric Deposition Program, 2016b). NOₓ are eventually converted to nitric acid (HNO₃) vapor or particulate nitrate which are removed from the atmosphere in wet or dry deposition (National Atmospheric Deposition Program, 2016b). Nationwide, anthropogenic NOx emissions reached their peak around 1980 at
24.6 million metric tons and declined to 11.3 million metric tons by 2014 mostly after 1995 when the 1990 CAAA was implemented (National Atmospheric Deposition Program, 2016b).

**Changes in Black Cherry Vitality and Regeneration**

Land managers began noticing problems with black cherry vitality and a lack of regeneration in 2000 that increased with time. Among the factors that may have affected black cherry vitality are changing climate and pests. Within the northeastern United States, climate change has impacted northern hardwood forests (Groffman *et al.*, 2012). Two particular areas of interest with respect to long-term impacts of climate change are the effects of changes in summer soil moisture and winter snow cover (Groffman *et al.*, 2012). Recordings at the HBEF have shown that over the last half century, the average annual air temperature has increased by 0.17 to 0.29 degrees Celsius (Groffman *et al.*, 2012). HBEF recordings have also shown that the long-term average annual precipitation has increased by 13% - 28% over 50 years (Groffman *et al.*, 2012).

Increased average temperature and precipitation, specifically earlier spring snowmelt, results in soil temperatures reaching biologically favorable conditions at earlier dates (Groffman *et al.*, 2012). The onset of northern hemisphere spring occurred approximately one week earlier in the 1990s than in the 1970s according to global data records (Hamburg *et al.*, 2013; Keeling *et al.*, 1996). However, it is predicted that longer growing seasons and higher temperatures may lead to increases in drought despite an increase in precipitation to the region (Huntington *et al.*, 2009). Therefore, plants during the growing season may be affected by these changes in seasonal timing because summer soil moisture is a strong driver of plant and microbial processes needed for decomposition and nutrient cycling, including the nitrogen cycle (Hamburg *et al.*, 2013; Groffman *et al.*, 2009).
Groffman et al. (2009) suggests that in the northeast, climate change will produce drier soils that freeze more frequently due to lack of snowpack and provide less nitrogen to support plant productivity. A warmer climate increases soil freezing in the winter and decreases soil moisture in the summer suggesting that nitrogen cycling and supply to plants will be reduced in northern hardwood forests (Groffman et al., 2009). An experiment at HBEF suggests that reduced rates of net nitrogen mineralization and nitrification in warmer lower elevation plots in both summer and winter were seemingly driven by soil moisture (Groffman et al., 2009). Changes in temperature and precipitation may contribute to shifting in species distribution.

Since climate can regulate vegetation and species distribution; it is expected that plant species will continue to shift in range and abundance as the climate changes (Iverson and Prasad, 2001). Potential changes in suitable habitat for black cherry are predicted to shift away from northwestern Pennsylvania with a significant decrease in suitable habitat by 2100 (Iverson and Prasad, 2001). The suitable black cherry habitat is predicted to decrease by 92% and be largely replaced by habitat suitable for oak- hickory and oak- pine (Iverson and Prasad, 2001). Climate change is not the only threat to black cherry on the Allegheny Plateau.

Allegheny hardwood forests contain the fungal disease, cherry leaf spot (\textit{Blumeriella jaapii}), affecting \textit{Prunus} species (Zabel et al., 1958). Cherry leaf spot colonizes on foliar tissues causing purple spots that can enlarge and develop necrotic centers that look like “shot- holes” (Stanosz, 1992). Both young seedlings and mature trees are susceptible to cherry leaf spot. As these spots become more numerous, leaves become chlorotic and necrotic, and then are prematurely shed (Stanosz, 1992). Cherry leaf spot fungus substantially reduces photosynthesis of the infected plants (Niederleitner and Knopnik, 1997). The fungus spreads by raindrop splash during periods when leaf surfaces remain wet and has a major impact on seedlings close to the
forest floor (Keitt et al., 1937). Within a nursery setting, cherry leaf spot may be delayed by removing the fallen leaves colonized the previous growing season. However, this method to control the fungus has not been implemented in a forest setting (Stanosz, 1992).

Other pathogens potentially harmful to black cherry are water molds in the genus *Pythium*. *Pythium* species are oomycetes that can live either as a saprophyte on dead plant and animal matter, or as a parasite on plant roots, including those of black cherry (Packer and Clay, 2003a). These soil-borne pathogens are common and can cause damping-off disease which affects plants of any age, but cause more damage during germination and seedling establishment (Martin and Looper, 1999).

Packer and Clay (2000) found that black cherry seedling mortality due to *Pythium* species was primarily distance dependent in the field; the closer seedlings are to their parent tree, the less likely the seedling will survive (Reinhart and Clay, 2008). Packer and Clay (2003a) also found that black cherry sapling growth had distance dependent effects and soil pathogens may build up rapidly in a monoculture of black cherry seedlings which reduces survival (Packer and Clay, 2003b). There is overall consistency between both field and laboratory experiments strongly suggesting that *Pythium* pathogens have a negative effect on the survival of black cherry seedlings in the eastern United States (Reinhart and Clay, 2008; Reinhart *et al.*, 2005; Packer and Clay, 2000). However, it is unclear whether the *Pythium* pathogen is a major contributing factor to the recent decline of black cherry vigor on the Allegheny Plateau.

Fungal diseases are not the only organisms that have a negative impact on black cherry vigor, but some insects are also detrimental. An outbreak of cherry scallop shell moth (*Hydria prunivorata*) occurred within the ANF region from 1994 to 1996 and 2015 to 2016 (USDA Forest Service Pennsylvania Forest Health Highlights, 2015; Lewis and Likens, 2000). Cherry
scallops shell moth larvae feed almost exclusively on black cherry (Schultz and Allen, 1977b). The larvae fold the margins of the leaves together to form a nest where they feed on the upper epidermis of the foliage (Schultz and Allen, 1975). This generally kills the leaves where they desiccate and fall or are removed by wind or rain (Schultz and Allen, 1977b). As larvae continue to feed, more foliage is incorporated into their nests or a new nest may be created (Schultz and Allen, 1975). Defoliation reduces the black cherry radial growth the following year after defoliation (Schultz and Allen, 1977b, 1975).

After 2-3 years of heavy defoliation, some stands are subject to rapid decline and mortality due to invasion of peach bark beetle (*Phloeotribus liminaris* (Harris)) which kills the black cherry after they are weakened by defoliation from the cherry scallop shell moth or other disturbances such as severe windstorms (DiGirolomo et al., 2003; Schultz and Allen, 1975). A recent study on the ANF that described the relative abundance of wood-boring insects infesting the boles of wind thrown black cherry reported that the peach bark beetle infestation was relatively low after the disturbance (DiGirolomo *et al.*, 2013). Black cherry stands that are at higher risk of mortality from these two insects are generally characterized by high percentage of black cherry, poor soil drainage, and low soil pH, all of which are associated with many sites on the ANF (Shultz and Harris, 1977a).

These pests not only affect the vigor of the black cherry, but also impact wood quality (Hough, 1963). Peach bark beetles reduce the quality of black cherry timber lumber and veneer by creating gum spots (Long *et al.*, 2012; Rexrode and Baumgras, 1984). Gum spots are discolored cell damage found within parenchyma flecks in black cherry wood (Rexrode and Baumgras, 1980; Kulman, 1964). Peach bark beetles not only attack weakened black cherry trees, but researchers have shown that their abortive attacks on healthy black cherry trees also
cause damage (Rexrode, 1981). Peach bark beetles are the major cause of gum spots in black cherry in West Virginia and the number of gum spots in residual trees increases with the level of the intensity of the previous cutting practice (Rexrode and Smith, 1990).

Both gum spots and dark growth rings degrade black cherry wood, reduce profits, and affect the local economy (Long et al., 2012; Rexrode and Baumgras 1980; Kulman 1964; Hough 1963). Some of the highest quality black cherry originates in northwestern Pennsylvania and it is one of the most valuable eastern hardwood species (Wiedenbeck et al., 2004). A decline in black cherry vigor will not only affect the local ecology, but the local economy as well.

Another problem affecting black cherry management is the lack of reliable seed production. A seed trapping study from 2010 to 2014 on the ANF has shown only one bumper seed crop year occurring in 2010 and below average seed production from 2011 to 2014 (Long et al., 2017). Within a network of Forest Health Monitoring plots on the ANF, decreased canopy vigor and increased mortality in black cherry plots have been confirmed (Long et al., 2017).

**Atmospheric Deposition Changes**

Within the last twenty-five years, wet nitrate deposition levels have significantly decreased within the Allegheny Plateau region due to policies such as the CAAA (National Atmospheric Deposition Program, 2016a). Before the CAAA, nitrate deposition at the Kane Experimental Forest within the ANF was approximately 25 kg/ha. At the same recording station, nitrate deposition was reduced to about 10 kg/ha in 2014 (National Atmospheric Deposition Program, 2016a). When black cherry began having problems, researches pieced together evidence from fertilization studies in the 1970s and from the liming study where cherry growth declined as soil pH increased (Auchmoody, 1979; Long et al., 1997). It was hypothesized that the period of high N deposition allowed cherry to thrive due to a continuous supply of nitrate,
and the recent declines were the result of declines in deposition (Ristau, personal communication).

Although the CAAA is beneficial to the environment, there may be unintended consequences of the decline of NO₃ resulting in black cherry regeneration and vigor decline across the Allegheny Plateau region. If declining nitrogen inputs are responsible for decreased black cherry vigor, addition of nitrogen could potentially reverse the decline. The purpose of this study is to test this hypothesis.

This thesis of nitrogen fertilizer effects on black cherry regeneration in Allegheny Hardwood Forests starts with a detailed literature review and is followed by a stand-alone manuscript intended for submission to SSSA journal. The manuscript precedes the referenced tables and figures. In addition, the appendix is provided for supporting information of official soil series descriptions and SAS statistical input.
Chapter 2. Manuscript: Nitrogen fertilizer effects on black cherry (*Prunus serotina* Ehrh) regeneration in Allegheny hardwood forests

Introduction

Black cherry (*Prunus serotina* Ehrh) is a prominent and important commercial timber species in the Allegheny hardwood forests located within the Allegheny High Plateau in Pennsylvania (Marquis, 1975a; Husch, 1954). Black cherry is a fast-growing, early-successional species and in addition to timber, provides soft mast, nesting material, and den sites for wildlife (Marquis, 1990). It has been a natural part of the ecosystem within this region since pre-settlement times, and due to the history of timber harvesting, deer pressure, and the development of regeneration guidelines, has been successfully harvested and regenerated since the 1970s (Marquis *et al.*, 1992; Whitney, 1990; Hough and Forbes, 1943).

Black cherry seed was produced reliably with good seed crops every 1-5 years and some seed was produced almost every year (Bjorkbom, 1979; Grisez, 1975; Husch, 1954). In the forest floor, the seeds remain viable for 3-5 years making propagule supply sufficient for successful regeneration at any time (Marquis, 1975b; Hough and Forbes, 1943). Seedlings can persist in moderately shaded areas but grow relatively slowly, and the species is considered to be shade intolerant (Marquis, 1990; Hough and Forbes, 1943).

Black cherry is more prominent in very acidic soils and studies have shown that more alkaline conditions from liming have negatively affected black cherry growth (Long *et al.*, 2011; Marquis, 1990). However, nitrogen (N) fertilization studies have shown both overstory and understory black cherry increase in growth, flowering, and seed production following fertilizer application in northwestern Pennsylvania (Horsley, 1988; Auchmoody, 1982; Bjorkbom, 1979).
Black cherry has a high nitrogen requirement for growth and relies on nitrate - nitrogen for seed germination (Auchmoody, 1982; Auchmoody, 1979).

The availability of nitrate - nitrogen within forest soils increases with the application of fertilizers and input through nitrogen deposition (Driscoll et al., 2001). Black cherry has shown a positive growth response to nitrogen deposition most likely due to the increased input of available N following nitrification (Thomas et al., 2009). Nitrogen deposition has a history of impacting forest soils within the northeastern United States and the Allegheny Plateau (Bailey et al., 2005; Driscoll et al., 2001).

Within the last 25 years, wet nitrate deposition levels have significantly decreased within the Allegheny Plateau region due to policies such as the Clean Air Act Amendment (CAAAA) enacted in 1990 (National Atmospheric Deposition Program, 2016a). Before the CAAA, nitrate deposition at the Kane Experimental Forest within the Allegheny National Forest (ANF) was approximately 25 kg/ha/yr. At the same recording station, nitrate deposition has decreased to about 10 kg/ha in 2014 (National Atmospheric Deposition Program, 2016a). Overall, the Clean Air Act (CAA), CAAA, and Clean Air Interstate Rule (CAIR) have had positive ecological effects with the reduction of acid deposition. In the early 2000s foresters and land managers reported that black cherry crown vigor and regeneration were frequently poor (Long et al., 2017). Using evidence from fertilization studies in the 1970s and from the liming study where cherry growth declined as soil pH increased, it was hypothesized that the period of high N deposition allowed cherry to thrive due to a continuous supply of nitrate, and the recent problems were the result of declines in deposition (Auchmoody, 1979; Long et al., 1997; Ristau, personal communication).
A seed trapping study from 2010 to 2017 in the ANF has detected only one bumper crop year occurring in 2010 and below average seed production from 2011 to 2014 (Long et al., 2017). In a network of Forest Health Monitoring plots on the ANF, decreased canopy vigor and increased mortality of black cherry plots have been confirmed (Long et al., 2017). While black cherry health seems to be in decline in the ANF, many other factors in addition to the reduction of nitrogen deposition could be negatively impacting black cherry canopy vigor and mortality; climate change, disease, and pests may play a role.

Within the northeastern United States, climate change has impacted northern hardwood forests. Recordings at the Hubbard Brook Experimental Forest (HBEF) have shown that over the last half century, the average annual air temperature has increased from 0.17 to 0.29 degrees Celsius (Groffman et al., 2012; Campbell et al., 2007). Long-term average annual precipitation has increased by 13% - 28% over 50 years (Groffman et al., 2012).

Groffman et al., (2009) suggest that the soils in the northeast will be warmer and drier. A warmer climate increases soil freezing in the winter and decreases soil moisture in the summer suggesting a slowing of nitrogen cycling and plant availability in northern hardwood forests. An experiment at HBEF also suggests that net nitrogen mineralization and nitrification in warmer, lower elevation plots in both summer and winter were reduced seemingly driven by soil moisture changes (Groffman et al., 2009). These changes in temperature and precipitation may contribute to a shift in species distribution. Iverson and Prasad (2001) predict a 92% reduction in black cherry habitat in northwestern PA by 2100, to be largely replaced by habitat more suitable for oak-hickory and oak-pine.

Climate change is not the only threat to black cherry within the ANF. The fungal disease cherry leaf spot (Blumeriella jaapii) is a threat to the Prunus species (Zabel et al., 1958). The
Cherry leaf spot fungus colonizes on fully developed leaves of seedlings or adults generating purple spots that can enlarge and develop necrotic centers that look like “shot-holes” (Stanosz, 1992). Cherry leaf spot fungus substantially reduces photosynthesis of the infected plants (Niederleitner and Knoppnik, 1997). As these spots become more numerous, leaves become chlorotic and necrotic, and are prematurely shed (Stanosz, 1992). The fungus spreads during moist periods when leaf surfaces remain wet and has a major impact on seedlings close to the forest floor (Keitt et al., 1937). Within a nursery setting, the development of cherry leaf spot may be delayed by removing the fallen leaves colonized the previous growing season. However, this method to control the fungus is not practical in a forest setting (Stanosz, 1992).

Other harmful black cherry pathogens are organisms in the genus *Pythium*. *Pythium* species are oomycetes, or a type of water mold, that can live either as saprophytes on dead plant and animal matter, or as parasites on plant roots, including those of black cherry (Packer and Clay, 2003a). These common soil-borne pathogens can cause damping-off disease, which affects plants of any age, but cause more damage during germination and seedling establishment (Martin and Looper, 1999). There is overall consistency between both field and laboratory experiments, strongly suggesting that *Pythium* pathogens have a negative effect on the survival of black cherry seedlings in the eastern United States (Reinhart and Clay, 2008; Reinhart et al., 2005; Packer and Clay, 2000). However, it is unclear whether *Pythium* pathogens are a major contributing factor to the recent decline of black cherry seedlings on the ANF.

Insects, in addition to fungal diseases, have had a demonstrable negative effect on black cherry. There were outbreaks of cherry scallop shell moth (*Hydria prunivorata*) (CSSM) within the ANF region from 1994 to 1996, and 2015 to 2016 (USDA Forest Service Pennsylvania Forest Health Highlights, 2015; Lewis and Likens, 2000). Cherry scallop shell moth larvae feed
almost exclusively on black cherry (Schultz and Allen, 1977b). The larvae fold the margins of
the leaves together to form a nest where they feed on the upper epidermis of the foliage (Schultz
and Allen, 1975). This generally kills the leaves; they remain on the tree and desiccate unless
they are removed by wind or rain (Schultz and Allen, 1977b). As the larvae continue to feed,
more foliage is incorporated into the nest or a new nest may be created (Schultz and Allen,
1975). Defoliation reduces the black cherry radial growth the year following defoliation (Schultz

After two to three years of heavy defoliation, some stands are subject to rapid decline and
mortality due to invasion of peach bark beetle (*Phloeotribus liminaris* (Harris)) which kills the
black cherry after they are weakened from defoliation from the cherry scallop shell moth or other
disturbances such as severe windstorms (Shultz and Allen, 1975; DiGirolomo *et al.*, 2003). A
recent study on the ANF that described the relative abundance of wood-boring insects infesting
the boles of wind thrown black cherry reported that the peach bark beetle infestation was
relatively low after the 2003 disturbance (DiGirolomo *et al.*, 2013). Black cherry stands that are
at higher risk of mortality from these two insects are generally characterized by high relative
importance of black cherry, poor soil drainage, and low soil pH, all of which are characteristics
of sites on the ANF Allegheny hardwood region (Shultz and Harris, 1977a).

Some of the highest quality black cherry originates in northwestern Pennsylvania and it is
one of the most valuable eastern hardwood species (Wiedenbeck *et al.*, 2004). A decline in black
cherry vigor will not only affect the local ecology, but the local economy as well. While many
factors may contribute to the decline in black cherry vigor within the region, the main focus of
this research is to examine the relationship between the reduction in nitrogen deposition and
black cherry vigor decline.
Although the CAAA is beneficial to the environment overall, there may be unintended consequences resulting in the decline in black cherry regeneration and vigor within the Allegheny Plateau region. The extraordinary success of black cherry since the 1960s may have resulted from the continuous fertilization by way of atmospheric inputs through deposition. To test whether declining nitrogen inputs are responsible for decreased black cherry vigor, this study will add nitrogen to test whether this could reverse the negative effects.

The specific objectives of this study were: (1) to compare growth and establishment of black cherry regeneration on control plots and plots amended with three different levels of nitrogen (2) to determine the soil and foliar nutrition status, and (3) to evaluate the effect of nitrogen amendment on seed production and crown vigor of overstory trees.

Methods

Site Establishment – Low N-Fertilized Sites

Based on black cherry regeneration failures, the ANF Ranger districts began a trial fertilizer application program to test whether fertilizer could help keep cherry seedlings competitive against black birch and other competitors. Twelve shelterwood seed cut stands treated three years prior were chosen to receive N and P fertilizer applications based on work done by Auchmoody (1982). These 12 shelterwood stands were evaluated for use as study areas, with criteria of being flat and having enough advance regeneration to respond to fertilizer. Three of these sites (Thomas Run, Wetmore East, and Wetmore West) cut to shelterwood seed cut were used where part of the stand was left untreated to allow for a low N-fertilized treatment and a control unit. Two additional shelterwood seed cut stands (Kinzua Creek and Glad Run) were used for the low N-fertilized and control treatments providing five low N-fertilized sites (Figure 1). Three of these sites contained flat topography in an area large enough to support a control
plot, and a low rate fertilizer application adjacent to the high rate fertilizer plot. All areas had a
recent shelterwood cutting and are similar in topographic conditions and species composition
(Appendix, Table 1). Each site was named after the areas they are located in for convenience.
Two treatment areas were established at each site: a fertilized area and a non-fertilized control
area (Figure 2). Within the treatment areas, eight sample points were established to assess
regeneration and six 0.04 ha overstory sample sub-plots were established (Figure 2).

The five sites, which will be referred to as the “low N-fertilized sites” were established in
May 2015. The treatment areas were laid out as 0.49 hectare rectangles with an interior 0.24
hectare rectangular measurement plot in the center delineated with four white fiber glass stakes.
There was some shifting in layout at two of the sites (Thomas Run, Glad Run) due to understory
conditions lacking uniformity in the 0.24 hectare measurement plots (Figure 3). Eight 1.8 meter
radius regeneration sampling plots were established within each 0.24 hectare measurement plots.
GPS data were collected and maps were created.

**Site Establishment –High N-Fertilized Areas**

At the three sites (Thomas Run, Wetmore East, and Wetmore West) that included an
adjacent high rate N and P fertilizer area, which will be referred to as the “high N-fertilized
sites,” the high rate application portion of each area was sloping ranging from 0 - 10%. In each
high N-fertilized area, two transect lines approximately 40 meters (2 chains) apart were
established, also in May 2015. Along each transect line, five circular 1.8m radius measurement
plots were established and center points were permanently marked with fiberglass rods.
Measurement plots were approximately 40 meters (2 chains) apart (Figure 3).
Field Methods and Data Collection

Treatment – Low N-Fertilized Sites

Within the five low N-fertilized sites, treatment plots were determined randomly by coin toss and were treated with Environmentally Smart Nitrogen (ESN) polymer coated (90 to 120 day slow release) urea in April 2016. The application was designed to replace nitrate-nitrogen that would have fallen on the sites without the emissions reductions of the CAAA.

Within the twenty-five year period of 1990 to 2015, the estimated decrease in nitrate due to the CAAA totals 15 kg/ha, or 3.39 N kg/ha (National Atmospheric Deposition Program, 2016a). The polymer coated urea fertilizer is 44% nitrogen; approximately 7.7 kg ESN/ha was applied to replace the nitrogen lost from the twenty-five year period. The treatment plots are 0.49 ha, so approximately 3.8 kg ESN was required for each fertilized plot. Note that this does not account for any loss due to volatilization, nor does it mimic delivery at the annual rate.

The polymer coated urea fertilizer was applied in early April 2016 (Figure 4). Two individuals walked 10m (half a chain) apart in one direction using a hand crank seed dispenser filled with fertilizer. When the edge of the plot was reached, the same line was walked in the opposite direction, but the fertilizer was dispersed in the other direction. This process continued until the entire area was treated.

Treatment – High N-Fertilized Areas

Within the three high N-fertilized areas, one of two levels of fertilizer was applied with a skidder mounted spreader from Turner Enterprises of Youngsville, PA in late April 2016. The Thomas Run plots were treated with 449 kg/ha Nutrisphere stabilized granular urea (134.7 kg N/ha) and 112 kg/ha diammonium phosphate (16.8 kg P/ha). Wetmore East and Wetmore West plots were treated with 218 kg/ha Nutrisphere stabilized urea (65.4 kg N/ha) and 56 kg/ha
diammonium phosphate (8.4 kg P/ha). For analyses, due to lack of replication, these plots were not separated into the two separate fertilizer treatments, but were categorized together as fertilized at a relatively high rate. The control plot at each low N-fertilized site was designed to serve as a control for both the high and low N-fertilized sites.

**Regeneration Measurements – Low N-Fertilized Sites**

Within the 0.24 ha measurement plots, eight 1.8m radius measurement plots were established for measuring regeneration. Regeneration data were collected pre- treatment (June 25, 2015 to July 9, 2015) and in the following post treatment growing seasons. All stems were counted by species and height class (new germinant class, 0.05 to 0.3m, 0.3 to 0.9m, 0.9 to 1.5m, and >1.5m). There was also a combined “all black cherry” category.

**Regeneration Measurements – High N-Fertilized Areas**

For the three high N-fertilized plots, regeneration measurements were recorded at every established wire flagged (20 plots/stand, total 60 plots) plot center using a 1.8m radius circular plot. Data were collected both pre- and post- treatment following the same methods used for the low N-fertilized sites.

**Soil Measurements – Low N-Fertilized Sites**

Within the 0.24 ha measurement plots, six 0.04 ha measurement plots were established and identified by the labeled regeneration stake plots (1-8). The 0.04 ha measurement plots were numbered 1-6; five were randomly selected for collection of soil samples from the plot center (totaling 50 samples) before treatment. Average thickness for organic horizons and average depth to B horizon are listed in Table 2 for each site. Soil samples from the Oa/A and upper B horizons were collected separately. If an E horizon was present, it was not collected.
Soil samples were collected in April 2016 before fertilizer was applied. Time constraints only allowed treated plots to be sampled with the assumption the control plots would be similar. Soil samples were collected post-treatment in June and July 2016 in both treated and control plots following the same procedure as previously mentioned. All soil samples from April, June, and July were analyzed for extractable ammonium and nitrate (Sparks et al., 1996). In addition, the soil samples from July were analyzed for pH, total carbon, and total nitrogen (Bicklehaupt and White, 1982). The samples were also analyzed for organic matter using the loss on ignition method and for texture via hydrometer method (Bicklehaupt and White, 1982; Saxton and Rawls, 2006).

The upper B horizon soil samples were analyzed at State University of New York – College of Environmental Science and Forestry (SUNY-ESF) for ammonium (NH₄), nitrate (NO₃), extractable phosphorus (P), total carbon (C), total nitrogen, organic matter (OM), extractable potassium (K), sodium (Na), aluminum (Al), calcium (Ca), magnesium (Mg), manganese (Mn), boron (B), zinc (Zn), iron (Fe), copper (Cu), molybdenum (Mo), and pH. Soil samples were extracted with 2M KCl and extracts were frozen until analysis of ammonium and nitrate on the THERMO Flash EA 1112 elemental analyzer at SUNY-ESF (Sparks et al., 1996). The upper B horizon samples were used due to a study by Bailey et al. (2004) that showed upper B horizon soil chemistry variables had the highest correlation with foliar chemistry compared to other horizons. The samples were analyzed for phosphorous using the Bray P-1 extraction method (Bicklehaupt and White, 1982). Total carbon and total nitrogen were analyzed from the samples using a C, N analyzer at SUNY-ESF (Bicklehaupt and White, 1982). The soil samples were analyzed for organic matter using the loss on ignition method (Bicklehaupt and White, 1982). The pH of the soil samples was measured following the procedure from Bicklehaupt and
White using a pH meter from SUNY-ESF (1982). An ICP was used at SUNY-ESF to analyze the soil solution extracts for potassium, sodium, aluminum, calcium, magnesium, manganese, boron, zinc, iron, copper, molybdenum.

Soil Measurements – High N-Fertilized Areas

Five soil samples from each of the three sites (totaling 15 soil samples) were collected in July 2015 and were analyzed for ammonium and nitrate following the same procedure used for the low N-fertilized sites (Sparks et al., 1996). Soil samples were collected in July 2016 and were analyzed for pH, organic matter, texture, total nitrogen, total carbon, nitrate, and ammonium (Sparks, et al., 1996; Bicklehaupt and White, 1982).

Overstory Measurements- Low N-Fertilized Sites

Complete inventories by species and diameter at breast height (DBH) (1.37m) were made for all trees greater than 2.54 cm within each 0.24 ha plot. All overstory black cherry trees within the 0.24 ha measurement plots were numbered and labeled. Crown conditions were assessed for each overstory tree for all five sites in 2015 and again in 2016 following Forest Health Monitoring and the North American Maple Project protocols (Schoemaker et al., 2007; Cooke et al., 1996).

Tree crown vigor and density were estimated in 2015 and 2016 for each labeled black cherry tree within the plots. Crown condition was classified into one of five vigor index categories and crown density was estimated using Forest Health Monitoring protocols (Schomaker et al., 2007; Cooke et al., 1996) (Appendix).

Within each 0.24 ha measurement plot, five trees were randomly selected (using a computer randomizer) for measurement of seed production. Two seed traps per tree (totaling 100 seed traps) were placed near the edge of the crown of each selected black cherry tree bole in a
south and in an east direction in accordance with the prevailing winds for the area, though the seeds are gravity dispersed as well as animal dispersed. Seed data were collected in fall 2015 pre-treatment and in fall 2016 post-treatment.

Within the 0.24 ha measurement plots, approximately 5 trees were randomly selected for foliar sampling (totaling 50 samples). Foliage was sampled by shooting small twigs from mid-crown with a shotgun and foliage was collected in pre-treatment and in the following post-treatment years following protocol from Horsley *et al.* (2000). Due to an infestation of cherry scallop shell moth within the area, foliage samples were taken after defoliation (mid-August) in the pre-treatment year 2015 from the trees assessed as having little or no defoliation. In the following post-treatment year, 2016, samples were taken from a random selection of black cherry trees before the defoliation (late July) from the cherry scallop shell moth. Foliar samples were oven dried at 70 degrees Celsius and ground to pass a 20 mesh screen at the Northern Research Station in Irvine, PA and were analyzed at SUNY-ESF for concentrations of aluminum, calcium, copper, iron, potassium, magnesium, manganese, phosphorus, and zinc. Analysis was conducted following procedures from Bickelhaupt and White (1982) using microwave digestion and an ICP. Total carbon and nitrogen were also analyzed using elemental analyzer, the THERMO Flash EA 1112 elemental analyzer at SUNY-ESF.

**Overstory Measurements – High N-Fertilized Areas**

From each measurement plot, foliage samples were obtained from three overstory black cherry trees (totaling 9 samples) during late July in 2016 (Horsley *et al.*, 2000). Foliar samples were oven dried at 70 degrees Celsius and ground to pass a 20 mesh screen at the Northern Research Station in Irvine, PA and were analyzed at SUNY-ESF for concentrations of aluminum, calcium, copper, iron, potassium, magnesium, manganese, phosphorus, and zinc.
following procedures from Bickelhaupt and White (1982) using microwave digestion. Total carbon and nitrogen were also analyzed using elemental analyzer, the THERMO Flash EA 1112 elemental analyzer at SUNY-ESF. Overstory crown vigor measurements and seeds were not collected within the three high N-fertilized sites. There were no overstory data collected in pre-treatment year 2015.

**Experimental Design and Statistical Analyses**

The study design is a randomized complete block with fertilizer (fertilizer – no fertilizer) and year (2015/ pre-treatment year - 2016/ post-treatment year) as the treatments. Statistical analyses were conducted with SAS version 9.4 using PROC GLM (SAS Institute Inc, 2013). Block, fertilizer, and year were treated as fixed effects. All models tested the fixed effects (fertilizer, year, fertilizer x year). Data were averaged by site and tested with analysis of variance to assess fertilizer effects on reproduction and nutrition pre-treatment year versus post-treatment year and treated versus control plots. The 0.15% level of probability was used as the interaction indicator of statistical significance and 0.05% level of probability was used for the main effects indicator of statistical significance. Pearson and Spearman correlations were conducted for significant fertilizer by year interactions of new seedlings to determine significant correlations from 2015 to 2016. The null hypothesis for this proposed study is that there is no effect in reproduction or nutrition of fertilized treatment plots compared to control plots and pre-treatment plots.

**Results**

The specific objectives of this study were to assess overstory, foliage, seedling, and soil measurements to determine if there was a statistically significant difference in responses between years and treatments. The fertilizer by year interaction would show a fertilizer response because
fertilizer was applied in 2016 and not in 2015. Results are presented and discussed in the following order: (1) seedling response, (2) soil measurements, and (3) overstory measurements including seed numbers and foliar nutrient concentration.

**Regeneration – Low N-Fertilized Sites**

There were no significant treatment effects for stem density of new germinant black cherry seedlings, black cherry seedlings <0.3m in height, black cherry seedlings 0.3- 1.0m in height, or all black cherry seedlings (Table 3). The number of stems per hectare of new red maple seedlings significantly differed from year to year (p <0.0001) (Table 4). The average new germinant red maple seedling density was higher in 2016 with 11935 seedlings/ha than in 2015 with 2491 seedlings/ha (Table 5). There were no significant treatment effects of stem density of other various hardwood new seedlings including: sugar maple, yellow poplar, and cucumber magnolia (Table 4).

There was a significant interaction effect of the stem density of new pin cherry seedlings between year and fertilizer treatments (p = 0.0797) (Table 6). The average stem density of new pin cherry seedlings significantly differed between fertilized plots in 2015 and in 2016. There was a higher stem density in fertilized plots in 2016 with 573 seedlings/ha than in 2015 with 129 seedlings/ha (Figure 5). The stem density of new pin cherry seedlings differed between control and fertilized plots in 2016. There was a higher stem density on fertilized plots with 573 seedlings/ha compared to control plots in 2016 with 117 seedlings/ha (Figure 5). The significant difference can be attributed to the fertilizer application due to non-significant Spearman and Pearson correlations between new pin cherry seedlings from 2015 to 2016 (p = 0.6829 and p = 0.8499, respectively).
There was a significant difference between years of average percent coverage of interfering species including: *Rubus*, grass, and fern (*p* = 0.015; = 0.001; = 0.015, respectively) (Table 6). There was a higher percent coverage of *Rubus*, grass, and fern in 2016 with 13%, 32%, and 7%, respectively than in 2015 with 5%, 12%, and 3%, respectively (Table 5).

**Regeneration – High N-Fertilized Areas**

There was a significant interaction effect of stem density of black cherry seedlings 0.3-0.9m in height between year and fertilizer treatments (*p* = 0.0932) (Table 7). The average stem density of black cherry seedlings 0.3-0.9m significantly differed between fertilized plots in 2015 and in 2016. There was a higher stem density in fertilized plots in 2016 (324 seedlings/ha) than in 2015 (148 seedlings/ha) (Figure 6). There was also a significant difference between control and fertilized plots in 2015 and in 2016. There was a higher stem density in fertilized plots with 148 seedlings/ha than in control plots with 13 seedlings/ha in 2015 and in fertilized plots with 324 seedlings/ha than in control plots with 52 seedlings/ha in 2016 (Figure 6). There were no significant treatment effects for new black cherry seedlings, black cherry seedlings <0.3m in height, or overall black cherry seedlings (Table 7). The significant difference can be attributed to the fertilizer application due to non-significant Spearman and Pearson correlations between black cherry seedlings 0.3-0.9m from 2015 to 2016 (*p* =0.0787 and *p* =0.1388, respectively).

There was a significant year and fertilizer treatments (*p* = 0.0808) interaction for stem density of new birch seedlings (Table 8). The stem density of birch seedlings differed in control plots with 37 seedlings/ha and fertilizer plots with 0 seedlings/ha in year 2016 (Figure 7). There were more seedlings in control plots than in fertilized plots in 2016. The significant difference can be attributed to the fertilizer application due to non-significant Spearman and Pearson
correlations between new birch seedlings from 2015 to 2016 (p = 0.3531 and p = 0.3483, respectively).

There was a significant difference of new red maple seedlings between years (Table 8). There were 4 times as many stems per hectare of new red maple seedlings in 2016 with 16024 seedlings/ha and 4283 seedlings/ha in 2015 (Table 9). There were no significant differences for new pin cherry seedlings in the high N-fertilized plots (Table 8).

Various percent coverage of interfering species were measured and treatment effects were analyzed (Table 10). There was a significant year effect for *Rubus*, fern, and grass (p = 0.0387, 0.0440, 0.0008, respectively) (Table 10). There was a higher percent coverage for all three species in 2016 (25%, 12%, 36%, respectively) than in 2015 (12%, 5%, 21%, respectively) (Table 9). There was a significant fertilizer effect for *Rubus* and grass (p = 0.0078 and p <0.0001, respectively) (Table 10). There was a higher percent coverage for both species in fertilized plots (28%, 40%, respectively) than in control plots (9%, 17%, respectively) (Table 11).

**Soil Measurements – Low N-Fertilized Sites**

Mean concentration of soil nutrients concentrations are listed in the appendix for the five low N-fertilized sites. There was a significant interaction effect of soil nitrogen concentrations between year and fertilizer treatments (p = 0.1187) (Table 12). Fertilized plots significantly differed between years. Soil total N concentration was higher in 2015 (1.84 g/kg) than in 2016 (1.48 g/kg) (Figure 8). There was no significance of treatment effects for pH, percent of organic matter, or carbon concentrations (Table 12).

There was a significant interaction effect of soil nitrate concentration between year and fertilizer treatments (p = 0.0365) (Table 13). Soil nitrate concentration significantly differed in
2015 between control (6.73 mg/kg) and fertilized plots (16.15 mg/kg). In 2015, nitrate concentration was higher in plots to be fertilized (Figure 9). Control plots and fertilizer plots significantly differed from 2015 to 2016 (p=0.0015) (Table 13). Nitrate concentrations were higher in control plots in 2015 than in 2016 (6.73 mg/kg, 2.5 mg/kg, respectively) and fertilized plots in 2015 than in 2016 (16.15 mg/kg, 0.46 mg/kg, respectively) (Table 14). There was a significant difference between years for soil ammonium concentration (p=0.0010) (Table 13). The average concentration of soil ammonium was higher in 2015 (11.17 mg/kg) than in 2016 (4.18 mg/kg) (Table 14).

**Soil Measurements – High N-Fertilized Areas**

There was a significant interaction effect of soil ammonium concentration between year and fertilizer treatments (p = 0.0885) (Table 15). There was also a significant difference between treatment (p= 0.0286) (Table 15). The mean concentration in the control plots (7.24 mg/kg) was significantly higher than in the fertilized plots (3.72mg/kg). It is suspected that the decrease of ammonium concentration between years in the control plots from 9.45 mg/kg in 2015 to 5.03 mg/kg in 2016 accounts for the significant interaction effect, more so than in the fertilized plots which slightly increased from 3.44mg/kg in 2015 to 4.01 mg/kg (Table 16 and Figure 10).

There was a significant difference between years and treatment for soil nitrate concentration. There was a higher concentration on control plots with 4.47 mg/kg than on fertilized plots with 1.87 mg/kg (Table 16). The average concentration of soil ammonium was higher in 2015 with 5.23 mg/kg than in 2016 with 1.12 mg/kg (Table 17).

There were no significant treatment effects for percentage of soil organic matter, pH, and concentration of carbon, or nitrogen (Table 18).
**Overstory Measurements- Low N-Fertilized Sites**

There was a significant interaction effect for crown density between year and fertilizer treatments \((p = 0.1266)\) (Table 19). The average crown density in control plots and fertilizer plots significantly differed in 2015 and 2016 (Figure 11). The average crown density was higher in 2016 in both control (32.81%) and fertilizer (36.3%) plots than in 2015 (29%, 28%, respectively), possibly due to a less severe infestation of cherry scallop shell moth in the 2016 growing season.

Vigor and seed response (seed/m\(^2\), seed/ha) are statistically different from pre-treatment year (2015) to post-treatment year (2016) \((p= 0.0335, p= 0.0110, p= 0.0085, \text{ respectively})\) (Table 19). The lower vigor class in 2016 (1.6) suggests that the overstory was healthier in 2016 than in 2015 (1.7) (Table 20). However, for analysis the data were treated as continuous and the average vigor class ratings of 1.7 and 1.6, may be statistically significantly different, but may not be different visually. Seed production was greater in 2015 (113457 seeds/ha), the pre-treatment year, than in 2016 (9356 seeds/ha), the first treatment year (Table 20).

There was a significant interaction effect of foliar nitrogen concentration between year and fertilizer treatments \((p = 0.0606)\) (Table 21). Control and fertilizer effects were found to be significant \((p < 0.0001 \text{ and } p < 0.0001, \text{ respectively})\). The control plot and fertilizer plots were higher in concentration of foliar nitrogen in 2015 (30123 mg/kg, 30982 mg/kg, respectively) than in 2016 (26895 mg/kg, 26271 mg/kg, respectively) (Figure 12).

Some foliar nutrient concentrations including: aluminum, calcium, iron, potassium, magnesium, manganese, and phosphorus differed significantly between 2015 and 2016 \((p = 0.0014; = 0.0006; =0.0230; =0.0238; = 0.0030; =0.0002; =0.0047)\) (Table 21 and Table 22). All values were greater in pre-treatment year 2015 (40 mg/kg, 6327 mg/kg, 91 mg/kg, 14883 mg/kg,
2527mg/kg, 2898mg/kg, 1830 mg/kg, respectively) than in post-treatment year 2016 (21 mg/kg, 3010 mg/kg, 67 mg/kg, 12977 mg/kg, 1752 mg/kg, 1470 mg/kg, 1367 mg/kg) (Table 23). There were no significant differences of copper, zinc, and carbon.

**Overstory Measurements – High N-Fertilized Areas**

The foliar nutrient concentrations from the high N-fertilized plots were not significantly different for treatment effect (Table 24-26).

**Discussion**

**Regeneration**

After one year of low N-fertilizer treatment, black cherry seedling growth and establishment did not increase. However, within the high N-fertilized sites, black cherry seedlings increased in all categories and significantly increased in the 0.3-0.9m height category after one fertilizer application. This response from black cherry at the high N-fertilized sites concurs with previous studies that have used fertilizer rates similar to the high N-fertilized sites (Horsley, 1988; Auchmoody, 1982). The low N-fertilizer application used in this study was applied at a much lower rate than previous research and may indicate that a higher rate of N-fertilizer may need to be applied to benefit black cherry regeneration and growth. Fertilizer may have been applied at a rate that was too low for black cherry use, but other species, such as red maple seedlings, pin cherry seedlings, *Rubus*, grass, fern, and even overstory trees may have benefitted from the low N-fertilizer (Tessier and Raynal, 2003; Horsley, 1993; Auchmoody, 1979).

Grass, fern, and *Rubus* percent cover increased in 2016, increasing competition for sunlight and nutrients in both low and high N-fertilized sites (Horsley, 1993, Marquis *et al.*, 1992). In the shelterwood cut, these interfering plant species spread quickly which restricted
black cherry seedling growth and establishment (Marquis et al., 1992; Horsley and Marquis, 1982). Typically after black cherry seedlings are established, a removal cut follows to release the established seedlings and herbicide is used to reduce the amount of interfering species (Marquis et al., 1992; Marquis et al., 1975; Husch, 1954). Also noted is the increase in crown density in 2016, possibly due to the less severe infestation of cherry scallop shell moth which could reduce the amount of sunlight reaching the forest floor. These factors could have contributed to the lack of black cherry regeneration from the fertilizer effect within the low N-fertilized sites.

Black cherry is a high nitrogen demanding species (Auchmoody, 1982). The use of slow release urea for this study was used to replenish the amount of nitrogen delivered in the region from nitrogen deposition before 1990; perhaps such a small application will need more time and additional applications before significant results are observed. This study did not take into consideration loss of nitrogen due to volatilization, immobilization, overstory or understory plant uptake which may have impacted the results along with other factors that may be more important than the decrease in nitrogen due to the CAAA (Tessier and Raynal, 2003; Nason and Myrold, 1992). Therefore, further investigation is needed to make conclusions about the relationship between the reduction of nitrogen deposition and decline of black cherry regeneration in this area. In fact, this study is being continued by USDA Forest Service scientists.

New red maple and pin cherry seedlings more than doubled in post treatment year 2016 in the low N-fertilized sites. New pin cherry seedlings had a significant response to the fertilizer treatment. Pin cherry is similar to black cherry in that nitrate-nitrogen stimulates germination (Auchmoody, 1979). The increase in soluble nitrogen concentration within the soil from the urea fertilizer likely triggered an increase in pin cherry germination (Auchmoody, 1979). Marquis (1975b) found in a seed storage study in the Allegheny Hardwoods that pin cherry seed were the
most abundant with the longest viability in underground storage. Perhaps the large abundance of pin cherry seeds out-competed the black cherry seeds for the use of nitrogen from the fertilizer treatment.

New pin cherry seedlings did not increase in the high N-fertilized plots as expected (Auchmoody, 1979). However, the percent coverage in interfering species such as fern, grass, and *Rubus*, increased more in the high N-fertilized sites than in the low N-fertilized sites, which created more shade in these sites. Pin cherry is a shade intolerant species that generally germinates more with increased light and in highly disturbed areas, so the increasing shade may contribute to the lack of new pin cherry seedlings in the high N-fertilized sites (Wendel, 1990; Auchmoody, 1979). Overstory measurements were not taken in the higher N-fertilized sites, but if crown density increased as it did in the low N-fertilized sites, that may have contributed to more shade and less pin cherry regeneration.

New red maple seedlings increased more than any other seedling species in fertilized and even on control plots in the low N-fertilized sites and on the high N-fertilized sites. Red maple is a shade intermediate species and can germinate with very little light (Walters and Yawney, 1990; Hutnik and Yawney, 1961). It also has few germination requirements given proper temperature and little moisture (Hutnik and Yawney, 1961). One fertilization study has shown an increase in red maple seed production and estimated the increase in seedling regeneration could be up to 10 times more red maple seedlings on fertilized sites than on unfertilized sites (Bjorkbom *et al.*, 1979; Bjorkbom, 1979). Although this study did not show such an increase in fertilized sites compared to unfertilized sites, there was a significant increase in new red maple seedlings in 2016, but not a statistically significant increase due to fertilization. Due to the increase of an intermediate shade tolerant species it can be assumed that the lack of sunlight, due to increased
crown density or interfering species, may have played a major role in the study sites. Perhaps with additional herbicide treatments after a shelterwood cut, the impact of interfering species such as fern, *Rubus*, and grass on new seedling establishment may be reduced.

In high N-fertilized sites birch significantly decreased in the fertilized plots, and decreased in both fertilized and unfertilized plots in low N-fertilized plots. Birch species typically grow better in height and biomass when fertilized with ammonium- nitrogen as opposed to nitrate- nitrogen (Crabtree and Bazzaz, 1992; Horsley, 1988). Birch seeds typically germinate in light shade conditions for the first 2 to 3 months of the growing season and it is speculated that low light availability within this study may have impacted seedling growth and establishment of intolerant species (Lamson, 1990; Leak, 1965). The combination of high N-fertilizer rate and shade may have reduced new birch seedling survival, but further investigation is needed.

**Soil and Overstory**

In the low N-fertilized sites, concentrations of soil N, NO₃, and NH₄ decreased in fertilized and control plots with no significant changes in soil pH, organic matter or soil carbon concentration. Although there were significant interaction effects between year and fertilizer treatments for soil nitrogen concentration and for nitrate concentration in the low N-fertilized sites, there were no increases of concentration due to fertilizer treatment in 2016. The concentrations were less in both the control and the fertilized plots in 2016 than in 2015. The small application of fertilizer may not have been sufficient enough to increase concentrations of nitrogen in the soil due to volatilization, immobilization, or understory plant uptake (Tessier and Raynal, 2003; Nason and Myrold, 1992). This is reflected in the significant decrease in foliage nitrogen concentration in the low N-fertilized sites in 2016 compared to 2015.
In the high N-fertilized sites, the significant interaction effect for the concentration of ammonium introduces some confounding. It is suspected that the interaction effect is attributed more so to a major decrease in concentration in control plots from 2015 to 2016 since there is also a significant difference between fertilized and control plots. The concentration decreased by about 4 mg/kg in control plots compared to the slight increase in fertilized plots from 3.44 mg/kg in 2015 to 4.01 mg/kg in 2016. Therefore, the slight increase of 0.57 mg/kg in fertilized plots will not be considered a significant increase of concentration of ammonium in this discussion.

With a high fertilization rate, one would expect major increases in concentration of total nitrogen within the foliage. Also, one would expect nitrate and ammonium concentrations to increase within soil on fertilized plots in 2016. However, there were no increases of the concentrations of soil nitrogen, nitrate, or ammonium on fertilized plots in 2016. Soil NO$_3$ concentration significantly decreased in fertilized and control plots in 2016, while total concentration of soil nitrogen showed no significant changes. Soil NH$_4$ concentration had a major decrease in 2016 in control plots, and slightly increased in fertilized plots in 2016. Possible factors that attribute to this occurrence could be the rapid conversion of NH$_4$ to NO$_3$ accelerating leaching or the available NO$_3$ was used by herbaceous vegetation or may have been leached away by high rainfall (Tessier and Raynal, 2003; Nason and Myrold, 1992).

If the fertilizer accelerated leaching of cations into the soil profile, one would expect it to be represented in a decrease in foliage nutrient concentrations from the displacement of soil nutrients during the nitrification process (Long et al., 2009; Bailey et al., 2004; Miegroet and Cole, 1984; Bowersox and Ward, 1977). However, there were no significant decreases in foliage nutrient concentrations in 2016. One would also expect a decrease in pH due to the nitrification process in which H$^+$ would displace nutrients from the soil profile (Miegroet and Cole, 1984). In
this study, the pH of the soil did not show any significant increase in acidity. Therefore, it is likely that the fertilizer was not detected in the soil due to vegetation uptake or leaching due to high rainfall. The low N-fertilizer rate was applied on April 19-21, 2016 and recordings from the KEF indicate that less than 3 centimeters of rainfall was recorded 7 days after fertilization. Vegetation uptake may have had a greater impact on the detection of fertilizer more so than heavy rainfall.

Overall, the average foliar concentrations from this study are comparable to black cherry average foliage concentrations reported for non-limed plots in a nearby liming study (Long et al., 2011; 2009). In the low N-fertilized sites, foliar concentrations of Al, Ca, Fe, K, Mg, Mn, P, Zn and total N in 2015 (pre-treatment year) exceeded those for post-treatment year (2016). Previous research has shown that foliar nutrient concentrations in hardwood species differ significantly by crown position, tree size and age, leaf age, individual tree, and sampling dates, which could account for the nutrient variability shown in this study (Erdmann et al., 1988; Morrison, 1984; Bowersox and Ward, 1977; Mitchell, 1936; McHargue and Roy, 1932). Foliar samples were taken in different months during each growing season and at different stages of cherry scallop shell moth infestation. Trees chosen were not heavily defoliated, but may have been impacted by frass inputs associated with the defoliation of adjacent trees. In 2015, the samples were taken after defoliation in mid-August, yet in 2016 the samples were taken before defoliation in late July. Differences in leaf growth, defoliation, and time of collection could account for the statistically significant differences between foliar nutrient concentrations between the pre-treatment and post-treatment years. Different factors came into play each year to account for the decreases in foliar nutrient concentrations.
There was no significant response in seed production after one year of fertilizer application. However, Bjorkbom et al. (1979) concluded that seed production did increase just one year after fertilization with rates of application much higher than that used for the low N-fertilized sites. Seed is not dispersed uniformly over the area, so the number of seeds caught in each seed trap was highly variable. Perhaps an increase in seed traps could provide better representation of the area, but due to resource limitations this was not an option for this study (Bjorkbom et al., 1979). Black cherry seed production varies considerably depending on year and location. Grisez (1975) observed in a 12 year study of black cherry flower and fruit production in the Allegheny region that seed production is highly variable; some stands produced no seeds in off years while others years have trace to fair crops, as was observed in this study. A seed trapping study from 2010 to 2014 on the ANF has shown only one bumper seed crop year occurring in 2010 and below average seed production from 2011 to 2014 (Long et al., 2017). The observed decrease in seed production from previous studies may lead to a depletion of the seed bank, which may also contribute to the lack of new black cherry seedling response on the low N-fertilized sites. Further examination of seed production on the high N-fertilized sites would be of interest to confirm this relationship.

This study was not without limitations. Greater replication will increase the power of the experiment. However, during the setup of this study time, monetary constraints, and lack of sufficient personnel posed an issue. This study analyzed the results after only one year of fertilization, and analysis of fertilization over a longer period could provide results more comparable to similar studies (Auchmoody, 1982). Also the infestation of cherry scallop shell moth provides major threats to black cherry in the overstory. The cherry scallop shell moth likely influenced crown ratings and perhaps foliar nutrients. Taking the foliage samples at different
points in the growing season, mid-August in 2015 and July in 2016 introduces additional variation. Future studies may consider monitoring for damage from this pest in reference to foliar nutrient uptake.

**Conclusion**

The evidence from this study is not strong enough to support the hypothesis of an unintended consequence of the CAAA of 1990 (reduced nitrogen input) and that the addition of nitrogen to replace the amount that has decreased within the last 25 years may have a significant effect on black cherry regeneration, vigor, and seed production. The fertilizer application to the low N-fertilized sites did not have a significant effect on growth or establishment of black cherry regeneration after one year of fertilizer application. More time is needed to evaluate whether the relatively small amount of nitrogen missing from deposition is enough to contribute to the decline in black cherry vigor and regeneration in this region.

The higher fertilizer application rate showed increases in all sizes of black cherry regeneration with a significant increase of seedlings 0.3-0.9m in height. New birch seedlings were suppressed due to fertilizer effect and an increase in new red maple seedlings suggests that managers can be confident that they can regenerate red maple and reduce birch regeneration in shelterwood stands by applying N and P fertilizer. The sites that have black cherry present in advance regeneration can keep black cherry in the mix by adding relatively high levels of fertilizer which this study shows reduces birch new seedling growth and favors other species. It may be that the Allegheny Plateau is heading back to the low percentage of black cherry and will have a different mix of species in the future.
Table 1: Site characteristics in each of the five low N-fertilized sites with mean merchantable stand diameter (MMSD) (cm), total basal area (m²/ha), relative density (%), and species basal area (%).

<table>
<thead>
<tr>
<th>Area</th>
<th>Treatment</th>
<th>MMSD</th>
<th>Total Basal Area</th>
<th>Relative density</th>
<th>Black Cherry</th>
<th>Red Maple</th>
<th>Sugar Maple</th>
<th>American Beech, Cucumber, Magnolia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas Run</td>
<td>Fertilized</td>
<td>48.0</td>
<td>31.01</td>
<td>60.1</td>
<td>40.9</td>
<td>57.1</td>
<td>2.0</td>
<td>0.0</td>
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<tr>
<td></td>
<td>Control</td>
<td>45.7</td>
<td>32.4</td>
<td>63.3</td>
<td>56.6</td>
<td>36.7</td>
<td>6.6</td>
<td>0.1</td>
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<tr>
<td>Wetmore East</td>
<td>Fertilized</td>
<td>43.2</td>
<td>19.7</td>
<td>33.0</td>
<td>81.8</td>
<td>17.7</td>
<td>0.0</td>
<td>0.3</td>
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<tr>
<td></td>
<td>Control</td>
<td>52.1</td>
<td>21.1</td>
<td>35.4</td>
<td>66.3</td>
<td>31.1</td>
<td>2.6</td>
<td>0.0</td>
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<tr>
<td>Wetmore West</td>
<td>Fertilized</td>
<td>54.9</td>
<td>26.4</td>
<td>44.7</td>
<td>64.5</td>
<td>28.0</td>
<td>1.7</td>
<td>5.3</td>
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<tr>
<td></td>
<td>Control</td>
<td>53.3</td>
<td>24.0</td>
<td>43.2</td>
<td>66.0</td>
<td>24.0</td>
<td>9.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Kinzua Creek</td>
<td>Fertilized</td>
<td>46.7</td>
<td>21.2</td>
<td>39.2</td>
<td>79.5</td>
<td>6.5</td>
<td>9.8</td>
<td>2.8</td>
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<tr>
<td></td>
<td>Control</td>
<td>49.3</td>
<td>21.7</td>
<td>36.9</td>
<td>78.9</td>
<td>11.9</td>
<td>3.0</td>
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<td>Glad Run</td>
<td>Fertilized</td>
<td>37.1</td>
<td>25.0</td>
<td>51.9</td>
<td>70.2</td>
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<tr>
<td></td>
<td>Control</td>
<td>41.7</td>
<td>24.0</td>
<td>49.3</td>
<td>46.3</td>
<td>50.3</td>
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</table>

Table 2: Average thickness (cm) of Oi, Oe, Oa/A, and E horizons and average depth (cm) to B horizon for each site from top of mineral soil. * = horizon not always present.

<table>
<thead>
<tr>
<th>Site</th>
<th>Treatment</th>
<th>Oi</th>
<th>Oe</th>
<th>Oa/A</th>
<th>E</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas Run</td>
<td>Fertilized</td>
<td>1.68</td>
<td>1.73</td>
<td>1.47</td>
<td>0.91</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.13</td>
<td>1.47</td>
<td>1.17</td>
<td>*12.83</td>
<td>6.20</td>
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<tr>
<td>Wetmore East</td>
<td>Fertilized</td>
<td>1.73</td>
<td>2.08</td>
<td>2.84</td>
<td>*1.78</td>
<td>3.81</td>
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<tr>
<td></td>
<td>Control</td>
<td>1.83</td>
<td>3.25</td>
<td>3.10</td>
<td>Not Present</td>
<td>3.10</td>
</tr>
<tr>
<td>Wetmore West</td>
<td>Fertilized</td>
<td>1.52</td>
<td>3.66</td>
<td>6.60</td>
<td>*4.15</td>
<td>4.06</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.73</td>
<td>2.74</td>
<td>2.34</td>
<td>*4.23</td>
<td>4.83</td>
</tr>
<tr>
<td>Kinzua Creek</td>
<td>Fertilized</td>
<td>1.27</td>
<td>0.76</td>
<td>1.42</td>
<td>3.05</td>
<td>3.73</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.47</td>
<td>1.68</td>
<td>1.93</td>
<td>1.22</td>
<td>3.05</td>
</tr>
<tr>
<td>Glad Run</td>
<td>Fertilized</td>
<td>1.37</td>
<td>1.83</td>
<td>1.57</td>
<td>3.10</td>
<td>4.67</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.47</td>
<td>3.10</td>
<td>1.47</td>
<td>1.12</td>
<td>2.59</td>
</tr>
</tbody>
</table>
Table 3: ANOVA model probabilities associated with black cherry seedlings (#stems/ha) in the low N-fertilized sites.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Black Cherry (new)</th>
<th>Black Cherry (&lt;0.3m)</th>
<th>Black Cherry (0.3-0.9m)</th>
<th>Black Cherry (all)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>&lt;.0001</td>
<td>0.0006</td>
<td>0.1827</td>
<td>0.0006</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>0.8757</td>
<td>0.0723</td>
<td>0.3990</td>
<td>0.0709</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.6646</td>
<td>0.3719</td>
<td>0.0600</td>
<td>0.3546</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>0.2484</td>
<td>0.8236</td>
<td>0.7476</td>
<td>0.8196</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: ANOVA model probabilities associated with hardwood seedlings (#stems/ha) in the low N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Red Maple (new)</th>
<th>Sugar Maple (new)</th>
<th>Yellow Poplar (new)</th>
<th>Cucumber Magnolia (new)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>0.0444</td>
<td>0.4449</td>
<td>&lt;.0001</td>
<td>0.0438</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>*&lt;.0001</td>
<td>0.3370</td>
<td>0.0593</td>
<td>0.1906</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.8626</td>
<td>0.3370</td>
<td>0.9100</td>
<td>0.6498</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>0.7948</td>
<td>0.3370</td>
<td>0.3726</td>
<td>0.3724</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Mean and standard error of new seedling density (#stems/ha) of hardwoods and coverage of interfering species (%) in 2015 and 2016 at the low N-fertilized sites. Note that in 2015 the fertilized plots were not yet fertilized. * = denotes significant difference between years.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Cherry</td>
<td>4537.91 (2861.97)</td>
<td>5137.65 (2926.37)</td>
<td>4837.78 (1932.16)</td>
<td>5359.74 (2396.95)</td>
<td>4066.45 (2374.78)</td>
<td>4713.09 (1983.80)</td>
</tr>
<tr>
<td>Red Maple</td>
<td>2559.07 (612.89)</td>
<td>2422.69 (716.86)</td>
<td>2490.88 (445.18)</td>
<td>11595.71 (5185.76)</td>
<td>12273.78 (3226.24)</td>
<td>*11934.59 (1774.43)</td>
</tr>
<tr>
<td>Sugar Maple</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
<td>7.77 (3.47)</td>
<td>0.00 (0.00)</td>
<td>3.88 (3.88)</td>
</tr>
<tr>
<td>Yellow Poplar</td>
<td>163.57 (128.22)</td>
<td>136.30 (101.92)</td>
<td>149.94 (77.35)</td>
<td>62.32 (27.87)</td>
<td>97.37 (71.79)</td>
<td>79.84 (42.51)</td>
</tr>
<tr>
<td>Cucumber Magnolia</td>
<td>43.62 (19.51)</td>
<td>17.37 (7.77)</td>
<td>13.64 (10.09)</td>
<td>0.00 (0.00)</td>
<td>8.69 (3.88)</td>
<td>10.09 (1.94)</td>
</tr>
<tr>
<td>Birch</td>
<td>109.59 (97.12)</td>
<td>129.58 (82.05)</td>
<td>119.58 (60.03)</td>
<td>76.32 (24.51)</td>
<td>82.15 (20.43)</td>
<td>79.24 (15.07)</td>
</tr>
<tr>
<td>Rubus</td>
<td>5.00 (1.26)</td>
<td>4.20 (1.36)</td>
<td>*4.60 (0.88)</td>
<td>11.80 (4.22)</td>
<td>14.20 (3.95)</td>
<td>*13.00 (2.76)</td>
</tr>
<tr>
<td>Grass</td>
<td>12.00 (3.18)</td>
<td>11.40 (5.20)</td>
<td>*11.70 (2.88)</td>
<td>36.80 (10.75)</td>
<td>27.00 (6.04)</td>
<td>*31.90 (6.04)</td>
</tr>
<tr>
<td>Fern</td>
<td>3.00 (1.05)</td>
<td>2.00 (0.84)</td>
<td>*2.50 (0.65)</td>
<td>8.60 (2.14)</td>
<td>4.40 (2.04)</td>
<td>*6.50 (1.56)</td>
</tr>
</tbody>
</table>
Table 6: ANOVA model probabilities for the hardwood species (#stems/ha) and coverage of interfering species (%) at the five low N-fertilized sites. PC0 = pin cherry new seedlings; BIR0 = birch new seedlings. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Pin Cherry (new)</th>
<th>Birch (new)</th>
<th>Rubus</th>
<th>Grass</th>
<th>Fern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>0.6628</td>
<td>0.5273</td>
<td>0.1226</td>
<td>0.0143</td>
<td>0.1226</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>0.1966</td>
<td>0.5578</td>
<td>*0.0152</td>
<td>*0.0014</td>
<td>*0.0152</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.1716</td>
<td>0.8502</td>
<td>0.0907</td>
<td>0.3094</td>
<td>0.0907</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>*0.0797</td>
<td>0.9175</td>
<td>0.2798</td>
<td>0.3662</td>
<td>0.2798</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: ANOVA model probabilities associated with black cherry seedlings (#stems/ha) at the high N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Black Cherry (new)</th>
<th>Black Cherry (&lt;0.3m)</th>
<th>Black Cherry (0.3-0.9m)</th>
<th>Black Cherry (all)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>2</td>
<td>0.0076</td>
<td>0.2645</td>
<td>0.8810</td>
<td>0.2683</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>0.3831</td>
<td>0.1127</td>
<td>0.0204</td>
<td>0.1091</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.2063</td>
<td>0.5301</td>
<td>0.0010</td>
<td>0.4966</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>0.9967</td>
<td>0.5103</td>
<td>*0.0932</td>
<td>0.5004</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8: ANOVA model probabilities for hardwood species (#stems/ha) at the high N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Red Maple (new)</th>
<th>Pin Cherry (new)</th>
<th>Birch (new)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>2</td>
<td>0.1545</td>
<td>0.0879</td>
<td>0.7720</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>*0.0030</td>
<td>0.1073</td>
<td>0.5484</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.1738</td>
<td>0.0501</td>
<td>0.1073</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>0.5026</td>
<td>0.1922</td>
<td>*0.0808</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 9: Mean and standard error of new seedlings stem density (# stems/ha) of hardwoods in 2015 and 2016 of the high N-fertilized sites. Note that in 2015 the treated plots were not yet fertilized. * = denotes significant difference between years.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Cherry</td>
<td>5511.69 (4791.79)</td>
<td>2428.12 (826.39)</td>
<td>3969.90 (2281.28)</td>
<td>4478.53 (5720.55)</td>
<td>7543.62 (3913.71)</td>
<td>6011.07 (3174.60)</td>
</tr>
<tr>
<td>Red Maple</td>
<td>3265.41 (786.27)</td>
<td>5301.39 (2447.71)</td>
<td>4283.40 (1236.59)</td>
<td>18790.92 (2357.18)</td>
<td>13256.30 (4634.34)</td>
<td>16023.61 (2634.06)</td>
</tr>
<tr>
<td>Pin Cherry</td>
<td>305.13 (152.73)</td>
<td>53.96 (13.49)</td>
<td>179.55 (88.63)</td>
<td>90.78 (56.57)</td>
<td>26.98 (26.98)</td>
<td>58.88 (31.45)</td>
</tr>
<tr>
<td>Rubus</td>
<td>5.00 (1.53)</td>
<td>19.67 (5.49)</td>
<td>*12.33 (4.15)</td>
<td>13.67 (6.23)</td>
<td>35.67 (11.86)</td>
<td>*24.66 (7.75)</td>
</tr>
<tr>
<td>Grass</td>
<td>9.00 (4.51)</td>
<td>32.00 (7.77)</td>
<td>*20.50 (6.53)</td>
<td>24.00 (4.36)</td>
<td>48.00 (8.39)</td>
<td>*36.00 (6.83)</td>
</tr>
<tr>
<td>Fern</td>
<td>4.00 (1.53)</td>
<td>6.33 (2.60)</td>
<td>*5.17 (1.45)</td>
<td>11.67 (1.86)</td>
<td>11.33 (3.71)</td>
<td>*11.50 (1.86)</td>
</tr>
</tbody>
</table>

### Table 10: ANOVA model probabilities for percent coverage of interfering species in 2015 and 2016 in fertilized and control plots for the high N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Rubus</th>
<th>Fern</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>2</td>
<td>0.0297</td>
<td>0.3546</td>
<td>0.0014</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>*0.0387</td>
<td>*0.0440</td>
<td>*0.0008</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>*0.0078</td>
<td>0.7022</td>
<td>*&lt;0.0001</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>0.4630</td>
<td>0.6119</td>
<td>0.8487</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 11: Mean and standard error of percent coverage of interfering species in 2015 and 2016 treatment of the high N-fertilized sites. * = denotes significant difference between treatment.

<table>
<thead>
<tr>
<th>Species</th>
<th>2015 Control</th>
<th>2015 Fertilized</th>
<th>2016 Control</th>
<th>2016 Fertilized</th>
<th>Mean 2015</th>
<th>2016 Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubus</td>
<td>5.00 (1.53)</td>
<td>13.67 (6.23)</td>
<td>*9.33 (3.46)</td>
<td>19.67 (5.49)</td>
<td>35.67 (11.86)</td>
<td>*27.67 (6.85)</td>
</tr>
<tr>
<td>Grass</td>
<td>9.00 (4.51)</td>
<td>24.00 (4.36)</td>
<td>*16.50 (4.37)</td>
<td>32.00 (7.77)</td>
<td>48.00 (8.39)</td>
<td>*40.00 (6.24)</td>
</tr>
</tbody>
</table>
Table 12: ANOVA model probabilities for organic matter (%), pH, and soil C and N concentrations (mg/kg) associated with the low N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>OM</th>
<th>pH</th>
<th>C</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>0.7615</td>
<td>0.4609</td>
<td>0.0004</td>
<td>0.0105</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>0.6915</td>
<td>0.9161</td>
<td>0.0684</td>
<td>0.0156</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.1537</td>
<td>0.6806</td>
<td>0.9180</td>
<td>0.7786</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>0.1546</td>
<td>0.4006</td>
<td>0.1648</td>
<td>*0.1187</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13: ANOVA model probabilities for average concentrations of soil NO₃ and NH₄ (mg/kg) at the low N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>NO₃</th>
<th>NH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>0.2249</td>
<td>0.2056</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>*0.0015</td>
<td>*0.0010</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.1556</td>
<td>0.7035</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>*0.0365</td>
<td>0.4091</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 14: Mean and standard error of soil NH₄ concentration (mg/kg) in 2015 and 2016 at the low N-fertilized sites. * = denotes significant difference between years.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>6.73</td>
<td>2.50</td>
</tr>
<tr>
<td>Fertilized</td>
<td>16.15</td>
<td>0.46</td>
</tr>
<tr>
<td>Mean</td>
<td>*11.44</td>
<td>*1.48</td>
</tr>
<tr>
<td>(0.44)</td>
<td>(5.04)</td>
<td>(1.37)</td>
</tr>
<tr>
<td>(2.74)</td>
<td>(0.32)</td>
<td>(0.84)</td>
</tr>
<tr>
<td>NH₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>10.16</td>
<td>4.56</td>
</tr>
<tr>
<td>Fertilized</td>
<td>12.18</td>
<td>3.81</td>
</tr>
<tr>
<td>Mean</td>
<td>*11.17</td>
<td>*4.18</td>
</tr>
<tr>
<td>(1.90)</td>
<td>(2.91)</td>
<td>(0.63)</td>
</tr>
<tr>
<td>(1.67)</td>
<td>(0.09)</td>
<td>(0.32)</td>
</tr>
</tbody>
</table>

Table 15: ANOVA model probabilities for concentrations of soil NO₃ and NH₄ (mg/kg) associated with the high N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>NO₃</th>
<th>NH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>2</td>
<td>0.7205</td>
<td>0.1475</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>*0.0066</td>
<td>0.1684</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>*0.0426</td>
<td>*0.0286</td>
</tr>
<tr>
<td>Year* Fertilizer</td>
<td>1</td>
<td>0.2942</td>
<td>*0.0885</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 16: Mean and standard error of soil NO$_3$ concentration (mg/kg) and soil NH$_4$ concentration (mg/kg) of fertilized and control plots at the high N-fertilized sites. * = denotes significant difference between treatment.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Control</th>
<th>Fertilized</th>
<th>Mean</th>
<th>Control</th>
<th>Fertilized</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3$</td>
<td>7.11</td>
<td>(0.37)</td>
<td>1.83</td>
<td>(0.75)</td>
<td>3.51</td>
<td>(1.40)</td>
</tr>
<tr>
<td>NH$_4$</td>
<td>9.45</td>
<td>(2.67)</td>
<td>5.03</td>
<td>(0.98)</td>
<td>3.44</td>
<td>(1.61)</td>
</tr>
</tbody>
</table>

Table 17: Mean and standard error of soil NO$_3$ concentration (mg/kg) in 2015 and 2016 at the high N-fertilized sites. * = denotes significant difference between years.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Control</th>
<th>Fertilized</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3$</td>
<td>7.11</td>
<td>(0.37)</td>
<td>3.35</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>2016</td>
<td>1.83</td>
</tr>
<tr>
<td></td>
<td>1.83</td>
<td>1.40</td>
<td>(1.65)</td>
</tr>
<tr>
<td></td>
<td>0.40</td>
<td>(0.08)</td>
<td>(0.74)</td>
</tr>
<tr>
<td></td>
<td>1.12</td>
<td>(0.80)</td>
<td>(0.80)</td>
</tr>
</tbody>
</table>

Table 18: ANOVA model probabilities for organic matter (%), pH, and soil C and N concentrations (mg/kg) at the high N-fertilized sites.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>pH</th>
<th>OM</th>
<th>Soil C</th>
<th>Soil N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>2</td>
<td>0.8139</td>
<td>0.8093</td>
<td>0.8843</td>
<td>0.8889</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.4688</td>
<td>0.9299</td>
<td>0.4765</td>
<td>0.5869</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 19: ANOVA model probabilities for overstory measurements at the low N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Crown Density</th>
<th>Vigor</th>
<th>Seed/m$^2$</th>
<th>Seed/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>0.0469</td>
<td>0.1235</td>
<td>0.1767</td>
<td>0.2053</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>0.0002</td>
<td>*0.0335</td>
<td>*0.0110</td>
<td>*0.0085</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.1908</td>
<td>0.4424</td>
<td>0.5920</td>
<td>0.6493</td>
</tr>
<tr>
<td>Year*Fertilizer</td>
<td>1</td>
<td>*0.1266</td>
<td>0.4899</td>
<td>0.2993</td>
<td>0.3633</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 20: Mean and standard error of vigor, number of seeds per square foot basal area, and number of seeds per hectare in 2015 and 2016 associated with the low N-fertilized sites. * = denotes significant difference between years.

<table>
<thead>
<tr>
<th>Overstory Response</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Fertilized</td>
</tr>
<tr>
<td>Vigor</td>
<td>1.79 (0.06)</td>
<td>1.69 (0.08)</td>
</tr>
<tr>
<td>Seed/M² BA</td>
<td>273.87 (84.19)</td>
<td>453.02 (219.08)</td>
</tr>
<tr>
<td>Seed/Ha</td>
<td>90071.51 (31364.42)</td>
<td>136841.57 (62917.76)</td>
</tr>
</tbody>
</table>

Table 21: ANOVA model probabilities for black cherry foliar nutrient concentrations (mg/kg) of Mg, K, P, Ca, and C at the low N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>N</th>
<th>Mg</th>
<th>K</th>
<th>P</th>
<th>Ca</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>0.0706</td>
<td>0.3033</td>
<td>0.5175</td>
<td>0.1571</td>
<td>0.1320</td>
<td>0.5350</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>&lt;.0001</td>
<td>*0.0030</td>
<td>*0.0238</td>
<td>*0.0047</td>
<td>*0.0006</td>
<td>0.5900</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.7487</td>
<td>0.3095</td>
<td>0.6938</td>
<td>0.5171</td>
<td>0.2890</td>
<td>0.5332</td>
</tr>
<tr>
<td>Year * Fertilizer</td>
<td>1</td>
<td>*0.0606</td>
<td>0.3325</td>
<td>0.4693</td>
<td>0.8609</td>
<td>0.2812</td>
<td>0.4520</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 22: ANOVA model probabilities for black cherry foliar nutrient concentrations (mg/kg) of Al, Zn, Cu, Fe, and Mn at the low N-fertilized sites. * = denotes statistical significance.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Al</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>4</td>
<td>0.1787</td>
<td>0.2563</td>
<td>0.1929</td>
<td>0.0224</td>
<td>0.1552</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>*0.0014</td>
<td>0.0628</td>
<td>0.6823</td>
<td>*0.0230</td>
<td>*0.0002</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.7230</td>
<td>0.7283</td>
<td>0.8213</td>
<td>0.8862</td>
<td>0.2041</td>
</tr>
<tr>
<td>Year * Fertilizer</td>
<td>1</td>
<td>0.2649</td>
<td>0.4212</td>
<td>0.7919</td>
<td>0.4585</td>
<td>0.3521</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 23: Mean and standard error of black cherry foliar nutrient concentrations (mg/kg) of Al, Zn, Cu, Fe, Mn, Mg, K, P, Ca, and C from trees sampled in 2015 and 2016 in the low N-fertilized sites. * = denotes significant difference between years.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>*Al</td>
<td>43.16 (7.66)</td>
<td>19.08 (1.35)</td>
<td>36.18 (5.52)</td>
<td>22.76 (3.20)</td>
</tr>
<tr>
<td>C (g/kg)</td>
<td>504.63 (1188.78)</td>
<td>515.37 (14757.50)</td>
<td>505.73 (1415.12)</td>
<td>503.92 (5242.88)</td>
</tr>
<tr>
<td>*Ca</td>
<td>7134.39 (1351.25)</td>
<td>3022.79 (390.11)</td>
<td>5520.27 (857.83)</td>
<td>3016.50 (204.93)</td>
</tr>
<tr>
<td>Cu</td>
<td>7.47 (1.38)</td>
<td>8.29 (1.64)</td>
<td>7.52 (1.37)</td>
<td>7.69 (0.63)</td>
</tr>
<tr>
<td>*Fe</td>
<td>95.29 (20.40)</td>
<td>64.33 (3.14)</td>
<td>86.92 (13.41)</td>
<td>70.02 (2.57)</td>
</tr>
<tr>
<td>*K</td>
<td>15010.23 (1154.09)</td>
<td>12553.24 (294.49)</td>
<td>14756.68 (694.38)</td>
<td>13401.39 (440.94)</td>
</tr>
<tr>
<td>*Mg</td>
<td>2743.99 (351.12)</td>
<td>1757.72 (90.90)</td>
<td>2310.20 (225.44)</td>
<td>1746.97 (95.66)</td>
</tr>
<tr>
<td>*Mn</td>
<td>3205.16 (426.95)</td>
<td>1519.54 (140.66)</td>
<td>2592.07 (387.35)</td>
<td>1420.00 (36.71)</td>
</tr>
<tr>
<td>*P</td>
<td>1887.44 (234.27)</td>
<td>1399.64 (29.21)</td>
<td>1774.06 (161.88)</td>
<td>1334.22 (89.15)</td>
</tr>
<tr>
<td>Zn</td>
<td>22.55 (3.05)</td>
<td>18.58 (2.90)</td>
<td>26.42 (5.45)</td>
<td>17.02 (0.76)</td>
</tr>
</tbody>
</table>

Table 24: ANOVA model probabilities for black cherry foliage nutrient concentrations (mg/kg) of Al, Zn, Cu, Fe, and Mn at the high N-fertilized sites.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Al</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>2</td>
<td>0.6922</td>
<td>0.6820</td>
<td>0.5444</td>
<td>0.7447</td>
<td>0.0337</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.8427</td>
<td>0.4548</td>
<td>0.3226</td>
<td>0.6181</td>
<td>0.5941</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 25: ANOVA model probabilities for black cherry foliage nutrient concentrations (mg/kg) of Mg, K, P, Ca, and C at the high N-fertilized sites.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Mg</th>
<th>K</th>
<th>P</th>
<th>Ca</th>
<th>C</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>2</td>
<td>0.0392</td>
<td>0.2380</td>
<td>0.9808</td>
<td>0.0320</td>
<td>0.4286</td>
<td>0.1835</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>1</td>
<td>0.4509</td>
<td>0.9821</td>
<td>0.9377</td>
<td>0.5568</td>
<td>0.2946</td>
<td>0.2611</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 26: Mean and standard error black cherry foliage nutrient concentrations (mg/kg) of Al, Zn, Cu, Fe, Mn, Mg, K, P, Ca, C, and N at the high N-fertilized sites.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Control 2016</th>
<th>Fertilized 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>20.39 (1.28)</td>
<td>19.83 (1.71)</td>
</tr>
<tr>
<td>C (g/kg)</td>
<td>500.49 (2502.36)</td>
<td>503.89 (741.19)</td>
</tr>
<tr>
<td>Ca</td>
<td>3002.90 (563.13)</td>
<td>3128.47 (433.06)</td>
</tr>
<tr>
<td>Cu</td>
<td>9.56 (2.62)</td>
<td>6.00 (0.12)</td>
</tr>
<tr>
<td>Fe</td>
<td>66.79 (3.92)</td>
<td>63.45 (2.56)</td>
</tr>
<tr>
<td>K</td>
<td>12262.11 (280.56)</td>
<td>12247.32 (800.77)</td>
</tr>
<tr>
<td>Mg</td>
<td>1701.51 (151.20)</td>
<td>1633.74 (211.95)</td>
</tr>
<tr>
<td>Mn</td>
<td>1567.90 (248.86)</td>
<td>1511.28 (241.90)</td>
</tr>
<tr>
<td>N (g/kg)</td>
<td>26.54 (712.17)</td>
<td>27.27 (301.31)</td>
</tr>
<tr>
<td>P</td>
<td>1440.16 (21.55)</td>
<td>1443.97 (22.03)</td>
</tr>
<tr>
<td>Zn</td>
<td>20.32 (4.72)</td>
<td>15.12 (1.07)</td>
</tr>
</tbody>
</table>
Figure 1: Locations of the five sites, Glad Run, Kinzua Creek, Thomas Run, Wetmore East, and Wetmore West, in the Allegheny National Forest in northwestern Pennsylvania.
Figure 2: General layout of each of the low N-fertilized sites. Each of the five sites has two treatment plots: fertilized plot and a non-fertilized control plot as identified by the four-digit treatment identification numbers. Each treatment plot has a 0.24ha measurement plot. Each measurement plot is divided into eight subplots (represented by the single-digit points) to measure regeneration and six subplots to collect samples for soil analyses.
Figure 3: General layout of the high N-fertilized sites as indicated with the parallel black dots along with the shifted layout of one of the low N-fertilized sites.
Figure 4: Depiction of path and direction for application of polymer coated urea fertilizer to each plot. Two individuals walked 10 m (about a half of a chain) apart in one direction using a hand crank seed dispenser filled with fertilizer. When the edge of the plot was reached, the same line was walked in the opposite direction, but the fertilizer was dispersed in the other direction.
Figure 5: Average pin cherry new seedlings (#stems/ha) in 2015 and 2016 in fertilized and control plots at the low N-fertilized sites.

Figure 6: Average black cherry seedlings 0.3-0.9m in height (#stems/ha) in 2015 and 2016 in fertilized and control plots at the high N-fertilized sites.
Figure 7: Average birch new seedlings (#stems/ha) in 2015 and 2016 in fertilized and control plots at the high N-fertilized sites.

Figure 8: Average soil N concentration (g/kg) in 2015 and 2016 in fertilized and control plots at the low N-fertilized sites.
Figure 9: Average concentrations (mg/kg) of soil NO₃ in 2015 and 2016 in fertilized and control plots at the low N-fertilized sites.

Figure 10: Average concentrations (mg/kg) of soil NH₄ in 2015 and 2016 in fertilized and control plots at the high N-fertilized sites.
Figure 11: Average crown density (%) in 2015 and 2016 in fertilized and control plots at the low N-fertilized sites.

Figure 12: Average concentrations (mg/kg) of foliage N in 2015 and 2016 in fertilized and control plots in the low N-fertilized sites.
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### Appendix

Table 1: Site description of each area.

<table>
<thead>
<tr>
<th>Area</th>
<th>Plot Number</th>
<th>Treatment</th>
<th>Landform</th>
<th>Terrain</th>
<th>Slope Length</th>
<th>Percent Slope</th>
<th>Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas Run</td>
<td>1050</td>
<td>Fertilized</td>
<td>Summit</td>
<td>Plane</td>
<td>Null</td>
<td>&lt;1</td>
<td>South</td>
</tr>
<tr>
<td></td>
<td>1051</td>
<td>Control</td>
<td>Summit</td>
<td>Plane</td>
<td>Null</td>
<td>1</td>
<td>South</td>
</tr>
<tr>
<td>Wetmore East</td>
<td>1052</td>
<td>Fertilized</td>
<td>Summit/Shoulder/Upper Slope</td>
<td>Plane</td>
<td>Null</td>
<td>1.5</td>
<td>East</td>
</tr>
<tr>
<td></td>
<td>1053</td>
<td>Control</td>
<td>Summit</td>
<td>Plane</td>
<td>Short/Null</td>
<td>2</td>
<td>North</td>
</tr>
<tr>
<td>Wetmore West</td>
<td>1054</td>
<td>Fertilized</td>
<td>Upper Slope</td>
<td>Plane</td>
<td>Null</td>
<td>1</td>
<td>East</td>
</tr>
<tr>
<td></td>
<td>1055</td>
<td>Control</td>
<td>Upper Slope</td>
<td>Plane</td>
<td>Null</td>
<td>1</td>
<td>East</td>
</tr>
<tr>
<td>Kinzua Creek</td>
<td>1056</td>
<td>Fertilized</td>
<td>Summit</td>
<td>Convex/Plane</td>
<td>Long/Null</td>
<td>&lt;1</td>
<td>North, Northeast</td>
</tr>
<tr>
<td></td>
<td>1057</td>
<td>Control</td>
<td>Summit</td>
<td>Plane</td>
<td>Flat</td>
<td>&lt;1</td>
<td>North, Northeast</td>
</tr>
<tr>
<td>Glad Run</td>
<td>1058</td>
<td>Fertilized</td>
<td>Summit</td>
<td>Plane/Concave</td>
<td>Null</td>
<td>&lt;1</td>
<td>North, Northeast</td>
</tr>
<tr>
<td></td>
<td>1059</td>
<td>Control</td>
<td>Summit</td>
<td>Plane</td>
<td>Null</td>
<td>&lt;1</td>
<td>North, Northeast</td>
</tr>
</tbody>
</table>
### Table 2: Vigor index categories.

<table>
<thead>
<tr>
<th>Vigor Index Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Healthy</strong>: trees appear to be in reasonably good health; no major branch mortality, crown is reasonably normal within stand situation, less than 10 percent branch or twig mortality, defoliation or discoloration present.</td>
</tr>
<tr>
<td>2</td>
<td><strong>Light decline</strong>: trees had branch mortality, twig dieback, or foliage discoloration present in 10 to 25 percent of the crown, broken branches or crown area missing based on presence of old snags is less than 26 percent.</td>
</tr>
<tr>
<td>3</td>
<td><strong>Moderate decline</strong>: trees had branch mortality, twig dieback, or foliage discoloration present in 26 to 50 percent of the crown, broken branches, or crown area missing based on presence of old snags is 50 percent or less.</td>
</tr>
<tr>
<td>4</td>
<td><strong>Severe decline</strong>: trees had branch mortality, twig dieback, or foliage discoloration present in more than 50 percent of the crown, but foliage is still present to indicate the tree is alive, broken branches, or crown area missing based on presence of old snags is more than 50 percent , branch breakage and crown are missing is recorded in the 10 percent classes</td>
</tr>
<tr>
<td>5</td>
<td><strong>Naturally dead</strong>: Trees are dead, either standing or down, phloem under bark has brown streaks, few epicormics shoots may be present on the bole</td>
</tr>
</tbody>
</table>

### Table 3: Mean concentrations (mg/kg) of soil micronutrients and Na at the low N-fertilized sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas Run</td>
<td>1.159</td>
<td>250.384</td>
<td>28.796</td>
<td>1.789</td>
<td>9.949</td>
</tr>
<tr>
<td>Wetmore East</td>
<td>0.704</td>
<td>201.018</td>
<td>43.387</td>
<td>1.089</td>
<td>9.787</td>
</tr>
<tr>
<td>Wetmore West</td>
<td>0.326</td>
<td>400.551</td>
<td>21.035</td>
<td>1.178</td>
<td>10.541</td>
</tr>
<tr>
<td>Kinzua Creek</td>
<td>1.393</td>
<td>266.541</td>
<td>32.855</td>
<td>1.327</td>
<td>9.952</td>
</tr>
<tr>
<td>Glad Run</td>
<td>0.650</td>
<td>273.774</td>
<td>30.096</td>
<td>1.403</td>
<td>9.330</td>
</tr>
</tbody>
</table>

### Table 4: Mean concentrations (mg/kg) of soil macronutrients and Al at the low N-fertilized sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Al</th>
<th>Ca</th>
<th>K</th>
<th>Mg</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td>Thomas Run</td>
<td>528.672</td>
<td>32.981</td>
<td>40.340</td>
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<td>2.069</td>
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<tr>
<td>Wetmore East</td>
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<td>44.098</td>
<td>8.909</td>
<td>3.048</td>
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<tr>
<td>Wetmore West</td>
<td>537.756</td>
<td>44.007</td>
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<td>11.623</td>
<td>1.225</td>
</tr>
<tr>
<td>Kinzua Creek</td>
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<td>35.699</td>
<td>47.936</td>
<td>9.985</td>
<td>1.181</td>
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<tr>
<td>Glad Run</td>
<td>464.185</td>
<td>27.844</td>
<td>39.701</td>
<td>7.755</td>
<td>1.817</td>
</tr>
</tbody>
</table>

**COOKPORT SERIES**

**LOCATION** COOKPORT WV+MD PA
Established Series
Rev. AWD-DGF-ART
08/2003

The Cookport series consists of deep and very deep, moderately well drained soils formed in residuum weathered primarily from sandstone but includes some materials from shale and siltstone. Permeability is moderate above the fragipan and slow in the fragipan. Slope ranges from 0 to 25 percent. Mean annual precipitation is about 50 inches, and mean annual temperature is about 52 degrees F.

**TAXONOMIC CLASS:** Fine-loamy, mixed, active, mesic Aquic Fragiudults

**TYPICAL PEDON:** Cookport loam, 3 to 8 percent slopes - in a hardwood forest. (Colors are for moist soil unless otherwise noted.)

- **Oe** -- 0 to 1 inch; moderately decomposed leaf litter.
- **A** -- 1 to 3 inches; dark grayish brown (10YR 4/2) loam; moderate medium granular structure; very friable; few coarse and very coarse roots, and many very fine, fine, and medium roots; very strongly acid; clear wavy boundary. (1 to 5 inches thick)
- **BA** -- 3 to 9 inches; brown (10YR 4/3) loam; moderate fine subangular blocky structure; friable; few coarse and very coarse roots, and many very fine, fine and medium roots; very strongly acid; clear wavy boundary. (0 to 10 inches thick)
- **Bt1** -- 9 to 17 inches; yellowish brown (10YR 5/6) loam; moderate medium and coarse subangular blocky structure; friable; few very fine, coarse and very coarse roots, and many fine and medium roots; few faint clay films on faces of peds and in pores; very strongly acid; clear wavy boundary.
- **Bt2** -- 17 to 22 inches; yellowish brown (10YR 5/4) loam; moderate medium subangular blocky structure; friable; few very fine, fine, and medium roots; few distinct clay films on faces of peds and in pores; common medium faint brown (10YR 5/3) and common medium distinct grayish brown (10YR 5/2) iron depletions, and common medium distinct brownish yellow (10YR 6/6) masses of iron accumulation; very strongly acid; abrupt wavy boundary. (combined thickness of Bt horizon is 8 to 18 inches)
- **Btx** -- 22 to 42 inches; brown (10YR 5/3) loam; moderate coarse and very coarse prismatic structure parting to moderate medium subangular blocky; firm; few very fine roots along faces of peds; few faint clay films in pores; common medium faint grayish brown (10YR 5/2) redoximorphic depletions and common medium distinct brownish yellow (10YR 6/6) masses of iron accumulation in vertical streaks throughout the horizon; very strongly acid; clear wavy boundary. (12 to 24 inches)
- **C** -- 42 to 49 inches; mixed yellowish brown (10YR 5/6), light yellowish brown (10YR 6/4), strong brown (7.5YR 4/6) and light brownish gray (10YR 6/2) loam; massive; firm; 10 percent sandstone rock fragments; very strongly acid; abrupt wavy boundary.
- **R** -- 49 inches; hard gray sandstone.
TYPE LOCATION: Greenbrier County, West Virginia; on Muddy Creek Mountain; approximately 2.7 miles east-northeast of the intersection of State Route 12 and State Route 40; approximately 0.5 mile southeast of State Route 40; USGS Fort Spring topographic quadrangle; latitude 37 degrees 44 minutes 47 seconds N. and longitude 80 degrees 35 minutes 26 seconds W.

RANGE IN CHARACTERISTICS: The thickness of the solum ranges from 28 to 48 inches. Depth to the fragipan ranges from 16 to 30 inches. Depth to bedrock is 40 to 72 inches. Rock fragments range from 0 to 30 percent in the solum and from 10 to 65 percent in the C horizon. Reaction is strongly acid through extremely acid in all horizons below an Ap horizon. The surface 2 to 8 inches in some pedons has a sequence of horizons similar to Spodosols. The A horizon has hue of 7.5YR, 10YR or 2.5Y, value of 2 or 3, and chroma of 2 or 3. Texture is silt loam, loam or sandy loam in the fine-earth fraction. The BA horizon has hue of 7.5YR, 10YR or 2.5Y, value of 4 or 5, and chroma of 3 to 6. Texture is silt loam, loam or sandy loam in the fine-earth fraction. The Bt horizon has hue of 7.5YR, 10YR or 2.5Y, value of 4 to 6, and chroma of 4 to 8. Texture is loam, sandy loam, clay loam, or sandy clay loam in the fine-earth fraction. The Btx horizon has hue of 7.5YR, 10YR, or 2.5Y, value of 4 or 5, and chroma of 3 to 8. Texture is loam, sandy clay loam, sandy loam, or clay loam in the fine-earth fraction. Consistence is very firm or firm and brittle. The C horizon has hue of 10YR or 2.5Y, value of 4 to 6, and chroma of 2 to 6. Texture is loam, sandy clay loam, or sandy loam in the fine-earth fraction.

COMPETING SERIES: These are the Belvoir, Buchanan, Calverton, Ernest, Glenville, Kedron and Raritan series in the same family. The Califon, Clarksburg, Monongahela, Nolo, and Tilsit series are in related families. Calverton and Ernest soils have less than 20 percent sand in the B2 horizons. Belvoir soils have rock fragments of quartz and granodiorite in the control section. Buchanan and Raritan soils have sola thicker than 40 inches. Glenville soils lack sandstone fragments and have sola strongly influenced by micaceous rocks. Kedron soils have hues of 5YR redder in the B horizon. Califon and Monongahela soils lack redoximorphic depletions in the upper 10 inches of the argillic horizon. Nolo soils have redoximorphic depletions immediately below the A or Ap horizon. Tilsit soil has less than 15 percent fine sand or coarser in the particle size control section.

GEOGRAPHIC SETTING: Cookport soils are on broad nearly level to gently sloping ridgetops and moderately steep sideslopes. They developed in material weathered from interbedded sandstone, siltstone and in places, a minor component of shale. The climate is humid cool temperate. Average annual precipitation ranges from 40 to 60 inches and the growing season is 120 to 160 days.

GEOGRAPHICALLY ASSOCIATED SOILS: Cookport soils are in a drainage sequence with the well drained Clymer, Hazleton, and Dekalb soils and the poorly drained Lickdale and Nolo soils. Gilpin, Wharton, and Cavode soils commonly are nearby, lack a fragipan and formed in finer textured material.

DRAINAGE AND PERMEABILITY: Moderately well drained. The potential for surface runoff ranges from medium to very high; permeability above the fragipan is moderate and slow in the fragipan.

USE AND VEGETATION: Much of the soil remains in forest; mainly oaks, cherry, maple. Cleared areas are cropped to corn, small grain, hay and buckwheat or are in pasture.

MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Morgantown, West Virginia.

SERIES ESTABLISHED: Indiana County, Pennsylvania, 1931.

REMARKS: Diagnostic horizons and features recognized in this pedon are: ochric epipedon - the zone from the surface to a depth of 9 inches (A, BA horizons); argillic horizon - the zone from 9 to 42 inches (Bt1, Bt2, Btx horizons); fragipan - the zone from 22 to 42 inches (Btx).

HAZLETON SERIES

LOCATION HAZLETON PA+KY MD NJ OH VA WV
Established Series
Rev. EAW-AWD-ART
05/2002

The Hazleton series consists of deep and very deep, well drained soils formed in residuum of acid gray, brown or red sandstone on uplands. Slope ranges from 0 to 80 percent. Permeability is moderately rapid to rapid. Mean annual precipitation is about 48 inches. Mean annual air temperature is about 51 degrees F.

TAXONOMIC CLASS: Loamy-skeletal, siliceous, active, mesic Typic Dystrudepts

TYPICAL PEDON: Hazleton sandy loam, very stony, from an area of Hazleton channery sandy loam, 0 to 3 percent slopes, in hardwood forest at an elevation of 1880 feet. (Colors for moist soil unless otherwise stated.)

Oe--0 to 2 inches; dark reddish brown (5YR 2/2) partially decayed forest litter; abrupt wavy boundary. (1 to 2 inches thick)

E--2 to 4 inches; dark gray (10YR 4/1) sandy loam; weak fine granular structure; very friable, nonsticky, nonplastic; common fine and medium roots; 5 percent rock fragments; very strongly acid; abrupt wavy boundary. (0 to 9 inches thick)

Bhs--4 to 6 inches; dark reddish brown (5YR 3/3) sandy loam; weak medium granular structure; very friable, nonsticky, slightly plastic; common fine and medium roots; 5 percent rock fragments; very strongly acid; abrupt wavy boundary.

Bs--6 to 8 inches; yellowish red (5YR 4/6) channery sandy loam; weak very fine granular structure; very friable, nonsticky, nonplastic; common fine and medium roots; 15 percent rock fragments; very strongly acid; clear wavy boundary.

Bw1--8 to 17 inches; reddish yellow (7.5YR 6/6) very channery sandy loam; weak fine subangular blocky structure; very friable, nonsticky, nonplastic; common medium and coarse roots; 40 percent rock fragments; very strongly acid; gradual wavy boundary.

Bw2--17 to 24 inches; strong brown (7.5YR 5/6) very channery sandy loam; weak fine subangular blocky structure; friable, nonsticky, nonplastic; common medium roots; 45 percent rock fragments; very strongly acid; gradual wavy boundary.

Bw3--24 to 34 inches; reddish yellow (7.5YR 6/8) extremely channery sandy loam; weak fine subangular blocky structure; friable, nonsticky, nonplastic; few fine roots; 60 percent rock fragments; very strongly acid; gradual wavy boundary. (Combined thickness of the B horizon is 24 to 39 inches.)
C--34 to 58 inches; reddish yellow (7.5YR 6/6) extremely channery coarse sandy loam; massive; friable, nonsticky, nonplastic; 60 percent rock fragments; very strongly acid; diffuse wavy boundary. (13 to 22 inches thick)

R--58 to 72 inches; yellowish brown (10YR 5/6) sandstone. Excavation difficulty is high. Excavation by a tile spade is difficult but easily done by pick using over-the-head swing.

**TYPE LOCATION:** Warren County, Pennsylvania; Watson Township, 0.5 mile southeast of the intersection of S.R. 3005 and Hearts Content Road (S.R. 2002), 500 feet west of road. USGS Cobham, PA topographic quadrangle; Latitude 41 degrees, 43 minutes, 19.2 seconds N, Longitude 79 degrees, 15 minutes, 31.2 seconds W. (NAD 83)

**RANGE IN CHARACTERISTICS:** Solum thickness ranges from 25 to 50 inches. Depth to lithic contact ranges from 40 to 80 inches. Rock fragments of angular sandstone, dominantly less than 10 inches in size, range from 5 to 70 percent in individual horizons of the solum and from 35 to 80 percent in the C horizon. Boulders, stones, flags and channers cover about 5 to 60 percent of the surface of some pedons. The control section averages less than 18 percent clay. Reaction ranges from strongly acid through extremely acid throughout where unlimed. The A horizon has hue of 10YR, value of 2 to 4, and chroma of 1 to 4. The Ap horizon, where present, has hue of 10YR, value of 2 to 4, and chroma of 1 to 4. The A or Ap horizon is fine sandy loam, sandy loam, or loam in the fine-earth fraction. The E horizon has hue of 10YR, value of 4 or 5 and chroma of 1 to 4. It is fine sandy loam, sandy loam, or loam in the fine-earth fraction.

The B horizon has hue of 10YR to 5YR, value of 3 to 6, and chroma of 3 to 8. The B horizon has more than 40 percent sand. The upper part of the B horizon is sandy loam or loam in the fine-earth fraction, and the lower part may range from loam to loamy sand in the fine-earth fraction. Structure is weak or moderate, fine to coarse subangular blocky, but can be granular in the Bh horizon.

The C horizon has hue of 5YR to 2.5Y, value of 3 to 6, and chroma of 3 to 8. It ranges from loam to loamy sand in the fine-earth fraction.

**COMPETING SERIES:** Dekalb and Wallen are the only other series in this family. They both have lithic contact 20 to 40 inches below the surface. Lehew, Marbleyard, and Hailey are in related families. Lehew and Marbleyard have lithic contact 20 to 40 inches below the surface. Hailey soils formed in cherty limestone residuum and are in a higher cation exchange activity class. The Sherando and Varilla series may become competitors as their classification is updated to the eighth edition of Soil Taxonomy. Sherando soils formed in water sorted materials. Varilla soils formed in colluvium.

**GEOGRAPHIC SETTING:** Hazleton soils developed in residuum from acid gray, brown, or red sandstone and are found on summits, shoulders, and the upper third of backslopes. Slopes are usually convex with gradients of 0 to 80 percent. The mean annual precipitation ranges from 36 to 60 inches, and the mean annual air temperature ranges from 47 to 55 degrees F. The average annual frost free season is 110 to 180 days.

**GEOGRAPHICALLY ASSOCIATED SOILS:** The competing Dekalb and Lehew soils and the Clymer, Cookport Edgemont, and Leetonia soils are on the same landscape. Buchanan, Gilpin, Laidig, and Rayne soils are nearby. Buchanan, Cookport, and Laidig soils have fragipans. Gilpin soils have bedrock within 40 inches. Clymer, Edgemont, and Rayne soils have argillic horizons. Leetonia soils have spodic horizons.
DRAINAGE AND PERMEABILITY: Well drained. The potential for surface runoff potential is negligible to high. Permeability is moderately rapid to rapid.

USE AND VEGETATION: Most Hazleton soils are in woodland of mixed oaks, maple, cherry and occasional conifers. Some areas have been cleared for pasture and cropland.

DISTRIBUTION AND EXTENT: Kentucky, Maryland, New Jersey, Pennsylvania, West Virginia, Virginia and possibly Ohio. MLRA’s 124, 126, 127, 147, 148. The series is of large extent.

MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Morgantown, West Virginia


REMARKS: The Hazleton series was in a mixed mineralogy family until 1995. Diagnostic horizons and features recognized in this pedon are:
1. Ochric epipedon - the zone from the surface of the soil to a depth of 8 inches (E, Bhs, and Bs horizons).
2. Cambic horizon - the zone from 8 to 34 inches (Bw horizon).
3. Loamy-skeletal feature - greater than 35 percent by volume weighted average rock fragments in the particle-size control section.

ADDITIONAL DATA: Laboratory data is available on the typifying pedon, Pennsylvania State University sample number S1967-PA-062-001(1-11).

SAS program code for data analysis

Analysis of variance to test for year and fertilizer effects

***density***;
proc GLM data=SAS2Density plots=diagnostics;
class block year fert;
model density= block year fert year*fert;
run;

***vigor***;
proc GLM data=SAS2vigor plots=diagnostics;
class block year trmt;
model vigor= block year trmt year*trmt;
run;

***BC0***;
proc GLM data=SAS2BCstems plots=diagnostics;
class block year trmt;
model BC0= block year trmt year*trmt;
run;

***BCLT1***;
proc GLM data=SAS2BCstems plots=diagnostics;
class block year trmt;
model BCLT1= block year trmt year*trmt;
run;

***BC13***;
proc GLM data=SAS2BCstems plots=diagnostics;
class block year trmt;
model BC13= block year trmt year*trmt;
run;
***BCAll***;
proc GLM data=SAS2BCstems plots=diagnostics;
   class block year trmt;
   model BCAAll= block year trmt year*trmt;
run;
***BCHT***;
proc GLM data=SAS2BCstems plots=diagnostics;
   class block year trmt;
   model BCHT= block year trmt year*trmt;
run;

***foliage Al***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model Al= block year trmt year*trmt;
run;
***foliage Ca***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model Ca= block year trmt year*trmt;
run;

***foliage Cu***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model Cu= block year trmt year*trmt;
run;
***foliage Fe***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model Fe= block year trmt year*trmt;
run;
***foliage K***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model K= block year trmt year*trmt;
run;
***foliage Mg***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model Mg= block year trmt year*trmt;
run;
***foliage Mn***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model Mn= block year trmt year*trmt;
run;
***foliage P***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model P= block year trmt year*trmt;
run;
***foliage Zn***;
proc GLM data=SAS2foliagenutrients plots=diagnostics;
   class block year trmt;
   model Zn= block year trmt year*trmt;
run;
***foliage Total C***;
proc GLM data=SAS2foliagetotalcn plots=diagnostics;
class block year trmt;
model C_ppm= block year trmt year*trmt;
run;

***foliage Total N***;
proc GLM data=SAS2foliagetotalcn plots=diagnostics;
class block year trmt;
model N_ppm= block year trmt year*trmt;
run;

***redmaple zero***;
proc GLM data=SAS2hardwood plots=diagnostics;
class block year trmt;
model RM0= block year trmt year*trmt;
run;

***sugar maple zero***;
proc GLM data=SAS2hardwood plots=diagnostics;
class block year trmt;
model SM0= block year trmt year*trmt;
run;

***yellow poplar zero***;
proc GLM data=SAS2hardwood plots=diagnostics;
class block year trmt;
model YP0= block year trmt year*trmt;
run;

***cucumber magnolia zero***;
proc GLM data=SAS2hardwood plots=diagnostics;
class block year trmt;
model CUC0= block year trmt year*trmt;
run;

***Soil NO3***;
data no3;
set SAS2NO3NH4;
if month=april then delete;
if month=june then delete;
proc GLM data=no3 plots=diagnostics;
class block year trmt;
model no3= block year trmt year*trmt;
run;

***Soil Nh4***;
data nh4;
set SAS2NO3NH4;
if month=april then delete;
if month=june then delete;
proc GLM data=nh4 plots=diagnostics;
class block year trmt;
model nh4= block year trmt year*trmt;
run;

***Soil monthly no3***;
data sequence;
set SAS2NO3NH4;
if year=2015 then delete;
proc GLM data=sequence plots=diagnostics;
class block month trmt;
model no3= block month trmt month*trmt;
run;
***Soil monthly nh4***;
data sequence2 ;
set SAS2NO3NH4;
if year=2015 then delete;
proc GLM data=sequence2 plots=diagnostics;
class block month trmt;
model nh4= block month trmt month*trmt;
run;

***OM***;
proc GLM data=SAS2OM plots=diagnostics;
class block year trmt;
model OM= block year trmt year*trmt;
run;

***pH***;
proc GLM data=SAS2ph plots=diagnostics;
class block year trmt;
model ph= block year trmt year*trmt;
run;

***seed***;
proc GLM data=SAS2seed plots=diagnostics;
class block year trmt;
model seed_sqft= block year trmt year*trmt;
run;
proc GLM data=SAS2seed plots=diagnostics;
class block year trmt;
model seed_acre= block year trmt year*trmt;
run;

***Soil N***;
proc GLM data=SAS2SoilCN plots=diagnostics;
class block year trmt;
model N_ppm= block year trmt year*trmt;
run;
***Soil C***;
proc GLM data=SAS2SoilCN plots=diagnostics;
class block year trmt;
model C_ppm= block year trmt year*trmt;
run;

SAS program code for data analysis for ANF plots.

*** ANF OM***;
proc GLM data=SAS2ANFOM plots=diagnostics;
class block trmt;
model OM= block trmt;
run;
*** ANF pH***;
proc GLM data=SAS2ANFpH plots=diagnostics;
class block trmt;
model ph = block trmt;
run;
*** ANF black cherry zero***;
proc GLM data=SAS2ANFBCstems plots=diagnostics;
class block year trmt;
model BC0 = block year trmt year*trmt;
run;
*** ANF black cherry less than 1ft***;
proc GLM data=SAS2ANFBCstems plots=diagnostics;
class block year trmt;
model BCLT1 = block year trmt year*trmt;
run;
*** ANF black cherry between 1to3 ft***;
proc GLM data=SAS2ANFBCstems plots=diagnostics;
class block year trmt;
model BC13 = block year trmt year*trmt;
run;
*** ANF black cherry all stems***;
proc GLM data=SAS2ANFBCstems plots=diagnostics;
class block year trmt;
model BCALL = block year trmt year*trmt;
run;
*** ANF black cherry tallest***;
proc GLM data=SAS2ANFBCstems plots=diagnostics;
class block year trmt;
model BCHT = block year trmt year*trmt;
run;
*** ANF foliage Al***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model Al = block trmt;
run;
*** ANF Ca***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model Ca = block trmt;
run;
*** ANF Cu***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model Cu = block trmt;
run;
*** ANF Fe***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model Fe = block trmt;
run;
*** ANF K***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model K = block trmt;
run;
*** ANF Mg***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model Mg = block trmt;
run;
*** ANF Mn***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model Mn = block trmt;
run;
*** ANF P***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model P = block trmt;
run;
*** Zn***;
proc GLM data=SAS2ANFfoliagenutrients plots=diagnostics;
class block trmt;
model Zn = block trmt;
run;
*** ANF foliage total n***;
proc GLM data=SAS2ANFfoliagetotalcn plots=diagnostics;
class block trmt;
model N_ppm = block trmt;
run;
*** ANF foliage total c***;
proc GLM data=SAS2ANFfoliagetotalcn plots=diagnostics;
class block trmt;
model C_ppm = block trmt;
run;
*** ANF BC zero***;
proc GLM data=SAS2ANFhardwood plots=diagnostics;
class block year trmt;
model BC0= block year trmt year*trmt;
run;
*** ANF RM zero***;
proc GLM data=SAS2ANFhardwood plots=diagnostics;
class block year trmt;
model RM0= block year trmt year*trmt;
run;
*** ANF no3 ***;
proc GLM data=SAS2ANFNO3NH4 plots=diagnostics;
class block trmt;
model no3= block trmt;
run;
*** ANF nh4 ***;
proc GLM data=SAS2ANFNO3NH4 plots=diagnostics;
class block trmt;
model nh4= block trmt;
run;
*** ANF soil C***;
proc GLM data=SAS2ANFSoilCN plots=diagnostics;
class block trmt;
model C_ppm= block trmt;
run;
*** ANF soil N***;
proc GLM data=SAS2ANFSoilCN plots=diagnostics;
class block trmt;
model N_ppm= block trmt;
run;
*** ANF rubus zero***;
proc GLM data=SAS2ANFyuckwood plots=diagnostics;
class block year trmt;
model rubus = block year|trmt;
run;
*** ANF ferncov zero***;
proc GLM data=SAS2ANFyuckwood plots=diagnostics;
class block year trmt;
model ferncov = block year|trmt;
run;
*** ANF grscov zero***;
proc GLM data=SAS2ANFyuckwood plots=diagnostics;
class block year trmt;
model grscov = block year|trmt;
run;
*** ANF birch zero***;
proc GLM data=SAS2ANFyuckwood plots=diagnostics;
class block year trmt;
model BIR0= block year|trmt;
run;
*** ANF pin cherry zero***;
proc GLM data=SAS2ANFyuckwood plots=diagnostics;
class block year trmt;
model PC0 = block year|trmt;
run;
Vita

Name: Nicolette A. Fruehan

Education

<table>
<thead>
<tr>
<th>Name and Location</th>
<th>Dates</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School Montrose Area Jr./Sr. High</td>
<td>2006-2010</td>
<td>--</td>
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<tr>
<td>School Montrose, PA</td>
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<tr>
<td>Undergraduate University of Pittsburgh at</td>
<td>2010-2014</td>
<td>B.S.</td>
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<tr>
<td>Bradford Bradford, PA</td>
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<tr>
<td>Graduate SUNY College of Environmental</td>
<td>2015-2018</td>
<td>M.S.</td>
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<tr>
<td>Science and Forestry Syracuse, NY</td>
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Employment

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<tr>
<th>Employer and Location</th>
<th>Dates</th>
<th>Position</th>
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<td>University of Pittsburgh at Bradford Bradford, PA</td>
<td>2011-2014</td>
<td>Chemistry Lab Aide</td>
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<tr>
<td>USDA Forest Service Bradford, PA</td>
<td>Summer 2013</td>
<td>Intern- Biological Science</td>
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<tr>
<td>USDA Forest Service Bradford, PA</td>
<td>Summer 2014, 2015, 2016</td>
<td>Biological Science</td>
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<tr>
<td>McKeever Environmental Education Center Sandy Lake, PA</td>
<td>2014</td>
<td>Environmental Educator</td>
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<tr>
<td>Lalor Family Dental Vestal, NY</td>
<td>2015</td>
<td>Dental Assistant</td>
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<tr>
<td>SUNY College of Environmental Science and Forestry</td>
<td>2015-2016, 2017-2018</td>
<td>Research Assistant</td>
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<tr>
<td>SUNY College of Environmental Science and Forestry</td>
<td>Fall 2016</td>
<td>Graduate Assistant</td>
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<tr>
<td>USDA Natural Resources Conservation Service</td>
<td>2017- Present</td>
<td>Soil Conservationist</td>
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