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Experimental greenhouse and field trials on American Ginseng, Panax quinquefolium: Implications for restoration in Appalachia

Emily Thyroff
James Madison University

Experimental greenhouse and field trials on American Ginseng, *Panax quinquefolium*: Implications for restoration in Appalachia

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by Emily C. Thyroff
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FACULTY COMMITTEE:

____
Project Advisor: Heather P. Griscom, Ph.D.
Associate Professor, Biology

____
Reader: Conley K. McMullen, Ph.D.
Professor, Biology

____
Reader: Wayne S. Teel, Ph.D.
Professor, Integrated Science and Technology

HONORS PROGRAM APPROVAL:

____
Philip Frana, Ph.D.,
Interim Director, Honors Program

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ABSTRACT

Panax quinquefolium, American ginseng, is one of the more valuable non-timber forest products, NTFPs, providing economic, cultural, and ecological ecosystem services in forests. Although ginseng has a broad distribution range, it is not abundant anywhere due to overharvesting and deer browse. This study included experimental field and greenhouse trials to determine optimal growing conditions given inconsistencies regarding aspect and soil. Three soil series and two aspects (represented by soil moisture in the greenhouse) were manipulated in a factorial design. We hypothesized that there would be significant differences in ginseng performance (germination, survival, leaf area, and height) due to soil and aspect. We predicted that ginseng would have greatest leaf area, height, and survival in loam soil that was limed and have lowest leaf area, height, and survival in sandy loam soils. We also predicted that ginseng would perform best on northern sites or high soil moisture and perform the worst on southern sites or low soil moisture. We found that soil type had a significant effect on height and leaf area in greenhouse and field trials (< 0.05). On average, field ginseng from the limed loam soil had 1284 mm^2 larger leaf area and 9 mm taller than ginseng from sandy loam. Percent survival was greater in the loam soil at 75% compared to 56% in the sandy loam. We found no effect of aspect or soil moisture on ginseng growth or survival. Having a better understanding of the ecology of ginseng, especially soil series, will help create a ginseng habitat model for national forests and private lands.

INTRODUCTION

Non-timber forest products (NTFPs) are commodities from the forest that do not require the harvesting of trees. There has been a shift in forest management plans to incorporate NTFPs on a larger scale because of their importance in species and structural diversity for sustainable management (Alexander and McLain, 2008; Titus et al., 2004). NTFPs are a provisioning ecosystem service that provides economic, cultural, and ecological importance to our forests (Kremen and Ostfeld, 2005). Economically NTFPs can provide a substantial supplemental income and raw resources for communities, however, the economic worth of NTFPs is difficult to quantify and left to estimations (Alexander and McLain 2008; Titus et al., 2004). Culturally, NTFPs can contribute to recreational, spiritual, and aesthetic values in addition to medicines (Kremen and Ostfeld, 2005). Ecologically, NTFPs promote sustainable forestry because with increased public interest, policy decisions have been created to enhance and maintain diverse NTFP populations (Alexander and McLain 2008).

American ginseng, *Panax quinquefolium,* is an herbaceous perennial plant part of the Araliaceae family and is one of the more valuable NTFPs due to the high market demands (Alexander and McClain, 2008; Teel W.S; McGraw et al., 2013). In 2014, NPR announced that market prices for wild American ginseng root went for up to $2,000 per pound dried (Johnsen, 2014). The ginseng root is valued by cultures, especially Asian and Native American, because of its long history of health-promoting properties (North Carolina State University Extension; Hrushka, A.M. 2014; Founier, A.R. et al 2008). Ginseng is valued for commercial utilization such as medicines, herbal teas, cosmetics, and energy drinks. Wild ginseng is more valuable than forest or commercially cultivated ginseng because the medicinal properties are more potent with higher levels of ginsenosides (Punja, et al., 2011; Fournier et al., 2004). Ginsenosides are the active pharmaceutical compound in ginseng and scientists have been working on isolating them from roots. Ginsenosides have been associated with anti-cancer properties, enhancing cellular metabolism, the circulatory, immune, and cardiovascular systems (Nam et al., 2004).

Ginseng has a broad distribution occurring in many different climates, aspects, and elevations, yet ginseng is not abundant anywhere due to overharvesting and deer browse (McGraw et al., 2003; McGraw et al., 2013). The illegal collection of ginseng in protected public and private lands also contributes to the depleting populations, but overharvesting can be limited by promoting non-timber forest products (Burkhart, 2008; Teel and Buck, 2002). According to NatureServe[1], in Virginia and West Virginia ginseng is considered both vulnerable and potentially secure, meaning it is at a moderate risk of extinction with few uncommon populations, but not rare. The demand for NTFPs including ginseng is increasing, which also increases the need for sustainable management practices (Alexander and McLain, 2008). Therefore, by restoring ginseng populations in Virginia and West Virginia, part of its Appalachian range where it was historically found in great abundance, local communities will have a supplemental income and more valuable forests by restoring a valuable NTFP.

In order to restore American ginseng, determining where it grows best is important. Ginseng is shade-requiring plant that possesses five leaves, red berries, and a root that resembles the human body (North Carolina State University Extension; McGraw et al., 2013). The Doctrine of Signatures is a theory that is now more of a symbolic pneumonic to transfer information, which states that physical characteristics of plants reveal their function. For ginseng, its human-like rhizome is referred to as a signature that indicates the medicinal use of panacea, a cure-all solution (Bennett, B.C., 2007). It is found within old growth deciduous forests from southern Canada to the Carolinas and to the Midwest (McGraw et al., 2003). Ginseng grows best with an average of 30% light and does not grow well with more than 35% light (Punja, 2011; Proctor et al., 2010; Fournier et al., 2004; Fournier, A.R. et al., 2008; Woo, S-Y., et al., 2004). Light is one of the ginseng requirements with few discrepancies in the literature, whereas the importance of most other requirements is debated. These differences in the ecology of ginseng obscure what is most important to sustain healthy ginseng populations. The two most reoccurring discrepancies are aspect and soil.

It has been suggested that ginseng grows best on northern or eastern aspects because it needs ample soil moisture, but also well-drained soils (Anderson et al., 1993; Burkhart, 2008; Nadeau et al., 1999). However, another study found that ginseng was often found on western aspects, more so than northern aspects (McGraw et al., 2003) and another study stated that southeast aspects are most ideal (Woo, S-Y et al., 2004). The underlying factor associated with aspect has not been determined. Soil moisture and leaf litter affect ginseng growth and are components of aspect, however, most ginseng literature focuses on soil moisture and refers back

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[1]http://explorer.natureserve.org/servlet/NatureServe.*Panax quinquefolium.*

to northern and eastern aspects supporting ideal soil moisture for ginseng (Lim et al., 2006; North Carolina State University Extension).

Both the soil series and moisture content are important to consider for ginseng habitat. Optimum soil moisture range is 50% - 75% and 25% moisture content results in deficient growth (Li and Berard, 1998). Lim et al. (2006) found that root growth length and weight responded to soil moisture, which was dependent on the soil series (Lim et al., 2006). Although ginseng appears to grow best in loam soil, characterized by high organic matter, it is tolerant of a variety of soils and has been found in textures from high sand to high silt to low clay concentrations (North Carolina State University Extension). Soil texture impacts the soils ability to drain, maintain optimal soil moisture, and hold micronutrients (Anderson et al., 1993). However, if soil moisture is too high, ginseng is susceptible to root rot (Li and Berard, 1998). Growing ginseng on a slight slope helps enhance soil drainage and limit root diseases (North Carolina State University Extension). The pH should not be too acidic and has been found with a range of 4.4 to 7.3 with a potentially optimal pH of 5.5 (North Carolina State University Extension; Anderson et al., 1993; Fournier et al., 2008). Ginseng does better in soils with high levels of calcium because it improves growth and decreases aluminum toxicity (Persons, 2008; Fournier et al., 2008; Burkhart, 2013; Nadeau et al., 1999).

Arbuscular mycorrhizal fungi (AMF) are the most common mycorrhizae associated with plant roots and have been reported in the root cortex of American ginseng (Cho et al., 2009). Mycorrhizal associations may explain ginseng's apparent ability to tolerate a wide range of soil series (Burkahrt, 2013). AMF are a part of most ecosystems because they enhance soil quality by benefitting host plant physiology, soil interactions, soil micro-ecology, and maintaining soil structure (Cho et al., 2009; Zeng et al., 2013). Consequently, AMFs are essential for sustainable management and restoration of ecosystems (Zeng et al., 2013). AMF inoculation enhances ginseng growth, plant yields, and increased ginsenoside content (Cho et al., 2009; Fournier et al., 2008). The rate of AMF colonization is impacted by soil properties such as pH, available phosphorous and nitrogen, and seasonal environment factors (Zeng et al., 2013).

A correlation exists between ginseng and sugar maple, but the foundation of the correlation is unclear. Sugar maples have strong hydraulic lift brining 50+ gallons of water from deep in the soil and sugar maple leaves retain calcium and other nutrients even after they fall from a tree (Beyfuss, 2008). Since ginseng requires ample water, but also good drainage to avoid root rot and other diseases, it could be that ginseng grows best in a very well-drained soil texture and relies on hydraulic lift as a water source rather than moisture retention (Li and Berard, 1998; North Carolina State University Extension).

The rationale for studying the ecology of ginseng is to better understand NTFPs' ecology within forest ecology in order to create sustainable forest management plans (Titus et al., 2004; Proctor et al., 2010). Monongahela National Forest in West Virginia is an ideal restoration location because it is on public lands where ginseng harvesting is legal and regulated. Ginseng harvesting is a part of the culture around Monongahela National Forest and the communities are likely to embrace the restoration of ginseng.

This study included experimental field and greenhouse trials in order to determine ginseng's optimal growing conditions given the discrepancies in the literature regarding aspect and soil moisture. The field trials provided a natural environment for ginseng and the greenhouse trials provided the ability to manipulate only two factors while controlling all other potential factors. For both field and greenhouse trials, three different soil series were tested and two aspects were manipulated in a factorial design resulting in six different treatments for each trial. In the field there were three northern and three southern aspect sites. Since aspect cannot be manipulated in the greenhouse, soil moisture, potentially the most important component of aspect, was manipulated and is representative of aspect in the greenhouse. Therefore, the 'northern' greenhouse trials had higher soil moisture than the 'southern' greenhouse trials.

We hypothesized that there would be a significant difference in ginseng leaf area, height, and survival relative to soil series: sandy loam, loam, and loam soil that were limed. We predicted that ginseng would have the greatest leaf area, height, and survival in limed loam soil and have the lowest leaf area, height, and survival in sandy loam soils. Limed loam soils have greater calcium levels, more organic matter, and higher water retention than sandy loam soils. We also hypothesized that there would be a significant difference in ginseng leaf area, height, and survival at northern and southern sites in the field (soil moisture in the greenhouse). We predicted that ginseng would have greater leaf area, height, and survival on northern sites (high soil moisture in greenhouse) than southern sites (low soil moisture in greenhouse).

METHODS

The field trials took place on private property in Erwin, West Virginia. Field sites were chosen based on canopy cover by looking for gaps. Hemispherical light photographs were taken at sites predicted to have understory light levels of approximately 30% and analyzed with HemiView Canopy Analysis software version 2.1 by DeltaT Devices. Light within these gaps ranged from 22.1% to 31.4%. Seedbeds, 12'x2', were divided into six 2'x2' subsections to control for microenvironments at each of the six sites and surrounded by deer fencing (Figure 1). Cardboard was laid down beneath each seedbed to reduce weeds and grasses and then the subsections were filled with their respective soils. Therefore, there are two replicates of the three soil series in each seedbed. Stratified ginseng seeds were purchased from Harding Ginseng Farm, Maryland and planted in October 2014 with 49 seeds per subsection spaced two inches apart and an inch deep (Figure 1).

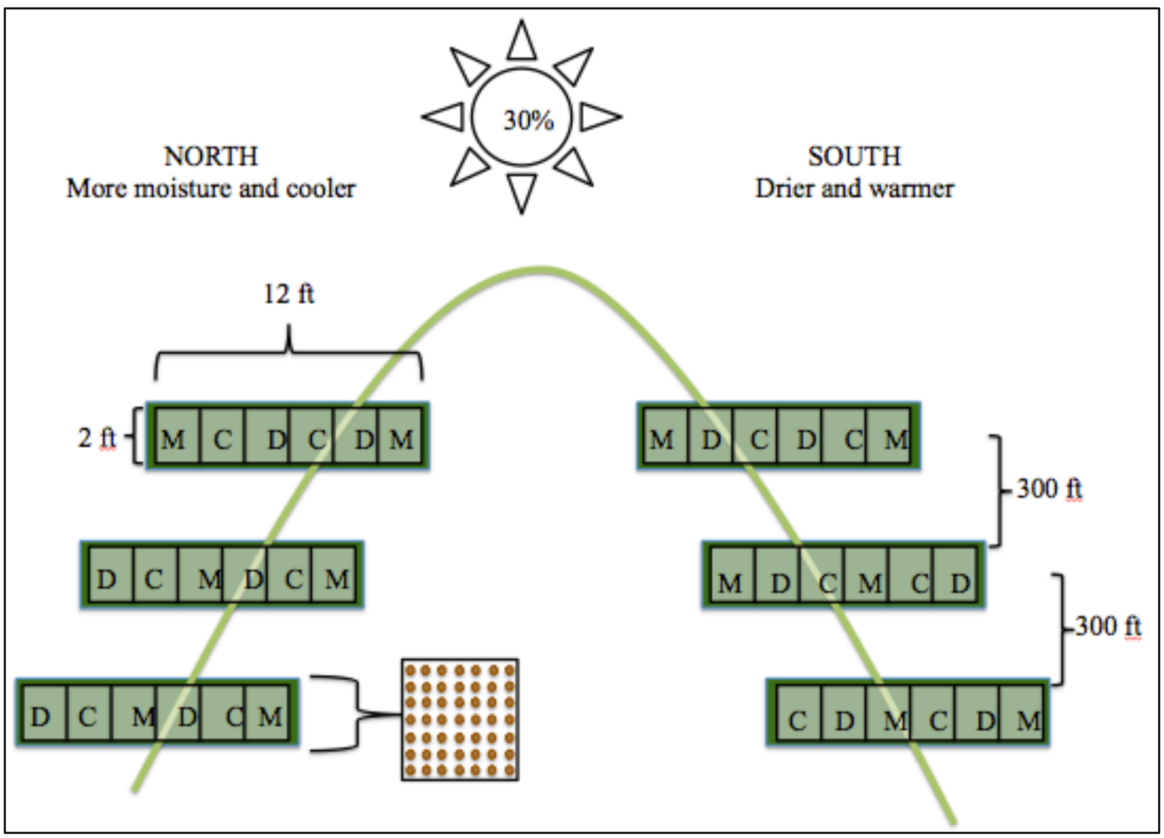

Figure 1. Experimental design for field trial sites. Each raised seedbed has six subsections, two replicates of each soil series, a deer fence (green rectangle), and 49 seeds were planted in each subsection. C = calvin limed loam D = dekalb sandy loam, M = macove loam.

Three different soil series were chosen based on abundance in West Virginia, specifically Monongahela National Forest, and how different they are from one another. The three chosen soil series were dekalb, macove, and limed calvin. The dekalb series is characterized as a cobbly sandy loam that is excessively drained and relatively low in nutrients. The macove series is characterized as a fertile loam that is well drained. The calvin series is similar to the macove, but dolomitic pelletized lime was added to increase calcium (Ca^{2+}) levels and to raise pH to 6.4[2]. The amount of lime added was based on Ca^{2+} and pH levels within Monongahela area. The three soil series were analyzed at the University of Georgia soils lab (Table 1). LBC is derived from dividing the ppm of $CaCO_3$ by pH. Cation Exchange Capacity (CEC) is the measure of the total negative charges within the soil that adsorb the basic cations Ca, K, and Mg. Whereas base saturation (BS) is the percentage of CEC occupied by basic cations Ca, K, and Mg and is generally proportional to soil fertility; the higher the base saturation, the more fertile the soil. Phosphorus is also believed to be critical to ginseng growth (Konsler et al., 1982). These soil series provided three different conditions to conduct experimental ginseng trials (Table 1).

The James Madison University (JMU) greenhouse in Harrisonburg, Virginia, is equipped with Micro Grow Greenhouse Systems technology. This allows control of temperature, humidity, air circulation, and water irrigation. Temperature was changed every month to mimic the natural seasonality in West Virginia. Within the two greenhouse rooms were a total of 36 trays, each containing eight 5"x5" pots. Three greenhouse tables mimicked a northern aspect with high soil moisture, and three mimicked a southern aspect with low soil moisture. Each table had two randomly arranged replicates of each soil series; therefore, each of the six treatments had six replicate trays in the greenhouse.

After a preliminary field collection and soil moisture analysis in September 2013, the northern soil moisture was assigned a value of 35% and the southern soil moisture a value of 20%. To achieve these soil moistures automatic watering regimes were created. The Micro Grow technology includes the WaterPro system, which has automatic watering based upon vapor pressure deficit (VPD) values[3]. To mimic light at the field site aluminet shade cloth was used

[2] Amount of lime added found by using these equations: $LBC_{Eq} = LBC_{30}$ x 2.90, LR = LBC_{Eq} x (Target pH - Initial pH) x 2 x 1.5. http://extension.uga.edu/publications/detail.cfm?number=C1040#Significance

[3] VPD values are based off of air temperature, relative humidity, and the temperature of the plant leaves and a VPD target must be set. Once the target is reached the system waters and procedure resets

because it allows 30% light transmission and does not create or hold in heat. The three soil series were transported back to JMU and the pots were filled with their respective soils. Two of the stratified ginseng seeds were planted per pot and later weeded to one if both seeds germinated.

Soil moisture in the field seedbeds and greenhouse trays were measured with an SM150 sensor and an HH150 meter from Delta-T Devices. In the field, Hoboware Data Loggers were also used to monitor soil moisture in the raised seedbeds on a daily basis and to track over time. In the greenhouse, the soil moisture levels were monitored and the watering regimes were changed as needed to maintain the northern aspect soil moisture of 35% and the southern aspect soil moisture of 20%.

Table. 1. Analysis of the three different soil series. Site is where the soil was collected and type is the general classification. Bolded pH and Ca^{2+} are the results after the lime was added.

Series	Type	pH	CEC	BS	Ca	K	Mg	P
Dekalb	Sandy Loam	3.45	15.60	5.24	98.20	41.43	20.48	5.96
Macove	Loam	3.71	15.42	12.77	265.30	88.62	43.81	7.28
Calvin	Limed Loam	4.11 **(6.40)**	**20.40**	**5.46**	136.00 **(2134.80)**	49.00	23.00	8.46

Leaf area (mm^2) and height (mm) were measured in June and September 2014, and survival compared the June 2014 germination data to ginseng counts in September 2014. Leaf area was determined by multiplying length and width for each plant. This method was compared with linear regressions to a leaf scanner method and to the biomass of the plants. Dependent factors for both the field and greenhouse include germination, leaf area and height in June 2014, leaf area and height in September 2014, and percent survival from June to September.

Data were analyzed using SPSS software version 22. First, data were tested for normality using Shapiro Wilks tests followed by ANOVAs. All field data was normal therefore a generalized linear mixed model ANOVA was used. The fixed effects were the soil series and aspect (soil moisture) and the random effect was site. Post-hoc tests for the field data were pairwise contrasts with Bonferroni correction. All of the greenhouse data were normal, except for percent survival. Therefore, leaf area and height for both June and September were analyzed with a univariate ANOVA and tukey-post hoc tests. Percent survival was analyzed with a Kruskal-Wallis, non-parametric ANOVA.

RESULTS

Ginseng leaf area and height were significantly affected by soil series in the field and greenhouse (Table 2). Aspect (represented by soil moisture in the greenhouse) had no significant effect on any of the measured dependent variables (Table 2). September data were used for further analysis because ginseng's growing season extends until September (Fournier et al., 2004; Proctor et al., 2010; Lim et al., 2006).

Table 2. ANOVA results for both the field and greenhouse trials. Both trials include F and p values for all six tested dependent variables. Bolded values are significant.

FIELD	Soil Series		Aspect	
	F value	**p value**	**F value**	**p value**
Germination	1.059	0.359	0.358	0.554
Height June	2.622	0.088	0.901	0.350
Height Sept	**4.648**	**0.017**	0.051	0.822
Leaf Area June	**17.978**	**$\leq$ 0.0001**	0.314	0.579
Leaf Area Sept	**13.491**	**$\leq$ 0.0001**	0.972	0.332
Survival	3.124	0.058	0.124	0.727
GREENHOUSE	Soil Series		Soil Moisture	
	F value	**p value**	**F value**	**p value**
Germination	**5.406**	**0.010**	0.852	0.363
Height June	1.855	0.174	0.035	0.853
Height Sept	**3.607**	**0.039**	1.245	0.273
Leaf Area June	**4.921**	**0.014**	0.806	0.376
Leaf Area Sept	**10.006**	**$\leq$ 0.0001**	0.574	0.454
Survival	**--**	**$\leq$ 0.0001**	--	0.907

In the field, germination was 7% greater in the limed loam than the sandy loam and 5% greater than the loam, but these differences were not significant. In the greenhouse, germination was 25% significantly greater in the sandy loam than the limed loam ($p = 0.009$) and 20% greater than the loam ($p = 0.659$) (Figure 2).

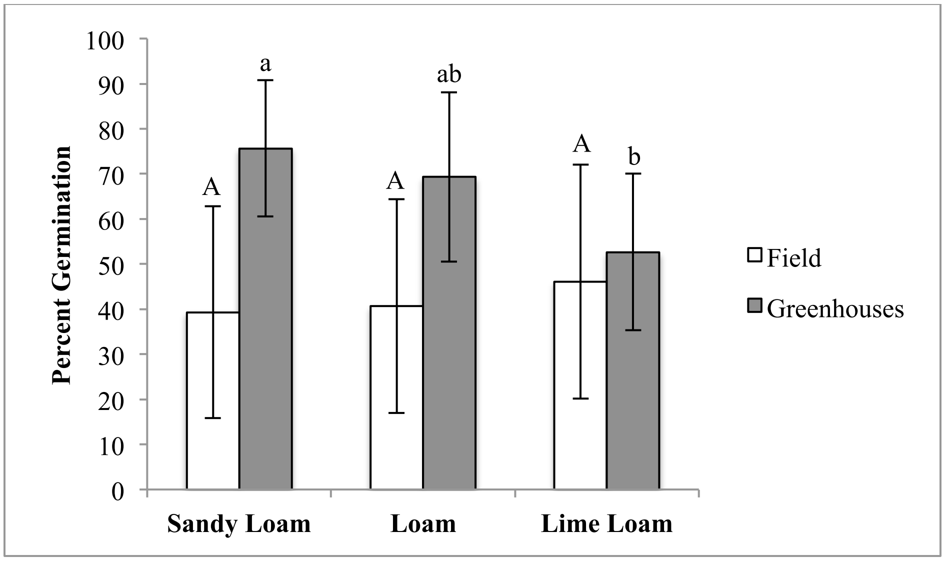

Figure 2. Percent ginseng germination in the field and greenhouse trials based on the three different soil series from September 2014 (after one growing season). Field studies were conducted in a West Virginia Appalachian cove forest.

Ginseng leaf area and height were similarly affected by the soil series in the field and in the greenhouse. Leaf area and height were significantly greater in limed loam soils than in sandy loam soils (the reverse trend shown with germination in the greenhouse). In the field, the limed loam soil ginseng had 1300 mm^2 more leaf area (10 mm taller) ($p \leq 0.001$; $p = 0.020$) than the sandy loam and 800 mm^2 more leaf area (7 mm taller) than the loam soil ($p = 0.061$; $p = 0.003$) (Figure 3; Figure 4). In the greenhouse, leaf area was 1100 mm^2 greater for both loam ($p = 0.003$; $p = 0.001$) and limed loam ginseng than the sandy loam, whereas the height varied only 3 mm on average between the three soil series (Figure 3; Figure 4). Overall, field ginseng for all soil series were 900 mm2 less leaf area, yet12 mm taller than greenhouse ginseng.

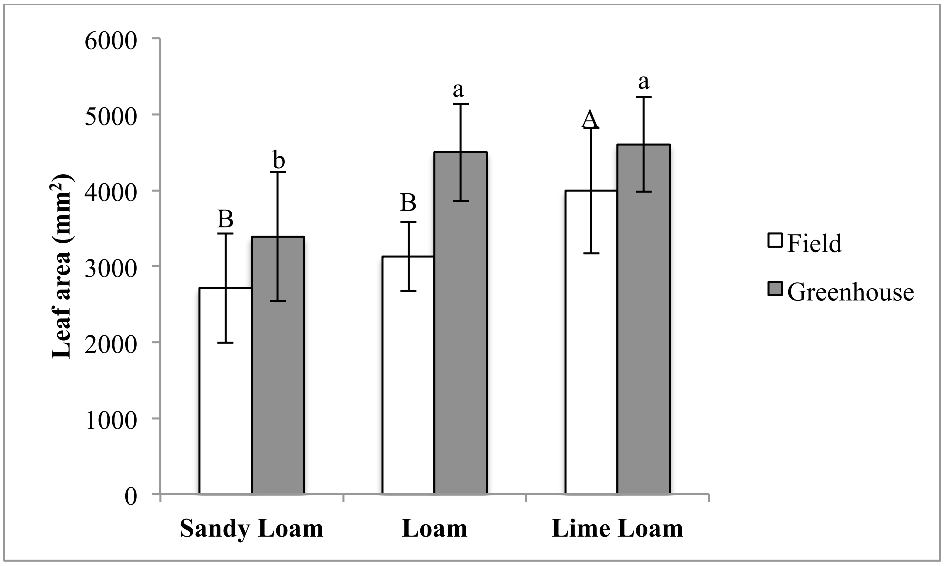

Figure 3. Average leaf area of ginseng in the field and greenhouse trials based on the three different soil series from September 2014 (after one growing season). Field studies were conducted in a West Virginia Appalachian cove forest.

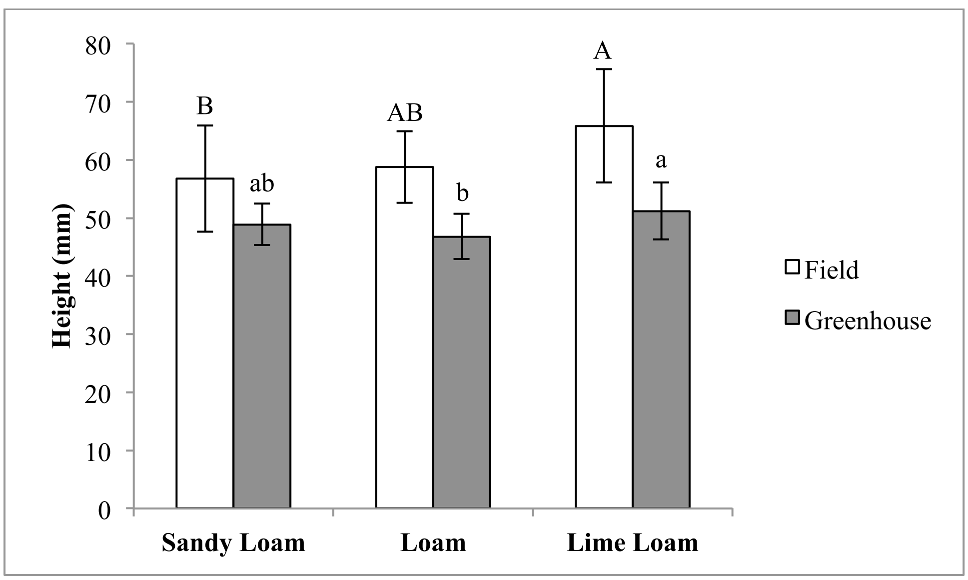

Figure 4. Average height of ginseng in the field and greenhouse trials based on the three different soil series from September 2014 (after one growing season). Field studies were conducted in a West Virginia Appalachian cove forest.

Overall field ginseng survival was not significantly affected by the soil series. Field ginseng survival was 20% greater in loam soil than the limed loam and sandy loam (Figure 5). Greenhouse ginseng survival was on average 37% significantly greater in loam and limed loam soils ($p \leq 0.0001$) than the sandy loam soils (Figure 5).

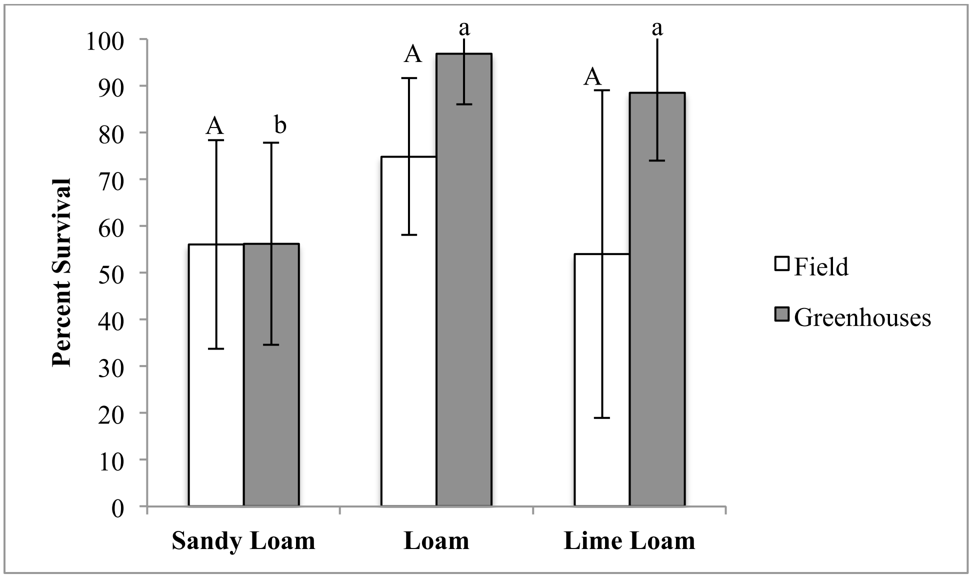

Figure 5. Percent ginseng survival in the field and greenhouse trials based on the three different soil series from September 2014 (after one growing season). Field studies were conducted in a West Virginia Appalachian cove forest.

DISCUSSION

The three different soil series resulted in significantly different results for ginseng leaf area and height for field and greenhouse trials and for greenhouse germination and survival (Figure 3; Figure 4). This was predicted, as the three soil series are characteristically different with regards to soil drainage and available nutrients (Table 1). The additional calcium in the limed loam soil was predicted to increase ginseng growth and development (leaf area, height, and survival) based on previous observational studies of wild ginseng in forests and planted ginseng in raised seedbeds. Ginseng has been found to greatly benefit from the addition of lime to soils by being larger and more abundant (Burkhart, 2013; Fournier et al., 2008; Nadeau, 1999). In our experimental trials, limed loam soil (2134 ppm Ca^{2+}) yielded the greatest ginseng leaf area (**F:** 3995 mm^2 **G:** 4603 mm^2) and height (**F:** 65 mm **G:** 51 mm). Overall, field ginseng had less leaf area, but were taller than greenhouse ginseng; this is due to the field ginseng had less leaf area due to insect herbivory and greater height because longer stems were needed to break through the leaf litter.

Leaf area was found to be the best indicator of ginseng growth despite herbivory in the field (Nadeau et al., 1999). Leaf area is a good indicator of health because it is closely correlated with biomass ($R^2 = 0.596$), which is a strong measurement of plant performance (Figure 6).

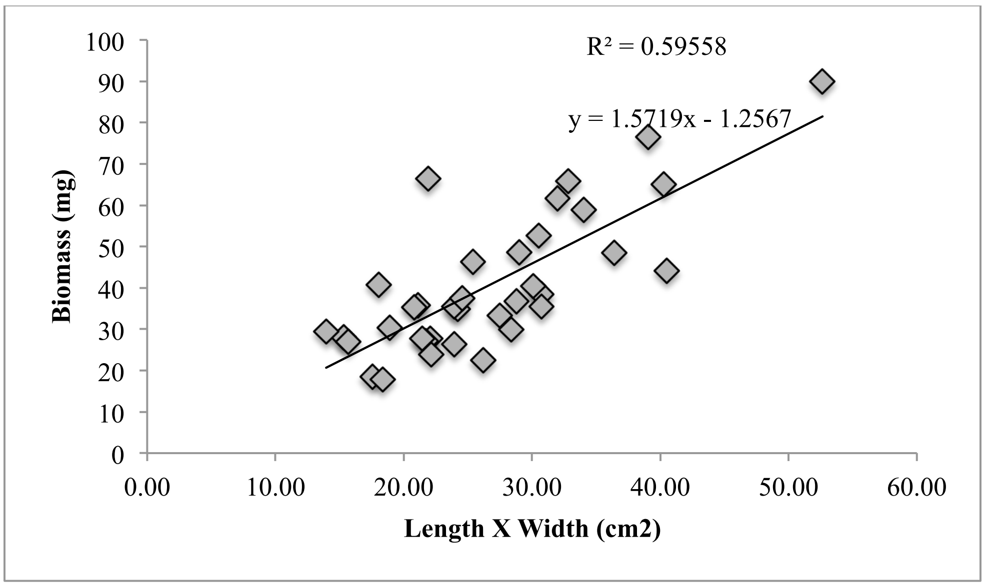

Figure 6. Linear regression of leaf area measurement (length times width methodology) and biomass (which was determined by weighing completely dried ginseng samples.

Germination in the greenhouse was significantly greater in sandy loam soil (76%) than limed loam soil (53%), but in the field germination was similar across the three soil series (Figure 2). Excellent drainage in sandy loam soil may have decreased seeds rot from too much moisture (North Carolina State University Extension). In the field germination was significant by site, which was not intended, therefore we added a seventh seedbed subsection to confirm our 2014, first year findings. While limed loam soil may have yield the largest and tallest ginseng, survival in the greenhouse was greatest in the loam soil (97%) (Figure 5). This could be due to the macove loam soil being not too wet while also not too dry and having greater nutrient levels (Table 1). Soil type did not have an effect on survival nor germination of ginseng in the field, which is due to the inherent high variability of field experiments as illustrated by high error bars (Figure 2; Figure 5). Field germination was similar for all soil series, which could be due to no difference in field soil moisture. Despite no significant differences in field survival, it followed a similar trend to greenhouse survival with loam soil having the greatest survival (75%) and sandy loam with the lowest survival (56%). Overall, germination was greater in the greenhouse (66%) than the field (42%) and survival was also greater in the greenhouse (81%) than the field (62%). Germination and survival were greater in the greenhouse trials because there is no seed or plant herbivory, milder conditions, and less chance of random events (i.e. animal interference or intense weather storms).

Surprisingly, aspect (represented by soil moisture in the greenhouse) had no effect on any of the measured variable, as in the literature there are many claims that certain aspects are better for ginseng than others. Northern and eastern aspect sites are usually described as the optimal locations for ginseng because they are more moist and moderate in climate than southern and western aspects based on observational studies (Anderson et al., 1993; Burkhart, 2008; McGraw, 2013). However, McGraw et al. (2013), found no difference in ginseng abundance with aspect in an observational study. Water moisture content was suggested to be the most important component of aspect because of the delicate balance between water for sufficient growth, but not too much to induce root disease (Li and Bernard; Lim et al., 2006). And in the greenhouse, the 20% and 35% greenhouse soil moistures may not have been different enough to mimic natural northern and southern aspects.

These experimental results support McGraw et al., (2013) in that aspect does not affect ginseng performance. However, a difference may emerge over time, especially because the summer of 2014 was unusually wet and cool. Dataloggers, which continuously monitored soil moisture, were used at the six different field sites and all six seedbeds had similar soil moisture content (30%) throughout the 2014 summer. This is in contrast to the soil moisture readings that were taken at soil near the seedbeds in September 2013, which had the northern sites at 35% soil moisture and the southern sites at 20% soil moisture in the driest month of the year. We do not believe the raised seed beds altered the natural soil retention given that other studies have used seedbeds to execute ginseng studies, suggesting that they do successfully drain (Fournier et al., 2008; McGonigle, T.P. et al., 1999). With ideal summer temperature and precipitation, most ginseng would grow well and there would not be a large difference between the northern and southern aspects because all aspects were cool and wet enough to promote great ginseng growth and survival. The six field sites may have had other differences besides those correlated with aspect such as wind and more exposure to harsher elements. Again, the extra subsection, added to the raised seedbeds in September 2014, will verify the first year data and see if the field results were impacted by an unusually moist and cool summer.

Long-term monitoring may result in different patterns. Perhaps aspect will have an effect with more growing seasons that have drier summers. Ginseng is not harvested until it is at least five years old, but wild ginseng collectors tend to wait up to fifteen years or longer. Therefore, a longer-term study is important for ginseng restoration. Sustained monitoring may yield different results or continue to support the findings from this study. In conclusion, soil series had a significant effect on ginseng germination, growth, and survival in both field and greenhouse trials. The calvin limed loam soil was the best for growth (leaf area and height) due to high calcium levels, while the macove loam soil was the best for ginseng survival, most likely because it was well drained and high in nutrients (Figure 7).

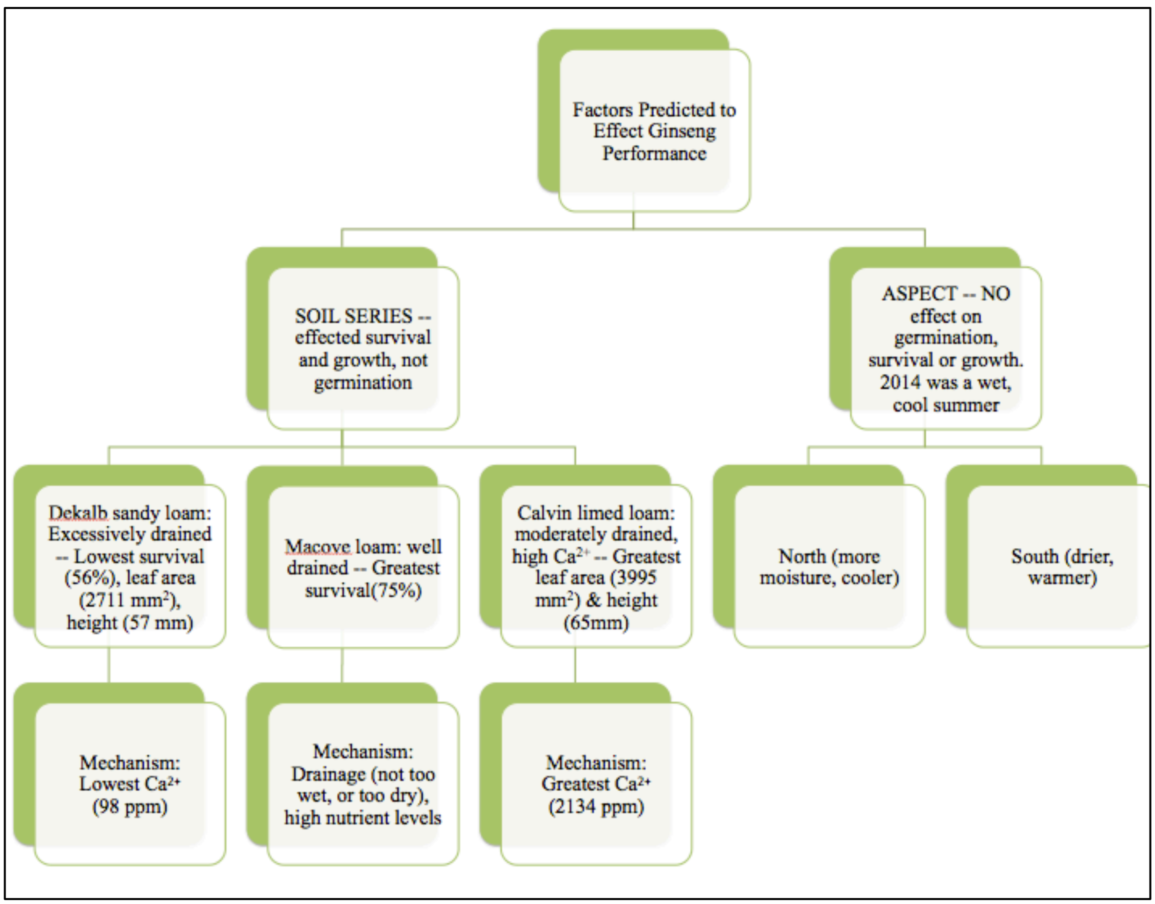

Figure 7. Conceptual model for ginseng germination, leaf area, height, and survival relative to soil series and aspect.

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