Establishment of a Temperate Agro-forest

C.M. Feldhake and C.M. Schumann
USDA-ARS Appalachian Farming Systems Research Center, 1224 Airport Rd. Beaver, West Virginia, 25813 USA

Key words: edge effects, PAR, soil moisture, protection, growth, fruit, nut, veneer, sustainable

ABSTRACT

Small farms in Appalachia are economically challenged due to complex topography and soil constraints that limit productivity. Most farms have considerable acreage in forest, some of which is on the least productive sites, which contributes little income. The purpose of this study was to determine management and microclimate impacts on the establishment of an agro-forest for increasing the economic value of the forested land resource. A 1.2 ha forest-clear cut was planted with red oak (*Quercus rubra*) as the desired mature forest species alternated with rows of Chinese chestnut (*Castanea mollissima*), paw paw (*Asimina triloba*), hazelnut (*Corylus americana*), and white pine (*Pinus strobus*) for generating income as the forest matures. Red oak and chestnut required protection from deer. Red oak had the lowest survival rate (61%) and chestnut had the highest survival rate (94%). While providing protection, Tubex plastic tubes also however, resulted in spindly tree growth. Plastic tubes did, however, improve paw paw survival. Red Oak did best on well-drained location. Chestnut and hazelnut were negatively impacted by forest edge more than red oak or paw paw. Overall there was a high degree of variability in tree growth suggesting that on low productivity sites, a planting density substantially higher than the desired final stand may be warranted to optimize the tree-vigor/micro-site match.

Introduction

The hilly Appalachian Region in the U.S. is 23% larger than the state of California. The region is dominated by highly productive forests having the greatest species diversity of any temperate forests on the planet. Post-logging erosion and fires degraded soils in many areas in the late 18th, 19th, and early 20th century (Clarkson, 1964). There is concern about increased future soil degradation as a result of shorter harvesting rotations and whole tree harvesting to supply the many recently constructed chip mills (Johnson, 1994). In this high rainfall region, most of the nutrients are tied up in biomass on some sites, thus site productivity may be compromised by frequent complete removal of above-ground biomass.

While there are some highly productive agricultural regions within Appalachia, most are not and instead hilly and difficult to farm (Barnes, 1938; Proctor and White, 1962). These hilly regions contain small labor-intensive farms and soils that are susceptible to erosion with nutrients readily leached by the high average rainfall. Until well into the

20th century agriculture persisted through a land-use rotation process that exploited the ability of woody vegetation to capture and accumulate nutrients. Woody vegetation was cut and burned to release nutrients which allowed production of annual grains such as corn, wheat, or oats for several years. The land was then used as pasture for a few additional years before allowing woody vegetation to again reclaim the field (Hart, 1977; Otto, 1983). Currently most small farms in Appalachia have little if any crop land and are a pasture and woodland mosaic.

With the recent interest in temperate agroforestry in North America, agroforestry principles may be applied to low-productivity sites that may increase small farm income and improve on-site nutrient retention compared to traditional forestry or agriculture. There are many examples in tropical regions of planting forests or managing existing forests to develop highly productive areas that requires little management and function as forest ecosystems (Michon and de Foresta, 1999). There is some evidence that in temperate North America agro-forests were managed by indigenous tribes prior to European settlement (Wykoff, 1991).

The objective of this research was to determine management, site characteristics, and microclimate impacts on establishing an agro-forest within a forest clear-cut.

Materials and Methods

The basic design involved making a 1.2 ha clear-cut and managing the way in which the forest regenerated to facilitate specialty crop harvests for the first few decades. The climax forest is to be dominated by red oak (*Quercus rubra*) for a high value timber crop. The red oak were planted in rows 12 m apart. In the center between oak rows, three other species, Chinese chestnut (*Castanea mollissima*), hazelnut (*Corylus americana*), or paw paw (*Asimina triloba*), were planted in rows for shorter term harvests. This gave a 6 m spacing between woody perennials with these specialty crop components' production targeted to begin within 5-10 years. Not included in this analysis, since they were not planted in the initial establishment year, are rows midway between the above mentioned species of either blackberry (*Rubus* spp.)or blueberry (*Vaccinium* spp.) intended for harvests starting in the 2-3 year time frame.

This research was located on the grounds of the USDA-ARS Appalachian Farming Systems Research Center, Beaver, West Virginia, U.S. which is 37^{o} 47' N , 81^{o} 07' W and at an elevation of 780 m. Precipitation averages 1.1 m yr^{-1} and is distributed fairly evenly throughout the year. Soil at the site was mapped as a Rayne silt loam, fine-loamy, mixed, mesic,Typic Hapludults. The research site was second growth forest comprised mostly of white oak (*Quercus alba*), red maple (*Acer rubrum*) and scarlet oak (*Quercus coccinea*) with their canopy top at about 25 m and an understory of sapling white pine (*Pinus strobus*).

In the winter of 1998 a 30 by 400 m clearcut was made with the long dimension oriented east-west. This orientation created a solar radiation gradient across the width such that at the equinox about half the clearing was to some degree shaded. The white pine understory was removed an additional 30 m from all clearing edges so that it did not contribute an edge effect component. Because of resource limitations, the agro-forest plot only occupied the middle 200 m of the clear-cut which also minimized effects due to differences in early or late day shading across the plot. All replacement trees were planted during the spring of 1998 except for hazelnut which were planted in August of 1998.

There were 9 rows of red oak oriented north-south across the clearing. There were three row treatments for oak randomized within the plot length. There were 4 rows of trees 1 m apart with an establishment treatment consisting of protection from deer browse using a 1.5 m plastic Tubex tube shelter, protection using a .9 m plastic mesh, and no protection. There were three rows with trees 1.5 m apart and all trees had 1.5 m tube shelters. There were 2 rows with oak in tube shelters 3 m apart but with a white pine between each and a row of white pine 1.5 m apart in rows 1.5 m on either side. This put these oaks in the middle of a square consisting of 8 white pine. The pine were pruned as holiday trees for an additional short term income source.

Between oak rows there were 3 rows of chestnut with the same three establishment treatments as the oak establishment, 1.5 m tubes, .9 m mesh or no protection. There were also 3 rows of paw paw that had either .6m tubes or no protection and 2 rows of hazelnuts with the same three protection treatments as red oak and chestnut except the tubes were .6m. All planted deciduous species had a 10g, twelve-month release fertilizer packet (16-6-8) placed under the root system at planting, and buried 15 cm to the north and south of each at the start of the third growing season.

Site soil characterization was done for a 25-point grid across the planted area for 0-10 and 10-20 depth increments (Table 1). Particle size analysis was done using the pipette method. Soil chemical analysis consisted of pH in H_2O (1:1) and S, Mn, Mg, Ca, Al, Na, and K by ammonium acetate soil extracts using ICP. Soil depth was measured for a 45 point grid using a thin sharpened rod which was pushed into the soil until striking rock.

Soil moisture was measured weekly during the growing season for the soil top 15 cm using a Trime-FM TDR soil moisture meter. Soil moisture was measured at plot edges and every 6 m along each row containing red oak. Wind speed profiles within the clearing were measured for the year 2001 with a grid of 9 Belfort mechanical totalizing anemometers that had been calibrated with a 03101-5 R.M. Young Wind Sentry Anemometer. The Wind Sentry anemometer was subsequently installed on the roof of a two story building on a hill about 100 m outside the clearing placing it near the height of the tree tops around the clearing. Photosynthetically active radiation (PAR) was measured using a system of 16 Li-Cor Line Quantum Sensors oriented east-west along oak rows 2, 4, 6, and 8, at 1, 5, 9, and 13 m from the south side of the clearing. After equinox additional data were collected at 17, 21, 25, and 29 m from the south side.

At the end of each of the four growing seasons all trees were evaluated to determine survival status. Those surviving had their height and stem diameter 10 cm above the ground measured except for white pine since they were pruned as holiday trees. Stem diameter was not measured the last two years for Paw Paw and Hazelnuts since they became shrubby, with Hazelnuts having multiple stems, and Paw Paw developing numerous root sprouts. Hazelnut height was only measured the last three years since they were planted at the end of the first growing season. Effect of protection treatment, soil depth, soil moisture under wet conditions, soil moisture under dry conditions, and distance from forest edge, on survival was analyzed using logistical regression. Correlation between growth and distance from forest edge was determined using linear regression. Impact of protection treatment on tree height and stem diameter was determined using analysis of variance and Tukey (HSD) separation of means.

Results and Discussion

Site Characteristics

Particle size analysis indicated the soils of the planted area were a sandy loam rather than a silt loam as mapped (Table 1). Consistent with this texture, exchangeable ion concentrations were low except for K which by agricultural soil standards was very high.

Table 1. Mean site soil chemical and physical properties.

	Exchangeable Ion Concentration (μg g^{-1})								Particle Size (%)		
0-10 cm	S	Mn	Mg	Ca	Al	Na	K	pH	Sand	Silt	Clay
Mean	62	83	26	150	32	6.4	148	4.8	65	29	6
Std. Dev.	22	67	13	80	16	2.6	55	0.3	7	6	3
10-20 cm											
Mean	106	32	9	37	28	5.2	78	4.8	59	30	11
Std. Dev.	40	36	6	31	13	1.6	36	0.2	8	6	4

Table 2. Average soil depth as a function of distance from clearing north edge.

Distance from N (m)	3	9	15	21	27
Average depth (m)	.40	56	.57	.46	.36
Std. Dev. (m)	.16	.16	.28	.24	.07
Grouping	ab	a	a	ab	b

Depth in same groupings are not significantly different at the .05 rejection level using the Tukey (HSD) comparison of means.

There were no major trends across the site in soil characteristics. Soil depth did show a trend of being shallower along the north and south edges than within the middle (Table 2).

Growing season precipitation was near normal during the 4 years of this study phase. The planting year had slightly above normal precipitation, the second year had slightly below normal, with the two remaining years close to normal (Table 3). The driest period was May and June of 1999 when precipitation was only about one third of normal. Volumetric soil moisture for that period was the lowest measured but still averaged above 20% across the study site (Figure 1). Soil moisture depletion (average soil moisture for periods above 40% minus average soil moisture for the period below 25%) was about twice as great along the north and south plot borders during this period compared to the center presumably due to utilization by forest trees along these borders (Table 4). However, rather than lack of soil moisture being a limitation, some parts of the site tended to stay very wet so that average soil moisture values are higher much of the time compared to what would be expected for a sandy loam.

Table 3. Growing season precipitation data from AFSRC.

Month	1998 (m)	1999(m)	2000(m)	2001(m)	30 yr. Avg.(m)
March	.087	.094	.063	.065	.086
April	.112	.084	.104	.032	.087
May	.178	.033	.088	.191	.101
June	.171	.030	.117	.078	.098
July	.091	.087	.137	.247	.119
August	.042	.086	.140	.041	.086
September	.042	.106	.074	.036	.085
Total	.72	.52	.69	.69	.66

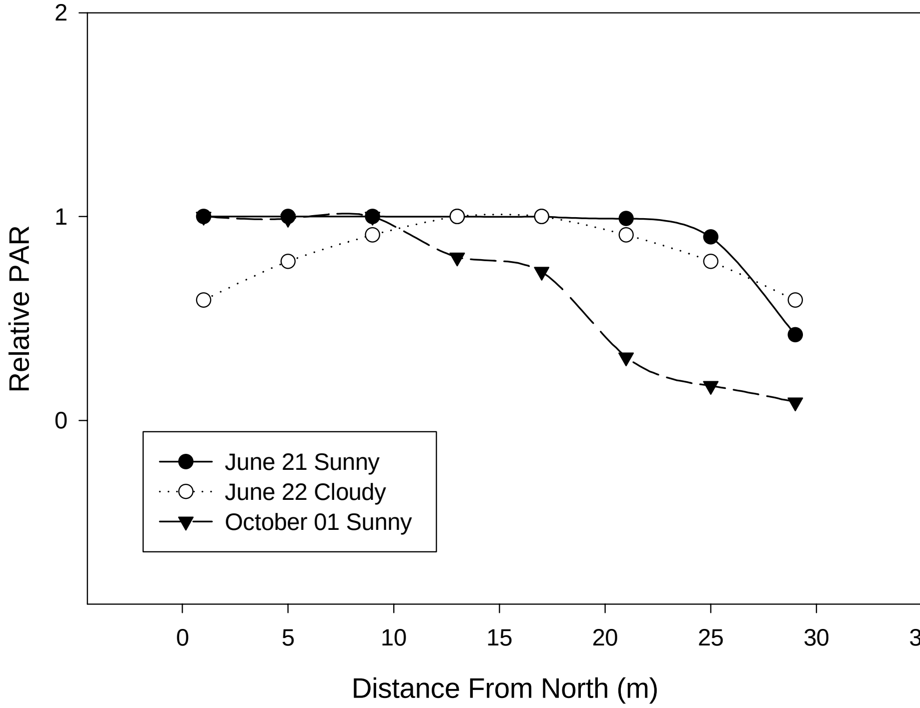

Figure 1. Relative photosynthetically active radiation across the clearing for a sunny and a cloudy day at summer solstice and for a sunny day after fall equinox.

Table 4. Maximum soil water depletion during the study as a function of distance from north.

Distance (m)	0	6	12	18	24	30
Depletion (%)	24	16	12	16	20	27
Std. Dev.(%)	7	7	4	3	7	4
Grouping	ab	cd	d	cd	bc	a

Depletion percent within the same grouping are not significantly different at the .05 rejection level using the Tukey (HSD) comparison of means.

Daily total photosynthetically active radiation (PAR) at the southern plot border for sunny conditions was 42% of the level in the center at summer solstice and decreased to 9% by Oct. 1 which was 10 days past fall equinox (Figure 1). At summer solstice the sun is only 15^{o} from vertical but the angle increases to 37.5^{o} by fall equinox at this latitude. The result is that not only does the shade extend further into the plot by fall equinox but the sun intercepts more vegetation along the path through the forest canopy thus reducing incident sunflecks within the shaded area.

Table 5. Average wind velocity across the clearing during periods with full leaf cover on trees and without leaves.

	Average Seasonal Wind Velocity (km hr^{-1})			
Forest Tree Status	North	Middle	South	Roof
Without Leaves	2.8 a	3.0 a	2.6 a	6.6
With Leaves	1.5 ab	1.9 a	1.2 b	4.4

Values in horizontal rows followed by the same letter are not significantly different at the .05 rejection level using the Tukey (HSD) comparison of means.

Tree Response

Tree survival rate varied widely between species. Red oak had the lowest survival rate at 61% and chestnut had the highest survival rate at 94% (Table 6). Of the 20 relationships tested by logistical regression (protection treatment, soil depth, soil moisture under wet conditions, soil moisture under dry conditions, and distance from forest edge for red oak, chestnut, paw paw, and hazelnut) only two relationships were significant, and both were highly significant ($p < .01$). There was a negative correlation between soil moisture under wet conditions and survival of red oak indicating red oak preferred well drained sites. The other significant trend was that paw paw had a much higher survival rate when planted seedlings were protected with tubes (Table 6).

The protection status of all species influenced early growth of all four deciduous species however there was a complicating factor. Deer browsing heavily damaged trees with no protection the first growing season and pruned those protected by mesh-to-mesh surfaces. It became evident that these treatments would not survive without more protection. During autumn of 1998 a ten-foot electric fence was erected around the entire plot area so that all trees were protected from deer the winter of 1998 and the following 3 years. At the end of the first growing season all species in protection tubes were taller than without any protection (Table 7). Red oak and chestnut were also taller in tubes than in mesh. After 4 growing seasons only chestnut was taller in tubes than in mesh or without protection. After four growing seasons both red oak and chestnut were significantly smaller in diameter 10 cm above the ground in the tube protection treatment compared to with no protection.

Table 6. Survival rate of planted tree species at the end of the 4th growing season.

Species	Survival (%)
Red Oak	61
Chestnut	94
Paw Paw (total)	67
With Tubes	83
Without Tubes	49
Hazelnuts	83
White Pine	69

At the end of four years the chestnut trees averaged more than twice as tall as red oak, hazelnut, or paw paw. Their stem diameter also averaged more than twice that of red oak for all protection treatments (Table 7). By the end of the fourth growing season the paw paw in the no protection treatment also surpassed the unprotected red oak in height.

There were three different treatment rows containing red oak in tubes, protection level, planted with white pine, and all red oak in tubes. At the end of 4 years there was no significant difference in tree height or diameter between these three row treatments (Table 8) so in the analysis of position effects within the plot area these data are pooled

There was no significant relationship between red oak height in the tube protection and proximity to either north or south border of the plot area (Figure 2). The variability in tree height was high with a few trees over 2.5 m tall and many under 0.5 m. Stem diameter was also highly variable with a few trees greater than 3 cm but most under 1 cm Figure 3). Stem diameter showed a slight decrease from the middle towards both north and south edge but the trend was not significant at the $p = .05$ level.

All protection treatment data was pooled for analysis of plot edge effects for Chestnut which grew much more vigorously on the site than red oak with more trees over 3 m in height than under 1 m (Figure 5). The decrease in tree height near the south edge compared to plot center was highly significant ($p > .01$). There appeared to be a slight decrease in height near the north edge but it was not significant. The depression of stem diameter near the north edge (Figure 6) was significant and near the south edge was highly significant.

There was a significant decrease in paw paw height near the north edge compared to the plot center but not near the south edge (Figure 7). In spite of the lack of significance for the south edge there is an apparent decrease in height of the tallest trees with increasing proximity to the south edge but there is a large variability in tree height. Hazelnut height decreased dramatically, and it was highly significant (Figure 8), as distance from the south edge decreased. There was no significant decrease as a function of distance from the middle to the north edge.

Table 7. Growth by year of planted deciduous tree species.

Tree Height (m)		Protection Type		
Species	Year	Tube	Mesh	None
Red Oak	98	0.54 a	0.44 b	0.44 b
	99	0.80 a	0.58 b	0.46 b
	00	1.03 a	0.85 ab	0.69 b
	01	1.19 a	1.05 a	0.89 a
Chestnut	98	0.93 a	0.64 b	0.44 c
	99	1.46 a	0.94 b	0.57 c
	00	1.84 a	1.50 b	1.28 b
	01	2.58 a	2.14 b	1.84 b
Hazelnut	99	0.41 a	0.33 ab	0.25 b
	00	0.68 a	0.53 a	0.50 a
	01	0.93 a	0.87 a	0.75 a
Paw Paw	98	0.41 a		0.19 b
	99	0.69 a		0.32 b
	00	0.89 a		0.63 b
	01	1.12 a		1.02 a
Tree Diameter (cm)				
Red Oak	01	1.3 b	2.5 a	2.1 ab
Chestnut	01	3.7 b	5.1 a	4.4 ab

Values in horizontal rows followed by the same letter and not significantly different at the .05 rejection level using the Tukey (HSD) comparison of means.

.

Table 8. Size of red oak trees within protection tubes for three planting treatments.

Treatment	Height (m)	Diameter(cm)
Oak Protection	1.19 a	1.3 a
Oak with Pine	1.06 a	1.5 a
Oak alone	1.28 a	1.6 a

Values in vertical columns followed by the same letter are not significantly different at the .05 rejection level using the Tukey (HSD) comparison of means

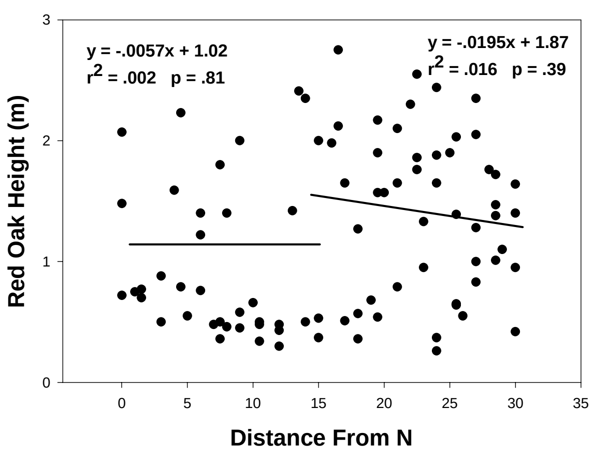

Figure 2. Height of red oak after 4 growing seasons as a function of distance from the gap's north edge.

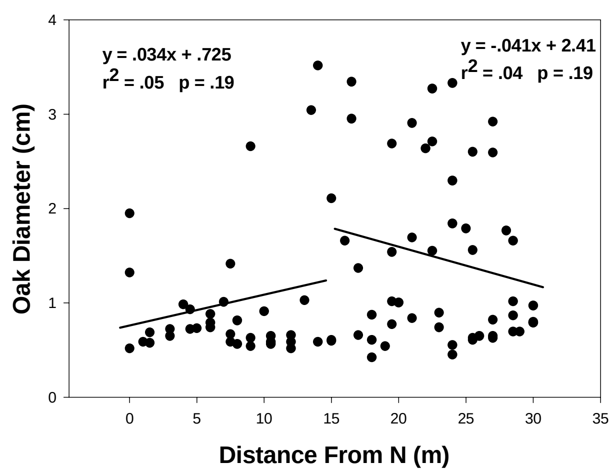

Figure 3. Stem diameter of red oak, 10 cm above the ground, as a function of distance from the gap's north edge.

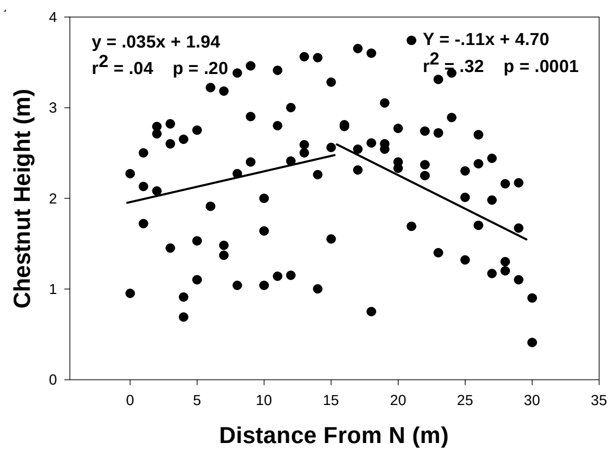

Figure 4. Height of chestnut after 4 growing seasons as a function of distance from the gap's north edge.

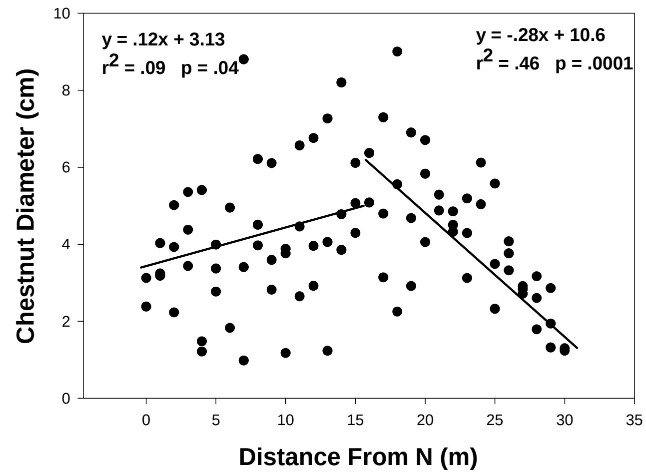

Figure 5. Stem diameter of chestnut, 10 cm above the ground, as a function of distance from the gap's north edge.

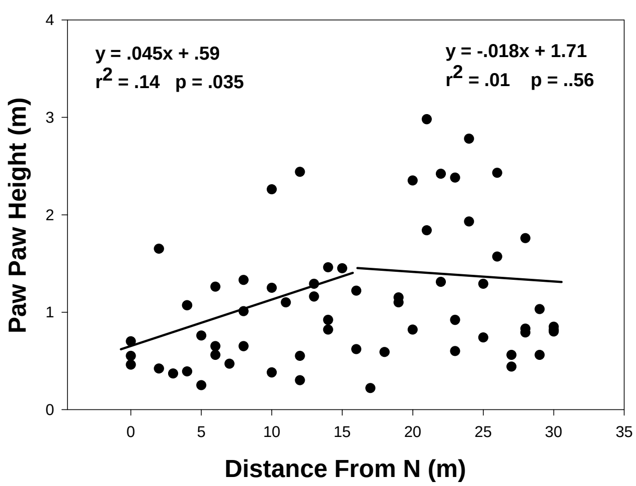

Figure 6. Height of paw paw after 4 growing seasons as a function of distance from the gap's north edge.

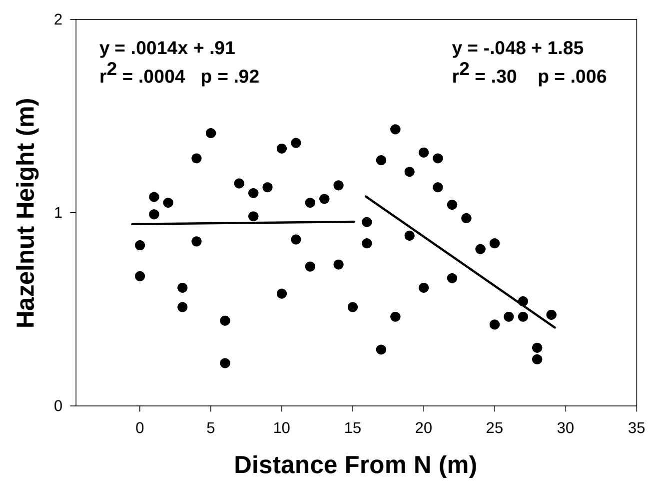

Figure 7. Height of hazelnut after 4 growing seasons as a function of distance from the gap's north edge.

There was a tremendous amount of variability in overall tree growth across this study site. This variability is related to each tree's genetic potential for exploiting the availability of resources at the site where planted. At the plot edges the planted trees were in competition with existing forest for these resources, at both edges for water and nutrients, and at the south edge for PAR where existing forest shaded. Both chestnut and hazelnut showed a statistical decrease in growth that might be attributed at least in part to shading but red oak and paw paw did not. Chestnut stem diameter and paw paw height were impacted by resource availability other than shading on the north edge. It is possible that on the north edge the paw paw was negatively impacted by too much PAR relative to other resources since survival was also improved by tube shelters which provided some shading the first two growing seasons.

Edge-effect growth inhibition, where seen, was dominantly exhibited in the first 5 m. This analysis is of survival and growth during the first 4 years and may not accurately predict yield of nuts, fruit, or even timber several decades into the future. A high initial planting density is warranted in a challenging site such as this in order to insure a good final stand of vigorous trees with good economic potential.

Literature Cited

Barnes CP (1938) The problem: land unfit for farming in the humid areas. United States Department of Agriculture Yearbook of Agriculture 1938. pp 60-67

Clarkson RB (1964) Tumult on the Mountains: Lumbering in West Virginia 1770-1920. McClain Printing Company, Parsons, West Virginia. 410pp

Hart JF (1977) Land rotation in Appalachia. Geographical Review 67:148-166

Johnson DW (1994) Reasons for concern over impacts of harvesting. p 1-12. In: Impacts of Forest Harvesting on Long-term Site Productivity. J.W Dyck D.W. Cole and N.B. Comerford Editors. Chapman & Hall Publisher, London, UK

Michon G and de Foresta H (1999) Agro-forests: Incorporating a forest vision in agroforestry. In: Agroforestry in Sustainable Agricultural Systems. L.E. Buck, J.P Lassoie, and E.C.M. Fernandes eds. CRC Press New York, NY pp381-406

Otto JS (1983) The decline of forest farming in Southern Appalachia. Journal of Forest History 27:18-27

Proctor RE and White TK (1962) Agriculture: a reassessment. In:The Southern Appalachian Region, A Survey. T.R. Ford ed. University of Kentucky Press. Lexington, KY. pp 87-101

Wykoff MW (1991) Black Walnut on Iroquoian Landscapes. Northeast Indian Quarterly. Summer 1991. pp 4-17