# **Linking Cattle, Forage and Tree Production in Silvopasture Systems**

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**Academic Abstract**

Silvopasture is the intentional integration of trees with forages and livestock. In Blackstone, Virginia a silvopasture management plan was created in a thinned, timber stand seeded with a cool-season forage mixture. Treatment pastures for this study included an open pasture, a thinned pine silvopasture, a thinned hardwood silvopasture, and a cleared and replanted new pine silvopasture. Cattle were introduced in 2017 and rotationally stocked within each pasture according to forage availability. Objectives were to determine the forage availability, forage nutritive value, and the performance of heifers in silvopasture and open pasture systems. Additionally, the new pine silvopasture was grazed to determine the effect of cattle on tree seedlings without protection. Forage availability was affected by date and year and was significantly lower in 2018 (3560 kg $ha^{-1}$) versus 2017 (5350 kg $ha^{-1}$). Pre-grazing forage availability was lowest in the pine and hardwood silvopastures in both years (4500 kg $ha^{-1}$) compared to the open pastures (4920 kg $ha^{-1}$; $p < 0.0001$). Date significantly influenced nutritive value, but only had date by treatment interaction in the 2017 grass crude protein and neutral detergent fiber sample. In 2017, the new silvopasture (61% TDN) had greater total digestible nutrients as compared to the open pasture and thinned hardwood silvopasture (57% TDN; $p = 0.0292$); there was no significant difference ($p=0.3733$) in total digestible nutrients in 2018 between pastures (58% TDN). In 2017, average daily gains of the heifers were greatest in the silvopastures in June ($p = 0.0346$). In 2018, average daily gain was lowest among silvopastures later in the summer compared to open pastures and new silvopastures ($p_{July} = 0.0051$; $p_{August} = 0.0008$). Remote temperature loggers were used to collect vaginal temperatures of the heifers over eight days in 2018. Silvopasture heifers had an average core temperature of 39.4 °C from 2-5 PM while heifers in the open pastures had an average temperature of 40.0 °C. A drone with a thermal

camera was used to collect external hide temperatures in the morning and afternoon. Heifers in the silvopastures had lower heat loads in the afternoon while animals without shade experienced a 65% greater temperature increase between morning and afternoon when compared to the shaded animals. Silvopastures provide an opportunity to improve the welfare of grazing livestock in the summer, while improving the overall productivity and efficiency of land. Tree seedlings that were planted into pasture to create a new silvopasture experienced a 16% mortality rate while over 75% of tree seedlings had less than 50% damage after two years and would continue to produce trees with future economic and shade value. Future research should focus on how to implement silvopasture as part of a holistic grazing and management plan while continuing to evaluate cattle, forage, and tree response to silvopastures over multiple years.

## General Audience Abstract

Silvopasture is the intentional integration of trees with forages and livestock. In Blackstone, Virginia a silvopasture management plan was created in a thinned, timber stand seeded with a cool-season forage mixture. Treatment pastures for this study included an open pasture, a thinned pine silvopasture, a thinned hardwood silvopasture, and a cleared and replanted new pine silvopasture. Cattle were introduced in 2017 and rotationally stocked within each pasture according to forage availability. Objectives were to determine the forage availability, forage nutritive value, and the performance of heifers in silvopasture and open pasture systems. Additionally, the new pine silvopasture was grazed to determine the effect of cattle on tree seedlings without protection.

Forage availability was lowest in the pine and hardwood silvopastures in both years compared to the open pastures. Nutritive value of forages was most greatly influenced by time rather than tree presence. In 2017, average daily gains of the heifers were greatest in the silvopastures in June. In 2018, average daily gain was lowest among silvopastures later in the summer compared to open pastures and new silvopastures. Internal and external body temperatures of heifers during the afternoon decreased with increasing shade availability with the greatest internal body temperatures occurring in unshaded animals. Silvopastures provide an opportunity to improve the welfare of grazing livestock in the summer, while improving the overall productivity and efficiency of land. Tree seedlings experienced minimal damage by cattle and would continue to produce trees with future economic and shade value. Future research should focus on how to implement silvopasture as part of a holistic grazing and management plan while continuing to evaluate cattle, forage, and tree response to silvopastures over multiple years.

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### Introduction

In a Beef 2017 Needs Assessment Survey performed by the USDA, beef industry stakeholders indicated that their top five priority management issues for research focus were: calf health, cow health, animal welfare, nutrition/feed management and environmental stewardship/sustainability (USDA, 2016). In terms of animal welfare, interest areas needing improvement in research and on farm adoption include animal comfort, heat stress management, and the overall value of heat stress abatement for producers and livestock. Most current research in heat stress focuses on the dairy and feedlot cattle industries while heavily ignoring grazing beef cattle, particularly in temperate regions. These studies often assess heat stress on reproduction, lactation, and finishing. There is a need for continued research and new solutions for producers seeking to balance needs and concerns for the environment, social perceptions, and profitability, specifically in the grazing cattle sector.

Heat stress costs the beef industry $369 million annually through decreased liveweight gains, increased mortality, and decreased reproduction. However, in the model-based study, the breakeven cost of providing heat mitigation in response to the economic cost of heat stress versus shade implementation was $2.60 per cow and an upwards of $6.07 in warmer cattle producing states like Texas. Lower feed costs in the industry were suggested as one reason for the lower value of shade (St-Pierre et al., 2003). Despite the low breakeven cost for the value of shade and heat mitigation, this does not take into account shade that could be accruing value overtime. Furthermore, the changing socioeconomic reality of agriculture and food sales is that over 70% of consumers are questioning the welfare of livestock and making food purchasing decisions in response (Boynton, 2015; Henderson, 2018). The summer slump has become an accepted inevitable for most cattle producers, especially in the Southeast, as temperature and humidity levels rise and livestock productivity declines. The pairing interest of animal welfare for consumers and producers demonstrates the need for continued research to understand the effects of heat stress and provide affordable options to alleviate heat stress. Management decisions for livestock, such as the provision of adequate shade, are critical to mitigate heat stress, optimize production, and produce healthy, productive animals that consumers want to buy.

Silvopasture is considered one of the five practices of agroforestry and is defined as an integrated system in which trees, forage, and animals are managed together. Some refer to silvopasture as an "old practice with a new name." As consumers want to know more about where their food comes from, the environmental impacts of agriculture are under scrutiny, and margins for beef cattle production systems tighten, silvopastures provide potential opportunities and solutions to these issues. Through the strategic utilization of facilitative relationships and competitive partitioning, silvopasture may use resources more thoroughly and efficiently while providing several ecosystem services, such as increased biodiversity and shade for cattle (Sharrow et al., 2009). The aim of this project is to understand the benefits of shade in silvopastures for beef cattle. Specifically, this project will assess the effect of silvopasture on animal production and internal and external body temperatures and forage availability and nutritive value. This project will also determine the effects of stocking cattle on young loblolly (*Pinus taeda* L.) trees in a newly established silvopasture system.

## Literature Review

The impacts of heat stress is an essential topic for agriculture research on crop and livestock production as the climate continues to change. The particular climate of a geographical region influences the suitability of a crop. For example, warm-season forages are suited to hotter climates while cool-season forages are adapted to temperate environments. Livestock production may be more flexible as cattle can often adapt and producers can manipulate the environment to compensate for climatic and geographical limitations. Cattle production is common in most parts of the world and in every state of the United States (USDA, 2016). Since cattle are subjected to all climate types while additionally facing the threat of increased climate change (Rojas-Downing et al., 2017), understanding livestock physiology and how to mitigate heat stress to reduce negative production impacts should be a top priority for cattle producers and agricultural research. Despite the apparent need for such research, few resources exist for beef cow producers since most heat stress and animal comfort studies in relationship to production focus on the dairy industry and feedlot cattle (Buffington et al., 1981; Brown-Brandl et al., 2005; Gaughan et al., 2008; Collier et al., 2009).

### Cattle Heat Stress

Livestock can regulate and maintain a somewhat constant range of internal body temperatures throughout various external conditions (Blackshaw and Blackshaw, 1994). The main factors influencing cattle heat stress are air temperature, radiation, humidity, and air movement or wind speed (Beede and Collier, 1986; Gaughan et al., 2008). An animal's ability to exchange heat with the environment is regulated by the processes of radiation, convection, conduction and evaporation (Bond et al., 1958; Albright and Alliston, 1972). The radiation an animal is exposed to is a combination of the absorption of direct radiant energy from the sun and diffuse solar radiation. Diffuse solar radiation is the scattering and reflection of solar energy as a result of clouds, the ground, and surrounding structures, such as trees (Bond et al., 1967; Blackshaw and Blackshaw, 1994; Langman et al., 2003). Coat color influences the absorption of radiation (REFs).

Animal comfort and stress levels, including heat related stress, has many causative factors. Animal characteristics such as breed, genetics, productivity, size, diet, parity, age and coat color all play a role into an individual animal's tolerance to heat (Van Laer et al., 2014; Veissier et al., 2017). For example, *Bos indicus* breeds are more tolerant of heat than *B. taurus*. Although both species are able to regulate some body processes in prolonged heat stress, *Bos taurus* animals show a quicker and more severe response to heat stress with increased core body temperature and respiration rate and significantly decreased feed consumption whereas *Bos indicus* animals did not experience any severe physiological responses and only minimal changes after a later period of prolonged heat stress (Beatty et al., 2006).

*Heat Stress Mechanisms and Responses*

When an animal's thermal comfort zone is exceeded, the animal responds physiologically and behaviorally. According to Albright and Alliston (1972), the body's first line of detection of thermal changes is the cutaneous receptors on the skin which may happen before the animal physically warming passed homeothermy; this detection sets off physiological body responses to change insulative ability. This can include initiating vasodilation, panting and increased respiration, and sweat secretion reflexes (Albright and Alliston, 1972; Farooq et al., 2010; Charkoudian, 2010). The brain works to maintain homeothermy as internal temperature signals response in the central nervous system through thermoreceptors and thermosensitive units which analyze thermal load and thus warm the pre-optic region of the hypothalamus (Baker, 1989;

Silanikove, 2000). The hypothalamus then signals for the initiation of heat loss mechanisms during periods of heat stress in the process of prioritizing maintenance over production (National Research Council (U.S.), 1996). Part of this response involves metabolic changes. Heat generation from external exposure to the environment and internal heat production from digestion stimulates the medial satiety center, signaling fullness and thus inhibiting the lateral appetite center through the rostral cooling center of the hypothalamus (Albright and Allison, 1972). As a result, an animal's desire to consume feed is reduced, which may impact health and growth. There is a variety of physiological parameters available to evaluate and assess the level of heat stress in livestock, including body temperature (tympanic, rectal, or vaginal), respiration rate, panting score, and cortisol levels (Gaughan et al., 2000, 2008; Brown-Brandl et al., 2005; Gaughan and Mader, 2014; Ghassemi Nejad et al., 2017; Veissier et al., 2017). Water consumption, feed consumption, mating behavior, and activity (lying, grazing, standing idle) have been measured as behavioral responses to heat stress (Mader et al., 2010; Rovira, 2014; Van Laer et al., 2015; Allen et al., 2015; Kanjanapruthipong et al., 2015; Hill and Wall, 2017). Performance parameters have been measured and correlated to environmental stress to better understand the impacts of heat stress; these studies often focus on growth rate or liveweight gain, milk production, and reproduction rates (West et al., 2003; Collier et al., 2006; Allen et al., 2015; Krishnan et al., 2017).

While sweating and panting may be a more immediate physiological response to heat stress, responses like body temperature and feed intake can experience a lag period of a few hours to a few days between the given heat stress event, its response, and total animal recovery after the initial environmental trigger (Baker, 1989; Beatty et al., 2006; Farooq et al., 2010). Several studies have measured a 1- to 5-hour delay in body temperature rise following ambient temperature changes (Hahn, 1999; Brown-Brandl et al., 2005). Collier et al. (1981) measured a 24- to 48- hour delay in milk production following a heat stress event. Feed consumption decreases in response to heat stress, subsequently decreasing metabolism, and thus reducing metabolic heat (Finch, 1986; Blackshaw and Blackshaw, 1994). Conversely, when feed intake increases, the need to dissipate heat from the body is higher in order to maintain body temperature in response to the heat and energy produced by metabolism (Blackshaw and Blackshaw, 1994). Metabolism is responsible for one-third of an animal's expressed heat load when exposed to high heat and radiation (Finch, 1986). Changes in respiration through panting may only reduce heat loads by approximately 15% within such an environment. Cattle must employ additional cooling methods, both behavioral and physiological, to regulate temperature and stay cool such as limiting their feed consumption. Feed consumption is unchanged when temperatures are between 15° and 25° C, while there will be a 10-35% drop in consumption when temperatures exceed 35ºC (Blackshaw and Blackshaw, 1994). Heat stress periods associated with temperatures above 32°C during peak milk levels reduced daily milk yield by 20-30% (Shearer et al., 1999). Wheelock et al. (2010) measured the effect of heat stress of lactating dairy cows in climate controlled chambers and found that dry matter intake was reduced by 30% while milk production dropped by 27% in cattle in heat stressed environments as compared to lactating cows in a neutral thermoregulated environment. Reduced milk production would be less evident in beef production systems as a function of the system (milking daily versus weaning a calf) and breed differences, but producers would be expected to see the effects of decreased milk production on weaning weights (Kallenbach, 2009).

*The Influence of Shade*

Cattle response to heat stress when temperatures are between 21 and 27 degrees Celsius, but this range is influenced by radiation, wind speed and humidity (Baliscei et al., 2013). Radiation is composed of direct and diffuse radiation, which may be reduced by the presence of shade (Blackshaw and Blackshaw, 1994; Langman et al., 2003). Radiant heat was 278 W $m^{-2}$ lower and short wave radiation declined by 43% under a shaded structure compared to an open environment (Langman et al., 2003). Blackshaw and Blackshaw (1994) found that over 30% of an animal's heat load in a hot environment could be reduced by adding a simple shade. The provision of shade to cattle can improve daily weight gain, milk production, and fertility (Coffey et al., 1999; Shearer et al., 1999; Collier et al., 2006; Kallenbach, 2009). In one example in Arkansas, average daily gain increased by over 20% when cattle were provided with artificial shade while cattle provided with tree shade had an almost 60% increase in daily gain as compared to cattle with no shade (Coffey et al., 1999). Research in Florida has demonstrated that shade increased milk production in dairy cows by 10-19% (Collier et al., 1981; Shearer et al., 1999). AI conception rates were 44.4% in cattle provided with shade compared to 25.3% in cattle without shade in Florida (Collier et al., 2006). Cows provided with shade had an overall pregnancy rate of 87.5% compared to a rate of 50.0% in cows without shade in Missouri (Higgins et al., 2011).

*Heat Stress Indices as a Function of Measuring Heat Stress*

There are several methods to measure and assess the surrounding environment and its impact on the thermal comfort of mammals. While a few studies will solely consider one environmental factor, mainly temperature, there is greater correlation between environment and animal response when an integrated model is utilized (Gaughan et al., 2008; Mader et al., 2010;

Da Silva et al., 2015). The temperature-humidity index (THI) was one of the first and simplest coordinated models and is still a widely accepted index for assessing environmental conditions. Initially created by Thom (1959), THI was used to evaluate human discomfort associated with temperature and humidity and has since been adapted to livestock as an indicator of heat stress (Albright and Alliston, 1972; Collier et al., 2009; Karvatte et al., 2016). A normal THI range is set at a level in which no heat stress and heat-stress related production losses occur; mild and severe levels of heat stress are set above a normal THI range with associated production losses for beef and dairy cattle at higher scores above 74 (Brown-Brandl et al., 2005; Van Laer et al., 2015). Based on Silanikove, (2000) normal thermal environments not associated with heat stress are classified at a score below 70, mild heat stress is defined as a THI between 70 and 74, moderate heat stress occurs between a THI of 74 and 77, and severe heat stress occurs when the THI exceeds 77 (Silanikove, 2000; Nienaber and Hahn, 2007; Rovira, 2014). The temperature-humidity index does not take into account radiation, and thus is limited in scope (Gaughan et al., 2008; Lopes et al., 2016).

Recent studies and models have explored more dynamic strategies to assess heat stress by adding parameters such as radiant heat and wind speed. Such approaches have proven to be valuable in assessing the impacts of shade and housing while serving as a more accurate predictor of stress (Gaughan et al., 2008; Mader et al., 2010). Black globe temperature was one of the first field measurements that measured the effect of radiation. The black globe temperature humidity index (BGHI) by Buffington et al. (1981) made black globe temperature more relevant to assessing heat stress; BGHI included dew point temperature and black globe temperature. The initial studies demonstrated a greater correlation of BGHI to rectal temperature and milk yield in dairy cows than previously obtained with THI but demonstrated a weaker correlation between

BGHI and heat stress parameters when shade was present (Buffington et al., 1981; Collier et al., 2009). Hahn et al. (2003) reevaluated black globe temperature (Tbg) and established a formula to calculate black globe temperature with ambient temperature and radiation intensity ($W\ m^{-2}$), making Tbg a more accessible calculation without requiring a black globe temperature sensor while still providing an objective metric. The black globe temperature (Hahn et al., 2003) was later used to formulate the Heat Load Index (HLI) which takes into account ambient temperature, radiation, wind speed, and relative humidity. Similar to THI, the heat load index provides a numerical number without units to determine mild, moderate, and severe heat stress (Gaughan et al., 2008). Most recently, the Comprehensive Climate Index (CCI), was established. Similar to the HLI, the CCI is calculated from ambient temperature, radiation, wind speed, and relative humidity, and is used to calculate a metric defined in degrees Celsius (Mader et al., 2010).

Silva et al. (2007) measured six climatic indexes for dairy cattle in a tropical environment and correlated index scores to rectal temperature and respiratory rate. Temperature humidity index, BGHI, and HLI were all evaluated finding correlation values ($r^2$) of 0.099, 0.155 and 0.542, respectively for respiration rate while finding no significant correlation between rectal temperature and THI and BGHI. Of the three, it was concluded that the HLI serves as the best predictor of heat stress for dairy cattle in a tropical environment whereas physiological responses could not be correlated with THI and BGHI in such an environment. Dry matter intake and panting scores have been correlated to CCI. Mild heat stress responses, based on decreases in feed intake and inadequate nighttime cooling, occurred at a CCI of 25°C to 30 and moderate heat stress responses occurred between 30°C and 35°C with decreases in DMI initially seen around a CCI of 20°C, especially observed in higher producing animals (Mader et al., 2010).

These indices have aided research and scientists to better understand the relationship between ambient environment and animal response.

**Table 1.1: Heat load indices, formulas, and thresholds**

| Index | Formula | Threshold | Literature |
|---|---|---|---|
| THI | 0.8 x Ta+ [(RH/100) x (Ta-14.4)]+46.4 | 68-74 depending on lit; 68 | Thom, 1959; Collier et al., 2009 |
| THIadj | 4.51 + THI - 1.992 x WS +0.0068 x Rad^2.5 | 68, similar to THI | Mader et al., 2006; Hill and Wall, 2017 |
| Tbg | 1.33 x Ta - 2.65 x Ta^.5 + 3.21 x log(Rad+1) + 3.5 | 25°C | Hahn et al., 2003-equation; Van Laer et al., 2015- limit |
| WBGT | .7 x Twb + .2xTbg + 0.1 x Ta | 25°C | Burr, 1991 |
| HLI (Tbg>25)<br>HLI (Tbg<25) | 8.62+.38 xRH +1.55 x Tbg - 0.5 x WS + e^(2.4-WS)<br>10.66 + 0.28 x RH + 1.3 x Tbg - WS | 70, 77, 86 for mild, moderate and severe | Gaughan et al., 2008 |
| CCI<br>CCI Eq 1 | Ta + RHadj Eq 1 + WSadj Eq 2 + RADadj Eq 3<br>e^((0.00182xRH+1.8x10^-5x TaxRH) x (0.000054xTa^2 +0.00192 x Ta - 0.0246) x (RH-30)) | 25°C (respiration rate basis) | Mader et al., 2010 |
| CCI Eq 2 | (-6.56)/ e^[(1/(2.26xWS+.23)^.45) x (2.9+1.1.4x10^-6 xWS^2.5 - log_.3 (2.26xWS+.33)^-2] - 0.00566xWS^2 +3.33 | | |
| CCI Eq 3 | 0.0076xRad -0.00002 xRadxTa + 0.00005 x Ta^2 x sqrt(Rad +.1xTa-2)x | | |

**Silvopasture Production**

Interest in silvopasture systems has been growing as ecologists and attempt to find ways to reduce the environmental impact of food production. Designed as an integrated system of forestry, forage, and animal production, silvopastures may be established by either thinning existing timber stands to establish forages or planting trees into open pastures (Clason and Sharrow, 2000). Although to some farmers and foresters, the idea of combining trees and cattle may sound problematic, it is not a new management practice. Cattle were once commonly managed along with trees throughout the southeastern U.S. in the early 1900s (Barlow et al., 2016). Forms of silvopasture and agroforestry have existed throughout history around the world from South and North America, Europe, and Africa (Clason and Sharrow, 2000). In more recent years, agroforestry has evolved, and unmanaged woodland grazing has been contrasted with more intensively managed silvopastures.

Research in silvopastoral focus on establishment, economic components, environmental impact, ecological interactions, and animal production. While trees provide timber and an added source of income, they also provide natural shade for animals in a pasture system among other ecological benefits (Kallenbach, 2009; Lopes et al., 2016; Pent, 2017). Silvopastures can provide an opportunity to improve an otherwise ignored or degraded forestry system. Silvopasture is not a single tree in a pasture nor is it unmanaged access of livestock in forests. Both of these practices are harmful to the livestock, trees, and system as a whole and can cause detrimental effects to the soil and environmental resources (Staley et al., 2008).

*Forages and animal production in Silvopastures*

Several studies demonstrate that forage quantity will be reduced in a silvopasture system due to the competition for light and nutrients, like water, and other soil nutrients between trees and forages, potentially impacting nutrient uptake in forages (Devkota et al., 2001; Dodd et al., 2005; Feldhake et al., 2010). However, some research suggests that although availability is reduced, forage nutritive value is increased in silvopasture systems (Kallenbach et al., 2006; Neel and Belesky, 2017). Other studies have found greater or no difference in forage biomass, nutritive value and digestibility when forages are grown in the presence of trees (Buergler et al., 2005; Mercier, 2017). In Buergler et al. (2005), emulated (no animals) silvopasture forage production, both forage variety and total yield, was influenced by tree species and tree density. Trees with medium tree density measured by shade provision and PAR admittance had 20% greater forage availability compared to silvopasture sites that had low and high tree density.

Additionally, both forage mineral content and fiber digestibility increased with increased tree presence in a silvopasture system whereas NDF was decreased (Buergler et al., 2006). Orefice et al. (2016) found that some forages had a crude protein significantly greater in silvopasture versus open pasture; in this study, orchardgrass (*Dactylis glomerata* L.) had a CP of 12.9% in silvopasture versus 10.7% in open pasture. Despite forage availability being reduced in some silvopasture systems, animal production does not always mirror this trend in studies; animal production is sometimes greater or equal in silvopasture systems as compared to open pasture systems (Costa et al., 2016; Pent, 2017). In Kallenbach et al. (2006), cattle gains were statistically similar in silvopasture versus open systems despite annual ryegrass (*Lolium multiflorum*) and cereal rye (*Secale cereal* L.) forage yields being decreased by 20% in the silvopasture system. Costa et al. (2016) demonstrated insignificant differences in herbage allowance, green herbage crude protein and animal daily gain between and open pastures and silvopastures in Brazil; additionally, the stocking rate was minimally affected by silvopastures versus open pasture and gain per area (kg $ha^{-1}$) had no treatment effect having similar liveweight gains in open pastures and silvopastures.

*Shade benefit in Silvopastures: Animal Response*

Chedzoy and Smallidge (2011) supported the value of shade provided in silvopasture systems in grazing livestock from added daily gain, reduced heat stress, better pastureland, forage utilization, and nutrient recycling in comparison to open system pastures. Coffey et al. (1999) found that cattle had greater average daily gain when under shade from trees versus artificial shade, and cattle preferred utilized both types of shade. Cattle were thought to have benefitted from the evaporative cooling of trees. Shade is not created equal; cattle prefer and perform better under natural shade as compared to artificial forms of shade (Van Laer et al., 2014; Kamal et al., 2014). Additionally, livestock under adequate shade have been found to have lower internal (rectal, vaginal, tympanic) temperatures throughout the day as compared to unshaded counterparts, specifically during the afternoon with a slower and less drastic rise in internal body temperature in response to ambient temperature, specifically in the heat of the day (Brown-Brandl et al., 2005; Rovira, 2014; Pent et al., 2018). This difference in temperature reflects the reduced heat absorbance due to decreased radiation and therefore overall heat load; cows with lower body temperatures have to expend less energy for maintenance, are less heat stressed, and are more comfortable. Furthermore, grazing was the typical behavior for cattle in silvopasture systems, with cattle in silvopastures grazing 36-52% more throughout the day compared to animals in open pastures, whereas loafing was a more common behavior exhibited by cattle in open pasture systems (Karki and Goodman, 2010). Shade use by livestock has been directly affected to the ambient environment, and temperature in response to increasing temperature and heat load as animals try to maintain body temperature and cool themselves (Rosselle et al., 2013; Van Laer et al., 2015; Veissier et al., 2017). Limited silvopasture studies have assessed behavioral trends among open and silvopastures in relation to the environment through the analysis of time grazing, lying, and standing idle (Lopes et al., 2016; Pent, 2017). Although Lopes et al. (2016) did not find eucalyptus (*Eucalyptus* spp.) silvopastures effective of preventing THI from reaching critical levels as compared to open pastures, animals in the silvopastures spent over half the day in the shade when provided in contrast to animals in treeless pastures which had no shade and were more restless. Lactating dairy cows with lower core body temperate were 50% more likely to initiate lying down whereas cows with higher core body temperature, especially when over 38.8°C, were more likely to stand up than lie down and stay standing longer compared to cows with cooler temperatures and therefore less heat stressed (Allen et al., 2015). Lambs in both black walnut *(Juglans nigra*) and honey locust (*Gleditsia triacanthos*) silvopastures grazed in accordance to the shade and spent more time lying down than lambs in the open pasture control; lambs in the black walnut silvopasture did spend the greatest amount of time grazing throughout the day (Pent, 2017). Most often, livestock in silvopastoral or shaded systems would graze and lie for longer percentages of the day and stand idle for a shorter period in comparison to their open system counterparts (Karki and Goodman, 2010; Pent, 2017), which indicates that animals in silvopastures are more comfortable than animals in open pastures. (Kallenbach, 2009) found that cows in silvopasture systems weaned calves on average 25 kg heavier as compared to cows weaning calves without access to silvopasture.

*Microclimate in Silvopastures*

While the ambient temperature does not change in versus out of the shade, the microclimate in a silvopasture can change (Baliscei et al., 2013; Karki and Goodman, 2013, 2015). Any slight change in temperature due to shade presence is a factor of evapotranspiration (Huang et al., 1990). Some data suggests mild and moderate temperature fluctuations between silvopastures and open systems, within a degree or two, both increasing and decreasing depending on the specific system. Karki and Goodman (2015) measured statistically lower average air temperatures in a Florida mature loblolly pine silvopasture in 10 out of 12 months during a two-year study, demonstrating a 1-15% decrease in temperature compared to the open pasture. In contrast, a young longleaf pine (*Pinus palustris*) silvopasture in south Georgia had statistically warmer air temperature during a 3-year study between May and September and as an overall year average as compared to the control open pasture (Karki and Goodman, 2013). Silvopasture affects more than just air temperature; humidity and wind speed have seen various fluctuations with overall decreases in silvopastures as compared to open pastures, and decreases in soil temperature have been observed following similar trends as air temperature (Karki and Goodman, 2013, 2015; Lopes et al., 2016). Radiation is often affected by the presence of trees and is measured in total solar radiation ($W\ m^{-2}$) and PAR ($\mu E\ m^{-2}\ s^{-1}$) in silvopastures versus open pastures (Karki and Goodman, 2013, 2015). In the mature loblolly pine silvopasture, total solar radiation had a 32-63% decrease while photosynthetic active radiation had a 46-73% decrease in silvopastures as compared to open pastures (Karki and Goodman, 2015). Total solar radiation in the young longleaf pine silvopasture was only lower in four months as compared to the open pasture while PAR was 1-11% lower in silvopastures in ten out of twelve months (Karki and Goodman, 2013). This change in radiation has an impact on forage production (Kephart et al., 1992; Neel et al., 2008; Neel and Belesky, 2017; Pang et al., 2019). When measuring microclimate effects, Karvatte et al. (2016) measured a 3.7% decrease in THI, a 10.2% decrease in BGHI and a 28.3% decrease of the radiant thermal load as a result of shade by silvopasture in contrast to an open system. Artificial shade cloths decreased the black globe temperature by 4.5 ºC and ambient temperature by 2.0 ºC on hot summer days in temperate pasture systems in Belgium (Veissier et al., 2017). Shade by trees also lowered black globe temperature by 3.8 ºC in Van Laer et al. (2015); however, temperature and THI have been found to not correlate to radiation suggesting that radiation cannot be predicted by THI, and thus making THI less relevant when assessing the impact of shade.

*Silvopastures: Forage and Benefits*

Silvopastures have the ability to provide additional ecosystem services while producing ample forage for cattle and supplementary timber for sale (Chedzoy and Smallidge, 2011; Nyakatawa et al., 2012; Orefice et al., 2016). Forage production can be maximized through utilizing cool-season forage mixtures in temperate regions and warm-season forages within tropical climates with an appropriate tree canopy allowing the necessary light in by adjusting canopy closure and PAR (Kephart et al., 1992; Dodd et al., 2005; Pang et al., 2019). Since cool-season forages are regulated by C3 photosynthetic pathways, they do not need full light and can thrive on a fraction of light becoming light saturated before full sunlight in which production plateaus, making them successful forage options in temperate silvopastures even with a degree of light being intercepted by the trees (Hopkins, 2006; Ball et al., 2015). Cool-season grasses have successfully been grown without significant reductions in forage production in shaded and silvopastoral systems as long as shade does not exceed 50% cover (Buergler et al., 2005; Mercier, 2017). Tree dynamics such as species, canopy, density and topography should be considered in silvopasture establishment to select complimentary production cycles in which forages can successfully coexist with the effects of tree canopy on understory growth and light availability. Tree species with thinner canopies are often suited for silvopasture production since they allow greater sunlight and photosynthetic active radiation transmittance to the forages (Buergler et al., 2005, 2006; Costa et al., 2016). Managed silvopastures provide additional economic benefits through diversification (Godsey, 2008; Karki and Diabate, 2015; Bruck et al., 2019). As most studies have depicted, forage and cattle production can be comparable to open pastures, and the added timber provides an opportunity for over-yielding while appreciating land value (Clason, 1999; Orefice et al., 2016). Over-yielding occurs when a land-equivalency ratio is greater in an intercropping system than when crops are managed separately. Even if individual component yields (e.g. forage and tree production alone) are lower in the systems managed separately, total output combined can still be greater. This occurs through facilitative relationships and competitive partitioning in which the components of the silvopasture system can interact to create beneficial effects and utilize resources more efficiently. Financial analyses of silvopastures demonstrated greater net present value and internal rate of return in silvopasture systems versus open systems; these analyses accounted for the cost and value of timber, forage, and animal production in the system, demonstrating economic viability where silvopasture establishment costs are reasonable (Godsey, 2008; Orefice et al., 2016; Bruck et al., 2019).

Additional ecosystem services can be provided from a silvopasture. One of the most evident benefits is simply the diversity in the system by intentionally integrating and managing forage, trees, and livestock in a collaborative system; diversity protects from volatility. Silvopastures have been identified as suitable wildlife habitats, often providing homes for various animals and increasing biodiversity (Moore, 2012; Colmore, 2015). Leguminous trees have additionally been used to provide shade in silvopastures systems while increasing an additional source of nitrogen fixation in the soil in combination with legume forages, like clovers typically included in silvopastoral systems (Sharrow et al., 2009; Costa et al., 2016). Other services include increased nutrient cycling, pollination, soil fertility, and carbon sequestration (Costa et al., 2016; Orefice et al., 2016). Through proper management, livestock provide a beneficial input of nitrogen and phosphorus fertilization, returning these plant nutrients to the soil through their manure. Since livestock utilize shade, nutrients may be more evenly distributed across silvopastures (Karki, 2008; Karki and Goodman, 2010; Pent, 2017). Consequentially, there may be less soil erosion since there is not a single trafficked spot for livestock shade

(Sharrow et al., 2009; Nyakatawa et al., 2012). Additionally, a single shade tree creates a concentrated area where animals lounge and defecate which could create a hub for parasites and disease (Staley et al., 2008; Nyakatawa et al., 2012).

Forest and grasslands are known for their ability to sequester carbon from the atmosphere and hold them in the roots underground; available research suggests that agroforestry systems and silvopastures have the potential to sequester more carbon than open pastures and forested (Albrecht and Kandji, 2003; Sharrow and Ismail, 2004; Nair et al., 2009). Additionally, despite typical concerns of water and nutrient competition between forages and trees in silvopasture systems, some studies indicate that tree-forage systems may allow hydraulic lift, thus benefitting the forage crop when water in the upper soils is limited. Hydraulic lift occurs when deep-rooted plants and trees bring water up from deeper soils and release that water into upper soil levels typically during nighttime cooling; that water would otherwise not be exploitable by the shallower forage roots (Dawson, 1993; Yu and D'Odorico, 2015). Ludwig et al. (2004) demonstrated that extreme competition between trees and grasses could minimize the benefit of hydraulic lift, but still found the grasses in near proximity received water input from adjacent trees by means of hydraulic lift. In contrast, hydraulic lift by trees has resulted in increased forage biomass and changed soil water potentials in savannas (Yu and D'Odorico, 2015). Water taken up above a fragipan was confidently classified as water from hydraulic lift; neighboring plants were benefited by hydraulic lift as a function of distance from the trees in a sugar maple and grass system (Dawson, 1993).

## Conclusion

Heat stress is already a pressing issue facing livestock producers across the globe. Extreme climatic events will continue to be a concern in the future exacerbating heat stress concerns (Parsons et al., 2001; Nienaber and Hahn, 2007; Thornton and Gerber, 2010; Rojas-Downing et al., 2017). Production losses associated with heat stress will continue to affect the livestock industry, requiring continued adaptations and solutions to ensure animal welfare and optimal production. These growing needs are supported by the 2017 USDA survey, which highlights the fact that the beef industry is aware of these challenges.

In addition to environmental changes, there are growing social and economic considerations and challenges as agriculture moves towards the future. Farmers are receiving cents on the dollar spent on food, environmental stewardship is receiving more attention, and consumers continue to want more say in their food supply (Boynton, 2015; Bennett et al., 2018; USDA, 2018; Henderson, 2018). Together, this presents opportunities for diverse solutions and niche producers to appeal to social and environmental interests; producers can diversify income through integrated production systems and implement environmentally sound practices with governmental and grant aid, including agroforestry practices like silvopasture. Silvopasture can be a practical on-farm tool to improve livestock welfare and production, farm profitability, and ecosystem services when managed as an intentional system. However, there are gaps in the scientific and practical understanding of different silvopastoral systems relating to animal welfare and the dynamic system as it impacts animal, forage, and young tree productivity.

The research in this project will focus on understanding the dynamic relationships between forage, cattle, and trees in order to understand the value of silvopasture systems. Liveweight gains of animals will be measured to calculate production. Internal and external body temperature of cattle will be measured to understand the impacts of shade on cattle heat stress. Forage samples will be collected in open pastures and silvopastures to determine differences in nutritive value and forage availability. Tree damage in silvopastures in which young trees have recently been planted will be assessed to determine if it is possible to graze cattle while establishing a silvopasture. This research will be used to evaluate the role of silvopasture as a potential tool in reducing heat stress in livestock while producing forages and trees in an integrated system.

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**Chapter 2: Forage Production and Nutritive Value in Silvopastoral Systems**

## Introduction

Silvopasture is one of the five types of agroforestry and is defined as the integration of forage, livestock, and trees (Clason and Sharrow, 2000). A goal for many silvopasture systems is to over-yield. This occurs when production of the integrated system is greater than production from systems where livestock, forage, and trees are managed separately. In most situations, forage production will determine the potential stocking rate or days of grazing that a pasture will provide. Over-yielding is possible in a silvopasture system even when the productivity of one or both components is reduced compared to when components are managed separately. The forages and trees compete for sunlight and water and nutrients from the soil which they would not be competing for in individual systems. Despite this competition, forages and trees grow in different time and space parameters where forage growth is seasonal, and trees can often take advantage of deeper roots for nutrients. As such, the two components competitively partition resources through facilitative relationships, tapping into otherwise untouched resources and making systems more efficient, leading to the potential for over-yielding. To accomplish this, silvopasture management must ensure that the livestock, forage, and trees all receive the nutrients and resources they need for consistent growth (Sharrow et al., 2009).

There has been limited research on silvopasture production in the southeastern U.S. Production is impacted by weather, climate, terrain, and soil type (Sharrow et al., 2009). Additionally, tree and forage variety selection and production cycles, fertilization, tree density, and sunlight transmission, and stocking management also influence silvopastoral reproductivity. Natural Resources Conservation Service (2011) recommends producers to thin trees to 35% tree canopy if planting warm-season forages and 50% canopy cover if planting a cool-season pasture to ensure adequate sunlight transmission. Several studies have demonstrated similar recommendations by showing similar trends in forage production and canopy cover, identifying decreases in forage production as radiation available for photosynthesis by forages decreases (Kallenbach et al., 2006; Neel et al., 2008; Lindgren and Sullivan, 2014; Orefice et al., 2016; Mercier, 2017). By selecting complimentary tree and forage species, reductions in forage production can be minimized; selecting cool-season forages in moderate climates and thinning trees to lower densities have been beneficial to forage growth (Buergler et al., 2005; Sharrow et al., 2009). The C3 photosynthetic pathway utilized by cool-season forages becomes saturated with light sooner than warm-season plants that use the C4 pathway; when a plant becomes light saturated, it is no longer able to effectively utilize light for plant growth to enhance photosynthetic potential (Hopkins, 2006). Cool-season forages are typically more tolerant of shade than warm-season forages (Lin et al., 1999).

Studies have shown various and sometimes contradictory changes in forage nutritive value in silvopasture systems. Several studies have measured no change to overall fiber (acid detergent fiber and neutral detergent fiber), higher nitrogen levels, and lower total non-structural carbohydrates in silvopasture systems (Kephart and Buxton, 1993; Buergler et al., 2005, 2006; Mercier, 2017; Neel and Belesky, 2017), suggesting that potential stress from reduced light are the cause for the increased nitrogen and therefore protein. Kallenbach et al. (2006) found that although forage production was decreased, forages in the silvopastures had greater or equal crude protein levels than forages in the open pastures. There were no differences between treatments in animal liveweight gains, suggesting that the increased forage quality by nutritive value in the silvopastures compensated to some extent for the decreased forage production.

The objectives of this study were to:

1. Determine the characteristics of a silvopasture versus an open pasture on forage availability.
2. Evaluate forage nutritive value in silvopasture systems as compared to open pasture systems.

## Materials and Methods

*Site Description*

This work was performed at the Southern Piedmont Agricultural Research and Extension Center (SPAREC) in Blackstone, Virginia (37.091889, -77.963632). This protocol was approved by the Virginia Tech Institutional Animal Care and Use Committee (Protocol #17-071). Soil series at the site location consisted primarily of a Durham coarse sandy loam, undulating (Fine-loamy, siliceous, semiactive, thermic Typic Hapludults) with smaller areas consisting of Worsham sandy loam (fine, mixed, active, thermic Typic Endoaquults) and Appling coarse sandy loam (fine, kaolinitic, thermic Typic Kanhapludults; Soil Survey Staff, 2018). An onsite WatchDog 2000 series 2900 ET weather station (Spectrum Technologies, Aurora, IL) collected weather data at SPAREC at 15-minute intervals. The average temperature and rainfall for the study and the 30-year average are listed in Table 2.1.

An existing timber stand was thinned or clear-cut to establish silvopasture and open pasture treatments beginning in 2014-2015. Treatment pastures (2 ha/experimental unit) were replicated twice and consisted of open pasture, newly planted pine silvopasture, thinned pine silvopasture, and thinned hardwood silvopasture. The open pastures and newly planted pine silvopastures were completely cleared of trees. The newly planted pine silvopasture was then replanted with loblolly pine seedlings at 2.4 m spacing between seedlings in triple row sets with varying alley widths between tree rows (6, 12, and 18 m). The two types of thinned silvopastures were thinned to 30% of the basal area of the previous tree density equating to 10.6 $m^2$ $ha^{-1}$ and 8.7 $m^2$ $ha^{-1}$ in the thinned pine and hardwood silvopastures, respectively. The presence of hardwood or pine trees was based on trees present in the original stand. All pastures were disked, mulched, and fertilized as recommended by the soil test and planted with a cool-season mixture of novel tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumont., syn. *Lolium arundinaceum* (Schreb.) Darbysh., formerly *Festuca arundinacea* Schreb.) infected with a novel endophyte (*Neotyphodium coenophialum* ‘E34’), meadow fescue (*Schedonorus pratensis* (Huds.) P. Beauv.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pretense* L.), ladino clover (*Trifolium repens* L.), and alfalfa (*Medicago sativa* L.). Half of the pastures were planted in the spring of 2016 along with a pearl millet (*Pennisetum glaugum* (L.) R. Br.) nurse crop, and the other half of the pastures were planted in the fall of 2016 without a nurse crop.

*Animal Stocking*

Prior to each summer season, forty fall-born heifers were brought to the Southern Piedmont AREC in May after being weaned in Blacksburg, Virginia. The animals were acclimated to the new farm for a few weeks each summer in a single herd. Following this period, treatment pastures were prepared for animal introduction by setting up temporary electrified tape in each pasture. Animals were weighed once daily on two consecutive days. After the initial weighing, animals were stratified according to their initial weights and then randomly assigned to one of eight groups at a rate of 5 heifers per 2 hectares, placing similar kilograms of animal per hectare on each treatment pasture. After the second day of weighing, animals were divided into their respective groups and moved to their respective pastures. Mean heifer weights of the start of the study were 279 kg and 268 kg in 2017 and 2018, respectively. Heifers were rotationally stocked throughout the summer in accordance with forage availability with the goal of leaving a 5-8 cm residual sward height. In 2017, heifers were stocked on pasture treatments in June, July, and October; heifers were removed at the beginning of August due to lack of forage availability in treatment pastures following the summer dry spell and were put back on treatment in October after forage regrowth. Pastures had not been grazed prior to June 2017. Heifers were stocked May-August in 2018 but were returned to Blacksburg for breeding prior to October grazing. Cattle were rotated every 1-2 weeks based on forage availability. Following heifer removal at the end of the study each year, all pastures were clipped with a rotary mower to a uniform height between 10-15 cm and again clipped the following spring of 2018 at 10-15 cm to keep forage in a vegetative state.

*Forage Availability*

A rising plate meter (RPM) was used to take 30 random samples in each paddock immediately prior to and following each rotation to estimate forage availability and residual using sward height measurements. Samples were calibrated using a double-sample approach. An RPM measurement was recorded at three random locations within each paddock. Once the RPM measurement had been recorded, the plate was lifted, and the forage directly underneath the plate was harvested to ground level. Samples were placed in paper bags and dried in a forced-air oven for a minimum of four days at 55° C. The dried sample was then weighed.

Forage weight from the double RPM sample and the associated rising plate meter measurement were recorded and correlated in a linear regression with the best-fit line using an $r^2$ value to determine best-fit. Grazing status, treatment, and date had little or negative influence on $r^2$ values, and thus a single equation was used each year. The regression equations were used to determine forage availability. Regressions and trendline equations are reported in Figures 2.1 and 2.2. A double RPM score was not collected in October of 2017.

Forage intake was calculated by finding the difference between forage residual and the preceded forage availability in each paddock which estimated forage removal. Forage removal was divided by the number of days between availability and residual collection (days of forage grazed) to calculate forage removal per day. Forage removal per day was multiplied by the hectare percentage that animals were on during the grazing period and divided by the five heifers to provide forage mass removed per animal per day.

*Forage Nutritive Value*

Nutritive value samples were taken throughout the treatment period once every three weeks within the paddock in each treatment. Composite samples of grass or of clover were collected by grabbing a minimum of 12-15 subsamples of grass and 12-15 subsamples of clover between 1200 h and 1400 h. Subsamples were merged into a composite sample, but grass and clover samples were processed and analyzed separately. Forage samples were clipped to a 5-10-cm residual height from the ground. Samples were dried for a minimum of four days in a forced-air oven at 55° C. Dried samples were ground in a Wiley Mill (Thomas Wiley, Philadelphia, PA) with a 2 mm sieve and then with a Cyclone Mill **(**Udy Corporation, Fort Collins, CO) with a 1 mm sieve. The ANKOM$^{200/220}$ Fiber Analyzer (Macedon, NY) was used to determine ADF and NDF as explained by Vogel et al. (1999). Crude protein was determined by measuring Nitrogen content using an Elementar Vario EL Cube (Langelselbold, Germany) and converted to CP using (NRC, 2000):

$$CP = \text{percent } N \times 6.25$$

Total digestible nutrients was calculated by (Vogel et al., 1999):

$$TDN = 100.32 – 1.118 X ADF$$

*Statistical Analysis*

Data were analyzed using JMP Pro 14.0 software from SAS (SAS Institute, Cary, NC). An ANOVA table was formulated using the Fit Model option in JMP to analyze forage availability measurements and nutritive value. Forage availability and residual dry matter did not have year by treatment interaction, so data were analyzed across years. Fisher's LSD was used to determine statistical differences between treatments. $\alpha = 0.05$.

Although nutritive value had no year by treatment interaction, years are presented separately; the year in itself did affect nutritive value. There was no block by treatment and no date by treatment interaction in any of the collections. However, nutritive value did differ by collection date. As to be expected, there was forage type interaction, so the grass mixture and the clover mixture were analyzed separately with wet chemistry for individual nutrient contents in ANOVA. Fisher's LSD was used to assess differences between treatments. $\alpha = 0.05$.

## Results and Discussion

*Forage Availability*

Rising plate meter calibrations had an $r^2$ value of 0.3749 and 0.2849 for 2017 and 2018 respectively (Figures 2.1 and 2.2). The 2017 regression for forage mass had a greater slope and higher intercept reflecting higher forage availability in 2017 versus 2018.

Although forage quantity fluctuated throughout the summer and between years, there was no treatment interaction with date, block, or year. In both years, the open pasture had significantly greater forage availability as compared to all other pasture types as expected; the thinned hardwood silvopasture had the lowest forage availability ($p<0.0001$). Residual forage

(Table 2.3, 2.6) was greater in the open pasture as compared to all other treatment pastures ($p=0.0104$).

Forage availability did differ by year with forage availability being lower in 2018 as compared to 2017 in both forage availability and residual ($p<0.0001$), but there was no year by treatment interaction (Table 2.4). Forage availability also was significantly affected by the collection date ($p<0.0001$), but the date did not influence post-grazing forage residual ($p=0.2617$). All treatment pastures showed similar production trends in forage availability by collection date across years (Figure 2.3; Table 2.5).

These fluctuations are likely in response to high temperatures and late summer dry spell in 2017; forages did not produce well in July of 2017 in response to lack of rain forcing an earlier end to the treatment period. Forages were still likely overgrazed in an attempt to prolong the study period in July. The increased stocking pressure and overgrazing of the young forage stand in 2017 likely inhibited forage growth in the following 2018 season. Increased precipitation in the 2018 grazing season and corresponding low PAR in July 2018 likely further hindered forage growth. Weather trends for both summers are in Table 2.1 and 2.2**.**

In Buergler et al. (2005), forage production increased almost 2000 kg $ha^{-1}$ in the second year of a two year experiment due to wetter environmental conditions, while warm-season forages and weeds were favored at the expense of fescue production. In this experiment, the decrease in forage production in the second year was likely due to weather. 2018 was a wet year across the southeastern U.S. and precipitation at the farm was 16.8 cm as compared to the 30-year average of 10.1 cm. Increased cloud cover could have limited forage production in silvopastures. Temperatures were also greater in 2018. In this region, cool-season forage production typically peaks in fall and spring while dipping in production during the summer, so the hotter summer of 2018 likely stressed the forages greater than in 2017 (Ball et al., 2015). Another consideration is the possibility that there was too much grazing pressure on the young stand in the first year. Overgrazing forage depletes the root system and inhibits subsequent growth. Young perennial forage stands are more susceptible to overgrazing (Ball et al., 2015).

An inverse trend between forage yield and tree density or canopy cover has often been reported (Neel et al., 2008; Lindgren and Sullivan, 2014; Pang et al., 2019). The newly planted pine silvopasture is most comparable to an open pasture since the trees are in alleys and not large enough yet to intercept light from the forages. Buergler et al. (2005) demonstrated that both black walnut (*Juglans nigra*) and honey locust (*Gleditsia triacanthos*) trees were suitable for silvopasture management in fescue-based systems, but did find increased forage mass under medium-density tree sites versus low- and high- density tree sites. However, the experiment took place in an emulated silvopasture without animals where forage preference and overgrazing effects play less of a role.

While environmental factors influenced forage growth across studies, Neel et al. (2008) measured forages with 80% solar radiation had greater DM yield as compared to systems that had 50% and 20% solar radiation, but forages within the 50 and 20% solar radiation sites did not differ from each other. Additionally, the plot with 80% solar radiation was similar in yield to a hardwood silvopasture in the same study, but both of those plots had approximately 40% of the forage yield in the open pasture (set as 100% yield) (Neel et al., 2008). In Kallenbach et al. (2006), forage production was around 30% greater in an open pasture as compared to a silvopasture. Lindgren and Sullivan (2014) looked at forage growth in silvopastures undergoing various degrees of commercialized thinning and found the greatest forage growth potential in low density tree stands that had been fertilized, while increasing tree density had minimal effect on nonfertilized forage stands. However, all experimental units looked at thinning existing timber stands into a silvopasture without considering clearcutting into an open pasture. In contrast, Orefice et al. (2016) measured no relationship in forage production between open pastures and silvopastures in two years out of a three year study as a result of shade in the presence of cattle grazing with approximately 40% canopy cover and 60% available PAR for forages which may have minimized light inhibition. As Mercier (2017) demonstrated by increased warm-season forages in warmer summers in Blackstone, VA, the summer drop in forage production could be potentially counteracted by the inclusion of warm-season forages to the system both in heavily thinned silvopastures and open pastures.

*Forage Nutritive Value*

In 2017, there was no date by treatment interaction nor block by treatment interaction for TDN in the grass mixture, but date did have an effect (p= 0.0143). The grass mixture (Table 2.7) for the open pasture and the thinned hardwood silvopasture had lower TDN as compared to the grass mixture from the newly planted pine silvopasture (p=0.0292). In 2018, TDN of the grass mixture was not statistically different between treatments (p= 0.3733) nor did date have any effect (p=0.5275). For TDN of the clover samples (Table 2.8), there was no date by treatment or block by treatment interaction in either year. There was no treatment effect in either year for TDN in the clover mixture (p= 0.6383 and p= 0.4837 for 2017 and 2018, respectively). Date did effect TDN in 2017 (p <0.0001), but did not affect TDN in 2018 (p=0.2835). For growing beef steers and heifers between 135 and 315 kg finishing at 545 kg, TDN requirements increase with desired average daily gain where 54% TDN is required for an ADG of 0.45 kg $day^{-1}$ and 69% TDN is required for an ADG of 0.90 kg $day^{-1}$ (National Research Council (U.S.), 1996).

Year had a significant effect on CP, but no treatment by year or block by treatment interaction. In the grass samples collected in 2017, there was treatment effect (p= 0.0113), was influenced by date (p <0.0001), and no date by treatment interaction (p= 0.2160); CP in the thinned hardwood silvopasture was greater than in the newly planted silvopasture as identified by Fisher's LSD. Grass samples collected in 2018 were not affected by treatment (p= 0.7756), were affected by sampling date (p= 0.0002). There was no date by treatment interaction (p= 0.4914). The clover samples collected in both years had greater crude protein that grass samples; in 2017, samples were influenced both by treatment (p= 0.0094) and date (p<0.0001) with no date by treatment interaction (p= 0.3358). The open pasture and the thinned hardwood silvopasture forage samples had greater crude protein in the clover sample as compared to the thinned pine silvopasture and newly planted pine silvopasture. The clover samples collected in 2018 had no treatment or date effect or date by treatment interaction. Crude protein levels were highest in samples collected in September and October for both clovers and grasses in 2017. Crude protein levels were adequate for growing heifers at all sample collections (National Research Council (U.S.), 1996). Overall, treatment had minimal effect on crude protein values in the 2017 and 2018 treatment seasons whereas date had the greatest influence.

Acid detergent fiber concentrations in forages did differ between year, but there was no date by treatment interaction in either 2017 or 2018. In 2017, the grass sample from the thinned hardwood silvopasture and open pasture had greater ADF than the grass sample from the thinned pine or newly planted silvopastures. In 2018, there was no treatment effect (p=0.4313) or date effect (p=0.6938) on ADF in the grass mixture. Acid detergent fiber in the 2017 clover mixture was not affected by treatment (p= 0.3265) but was impacted by date (p <0.0001). In contrast, in

2018, the clover mixture from the thinned hardwood silvopasture had greater ADF as compared to the clover mix from the newly planted silvopasture and open pasture ($p = 0.0357$).

Neutral detergent fiber in the 2017 grass mixtures was greatest in the thinned hardwood and newly planted silvopastures as compared to the open pasture and thinned pine silvopasture ($p = 0.0142$). Neutral detergent fiber was affected by date ($p<0.0001$). In 2018, the NDF grass sample was not affected by treatment ($p=0.2194$) but was influenced by date ($p = 0.0002$). The 2017 clover mixture trended towards increased NDF in the thinned pine and newly planted silvopastures as compared to the open pasture ($p = 0.0909$). In the clover mix, NDF was affected by the sampling date. In 2018, there was no treatment effect on NDF ($p = 0.8142$).

Neel and Belesky (2017) measured high TDN in forages from silvopastures and open pastures and concluded it was mostly due to keeping forages in a vegetative state through their intensive management; season did affect TDN three of five years, but there was only a treatment effect in two of the five years. This is similar to the present study where treatment did not always affect TDN while date typically did have an effect; the present study only spans over two summers versus multiple seasons. Mercier (2017) found significant shade by season interaction in forage nutritive value in a Blackstone, Virginia using shade structures; shade was found to have minimal effect on CP, but did on occasion result in increases in crude protein during the summer and fall as compared to non-shaded forages. Over the two years, shade did not effect TDN but did fluctuate between seasons where TDN was greater in shaded systems some seasons, but not always; ADF and NDF also displayed inconsistent trends in relation to shade and season. However, this study was designed using artificial shade without animals trying to emulate the shaded environments in silvopasture (Mercier, 2017). In Kallenbach et al. (2006), when annual cool-season forages were planted into both an open pasture and a 6- to 7- year-old mixed tree stand, CP in the forages from silvopasture system was greatest or equal in all collection dates over a 2-year study as compared to the open pasture system.

In contrast, ADF and NDF in forages from the silvopasture system was always less than or equal than fiber levels from forages from the open pasture across the two years. Seasonal differences were observed with a greater degree of difference between forages from the open pastures and silvopastures later in the summer reflecting the increase in ambient temperature and the effect of altered microclimate in the silvopastures (Kallenbach et al., 2006). Crude protein has been directly correlated with tree density in several studies in silvopastoral studies with older tree stands. The result was a 3-4% rise in CP levels above former CP percent in herbs and pinegrass between 40% and 95% canopy closure 5 years after fertilization and 14 years after pre-commercial thinning (Lindgren and Sullivan, 2014). Kephart and Buxton (1993) demonstrated an inverse relationship between ambient sunlight and nitrogen concentration in several C3 and C4 forages; although there were differences among forage species and sampling date, increased shade, although hindered forage development and photosynthesis, did increase forage nitrogen levels. Neel and Belesky (2017) found increased levels of CP in forages from silvopastures versus open pastures due to insufficient light; nitrogen levels subsided in forages in the silvopastures following tree thinning. Lindgren and Sullivan (2014) found that ADF decreased from approximately 40% ADF at a 40% canopy closure to 30% ADF at 95% canopy closure. Overall, nutritive value seems to be most consistently affected by date and season more so than treatment. Cool-season forages have been reported to mature at slower rates due to shade (Ryle, 1967; Neel et al., 2016). This could be attributed to the inverse relationship between forage quantity and forage nutritive value, whereas forage matures, forage quantity increases but forage quality and value decreases (Ball et al., 2015).

It can be concluded that forage availability is likely to decrease in silvopastoral systems at some points as a result of silvopasture management. Forage nutritive value may fluctuate depending on the season, but it will unlikely be a limiting factor on animal performance. Canopy growth over time, later thinning of trees, and management decisions such as fertilization may shift forage-tree relationships in response to added stress for light and soil nutrients.

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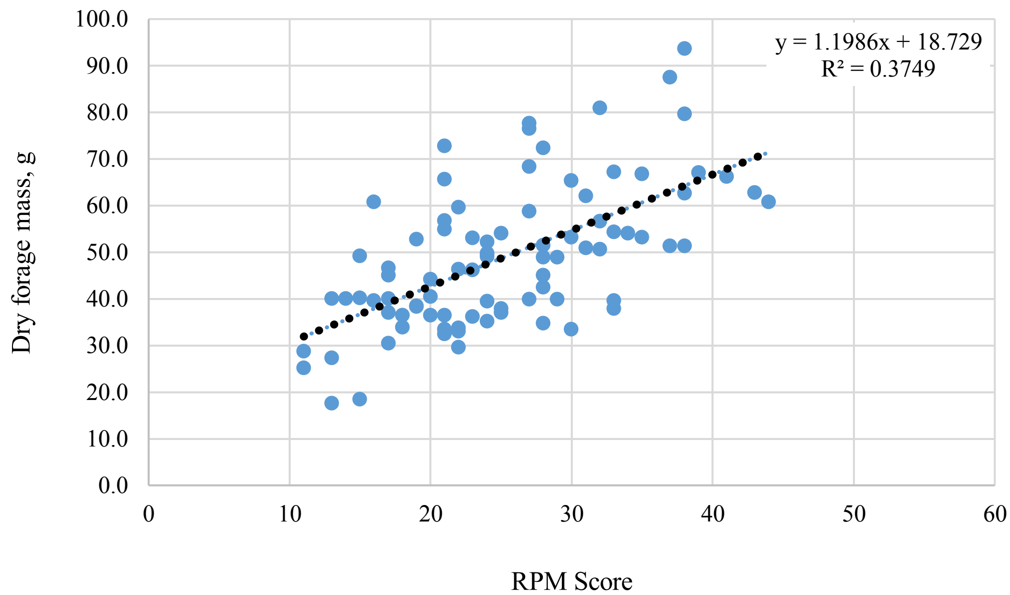
# Appendix

**Figure 2. 1: Rising plate meter regressions and fit for 2017 and 2018.**

**A. 2017**




**B. 2018**

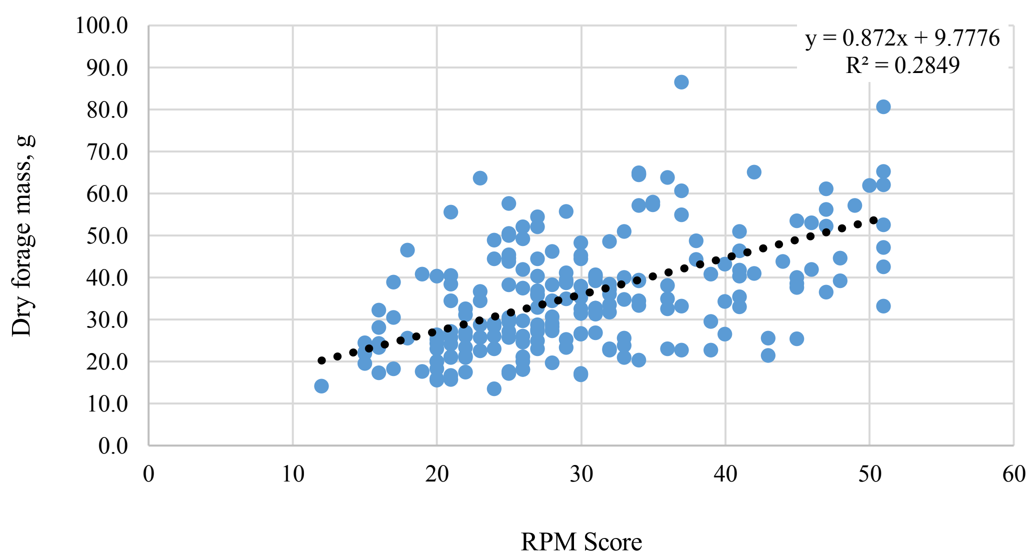
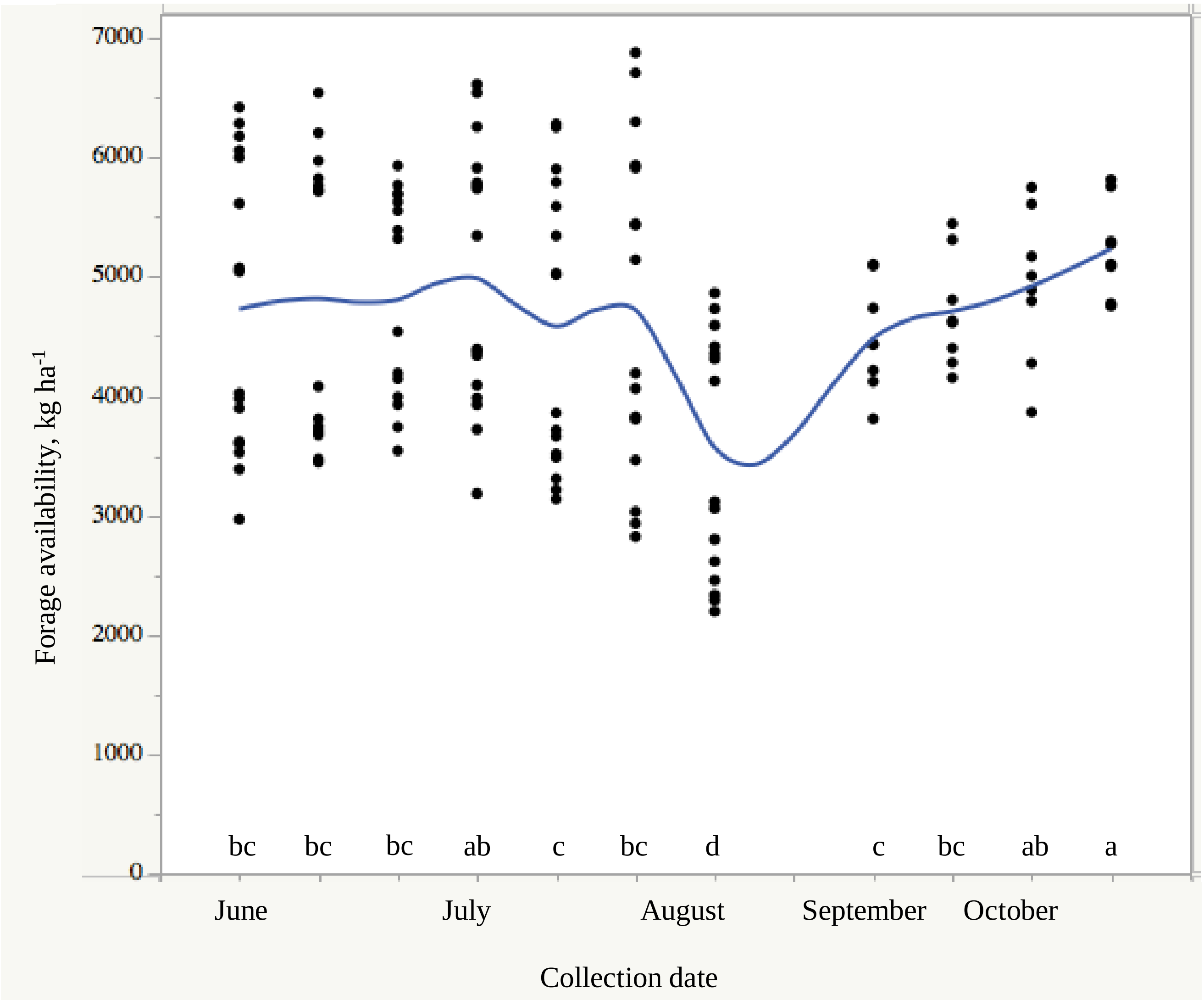


**Figure 2. 2: Forage availability by collection date across years**




*means with differing letters are significantly different α=0.05

**Table 2. 1: Weather data from the Southern Piedmont AREC, Blackstone, VA**

| | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2017 | | | | | 2018 | | | | | 30-year average | | | |
| Month | T avg | T min | T max | RH avg | Precip | T avg | T min | T max | RH avg | Precip | T avg | T min | T max | Precip |
| May | - | - | - | - | 16.9 | 22.4 | 7.2 | 33.1 | 68.0 | 24.2 | 19.0 | 12.7 | 25.3 | 10.0 |
| June | 22.9 | 11.1 | 33.7 | 70.0 | 9.7 | 24.0 | 14.5 | 35.5 | 73.0 | 15.5 | 23.7 | 17.5 | 29.8 | 9.2 |
| July | 26.6 | 14.3 | 37.6 | 65.0 | 10.0 | 24.6 | 12.8 | 34.7 | 74.0 | 16.0 | 26.1 | 20.2 | 32.1 | 11.1 |
| Aug | 24.0 | 14.5 | 34.2 | 72.0 | 19.8 | 25.0 | 13.1 | 34.2 | 76.0 | 11.6 | 25.2 | 19.3 | 31.1 | 9.9 |
| Sept | 20.6 | 9.1 | 32.1 | 75.0 | 3.8 | - | - | - | - | - | 21.4 | 15.6 | 27.3 | 10.9 |
| Oct | 16.6 | 2.7 | 30.6 | 74.0 | 10.2 | - | - | - | - | - | 15.5 | 9.1 | 21.8 | 8.6 |

T avg, T min, T max = temperature average, minimum, and maximum respectively, °C

RH avg = relative humidity, %

Precip = precipitation, cm

**Table 2. 2: $PAR_{Max}$ data from the Southern Piedmont AREC, Blackstone, VA**

| | Year | |
|---|---|---|
| Month | 2017 | 2018 |
| May | 1852 | 1950 |
| June | - | 1636 |
| July | 2120 | 832 |
| August | 1939 | - |
| September | 1642 | - |
| October | 1330 | - |

PAR = Photosynthetic active radiation, $\mu M\ s^{-1}m^{-2}$

*Sensor disfunctions in June 2017 and August 2018

**Table 2. 3: Forage availability (pre-graze), residual (post-graze), and intake (removal) across years**

| | **Forage, kg ha$^{-1}$** | | **Forage, kg hd$^{-1}$ day$^{-1}$** |
|---|---|---|---|
| | Availability | Residual | Intake |
| **Open** | 4918 a | 3595 a | 6.8 a |
| **Newly planted pine** | 4692 b | 3320 b | 7.2 a |
| **Pine** | 4507 bc | 3290 b | 6.0 a |
| **Hardwood** | 4502 c | 3231 b | 6.7 a |

*means within a column with differing letters are significantly different
Availability $\alpha$= 0.001
Residual $\alpha$=0.05
Intake $\alpha$=0.05

**Open = Open pasture, Newly planted pine = Newly planted pine silvopasture, Pine= Thinned pine silvopasture, Hardwood= Thinned hardwood silvopasture

**Table 2. 4: Forage availability by years**

| | **Forage, kg ha$^{-1}$** | | **Forage, kg hd$^{-1}$ day$^{-1}$** |
|---|---|---|---|
| | Availability | Residual | Intake |
| **2017** | 5351 a | 3936 a | 8.1 a |
| **2018** | 3561 b | 2534 b | 4.6 b |

*means within a column with differing letters are significantly different
Availability $\alpha$= 0.001
Residual $\alpha$=0.05
Intake $\alpha$=0.05

**Open = Open pasture, Newly planted pine = Newly planted pine silvopasture, Pine= Thinned pine silvopasture, Hardwood= Thinned hardwood silvopasture

**Table 2. 5: Pre-graze forage availability (kg $ha^{-1}$) by date and treatment**

| Collection Date | Open pasture | Newly planted pine silvopasture | Thinned pine silvopasture | Thinned hardwood silvopasture |
|---|---|---|---|---|
| **6/13/17** | 6300 | 5665 | 5537 | 5836 |
| **6/20/17** | 6153 | 6015 | 5850 | 5721 |
| **6/26/17** | 5591 | 5693 | 5579 | 5626 |
| **7/1/17** | 6400 | 6188 | 5565 | 5826 |
| **7/13/17** | 5798 | 5847 | 5304 | 5656 |
| **7/19/17** | 6162 | 6323 | 5528 | 5866 |
| **7/28/17** | 4453 | 4544 | 4730 | 4271 |
| **9/28/17** | 4914 | 4768 | 4168 | 4124 |
| **8/6/17** | 4712 | 4800 | 4341 | 4970 |
| **8/13/17** | 5679 | 4331 | 4949 | 4723 |
| **8/20/17** | 5544 | 5257 | 5096 | 5036 |
| **5/22/18** | 3706 | 3248 | 3939 | 3610 |
| **6/4/18** | 3945 | 3589 | 3727 | 3560 |
| **6/19/18** | 4343 | 3961 | 3970 | 3642 |
| **7/3/18** | 4243 | 4151 | 4163 | 3452 |
| **7/17/18** | 3689 | 3687 | 3397 | 3175 |
| **7/25/18** | 4128 | 3816 | 2878 | 3247 |
| **8/2/18** | 2758 | 2566 | 2405 | 2702 |

**Table 2. 6: Post-graze forage residual (kg ha$^{-1}$) by date and treatment**

| Collection Date | Open pasture | Newly planted pine silvopasture | Thinned pine silvopasture | Thinned hardwood silvopasture |
|---|---|---|---|---|
| **6/20/17** | 4677 | 4173 | 4280 | 4224 |
| **6/26/17** | 4425 | 4404 | 4371 | 4520 |
| **7/1/17** | 4464 | 4161 | 4133 | 4441 |
| **7/13/17** | 3653 | 3133 | 3100 | 3058 |
| **7/19/17** | 5008 | 4325 | 3977 | 4429 |
| **7/28/17** | 4210 | 4283 | 4252 | 3958 |
| **8/2/17** | 3846 | 3849 | 4185 | 3606 |
| **10/6/17** | 3084 | 3054 | 3301 | 2853 |
| **10/13/17** | 4523 | 3984 | 3877 | 3513 |
| **10/20/17** | 3639 | 3040 | 3714 | 3707 |
| **6/4/18** | 2803 | 2443 | 2675 | 2582 |
| **6/19/18** | 3134 | 2787 | 2503 | 2710 |
| **7/3/18** | 3061 | 2913 | 2613 | 2563 |
| **7/17/18** | 3073 | 3068 | 2833 | 2584 |
| **7/25/18** | 3160 | 2923 | 2778 | 2591 |
| **8/2/18** | 2458 | 1927 | 1665 | 1775 |
| **8/13/18** | 1895 | 1966 | 1672 | 1810 |

*no significant differences existed in residual post-grazing forage, $\alpha=0.05$

**Table 2. 7: Forage nutritive value for each collection date per pasture type for composite grass sample**

| | 2017 | | | | | 2017 Total | 2018 | | | | 2018 Total | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6/21 | 7/13 | 8/1 | 9/28 | 10/13 | | 6/6 | 6/14 | 7/9 | 7/27 | | |
| **ADF, %** | | | | | | | | | | | | |
| Open pasture | 39.2 | 39.0 | 41.3 | 32.3 | 38.3 | 38.0 ab | 37.7 | 36.3 | 37.5 | 37.4 | 37.2 a | 37.7 |
| Newly planted pine silvopasture | 33.2 | 36.1 | 39.3 | 31.3 | 34.9 | 35.0 c | 37.7 | 38.0 | 38.5 | 35.6 | 37.5 a | 36.1 |
| Thinned pine silvopasture | 36.6 | 38.6 | 39.5 | 34.8 | 38.0 | 37.5 b | 41.0 | 38.5 | 37.6 | 38.3 | 38.8 a | 38.1 |
| Thinned hardwood silvopasture | 40.8 | 39.1 | 43.0 | 32.7 | 39.4 | 39.0 a | 37.0 | 38.8 | 40.9 | 37.9 | 38.6 a | 38.8 |
| **NDF, %** | | | | | | | | | | | | |
| Open pasture | 57.8 | 50.1 | 60.0 | 51.4 | 62.0 | 56.2 b | 63.6 | 57.5 | 58.0 | 57.0 | 59.0 a | 57.5 |
| Newly planted pine silvopasture | 54.4 | 56.9 | 61.6 | 51.1 | 78.0 | 60.4 a | 75.6 | 60.6 | 53.4 | 59.0 | 62.1 a | 61.2 |
| Thinned pine silvopasture | 56.8 | 54.9 | 58.9 | 51.8 | 55.7 | 55.6 b | 77.5 | 60.8 | 57.2 | 59.5 | 63.8 a | 59.2 |
| Thinned hardwood silvopasture | 62.2 | 57.7 | 63.2 | 50.0 | 73.2 | 61.3 a | 63.1 | 59.3 | 61.6 | 56.5 | 60.1 a | 60.7 |
| **TDN, %** | | | | | | | | | | | | |
| Open pasture | 56.5 | 56.7 | 54.1 | 64.2 | 57.6 | 57.8 b | 58.2 | 59.7 | 58.4 | 58.6 | 58.7 a | 58.2 |
| Newly planted pine silvopasture | 63.2 | 60.0 | 56.4 | 65.3 | 61.3 | 61.3 a | 58.1 | 57.8 | 57.3 | 60.5 | 58.4 a | 60.0 |
| Thinned pine silvopasture | 59.4 | 57.2 | 56.2 | 61.5 | 57.9 | 58.4 ab | 54.5 | 57.3 | 58.3 | 57.6 | 56.9 a | 57.8 |
| Thinned hardwood silvopasture | 54.7 | 56.6 | 52.3 | 63.8 | 56.3 | 56.7 b | 59.0 | 57.0 | 54.6 | 57.9 | 57.1 a | 56.9 |
| **Crude protein, %** | | | | | | | | | | | | |
| Open pasture | 10.8 | 11.5 | 9.7 | 13.7 | 13.4 | 11.8 ab | 13.1 | 13.7 | 9.7 | 11.9 | 12.1 a | 11.9 |
| Newly planted pine silvopasture | 10.0 | 8.7 | 7.8 | 11.1 | 11.3 | 9.8 ab | 10.2 | 14.1 | 10.1 | 11.0 | 11.3 a | 10.5 |
| Thinned pine silvopasture | 10.8 | 10.5 | 9.6 | 13.6 | 12.9 | 11.5 b | 9.3 | 16.9 | 9.6 | 11.8 | 11.9 a | 11.7 |
| Thinned hardwood silvopasture | 9.0 | 10.8 | 8.4 | 16.8 | 16.7 | 12.3 a | 12.3 | 15.7 | 8.9 | 12.3 | 12.3 a | 12.3 |

*means within a year followed by different letters are significantly different, $\alpha$= 0.05.
**ADF = Acid detergent fiber, NDF = Neutral detergent fiber, TDN = Total digestible nutrients

**Table 2. 8: Forage nutritive value for each collection date per pasture type for composite clover sample**

| | 2017 | | | | | 2017 Total | 2018 | | | | 2018 Total | Grand total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6/21 | 7/13 | 8/1 | 9/28 | 10/13 | | 6/6 | 6/14 | 7/9 | 7/27 | | |
| **ADF, %** | | | | | | | | | | | | |
| Open pasture | 37.8 | 36.1 | 39.1 | 27.0 | 31.4 | 34.3 a | 37.7 | 32.3 | 36.7 | 35.9 | 35.6 b | 34.9 |
| Newly planted pine silvopasture | 35.1 | 33.0 | 36.8 | 26.6 | 31.2 | 32.5 a | 35.2 | 33.1 | 40.2 | 36.0 | 36.1 b | 34.1 |
| Thinned pine silvopasture | 33.8 | 35.7 | 38.2 | 30.4 | 31.9 | 34.0 a | 38.1 | 32.2 | 40.5 | 37.2 | 37.0 ab | 35.3 |
| Thinned hardwood silvopasture | 38.1 | 33.3 | 38.9 | 28.1 | 30.6 | 33.8 a | 39.1 | 34.5 | 44.3 | 35.2 | 38.3 a | 35.8 |
| **NDF, %** | | | | | | | | | | | | |
| Open pasture | 41.9 | 40.6 | 39.8 | 27.9 | 38.1 | 37.6 b | 48.7 | 38.3 | 45.5 | 43.3 | 43.9 a | 40.4 |
| Newly planted pine silvopasture | 41.2 | 41.7 | 45.7 | 33.9 | 43.4 | 41.2 a | 48.9 | 38.8 | 55.8 | 40.7 | 46.0 a | 43.3 |
| Thinned pine silvopasture | 39.3 | 47.5 | 50.3 | 32.1 | 39.3 | 41.7 a | 50.1 | 39.7 | 48.4 | 42.7 | 45.2 a | 43.3 |
| Thinned hardwood silvopasture | 42.0 | 39.7 | 49.7 | 33.4 | 40.9 | 41.1 ab | 48.7 | 39.3 | 51.7 | 39.4 | 44.8 a | 42.8 |
| **TDN, %** | | | | | | | | | | | | |
| Open pasture | 58.1 | 59.9 | 56.6 | 70.2 | 65.3 | 62.0 a | 58.2 | 64.2 | 59.3 | 60.2 | 60.5 a | 61.3 |
| Newly planted pine silvopasture | 61.1 | 63.5 | 59.1 | 70.6 | 65.5 | 64.0 a | 60.9 | 63.4 | 55.3 | 60.1 | 59.9 a | 62.2 |
| Thinned pine silvopasture | 62.6 | 60.4 | 57.6 | 66.3 | 64.6 | 62.3 a | 57.8 | 64.4 | 55.0 | 58.8 | 59.0 a | 60.8 |
| Thinned hardwood silvopasture | 57.7 | 63.1 | 56.9 | 68.9 | 66.1 | 62.5 a | 56.6 | 61.7 | 50.8 | 61.0 | 57.5 a | 60.3 |
| **Crude protein, %** | | | | | | | | | | | | |
| Open pasture | 16.7 | 16.6 | 14.3 | 20.6 | 18.3 | 17.3 a | 13.0 | 12.6 | 13.6 | 14.9 | 13.5 a | 15.6 |
| Newly planted pine silvopasture | 14.0 | 14.6 | 13.4 | 18.5 | 18.6 | 15.8 b | 15.7 | 10.3 | 12.6 | 14.5 | 13.3 a | 14.8 |
| Thinned pine silvopasture | 15.0 | 12.8 | 12.0 | 18.8 | 19.7 | 15.6 b | 14.7 | 10.1 | 13.2 | 14.8 | 13.2 a | 14.6 |
| Thinned hardwood silvopasture | 15.0 | 16.8 | 14.1 | 19.9 | 22.1 | 17.6 a | 13.5 | 14.0 | 13.0 | 14.7 | 13.8 a | 15.9 |

*means within a year followed by different letters are significantly different, $\alpha$= 0.05

**ADF = Acid detergent fiber, NDF = Neutral detergent fiber, TDN = Total digestible nutrients

## Chapter 3: Animal Production, Average Daily Gains and Body Temperatures

### Introduction

Livestock producers must balance their desire to farm, economics, environmental impact, and animal productivity to maintain farm vitality and success. A USDA survey of cattle producers identified animal welfare as a top need for research needs (#3) among cow health (#1), calf health (#2), nutrition (#4), and biosecurity (#5) (USDA, 2016). Producers have the desire to improve animal welfare on their operations. Current research indicates that animal welfare and animal comfort are related to animal productivity (Silanikove, 2000; USDA, 2016; Polsky and von Keyserlingk, 2017). Furthermore, consumers are more interested in animal welfare as consumers want to be more involved in their food making decisions and knowledgeable about where their food comes from (Henderson, 2018). Animal production and animal welfare both play a role in producing healthy, profitable, and desirable animal and food products.

Animal production is a complex process involving the specific animal and its requirements, feed consumption, environment, health, and genetics. Basic animal science teaches that an animal's phenotype or outward performance is the combination of genetics plus environment. The environment is not only measured by the physical surroundings but is also impacted by stress management and welfare (National Research Council, 1996). Animals partition energy (input and output) towards different needs to meet their requirements. The four main categories of animal energy expenditure are maintenance, lactation, growth, and reproduction. Maintenance is an animal's first priority in determining energy requirements before spending energy on growth, lactation, and reproduction; if an animal is nursing offspring, then nutrients may be diverted for lactation as a higher priority (National Research Council, 1996).

When animals are under heat stress, one typical response is to decrease feed intake, which limits nutrients available for energy expenditure (Blackshaw and Blackshaw, 1994; National Research Council (U.S.), 1996). Two major measures of heat stress are external and internal body temperature (Scharf et al., 2011). External hide temperature is directly related to the heat load an animal is exposed to as a result of their environment. Meanwhile, internal body temperature is a function of an animal's ability to maintain body temperature in response to heat stress (Collier et al., 2017). Increases in body temperature, both internal and external, identify heat stress on the animal. Natural behaviors and animal processes are expected to cause some fluctuations in internal temperature; specifically, digestion and metabolism produce heat which impacts an animal's heat load (Blackshaw and Blackshaw, 1994). If an animal is not capable of handling this heat load, they will, in response, decrease feed intake. As a result, when an animal is not consuming enough energy through feed, whether by a lack of availability or by decreased consumption in response to environmental stress, those secondary processes requiring energy (growth, lactation, reproduction) are inhibited. Stress, whether brought out by heat, handling, or disease, may additionally aggravate animal production, welfare, and health (Blackshaw and Blackshaw, 1994; Nienaber et al., 1999).

Liveweight gain is a primary benchmark of production in the beef cattle industry since animals are sold based on body weight. Any business or production change, and therefore any research claim, in the beef cattle industry must ensure that recommendations are complementary to production and thus, economically feasible. In a silvopasture system, animal liveweight gains are only part of the total equation. Even lower gains in silvopastures than in open pastures may still result in more productive systems. Silvopastures also produce economically valuable trees for timber, among other environmental and aesthetic services. A *land equivalency ratio* may be used to compare the productivity of an integrated system, like silvopasture, versus the production of commodities raised or grown separately (Mead and Wiley, 1980; Sharrow et al., 2009).

$$LER = \frac{Integrated\ yield\ A}{Sole\ yield\ A} + \frac{Integrated\ yield\ B}{Sole\ yield\ B}$$

In a silvopasture, the LER would be calculated by the production of the animals in a silvopasture as compared to an open pasture, plus the production of trees in a silvopasture over typical forest production. If this ratio is greater than one, the integrated system is more productive than when the production of trees and livestock are managed separately.

The presence of shade has often resulted in increased production of animals (Blackshaw and Blackshaw, 1994; Silanikove, 2000; Veissier et al., 2017). However, other studies, specifically within silvopastures, have seen no change or minimum differences in ADG among animals in silvopasture systems compared to animals in open systems (Kallenbach et al., 2006; Costa et al., 2016; Pent, 2017). As such, the stocking rate was not adjusted in accordance with the reduced forage availability. Heat stress negatively impacts animal reproductive success, including reproductive system development and conception and pregnancy rates (Shearer et al., 1999), and decreased lactation. Livestock under heat stress exhibit increased panting, respiration rate, and internal temperature, but these physiological and behavioral responses may be ameliorated through the provision of shade (Silanikove, 2000; Rovira, 2014; Allen et al., 2015; Ammer et al., 2016; Veissier et al., 2017).

The objectives of this study were to:

1. Evaluate change in liveweight gain among heifers in open pastures and silvopastures throughout the summer.
2. Identify fluctuations in internal vaginal temperature in heifers without access to shade and heifers with access to either shade from pine trees or hardwood trees.

3. Compare changes in external hide temperatures of heifers in the morning and afternoon with and without access to shade.

## Materials and Methods

*Site Description*

This work was performed at the Southern Piedmont Agricultural Research and Extension Center (SPAREC) in Blackstone, Virginia (37.091889, -77.963632). This protocol was approved by the Virginia Tech Institutional Animal Care and Use Committee (Protocol #17-071). Soil series at the site location consisted primarily of a Durham coarse sandy loam, undulating (Fine-loamy, siliceous, semiactive, thermic Typic Hapludults) with smaller areas consisting of Worsham sandy loam (fine, mixed, active, thermic Typic Endoaquults) and Appling coarse sandy loam (fine, kaolinitic, thermic Typic Kanhapludults; Soil Survey Staff, 2018). An onsite WatchDog 2000 series 2900 ET weather station (Spectrum Technologies, Aurora, IL) collected weather data at SPAREC at 15-minute intervals. The average temperature and rainfall for the study and the 30-year average are listed in Table 3.1.

An existing timber stand was thinned or clear-cut to establish silvopasture and open pasture treatments beginning in 2014-2015. Treatment pastures (2 ha/experimental unit) were replicated twice and consisted of open pasture, newly planted pine silvopasture, thinned pine silvopasture, and thinned hardwood silvopasture. The open pastures and newly planted pine silvopastures were completely cleared of trees. The newly planted pine silvopasture was then replanted with loblolly pine seedlings at 2.4 m spacing between seedlings in triple row sets with varying alley widths between tree rows (6, 12, and 18 m). The two types of thinned silvopastures were thinned to 30% of the basal area of the previous tree density equating to 10.6 $m^2$ $ha^{-1}$ and

8.7 $m^2$ $ha^{-1}$ in the thinned pine and hardwood silvopastures, respectively. The presence of hardwood or pine trees was based on trees present in the original stand. All pastures were disked, mulched, and fertilized as recommended by the soil test and planted with a cool-season mixture of novel tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumont., syn. *Lolium arundinaceum* (Schreb.) Darbysh., formerly *Festuca arundinacea* Schreb.) infected with a novel endophyte (*Neotyphodium coenophialum* 'E34'), meadow fescue (*Schedonorus pratensis* (Huds.) P. Beauv.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pretense* L.), ladino clover (*Trifolium repens* L.), and alfalfa (*Medicago sativa* L.). Half of the pastures were planted in the spring of 2016 along with a pearl millet (*Pennisetum glaugum* (L.) R. Br.) nurse crop, and the other half of the pastures were planted in the fall of 2016 without a nurse crop.

*Animal Stocking*

Prior to each summer season, forty fall-born heifers were brought to the Southern Piedmont AREC in May after being weaned in Blacksburg, Virginia. The animals were acclimated to the new farm for a few weeks each summer in a single herd. Following this period, treatment pastures were prepared for animal introduction by setting up temporary electrified tape in each pasture. Animals were weighed once daily on two consecutive days. After the initial weighing, animals were stratified according to their initial weights and then randomly assigned to one of eight groups at a rate of 5 heifers per 2 hectares, placing similar kilograms of animal per hectare on each treatment pasture. After the second day of weighing, animals were divided into their respective groups and moved to their respective pastures. Mean heifer weights of the start of the study were 279 kg and 268 kg in 2017 and 2018, respectively. Heifers were rotationally stocked throughout the summer in accordance with forage availability with the goal of leaving a 5-8 cm residual sward height. In 2017, heifers were stocked on pasture treatments in June, July, and October; heifers were removed at the beginning of August due to lack of forage availability in treatment pastures following the summer dry spell and were put back on treatment in October after forage regrowth. Pastures had not been grazed prior to June 2017. Heifers were stocked May-August in 2018 but were returned to Blacksburg for breeding prior to October grazing. Cattle were rotated every 1-2 weeks based on forage availability. Following heifer removal at the end of the study each year, all pastures were clipped with a rotary mower to a uniform height between 10-15 cm and again clipped the following spring of 2018 at 10-15 cm to keep forage in a vegetative state.

*Animal Daily Gain*

Prior to animals being introduced to treatment pastures, animals were weighed once daily for two days to obtain an initial weight and placed out on treatments. Heifers were weighed every 28 days. Weight changes were divided by the duration between weigh dates to determine average daily gain.

In 2017, animals were on treatment between June 19, 2017, and August 4, 2017, and again between September 6, 2017, and October 26, 2017. Heifers were removed from treatments at the end of the summer period on day 56, as a result of inadequate forage. Animals were then grouped together in a nearby open pasture until the forage had regrown to sufficient levels. Heifers were weighed prior to reintroduction on day 91 and 92. Animals were rotated in treatment pastures until day 140, for a total of 51 days on treatment in fall. In 2018, heifers were on treatment between June 19, 2018, and August 13, 2019.

*Evaluating Cattle Internal Temperatures with Blank CIDRs*

A blank controlled internal drug release (CIDR) device was hollowed out using a utility knife to fit a cylindrical Star-Oddi DST micro-T temperature logger (Star Oddi, Iceland). Mercury 4.91- DST micro-T software was used to synch Star-Oddi temperature loggers, and loggers were placed in the blank CIDRs (Fig 3.1). The devices were secured with electrical tape similar to Burdick et al. (2012). The CIDR and temperature probe were inserted with an Eazi-Breed CIDR applicator for cattle and lube using standard CIDR implant protocol (45 degrees in, straightening, cleaning). CIDRs were inserted into two heifers from each group with the exception of animals in the newly planted pine silvopasture treatments. Animals were returned to treatment pastures for the collection period. Vaginal temperatures were recorded every 10 minutes for a period of 4 days before the device was removed from the heifers. Temperature probe data was downloaded with the software and then analyzed for temperature changes throughout the day between groups. CIDR implant insertion occurred on July 17 and August 9, 2018. CIDR implants were removed on July 20 and August 13, 2018.

*Evaluating Cattle Heat Stress with UAV Thermal Camera*

Cattle were marked with different color cow chalk on their flanks during their monthly weighing to identify different animals in 2018. Throughout the treatment period (once/month in 2018), a DJI Matrice 100 (DJI, China) unmanned aerial vehicle (UAV) drone with a Zenmuse XT thermal camera (DJI, China) was flown at approximately 12.5 meters above the cattle in treatment groups to record cow hide temperature and assess change in external temperature between morning and afternoon among shaded and unshaded cattle. The drone launched from the road adjacent to the pastures and obtained height before flying above the pastures to reduce stress on the cows. On flying days, the drone was taken out in the morning between 0830 h and

0930 h and again in the afternoon between 1430 h and 1530 h PM in all treatment types. Type of shade (none, hardwood tree, or pine tree) utilized by cattle was recorded during the flight. While the newly planted silvopastures may provide some shade and heifers in this treatment were often observed lying or standing within the tree rows, the trees did not provide significant shade and in most cases were most similar to the open pasture. Unless animals in the newly planted pine silvopastures or open pastures had access to shade from a nearby thinned silvopasture, those animals were classified as not being in the shade. The location of individual animals in relation to the drone image was recorded. The drone was flown directly above the cattle with camera facing down on June 5, July 19, and August 8 in 2018.

Using FLIR Tools software, the rJPEG images were analyzed by drawing a parallel line, approximately two centimeters wide equivalent in real size, down the spine of each heifer's back to assess heat load and hide temperature. The software calculated the mean temperature from multiple measurements at each point in the line.

*Statistical Analysis*

JMP Pro 14.0 software from SAS (SAS Institute, Cary, NC) was used to analyze data. An ANOVA table was formulated using the Fit Model option to determine the effect of treatment pasture on average daily gain and internal vaginal temperature. The two replications were tested for a block by treatment interaction; no significant interaction was found, so treatments were analyzed across blocks. Date was tested for treatment interaction; where date had interaction with treatment, data are displayed by date. Fisher's test was completed on data sets. $\alpha = 0.05$.

Analysis of variance was run on hide temperature. Animals were identified by the shade type they were in (treatments included no shade, pine shade, and hardwood shade) and the time of day. Change in hide temperature between PM and AM was calculated for each shade type.

Differences of least square means between treatments were determined. Data were analyzed with Tukey's test, $\alpha = 0.05$.

## Results and Discussion

*Animal Daily Gain*

There was no block by treatment interaction for ADG, but there was a month by treatment interaction. In June of 2017, heifers in both thinned silvopasture treatments had greater average daily gains as compared to heifers in the open pasture and newly planted loblolly pine silvopasture ($p = 0.0346$). In July and October 2017, there were no significant differences among average daily gains for heifers in each treatment ($p = 0.5138$, $0.5212$, respectively). In June of 2018, there was no significant difference among heifer ADG in open pastures and thinned silvopasture treatments ($p = 0.1903$). In July 2018, heifers in the newly planted pine silvopasture had greater ADG as compared to heifers in the thinned pine and hardwood silvopastures; ADG in the thinned pine silvopasture was the lowest as compared to heifer ADG in other treatments ($p = 0.0051$). In August 2018, heifers in the open pasture had the greatest ADGs, heifers in the thinned pine silvopasture had gains similar to heifers in the newly planted and thinned hardwood silvopastures, and heifers in the thinned hardwood silvopastures had the lowest ADG as compared to heifers in other treatment pastures ($p = 0.0008$).

There are several potential factors that could impact the lower weight gains in 2018. First, these heifers came from Blacksburg, Virginia- a cooler location in the mountains as compared to Blackstone, Virginia. In 2017, the heifers in the silvopasture may have had an initial advantage as compared to heifers in the open pasture due to the shade from the trees which may have provided an adaptation period to the warmer Southern Piedmont climate. The heifers in the open pastures may have experienced some compensatory gain compared to silvopasture heifers with an accelerated growth period later in the summer following the initial environmental shock. Cattle have experienced compensatory performance after periods of environmental stress where animals are able to catch up and modify their physiological responses to meet similar final production goals (Nienaber et al., 1999; Nienaber and Hahn, 2007). Since 2017 was warmer and dryer than in 2018, it would be reasonable to expect to see a greater beneficial response to shade in 2017 versus 2018.

Several studies have demonstrated decreases in dry matter intake and production by cattle experiencing heat stress. Lactating dairy cows in a heat stressed climate chamber experienced a 30% drop in DMI and a 27.6% drop in milk production as compared to lactating cows in a thermal neutral environment (Wheelock et al., 2010). However, Rhoads et al. (2009) found that not all changes in milk production were accounted for by changes in DMI, supporting that the animal losses associated with heat stress cannot be directly measured by one parameter like dry matter intake. As observed in dairy cattle research, milk production is dramatically and immediately impacted by heat stress, whereas liveweight gain may be a more difficult parameter to measure in response to heat stress (Albright and Alliston, 1972; Silanikove, 2000; Collier et al., 2017). Additionally, there has been variable animal gain responses in silvopasture systems against open pasture. In Neel and Belesky (2017), sheep performance was best in spring versus the summer in silvopasture and open pasture systems, but treatment response varied between year. In the first summer of the study, sheep with access to a combined open pasture and silvopasture outperformed sheep in both the open pasture and sheep that had delayed access to silvopasture. In the following spring, sheep in the open pasture outperformed sheep with access to silvopastures while in the subsequent year animals with silvopasture access had the greatest average daily gains in spring and saw no performance differences in summer. Costa et al. (2016) measured no liveweight gain differences between cattle grazing in open pastures versus cattle grazing in two different leguminous silvopastures with gliricidia (*Gliricidia sepium*) and sabía (*Mimosa caesalpiniifolia*) trees, but livestock performance was affected by collection date in a similar way to forage availability.

Secondly, there was lower forage availability in the silvopastures in 2018 with a visible reduction of forage availability later in the summer in July and August. Despite the expected reduction in forage availability, the stocking rate was not adjusted between silvopastures and open pastures since several previous studies have demonstrated no change in animal production in silvopastures where forage availability had been reduced. In a 3-year grazing study, the stocking rate of sheep was reduced in a black walnut silvopasture system in Virginia to meet nutrient requirements while improved forage in honey locust silvopastures and open pastures supported more animals per hectare (Pent, 2017). In a research-based farm-simulation model for agroforestry systems, increased tree basal area was linearly correlated with decreased forage production and decreased animal gains (Ares et al., 2003).

It is important to note that all heifers on this trial at SPAREC were on tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumont., syn. *Lolium arundinaceum* (Schreb.) Darbysh., formerly *Festuca arundinacea* Schreb.) infected with a novel, nontoxic endophyte (*Neotyphodium coenophialum*, formerly *Acremonium coenophialum*). Toxic endophyte-infected tall fescue is the primary forage in Virginia and much of the southeastern U.S. and is known to cause vasoconstriction in response to the ergot alkaloids produced by the endophyte. Such vasoconstriction impairs livestock thermoregulation by limiting an animal's ability to move blood and release heat to the environment (Smith et al., 2009; Ball et al., 2015). Since the heifers in this study were not exposed to toxic fescue, they are relieved of a typical stress experienced by most animals in the region. However, shade may have had an improved production benefit where toxic fescue was present since toxic fescue further exacerbates heat stress and inhibits heat dissipation.

A final factor for consideration is that there were few replications due to limited land and resources. As such, some factors, or background noise, cannot be reasonably removed from the results. For example, some of the heifers were hot-tempered. A handful of these animals in pastures ran excessively and would run through the electric fence in the presence of field workers, and therefore these animals may have expelled more energy than they were consuming, and thus may not have been gaining efficiently. These animals can cause handling issues, stress other animals, and may create outliers in weight gain since they do not put on weight, and in some cases, lose weight (Voisinet et al., 1997; Grandin et al., 1998).

*Cattle Internal Temperatures*

Heifers in the open pasture were significantly cooler than heifers in the silvopastures between 720 h ($p = 0.0184$) and 840 h ($p = 0.0213$) (Table 3.3). Nighttime cooling has been considered as an important recovery tool for livestock undergoing heat stress where lower evening temperatures are necessary for animals to adequately relieve themselves of daytime heat stress (Hahn, 1999). Lower morning internal body temperatures in the open pasture likely reflect the diurnal cooling which may have been further facilitated in an open pasture as compared to a silvopasture where the tree canopy reduces microclimate fluctuation. However, between 1140 h ($p = 0.0452$) and 1740 h ($p = 0.0157$), heifers in the thinned pine and hardwood silvopastures had cooler vaginal temperatures than heifers in the open pastures.

Additionally, heifers in the hardwood silvopasture remained internally cooler than heifers in the open pasture until 1950 h ($p = 0.1040$) (Fig 3.3). Pent et al. (2018) found that sheep grazing in black walnut silvopastures had lower vaginal temperatures than sheep grazing in open pastures between 1200 h and 1900 h; however sheep in the same study grazing in honey locust silvopastures only had lower vaginal temperatures at 1500 h compared to sheep in the open pasture. Nighttime cooling was greatest among sheep in open pastures as compared to sheep in silvopastures, a trend similar to heifers in this study (Pent et al., 2018). Conversely, shaded cattle in a feedlot had lower body temperatures for some portion of the afternoon as compared to their non-shaded counterparts as measured with a temperature probe in the abdominal cavity. However, the presence of shade did reduce internal body temperature during danger and emergency levels of heat stress, quantified by a THI of 78 to 84 and above 84, respectively. At the maximum difference, shaded cattle had internal temperatures that were 0.5°C cooler than non-shaded cattle (Brown-Brandl et al., 2005). Although welfare is a difficult parameter to measure and there were no clear production benefits due to the provision of shade in this study, internal body temperature is directly related to heat stress and was improved by the presence of tree shade.

*Cattle External Temperatures*

Figure 3.4 shows thermal drone images similar to those taken to measure hide temperature with an estimated thermal scale for visual reference. Morning hide temperatures of animals in hardwood shade were significantly cooler than hide temperatures of animals with no shade ($p < 0.0001$). In the afternoon, heifers in no shade had significantly warmer hide temperatures than shaded heifers ($p < 0.0001$). Increase in hide temperature (AM-PM) was 62.6%

and 66.4% greater in heifers with no shade versus heifers in pine shade and hardwood shade respectively (Fig 3.5; Table 3.4).

Badakhshan and Mohammadabadi (2015) demonstrated that adult cattle and calf external temperature of the left flank, rump, tail, abdomen, foreleg, dewlap, neck, ear, and forehead were all significantly affected by season in relation to weather-related stress, fluctuated throughout a day along with ambient temperature, and were statistically correlated with respiration rate, and heart rate. However, these cattle had low energy requirements, and no production parameters were measured. In contrast, Umphrey et al. (2001) measured no correlation between skin temperature and rectal temperature and little correlation between skin temperature with other physiological parameters in lactating Holstein cows. Although hide temperature and vaginal temperatures in this study were not correlated to one another ($r^2$=0.006, Fig. 3.6), hide temperature was moderately correlated to ambient temperature when cattle had no shade ($r^2$=0.4778). In contrast, there was practically no correlation between hide temperature and ambient temperature when cattle were in shade ($r^2$= 0.0213), illustrating the benefit of shade in reducing hide temperature (Figures 3.7 and 3.8). Core temperature and external temperature may not necessarily be correlated since an animal has some ability to thermoregulate, but higher hide temperatures are a reflection of increased heat loads which require an animal to expend more energy or reduce DMI to maintain internal body temperature (Finch, 1986; Blackshaw and Blackshaw, 1994).

Additionally, changes in internal body temperature can lag behind environmental stressors (Hahn, 1999; Brown-Brandl et al., 2005). Comparably, skin temperature across the body was significantly increased as ambient temperature increased, demonstrating the use of skin temperature as an indicator of heat load (Yadav et al., 2017). Additionally, body surface temperature at the rump, barrel, flank, and foot was highly correlated to the environmental climate in addition to showing moderate and high correlation to rectal temperature and respiration rate in dairy heifers (Zotti et al., 2011). Correlation and lag-time between the ambient environment and animal response may be influenced by each specific environment, animal requirements and energy outputs, and feed intake (Collier et al., 1981; Brown-Brandl et al., 2005; Beatty et al., 2006).

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# Appendix

**Table 3. 1**: **Weather data from the Southern Piedmont AREC, Blackstone, VA**

| | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2017 | | | | | 2018 | | | | | 30-year average | | | |
| Month | T avg | T min | T max | RH avg | Precip | T avg | T min | T max | RH avg | Precip | T avg | T min | T max | Precip |
| May | - | - | - | - | 16.9 | 22.4 | 7.2 | 33.1 | 68.0 | 24.2 | 19.0 | 12.7 | 25.3 | 10.0 |
| June | 22.9 | 11.1 | 33.7 | 70.0 | 9.7 | 24.0 | 14.5 | 35.5 | 73.0 | 15.5 | 23.7 | 17.5 | 29.8 | 9.2 |
| July | 26.6 | 14.3 | 37.6 | 65.0 | 10.0 | 24.6 | 12.8 | 34.7 | 74.0 | 16.0 | 26.1 | 20.2 | 32.1 | 11.1 |
| Aug | 24.0 | 14.5 | 34.2 | 72.0 | 19.8 | 25.0 | 13.1 | 34.2 | 76.0 | 11.6 | 25.2 | 19.3 | 31.1 | 9.9 |
| Sept | 20.6 | 9.1 | 32.1 | 75.0 | 3.8 | - | - | - | - | - | 21.4 | 15.6 | 27.3 | 10.9 |
| Oct | 16.6 | 2.7 | 30.6 | 74.0 | 10.2 | - | - | - | - | - | 15.5 | 9.1 | 21.8 | 8.6 |

T avg, T min, T max = temperature average, minimum, and maximum respectively, °C
RH avg = relative humidity, %
Precip = precipitation, cm

**Table 3. 2: $PAR_{Max}$ data from the Southern Piedmont AREC, Blackstone, VA**

| | Year | |
|---|---|---|
| Month | 2017 | 2018 |
| May | 1852 | 1950 |
| June | - | 1636 |
| July | 2120 | 832 |
| August | 1939 | - |
| September | 1642 | - |
| October | 1330 | - |

PAR = Photosynthetic active radiation, $\mu$M $s^{-1}m^{-2}$

*Sensor disfunctions in June 2017 and August 2018

**Table 3. 3**: **Average daily gain (kg day$^{-1}$) per treatment per month**

| Treatment | | | | | P-values | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Op | NS | PS | HW | Standard Error | PS-Op | PS- NS | PS-HW |
| June 2017 | 0.36 | 0.52 | 0.64 | 0.57 | 0.0668 | 0.0069 | 0.9571 | 0.3896 |
| July 2017 | 0.48 | 0.39 | 0.30 | 0.41 | 0.0848 | 0.2648 | 0.9455 | 0.795 |
| October 2017 | 0.75 | 0.78 | 0.79 | 0.82 | 0.0316 | 0.2594 | 0.7409 | 0.2159 |
| June 2018 | 0.51 | 0.44 | 0.67 | 0.53 | 0.0815 | 0.4832 | 0.0322 | 0.3546 |
| July 2018 | 0.35 | 0.50 | 0.22 | 0.28 | 0.0657 | 0.5009 | 0.0052 | 0.7107 |
| August 2018 | 0.59 | 0.43 | 0.36 | 0.28 | 0.055 | 0.0004 | 0.6043 | 0.002 |

*Adjusted with Tukey's test, $\alpha$=0.05
**Op= Open pasture, PS= Thinned pine silvopasture, NS= Newly planted silvopasture, HW= Thinned hardwood silvopasture

**Table 3. 4: Vaginal temperatures (°C) by time of day and pasture type**

| Time | Open | Pine | Hardwood |
|---|---|---|---|
| 0000 | 38.9 | 38.9 | 38.9 |
| 0010 | 38.8 | 38.9 | 38.9 |
| 0020 | 38.8 | 38.9 | 38.9 |
| 0030 | 38.7 | 38.9 | 38.9 |
| 0040 | 38.8 | 38.8 | 38.8 |
| 0050 | 38.8 | 38.8 | 38.8 |
| 0100 | 38.8 | 38.8 | 38.8 |
| 0110 | 38.7 | 38.8 | 38.8 |
| 0120 | 38.7 | 38.8 | 38.8 |
| 0130 | 38.7 | 38.8 | 38.8 |
| 0140 | 38.7 | 38.8 | 38.8 |
| 0150 | 38.6 | 38.8 | 38.7 |
| 0200 | 38.6 | 38.8 | 38.7 |
| 0210 | 38.6 | 38.8 | 38.7 |
| 0220 | 38.6 | 38.8 | 38.7 |
| 0230 | 38.6 | 38.8 | 38.7 |
| 0240 | 38.6 | 38.8 | 38.7 |
| 0250 | 38.6 | 38.7 | 38.7 |
| 0300 | 38.6 | 38.7 | 38.7 |
| 0310 | 38.6 | 38.7 | 38.7 |
| 0320 | 38.6 | 38.7 | 38.7 |
| 0330 | 38.6 | 38.7 | 38.7 |
| 0340 | 38.6 | 38.7 | 38.7 |
| 0350 | 38.7 | 38.7 | 38.7 |
| 0400 | 38.6 | 38.7 | 38.6 |
| 0410 | 38.6 | 38.7 | 38.6 |
| 0420 | 38.7 | 38.7 | 38.7 |
| 0430 | 38.7 | 38.7 | 38.7 |
| 0440 | 38.6 | 38.7 | 38.7 |
| 0450 | 38.6 | 38.7 | 38.7 |
| 0500 | 38.6 | 38.7 | 38.6 |
| 0510 | 38.6 | 38.7 | 38.6 |
| 0520 | 38.5 | 38.7 | 38.6 |
| 0530 | 38.5 | 38.7 | 38.6 |
| 0540 | 38.5 | 38.6 | 38.5 |
| 0550 | 38.5 | 38.6 | 38.5 |
| 0600 | 38.4 | 38.5 | 38.5 |
| 0610 | 38.4 | 38.5 | 38.4 |
| 0620 | 38.3 | 38.4 | 38.4 |
| 0630 | 38.2 | 38.4 | 38.3 |

| Time | Open | Pine | Hardwood |
|---|---|---|---|
| 1210 | 39.8 a | 39.4 b | 39.2 b |
| 1220 | 39.8 a | 39.4 b | 39.2 b |
| 1230 | 39.8 a | 39.4 b | 39.2 b |
| 1240 | 39.9 a | 39.4 b | 39.2 b |
| 1250 | 39.8 a | 39.4 b | 39.2 b |
| 1300 | 39.9 a | 39.4 b | 39.2 b |
| 1310 | 39.9 a | 39.4 b | 39.3 b |
| 1320 | 39.9 a | 39.4 b | 39.3 b |
| 1330 | 39.9 a | 39.4 b | 39.3 b |
| 1340 | 39.9 a | 39.4 b | 39.3 b |
| 1350 | 39.9 a | 39.4 b | 39.3 b |
| 1400 | 39.9 a | 39.5 b | 39.3 b |
| 1410 | 40.0 a | 39.5 b | 39.3 b |
| 1420 | 39.9 a | 39.5 b | 39.3 b |
| 1430 | 39.9 a | 39.5 b | 39.3 b |
| 1440 | 40.0 a | 39.5 b | 39.3 b |
| 1450 | 39.9 a | 39.5 b | 39.3 b |
| 1500 | 40.0 a | 39.5 b | 39.3 b |
| 1510 | 40.0 a | 39.5 b | 39.3 b |
| 1520 | 40.0 a | 39.5 b | 39.3 b |
| 1530 | 40.0 a | 39.5 b | 39.3 b |
| 1540 | 40.0 a | 39.6 b | 39.3 b |
| 1550 | 40.0 a | 39.6 b | 39.4 b |
| 1600 | 40.1 a | 39.6 b | 39.4 b |
| 1610 | 40.1 a | 39.5 b | 39.4 b |
| 1620 | 40.1 a | 39.5 b | 39.3 b |
| 1630 | 40.0 a | 39.5 b | 39.3 b |
| 1640 | 40.0 a | 39.4 b | 39.3 b |
| 1650 | 39.9 a | 39.4 b | 39.3 b |
| 1700 | 39.9 a | 39.4 b | 39.3 b |
| 1710 | 39.9 a | 39.4 b | 39.3 b |
| 1720 | 39.8 a | 39.5 b | 39.4 b |
| 1730 | 39.8 a | 39.5 b | 39.4 b |
| 1740 | 39.8 a | 39.5 b | 39.3 b |
| 1750 | 39.8 a | 39.5 b | 39.4 b |
| 1800 | 39.8 a | 39.5 b | 39.3 b |
| 1810 | 39.8 a | 39.6 ab | 39.4 b |
| 1820 | 39.8 a | 39.6 ab | 39.4 b |
| 1830 | 39.8 a | 39.5 ab | 39.4 b |
| 1840 | 39.8 a | 39.5 ab | 39.4 b |

| | | | |
|---|---|---|---|
| 0640 | 38.2 | 38.3 | 38.3 |
| 0650 | 38.2 | 38.3 | 38.3 |
| 0700 | 38.1 | 38.3 | 38.3 |
| 0710 | 38.1 | 38.3 | 38.2 |
| 0720 | 38.0 | 38.3 | 38.3 |
| 0730 | 38.0 | 38.3 | 38.3 |
| 0740 | 38.0 b | 38.3 a | 38.3 a |
| 0750 | 38.0 b | 38.3 a | 38.3 a |
| 0800 | 38.0 b | 38.3 a | 38.3 a |
| 0810 | 38.0 b | 38.3 a | 38.3 a |
| 0820 | 38.1 b | 38.3 a | 38.3 a |
| 0830 | 38.1 b | 38.3 a | 38.32 a |
| 0840 | 38.1 | 38.3 | 38.3 |
| 0850 | 38.2 | 38.4 | 38.3 |
| 0900 | 38.3 | 38.4 | 38.4 |
| 0910 | 38.3 | 38.4 | 38.3 |
| 0920 | 38.3 | 38.4 | 38.4 |
| 0930 | 38.4 | 38.5 | 38.4 |
| 0940 | 38.5 | 38.5 | 38.4 |
| 0950 | 38.6 | 38.5 | 38.5 |
| 1000 | 38.7 | 38.6 | 38.6 |
| 1010 | 38.7 | 38.6 | 38.6 |
| 1020 | 39.0 | 38.9 | 38.8 |
| 1030 | 39.0 | 39.0 | 38.8 |
| 1040 | 39.1 | 39.1 | 38.9 |
| 1050 | 39.2 | 39.2 | 38.9 |
| 1100 | 39.2 | 39.2 | 39.0 |
| 1110 | 39.3 | 39.2 | 39.1 |
| 1120 | 39.4 | 39.2 | 39.1 |
| 1130 | 39.5 | 39.2 | 39.0 |
| 1140 | 39.5 a | 39.2 ab | 39.0 b |
| 1150 | 39.5 a | 39.2 b | 39.0 b |
| 1200 | 39.5 a | 39.2 b | 39.0 b |

| | | | |
|---|---|---|---|
| 1850 | 39.8 a | 39.4 ab | 39.4 b |
| 1900 | 39.8 a | 39.4 ab | 39.4 b |
| 1910 | 39.7 a | 39.4 ab | 39.3 b |
| 1920 | 39.7 a | 39.4 ab | 39.3 b |
| 1930 | 39.6 a | 39.4 ab | 39.3 b |
| 1940 | 39.6 a | 39.4 ab | 39.2 b |
| 1950 | 39.6 a | 39.4 ab | 39.2 b |
| 2000 | 39.5 | 39.3 | 39.2 |
| 2010 | 39.4 | 39.3 | 39.1 |
| 2020 | 39.3 | 39.3 | 39.1 |
| 2030 | 39.2 | 39.2 | 39.1 |
| 2040 | 39.2 | 39.2 | 39.1 |
| 2050 | 39.1 | 39.1 | 39.0 |
| 2100 | 39.1 | 39.1 | 39.0 |
| 2110 | 39.0 | 39.1 | 39.0 |
| 2120 | 39.0 | 39.0 | 39.0 |
| 2130 | 38.9 | 39.0 | 38.9 |
| 2140 | 38.9 | 39.0 | 38.9 |
| 2150 | 38.9 | 39.0 | 38.9 |
| 2200 | 38.9 | 39.0 | 38.9 |
| 2210 | 38.9 | 39.0 | 38.9 |
| 2220 | 38.9 | 39.0 | 38.9 |
| 2230 | 38.9 | 39.0 | 38.9 |
| 2240 | 39.0 | 39.0 | 38.9 |
| 2250 | 39.0 | 39.0 | 38.9 |
| 2300 | 39.0 | 39.0 | 38.9 |
| 2310 | 39.0 | 39.0 | 38.9 |
| 2320 | 38.9 | 39.0 | 38.9 |
| 2330 | 38.9 | 39.0 | 38.9 |
| 2340 | 38.9 | 39.0 | 38.9 |
| 2350 | 38.9 | 38.9 | 38.9 |

*means within a row followed by different letters are significantly different, $\alpha$= 0.05
** Open = Open pasture, Pine = Thinned pine silvopasture, Hardwood = Thinned hardwood silvopasture

**Table 3. 5: External hide temperature by time of day**

| | None | Pine | Hardwood | NS-PS | NS-HW | PS-HW |
|---|---|---|---|---|---|---|
| | | | **AM** | | | |
| Estimate, °C | 38.91 | 36.81 | 33.92 | -15.67 | -12.78 | -14.89 |
| Std Error | 1.1511 | 1.6279 | 1.4561 | 1.9938 | 1.8561 | 2.1841 |
| P-value | <.0001 | <.0001 | <.0001 | 0.0607 | <.0001 | 0.0195 |
| Adj P | - | - | - | 0.1445 | <.0001 | 0.0506 |
| | | | **PM** | | | |
| Estimate, °C | 49.59 | 40.79 | 37.56 | 15.83 | 21.70 | 5.87 |
| Std Error | 1.8617 | 2.6764 | 1.7777 | 3.2602 | 2.5741 | 3.2130 |
| P-value | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0714 |
| Adj P | - | - | - | <.0001 | <.0001 | 0.1672 |

*Adjusted using Tukey's HSD, α=0.05
**None= no shade, Pine = Pine shade, Hardwood= Hardwood shade
***NS = no shade, PS= Pine shade, HW= Hardwood shade

**Figure 3. 1**: **Blank CIDR cut out for temperature probe.**

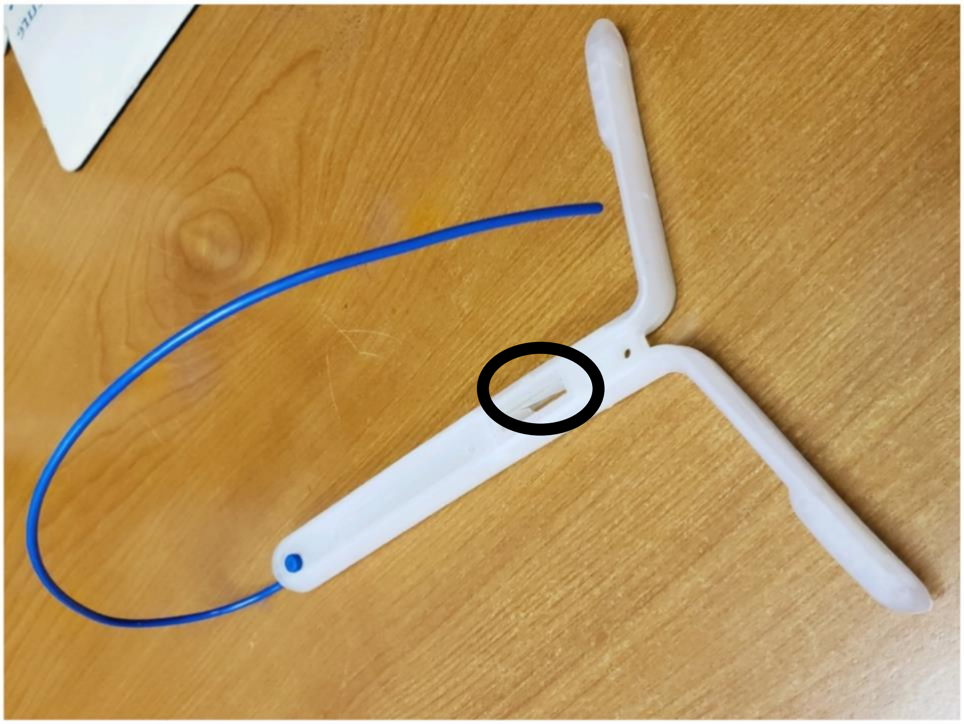
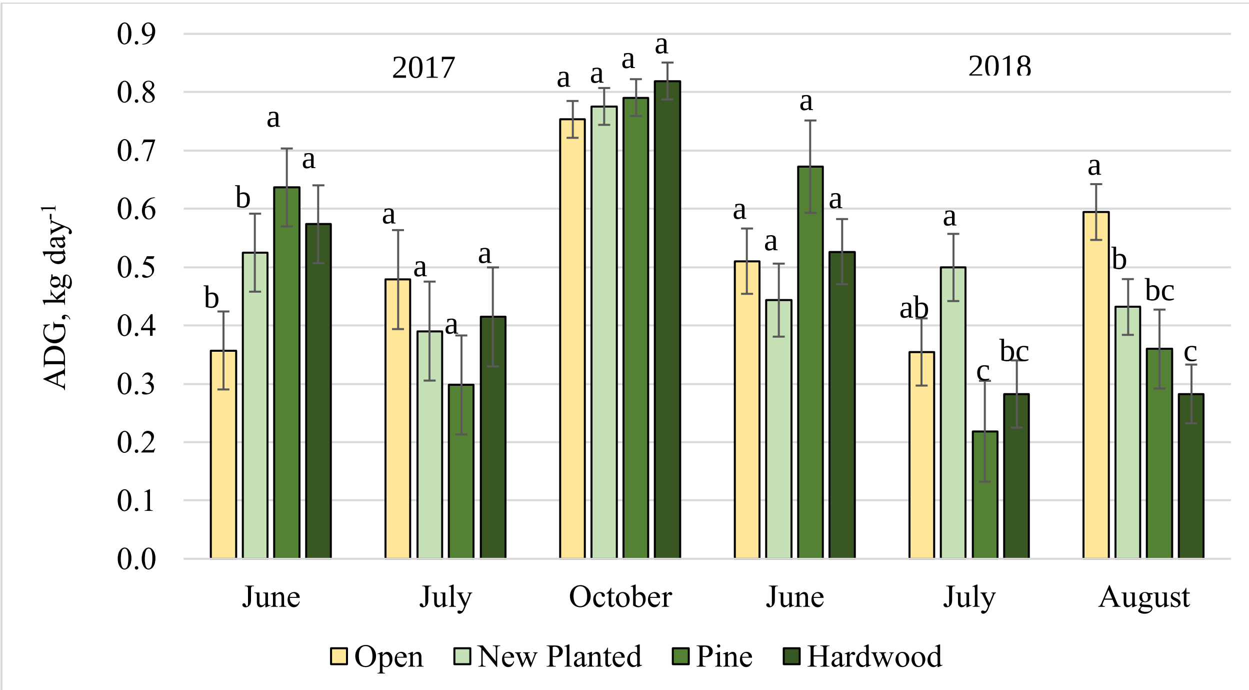
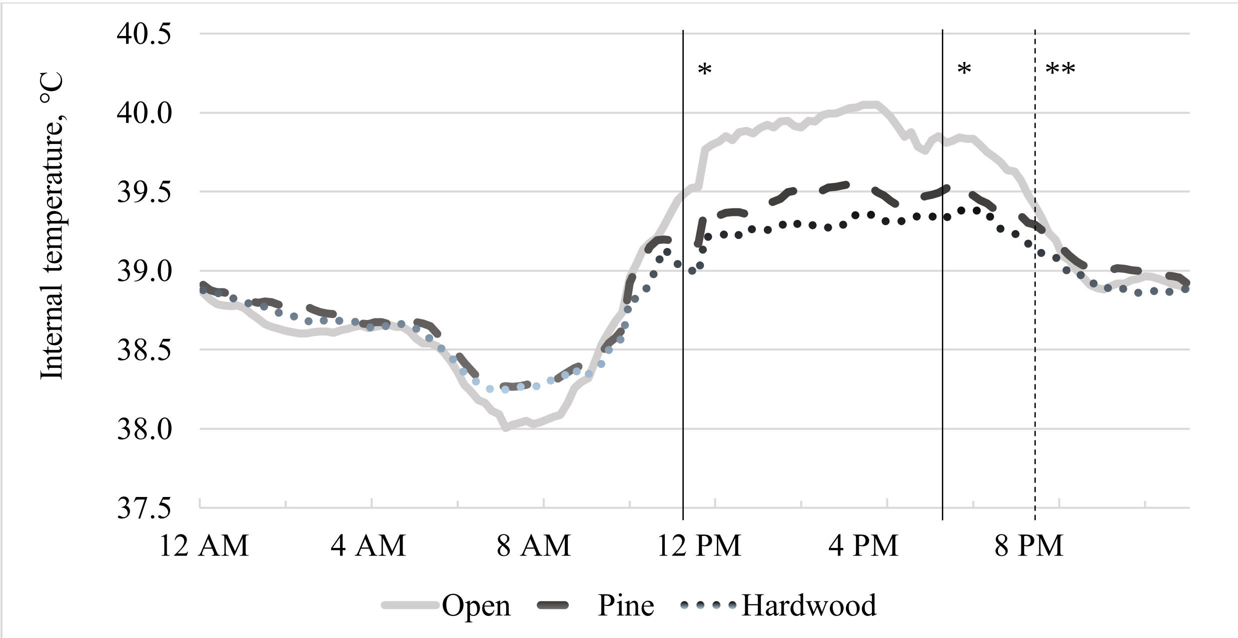


**Figure 3. 2**: **Average daily gain by month**




*Means with differing letters within a month are significantly different, α=0.05
**Open= Open pasture, New planted= Newly planted silvopasture, Pine= Thinned pine silvopasture, Hardwood= Thinned hardwood silvopasture

**Figure 3. 3**: **Internal vaginal temperature over a 24-hour period for heifers in open pasture, pine silvopasture, and hardwood silvopasture.**




α=0.05

*Open = open pasture, Pine= thinned pine silvopasture, Hardwood = thinned hardwood silvopasture
Lines represent the periods where heifers in open pasture have statistically (α= 0.05) hotter internal temperatures.

*Both pine and hardwood silvopastures heifers have cooler internal temperatures than the open pasture heifers between lines (α= 0.05)

** Hardwood silvopasture heifers remains cooler than open pasture heifers until ** line (α= 0.05).

**Figure 3. 4**: **Thermal images of hide temperature taken with drone and relative temperature.**

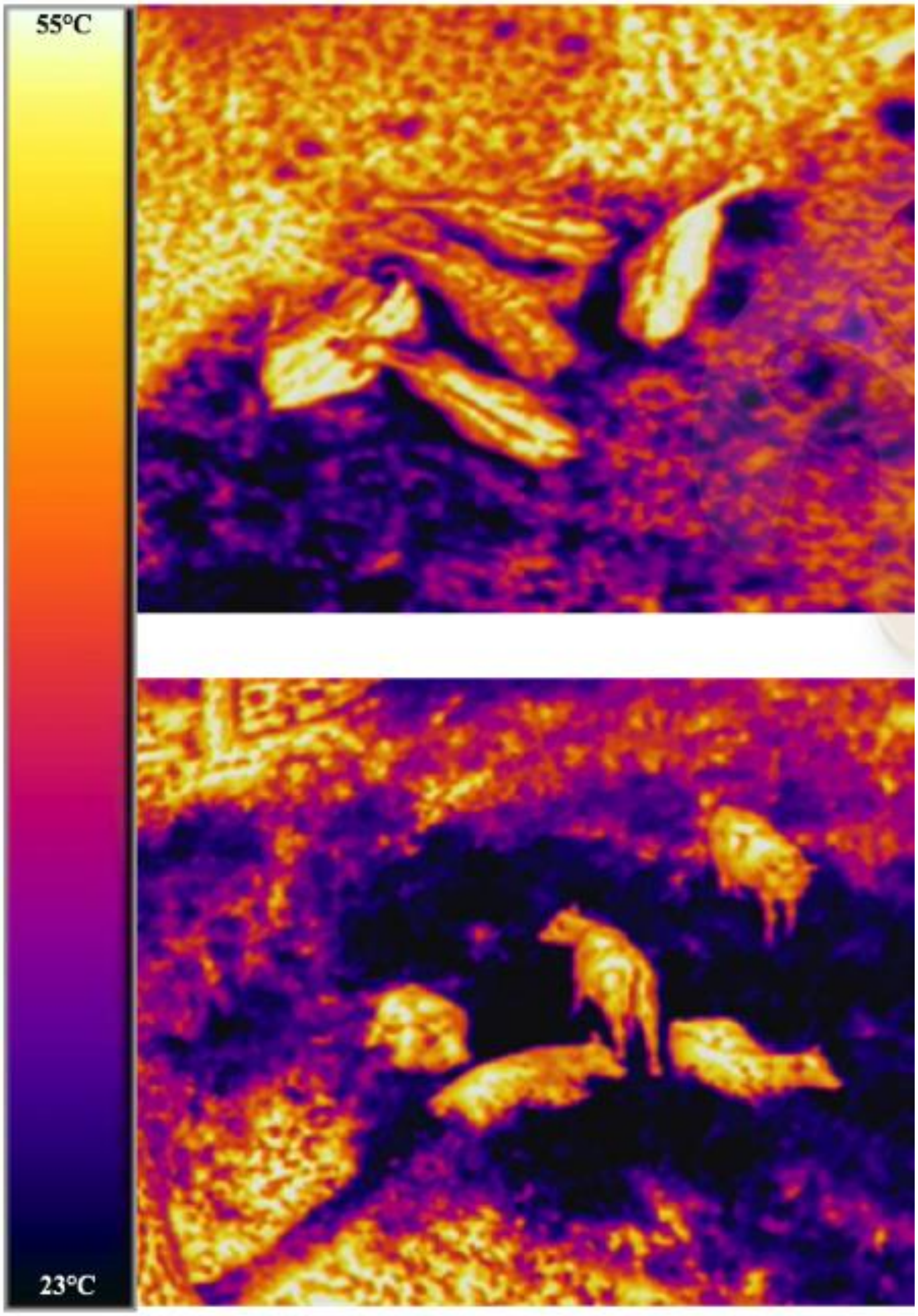


**Figure 3. 5**: **External hide temperature by time of day**

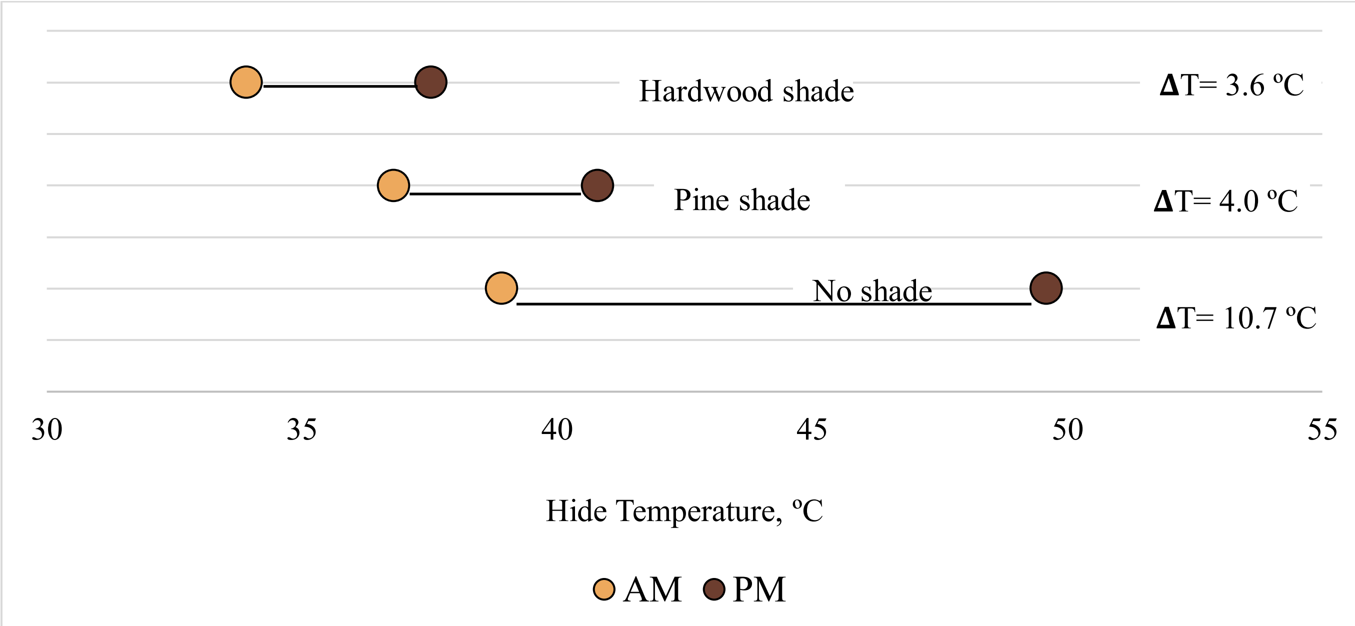



**Figure 3. 6**: **Correlation of vaginal temperature to external hide temperature (all treatments)**

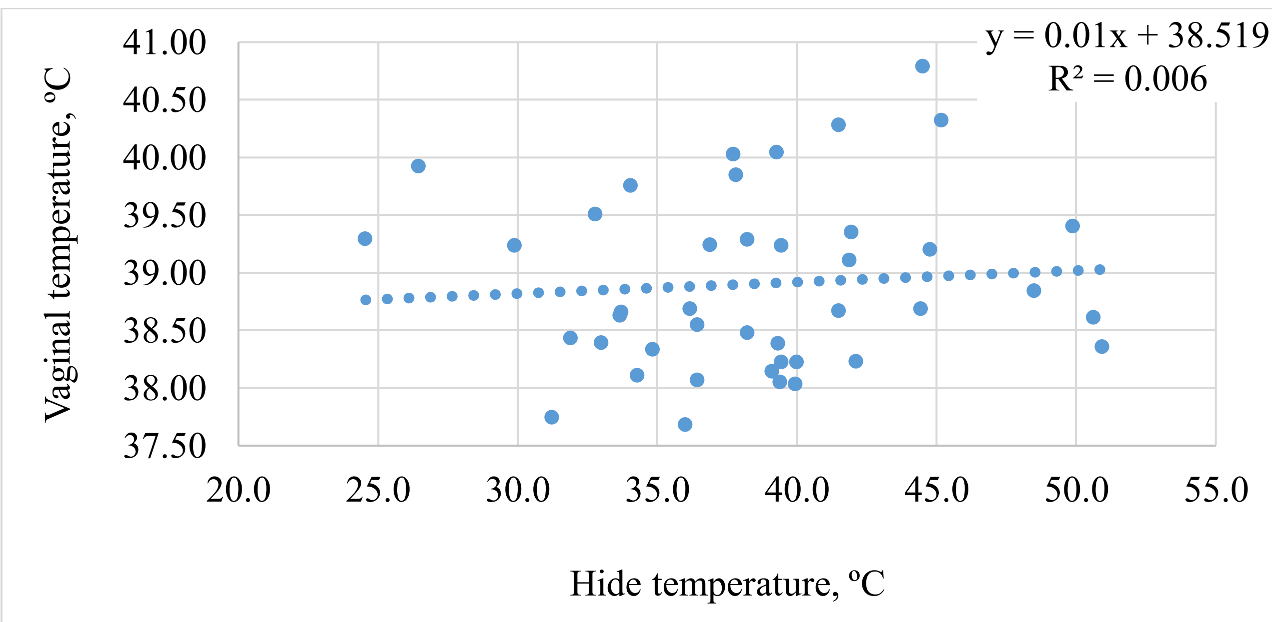
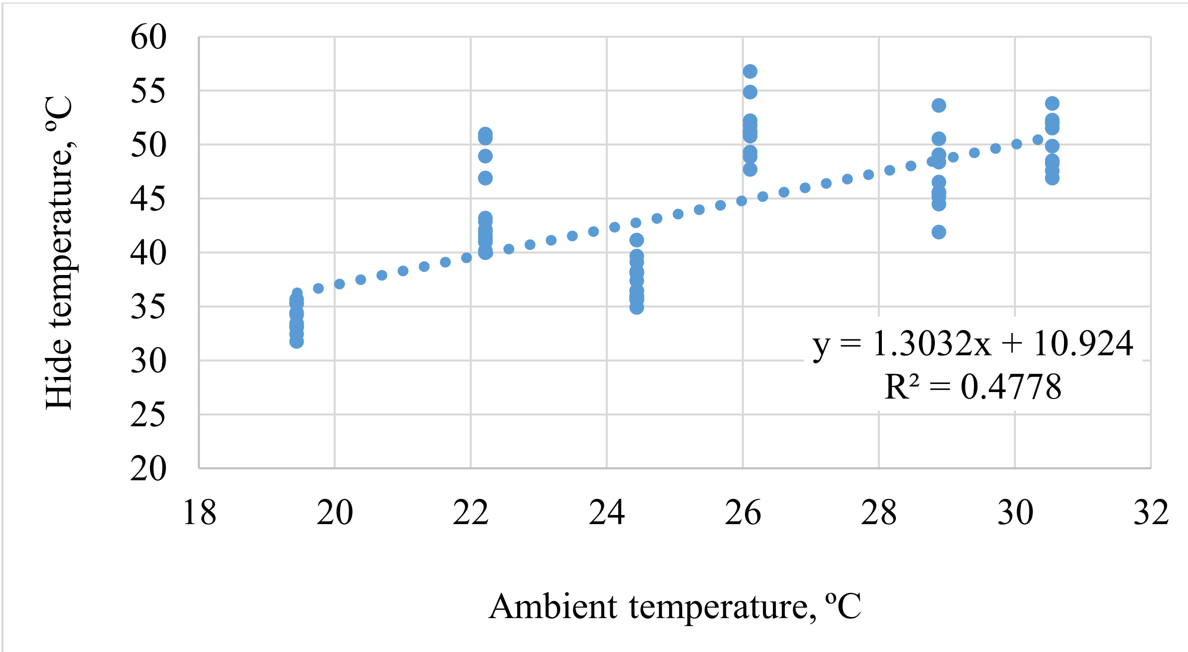
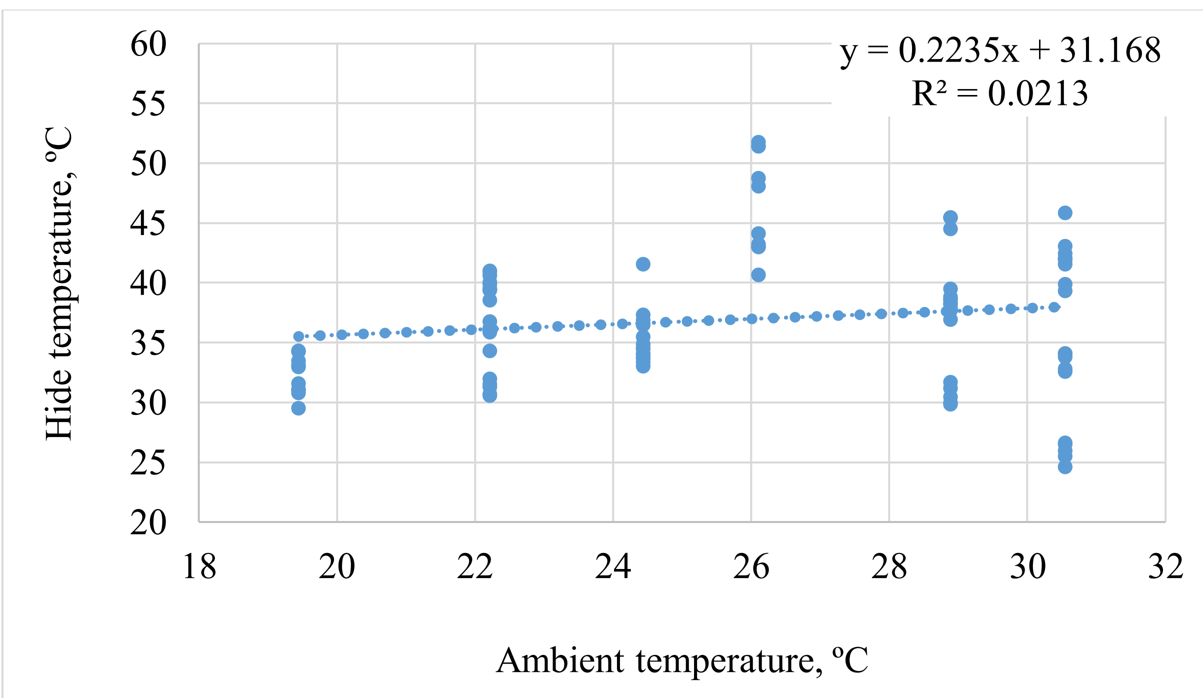


**Figure 3. 7**: **Correlation between ambient temperature and hide temperature of heifers without shade (open pasture and newly planted pine silvopasture)**




*Ambient temperature was recorded during drone readings of hide temperature

**Figure 3. 8**: **Correlation between ambient temperature and hide temperature of shaded heifers (both pine and hardwood shade)**




*Ambient temperature was recorded during drone readings of hide temperature

## Chapter 4: Growing a Silvopasture

### Introduction

Silvopastures have been called a “new name for an old practice.” Silvopasture practices are not new to the North American continent: native Americans utilized controlled fires to maintain an open tree canopy with forages covering the savanna floor (Sharrow et al., 2009). Following colonization, lumber was a valuable crop exported to Europe and colonists cleared the forest to make room for agriculture, viewing timber as an unlimited resource. The 20$^{th}$ century brought forest management and conservation as tree populations rose again and society gave recognition to the environmental value of trees and forests (MacCleery and Forest History Service, 1993; Bronaugh, 2012). However, as farmers moved away from intercropping practices over time to accommodate larger machinery and monocultural production, savanna-like pastures were largely removed (FAO, 2006). Additionally, in the last century, foresters and conservationists pushed to keep cattle out of woodlots and forests due to the damage that unmanaged cattle may cause to trees (Smout, 2006; Arbuckle, 2009). To many farmers and foresters, combining trees, forages, and cattle is counterintuitive, but there is a growing interest among producers and researchers in agroforestry systems for environmental and production reasons.

Narrow profits in agriculture and forestry create incentives for landowners to introduce new ideas to their operations. If adequately managed, silvopasture may be able to provide an opportunity for producers to economically diversify their production systems, improve carbon sequestration of their land, improve wildlife habitat, and improve the welfare of livestock (Clason and Sharrow, 2000; Colmore, 2015; Orefice et al., 2016). Despite the interest in diverse intercrop systems, there is minimal research in establishing a silvopasture into a pasture while still maintaining normal cattle stocking practices. In Orefice et al. (2017), producers identified tree care, regeneration strategies, and management as top areas for research in silvopasture practices. When establishing a silvopasture from an open pasture, trees are typically planted into an open pasture and animals are removed from that pasture for a number of years until the specific type of trees are large enough to withstand potential damage from livestock. While the trees are young, land may be used for hay production, but removing livestock from grazing land may present significant costs for some landowners (Clason and Sharrow, 2000; Fike et al., 2017). Some silvopasture establishment studies have tested different forms of protection for hardwood and pine trees while stocking cattle on the pasture, often finding higher tree survival when trees are protected (Pearson et al., 1990a; b; Pent et al., 2019). However, all tree plantings are expected to have some degree of natural mortality, but young trees are resilient and often can recover from moderate damage (Zeide and Zhang, 2006; Pickens, 2015). To bring back this traditional landscape, silvopastures are typically established in one of two ways: by thinning an established timber stand and establishing forages or by planting trees into an open pasture (Clason and Sharrow, 2000). Trees are sometimes thinned at random to develop a natural savannah-like appearance or rows of trees may be thinned or planted so that alleys of forages may easily be managed between the trees (Fike et al., 2017).

The objectives of this study were to:

1. Assess potential damage on young loblolly pine (*Pinus taeda*) trees in a silvopasture where cattle were grazing.

## Materials and Methods

*Site Description*

This work was performed at the Southern Piedmont Agricultural Research and Extension Center (SPAREC) in Blackstone, Virginia (37.091889, -77.963632). This protocol was approved by the Virginia Tech Institutional Animal Care and Use Committee (Protocol #17-071). Soil series at the site location consisted primarily of a Durham coarse sandy loam, undulating (Fine-loamy, siliceous, semiactive, thermic Typic Hapludults) with smaller areas consisting of Worsham sandy loam (fine, mixed, active, thermic Typic Endoaquults) and Appling coarse sandy loam (fine, kaolinitic, thermic Typic Kanhapludults; Soil Survey Staff, 2018).

An existing timber stand was thinned or clear-cut to establish silvopasture and open pasture treatments beginning in 2014-2015. Treatment pastures (2 ha/experimental unit) were replicated twice and consisted of open pasture, newly planted pine silvopasture, thinned pine silvopasture, and thinned hardwood silvopasture. The open pastures and newly planted pine silvopastures were completely cleared of trees. The newly planted pine silvopasture was then replanted with loblolly pine seedlings at 2.4 m spacing between seedlings in triple row sets with varying alley widths between tree rows (6, 12, and 18 m). The two types of thinned silvopastures were thinned to 30% of the basal area of the previous tree density equating to 10.6 $m^2$ $ha^{-1}$ and 8.7 $m^2$ $ha^{-1}$ in the thinned pine and hardwood silvopastures, respectively. The presence of hardwood or pine trees was based on trees present in the original stand. All pastures were disked, mulched, and fertilized as recommended by the soil test and planted with a cool-season mixture of novel tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumont., syn. *Lolium arundinaceum* (Schreb.) Darbysh., formerly *Festuca arundinacea* Schreb.) infected with a novel endophyte (*Neotyphodium coenophialum* 'E34'), meadow fescue (*Schedonorus pratensis* (Huds.)

P. Beauv.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pretense* L.), ladino clover (*Trifolium repens* L.), and alfalfa (*Medicago sativa* L.). Half of the pastures were planted in the spring of 2016 along with a pearl millet (*Pennisetum glaugum* (L.) R. Br.) nurse crop, and the other half of the pastures were planted in the fall of 2016 without a nurse crop.

*Animal Stocking*

Prior to each summer season, forty fall-born heifers were brought to the Southern Piedmont AREC in May after being weaned in Blacksburg, Virginia. The animals were acclimated to the new farm for a few weeks each summer in a single herd. Following this period, treatment pastures were prepared for animal introduction by setting up temporary electrified tape in each pasture. Animals were weighed once daily on two consecutive days. After the initial weighing, animals were stratified according to their initial weights and then randomly assigned to one of eight groups at a rate of 5 heifers per 2 hectares, placing similar kilograms of animal per hectare on each treatment pasture. After the second day of weighing, animals were divided into their respective groups and moved to their respective pastures. Mean heifer weights of the start of the study were 279 kg and 268 kg in 2017 and 2018, respectively. Heifers were rotationally stocked throughout the summer in accordance with forage availability with the goal of leaving a 5-8 cm residual sward height. In 2017, heifers were stocked on pasture treatments in June, July, and October; heifers were removed at the beginning of August due to lack of forage availability in treatment pastures following the summer dry spell and were put back on treatment in October after forage regrowth. Pastures had not been grazed prior to June 2017. Heifers were stocked May-August in 2018 but were returned to Blacksburg for breeding prior to October grazing. Cattle were rotated every 1-2 weeks based on forage availability. Following heifer removal at the end of the study each year, all pastures were clipped with a rotary mower to a uniform height between 10-15 cm and again clipped the following spring of 2018 at 10-15 cm to keep forage in a vegetative state.

*Tree Score Evaluation*

A pine tree score sheet was developed using tree health and growth indicators. The five-point scale was created based on the fundamental growth of pine trees and their economic value with the aid of the Virginia Department of Forestry, Western Regional Forester, W.C. Thomsen (personal communication, May 25, 2017). The goal of the five-point scale was to determine tree state prior to cattle introduction and then to assess damage following cattle removal in order to evaluate a tree's potential to grow and produce shade and timber. Each tree was evaluated to determine whether it had been browsed by cattle. Trees were then physically examined for any evidence of trampling, broken limbs, and overall damage. The top terminal bud, leader, and bark of each tree were examined. Based on communication with VDOF (Thomsen, personal communication, May 25, 2017) key evaluation points to determine continued healthy growth and potential of a tree were the presence of:

- 30% foliage minimum at the top of the tree
- A healthy top terminal but and less than 50% bark knocked off the bottom.

Other points of evaluation that were considered are included in Table 4.1.

Twenty trees were randomly marked with flagging tape in each newly planted pine silvopasture paddock (80 trees a pasture; 160 trees total) prior to animal entry. Trees were graded on the 1-5 scale (Table 4.2). Following stocking of the pasture with heifers, marked trees were scored again to determine damage. All marked trees were checked for any presence of any nibbling or use as a feed source. Based on the five-point scale and evaluation points, any tree scored at a 3 or below would continue to grow and have economic and shade potential. Trees with a score of 4 would have partial or minimal recovery, whereas trees with a score of 5 would exhibit no recovery.

*Statistical Analysis*

JMP Pro 14.0 software from SAS (SAS Institute, Cary, NC) was used to analyze data. Using the analyze: distribution function in JMP, tree scores were tested by year for the overall distribution of the final tree scores across both pastures. Additionally, tree scores were separated by the paddock and separated between the first rotation score versus the final rotation score to assess mean score distribution.

## Results and Discussion

*Tree Score Evaluation*

Prior to the treatment period in summer 2017, cattle had not been introduced to the treatment pastures and all selected trees showed no sign of damage. Following one complete stocking rotation through the pasture in 2017, trees in pasture 1 had an average score of 2.7 (SE= 0.1342). Following the entire grazing season and a second exposure of heifers, the mean score was a 2.8 (SE= 0.1305) in pasture 1. Of these 80 scored trees in the first pasture, 9 trees had a score of 5.0 or were dead while 8 trees maintained a score of 1.0. In the second pasture, the average tree score after a stocking rotation was 2.8 (SE= 0.1368); following the second rotation, the overall average tree score increased to 2.9 (SE=0.1403). Out of the 80 scored trees in the second pasture, there were 8 trees with a score of 5.0 and 12 trees with a score of 1.0. The overall mean score of both pastures of 2.8 indicated that most trees sustained minimal damage with a few bent and broken limbs. Some trees were slightly bent, but the majority of trees would continue to grow, potentially at a slower rate, than trees growing in pastures if livestock had been excluded. However, some pruning of the lower limbs of these trees may be considered beneficial to the tree by promoting clean growth upwards instead of the branches, thus potentially increasing economic value (Gilman, 2002).

In 2018, one-third of the trees measured in 2017 were able to be identified and used again while two-thirds of the trees did not have previous score records. Trees had an initial score of 2.1 and 1.9 in the newly planted pine silvopastures 1 and 2, respectively. Such an improvement over terminal scores collected in 2017 demonstrates that the trees continued to grow and recover from the damage inflicted by cattle in the first year. After one complete rotation with cattle through the pastures, pasture 1 had a tree score average of 2.8 (SE= 0.1325). Pasture 1 had a final overall average tree score of 3.2 (SE=0.1327) at the end of the grazing season after being exposed a second time to heifers. Pasture 2 had an average tree score of 2.6 (SE= 0.1364) following one complete rotation and a final overall average tree score of 3.0 (SE= 0.1301). There were a total of 17 trees and 8 trees that were classified with a score of 5.0 in pastures 1 and 2, respectively. It should be noted that a number of the larger trees that were scored as a 5.0 in 2018 had been used as scratching posts for cattle, which likely contributed to their demise. Each of the pastures had two trees with a score of 1.0 after the second treatment period.

Despite recognizable damage by cattle, due to the experimental setup, there is no true control to compare pine tree damage by cattle versus natural tree mortality and damage from wildlife or weather events. Loblolly pine trees are known to be hardy and vigorous trees with an estimated tree mortality between 0.8% and in extreme cases upwards of 26-30% as found after an ice storm (Zeide and Zhang, 2006; Bragg, 2016). VDOF stated that equal to or less than 10% mortality should be expected typically for loblolly pine seedlings (Thomsen, personal communication, April 20, 2019). In the future, various newly planted silvopastures should be set up to evaluate different variations of protection and cow exposure while ensuring a control treatment with no cattle access.

Pearson et al. (1990a) similarly stocked cow-calf pairs and a bull in pine seedlings arranged in strips for the first 3-years of silvopastoral establishment; treatments included: ungrazed pines fenced off by electric fence, limited grazed seedlings with one strand of electric wire over the seedling row, and fully grazed pines with no protection. There were no differences in tree growth or survivability between the ungrazed and limited grazed seedings; however, seedlings in the grazed seedlings had the greatest mortality of trees in response to browsing, rubbing, and trampling. Despite damage to trees in the grazed treatment, by the end of the third year, grazed tree height was not statistically different than ungrazed trees (Pearson et al., 1990a). Similar to this study, although there was some mortality among trees in grazed pastures, many injured trees will recover. In a follow-up study, Pearson et al. (1990b) found that a single electric line above a row of Virginia pine (*Pinus virginiana* Mill.) seedlings was an adequate way to prevent grazing and trampling damage in the first year. In the second and third year, some seedlings had no protection from cattle while electric wire remained above other seedlings. There was minor (5%) trampling damage in seedlings protected with the electric wire while damage from cattle was an issue in unprotected seedlings with over 50% of unprotected seedlings trampled or rubbed at the end of the 3-year study.

Another study observing the establishment and growth of slash pine *(Pinus elliottii*) saw no difference in tree survival between lightly grazed and ungrazed rows of trees, but tree survival was reduced in heavily trafficked areas (Grelen et al. 1985). However, after 5- and 18- years no height difference was observed between surviving trees in ungrazed, lightly stocked, and heavily stocked pastures; additionally, trees in heavily stocked pastures had greater tree diameters after 18-years as compared to the ungrazed and lightly stocked pastures. This compensated for the increased tree mortality, and timber value per unit land was similar between treatments (Grelen et al. 1985). A study in Virginia evaluated various tree protection methods (tree tubes, fixed-knot wire cages, and commercial tree protectors) for individual trees in comparison to no protection in a young hardwood silvopasture (Pent et al., 2019). Following grazing, trees protected with wire cages and commercial protection methods, had the greatest survival rate while no trees survived without protection. In contrast, Houx III et al. (2013), found that black walnut seedlings grew tallest when there was a minimum 0.9 m vegetation-free zone and had the greatest diameter with a 1.2 m vegetation-free zone where planting trees into vegetation, as typically done in a silvopasture, had less success.

Likely, a majority of damaged trees were in response to cattle entry. However, as demonstrated by the improved score and natural recovery between 2017 and 2018, most of this damage is not severe. Also, although 15% mortality after the second year is higher than most loblolly pine seedlings, it is below extreme events of mortality. For further analysis of true damage, trees would need to be evaluated over a period of years comparing no protection, some protection by a single electric wire, and full protection of trees. Additionally, tree heights and change over time should be recorded to assess any inhibited growth of trees in response to cattle exposure.

Producers may be able to account for some of the damage inflicted on young pine trees by livestock by overplanting seedlings or by protecting the trees by use of a tree guard or by fencing out rows of trees with electrified tape. Understanding the final yield and quality of the timber produced by trees in silvopastures will be the ultimate factor affecting the economic value of the trees in these silvopastures compared to trees grown in a forest. Based on the results of this work, stocking cattle in newly planted pine silvopastures may be a viable option for producers interested in establishing a silvopasture.

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## Appendix

**Table 4. 1: Criteria for tree recovery after damage**

| Evaluation topic | Full Recovery… | Partial (60-80%) recovery | No recovery |
|---|---|---|---|
| Amount crown present | > ¾ crown | ½ to ¾ crown present | < ¾ crown present |
| Vertical tree angle bent | < 15 degrees | 15-30 degrees | > 40 degrees |
| Adapted from Pickens, 2015. | | | |

**Table 4. 2**: **Pine tree seedling silvopasture evaluation scale**

| Grade | Description |
|---|---|
| **1** | No damage to the tree. No evidence of trampling or broken branches. Top terminal bud and leader are healthy, showing no signs of animal interference. No bark appears to be missing at the bottom of the tree and handle. |
| **2** | Minimal damage observed. Estimated less than 25% damage to branches (bent, broken, etc.) and tree as a whole. Minimum of 60% foliage and canopy up top. Minimal to no bark scraped off at the bottom. No visible root damage. |
| **3** | Estimated between 25% and 50% damage to branches (bent, broken, etc.) and tree. Multiple branches have been broken or tree is slightly bent. Minor damage to top terminal bud and less than 50% bark knocked off at bottom. No visible root damage. |
| **4** | Estimated between 50% and 75% damage to branches (bent, broken, etc.) and tree. Less than 30% foliage and green canopy at the top present. More than 50% bark knocked off at bottom. Major damage to top terminal bud and leader and significantly bent base and tree. Visible root damage. |
| **5** | Excessive damage past future growth, fully trampled or dead from cattle. Leader and/or trunk snapped and broken. |

**Table 4. 3**: **Tree score summary by year.**

| | Trees | Pre-stocking score | Std Error | Post-stocking core | Std Error | No damage, % | Dead, % |
|---|---|---|---|---|---|---|---|
| 2017 | 160 | 1.00 | 0.0000 | 2.83 | 0.0940 | 12.50 | 10.60 |
| 2018 | 160 | 2.04 | 0.0660 | 3.10 | 0.0883 | 2.50 | 15.60 |

Means are presented above
No damage: trees with a score of 1.0
Dead: trees with a score of 5.0

## Chapter 5: Conclusions

### Conclusions and Future Research

*Forage Availability and Nutritive Value*

Forage biomass production varied over each season more than treatment effects in either 2017 or 2018. Overall, silvopasture systems resulted in similar or decreased forage production compared to open pasture systems. Reduced forage availability in silvopastures may be expected due to the competition for light, water, and soil nutrients between trees and forages. As this took place in the two years after pasture establishment, further research is necessary to understand how climate changes and competition for resources influence forage growth and availability over time. Some losses in forage production may not translate to reductions in overall land productivity in silvopasture systems because of the additional value of the trees. Most reductions in forage production may be managed by adapting stocking rates and increasing forage rest time in silvopastures.

Forage nutritive value was not affected by the presence of trees in pasture. Time of year (collection date) had the greatest influence on nutritive value. The present study indicates that forage nutritive value is not reduced in a silvopasture system, and silvopastures, therefore, would not be expected to have a negative effect on livestock production if stocking rates match forage supply. Future research in silvopasture systems with forages is still needed, both in assessing the growth and success of different forage types in silvopasture systems. Warm-season forages may be viable forage options in silvopastures in the southeastern U.S. if paired with lower tree canopy cover; these forages would likely not see the same production decline later in the summer as experienced by the cool-season forages in this study. Forage production in silvopastures with toxic fescue should also be analyzed since that is the predominant forage species in the U.S.

Additional research is also needed assessing different stocking rates in silvopastures and the effect of increased rest time of forages and in understanding if hydraulic lift and other ecosystem services from trees provides water to upper soil levels for the forages to utilize. A better understanding of the competition and mutualism of soil nutrients and moisture between trees and forages will allow researchers and producers to make informed management decisions from fertilization to tree thinning for more efficient silvopastures.

*Livestock Production in Silvopastures*

In 2017, heifers in silvopastures had greater average daily gain than heifers in the open pastures and newly planted pine silvopastures, despite equal or less forage in the silvopastures. Alternatively, in 2018, heifers in silvopastures had lower ADG later in the summer as compared to heifers in open pastures and newly planted pine silvopastures. Factors such as decreased forage availability in silvopastures, compensatory gain, and animal temperament likely played a role in decreased heifer gains in 2018. This study demonstrated that animals in silvopastures can produce and perform similarly to animals in open pastures in some years.

Heifers in silvopastures had reduced internal and external body temperatures. Heifers in the thinned pine and hardwood silvopastures had afternoon hide temperatures that were 17.7% and 24.3% lower, respectively, as compared to heifers with no shade. Lower hide temperatures are a result of lower heat loads, and lower vaginal temperatures indicate improved welfare of heifers in silvopastures. Silvopastures are a valuable way of reducing heat stress and heat loads while maintaining animal welfare despite higher ambient temperatures.

Silvopasture can be a viable option for animal production with proper stocking management to reduce heat stress on animals and therefore improve animal welfare. Silvopastures may be best used at specific times of the year in relation to the environment and animal needs. There is a research need to focus on utilizing silvopastures as a part of a holistic grazing plan. Specifically, research on silvopasture systems with toxic fescue is needed to assess the value of shade when cattle heat stress is exacerbated by fescue toxicosis. Additional research is needed in determining best management practices for silvopasture systems and quantifying the value of the microclimate environment- both from a consumer perception and a production standpoint. Silvopastures are likely most valuable during times of greater stress to take advantage of a more comfortable environment, such as exceptionally hot temperature periods during the year, during the calving season or breeding season, or when introducing animals to a new farm.

*Growing a Silvopasture*

As demonstrated in this study, it is possible to grow trees in the presence of cattle without substantial damage. However, a percentage of planted trees should be expected to be dead if no form of protection or barrier is provided. Non-trampled, damaged trees may make a full recovery, or may experience some delayed growth or marginalized timber value depending on the extent of the damage. However, even damaged trees will continue to grow and produce shade within a few years, fulfilling some purpose while still maintaining economic value. The ability to grow trees in a pasture while still maintaining land in grazing is a valuable opportunity for producers interested in adopting silvopasture systems. Continued research on establishing a silvopasture, both from planting and thinning, is necessary. There are many gaps in research on how and where to plant trees in a planted silvopasture. In the case of thinning existing woodlots, it will be helpful to determine the proper extent to thin trees without making trees susceptible to storm, disease, and damage.

*Conclusion*

Silvopastures require intensive and intentional management, requiring both the right resources and the right manager. Since combining trees, pasture, and livestock is contrary to current traditional practices, it may be slowly adopted and may require a phase where innovators implement forms of silvopastures in their own systems before becoming widespread. Silvopastures can take many different forms from alleys of trees to a natural distributed arrangement, with a combination of a variety of trees and forages. Silvopastures can be created from thinning existing stands or by planting trees in a pasture. Although silvopastures may require additional labor, silvopastures can provide an opportunity to improve overall land productivity. Silvopasture systems still require more research both in long-term production, application, and economic factors to better understand the many factors influencing silvopasture adoption and success. Among the many ecosystem services silvopastures provide, silvopastures can reduce overall livestock heat stress and improve animal welfare while maintaining comparable livestock production to pastures in addition to the production of trees. Silvopastures can be managed as part of a holistic system providing environmental, economic, welfare, and production benefits.