ABSTRACT

BARNES, THOMAS. Assessing Economic Viability of Loblolly Pine and Industrial Hemp Intercropping in North Carolina (Under the direction of Dr. Zakiya Leggett and Dr. Rajan Parajuli).

Industrial hemp (*Cannabis sativa* L. <0.3% THC), a non-psychoactive chemotype of cannabis, was reclassified and made legal for growing across the United States following the signing of the 2018 Farm Bill. With proper licensing, testing, and fees, growers in North Carolina can cultivate industrial hemp for its myriad of uses. Given that resources, knowledge, and interest for this novel crop are expanding rapidly, we explored the possibility of intercropping industrial hemp for fiber with loblolly pine (*Pinus taeda*), one of the most commercially important tree species in the Southern United States. Following a previous greenhouse study confirming hemp's ability grow in pine-influenced soils, we examined the financial feasibility of this potential agroforestry system. We simulated the Loblolly pine tree growth information using PTAEDA4.0, a growth and yield decision support system. We modified the industrial hemp budget sheet prepared by the University of Missouri Extension to represent hemp cultivation in North Carolina. We also examined survey results from hemp growers throughout the US Southeast to document the perspectives and challenges that accompany the growing of industrial hemp.

Our results indicate that pine-hemp intercropping can produce greater economic returns than conventional pine plantation management. The early rotation cash-flow and the complimentary benefit afforded to the pines through intercropping result in a more efficacious, long-term investment. However, intercropping practitioners may need to plant about 20-40 acres of intercropped hemp, depending upon additional costs like machinery rental, in order to break-even on their hemp investment. Data collected from the grower survey found that despite large issues in the marketing and sale of their product, most practitioners intend to grow hemp again even when their operations performed poorly.

Assessing Economic Viability of Loblolly Pine and Industrial Hemp Intercropping in North Carolina

by

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BIOGRAPHY

Thomas Barnes was born and raised in Charleston, South Carolina. He is the son of Rosalba Adrian and Mark Barnes; he is the younger brother of Dr. Jessica Ann Barnes and older brother of Christopher Barnes. At age 13 he was one of the first students to attend Palmetto State Scholar's Academy, a charter school for the gifted and talented. Five years later he graduated with honors from Bishop England Highschool and went on to be accepted into Clemson University's Mechanical Engineering Program. While attending Clemson University, Thomas soon discovered his passion within the school of forestry and by the end of his first year switched his major to a Forestry degree. During his time at Clemson Thomas spent an academic year studying forestry abroad in Europe and also spent an entire year working at a research station of The American Chestnut Foundation. He achieved his bachelor's degree in 2019 graduating cum laude with a major in forestry and a minor in fish and wildlife sciences. Thomas then went on to accept a fellowship offer from the USDA's National Needs Fellowship and began earning his Master of Science in Forestry in the Autumn of 2020. In his free time Thomas enjoys hiking, camping, recreational reading, and traveling.

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Industrial Hemp

Industrial hemp (*Cannabis sativa* L <0.3% THC) is an herbaceous, annual plant native to the temperate regions of central Asia (Susaeta, et al. 2016). The plant is extremely fast growing reaching ideal harvesting conditions at 90 to 120 days (Clarke, 2010). Depending upon the genetic cultivar and site conditions, hemp plants can reach heights up to 6m tall, with more densely planted fiber-hemp varieties attaining greater heights (Fike, 2016). Hemp grows best in moist, yet well-drained soils that are deep, rich, and have a PH between 6.0 and 7.5 (Roseburg et al, 2019). Hemp is commonly known for its relationship and similarity to Marijuana (*Cannabis sativa* >0.3% THC*)*, a high THC producing chemotype of the species. This herbaceous crop provides a plethora of uses from fibers for canvas and textiles, seed for human and animal consumption, oils for CBD products, structural fibers for novel building techniques, and raw biomass (Cherney & Small, 2016).

Industrial hemp's history stretches far back into human history. Hemp was first used and cultivated by humankind around 8,500 years ago in temperate Asia (Fike, 2016). Even though it has only recently been made eligible for cultivation through the 2018 Farm Bill, hemp had been previously grown in the United States and the earlier British colonies. In colonial days, hemp could be given in place of taxes, and in WWII the "Hemp for Victory" campaign encouraged American farmers to grow hemp for the war effort (Fike, 2016).

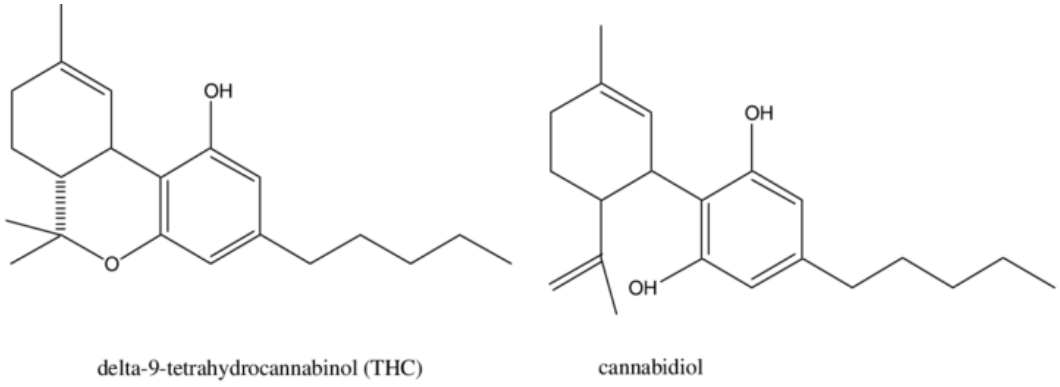

Figure 1. THC, (−)-trans-Δ9-tetrahydrocannabinol and CBD, cannabidiol (Russo & Guy. 2006)

Industrial hemp was banned in the early 20th century alongside its psychoactive sibling, or more commonly known as marijuana. Marijuana has been banned in the United States, and in many other nations, due to the high concentration of the psychoactive chemical THC (Δ^9 -tetrahydrocannabinol) produced by the plant (USDA, 2000) (Figure 1). Though hemp produces significantly less THC (<1%) than marijuana, both plants were legally considered similar in terms of the purpose of drug enforcement (Cherney & Small, 2016). Today, most nations allow for the cultivation of industrial hemp if it does not exceed 0.3% THC content, whereas marijuana often contains 1%-20% THC content (Fike, 2016). The 2018 Farm Bill has preserved the FDA's authority to regulate hemp products but has allowed for nationwide cultivation of hemp for fiber, CBD, and other commercial uses under close legal oversight (Abernethy, 2019).

For the purposes of this study, industrial hemp cultivated for fiber was examined and referenced throughout. Fiber hemp is cultivated and harvested for its bast fibers, which can be processed to produce a variety of textiles (Cherney & Small, 2016). However, historical uses of hemp for fiber have been replaced by plastics, paper, and other natural fibers such as cotton (USDA, 2000). With strong support for the plant and its products rising, the hemp market has made a resurgence in the United States with planted acres increasing by 2,284% between 2016 and 2019 (Dhoubhadel, 2021). Today, industrial hemp is planted on over 54,000 acres across the US with hemp production value being estimated at $824 million in 2021 (USDA, 2022).

Hemp for Fiber in the Field

The cultivation methods for hemp fiber differ from those used in growing hemp for essential oils. Initial soil cultivation is similar to that of spring small grains, and planting dates are usually between May and June (Roseburg et al, 2019). Differing from conventional small grains, hemp can grow up to 5 meters (19 feet) tall, an immense height for an herbaceous crop, as shown in Figure 2 (Ehrensing & Oregon, 1998). Seeding densities can vary depending upon seed size and weight, but plant densities are recommended to fall between 100 and 200 stems per m^2, with higher densities often resulting in taller stems and potentially longer fibers (Fike, 2016). However, a fair estimate would be about

1,000,000 seeds per acre, or 50-80lbs of seed per acre (David Suchoff, personal communication 2021). This high density of stems will result in shorter time to canopy closure and a reduced risk of damages or losses from weedy competition.

Figure 2. The tall growth form of fiber hemp (Adapted from NC State Extension, 2021) https://cals.ncsu.edu/crop-and-soil-sciences/news/new-hemp-research-consortium-taps-david-suchoff-to-lead/

Hemp inflorescence is determined by day-length, a value which changes depending upon the genetics of the seed. While flowering is essential for the production of oil, seed, and grain, flowering results in decreased fiber quality, and therefore should be avoided if growing hemp strictly for fiber (Clarke, 2010).

Once the hemp is ready for harvest it may be cut, such as with a sicklebar mower, but still needs to remain in the field to undergo a process known as retting. Retting is the intentional, microbial decomposition of the stems to release the desirable bast fibers of the stem from the hurd: the inner core of the plant (Roth et al, 2018). Stalks are left to lie in the field for up to five weeks, depending

upon decomposition rate, and may be raked one to three times throughout the process until the stems are finally baled and shipped to processors.

While hemp is often marketed as a sustainable, low-impact crop, repeated plantings of any crop result in reduced yields and greater susceptibility to weeds and disease (Bullock, 1992). As such, it is important to rotate crops when farming in a monoculture system. A USDA bulletin from 1943 claims that hemp grows well in fields previously used for clover or soybean cultivation, and that corn is a good rotation to follow after a hemp harvest (Robinson, 1943). Table 1 shows three suggested crop rotations from 1901 that include the cultivation of hemp (Dewey, 1902). More recently, it was found that wheat yields improved significantly for two years following a dual-purpose hemp rotation (Gorchs et al, 2017). However, there is a distinct lack of modern recommendations for viable hemp crop rotations, especially for climates akin to the US Southeast.

Table 1. Suggested crop rotations for hemp cultivation (Dewey, 1902)

Year/Plot	1st	2nd	3rd	4th	5th
One	Hemp	Corn	Wheat	Clover	Grass
Two	Hemp	Onion, potato, or sugar beet	Wheat	Clover	Grass
Three	Corn	Beans, peas	Hemp	Oats, barley	Clover

Loblolly Pine

Loblolly pine (*Pinus taeda*) is the most commercially important tree species in the southeastern USA, comprising about 29 million acres (11.7 million ha) of the South's forest land (Baker & Langdon, n.d.) (Figure 3). With a relatively short rotation length (25-50 years), adaptability to a variety of different soils, and the highest valuation of any agricultural crop in the South, loblolly pine serves as the forest industry standard in the South (Cunningham & Barry, n.d.). Additionally, loblolly

pine plantations can be managed in numerous ways and at varying intensities, such as different site prep methods, the use of herbicide, intermittent thinnings, and planting spacings.

Figure 3. Native range of *Pinus taeda* (Baker & Langdon, n.d.)

Site preparation is the preparation of non-forested land to accommodate the establishment of tree seedlings. Site preparation yields benefits such as the ease of planting, which in turn may lead to greater survivability and growth, reduced competition, and even shorter harvest times (Barry & Cunningham, n.d.). Methods of site preparation include herbicide burndown, chop and burn, windrowing, v-shearing, and bedding. In the Southeast, chop and burn is a common method of site preparation as it removes slash, exposes mineral soil, and accelerates nutrient mineralization; all of which could benefit the planting and cultivation of industrial hemp directly.

Thinning is an essential part of forest management, in both plantation style and naturally regenerated stands. Thinning is a form of stand density control, which seeks to distribute growing space to vigorous, well-performing trees (Cunningham & Barry, n.d.). It is a standard practice in forest management to thin a loblolly stand once the basal area of the stand reaches 120 ft^2 and to reduce the basal area to 70-80 ft^2. In practice, thinning often entails the removal of small, underperforming trees to favor the larger, more merchantable ones.

Agroforestry and Intercropping

Agroforestry is a form of intensive land management that seeks to optimize the benefits from the interactions introduced when trees are planted alongside one or more secondary crops (Agroforestry Manual, 2015). The practice of integrating trees with other crops extends throughout history and cultures and is still widely practiced today throughout the world. Some examples of modern agroforestry practices include understory coffee farms in tropical regions, silvopasture, windbreaks, and alley cropping (Idol, 2020). Agroforestry has been found to be a more efficient land use with a global meta-analysis finding that intercropping produced 38% more gross energy and 33% more gross income compared to their monoculture counterparts while using 23% less land (Martin-Guay et al., 2017). Therefore, agroforestry practices may yield significant returns to smaller landowners looking to maximize benefits on their land. As such, the US Southeast provides an ideal recipient for agroforestry practices with 86% of all forest land being owned by private landowners and 40% of these landowners possessing less than 100 acres of forest land (Butler & Wear, 2013).

Within North America, the most common agroforestry practice is silvopasture: the sustainable inclusion of livestock, forage, and trees within the same land area (Orefice et al., 2017). Most often, silvopasture in the USA combines cattle reared for beef production and plantation style forests intended for timber production. To promote sufficient light for forage and space for cattle, trees are most often planted to accommodate for alleyways, with a common planting spacing being 20ft x 5ft (6.1m x 1.5m). The same spacing is used regularly by some industrial forest managers, such as Weyerhaeuser, but is also often incorporated in intercropping studies, such as those examining biomass intercropping (Cacho et al, 2015). Figure 4 shows the spacing and sampling methods incorporated within a loblolly-switchgrass intercropping study (Cacho et al, 2015). This spacing not only provides for marketable sawtimber, but also ensures large enough alleys in which a secondary crop may grow.

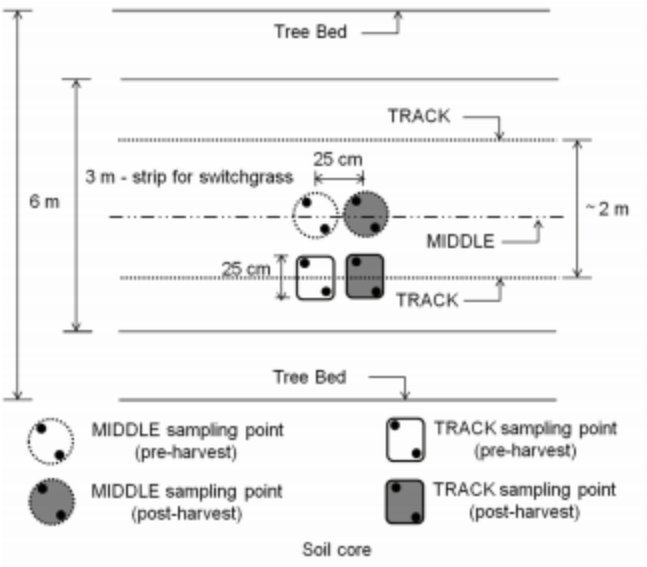

Figure 4. Spatial Arrangement of Loblolly-switchgrass interplant (Adapted from Cacho et al, 2015)

Intercropping is an agronomic practice that incorporates two or more crops within the same production area (Agroforestry Manual, 2015). While not widely practiced throughout the western forestry systems, other cultures, especially indigenous cultures, still incorporate intercropping within their forest production systems (Steppler & Nair, 1987).

There have been a multitude of field studies analyzing various loblolly intercrop regimes including the intercropping of switchgrass (*Panicum virgatum*), oilseed crops, and maize. Loblolly-switchgrass intercrops were found to be financially viable when switchgrass biomass prices were greater than \$30 Mg^{-1} and competition between the two species was minimal (Susaeta et al, 2012). Additionally, there were no significant differences in switchgrass biomass or gross primary productivity for both switchgrass and loblolly when intercropped two years following loblolly planting- though shading would likely impact these metrics as the stand advanced (Albaugh et al, 2012, 2014). A Brazilian field study found that intercropping maize for the first three years of a 22 year loblolly rotation is an economically viable practice that could help reduce pine planting costs (Oliveira et al, 1998). Field trials of loblolly pine intercropped with oilseed crops such as carinata (*Brassica carinata*) and white lupin (*Lupinus albus* L.) found that Land Expectation Value (LEV) was

considerably higher within intercropped stands ($3,346/ha and $3,607/ha) than in pine monocultures ($2,816/ha); however, the intercropped sites were more susceptible to price changes and had a greater than 50% probability to become less profitable than loblolly monocultures (Akter et al, 2021).

By planting loblolly pine at a 20ft x 5ft spacing hemp can be intercropped in the alley between the trees; a space that would otherwise go unutilized in the early development of the pines. In the 5 to 7 years preceding canopy closure, industrial hemp can be sown, grown, and harvested between the growing pines. Preceding research has found that it is feasible to grow industrial hemp on pine soils such as Norfolk loamy fine sand and Cecil sandy loam (Cooper et al, 2021). However, heavy clay soils such as Cecil are vulnerable to compaction which could impede hemp root expansion, stress hemp, and potentially lead to mortality (Cooper et al, 2021).

Study Objectives

As interest and opportunity in hemp production consistently increases across the United States, intercropping this crop within pine plantations could provide an opportunity for diversified income, greater land use efficiency, and higher economic returns. Hemp can be grown in pine influenced soils and 20ft by 5ft pine spacing provides enough open space early in the rotation to alley crop hemp. The first objective of this study was to perform a financial analysis to examine and compare the financial viability of standard pine plantations, intercropped scenarios, monoculture scenarios, and complimentary benefits. These scenarios will be evaluated through: Net Present Value (NPV), Equal Annual Equivalent (EAE), Return on Investment (ROI), and Land Expectation Value (LEV). The second objective was to examine survey responses from hemp growers and other stakeholders to garner a greater understanding of the attributes, issues, and perspectives towards the cultivation of industrial hemp in the Eastern United States. Specifically, these surveys provided data on the size of growing operations, the issues these growers face, the products they are producing, the success of their operations, and their intentions on cultivating hemp in the future. This study will further advance the knowledge base required to accurately inform and assist landowners and other stakeholders who

are interested in intercropping loblolly pine and industrial hemp or are seeking additional financial benefit from their pine operations.

Chapter 2. Assessing Economic Viability of Loblolly Pine and Industrial Hemp Intercropping in North Carolina

Introduction

While there are many benefits- ecological, societal, and personal- that may be derived from the planting of timber and agricultural crops, economic benefits are more often than not the determining factor in pursuing investments. Timber, particularly in the form of southern pine plantations, is one of the most valuable agricultural products of the Southeast, with the forest sector directly contributing $21.6 billion in industry output for North Carolina alone (Parajuli & Bardon, 2021). Hemp production within the United States, only recently legalized by the 2018 Farm Bill, totaled $824 million across the nation in 2021 (USDA, 2021). As the market for industrial hemp continues to develop, there remains abundant opportunity for investment in this new, specialty crop even within the forest sector.

Complimentary benefit is a term used to describe the beneficial, additive interaction that takes place when two factors combined increase one or both of their outputs. For example, a study out of Central Kenya found that crop yields and economic benefits increased when maize was intercropped with legumes compared to monoculture maize production, due to the nitrogen inputs added by the nitrogen fixing legumes (Mucheru-Muna et al, 2010). Complimentary benefit is often expressed within a production possibility frontier which "express the various combinations of output of two commodities…" usually showing the commodities to have complementary, independent, or competitive interactions (Savosnick, 1958). An example of a competitive interaction would be that of a weed and a crop competing for growing space, in which case one or both plants may be disadvantaged due to resource competition. Production possibility frontiers are especially beneficial in examining agroforestry and intercropping scenarios, such as the potential compliments and competitions that may be derived from silvopasture as shown in Figure 5 (Chizmar et al, 2018). A potential benefit of hemp-loblolly intercropping may be expressed through weed and pest suppression. A meta-analysis found a higher abundance of natural enemies for pest control and that both parasitic and non-parasitic weeds were substantially less abundant in agroforestry systems (Pumarino et al, 2015). Perennial intercrops also

benefited from lower pest counts and crop damages whereas there was no significant difference between annual intercrops and annual monocultures (Pumarino et al, 2015). Within a pine-hemp intercropping scenario there are many possibilities for both competitive and complimentary interactions; this study assumes that the reduced weed pressure, enhanced nutrient cycling, and fertilizer inputs instituted by the hemp will convey complimentary benefit for the growth and yield of the pines.

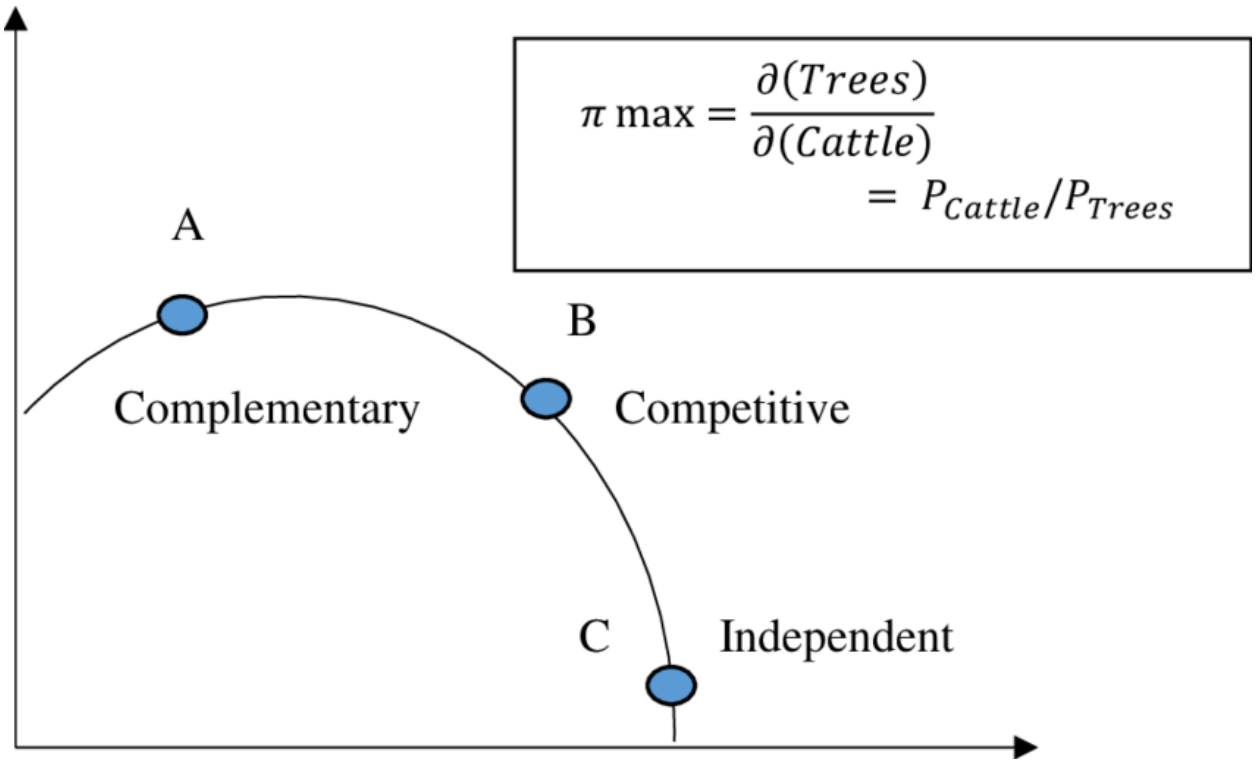

Figure 5. Production Possibilities Frontier of land use combinations of tree and cattle stocking rates (Adapted from Chizmar et al, 2018)

Forestry is a long-term investment, often taking decades before significant financial returns are produced. As such, economic analyses of the forest sector often utilize capital budgeting and discounted cash flows to determine the value of a forest investment. Capital budgeting provides the means to examine the efficacy and profitability of an investment through multiple methods and metrics. A discounted cash flow measures the value of an investment based upon the expected future cash flows it generates utilizing the expected present value of the investment for calculations (Bullard & Straka 2011). These cash flows can be expressed through various means including: net present value, equal annual

equivalent, return on investment, and land expectation value (LEV). All of these calculations provide a different perspective on the value of an investment that takes place over time and as such are frequently implemented in agroforestry economic analyses.

Agroforestry intercropping has been found to possess increased benefits/returns when compared to monocultures of their constituent crops. An analysis of Peruvian silvopastoral systems examining pine, livestock, and silvopasture found that all of the silvopasture operations studied yielded higher returns than any pure crop, livestock, or tree system examined (Chizmar et al, 2020). Oilseed intercrops with loblolly found that intercrop possessed significantly higher LEVs at the end of a 21 year rotation, but were far more sensitive to the discount rate, price, and yield (Akter et al, 2021).

Methods

The economic modeling of this study was accomplished through the use of computer-based modeling, agricultural extension resources, and the cooperation of extension agents and industry professionals from North Carolina. The timber growth and yield modeling was performed through PTAEDA4.0 which provided the means to examine plantations throughout varying configurations, inputs, and parameters. Timber prices were derived from North Carolina State University Extension Forestry's 2021 Third Quarter price report. The hemp modeling was primarily derived from The University of Missouri Extension's Industrial Hemp Budget Generator, which was modified from the findings and testimony from North Carolina State Extension professionals and NC fiber hemp processors.

Loblolly pine plantations were examined in four different scenarios. The first scenario was a 10ft by 8ft spacing for planting; a common planting density implemented throughout the southeastern US. The second scenario was a 20ft by 5ft spacing for planting; a less common density but still implemented for sawtimber production by the Weyerhaeuser corporation. The third scenario express pine-hemp intercropping: a 20ft by 5ft spacing with the complimentary benefit of intercropping along with the costs and benefits of six years of hemp cultivation. The fourth third scenario, intercropped "trees only," is

included to reveal the complimentary benefit conferred to the trees without the costs and returns of the hemp crop. All four stands were modeled with the same factors and treatments, excluding the changes made to accommodate complimentary benefit in the intercropped scenarios, which are now described (Table 2). The trees were modeled in a Coastal Plain region, on a well-drained site, with a site index of 80, and rotation length to 35 years. Site preparation techniques were Chop and Burn with no herbaceous control, no hardwood release, and no fertilization for the BAU scenarios. The intercropped scenario(s) received 2 years of herbaceous control and initial fertilization. Sites were thinned at 120ft^2 BA down to 80ft^2 BA. Timber products were priced as follows: pulpwood at $9.99/ton, Chip n' Saw at $16.71/ton, and sawtimber at $30.85/ton. Operational costs were as follows: $200 for establishment, thinning costs at 5% of thinning revenue, harvest costs at 10% revenue, and annual costs covering property tax and maintenance expenses at $5 per year.

Table 2. PTAEDA4.0 Parameter inputs for Pine Plantation simulations.

Stand Information		**Site Information**		**Economic Parameters**			
Site Index	80	Chop and Burn	Yes	Establishment	$200.00	Timber Prices ($/ton)	
Rotation Length	35 years	Herb Control (BAU)	No	Hardwood Rel	No	Pulp	$9.99
Thin at (BA)	120 ft^2	Herb Control (Inter)	Yes (2y)	Annual Costs	$5.00	Chip n' Saw	$16.71
Thin to(BA)	80 ft^2	Y1 Fertilizer (BAU)	No	Fertilizer	No	Sawtimber	$30.85
Merchandising		Y1 Fertilizer (Inter)	Yes	Thinning %	8		
Add topwood	Yes	Region	Coastal	Pruning	No		
		Drainage Class	Well	Harvest %	10		

Hemp costs, revenues, and yields were derived from recent, publicly available extension resources, primarily those of the University of Missouri Extension and North Carolina State University Extension (Massey, 2021). Both intercrop and monoculture scenarios were evaluated at 40 acres with no rental costs included for the intercrop scenario. Break-even points of cultivated acres are calculated for

both rental and non-rental scenarios. Yields were primarily modeled at 4 tons per acre for monoculture hemp and 2.8 tons per acre for intercropped hemp, corresponding to a 30.9% loss of arable land. Final product prices were primarily estimated at $0.10 per pound (lb), with alternate scenarios of $0.05, $0.10, and $0.15 also being considered. Seed inputs were modeled at 75 lbs of seed per acre costing $3.50 per pound of seed. Nitrogen, phosphorus, and potassium fertilizers were modeled at 50 lbs/acre, 50 lbs/acre, and 40 lbs/acre respectively, costing $0.70, $0.65, and $0.58 per pound. THC testing is modeled at two tests per field for $150 each. Machinery and rental rates for the hemp operations are as follows: tractor at $800 per day (used 4 times per year), grain drill, sicklebar mower, rake, and baler for $400 a day each (used once per year). Rental inputs are only calculated for the "break even" analysis and the hemp sensitivity analysis.

We used capital budgeting analysis to determine the efficacy of the scenarios comparative to one another. Specifically, we examined the scenarios through Net Present Value, Equal Annual Equivalent, Return on Investment, and Land Expectation Value.

Net Present Value (NPV) examines the current (year 0) value of an investment's returns against the current value of its costs. This allows for the examination of costs and returns over a long investment period, such as that of a timber rotation. In this example both the costs and returns of establishment, thinning, and harvests are all brought to the present through a known discount rate. Assessing investments through NPV provides a means to equalized investments with varying lengths and return increments. The formula for Net Present Value is as follows :

$$NPV = [Present\ Value\ of\ all\ revenues] - [Present\ Value\ of\ all\ costs]$$

Equal Annual Equivalent (EAE), Equal Annual Annuity (EAA) or Equivalent Annual Income (EAI) presents returns on investment as though they were an annual cash flow. This method is valuable in comparing investments of various lengths, or those of extended lengths, as it equalizes the returns as an

annual payment. More simply, this method presents a landowner's earning on a per acre per year basis. The formula for Equal Annual Equivalent is as follows, where i=discount rate and n=time:

$$EAE = NPV\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

Return on Investment (ROI) is a profitability metric that attempts to assess the efficiency of an investment. This metric measures the amount of return of an investment relative to the cost of the investment. ROI provides a simple means by which investments can be compared and investment decisions can be made. The higher the ROI percentage, the greater returns are gained relative to the costs. Return on investment is calculated by determining the discount rate at which NPV = 0 (Bullard and Starka 2011).

Land Expectation Value (LEV) or Soil Expectation Value is a discounted cash flow analysis technique used frequently to evaluate timberland investment. This analysis method displays the NPV of all future returns and costs in perpetuity for an area of forested land. This perpetual value gives insight into the value of bare land were it to remain in use for timber investment forever. As such, this method of analysis is an important economic marker when considering forested lands used in timber production. The formula for Land Expectation Value is as follows:

$$LEV = \frac{NFV}{(1+i)t - 1}$$

Additionally, we utilized the sensitivity analysis included in the Hemp budget sheet to assess how the profitability of a hemp operation may alter in regard to variability in yield and product sale price at a discount rate of 6%. A sensitivity analysis examines how data changes in regard to uncertainty. In economic analyses uncertainty is often present in the forms of sale price and discount rate; in agricultural assessments yield is also considered. As these values fluctuate the revenue of an investment will change as well, potentially losing its profitability. As such, a sensitivity analysis will evaluate changes in revenue as variables, such as yield and market price, fluctuate.

Lastly, we examined the "Break-Even" point for hemp acreage to determine how much land needs to be planted and harvested in order to have a net positive return for both monoculture and intercropped settings. The break-even-point, as implemented here, described the minimum acreage required to earn a NPV ≥$0. In the scenarios given in Tables 4 and 5, the minimum acreage required to return a NPV ≥$0 is portrayed under varying discount rates and sale prices: 4%, 6%, and 8% for the discount rate and $100/ton, $200/ton, and $300/ton for the sale prices. The monoculture scenario is portrayed with a yield of 4 tons/acre and the intercrop scenario with 2.8 tons/acre. The "Full Rental" cost is $4,800 per rotation, which is divided amongst the acreage for this analysis. The No-Rental scenario does not factor in any machinery costs.

Results

Net Present Value (NPV)

Timber investments occur over several decades and require several intermittent treatments throughout a single rotation. This long investment duration can complicate financial comparison, especially when considering scenarios like hemp-pine intercropping, which incurs greater costs and returns early on within the rotations. As such, all four timber scenarios have been plotted in Figure 6 to compare the NPV of each scenario. Figure 6 reveals that at all discount rates the intercropped scenario posses the greatest NPV of all the modeled scenarios. At a 4% discount rate the intercrop scenario has an NPV of $911.42 per acre, $139.29 higher than the $772.13 NPV of the 10x8 BAU and $168.41 higher than the $743.01 NPV of the 20x5 BAU scenario. $106.09 of this additional benefit (at 4%) is derived from the complimentary benefit of intercropping conferred onto the pines, as shown by comparing the Intercrop, Trees Only scenario- which possesses a total NPV of $849.10- to the 20x5 BAU scenario. The lowest NPV at every discount rate was found in the 20x5 BAU scenario.

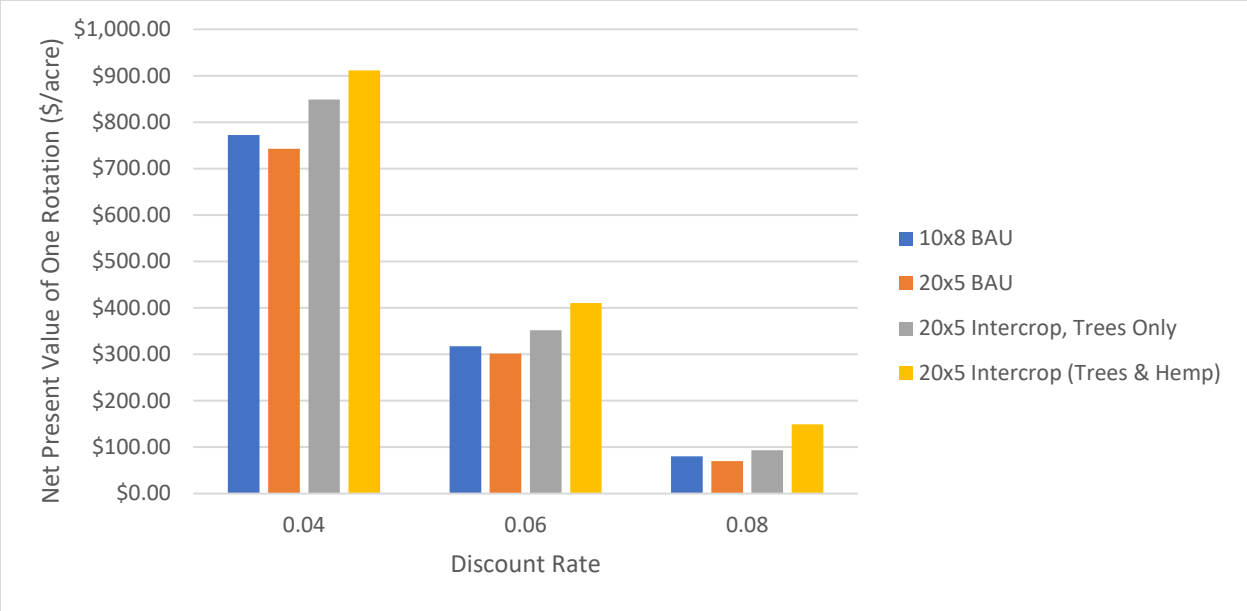

Figure 6. Net Present Value of One Rotation: Timber and Intercrop Scenarios

Equal Annual Equivalent (EAE)

EAE expresses investment returns as annual payments, as opposed to the more sporadic schedule of returns and costs found throughout a timber investment. At every discount rate the intercropped scenario was found to return the highest EAE being valued at $48.83, $28.30, and $12.78 at the discount rates of 4%, 6%, and 8% respectively as reveled in Figure 7. The BAU scenarios were more similar in terms of EAE, but the 20x5 BAU scenario was slightly lower at all discount rates than the 10x8 BAU.

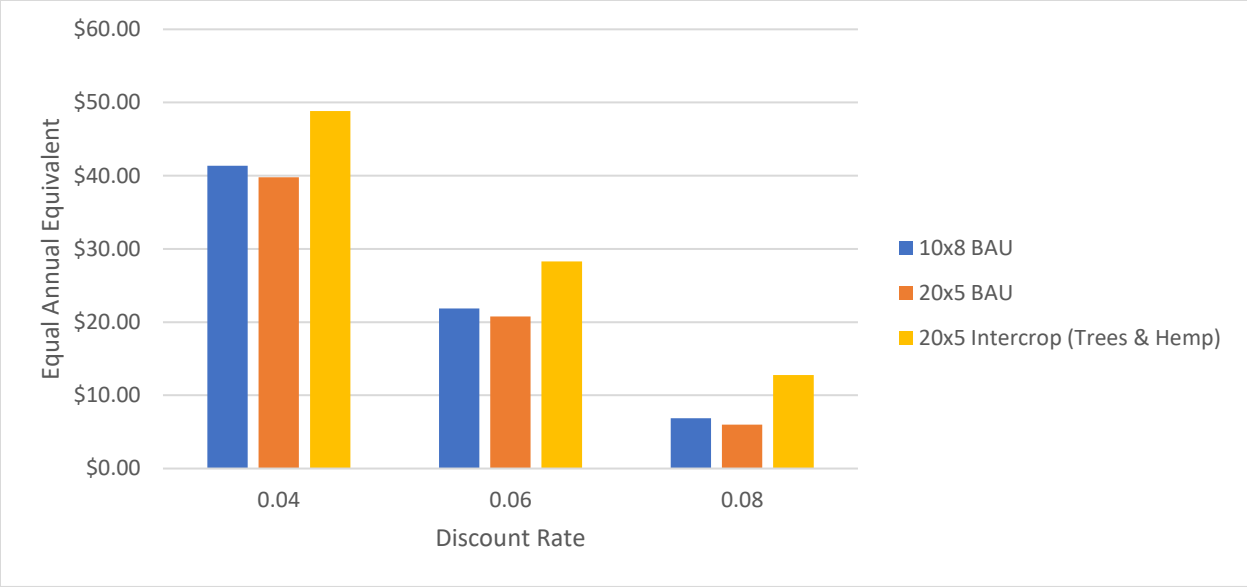

Figure 7. Equal Annual Equivalent: Pine Plantations, Intercrop, and Hemp Monoculture

Return on Investment (ROI)

The 10x8 BAU, 20x5 BAU, and 20x5 intercrop scenarios returned ROI's of 9.10%, 8.9%, and 10.4% respectively. The intercropped scenario evidently yields the highest ROI, making more efficient returns than either of the BAU scenarios.

Land Expectation Value (LEV)

The results of our LEV analysis can be found in Figure 8. The intercropped scenario returned a substantially higher LEV than either of the BAU scenarios. With a LEV of $1,220.78 per acre at a 4% discount rate, the intercropped scenario surpasses the LEV's of the 10x8 BAU ($772.12) and the 20x5 BAU ($995.21). The 20x8 and 20x5 BAU scenarios were once again similar, though the 20x5 scenario possesed the lowest LEV at all discount rates.

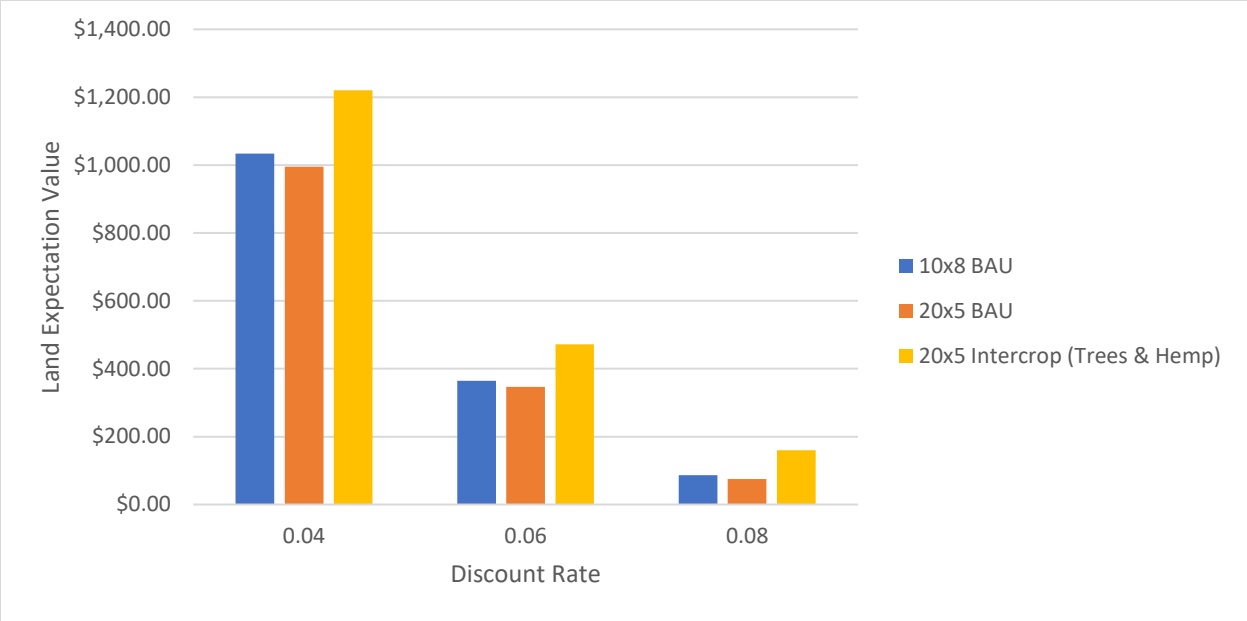

Figure 8. Land Expectation Value: Pine Plantations and Intercrop

Hemp Sensitivity Analysis

Figures 9 and 10 portray a slightly modified sensitivity analysis included within the University of Missouri Extension's "Industrial Hemp for Fiber Budget Sheet." This sensitivity analysis is conducted with a discount rate of 6%. Industrial hemp for fiber sells for between $0.07 and $0.10 per pound for retted, baled stalks in North Carolina; this is expressed as $140 and $200 per ton respectively. Current per acre yields of hemp in North Carolina tend to fall between 2 and 5 tons. In this intercropping scenario about ~30% of the land area is dedicated to pines, with the remaining ~70% open for hemp cultivation. As such. 70% of 4- and 5-ton yields are 2.8 and 3.5 tons respectively, which models a scenario in which the pines and hemp grow independently of one another. The sensitivity analysis reveals that at prices as low as $140/ton a yield of 5 tons/acre would be necessary to turn a profit of $122.48/acre, whereas a yield of 4 tons/acre at this price would result in a net loss. At $200/ton all scenarios would result in a positive return except for a yield of 2.8 tons/acre. This sensitivity analysis reports that should prices remain stable intercropped scenarios will remain viable at all but the lowest yields.

Hemp Sensitivity Analysis: No-Rent Net Present Value

Market Price ($/ton) \ Yield (tons/acre)	2.8	3.5	4	5	6
$100.00	($297.52)	($227.52)	($177.52)	($77.52)	$22.48
$140.00	($185.52)	($87.52)	($17.52)	$122.48	$262.48
$200.00	($17.52)	$122.48	$222.48	$422.48	$622.48
$250.00	$122.48	$297.48	$422.48	$672.48	$922.48
$300.00	$262.48	$472.48	$622.48	$922.48	$1,222.48

Figure 9. Hemp Sensitivity Analysis No-Rent NPV per acre

We also performed the sensitivity analysis with the added cost of machinery rentals, as shown in Figure 10. As expressed earlier, machinery rentals are estimate to cost $4,800 per year. This analysis reveled that price/ton combinations for net losses remained the same, excluding $100/ton at 6 tons/acre now resulting in a net loss. Instead of requiring greater yields or higher prices to return a profit, machinery rental instead lowers the profitability, or increases the losses, of all scenarios expressed in the analysis. As such, hemp operations can still prove profitable even with the added cost of machinery rental.

Hemp-Rental Sensitivity Analysis: Equipment Rent - Net Present Value

Market Price ($/ton) \ Yield (tons/acre)	2.8	3.5	4	5	6
$100.00	($388.20)	($318.20)	($268.20)	($168.20)	($68.20)
$140.00	($276.20)	($178.20)	($108.20)	$31.80	$171.80
$200.00	($108.20)	$31.80	$131.80	$331.80	$531.80
$250.00	$31.80	$206.80	$331.80	$581.80	$831.80
$300.00	$171.80	$381.80	$531.80	$831.80	$1,131.80

Figure 10. Hemp Sensitivity Analysis Equipment Rent - NPV per acre

Break Even Point for Acreage

All hemp monoculture scenarios are feasible at prices of $200 and $300/ton if the grower has access to enough acreage for planting. Without rental costs, the grower would need 21 acres at 4% and 22 acres at 6% and 8% to break even at a sale price of $200/ton. At a sale price of $300/ton a grower would need at least 8 acres of land to break even at 4% and 6% and 9 acres at 8%. With full rental costs a grower

would then need 40, 41, or 42 acres at a sale price of $200/ton and a discount rate of 4%, 6%, and 8% respectively. At a sale price of $300/ton a grower would need at least 16 acres of growing space in order to break even at any discount rate.

Table 3. Break Even Acreage Point for Hemp Monoculture: Full Rental and No-Rental

Hemp-Monoculture Break Even Acreage (Yield=4tons)					
No Rental					
Break Even (4%)		Break Even (6%)		Break Even (6%)	
Price/ton	Acres	Price/ton	Acres	Price/ton	Acres
$100	NA	$100	NA	$100	NA
$200	21	$200	22	$200	22
$300	8	$300	8	$300	9
Full Rental					
Break Even (4%)		Break Even (6%)		Break Even (6%)	
Price/ton	Acres	Price/ton	Acres	Price/ton	Acres
$100	NA	$100	NA	$100	NA
$200	40	$200	41	$200	42
$300	16	$300	16	$300	16

Due to a potential decrease in yield, intercropped scenarios do not appear feasible at prices of $100 or $200/ton. At $300/ton with no rental costs a grower would require 18 acres at discount rates of 4% or 6% or 19 acres to break even at a discount rate of 8%. With full rental costs at a sale price of $300/ton a grower would require 35 acres at a discount rate of or 36 acres to break even at discount rates of 6% and 8%. All scenarios are consistent in that a sale price of $100/ton is never a feasible price under which to grow hemp given a yield of 2.8 tons per acre.

Table 4. Break Even Acreage Point for Hemp Intercrop: Full Rental and No-Rental

Hemp-Intercrop Break Even Acreage (Yield=2.8tons)					
No Rental					
Break Even (4%)		Break Even (6%)		Break Even (6%)	
Price/ton	Acres	Price/ton	Acres	Price/ton	Acres
$100	NA	$100	NA	$100	NA
$200	NA	$200	NA	$200	NA
$300	18	$300	19	$300	19
Full Rental					
Break Even (4%)		Break Even (6%)		Break Even (6%)	
Price/ton	Acres	Price/ton	Acres	Price/ton	Acres
$100	NA	$100	NA	$100	NA
$200	NA	$200	NA	$200	NA
$300	35	$300	36	$300	36

Discussion

From our economic analysis it appears that intercropping industrial hemp within loblolly pine plantations could provide substantial benefit over standard pine plantation management. The early income generated from hemp cultivation not only increases the long term efficacy of the investment, but also aids in offsetting the initial timber investment costs with early-rotation income from hemp sales. However, changes to market prices or input costs, such as fertilizer prices, can impact hemp returns. Current fertilizer prices have, in some cases, more than tripled since the beginning of this study in 2020 reducing the revenue generated from growing hemp (Washburn, 2022).

Furthermore, it is unknown how hemp and loblolly pine will interact in an intercropped scenario. Previous studies examining switchgrass-loblolly intercropping have found that in the first three years there was no change in gross primary productivity of either loblolly or switchgrass and that there was no significant difference in switchgrass biomass when compared to monoculture stands (Albaugh et al, 2012, 2014). A Brazilian study intercropping loblolly and maize found that all of their intercropped scenarios

provided additional benefit in comparison to monoculture loblolly (Oliveira, 1998). These studies would indicate, at the very least, an independent interaction between loblolly and other intercropped species where the growth of both crops is unaffected by the presence of the other. For this study we assumed complimentary benefit for the pines, but did not make any assumptions on how the hemp will be affected via intercropping.

It is possible that complementary benefit for the hemp may be derived from this intercropping scenario. Previous studies have found various means by which agroforestry intercrops have conferred increased benefits from the interactions off the two crops. An analysis of a tropical agroforestry system found that the intercropping of *Dalbergia sissoo* (a N_2-fixing tree), wheat, and *Vigna sinesis* (cowpea: a N_2-fixing crop) improved soil organic matter, increased available soil nutrients, and enhanced soil microbial activity (Chander et al, 1998). Future field trials of loblolly-hemp intercrops will need to observe and identify the interactions between hemp and loblolly to ascertain any complimentary or competitive interactions between the two crops. Additionally, a future study should examine the benefit of winter legume cover cropping to offset nitrogen fertilizer inputs and enhance crop yields- an agronomic practice shown to provide these benefits to corn (Torbet et al, 1996). Leguminous cover cropping has been found to "improve nitrogen cycling and soil health while reducing the need for synthetic nitrogenous fertilizers" in agroforestry systems- a benefit that could aid substantially in combatting climbing fertilizer prices (Shults, 2017)

Lastly, this study only examined one potential avenue of additional benefit from agroforestry practices in the rotation. We theorized that hemp could be grown for 6 years before shading from canopy closure would begin to negatively impact hemp growth after which the stand would continue to be managed as a pine monoculture. However, pine stands aged 7 years or older with a 20x5ft spacing can often be managed as a silvopastoral system. Silvopasture, the inclusion of livestock within a forested system, was found to "produce higher returns than any current conventional land use system in North Carolina at 4, 8, and 12 percent discount rates" (Chizmar et al, 2018). These increased returns could be attributed to the enhanced productivity of both systems through complimentary benefit (Chizmar et al,

2018). There is potential for landowners to introduce silvopasture systems into their forested lands (themselves or through leases) after hemp intercropping is no longer feasible and receive further benefit from agroforestry practices throughout the pine rotation.

Conclusion

Loblolly pine and industrial hemp intercropping has been shown to provide greater benefit over standard, business as usual timber practices throughout our modeled scenarios. Pine-hemp intercropping was found to posses higher NPV, EAE, ROI, and LEV at discount rates of 4%, 6% and 8% when compared to 10x8 ft and 20x5 ft spacing, BAU pine plantation management.

The success of an intercropping investment will be determined by the volume of hemp fiber produced. Should a competitive interaction between hemp and pines be found, it is possible that the resultant reductions in yield could render the investment infeasible. However, previous studies examining agroforestry intercropping have found various means by which complimentary benefit is conferred through intercropping, and several loblolly intercropping studies have evidenced independent interactions between loblolly and intercropped plants. As research and knowledge surrounding hemp cultivation expands it is ever more likely that hemp yields may be increased through improved management techniques, such as crop rotations, or even the introduction of hemp varieties suited for Southeastern climates. While further research is required to understand the field interactions of pine and hemp intercropping, it appears likely that this agroforestry technique could produce greater economic returns than our standard pine plantation management techniques.

Chapter 3. Hemp Growers in the Southeastern United States: Perceptions and Operations

Introduction

Hemp was first introduced to the US by Spanish colonists and remained an important crop up to and through the developing of the United States as a nation (Fike, 2016). However, by the 20th century hemp's importance had begun to dwindle due to competition from cheaper, imported textiles and the crop was eventually phased out of domestic production, excluding a brief resurgence when international trade was interrupted during WWII (Williams, 2020). Popular interest in the crop began to increase both in domestic and international markets in the 21st century. Through the 2018 Farm Bill production of hemp has been legalized and removed from the Drug Enforcement Agency's schedule of controlled substances (2018 Farm Bill).

Prior to the passing of the 2018 Farm Bill popular support for hemp cultivation was growing and farmers began to take interest in this new specialty crop. A survey was conducted in the spring of 2018 to assess knowledge and interest of hemp among North Carolina organic growers (Dingha et al, 2019). This study reported that out of 35 respondents 85% expressed some degree of interest in growing hemp on their farms and 65% desired to be one of the first farmers to grow hemp within North Carolina (Dingha et al, 2019). The passing of the 2018 Farm Bill has enabled North Carolina to become one of the largest hemp producers in the nation with 1,850 acres of the crop harvested in 2021 alone (USDA 2021). While this specialty crop is just beginning to establish itself in American domestic markets, it is clear that hemp will continue to be grown and planted throughout the nation.

Methods

In December of 2020 a 12-question survey was sent to hemp growers, processors, and other stakeholders throughout the Southeastern United States. The complete questionnaire form used in this survey is appended in Appendix 1. There were 152 respondents to the survey spread across five states: Kentucky, North Carolina, Tennessee, Virginia, and West Virginia.

Results

Operation Size

Survey recipients were asked to select the categories that best represented the size of their operation: +15 acres, 1-15 acres, less than 1-acre, high tunnel/greenhouse, or other. Just over half of the respondents had an operation size between 1 and 15 acres. The second largest group were those growing on less than one acre, comprising 32% of respondents. Just under 10% of growers had an operation size over 15 acres, 5% grew within greenhouses or high tunnels, and 2% selected other for various reasons (Figure 11).

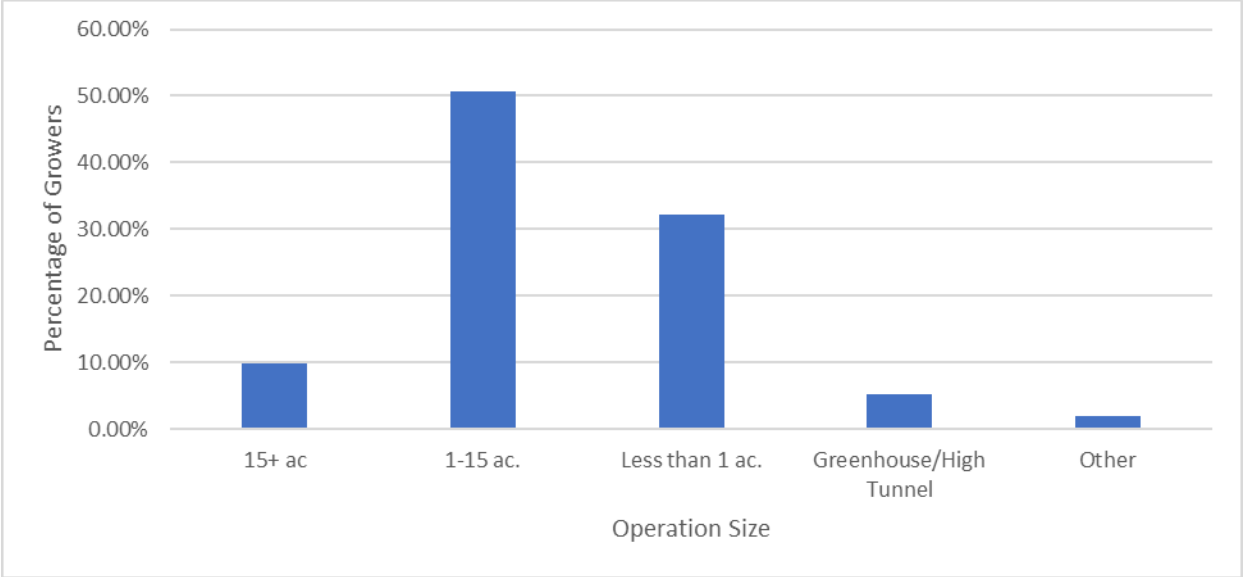

Figure 11. Operation Size by Percentage of Growers

Perceived Issues in Growing Hemp

Respondents were asked to describe what their largest issue was with growing hemp. A variety of answers were submitted and sorted into overarching categories (Figure 12). The issue most frequently expressed was problems involving hemp markets and marketing their own products, as 34% of respondents claimed they had struggled with. The second most frequent issue was from various pests and resultant damages, of which 23% of respondents reported to have had issues with. After these two most prominent issues, the issues described become less mutual. For example, about 6% of respondents

expressed issues in the THC content of their plants and about 5% stated that combating disease were one of their largest issues.

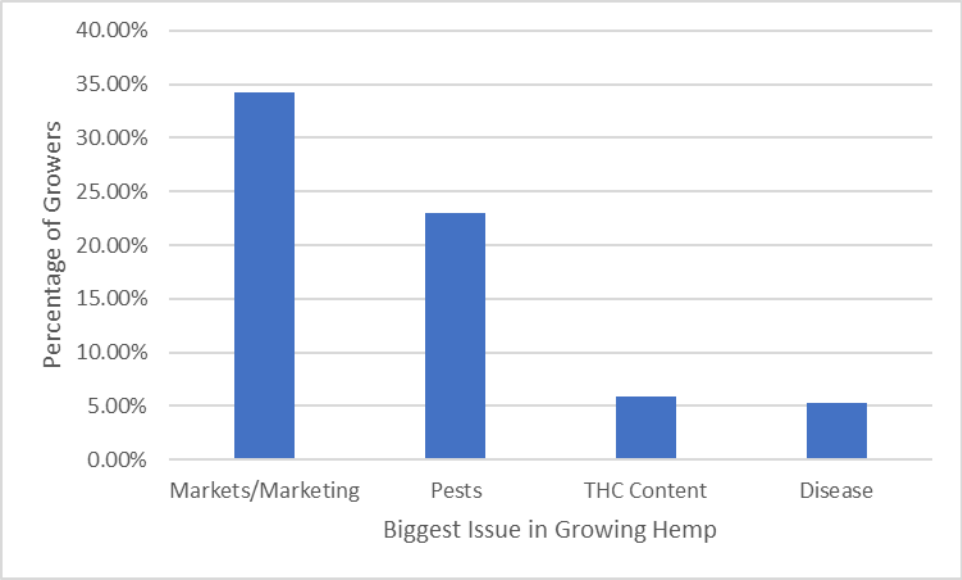

Figure 12. Issues in Growing Hemp by Percentage of Growers

Hemp Product

Respondents were asked about the product they were growing industrial hemp for. The survey listed product options which included CBD oil, biomass/flower, fiber/stalk, grain/seed, and other. Most respondents, 67%, were growing hemp for the production of CBD Oil while 23% of growers were cultivating hemp for biomass/flower production (Figure 13). Lastly, 9% of growers grew hemp for some other purposes, 2% grew hemp for fiber/stalk, and 1% grew hemp for grain/seed production.

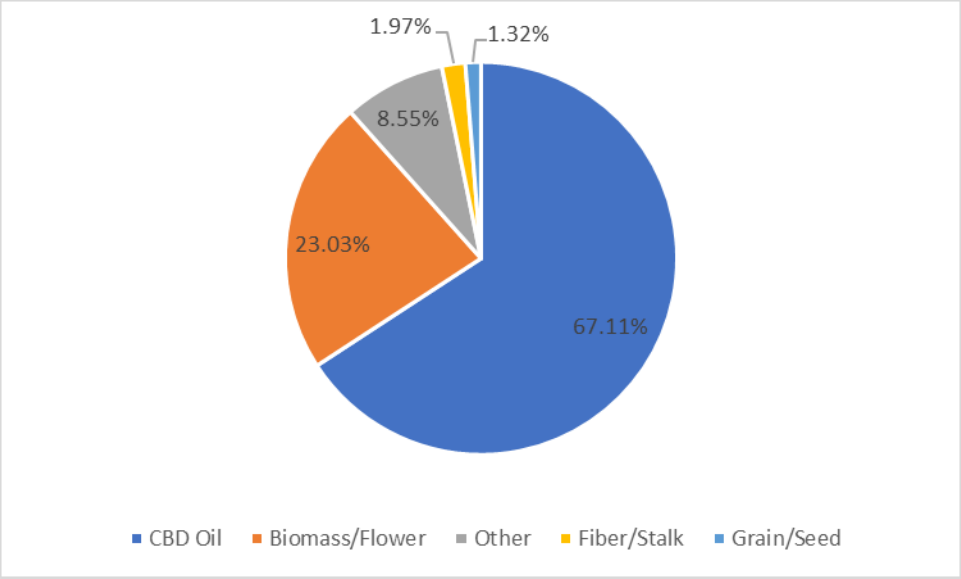

Figure 13. Hemp Products Grown for by Percentage of Growers

Success of Operation and Intent to Grow Again

Survey respondents were also asked to rate the success of their operation and to state their intent to grow hemp again in the future. Operational success was gauged through positives of very good and good, negatives of very poor and poor, and a neutral option; these metrics were condensed into good, neutral, and poor. Intent to grow again was assessed through the options of definitely yes, probably yes, might or might not, probably not, and definitely not; these options were consolidated into yes, maybe, and no (Figure 14). Regardless of operational success, 68% of growers intended to grow hemp into the future while 19% and 13% were unsure or did not intend to grow hemp again, respectively. From each of the respective operational success metrics: good, poor, and neutral, most growers from each category intended to plant hemp again. More growers (19.1%) were unsure if they would grow hemp again than growers intending not to grow hemp again (12.5%).

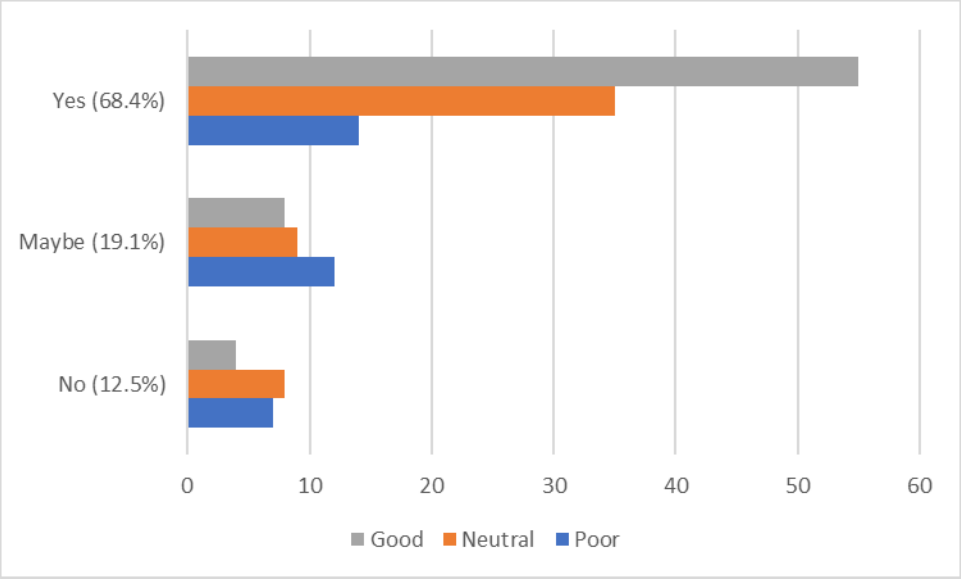

Figure 14. Success of Operation and Intent to Grow Hemp Again by Percentage of Growers

Conclusion

The data collected from this survey provides valuable insight into hemp growing operations throughout the Southeast and the perspectives of these growers. Most growers appear to have grown hemp on a smaller scale, between 1 and 15 acres. CBD oil was the most common product hemp was grown for constituting the majority of grown product by the respondents. A large portion of the growers encountered issues in the marketing and sale of their product, often citing a lack of networks and connections to buyers. Most growers, whether their operation was successful or not, intended to plant hemp again at some point in the future. As an emerging product since its legalization by the 2018 Farm Bill- resources, knowledge, and tools relevant to the production and growing of industrial hemp are still developing. There is a strong interest and passion in growing hemp, shared amongst landowners of various holding sizes and product opportunities. As the markets and knowledge bases develop for industrial hemp, there remains interest and opportunity amongst a diverse range of growers to cultivate this novel crop.

Chapter 4. Conclusion/Future Studies

Project goals

The goal of this study was to assess the financial feasibility of growing industrial hemp (*Cannabis sativa L*) as a secondary crop within loblolly pine (*Pinus taeda*) plantations. This was accomplished by comparing three pine plantation scenarios: 10ft by 8ft BAU (business-as-usual), 20ft by 5ft BAU, and 20ft by 5ft hemp intercrop scenario. These scenarios were examined through various discounted cash flow analyses and discount rates. Additionally, this study examined results from a hemp grower survey distributed to hemp practitioners in December of 2020 that provided insight in the operations and perspectives of these growers.

Having been federally reclassified and legalized by the 2018 Farm Bill, research opportunities for hemp have been greatly expanded but knowledge of the plant is still limited. The main method of analysis used in this study was that of comparing business as usual pine plantation scenarios to an intercropped scenario that conferred complimentary benefit to the pines but also entailed reduced yields for hemp due to reduction of arable land when intercropped with the pines. The results of this study indicate that hemp intercropping can provide greater economic benefit than BAU pine plantation management. Through this study we are able to conclude the overarching question of: 'Is it economically feasible to intercrop industrial hemp for fiber within loblolly pine plantations?"

Takeaway and contributions

Industrial hemp yields from intercropped plantations will differ from that of monoculture hemp production due to both the reduction in per acre planting area and the interactions inherent in an intercropped setting. About 30% of the growing space will be occupied by the pines, should a buffer of six feet in length be maintained around the planted pine rows. At minimum this constitutes as 30% decrease in hemp yields exempting any other interaction, complimentary or competitive. However, it is possible that the benefits of intercropping may enhance fiber production in hemp. It is also possible, however that there may be competitive interactions between the two crops. The success of intercropping will depend upon the influence this system expresses on hemp fiber yields.

This study proves an effective precursor to further understanding the economic nature of industrial hemp-loblolly pine intercropping. We identified key characteristics influencing the economic feasibility of intercropped hemp and how intercropped stands compare to standard pine plantation management. As research continues with field trials and other analyses this study will provide valuable insight into the limitations and risks that need to be addressed in order for hemp intercropping to succeed as an economically viable agroforestry investment.

Management implication

While it has been proven that industrial hemp can be grown in pine influenced soils it is not yet clear how hemp yields would be influenced in the field. Our results show that should there be no further complimentary or competitive interactions between the hemp and pine, outside of the complimentary benefit assumed for the pines, the intercropping of hemp in pine plantations is a viable economic strategy providing greater benefit than standard pine plantation management.

The data from this analysis will prove useful for the intended, subsequent field study for intercropping industrial hemp. Such a field study will need to examine how hemp yields are affected by the intercropped environments and identify any complementary or competitive interactions between the two crops.

Project limitations and future work

This study examines hemp growth and yields in an intercropped pine plantation through a theoretical lens, as no field study for any form of hemp intercropping has been published as of this thesis. Due to its past, criminalized history there is very little knowledge or resources available for those who would grow or research hemp. Similarly, the novelty of this product has resulted in newly developing markets, which have crashed and fluctuated since their establishment. Recent, national increases in fertilizer prices have also drastically affected the costs associated with growing hemp and many other crops. Additionally, genetic cultivars of hemp are limited, capping the potential of hemp to grow in warmer climates like the US Southeast or, potentially, to grow and thrive in intercropped environments. The uncertainty expressed through these knowledge gaps and the recent market fluctuations surrounding

hemp cultivation have posed an issue in examining hemp returns at this point in time. Additionally, PTAEDA4.0 is a markedly conservative model that possess certain limitations, especially in regard to portraying agroforestry management. For example, beginning of rotation herbaceous control can only be expressed up to year two, whereas herbaceous control would be expressed throughout the six years of hemp cultivation. These simulations also return conservative estimates of 20x5ft growth and yield, with average tree diameters being considerably lower in the model than what could be expected from an actual 20x5 ft stand under similar site conditions.

Most importantly, future field studies need to examine how intercropping affects hemp fiber yields. Second, future studies should attempt to discern the causes for competitive or complementary effects that would affect fiber yields. As knowledge gaps fill and hemp cements itself in the American market there will be greater opportunity to examine the possibility of intercropping industrial hemp and loblolly pine.

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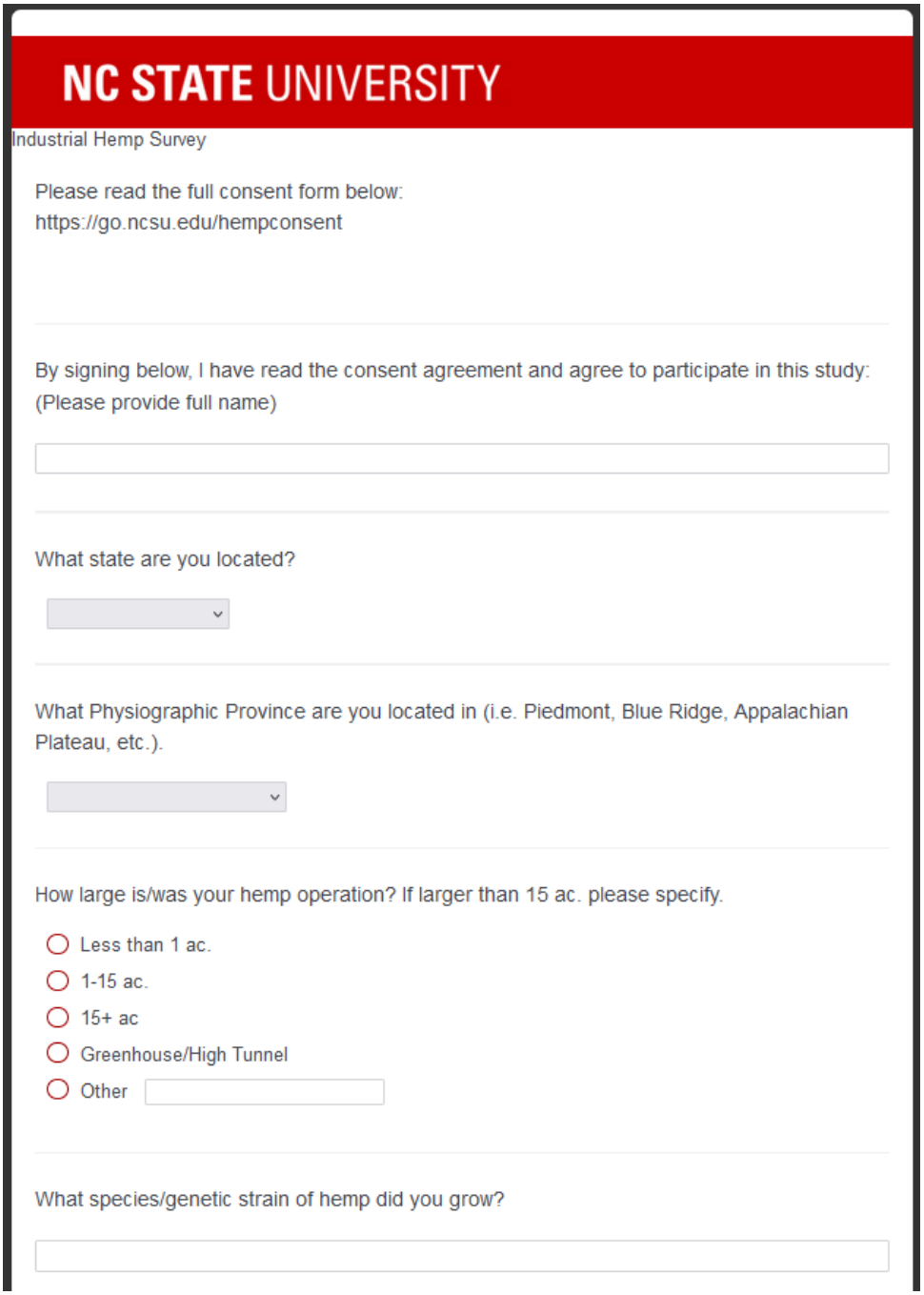
APPENDIX

Appendix 1. Hemp Grower Survey (Burris, 2020)



NC STATE UNIVERSITY

Industrial Hemp Survey

Please read the full consent form below:
https://go.ncsu.edu/hempconsent

By signing below, I have read the consent agreement and agree to participate in this study: (Please provide full name)

What state are you located?

What Physiographic Province are you located in (i.e. Piedmont, Blue Ridge, Appalachian Plateau, etc.).

How large is/was your hemp operation? If larger than 15 ac. please specify.

- Less than 1 ac.
- 1-15 ac.
- 15+ ac
- Greenhouse/High Tunnel
- Other

What species/genetic strain of hemp did you grow?

What did you grow hemp for? (select all that apply)

- [ ] CBD Oil
- [ ] Fiber/Stalk
- [ ] Biomass/Flower
- [ ] Grain/Seed
- [ ] Other

Have you had your soils tested?

- ○ Yes
- ○ No

If the previous was 'yes' would you be willing to share the results? If so please type your email below.

Rate the success of your operation.

	1	2	3	4	5
1=worst 5=best	○	○	○	○	○

What is your biggest issue with growing hemp?

What is the best thing about growing hemp?

Are you planning on growing hemp again?

- ◯ Definitely yes
- ◯ Probably yes
- ◯ Might or might not
- ◯ Probably not
- ◯ Definitely not

Do you have any questions?

If there is any other information that you would be willing to share with me please contact me at:
jcburris@ncsu.edu

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