Spring 2021

Modeling the Growth and Establishment of Plantation and Converted Silvopasture Systems in the Missouri Ozarks Region

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MODELING THE GROWTH AND ESTABLISHMENT OF PLANTATION AND CONVERTED SILVOPASTURE SYSTEMS IN THE MISSOURI OZARKS REGION

A Master's Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Plant Science

By

Stewart James McCollum

May 2021

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Agriculture

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ABSTRACT

The Missouri Ozarks are well known for high production in both timber products and cattle production. Most areas are also not well suited for many other agricultural practices such as row cropping, so forests and grazing lands dominate the landscapes. Such characteristics provide high potential for the agroforestry practice known as silvopasture. This study monitors the establishment of two different types of silvopasture systems, plantation and conversion types. In the plantation silvopasture, two cultivars of black walnut (*Juglans nigra*) were planted, Football and Kwikrop. Health and growth were monitored for those cultivars over the first year. The converted silvopasture consisted of a manually thinned upland forest area containing many different oak (*Quercus*) species as well as a few other hardwood species such as hickory (*Carya*) and ash (*Fraxinus*). The converted stand was monitored using an unmanned aerial system (UAS) equipped with a multispectral sensor. The multispectral imaging was used to create canopy height models as well as build models predicting seasonal climate stress variables such as leaf water potential and leaf chlorophyll content of the trees within the converted silvopasture system. The final seasonal climate stress models displayed relatively high prediction potential for important seasonal climate stress variables using remote-sensed data for different forest ecosystems in the Missouri Ozarks region.

KEYWORDS: agroforestry, silvopasture, Ozarks, UAS, black walnut, hardwood

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ACKNOWLEDGEMENTS

I would like to thank the long list of people that have assisted me along this journey. First, I would like to thank each and every person that encouraged me to continue my education and pursue a master's degree. Without their encouragement I would not be in this position today. Next, all of the faculty members and students that helped with long days of data collection, this would not have been possible without each and every one of you. Also, Dr. Toby Dogwiler for all of his work with the remote sensed data collection and data post processing. Next, I would like to thank my family for being such a wonderful support system through these years. This would not have been possible without their support and encouragement. Lastly, and most importantly, I would like to thank my advisor Dr. Michael Goerndt. Not only has he been an amazing advisor, but a mentor in the field of forestry and all aspects of life. None of this would have been possible without his support and guidance along this journey.

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INTRODUCTION

The Ozark Highland Ecoregion is approximately 108,332 square kilometers (10,833,200 hectares) primarily in southern Missouri, but also in northern Arkansas, southeastern Kansas, and northeastern Oklahoma (Karstensen 2010). Of that land, a survey in 2000 stated that 56.2% and 36.8% of the land use was forest and agriculture, respectively (Karstensen 2010). Missouri is known for its abundant forest resources with nearly 6 million hectares of forest land across the state (Leatherberry and Treiman 2002). This allows Missouri to be a leading producer in a variety of forest products including wood pallets, charcoal, oak barrels, and walnut products (Leatherberry and Treiman 2002). However, Missouri is better known for its cattle production. In 2017, Missouri ranked second among all states in beef cattle production, as well as second in cow-calf production in 2018 (USDA 2018). These two commodities provide great opportunity for the use of the agroforestry practice known as silvopasture.

As the world population continues to increase, the need for food also increases. This leads to an increased demand of agricultural lands. The rocky slopes of the Ozarks are not well suited for many crop species, so grazing lands dominate the landscapes. Searcy County of northern Arkansas has been experiencing vast amounts deforestation for the expansion of pastures (Wall 1996). “The increase in cattle production is directly linked to increased deforestation,” states Wall (1996). Not only has northern Arkansas experienced deforestation, the entire Ozark Highland Ecoregion has also been subject. In a land use study of the Ozark Highland Ecoregion from 1973-2000, the most common type of land use conversion was from forest to agriculture (Karstensen 2010). The percent of forest cover across the region decreased 2.3% while the agricultural land use increased 1.7% over the study period (Karstensen 2010).

Proper education of silvopasture could promote its use and potentially slow the crisis of deforestation across the region.

What is Silvopasture

Silvopasture is the intentional combination of trees and forage in the same location. This can be accomplished by the establishment of trees into a pasture or the establishment of a forage into managed forest stands (Klopfenstein et al. 1997, Garrett et al. 2004, Hamilton 2008). Silvopasture must be intensively managed to maintain productivity (Jose et al. 2019). Silvopasture, as well as other types of agroforestry practices, have been used around the world for centuries, commonly in areas with subsistence farming (Nair 2011). However, modern agroforestry began primarily in the tropics as a way to combat tropical deforestation, soil degradation, and biodiversity decline (Nair 2011). Then, around the 1980s and 1990s, agroforestry practices became more recognized and used in many developing countries (Nair 2011).

To receive the potential benefits of silvopasture, it is important to understand the difference between silvopasture and forest grazing or woodland grazing. With the idea of it being beneficial, farmers will often times allow livestock to graze within woodlands, even if pasture is available (DeWitt 1989). This is different from silvopasture because proper management has not been applied with concerns for trees and/or livestock (Orefice and Carroll 2017). In a natural forest or woodland, it could take up to 40 hectares to provide the equivalent forage of one hectare of pasture, leading to lower weight gains and poorer quality meat in cattle (DeWitt 1989). Without proper management, many plants can be present in a woodland environment that may be harmful to livestock. Some of these being black cherry and poison ivy, both being common in

Missouri woodlands (DeWitt 1989). Soil erosion can also be high in a grazed woodland due to less low growing vegetation than in a silvopasture (DeWitt 1989). Without proper management to create a silvopasture, the cost of woodland grazing can easily outweigh the benefits.

Why Use Silvopasture

Silvopasture is often used to provide multiple sources of income from one piece of land. However, the benefits go far beyond economics. Trees can benefit from grazing as grass competition is reduced. Grazing also helps control weeds and brush that potentially have negative impacts on tree growth and quality. Grazing livestock allows nutrients to be recycled back into the soil through manure and urine reducing fertilization costs (Klopfenstein et al. 1997). Trees can also recycle nutrients by absorbing nutrients below the rooting zone of the forage and applying them back to the surface through leaf litter (Buresh et al. 2004). Furthermore, forage typically has lower fiber content and is more digestible to the livestock when grown in an environment with trees. Livestock also benefit from the shade of trees for less heat stress in summer and trees as a windbreak can reduce wind-chill of livestock in winter (Klopfenstein et al. 1997). With a properly managed practice, silvopasture can be successful and have many benefits (Orefice and Carroll 2017).

Farmers however, are not the only one that reap the benefits of silvopasture. Silvopasture as well as other agroforestry practices have proven to benefit the environment in a variety of ways (Nair 2011). Trees are able to take up nutrients that have leached below the forage root zone that would otherwise leach into ground water or surface water causing pollution (Michel et al. 2007). Carbon sequestration is another huge benefit. Silvopastures have a greater potential to capture and store more carbon than a traditional pasture (Nair 2011). Improved water quality,

slowing of climate change through carbon sequestration, and higher biodiversity are important benefits of silvopastures (Nair 2011).

Black Walnut in Silvopasture

Black walnut (*Juglans nigra*) is a very common species chosen for agroforestry practices in Missouri because of its high valued wood and nut crop (Garrett et al. 1991, Garrett et al. 1996), and Missouri is a well-known producer for both the wood and nut crop of black walnut. Aside from being a profitable crop, some of its traits pair well with many crops or forage species. The growth period of black walnut is about 90-135 days and is one of the shortest for tree species (Garrett et al 1996). The extra time in the spring and fall without leaves on the trees is important for understory growth of some forage species. Not only is the growing season shorter, but also the crowns of black walnut are fairly sparse and allow a sufficient amount of light through to the ground for successful growth of many cool-season grasses (Garrett et al 1996).

Black walnut, however, can draw some concerns when it comes to using it in agroforestry practices. This is because of the allelopathic chemical juglone, produced in the roots of black walnut (Funt and Martin 1999, Jose and Holzmueller 2008). Effects of juglone have been studied on many different species, with a list of plants that are susceptible continuing to grow. However, select species have been found to be useful in agroforestry practices paired with black walnut (Scott and Sullivan 2007). Most grass species fall within this category or have been observed under black walnut (Funt and Martin 1999), suggesting good potential for black walnut in silvopastoral systems.

Remote Sensing in Forestry

Remote sensed data is a term that is being used more frequently in many different fields of science, including forestry and agriculture. With increases in technology, satellite imaging as well as unmanned aerial systems (UAS) have become much more popular for forest monitoring over the past few decades (Grenzdörffer et al. 2008, Tang and Shao 2015, Banu et al. 2016). Arial photography has been used as far back as the 1860s, and increased in use with the introduction of Earth Orbiting satellites around 1960 (Tang and Shao 2015). Since the 1970s, more satellites began to be equipped with digital sensors and became more available for civil applications (Tang and Shao 2015). Since then satellite imaging has become more popular but with limited spectral resolution (Banu et al. 2016). UASs however have the ability to provide much higher spectral resolution when needed (Banu et al. 2016). UASs have also become more accessible and affordable over the years, increasing the popularity of UAS remote sensed data (Mahjan and Bundel 2016).

A wide variety of forest data can be obtained from the use of multiple different sensors equipped on the UAS. These can be as simple as mapping forest boundaries and as specific as estimated volume or trees per hectare. LiDAR (Light Detection and Ranging) sensors are a common tool used to determine tree height and canopy coverage (Tang and Shao 2015, Banu et al 2016). LiDAR is a method to measure height by using a laser pulse emitted from the UAS to determine distance from the object below the UAS. The time it takes for the laser pulse to return determines the distance (Lefsky et al. 2002). This is done repeatedly over an area of the earth's surface providing a model of tree canopy dynamics. Another popular sensor would be multispectral and hyper spectral sensors (Tang and Shao 2015). These sensors are able to collect light wavelengths outside of the visible light spectrum (red, green, and blue). Using the spectral

reflectance in these wavelengths allows us to identify differences in species and stressed plants from insects, diseases, or other causes (Minarik and Langhammer 2016, Dash et al. 2017). This is an important tool in forest management as it allows ease of monitoring, evaluating, and predicting different aspects of the forest.

Study Objectives

The primary goal of this study is to build the capacity for future research. Future research providing information regarding economics, establishment, sustainability, and production potential of silvopasture systems. In light of this goal, the initial objectives of this study were to establish two different functioning silvopasture systems using planting and thinning methods.

Planting silvopasture consists of planting a desired tree species or group of multiple species into a pre-existing grassland. Planting density and spacing would follow a plan determined by both tree species and forage species that will be grown as well as the long term goals of the user. This method takes longer for trees to reach a size that can attribute to the benefits of silvopasture.

Conversely, converting timberland or forest to silvopasture consists of selecting desirable trees to keep and removing the remaining trees and shrubs using thinning methods and then establishing a desirable forage species. Density and spacing will be much more variable depending on tree species, tree size, and initial tree spacing within the forest. The variable spacing of trees can make management more challenging, however, the silvopasture system is ready immediately following successful forage establishment.

Additionally, remote sensing was used to create canopy height models and climate stress models of the conversion silvopasture system. The stress models were created to evaluate the

effects of climate changes and stressors throughout the year and build models to predict plant stress from remote sensed data. These models can be used not only to predict seasonal climate stress in silvopasture systems but also to potentially model and predict climate stress in addition to other biophysical attributes such as species composition, crown structure, and disease presence in other forest ecosystems.

MATERIALS AND METHODS

Study Site

This research was conducted at Missouri State University's (MSU) Journagan Ranch property in Douglas County of south central Missouri. Journagan Ranch is a 1335 hectare ranch that houses the largest pure-bred Hereford heard in the state of Missouri. It also consists of very diverse landscapes and soil types (Figure 1). This area falls centrally within the Ozark Highland Ecoregion. The specific site consisted of two study areas: 1) plantation silvopasture, and 2) existing forest stand thinned for silvopasture.

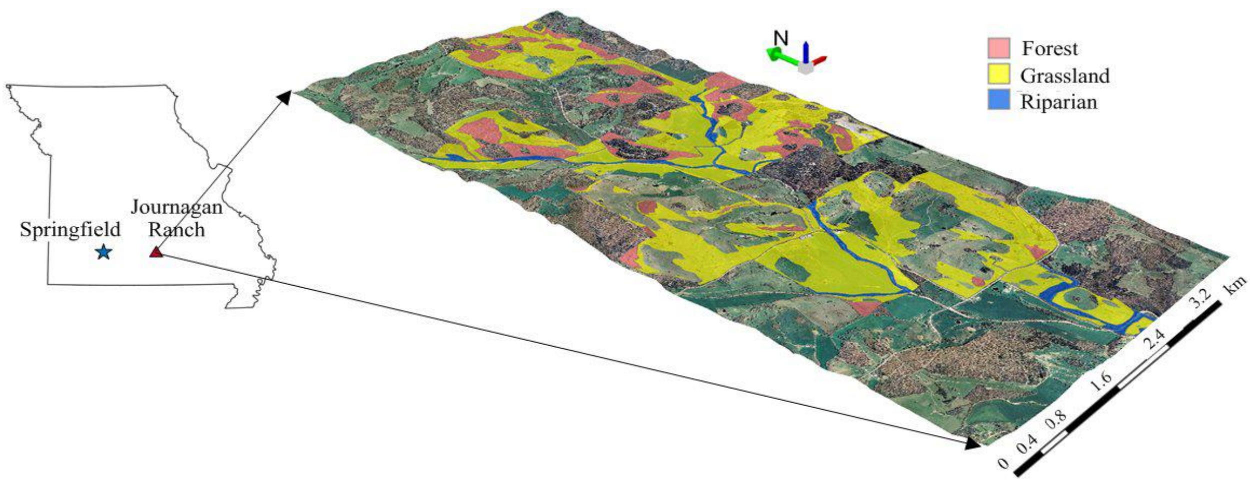

Figure 1. Map of Missouri State University's Journagan Ranch property.

Weather Data

A weather station was set up toward the center of both of the silvopasture study areas to monitor specific site weather for years to come. Metrics recorded over the 2020 growing season included: rainfall, air temperature, soil temperature, water content, relative humidity, wind direction, wind speed, and evapotranspiration. These stations were set up and began recording

data on July 1, 2020. The University of Missouri weather station located in Mountain Gove, MO was used for long term weather metrics for the local vicinity. This weather station is located 15 kilometers north of the study area. Annual and monthly averages of rainfall and air temperature were calculated based upon data from 2008 to 2020.

Plantation Silvopasture

The newly established plantation silvopasture measures 219.45 m by 73.15 m. This site was planted with two cultivars of black walnut: Football and Kwikrop. Walnuts from these two cultivars were collected from the University of Missouri Southwest Research Center in Mt. Vernon, MO. Following collection, the black walnuts were placed in five gallon buckets with holes drilled for water drainage and buried in the soil for stratification over the winter of 2018/19. Following stratification, the black walnuts were planted into raised planting beds at MSU's Shealy Farm near Fair Grove, MO. The planting beds were roughly 25 cm tall with the bottom four to five cm filled with small gravel to allow drainage. The remainder of the bed was filled with topsoil. The black walnuts germinated and grew in the beds through the year of 2019. A surplus of black walnut seedlings were grown to provide selection of better individuals as well as to have replacements for following years. On December 18, 2019, seedlings appearing healthy with large healthy appearing root systems were collected. The selected individuals were planted at the Journagan Ranch study site the following day (December 19, 2019). The plantation design is comprised of 72 trees, including 36 of each cultivar. Trees were planted at a spacing of 12.2 m within rows and 18.3 m between rows. Tree spacing was chosen to allow sufficient light for forage growth and crown expansion for nut production. A mature walnut tree crown, when open-grown in a nut plantation setting, will get to approximately 12x12 m crown area on average

(Garrett et al. 1996). The selected spacing between trees will also facilitate the movement and operation of heavy farm equipment in future years. The seedlings were planted into 12 rows of six trees across the pasture. The pasture was divided into three equal blocks, each containing four rows of trees (two of each cultivar). The cultivars were randomly assigned to rows in each block (Figure 2). Competition from grass is a big limiting factor when it comes to seedling growth (Hamilton 2008, Houx III et al. 2013). An ideal weed-free zone is around a 0.6-0.9 m radius around established seedlings (Hamilton 2008), with studies finding that tree growth rates stop increasing with a weed-free zone radius greater than 1.2 m (Houx III et al. 2013). In this study, a 2.5% concentration of glyphosate was applied in a 0.75 m radius circle around each planting location for site preparation in the fall of 2019. An additional application (same concentration) was done the third week of July 2020 to maintain the weed-free zone. A wire cage was placed around each seedling to prevent wildlife predation and damage. The cages were made from welded wire and were 1.5 m tall and 30 cm in diameter. Many of the seedlings were infected with *Gnomonia leptostyla*, a fungal anthracnose that effects walnut trees, during 2020. Daconil fungicide was applied the third week of July 2020 to combat the anthracnose.

Measurements of black walnut seedlings for the first year's growth at the Journagan ranch site included survival rate of the cultivars, height growth, and diameter growth. Height growth was measured at planting (before growth began) and at the end of the growing season in centimeters. Diameter growth was taken in millimeters using electronic calipers at initial planting and at the end of the growing season at 20.3 cm above the ground. The measurement height of 20.3 cm for diameter was chosen as a logical standard based on the average initial height of seedlings and the fact that a diameter at breast height (dbh) measurement was not

possible for seedlings. At the end of the growing season, the mortality and growth rates of surviving trees were measured using the same standards as the initial measurements.

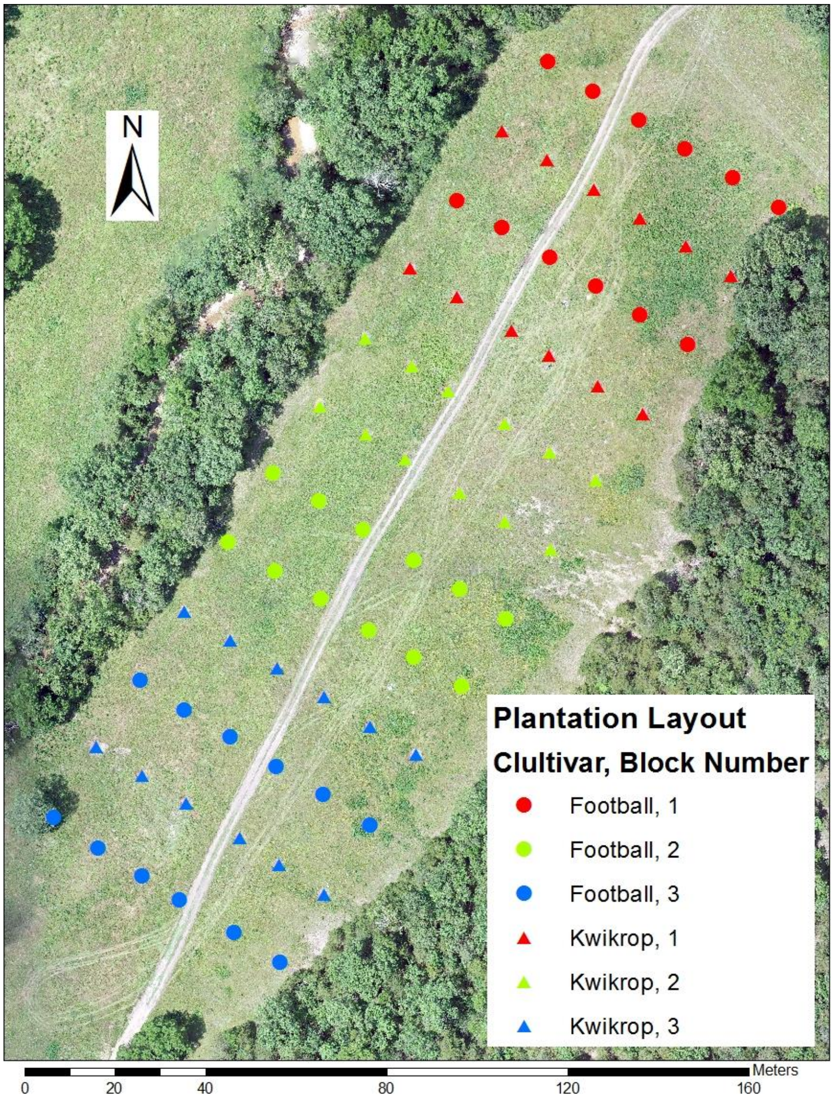

Figure 2. Walnut plantation silvopasture layout and design.

Health was assessed for the trees throughout the growing season and those that did not survive or were in poor condition were taken note of for replacement. In January of 2021, the individuals that did not survive were replaced with two new seedlings from the remaining

seedlings in the Shealy Farm germination beds so they are the same age as the others within the silvopasture plantation. The individuals that were in poor condition but not dead were retained but an additional seedling was planted immediately next to the original tree and marked as a back-up. The locations with multiple seedlings will be re-evaluated in the future years and the stronger seedling will be kept.

Conversion Silvopasture

The converted forest stand was an uneven aged forest stand that was thinned for silvopasture. The area measures about two hectares and the dominant and codominant species composition of the stand consisted primarily of White oak (*Quercus alba*), Post oak (*Quercus stellata*), Red oak (*Quercus rubra*), Black oak (*Quercus velutina*), Hickory (*Carya spp.*), with the occasional Ash (*Fraxinus spp.*), and Black Walnut (*Juglans nigra*). Before thinning, a forest inventory was taken using eight systematically spaced .02 hectare circular plots. In each plot every tree was tallied, identified by species, given a crown classification, and measured for DBH. The stand had an average of 19.2 square m of basal area per hectare, an average of 389 trees per hectare, and a mean diameter of 23.1 cm (Table 1). The stand was then thinned with the goal to remove 50% of the crown cover (Garrett et al. 2004). This would be reducing the stocking level to about 30% stocked according to the Gingrich stocking chart (Gingrich 1967). 30% stocking allows about 50% light transmittance (Sander 1979) which is recommended for maximum cool season forage growth (Gardner et al. 1985). Following the thin, 18 .04 hectare circular plots were set up for a follow up inventory and repeat measurements in the future (Figure 3). Every tree within the plot was tallied, identified, and diameter was measured. The average basal area after the thin was 9.3 square m per hectare, there was an average of 110 trees per hectare, and the

mean diameter was 32 cm (Table 1). Along with the basic inventory measurements, following the thin crown width and crown density were collected and will be collected annually to monitor growth over time.

Table 1. Basal area per hectare (m^2), trees per hectare, and tree diameter (cm) across the converted stand.

	BA/H	TPH	DBH
Before Thin			
Mean	19.2	389	23.1
CV %	11.6	88	106.9
Min	10.1	198	10.2
Max	37.3	593	49.2
After Thin			
Mean	9.3	110	32
CV %	10.5	118	57.4
Min	3.4	25	17
Max	17.4	222	54.4

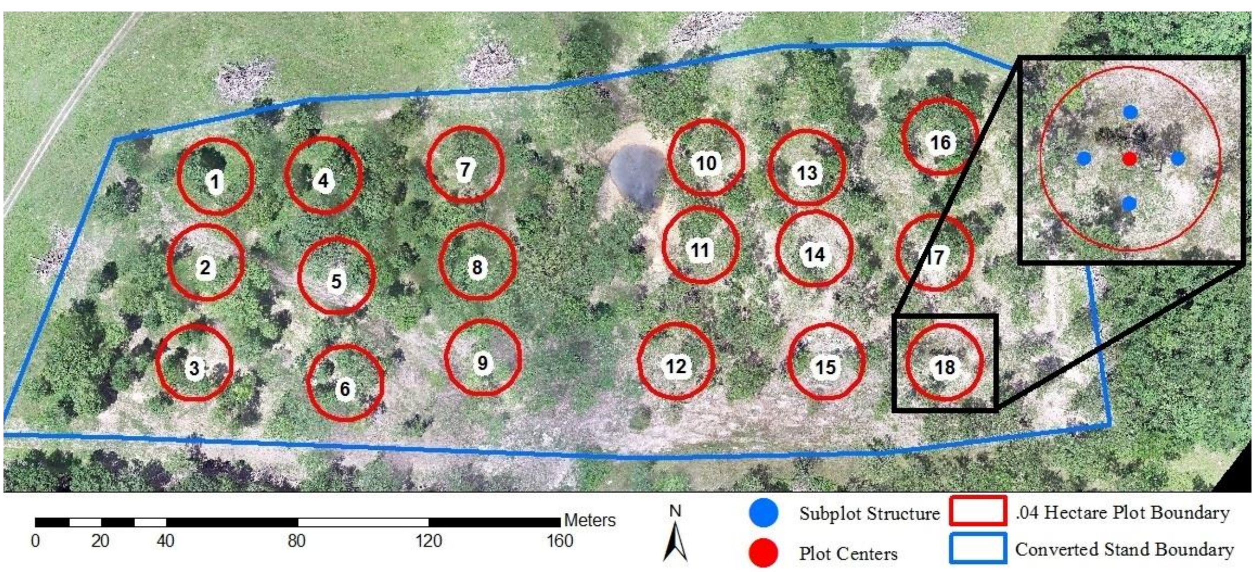

Figure 3. Layout of the .04 hectare plots and the nested sub-plot structure.

Other measurements were taken at different times during the growing season to correspond with the remote sensed data collection. These dates were, July 8 and September 20. For those dates, in each of the 18 .04 hectare plots the following measurements were taken at the plot center and halfway between the plot center and boundary in each cardinal direction for five total measurements: Light intensity, soil moisture, and soil temperature (Figure 3). Those values were then used to calculate a plot-level mean estimate. Light intensity was taken using an Apogee Instruments MQ-306 Line Quantum PAR (Photosynthetically Active Radiation) sensor. Soil moisture was taken using a Campbell Scientific® HydroSense II handheld soil moisture meter that gives volumetric water content in percent. Soil Temperature was taken using a SpotOn® digital temperature probe witch gives values in degrees Fahrenheit. Leaf chlorophyll and water potential were also measured on both dates. For these measurements, one tree per plot was selected and marked to be used for resampling throughout the years. A leaf sample was collected from as high as possible in the tree crown using a shotgun to shoot down a cluster of leaves. An Apogee Instruments MC-100 chlorophyll meter was used to measure chlorophyll concentration of the leaf in $\mu mol\ m^{-2}$. An average value of leaf chlorophyll content was recorded from eight measurements on one leaf. Water potential was measured for one leaf per plot using the Model 600 pressure chamber instrument by PMS Instrument Company. For consistency, an oak tree was selected for the leaf measurements in every plot except for plot three and plot nine, where no oak was present so a hickory and ash were chosen respectively.

Remote Sensed Data Collection

Remote sensed data was collected using a phantom 4 professional unmanned aerial system (UAS) by DJI. This UAS is known as a quadcopter UAS meaning it is controlled using

four rotors to control flight. This is different than a fixed-wing UAS which resembles an airplane. The quadcopter UAS require much less space to take off and land opposed to the fixed wing style (Mahjan and Bundel 2016). The UAS was flown on the two dates from above during the 2020 growing season: July 8 and September 20. For each of these dates RGB data was collected as well as Multispectral data that includes RGB bands, Red Edge and Near-infrared data (Figure 4). Multispectral imaging was collected using a Micasense RedEdge-M sensor.

Data collection was performed at mid-day (10 AM – 2 PM) on each flight to minimize shadows and maximize consistent light transmittance. For both flight dates the UAS was flown at a height of 85 m above the ground for both RGB and Mulitspectral data collection. Ground resolution of the RGB photos was set to 2.3 cm for both flights while the Multispectral resolution was 5.9 cm for both. Flight path and capture speed were established to provide 80% forward and side overlap to the next picture, allowing each location on the ground to be captured by approximately 25 images.

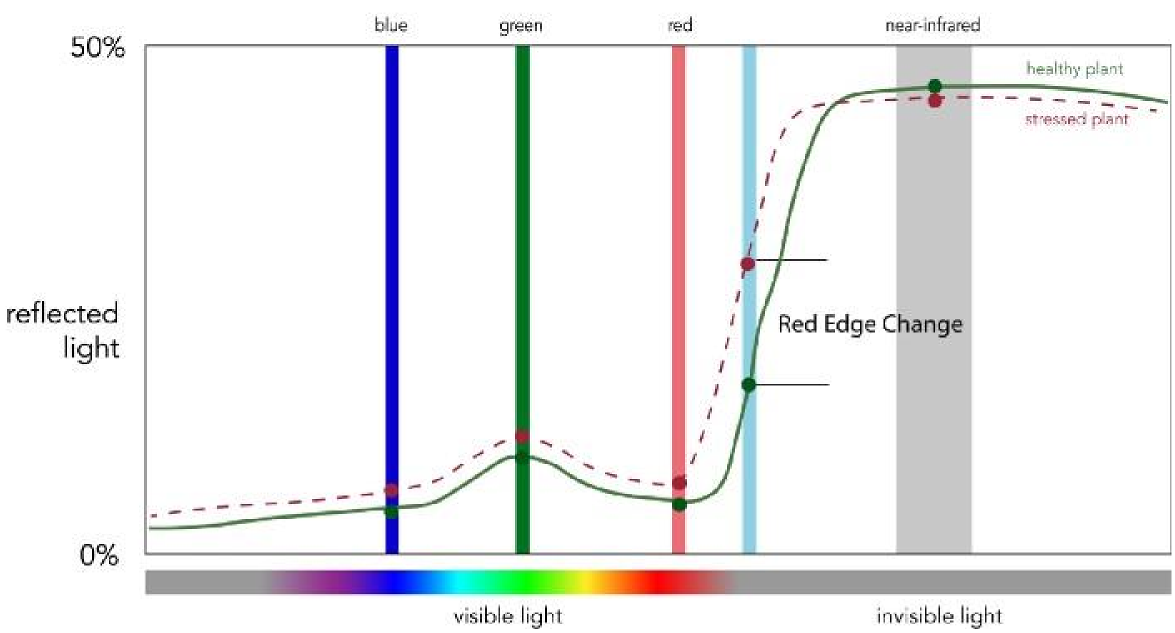

Figure 4. Reflectance bands captured by the Micasense RedEdge-M camera and common reflectance of vegetation (Micasense 2018)

Canopy Height Model (CHM)

Following the UAS flights, data was post processed using the Agisoft Metashape Photoscan program. For all flights, the Unmanned Aircraft Systems Data Post-Processing workflow was primarily followed (USGS 2017). Two different digital elevation models (DEM) were created using the program. One is elevation of the highest points in each pixel, which can represent the upper canopy of trees, peaks of higher elevation bare ground, birds, or other objects above typical ground elevation. The other is the lowest point in each pixel, which can represent ground level, but can also be influenced by low-lying vegetation and other objects on the ground. Using these two DEMs a raster set that displays values of the height of the vegetation by subtracting the ground only DEM from the highest point DEM in Esri ArcMAP was created (Figure 5). This is considered a form of canopy height model (CHM), such as the typical canopy representation often calculated using LiDAR point cloud data. The CHM was then used to delineate tree crowns within the converted silvopasture. To facilitate tree crown delineation, only pixels with a raster pixel value greater than 6 m were considered, as lower values often represent low-lying vegetation and ground variability. Finally, polygons were created around conspicuous clusters of retained pixels to represent tree crown edge (Figure 6) (Appendix).

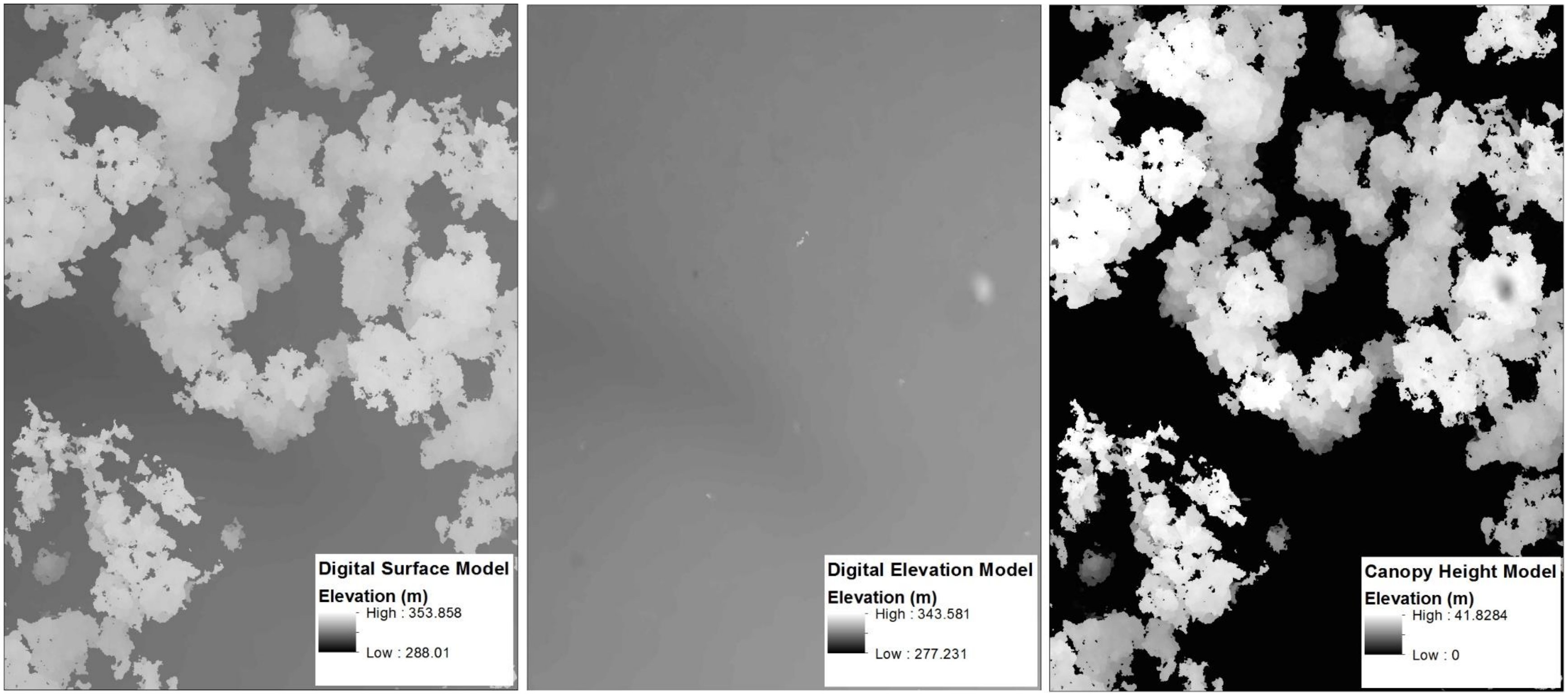

Figure 5. Example of the highest points (left), lowest or ground points (center), and the difference of the two creating a CHM (right).

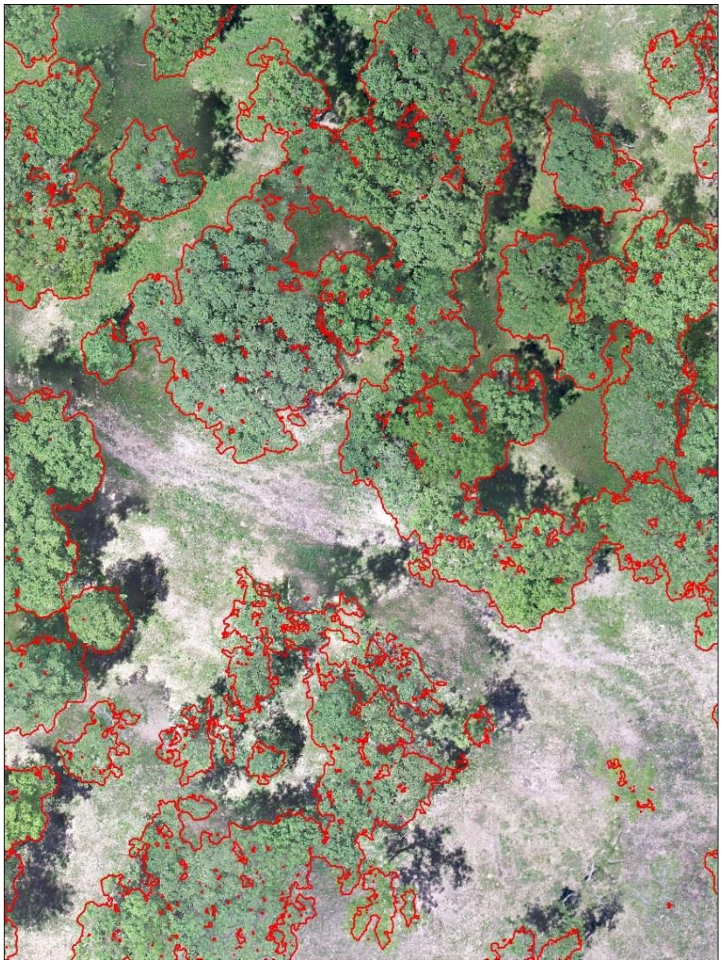

Figure 6. Crown polygon from crown delineation.

Seasonal Climate Stress Models

Stress models were created using a combination of the UAS data and ground data. The models were built to predict the water potential and leaf chlorophyll for trees within the converted silvopasture. A model was created for each flight, as well as a combined prediction model for the entire season. The potential covariates for the models included all reflectance values collected from the UAS, multiple vegetative indices derived from the original reflectance values, soil moisture, and soil temperature (Table 2). Zonal statistics in ArcMap was used to extract a mean value for each of the multispectral covariates in each of the .04 hectare plots. Mean values were calculated manually for soil moisture and soil temperature in each plot. For

the reflectance values and vegetative indices, the canopy model was used to extract values that represent tree crown only. Two different models were created for each flight date and the combined season model, one using all covariates listed above, and the other excluding soil moisture and soil temperature as potential covariates. This was done to assess the statistical importance of soil moisture and temperature on predicting water potential and leaf chlorophyll.

Table 2. Potential covariates for predicting leaf chlorophyll and water potential.

Description	Variable
Multispectral Bands	Blue
	Green
	Red
	Red Edge
	NIR
Multispectral Indices	NDVI
	GNDVI
	RENDVI
	NLI
Ground Measurements	Soil Moisture
	Soil Temperature

Climate stress models were created using the lm and lme toolpacks in R statistical software. Multiple linear regression was used to create both the flight-specific and seasonal models with all covariates listed above. Stepwise selection was used for each flight-specific model to determine which covariates resulted in the strongest model fit for that specific data set. Final flight-specific models were then created using only the ideal covariates selected through stepwise regression. A linear mixed model was used to create the combined seasonal model using both flight dates. Linear mixed models were used instead of ordinary least squares (OLS) regression due to the intrinsic use of multiple flight times. This essentially represents a case of repeated measures, as the same observations (plots) are remeasured for each flight time.

Therefore, the linear mixed models included flight time as a random variable with all other covariates fixed. The stepwise selection method was used again to determine the strongest covariates for the mixed models.

Study Limitations

For the plantation silvopasture, the sample size was fairly small with only 36 individuals per cultivar. A much larger sample would be ideal, but this specific area did not allow for a more spatially extensive design. Tree planting by hand was another limitation. Multiple people took part in the tree planting operation, in part to provide opportunities for field experience to students. To be more consistent and avoid potential human errors, a mechanical planter with two operators could have benefitted the study, though such precise spacing would have been more challenging. Uncontrollable weather is also a limitation to the study. Without easy access to irrigation, some aspects of success are ultimately dependent upon weather.

In the converted stand, the primary limitation is tree spacing. Because this area was a naturally grown forest, trees of all sizes were spaced randomly across the entire stand. When selecting dominant and co-dominant trees to retain, it was impossible to keep consistent spacing. Size of the trees were also a limitation for the same reasons. Trees with larger canopies would need more spacing to other trees for adequate light transmittance for forage growth. These factors made each plot different from one another in the aspects of canopy coverage, trees per hectare, and light transmittance. While considered a limitation, the aforementioned issues with spacing are not unusual for mixed hardwood forests in the Ozarks region. Variations in tree size and natural clustering of species across the landscape are challenges that every forester and landowner have to contend with in any forest management scenario.

Lastly, with only one growing season of data collection complete, the short duration of the study is a major limitation. In addition, most data collection came later in the growing season verses throughout the entire growing season. Continual data collection should greatly increase this study's potential.

RESULTS

Weather Data

Annual average of precipitation from 2008-2020 was 117.9 cm while the year 2020 was well above the average receiving 143.8 cm of precipitation. When split by month during the active growing season of May, June, July, August, and September the mean rainfall values were 15.5, 10.6, 10.7, 9.9, and 9.2 cm respectively. For the year 2020 the monthly rainfall for those months were 25.9, 12.6, 13.6, 3.8, and 3.4 cm respectively. For May, June, and July, rainfall was at average or better during 2020. August and September however, were well below the average (Table 3).

Table 3. Average and 2020 precipitation from Mountain Grove weather station and precipitation from the weather station at the study site.

	Average Rainfall (cm)	2020 Rainfall (cm)	Study Site (cm)
May	15.5	25.9	N/A
June	10.6	12.6	N/A
July	10.7	13.6	7.4
August	9.9	3.8	4.1
September	9.2	3.4	2.5[1]
Year Total	117.9	143.8	N/A

[1] Rainfall from September 1st through September 20th

The site-specific weather station began tracking on July 1st, 2020 and continued through the September UAV flight date, September 20th. The study site received 7.4 cm of precipitation during the month of July while the weather station in Mountain Grove recorded 13.6 cm. August received 4.1 cm at the study site compared to 3.8 cm recorded at Mountain Grove. The study site received 2.5 cm of precipitation from September 1st through 20th while Mountain Grove received

1.5 cm during that time frame and 3.4 cm for the entire month of September. The comparatively low precipitation for the months of August and September is an important factor to remember with regard to the discussion of climate stress model results in the next section.

Plantation Silvopasture

Mortality was recorded for both cultivars across the plantation. The Kwikrop cultivar had a slightly higher mortality rate of 33.3% compared to a 25% mortality rate for the Football cultivar (Figure 7). In addition to mortality, many individuals experienced top kill where the terminal bud did not survive but a lateral bud did. Of the surviving seedlings, 33.3% of the Football cultivar suffered from top kill and 83.3% of the Kwikrop cultivar experienced top kill (Figure 7). Height growth was calculated from the surviving individuals that did not die or experience top kill. Based on a simple t-test, there was no significant difference in height growth between the cultivars. Football and Kwikrop had a mean height growth of 2.11 centimeters and 1.83 centimeters respectively (Figure 8). The five Football seedlings and three Kwikrop seedlings with negative height growth were excluded when calculating mean height growth. We again saw no significant difference between the two cultivars. Football and Kwikrop both had a mean diameter growth of .35 mm (Figure 8).

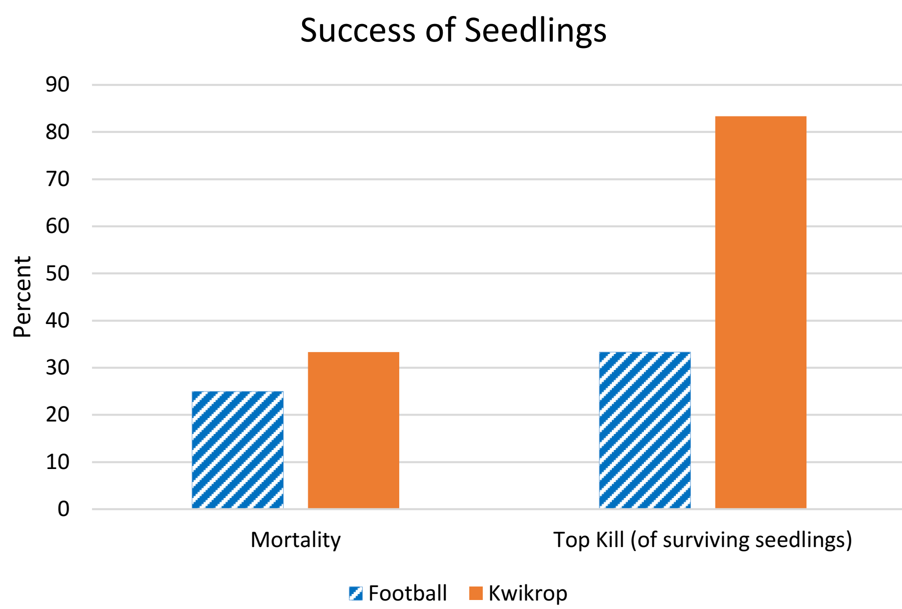

Figure 7. Mortality (n=36) and top kill rates of football (top kill n=27) and Kwikrop (top kill n=24) cultivars.

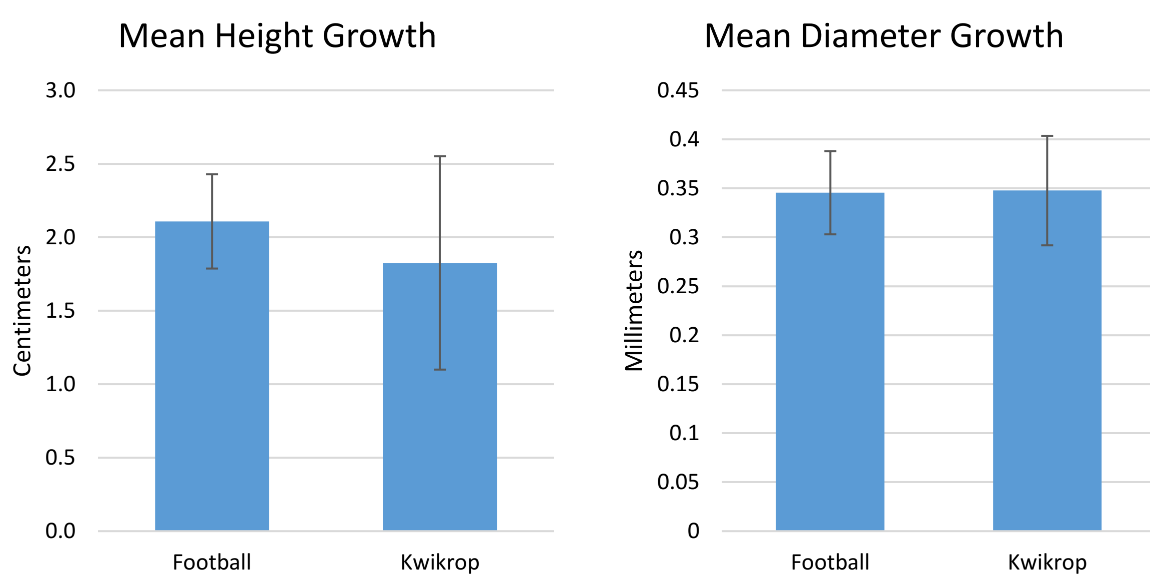

Figure 8. Mean ± SE of height and diameter growth of football (height n=18, diameter n=22) and Kwikrop (height n=4, diameter n=21) cultivars.

Seasonal Climate Stress Models

July Models. For July, the model predicting water potential was very strong for both inclusion and exclusion of ground-measured soil moisture and soil temperature. Without inclusion of ground metrics, this model had an adjusted R-squared value of 71.3%. When the ground metrics of soil moisture and soil temperature were included, the adjusted R-squared value increased to 79.2%. The same covariates were chosen in both models with the addition of soil moisture in the ground metrics model (Table 4). For the model predicting chlorophyll in July, the adjusted R-squared values were 29.5% and 20.6% for models excluding ground metrics and including ground metrics respectively (Table 4).

Table 4. July climate stress model selected coefficients used and model strength (R^2(adj)). Label A represents models excluding ground metrics and label B represents models including ground metrics.

Coefficient	Water Potential (Bars)		Chlorophyll (µmol/m²)	
	A	B	A	B
Intercept	0.0008*	0.0028*	0.1785	0.3131
Blue	0.0003*	0.0018*		0.2326
Green	0.0086*	0.0851		0.2074
Red	0.0534	0.1135		0.1635
Red Edge	0.0004*	0.0017*	0.1084	
NIR	0.0001*	0.0006*		0.1435
NDVI	0.0006*	0.0018*		
GNDVI			0.0112*	
RENDVI			0.0444*	0.0592
NLI			0.1791	0.3142
Soil Moisture		0.046*		0.2525
Soil Temperature				0.1979
R^2(adj), %	71.3	79.2	29.5	20.6

*Coefficients that show significance (p-value <0.05)

September Models. In September, both models predicting water potential used the same three covariates with an adjusted R-squared value of 3.3% (Table 5). The model that included

soil moisture and soil temperature as potential covariates did not actually use these metrics, as they did not increase model fit strength based on the stepwise regression procedure. The models predicting chlorophyll had adjusted R-squared values of 46.5% and 52.2% for exclusion of ground metrics and inclusion of ground metrics models respectively (Table 5). The model excluding ground metrics used most of the covariates while the ground metrics model used all covariates except for soil moisture.

Table 5. September climate stress model selected coefficients used and model strength (R^2(adj)). Label A represents models excluding ground metrics and label B represents models including ground metrics.

Coefficient	Water Potential (Bars)		Chlorophyll (µmol/m²)	
	A	B	A	B
Intercept	0.112	0.112	0.0011*	0.3867
Blue	0.108	0.108		0.3815
Green			0.0047*	0.0877
Red			0.0196*	0.133
Red Edge			0.0405*	0.144
NIR			0.0018*	0.0026*
NDVI	0.111	0.111	0.0147*	0.0583
GNDVI			0.0042*	0.1041
RENDVI				0.2032
NLI	0.112	0.112		0.3861
Soil Moisture				
Soil Temperature				0.084
R^2(adj), %	3.3	3.3	46.5	52.2

*Coefficients that show significance (p-value <0.05)

Combined Seasonal Models. The mixed model strength was evaluated using residual plots as R does not provide adjusted R-squared values in a mixed model. Additionally, residual plots are extremely useful, as they allow direct comparison of the prediction potential between the various models and allow for assessment of regression assumptions (Figure 9). The chlorophyll models used the same covariates with the exception of the ground data not using the

blue band and including soil moisture. The water potential models used different covariates for each one (Table 6). Both water potential and chlorophyll models utilized a higher number of significant covariates when including the ground data indicating stronger models.

Figure 9 illustrates that both water potential and chlorophyll models had slightly tighter residuals when ground-based metrics of soil moisture and soil temperature were included in the model. This feature indicates a relatively higher model fit when compared to the models that excluded the ground-based variables. Also, it was determined by assessing the residual plots that none of the models display any conspicuous issues with heteroskedasticity, non-linearity or inappropriate scaling of values. It is also worth pointing out that there was an obvious trend between the flight-specific models and seasonal climate stress models for both the Red-Edge and NIR covariates to be significant, particularly for predicting changes in chlorophyll. This factor will be expanded upon further in the discussion section.

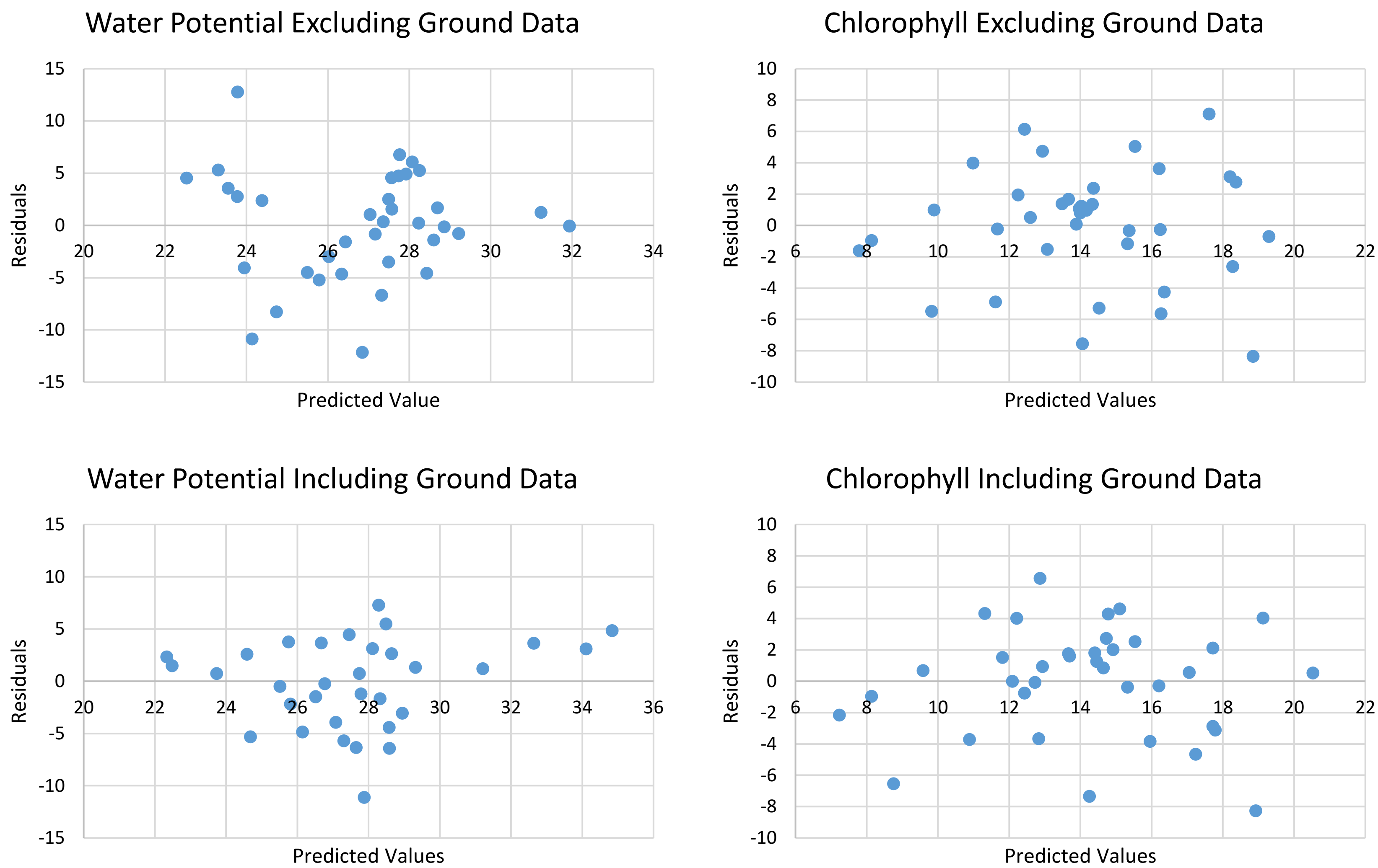

Figure 9. Residual plots for all mixed models.

Table 6. Season long climate stress model selected coefficients used. Label A represents models excluding ground metrics and label B represents models including ground metrics.

Coefficient	Water Potential (Bars)		Chlorophyll (µmol/m²)	
	A	B	A	B
Intercept	0.0003*	0.0187*	0.0002*	0.0003*
Blue			0.1424	
Green		0.0612		
Red				
Red Edge	0.106		0.0016*	0.0007*
NIR		0.0365*	0.001*	0.0004*
NDVI		0.0568	0.1988	0.0266*
GNDVI				
RENDVI	0.1028		0.0015*	0.0005*
NLI				
Soil Moisture		0.0017*		0.0189*
Soil Temperature		0.004*		

*Coefficients that show significance (p-value <0.05)

DISCUSSION

Plantation Silvopasture

Mortality of Seedlings. The mortality rates of 33.3% for Kwikrop and 25% for Football where higher than preferred, but not entirely unexpected as there are several factors that may have influenced this. First, multiple people assisted in the planting procedure and even very skilled tree planters can occasionally damage a root system during the planting process or perhaps fail to adequately close the soil around the roots. Additional mortality may have been either a direct or indirect effect from anthracnose infection observed on most of the seedlings. Anthracnose is a fungal disease that can affect many different species. When black walnut trees are infected, the leaves begin to get black spots or lesions and the trees can eventually defoliate (Siegel 2007). Although in most cases anthracnose will not directly lead to death, with the seedlings being young and already under stress from planting, anthracnose could have very well attributed to mortality. Top kill could also be attributed to anthracnose. Many of the seedling lost all of their foliage at some point due to anthracnose combined most likely with general transplant and site stress. Some seedlings never re-emerged "woke up" at the beginning of the growing season, while some others did but lost the primary leader and began to grow vertically from a lateral bud. The football and Kwikrop cultivars are not known to have the relatively higher anthracnose resistance of other cultivars such as Sparrow (Reid et al. 2004, Land 2019). This fact may raise the question: "why did you plant Kwikrop and Football instead of cultivars known to have anthracnose resistance"? However, recall that one of the primary considerations of cultivar selection for this project was survivability of the rootstock as a base for later grafting of high production cultivars. While not anthracnose resistant, Kwikrop and Football are known to

produce strong rootstock that is more resistant to drought and other adverse site conditions. An important consideration when utilizing a fairly remote site where artificial irrigation is impractical.

Height and Diameter of Seedlings. The relatively minimal height growth of seedlings over the first growing season was not entirely unexpected. The seedlings were originally growing in a confined area where competition for light was very high. Once they were moved to the study site, they had no direct competition for light, therefor they could allocate more of their resources for root and diameter growth. This assumption is not only supported by traditional knowledge of tree growth and forest stand dynamics, but is actually necessary for seedlings that have been transplanted to a fully exposed microenvironment where adaptation to withstand harsh site conditions takes priority over competitive adaptation (e.g. height growth). The five football and three Kwikrop seedlings with negative diameter growth are an anomaly. The most likely cause would be slight errors in measurement. We attempted to measure diameter from the same side of the tree each time, however that may not have been exact. Those individuals were not necessarily poor in survival or rigor, as many of them with negative diameter growth had positive height growth and vice versa. Conversely, desiccation due to a very dry late season may have also contributed to this anomaly. While contraction of stems and branches due to decreased water content is very difficult to detect in larger trees, it most likely can lead to a more perceptible change in diameter for a young seedling as even a small change represents a much higher percent of the overall diameter.

Seasonal Climate Stress Models

Water Potential. The July data provided a very strong model for predicting water potential with both the exclusion and inclusion of ground-based soil moisture and soil temperature as covariates, those having adjusted R-squared values of 71% and 79% respectively. While the September data did not provide a relatively strong model regardless of the covariates used. In the case of July, all of the individual multispectral bands as well as NDVI (Normalized Difference Vegetative Index) were selected by the stepwise procedure as important variables with the addition of soil moisture when the ground data were included as potential covariates. In contrast, the September models used only the blue band, NDVI, and NLI for UAS covariates. As expected, including soil moisture and soil temperature as potential covariates did improve the model for July, with an increase of 8% adjusted R-squared. This is logical, as soil moisture should be strongly correlated to plant available water and water potential. Nevertheless, soil moisture was only measured in the top 15 cm of soil while tree roots procure water from much deeper within the soil profile. Therefore, some of this effect may be circumstantial and will be investigated further in upcoming seasons.

The poor prediction performance of the September models could very likely be attributed to extreme water stress. The year 2020 did see above average rainfall, but was well below average for the months of August and September. 75% of the year's rainfall occurred from January through July while August and September received only 5% of the annual rainfall. In addition, the study site had no direct precipitation for two weeks preceding the September flight. Average moisture readings were also drastically lower in September than in July. Given these observed differences in precipitation, temperature and soil moisture, it is very possible that the poor performance of the September models may be at least partial correlated to a critical

threshold in water potential. It is important to remember that water potential is a combined effect of not only the conditions at one specific time, but the climatic conditions leading up to that moment over the preceding days or even weeks. It is very possible that the trees simply reached a point at where water potential had effectively "maxed out" and was therefore not as directly correlated with variation in multispectral bands and vegetative indices that were describing vegetative conditions only during the duration of the September flight.

When looking at the mixed model from both months of data, there was a drastic change in UAS covariates used when soil moisture and temperature were included. Red-edge and RENDVI were the only covariates chosen by stepwise regression for the model excluding the ground metrics. When looking at the graph of multispectral reflectance (Figure 4), the greatest observable contrast between a healthy and stressed plant occurs in the red-edge band. That is likely indicator of why red-edge and RENDVI, a vegetative index using red-edge and near infra-red, were selected as important covariates. The model including the ground metrics, however, did not use those covariates. This illustrates how the relationship of soil moisture and soil temperature with individual bands and indices can affect the climate stress model. When looking at the residuals, they are slightly tighter when ground data is included, however, not so much that it would be impossible to predict water potential from UAS metrics only. Aside from testing linear regression assumptions and assessing general model fit, the residual plots are instrumental in illustrating how the models are relatively unbiased, even in the presence of somewhat lower overall precision, as is the case with the models excluding the ground metrics. This is a critical factor to consider when developing prediction models, as a lack of inherent bias helps to ensure that the model is not consistently overestimating or underestimating. The fact that obvious bias

was not observed for the seasonal climate stress models is very encouraging for future development and application of such models.

Leaf Chlorophyll. The chlorophyll models were much more consistent with each other. Like we would expect, the September model did improve with a 6% higher adjusted R-squared value when the ground metrics were included. The July model however, illustrates a slightly weaker model with a 9% lower adjusted R-squared value when the ground metrics were included. This does not immediately constitute a weaker model though. The July model excluding ground metrics used four covariates in the model while the model including ground metrics used eight. When more variables are included within the model, the degrees of freedom is reduced, lowering the adjusted R-squared value. Adjusted R-squared is only an estimate of the model strength. The more variables is also an indicator of how the variable work together like mentioned above.

The September models have a better overall model fit based upon higher adjusted R-squared values for both inclusion and exclusion of ground metrics than in July. This is opposite of what was illustrated in the water potential models, leading me to believe that leaf chlorophyll is not as effected by extreme stress or does not have the same type of threshold as potentially found in the water potential models.

The combined models were very similar except blue was dropped and soil moisture was added for the model including ground metrics. Red-edge and RENDVI were used in both models and were significant (p-value <0.05) in predicting chlorophyll content. As mentioned above, red-edge illustrates the largest change in reflectance from a healthy to a stressed plant. When looking at the residuals of these models, we see similar results as water potential. The residuals are evenly distributed illustrating little bias within the model. Furthermore, the model including

ground metrics does not appear to have had large effects on improving the predicting success. Again, this illustrates that the ground metrics are not necessarily needed to provide an accurate model further encouraging the expansion of these models.

CONCLUSIONS

Availability of a diverse list of tree species and forage species that can be grown in the Missouri Ozarks making establishing silvopasture systems an achievable goal. Both methods of establishment, plantation and conversion, have potential for successful establishment. However, some struggles should be expected when establishing a silvopasture system. When establishing a walnut plantation for silvopasture, mortality should be expected to some degree. Even when walnut cultivars are chosen that should be well suited for that site, other factors come into play. Fungal diseases such as anthracnose combined with limited rainfall during the summer and fall can be harsh on new seedlings. For this study, the Football cultivar appears to be slightly more successful when looking at survival rates and top kill. However, growth rates of the two cultivars were minimal and indistinguishable.

Creating accurate models to predict seasonal climate stress of trees within the Ozarks region is feasible, despite a few anomalies to models potentially from extreme water stress. Models including the ground metrics did appear to provide a better fit, although it is still clear to see that models can be created from multispectral imaging only. In most cases the red-edge and RENDI covariates were significant in the models confirming the importance of the invisible light wavelengths, particularly red-edge.

These models have potential to have even better fit with increased data collection. In future years, data collection will begin earlier in the growing season and capture conditions throughout the entire year. In addition, multiple measurements of water potential should be collected as well as leaf chlorophyll content taken on multiple leaves. This will give multiple values to average and potentially reduce the effect of outliers. This study has provided great

potential for future research regarding establishment, economics, sustainability, and production potential of silvopasture systems. In addition, it has provided encouragement for extended climate stress models into future years. All of this being important to provide to land owners, managers, and researchers alike.

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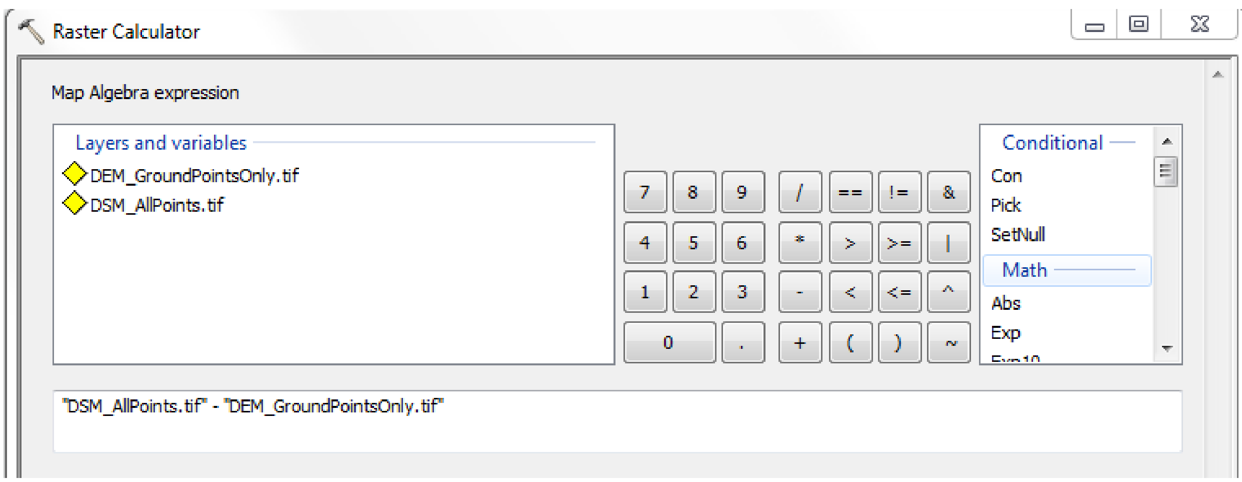
APPENDIX

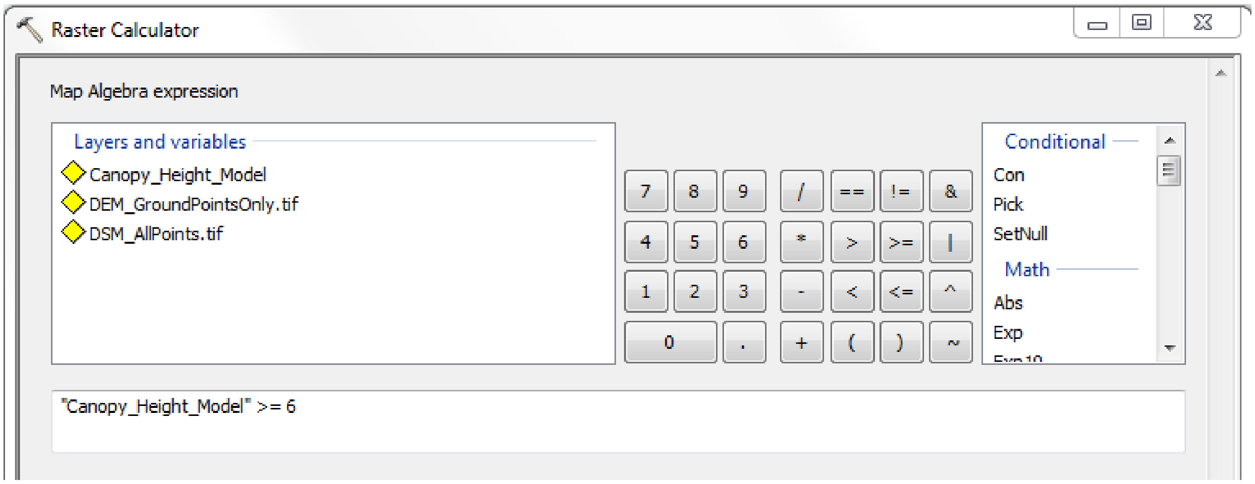
Crown Delineation Workflow

1: Export a digital elevation model (ground points only) and a digital surface model (highest points) from Agisoft Metashape Photoscan following the workflow used (USGS 2017).

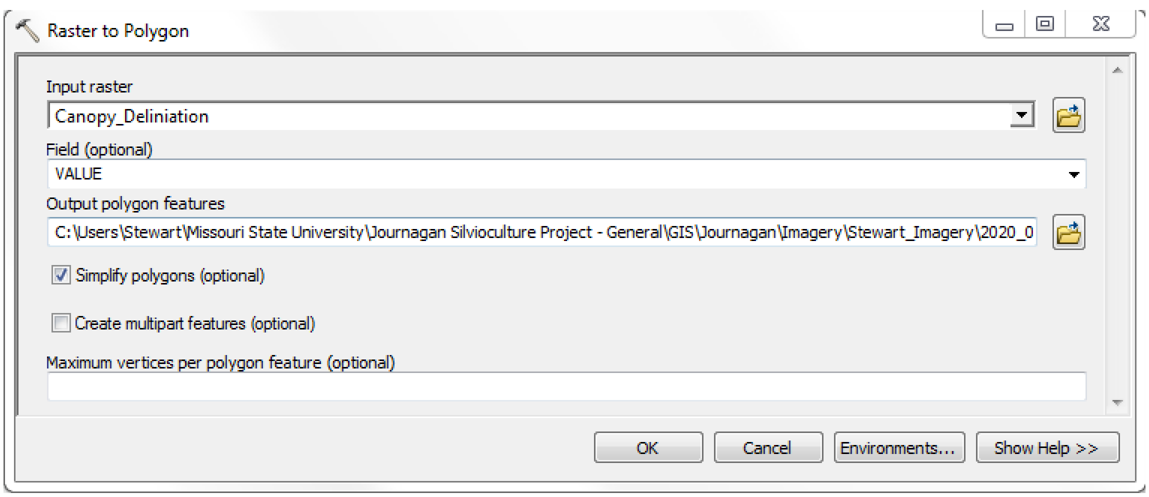
2: Using the raster calculator tool in arc map, take the DSM raster file and subtract the DEM raster file.



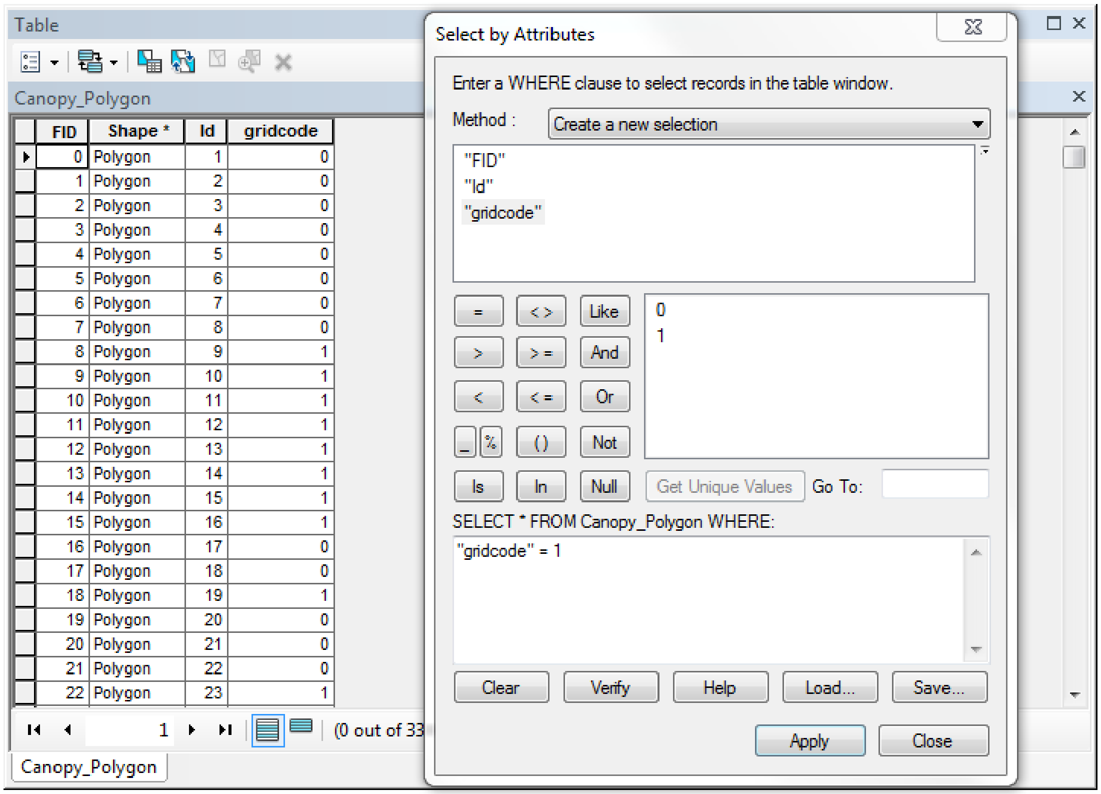
3: Use the raster calculator again to split the canopy height model into two section, tree canopy and non-tree canopy. For this situation, I used the value of six meters as the threshold. This will put any cell with an elevation of six meters or greater into one category and the cells under six meters into another. This step creates an attribute table where the cells under six meters are given a value of '0' and the cells six meters and above are given a value of '1'.



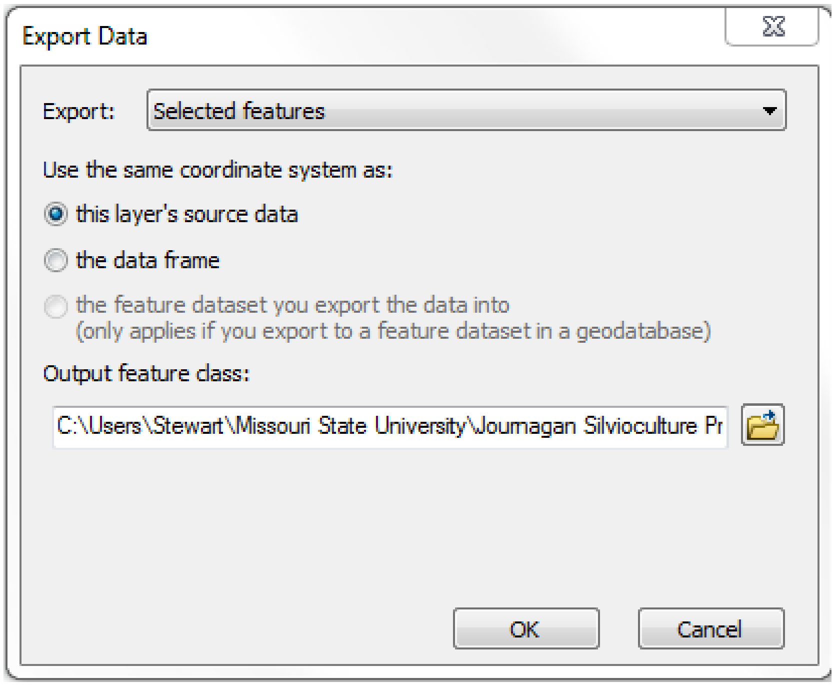
4: Using the 'Raster to Polygon' tool in ArcMap, create a polygon of the tree canopy from the delineated canopy raster.



5: Using select by attributes in the attribute table of the created polygon file select all of the polygons that have the value of '1' (gridcode = 1).



6: After selection export the selected features. Right click on the polygon layer which has the selected attributes → select 'Data' → select 'Export Data'. Note: Be sure to export the selected features from the drop down menu.



Final polygon of tree crown.