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Forage species selection for transitional organic production in the Southeastern United States

Jonathan Kubesch
jkubesch@vols.utk.edu

To the Graduate Council:

I am submitting herewith a thesis written by Jonathan Kubesch entitled "Forage species selection for transitional organic production in the Southeastern United States." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant Sciences.

Renata L.G. Nave, Major Professor

We have read this thesis and recommend its acceptance:

Song Cui, Gary E. Bates, David M. Butler, Vince R. Pantalone

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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DEDICATION

To my grandparents, Joey and Sid Kubesch

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ABSTRACT

Despite the vast production markets for forage and organic products nationally, so far limited work has been done to develop organic forages specifically for Middle Tennessee or the mid-South in general. The present organic research field focuses on vegetable and grain production; however, forage production offers an easier transition for producers moving into certified organic agriculture. The present study seeks to evaluate several forage blends for optimizing forage production under low-input transitional organic conditions. Ideally a forage system could be tailored to the beef cattle operations of Middle Tennessee, the dominant forage consumption market in this region of the mid-South. I hypothesize that organic forage production offers a sustainable pathway for beef cattlemen. This study is being conducted at the Middle Tennessee AgResearch and Education Center, in Spring Hill, TN. The forage selections consisted of the following: a tall fescue (*Schedonorus arundinaceus*) monoculture, a bermudagrass (*Cynodon dactlyon*) monoculture, a tall fescue and alfalfa mixture (*Medicago sativa*), a bermudagrass and alfalfa mixture, and an annual rotation (winter wheat [*Triticum aestivum*] and winter pea [*Pisum sativum*] mixture rotated with a sorghum-sudangrass [*Sorghum bicolor x Sorghum sudanese*] and cowpea [*Vigna unguiculata*] mixture). Plots were established during the 2017-2018 growing season following a fallow orchard. Regular production measurements began in the 2019 calendar year when the plots achieved full organic certification status. On the basis of both agronomy and economics, the annual rotation is the optimal species selection for transitioning producers, though the tall fescue and tall fescue-alfalfa selections require reduced labor inputs and would better serve soil conservation outcomes, pursuant to the organic production paradigm.

TABLE OF CONTENTS

INTRODUCTION 1

CHAPTER 1 20

Abstract……..21

Introduction…....22

Materials and Methods…...…24

Results and Discussion……..33

Conclusions……54

Chapter 1 Tables and Figures……56

Appendix 1…….69

CHAPTER 2 71

Abstract……..72

Introduction……73

Materials and Methods……...……75

Results and Discussion……..80

Conclusions…....90

Chapter 2 Tables and Figures…....91

REFERENCES 95

VITA 126

LIST OF TABLES

Table 1.1: Average forage grass proportion of five species combinations during two consecutive years under a low-input organic forage system in Tennessee……..………..58

Table 1.2: Average forage legume proportion of five species combinations during two consecutive years under a low-input organic forage system in Tennessee……................59

Table 1.3: Average weed proportion of five species combinations during two consecutive years under a low-input organic forage system in Tennessee ……………………….......60

Table 1.4: Botanical composition on a pooled annual sum of biomass basis of of five species combinations during 2020 under a low-input organic forage system in Tennessee..61

Table 1.5: Correlations (P = 0.05) between forage grass and legume components with respective grass, legume, and broadleaf weed components under low-input organic forage systems in Tennessee………………..………….......62

Table 1.6: Weed richness level associations of grass, legume, and broadleaf forb functional groups with five species combinations and years by Fisher's exact test under low-input organic forage systems in Tennessee…………………...……..………….......63

Table 1.7: Total forage mass (FM) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee………..……...64

Table 1.8: Average monthly forage mass (FM) of five different species combinations during two consecutive years under a low-input organic forage system in Tennessee……………………………………………………………………………..….65

Table 1.9: Crude protein (CP) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee………..….......66

Table 1.10: Amylase neutral detergent fiber (a-NDF) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee..……........67

Table 1.11: In-vitro dry matter digestibility (IVDMD48) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee...………………………………………………………………………........68

Table 2.1: Establishment budgets for 5 species selections under low-input organic forage system in Tennessee on an acre basis……………………………………………………92

Table 2.2: Production budgets for 5 species selections under low-input organic forage system in Tennessee on an acre basis.………………………….…...……………….......93

Table 2.3: Cost per kg forage and cost per kg crude protein (CP) of 5 species selections under low-input organic forage systems in Tennessee……………………..……........94

LIST OF FIGURES

Figure 1.1: Air Temperature (°C) for Middle Tennessee AgResearch and Education Center, Spring Hill, TN, 2018-2020 including 30-year average………………..…………..56

Figure 1.2: Precipitation (mm) for Middle Tennessee AgResearch and Education Center, Spring Hill, TN, 2018-2020 including 30-year average…………………………...……..57

ABBREVIATIONS AND SYMBOLS

aNDF	amylase neutral detergent fiber, g NDF kg^{-1} DM
C_3	cool-season grasses, legumes, and broadleaf forbs
C_4	warm-season grasses, legumes, and broadleaf forbs
CP	crude protein, g CP kg^{-1} DM
DM	dry matter, kg ha^{-1}
FM	forage mass, kg ha^{-1} DM
NIRS	near-infrared spectroscopy
MTREC	Middle Tennessee AgResearch and Education Center- Spring Hill
IVDMD48	In-vitro dry matter digestibility after 48 hour incubation period

INTRODUCTION

Organic Agriculture General History

The modern organic movement emerged in the 1940s from the Anglosphere. Sir Albert Howard and Lord Northbourne of the British Empire expanded on nutrient cycling practices in South Asia to develop a systems approach to agriculture (Heckman, 2006). Howard and Northbourne viewed agriculture from the soil perspective rather than the cropping perspective. The Law of Return focused on cycling nutrients within the soil-crop-human loop in order to maintain a closed system (Heckman, 2006).

Together, they drew up a vision of sustainable agriculture, which centered on a comprehensive agricultural system. The majority of organic practitioners focused on the traditional integrated farms of cattle, corn, and orchards (Heckman, 2006; Cronon, 2003). Louis Bromfield developed Malabar Farm in Ohio as a demonstration of organic practices. American progenitors of organic agriculture hailed from the Midwestern and Northeastern United States, though southern agrarians adopted and carried the practices into the mid-South forward to the 1970s (Berry, 1981). Southern agrarian thought started with the preservation of traditional smallholder lifestyles, but grew to encompass the environmental and economic consequences of intensive production agriculture (Berry, 1981). Geography and climate limited the farm consolidation possible in the southeastern United States. In the Midwest, population move to urban areas allowed remaining operators to capitalize on the economics of scale to run large grain operations or concentrate livestock into feeding operations (Berry, 1981; Berry, 1977).

From this point onward the organic movement covered both the scientific and sociological consequences of conventional agricultural practices, with the case studies of individual farms offering a contrast to the industrial paradigm (Berry, 1977; Kristiansen et al. 2006). These advocates pursued careers outside of production agriculture to support their initial forays into organic production, but the concepts developed by organic advocacy have proven practical even to those outside of the certified organic paradigm (Pimentel et al., 2005; Moyer, 2013).

Organic agriculture strives for increased sustainability within a physical, societal, and economic context, but focuses on the physical in hopes of improving societal and economic outcomes (Heckman, 2006). From Sir Albert Howard onward, organic agriculture tries to mimic ecosystem processes in order to meet agricultural needs. This mimicry gave way to understanding the common biogeochemical and ecological processes inherent in managed and unmanaged ecosystems. The paradigm applies even in well-maintained conventional systems as agroecology. However, sustainability is a wider concept that extends beyond the organic practices and concepts (Tilman et al., 2002; Carson, 1990).

Sustainability encompasses the wider social and economic contexts that agriculture serves and refers to how long a society might practice some activity without reducing the ability of future generations to pursue the same activity (Tilman et al., 2002). Renewable resources are generally more sustainable than nonrenewable resources, though such classifications are scale-dependent. For example, soil is renewable given its ability to develop at geological timescales, though it is considered nonrenewable because it can be exhausted within decades through erosion or mining (Brady and Weil, 2010).

Organic production standards can be met without regard for social welfare or economic profitability. Similarly, some conventional systems can be more sustainable than organic systems as a consequence of crop selection, soil management, or site selection. Beyond environmental stewardship, production systems must address their ability to continue over time, even in the face of climatic instability (Tracy et al., 2018).

The perception of the organic label conveys a move back towards a hypothetical period of small cottage farms surrounded by old-growth forests, contrary to the ecological realities of the American continent (Noss, 2013; Veldman et al., 2015). The human alteration of the American landscape predates European settlement; indigenous agricultural practices were far from sustainable, albeit on smaller land tracts with lower population densities (Cronon, 2003). A return to nature conflicts with the ecological and anthropological debates regarding the original vegetation and herbivore impact on the United States (Holt, 2018; Noss, 2013; Fuhlendorf et al., 2008; Vera, 2000). An accepted consensus is that the original vegetation was not as productive as introduced Eurasian forage species (Noss, 2013; Fribourg and Waller, 1997). Organic agricultural production should not be confused with restoration ecology. As highlighted in Washburn et al. (2007), management objectives often seek to delineate working lands and natural areas; in contrast, merged conservation and cropping objectives might serve for restoration (Fuhlendorf et al., 2008). Instead, organic production should be seen as mimicry of ecosystem cycling in landscapes altered from natural ecological conditions.

Academic organic research started in the 1990s and parallels the federal certification development (Heckman, 2006). Economic premiums and historical adoption favor Northern production systems or high-value commercial crops (Williams et al., 2017; Eichler-Inwood et al., 2015; Heckman, 2006). The producer number and involvement with research institutions in these areas is sufficient to develop research programs on these interests. An intersection between conventional and organic programs is the area of low-input production systems. For a 0.5-ha vegetable operation, the return on purchased inputs and tillage justify their use. Importing fertility into larger operations, such as grain or forage programs, is less practical, and so practices to secure nutrients on-farm takes priority and may reduce the negative externalities associated with synthetic inputs (Chapin III et al., 2011; Robertson, 1998; Robertson and Vitousek, 2009). In these larger operations, organic standards are challenging to maintain in conjunction with productivity. In the literature, organic crops are assessed a yield penalty for their relatively reduced performance relative to conventional standards (Seufert et al., 2012). Sustainable practices that work within current production paradigms and prepare farmer for further adoption could be useful, such as integrated crop-livestock systems. These sustainable practices including integrated crop-livestock systems, systems with increased species diversity, and changes in agricultural policy have been suggested as part of the sustainability paradigm (Sulc and Franzluebbers, 2014; Tracy et al., 2018; Sanderson et al., 2007; Tilman et al., 2002).

Organic Transition and Certification Processes

The United States Department of Agriculture National Organic Program [USDA-NOP, 2020] arose in the 1990s and the Certified Organic label appeared in 2002 (Heckman, 2006). Developing standards both geographically and agriculturally across the United States required that producers pursue practices deemed regionally appropriate to meet the objectives of the USDA-NOP (Baier, 2008). Commercial use of the word organic requires adherence to the USDA-NOP

Commercial farmers must proceed through a monitored transition process to become certified organic systems (Baier, 2005). This transitional process starts three years before the harvest of the first certified crop when any inputs from a list of prohibited substances are no longer applied to a designated site. A comprehensive Organic Systems Plan includes all activities for a well-defined production site (Baier, 2008; Baier, 2005). A certification group evaluates the plan and maintains the organic certification for a producer following the development of the plan. Successful farm inspections and feedback eventually result in USDA-NOP certification (Baier, 2005).

Under organic dairy and beef regulations, animals must spend at least one year under organic management to enter into the certified organic food supply (Baier, 2010). The mother animal must be under organic management during the last third of gestation, and dairy cows must remain under organic management for a year prior to milking (Baier, 2010). Feed supplementation is regulated. The USDA-NOP is not responsible for nutritional requirements necessary for maintained animal production (i.e. energy and protein requirements) other than the source of feeding. Grazing regulation is somewhat simple for the complex interaction of livestock-forage systems. USDA-NOP has a minimum grazing period of 120 days, which does not have to be continuous (Baier, 2010). Animals must consume at least 30% of the dry matter (DM) intake from grazing. The intake is accounted for across the whole year and can vary with forage availability (Baier, 2010). While vaccines are allowed under USDA-NOP, synthetic medicines are prohibited as preventatives. Synthetic parasiticides are only allowed on breeding animals or dairy animals 90 days before milking (Baier, 2010).

Organic Forage Production

While nationally there exists a drive towards sustainable and organic agricultural systems, the development of organic forage systems remains a novel niche. Most organic producers develop input-intensive row crop or vegetable regimes to generate high-value enterprises on high quality ground. Following production trends, organic research prioritizes row crops or vegetables, while forages remain below the parity of such crops. Rather than the integrated organic vision promoted by early organic practitioners, the modern organic paradigm generally focuses on direct consumption and conventional nutrient management (Heckman, 2006).

The indirect marketing of most forages—producers sell livestock and its products rather than grass—presents an economic challenge to studying forages in the developing organic market paradigm (Cherney, 2018). The high pre-existing premiums on many other crops draw away industry and academic interest in researching forage systems as a whole, especially organic forages (Ball et al., 2015; Eicher-Inwood et al., 2015; Cherney, 2018). However, the premiums possible with organic animal products might indirectly translate into improved profitability for forage management. As grazing lands are the most economical and efficient source of animal feeds, and required under USDA-NOP guidelines for ruminant production, then pastures are an indispensable component of organic beef and dairy systems.

Early on, sustainability proponents realized the importance of transitioning pre-existing low-input agriculture into organic standards (Heckman, 2006; Logsdon, 1993; Berry, 1981; Jackson, 1980). Low-input systems transition more readily towards organic production than high-input systems. Most transitional changes are managerial as opposed to structural (e.g. increased forage harvests as opposed to changing entire cropping systems)(Savory, 1994; Savory, 1969). Forages offer a variety of short- and long-term grazing and hay opportunities (Tracy et al., 2018; Savory and Parsons, 1980). Indeed, depending on species selection, a producer can shift between a one-season forage/row crop system and a 10-year permanent pasture system (Sulc and Franzluebbers 2014, Sulc and Tracy 2007). Forages best meet the "Law of Return" as originally expressed by Howard (Heckman, 2019; Heckman, 2015). Howard's Law of Return regarded recycling plant and animal residues from their point of origin. Nutrients collected by a grazing animal largely cycle back to pasture (Robertson and Vitousek, 2009; Chapin III et al., 2011; Savory and Parsons, 1980).

Organic forage production is applicable to all levels of the beef and dairy lifecycles. In beef operations, calves start out in cow-calf herds on pasture where they initially nurse milk. Following this period, calves are weaned off milk and onto forage (Thomas, 2005). From these herds, calves then move through a stockering or backgrounding process in order to mature to a sufficient weight before finishing in a feedlot (Thomas, 2005). The pasture-to-plate process is spread across North American farms.. In dairy operations, heifers are raised separately from the milking herd. These heifers enter the milking herd after their first calving (Thomas, 2005). Given the gestation requirements for organic livestock, artificial insemination might be the most effective way to transfer genetics from conventional sires to organic dams.

Organic production in the Southeast

Like much of the United States, Southeastern organic production is focused on horticultural and grain crops (Delate and Cambardella, 2004). In the Southeast however, forages are a prominent component of the agricultural landscape. Much of the region favors the production of C_3 and C_4 forage species (Ball et al., 2015; Belesky et al., 2002). Extremes in the winter and the summer favor the development of complimentary functional groups within a production system to meet animal needs (Nave and Corbin, 2018; Belesky et al., 2002). The organic paradigm emphasizes the need for diversity in order to maintain consistent biomass productivity, but the different species are generally grown separately (Tilman et al., 2006a; Tilman et al., 2006b; Tilhou et al., 2018; Tracy et al., 2010).

The organic dairies of the Southeast are a growing share of the dairy industry in the region, though as a whole the sector is declining. In contrast, the cow-calf and stocker operations of the Southeast are relatively stable (Thomas, 2005; Backus et al., 2017; Lowe et al., 2016a). Dairy producers generally confine cattle and produce annual forages such as corn (*Zea mays*) silage and small grains baleage. Beef animal producers graze animals on permanent pastures from weaning until the feedlot, and then in the feedlot the cattle finish on grain and harvested roughage (Heckman, 2015; Thomas, 2005; Lomas et al 2004). For permanent pastures, tall fescue (*Schedonorus arundinaceus*) and bermudagrass (*Cynodon dactylon*) are the most common species in the Southeast. Forage inventory and livestock management are based around the availability and growth of these species (Roberts et al., 2009).

In Middle Tennessee, where many high-value certified organic crops make up a small proportion of the agricultural landscape, developing forage management for organic systems would serve the growing producer interest in certified organic as well as meet the needs of the state's stocker and cow-calf beef operations (NASS, 2012). Middle Tennessee livestock producers generally run only 35-40 head cattle herds on well-established tall fescue and bermudagrass pastures. These pastures can date back to the commercial introduction of Kentucky-31 tall fescue and are managed by continuous stocking for most of the growing season (Tilhou et al., 2018; Hoveland, 2009). This management hinders the productivity of the pastures as well as animal performance; however, the low-input conditions allow the farmer to maintain ownership. These producers are the primary target of present research efforts, as well as the producers necessary to implement best management practices (BMPs) regionally; they would also be the most-benefitted stakeholders of transitional organic research (Lambert et al., 2014). Cow-calf operations would, by nature, meet the organic standard animal requirements of minimum 30% DM intake from grazing throughout the grazing season (USDA-NOP, 2020; Heckman, 2015). Present best management practices favor developing productive pasture-based systems with an emphasis on environmental stewardship and direct livestock grazing (Lambert et al., 2014; Roberts et al., 2009; Savoy, 1999; Bates et al., 2015; Bates, 1995; Bates, 1998; Bates, 2007; Bates, 1997; Couture et al., 2018; Savoy, 2007).

With the mid-South's subtropical climate, grass-fed organic production might be especially feasible (Thomas, 2005, Thomas, 2018). However, according to regional statistics, most of the mid-South, including Middle Tennessee, is heavily based on cow-calf production (USDA NASS, 2012). Previous work in East Tennessee suggests that short-term forage systems greatly improve soil health and quality quickly, especially in annual rotations (Eichler-Inwood et al., 2015). Developing forage species selection recommendations for the climatically different Middle Tennessee based on the parameters of forage mass (FM) and nutritive value might differ from this earlier work.

The 3-year transition period used for organic certification requires producers to follow costly cultural practices that will not immediately generate organic premiums in the interim (USDA, 2018). This hurdle hinders many high-value producers from crossing over into organic production; in Middle Tennessee, producers might bypass the labelling regulations by employing the terms "natural" or "raised with organic methods" (Caldwell et al., 2014; Tony Foster, personal communication). A share of the organic beef market already overlaps with the grass-fed movement and thus premiums can be maintained using that labelling (David Butler, personal communication). Dairies have disappeared from the region, and perhaps, developing appropriate organic forage systems could incentivize dairy producers to pursue dairying for the organic premium. Low-inputs necessary for organic forage management would likely be more easily managed during a conversion period, as well as smother the resultant weed pressure more effectively than the row crop alternates (Mohler et al., 2016; Teasdale and Mohler, 2000; Mohler et al., 1997; Ball et al., 2015). Given the low input conditions present throughout Middle Tennessee, where most of the state's forage production takes place, developing management and species recommendations for transitioning farmers in an organic equivalent is essential. Transitional organic research must address the following: forage quality and quantity, weed management, and fertility management.

Species Selection

The forage base for Tennessee is the cool-season tall fescue, which was widely planted in the second half of the 20^{th} century (Hoveland, 2009). The forage potential of the species, as well as its tolerance to mismanagement, supported its adoption among producers. Most livestock graze on tall fescue pastures or hay in Middle Tennessee. Tall fescue, even though a cool-season perennial grass, has an extended season with potential use from March to July and September to December in the Southeast. This availability allows producers to rely on tall fescue for most of their forage-based pasture systems. Management around endophyte and extended use have been major areas of tall fescue research.

Widely introduced Kentucky-31 variety carried an endophyte which reduces animal performance during reproductive cycles and the summer months (Strickland et al., 2009; Hoveland, 2009; Burns, 2009). Research in West Tennessee suggests that grazing intensity can influence endophyte levels in pastures (Gwinn et al., 1998). Animal health concerns from the endophyte-related fescue toxicosis can be managed on existing toxic endophyte Kentucky-31 tall fescue, or by renovating pastures with commercially-available novel endophyte varieties (Hoveland 2009; Roberts et al., 2009; Fribourg and Milne, 2009; Bouton, 2009). Capital investment in endophyte-free or novel endophyte tall fescue varieties requires that producers can avoid recolonization by toxic endophyte plants (Barker et al., 2005). Tall fescue stockpiling in the Middle Tennessee region—

specifically Spring Hill and Dover, TN—followed the work of Fribourg and Bell (1984), and subsequent research efforts in Crossville, TN (Nave et al., 2016). This technique allows producers to utilize tall fescue for an extended grazing season.

Bermudagrass serves as a complementary warm-season grass forage to tall fescue in the mid-South, and as the base of forage programs in the Deep South. As tall fescue declines in productivity in the summer heat, bermudagrass offsets shortfalls in forage availability. In West Tennessee, mixed swards of bermudagrass and tall fescue with N fertilization were more productive than mixed tall fescue and legume swards, though N was speculated to limit productivity (Mitchell et al., 1986). In other regions bermudagrass is stockpiled for winter forage; however, in Middle Tennessee tall fescue is the preferable stockpiled forage (Lalman et al., 2000; Nave et al., 2016). Improvements on the common bermudagrass introduced with settlement include hybrid bermudagrass and seeded bermudagrass.

Seeded bermudagrasses are less productive than hybrid bermudagrasses, but the genetic diversity within genus *Cynodon* has offered improvements over the past 30 years (Huang et al., 2018; Hill et al., 2001). Many improved bermudagrass varieties are sprigged, that is, vegetatively propagated and then spread into producer fields (Ball et al., 2015). The costs and effort required to sprig bermudagrass have encouraged the development of seeded bermudagrass. Additionally, untreated seed offers an organic alternative to treated stolon sprigs. Most stolon sprigs are treated with prohibited substances to prevent damage in transport. Bermudagrass meets livestock nutritional needs, but is considered less nutritious than cool-season forages (Rouquette, 2005).

Alfalfa (*Medicago sativa*) is nationally praised for its forage productivity and quality, and regionally spurned for its agronomic performance (Thinguldstad et al., 2020; Hendricks et al., 2020; Quinby et al., 2020). Edaphic conditions in Middle Tennessee did not favor historical alfalfa agronomy due to available varieties and management strategies (Quinby et al., 2020; Henry Fribourg, personal communication). However, varietal improvements and the development of alfalfa management suggestions may improve future adoption (Quinby et al., 2020; White and Lemus, 2015; Kallenbach et al., 2002). Alfalfa establishment requires advanced planning in order to meet high soil fertility and pH requirements. Establishment and long-term management must account for the species' autotoxicity; stands cannot be overseeded with additional alfalfa, above certain population numbers. This autotoxcity is also influenced by soil texture, hydrology, and plant-soil nutrient dynamics; the effects of autotoxicity differ among plant material and assessing autotoxicity can be challenging (Jennings and Nelson, 1998; Chon et al., 2000; Jennings and Nelson, 2002). Jennings and Nelson (2002) found an autoxoic zone around field plants that precludes reseeding into moderately dense stands. At extremely low stand densities, replanting has been successful in previous research (Quinby et al., 2020; Corbin et al., 2018).

Alfalfa is susceptible to pests and diseases, such as potato leafhopper (*Empoasca fabae*) and alfalfa weevil (*Hypera postica*). Potato leafhoppers will leave a hopperburn on the leaf tips. Alfalfa breeding has improved potato leafhopper tolerance, but at no added genetic gains in forage mass production. (Sulc et al., 2015; Lamp et al., 2004; Chasen et al., 2014). Alfalfa weevil will eat holes in the leaves to the point of stand failure. Alfalfa weevil influenced producer species selections in the second half of the 20th century

(Osteen et al., 1981). *Sclerotinia* crown rot (*Sclerotinia trifoliorum*) is an important disease afflicting young alfalfa plants. The disease requires intensive management during alfalfa establishment in order to avoid the fall spread of acrospores (Sulc and Rhodes, 1997). Producers are encouraged to establish alfalfa conventionally as opposed to no-till in the fall to minimize the risk of *Sclerotinia* crown rot and reduce the reproductive success of the fungal pathogen (Sulc and Rhodes, 1997). Conventional establishment might improve the growth rate of alfalfa seedlings in order to improve survival rate when the pathogen infests a stand. Improved cultivar development has improved disease resistance and tolerance to abiotic stress. These advantages over older cultivars only offer crop protection rather than an increase in forage mass (Ariss et al., 2007; Lamb et al., 2006; Ariss et al., 2004).

Annual forage crops offer producers flexibility in production. Cropland can be converted to grazing land as needed. Mixed operations might more efficiently balance row crop and livestock operations, especially in the growing movement to integrate crop and livestock systems (Franzluebbers et al., 2014; Sulc and Franzluebbers, 2014; de Moraes et al., 2018; Sulc and Tracy, 2007). Cool-season annual crops are regularly recommended for soil cover in row crop systems and as grazing forages for late winter or early spring; these cover crops can be used to suppress the weed seed bank in grain operations as well as feed livestock if properly tuned (de Moraes et al., 2018; Schuster et al., 2018; Schuster et al., 2016; Schuster et al., 2019). These recommendations arose out of a renaissance of cover cropping in the 1960s. In turn the renaissance followed earlier promotional efforts prior to synthetic fertilization (Groff, 2015). Popular cool-season cover crops include the following: wheat (*Triticum aestivum*), cereal rye (*Secale cereale*), Austrian winter pea (*Pisum sativum* spp *arvense*), and brassicas (*Brassica* spp.)(Groff, 2015). Species mixtures have been recommended by the National Resources Conservation Service (NRCS) along the lines of ecosystem services and the proposed functional diversity hypothesis, but such evaluations have not been empirically tested (Florence et al., 2019; Grace et al., 2007; Tilman et al., 2006a; Tilman et al., 2006b; Tilman et al., 2002; Lhomme and Winkel, 2002).

Warm-season annual grasses such as sorghum (*Sorghum bicolor*), sorghum-sudangrass hybrids (*Sorghum bicolor* x *Sorghum sudanese*), and pearl millet (*Pennisetum glaucum*) were recommended to Middle Tennessee producers beginning in the 1960s (Fribourg, 1963). These warm-season annual grasses offer an alternative to tall fescue during the summer slump similar to bermudagrass (Nave and Corbin, 2018; Brainard et al., 2011; Belesky et al., 2002). Potential barriers to adoption include the following: annual re-establishment costs, differential management requirements from perennial forages, and prussic acid poisoning (Staggenborg, 2016; Ball et al., 2015). Sorghum and sorghum-sudangrass management can influence yield potential; management along plant development and residual stubble height may result in different yield management along plant height (Creel and Fribourg, 1981; Gelley et al., 2017; Roozeboom and Prasad, 2019; Brainard et al., 2011). Fortunately, sorghum-sudangrass varietal improvements have sought to simplify field management and specify the diversity of the sorghum-sudangrass hybrid complex (Ashok Kumar, 2019).

Cowpea (*Vigna unguiculata*) is a forage and field crop of regular popularity in the Southeast. The species is a warm-season annual legume. Initial research suggested cowpea and sorghum-sudangrass mixtures are moderately effective in smothering noxious weeds (Brainard et al., 2011). Incorporation into forage programs includes its use in forage mixtures and intercropping (Nave et al., 2019; Nave and Corbin, 2018; Corbin et al., 2018). The N credit that cowpea can provide to subsequent and companion crops have encouraged pairings with other warm-season annual crops, such as sorghum-sudangrass (Nave et al., 2019; Corbin et al., 2018; Snapp et al., 2005).

Challenges of Organic Forage Production

Contemporary organic research has primarily focused on temperate production systems or high-value commercial crops (Williams et al., 2017; Eichler-Inwood et al., 2015; Heckman, 2006). Research efforts in organic forages have focused on dairy production systems in the northern United States as well as Europe (McBride and Greene, 2009). Forages are often not a primary consideration by the livestock community, as most producers focus the saleable product—beef or dairy—rather than the input forages. Forages are not directly marketed in the same fashion as beef and dairy products. Beef and dairy farmers opt to produce at least a major portion of livestock feed on-site. The knowledge base of a livestock manager may not encompass the challenges inherent in conventional agronomy, much less organic agronomy. Economics and public policy can dictate agronomic practices even amongst the ardent producer (Bohman et al., 2020). An ecological approach is necessary in an organic context, given that weeds will be inherent to transitioning fields.

Weed issues in row crop systems led to the development of a chemical suite and recommendation guidelines to meet contemporary production practices (Mohler et al., 1997; Mohler and Callaway, 1985; Ward et al., 2013; Steckel, 2007; Mann et al., 1983; Steckel et al., 2020). Increased chemical control allowed producers to move away from cultural practices such as regular cultivation. Reduced cultivation in turn reduced erosion as well as weed seedling recruitment at the outset of modern herbicides (Little et al., 2015; Lal, 2004; Anderson, 1999). Herbicide resistant noxious weeds, such as pigweeds (*Amaranthus* spp.) can subvert chemical controls, and so cultural practices such as switching to forage production might hinder resistant pigweed biotypes from dispersing to other farms (Heap, 2020; Steckel, 2007; Sulc and Tracy, 2007). Amaranthaceae can compete against other weeds, such as crabgrass, which may provide some forage value to livestock (Brainard et al., 2011; Morris et al., 1986; Marks and Mohler, 1985). Thompson et al. (2017) suggest that crop rotation should assist a producer using conventional herbicides.

Maintaining ground cover via cover crops has become a popular strategy to prevent weeds from establishing on bare ground; it follows that forages maintain ground cover much more effectively than row crops and might increase the amplitude of the smothering effect (Brainard et al., 2011; Mohler, 2009). Weed control in pastures and hayland can be achieved through selective herbicides and clipping; however, this will affect mixed swards of grasses and legumes or forbs. Common pasture weeds include milkweed (*Asclepsias* spp.), horsenettle (*Solanum caroliniense*), and tall ironweed (*Vernonia gigantea*), which can accumulate in well-managed pastures without integrated management strategies (Phillips et al., 2016; Toison et al., 2012; Bryson and DeFelice, 2009; Kim and Albrecht, 2008; Dekker, 1997).

Grazing systems conserve nutrients on site and reduce the need for fertilizer inputs; in developing guidelines in line with haying operations, a transitional operation manages and cycles nutrients, especially P and K (Stanley et al., 2018; Ball et al., 2015, Brady and Weil, 2010, Chapin, 2011). Forages offer a pathway for soil improvement and development by gradually accumulating soil organic matter and efficiently cycling macronutrients (Heckman, 2015). Grazing systems could address P and K export from soils by minimizing the physical movement of plant material off-site. Certain P and K cycling additives are prohibited (e.g. sewage sludge), and minimizing initial export would improve overall sustainability (Heckman, 2006, USDA-NOP, 2020). Nutrient management plans and regular soil sampling follow this pathway's progression introduction of mixed grass-legume pastures can increase N availability. The need for fertilization can be a challenge for organic production (Heckmna, 2015; Brady and Weil, 2010, USDA, 2018). Nitrogen management can be addressed through the use of animal manures, legumes, and other approved substances (Williams et al., 2017; USDA-NOP, 20120). Given the economic margins involved, most producers are likely to opt for incorporation of manure fertilization or legumes into forages.

Adoption of organic practices does not necessarily require compliance with certified organic regulations, though the premium incentivizes adoption. As seen with other moves towards sustainability, such as integrated crop and livestock systems, organic production has a social component (Heckman, 2019; Franzluebbers et al., 2014). Transitioning to organic production requires a sustainable ecological framework, a suitable marketing outlet, and a supportive economic structure, as described within the sustainability framework proposed by Tilman et al. (2002). Without a market outlet or a cost-effective productive system the operation will not persist.

Forage species selection is seen as the appropriate approach to transitional production in order to identify existing pasturelands a producer might easily transition, or establish with ease. In low-input settings, the general status of Southeastern forage production, the farmer needs a competitive crop that establishes readily against weed seed bank (Heckman, 2019; Heckman et al., 2013). Weed control in organic forages is mowing, grazing, or smother crops. Planting a competitive crop serves as a smother crop to the weed seed bank, and can build on the weed suppression observed in permanent pastures (Nave and Corbin, 2018; Brainard et al., 2011; Sanderson et al., 2007).

Objectives

The present study seeks to determine evaluate five species selections for transitional organic forage production in Middle Tennessee. The resulting information on forage mass, nutritive value, weed pressure, and economic balance will also be useful for low-input production systems. The optimal selection would meet animal needs, and stay within certification standards, while maintaining profitability over the transition period and avoiding challenges inherent to organic forage establishment. Based on these criteria, the hypothesis of our study is that annual species are able to provide higher forage mass while maintaining forage nutritive value, therefore the optimal selection for an organic transitional program.

CHAPTER 1:

Forage mass and nutritive value under low-input transitional organic production.

ABSTRACT

Despite the vast production markets for forage and organic products nationally, limited work has been done to develop organic forage programs, especially for the Southeast. The present study seeks to evaluate several species selections for optimizing forage production for beef cattle under low-input organic conditions, with nutritive values tailored to the beef cattle operations. This study was conducted at the Middle Tennessee AgResearch and Education Center, in Spring Hill, TN. The forage selections consisted of: a tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort.) monoculture, a bermudagrass (*Cynodon dactlyon* (L.) Pers.) monoculture, a tall fescue and alfalfa mixture (*Medicago sativa* L.), a bermudagrass and alfalfa mixture, and an annual rotation (winter wheat [*Triticum aestivum* L.] and winter pea [*Pisum sativum* L.] mixture rotated with a sorghum-sudangrass [*Sorghum bicolor* (L.) Moench *x Sorghum sudanese* (Piper) Stapf.] and cowpea [*Vigna unguiculata* (L.) Walp.] mixture). Perennial treatments were established during the 2017-2018 growing season. Regular production measurements occurred in 2019 and 2020. Botanical composition fluctuated as a consequence of establishment dynamics and weed competition, generally between 200 and 800 g kg^{-1} in the perennial swards, and affected forage quantity and quality. Nutritive value was sufficient for beef cow-calf operations across treatments, with average crude protein or all treatments remaining ~150 g kg^{-1} across two growing seasons. The annual rotation was the highest-yielding forage species selection, producing more than 6000 kg ha^{-1}, though tall fescue and tall fescue-alfalfa selections produced (~4000 kg ha^{-1}) without associated establishment concerns.

INTRODUCTION

Organic production in the United States is increasing as a result of increasing consumer awareness and corresponding demand. The USDA National Organic Program [USDA-NOP] has been developed in order to improve agricultural sustainability and to standardize the organic paradigm across production schemes and regions (heckman, 2006; Rigby and Caceres, 2001). While a sizable body of literature exists for grain and specialty crops, organic forages are a potential market segment for livestock producers as well as cropping operations (Brandao et al, 2012; Delate, 2009).

Forage production has been a component of agricultural sustainability because of grassland resilience (Tracy et al., 2018; Tilman et al 2006a). Grassland agriculture better conserves and cycles nutrients, soil, and water, leading to positive impacts on ecosystem services compared to most grain and fiber cropping systems (Sulc and Franzelubbers, 2014; Wedin and Fales, 2009; Singer et al., 2009; Bird et al., 1998; Cavigelli et al., 1998; Cavigelli, 1998).

The transition period is a 3 yr regulatory period after which land can be certified organic (Porter, 2009). The literature bias towards specialty crops in cooler climates puts preference on using forage crops within the context of cover crop or sod-based rotation systems for vegetable production (Mohler, 2009; Liebman and Davis, 2009; Kristiansen and Merfield, 2006; Delate, 2009; Porter, 2009; Delate and Cambardella, 2004). Even in local Southeastern organic research, forage crops have been evaluated within the context of diversified production systems (Eichler-Inwood et al., 2015).

The Southeast has been a place of limited organic research, much less transitioning organic research. The economically active market sector favors organic dairy and vegetable production (Eichler-Inwood et al., 2015; Heckman, 2006). The decline of dairy operations in the Southeast limits the present research to high-quality forage production for dairy nutrition. However, many classes of beef and developing dairy cattle, as well as horses, can be successfully raised on a wider window of nutritive value (Ball et al., 2015). Forage operations are low-input enterprises that favor controlling production costs (Biermacher et al., 2012; Baker et al., 1988). Conventionally-managed land transitioning to organic production often suffers a yield or forage mass (FM) slump as management practices, particularly elimination of industrially-fixed N fertilizer, change to meet organic standards (Brandao et al., 2012; Porter, 2009; Mohler, 2009). Fertility control is limited by nutrient cycling, such as N supplied by biological N fixation or N mineralization from organic matter (Chapin III et al., 2011; Magdoff and van Es, 2009; Cooperband, 2002). Similarly, weeds normally suppressed by chemical herbicides may dramatically increase (Brainard et al., 2011; Liebman and Davis, 2009). Rigby and Caceres (2001) make a case that sustainable and organic agriculture should in principle be low-input systems. Given the overlap in fertility status, pest management, and weed control, low-input and transitioning organic forage systems are likely comparable in terms of species selection.

Species selection is crucial in transitioning organic production. Challenges to transitioning swards include weed competition and fertility limitations. A crop in an organic system needs to remain competitive with weeds as well as resource efficient (Davies et al., 2012; Brainard et al., 2011; Liebman and Davis, 2009; Lammert van Bueren and Verhoog, 2006). Competitive species that establish quickly and form closed canopies or thick sods are preferable for weed control (Liebman and Davis, 2009). Of the existing forage and dual-use cover crop species employed in the Southeast, some species may provide a smoother transition than others in terms of consequential management issues.

The present study seeks to evaluate the impact of species selection for transitional organic forage production in Middle Tennessee. The resulting information on forage mass, nutritive value, and weed pressure will also be useful for conventional, low-input production. The optimal selection will meet animal needs, and stay within certification standards, while minimizing challenges inherent to organic forage establishment. Based on these criteria, the hypothesis of our study is that annual species are able to provide higher forage mass while maintaining forage nutritive value for an organic transitional program.

MATERIALS AND METHODS

Site description

The study was conducted at the Middle Tennessee AgResearch and Education Center (MTREC) in Spring Hill, TN (35.68° N, 86.91°W, 247 m altitude). The entire experimental area totaled 0.405 ha with individual plots spread across several soil types. The southern plots consisted of Huntington silt loam, local alluvium phosphatic phase. The middle plots consisted of Maury Silt Clay Loam, eroded sloping phase. The northern plots consisted of Maury Silt Loam, but eroded gently sloping phase. The site was historically part of an orchard managed under conventional practices, such as spraying, fertilization, and irrigation. The trees were removed from the site in 2016, and the site remained fallow until the start of the project in Oct. 2017. Initial soil nutrient levels on the experiment site were determined by Mehlich 1 extract to be pH = 6.3, P = 62.65 mg kg^{-1} High, K = 160.31 mg kg^{-1} High, Ca = 1009.02 mg kg^{-1}, and Mg = 160.95 mg kg^{-1}.

The experiment was conducted utilizing 20 experimental units that were 1.3 m x 3.9 m, arranged in a randomized complete block design to account for both a slight slope gradient as well as fertility variation as a result of field history (Clewer and Scarisbrick, 2008). The primary species were consistent throughout the site and were bermudagrass, tall fescue, cheatgrass (*Bromus spp.*), Carolina geranium (*Geranium carolinianum*), and white clover (*Trifolium repens*).

The treatments consisted of five species combinations with four replications. The species selection treatments were 1) tall fescue (cv. Kentucky 31), 2) bermudagrass (cv. Cheyenne II), 3) tall fescue grown as a mixture with alfalfa (cv. WL 358 LH), 4) bermudagrass grown as a mixture with alfalfa, and 5) an annual rotation composed of a cool-season mixture of wheat (cv. LG 334 SRW) and Austrian pea (cv. not stated), followed by a warm-season mixture of sorghum-sudangrass (cv. AS 6501) and cowpea (cv. 'Iron & Clay'). Grass-alfalfa mixtures were selected based on similar studies conducted under conventional management regimes (Quinby et al., 2020; Corbin et al., 2018; White and Lemus, 2015). On 12 Oct. to 16 Oct. 2017, the site was plowed, and a disk harrow (John Deere, Deere and Company, Moline, IL) was used to prepare the soil. Following plowing, irrigation pipes and tree roots were removed. A tractor-mounted rotary tiller box (John Deere, Deere and Company, Moline, IL) was used for seedbed preparation.

On 27 Oct. 2017, tall fescue (drilled seeded at 22.4 kg ha^{-1}) and the cool-season annuals were drilled at seeding rate of 112 kg ha^{-1} wheat and 56 kg ha^{-1} Austrian pea, using a Tye Estate Planter drill (The Tye Co., Lockney, TX). Alfalfa was drilled on 16 March 2018 at 16.8 kg ha^{-1} using a Hege 1000 series plot drill (Hege Equipment Inc., Colwich, KS). All plots containing alfalfa were mowed to a 7.5-cm stubble height before being drilled (Quinby et al., 2020). Bermudagrass plantings were attempted twice in June 2018, where the monocultures were rotary tilled, cultipacked, and then hand-broadcasted on 4 Jun. 2018. These seedbeds were cultipacked following seeding with a Brillion cultipacker (Landoll Company, LLC., Marysville, KS). Bermudagrass-alfalfa mixtures were drilled using a Hege 1000 series drill (Hege Company, Waldernburg, Germany) on the same day. In both monocultures and mixtures, the bermudagrass was seeded at a rate of 6.73 kg ha^{-1}. In the second planting attempt, respective procedures were repeated for the monocultures and mixtures, though seeding rates were modified to 16.8 kg ha^{-1} for the bermudagrass monocultures and 11.2 kg ha^{-1} for the mixtures. Both establishment attempts were unsuccessful, and crabgrass (*Digitaria* spp.) volunteered into the plots. Each season of annuals terminated through the use of a rotary tiller. The cool-season annuals were terminated on 27 May 2018. Sorghum-sudangrass and cowpea were planted together at seeding rates of 33.6 kg ha^{-1} and 84.1 kg ha^{-1} respectively, using a Hege 1000 series. These warm-season annuals were terminated 10 October 2018.

Fertility management began 7 Mar. 2019 with the application of boron and horse manure. Boron is a critical micronutrient for alfalfa in Tennessee and was applied at 1.78 kg ha^{-1} to all grass-alfalfa mixtures (Maxi Granular Boron 15%, Cameron Micronutrients, Virginia Beach, VA) (Savoy, 1999). Grass monocultures were supplemented with an approved and industry-popular organic N source (Rinehart and Baier, 2011; Savoy, 2007; Savoy, 1999). The MTREC station maintains a small horse paddock system which does not received prohibited substances, and it was selected over dairy and beef bull manures due to reduced risk of herbicide residuals and weed seed contamination from pigweeds present in the cattle pastures but not observed in the horse paddocks. Pigweeds (*Amaranthus* spp.) were the primary weeds of concern on the research station. The manure was collected and stored in a walk-in cooler from 8 Feb. 2019 to 4 Apr. 2019 and from 3 Feb. 2020 to 3 Apr. 2020. Prior to applications in 2019 and 2020, representative samples were taken from the collected manure, and sent to the University of Arkansas Agriculture Diagnostic Laboratory (Fayetteville) for analysis (Peters et al., 2003). The horse manure sourced from the unsprayed MTREC pastures was applied at 84 kg ha^{-1} N to the tall fescue monoculture plots on 7 Mar. 2019 and 5 Mar. 2020. The same manure and rate was applied to the bermudagrass monocultures on 4 Apr. 2019 and 3 Apr. 2020. Horse manure nutrient concentration for 2019 (DM basis) were: pH, 7.7; moisture, 72.0%; NO_3–N, 44.0 mg kg^{-1}; NH_4– N, 111.9 mg kg^{-1}; total N, 2.57 g kg^{-1}; total P, 0.96 g kg^{-1}; total K, 0.85 g kg^{-1}; and total Ca, 4.40 g kg^{-1}. Horse manure nutrient concentration for 2020 (DM basis) were: pH, 8.0; moisture, 73.4%; NO_3–N, 35.3 mg kg^{-1}; NH_4–N, 22.5 mg kg^{-1}; total N, 1.65 g kg^{-1}; total P, 0.64 g kg^{-1}; total K, 0.45 g kg^{-1}; and total Ca, 1.88 g kg^{-1}.

On 10 Oct. 2018, the cool-season mixture was planted (procedure and rates listed above), marking the beginning of the experimental production period. Plots were allowed to go unharvested through the winter due to reduced growth.

Failures to establish optimum alfalfa plant densities (<5 plants / 1 m^2) and seed selection issues with the bermudagrass required rectification in the spring. Despite concerns for alfalfa's autotoxicity, the plant density was considered low enough to replant alfalfa into the grass mixture plots (Chon et al., 2006; Jennings and Nelson, 2002). On 14 May 2019 all bermudagrass plots (mixture and monoculture) were tilled with a rotary tiller. Due to the width of the available cultipacker (John Deere, Deere & Company, Moline, IL), the whole research site was cultipacked before and after reseeding the bermudagrass during this time. Bermudagrass seed (cv. Cheyenne II) was hand-broadcasted on the assigned plots, at 16.8 kg ha^{-1} in the monocultures and at 11.2 kg ha^{-1} in the mixtures. Alfalfa (cv. WL 358 LH) was drilled concurrently into the tall fescue and bermudagrass mixtures on 14 May, 5 Sep. and 8 Oct. 2019, at 16.8 kg ha^{-1}. Drought conditions led to the replanting effort in Oct. 2019.

The warm-season annual composed of sorghum-sudangrass and cowpea mixture were planted at 33.6 kg ha^{-1} and 84.1 kg ha^{-1} respectively, in a conventional seedbed on 5 Jun. 2019. This planting was repeated on 2 Jun. 2020. The cool-season annual rotation composed of winter wheat and Austrian winter pea were planted at 112 kg ha^{-1} and 56 kg ha^{-1} respectively in a conventional seedbed on 8 Oct. 2019.

Forage mass measurements

Harvests to measure forage mass were taken using a Swift silage flail chopper (Heavy Duty Walk Behind Forage Harvester, Swift Machine & Welding Ltd., Saskatoon, Canada). These harvests were taken following monthly botanical composition sampling of the treatments. Forage mass production harvests for the 2019 growing season (April through September) began on 4 Apr. for the annual rotation as well as the tall fescue mixture and monoculture, and occurred subsequently on 3 May, 4 Jun., 1 Jul., 7 Aug. and 5 Sep. for all treatments. Because the bermudagrass monocultures and mixtures were re-establishing, they were not harvested in June. Harvests were taken with a flail chopper at 7.5-cm stubble height for all species except for the warm-season annuals, which were harvested at 15.2-cm stubble height in 2019 and 2020 to manage grasses for growth points. Forage mass harvests for the 2020 growing season resumed on 3 Apr for all treatments and occurred subsequently on 7 May, 2 Jun., 1 Jul., 4 Aug., 1 Sep. Stubble heights were consistent for treatments in 2020. A 0.71-m x 3.9-m strip was cut from each plot and weighed. A bulk sample was then collected from each plot, fresh weights were recorded, and then samples were dried for 72 hr at 58 ℃ up to constant weight for determination of total DM forage mass.

Botanical composition

Prior to harvesting, two 0.1-m^2 quadrats were collected at random from each plot monthly from Apr. to Sep. 2019 and 2020. Samples were taken on 4 Apr. 2019, 3 May 2019, 4 Jun. 2019, 1 Jul. 2019, 6 Aug. 2019, 4 Sep. 2019, 3 Apr. 2020, 7 May 2020, 2 Jun. 2020, 1 Jul. 2020, 4 Aug. 2020, and 1 Sep. 2020. These samples were collected to a 5-cm stubble height and separated. Samples were dried at 58℃ for 72 hours up to constant weight, then weighed to determine composition. The DM weight of each component was then recorded. If the weighed material of some components was physically present, but not detected by the scale (<0.1 g), then records to classify species as trace were taken.

For the 2019 growing season, botanical components consisted of planted grass species, planted legume species (if present), and a collective weeds component. Due to further evaluation and since the weed component was highly variable during this initial period, the weed component was separated into additional categories (grass weeds, legume weeds, and broadleaf weeds), for the 2020 growing season. This protocol modification was adjusted and noted as per the guidelines of Oakley et al., (2003).

To complement general botanical composition measurements, frequently observed weeds were noted at the time of sampling. Warm-season weeds were identified during the growing season in separate weed forays. Weeds were identified in each of the 20 plots on 2 Jul. 2018, 1 Jul. 2019, and 1 Jul. 2020 using Bryson and DeFelice (2009). The identities of these weeds were collected to complement the description of weed biomass by percent forage mass and nutritive value (Ball et al., 2015, Bryson and DeFelice, 2009). Weed presence was determined as the species present in a majority of the plots for each treatment. Weed species were counted and categorized into an overall species richness as well as grass, legume, and broadleaf weed species richness. Species richness, or the number of weed species in a given plots, and richness by functional grouping (grass, legume, or broadleaf weed) was also compared. Categories of weed species richness were set by equally subdividing the range of species richness values observed across all 3 yr. Species richness of the weeds and broadleaf species richness was divided into 3 categories: Low (0-3 species), Medium (4-6 species), and High (> 6 species). Grass species richness was divided into Low (<3) and High (>3) categories. Legume species richness was divided into None (<1) and Present (>1) categories. Categorical weed analysis was conducted based on the species counts within treatments and years.

Nutritive value measurements

After measuring DM forage mass, the same samples described above were ground through a Wiley Mill Grinder (Model 4,Thomas Scientific, Swedesboro, NJ) using a 1-

mm screen, then further ground through a Cyclone Sample Mill (UDY Corporation, Fort Collins, CO). The samples were then scanned on a Unity SpectraStar XL-R near-infrared spectroscopy (NIRS) instrument using software InfroStar version 3.11.3 (Unity Scientific, Milford, MA). Samples were analyzed using the 2018-2020 Grass Hay calibrations developed by the NIRS Forage and Feed Consortium (NIRSC, Berea, KY). Predictions for Crude Protein (CP), neutral detergent fiber (NDF), and 48 hour in-vitro dry matter digestibility (IVDMD48) were utilized. The Global H value statistical test compared the samples against the model and other samples within the database for accurate results, where all forage samples fit the equation with the ($H < 3.0$) and are reported accordingly (Murray and Cowe, 2004).

Organic Certification

The experimental site was certified throughout the transition process by Quality Certification Services (QCS, Gainesville, FL). As requisite with the certification program, a system plan was developed for the whole site; the document was QCS Organic Growers Plan. A separate field history record described the prior peach orchard preceding the present study. The plan maintains that the plots were to be setup for the present study. Equipment sanitation and use was recorded electronically for certifiers. Inputs were allowed from an Approved Materials List, and applied with approval from QCS by telephone or email. Inspections were conducted on 12 Sep. 2018 and 28 Jan. 2020 in order to inspect seed, facilities, equipment, and records on the research station.

Statistical analysis

Statistical analysis and reporting was conducted with consideration for the recommendations of Kramer et al. (2019) and Onofri et al. (2010) as well as other – sources (Schweiger et al., 2016; Vargas et al., 2015; Gates, 1991). Total annual forage mass, monthly forage mass, nutritive value measurements (CP, aNDF, and IVDMD48) were evaluated by an ANOVA of the randomized complete block design with 4 blocks. Botanical composition was also evaluated by an ANOVA of the randomized complete block design with sampling of 4 blocks and 2 samples per experimental plot. Fixed effects included treatment. Random effects included block and block X treatment. The entire plot was harvested each time after sampling, thus, the following month sampling is the monthly initiation. Analysis proceeded through SAS statistical software using PROC GLIMMIX (SAS v9.4, SAS Institute, Cary, NC). Data normality was tested as a requisite assumption of ANOVA. Alpha remained set at 0.05 for statistical significance evaluation in all cases. Mean separation was achieved through Tukey's Honest Significant Differences in order to be conservative in protecting against experiment-wise Type I error rate. If significant treatment effects were detected by ANOVA but were not captured by Tukey's Procedure, Fisher's Least Significant Difference Procedure was used for mean separation. Forage mass and the derived nutritive value was analyzed within each month in a randomized complete block design of 4 blocks as a mixed model ANOVA. Fixed effects included treatment. Random effects included blocking.

For the weed species survey data, species counts were analyzed categorically. Weed presence was determined by identifying which weeds occurred in a majority of the plots for each treatment and compared between treatments where possible. Species richness, and richness by functional grouping (grass, legume, or broadleaf weed) were also compared. Categorical weed analysis was conducted based on the species counts within treatments and years by means of Fisher's exact test. Fisher's exact test was used instead of Chi-square test because of the limited number of observations which would subsequently limit the expected counts (McDonald, 2014). Plots were categorized within treatment or year on the basis of these levels and then analyzed. Correlations were analyzed using Pearson Correlation Coefficient based on simple correlations made between quadrat FM data and the forage mass present in the weed data using PROC corr (SAS v9.4, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Weather

Mean temperature and monthly rainfall were collected from Neapolis/MTREC weather stations located on-site (Figures 1.1-1.2). Weather data from the project period were compared with the long-term 30-yr average (1981-2010) from these weather stations. Temperature was relatively more stable than precipitation (Figures 1.1 and 1.2). In 2018, which was the establishment year, temperature was relatively higher than the 30-yr average, whereas 2019 and 2020 were lower than the 30-yr average, with the exception of the late summer through early fall drought in 2019 (Figure 1.1). Of note, the MTREC station was historically a stress testing location for state variety trials. Drought stress was noted at different periods during tests, either during early or late in the season. The precipitation variability within years has presented challenges to other crops at the site, and has been observed in recent forage experiments (Nave et al., 2019; Nave and Corbin, 2018). The distribution of precipitation was somewhat inconsistent during the transition period relative to the 30-yr average (Figure 1.2). Spring and fall 2018 both had higher precipitation than the 30-yr average, though the late summer of 2019 was exceptionally dry (Figure 1.2).

Botanical Composition

The planted grasses were consistently present in each of the 5 species selections throughout the entire growing season in 2019 and 2020, as would be anticipated (Table 1.1). Cowpea has been noted as a vigorous component of conventional sorghum-sudangrass and cowpea mixtures (Nave et al., 2019). Interspecies competition was more balanced in the annual rotation than in the grass-alfalfa mixtures. The twice annual planting of cool and warm season components balanced the variability of components by virtue of regular re-establishment between the forage grass and legume species. However, at the beginning of the 2019 growing season, bermudagrass and bermudagrass-alfalfa showed inconsistencies in the grass proportions, based on the necessary reestablishment of bermudagrass during that period. Bermudagrass was re-established prior to the June sampling, and was competing against an active weed seedbank from the outset. In both the monoculture and mixture, bermudagrass was a minority of the total forage grass present (Table 1.1). Tall fescue was a majority component of the monoculture and mixture treatments for most of the growing season (Table 1.1). Declines in the grass component in 2019 align with the onset of drought conditions (Figures 1.1-1.2; Table 1.1). A similar trend was observed in 2020, which corresponds to the seasonal growth of warm-season weed species (Table 1.3).

Legume presence was consistent in the annual rotation (Table 1.2), especially in 2019 with the greatest legume proportion throughout the growing season as compared to other treatments. Challenges with alfalfa are below mentioned, but Austrian pea and cowpea regularly appeared as measurable components of the annual treatments (Table 1.2). Alfalfa was detectable, but inconsistent throughout 2019, due to a poorly established sward and intense competition with planted grasses and weeds. Fluctuation in the wheat and cowpea presense (as observed in June to September of both years) in the annual rotation aligns with similar observations in a conventional study at MTREC (Tables 1.2; Nave et al., 2019).

Weeds were the dominant component of the bermudagrass monocultures and mixtures in multiple months of 2019 and 2020, likely as a consequence of earlier weedy swards as well as the summer 2019 re-establishment conditions (Table 1.3). The presence of grass weeds was notable in the surprisingly consistent weed competition through a majority of the 2020 growing season, which did not differ among treatments (Table 1.4). Of the botanical components, broadleaf weeds were the dominant weed category across the growing season season (Table 1.4). Part of this dominance may be explained by niche parititioning between functional groups, but also seed dormancy in the weed seedbank (Bryson and DeFelice, 2009). In addition, there was great competition between bermudagrass, common bermudagrass, and crabgrass in 2019 and 2020. Weed dominance in a bermudagrass sward by comparable crabgrass grass species was notable in both botanical composition and weed surveys (Tables 1.1-1.4).

Correlations between forage mass of grass and legume, and general weed competition, expressed as a percentage of FM, were moderately negative for the spring and summer of 2020 (Table 1.5). This general trend across treatments is consistent with the literature regarding CSR theory as well as conventional wisdom (White et al., 1997).

Exceptions were the June and July sampling periods (Table 1.5). In 2020 there was a significant association between planted grass and broadleaf weed FM from April-July (Tables 1.5). These associations confirm conventional wisdom on weeds in planted grasslands. The only significant association between planted legumes (e.g. Austrian winter pea, cowpea, and alfalfa) and broadleaf weed FM was detected in May 2020 (Table 1.5). The lack of the association over the season might come as a consequence of the low levels of alfalfa in the perennial mixtures and the low levels of broadleaf weeds in the annual rotation, offsetting the trends within each treatment (Tables 1.2-1.5).

Weed competition as a whole was greater in the bermudagrass monocultures and mixtures from April to August in 2019 and from April to June 2020 (Table 1.3). During this period, the annual rotation and tall fescue, and tall-fescue-alfalfa treatments were less weedy likely as a consequence of effective competition when weeds germinated. In August 2020 this trend was reversed, as the bermudagrass monocultures and mixtures composition had increased grass proportion than previously observed, therefore the proportion of grass at the end of the 2020 growing season did not differ among treatments (Table 1.1, 1.4).

Overall, weed species richness was not significantly associated with specific treatments (P = 0.06, Table 1.6). However, the overall weed species richness was associated with year, as plots gradually became weedier (Table 1.6). Broadleaf weed species richness was not significantly associated with species selections, though the broadleaf richness increased over time (Table 1.6). All treatments gradually moved from low and medium levels of richness to high levels of broadleaf species richness (Table 1.6). Overall weed species richness aligns with broadleaf species richness, and likely drove the richness of the species. The grass and legume weeds present are considered acceptable forage species overall, even though not directly desired when plots were established. The 2020 presence of white clover in the plots likely improved the nutritive value of the stands as well as the summer performance of the tall fescue stands. Treatments were associated with higher weedy grass species richness (Table 1.6). This could be consequence of the disturbance generated by planting alfalfa into these stands as well as the competition between establishing alfalfa and the established grass. Grass weediness did not change over the transition period (Table 1.6). Grass and legume weeds were the primary forage weeds, whereas the broadleaf weeds were the main weeds of concern to livestock. Weedy legume species richness was not strongly associated with any treatments other than the tall fescue-alfalfa (Table 1.6). The greater presence of clover species in the cool season sward is probably due to their similar growth pattern with alfalfa as well as the limited alfalfa presence (Table 1.2). Legume richness was associated with year, which is tied to a 50-day drought in 2019 coupled with favorable precipitation in 2020 (Table 1.6; Figure 1.2).

Swards gradually became weedier over the course of the study, with the exception of the annual rotation (Tables 1.3-1.6). Weed competition was most reduced in the annual rotation. The identity of the species determined by weed surveys suggested that the weedy species present were still generally favorable for livestock. Orchardgrass (*Dactylis glomerata*) and white clover were present across all years of the study from the existing seedbank, though red clover (*Trifolium pratense*) appeared in July 2020. White clover was the primary species detected in the 2020 botanical composition by functional groups. Weed population shifts were not as pronounced in the study as were expected from the organic literature (Rosenfeld et al., 2012; Turner, 2012). Some weeds appeared in some years of the transition but not others as a consequence of changing precipitation and temperature, such as the mare's tail, or horseweed (*Conyza canadensis*) and hop clovers (*Trifolium campestre* and *Trifolium dubium*) seen at the site. As would be expected in a conventionally tilled site, no conservative grassland species, that is species indicative of climax native grasslands, were present (Veldman et al., 2015). The lack of a major shift in weed species was likely an artifact of land use history as well as the objectives of the study. The orchard baseline vegetation was a happenstance mixture of bermudagrass, white, red, and hop clovers, and orchardgrass. Given the study examined forages rather than row crops, these elements in the weed seedbank could re-establish in the planted forage species selections.

Species richness alone is not the best measure of resiliency in natural systems, because of species identity and function matter (Tracy et al., 2018; Vermeire et al., 2018; Noss, 2013; Fleishman et al., 2006). Of particular note was crabgrass (*Digitaria sanguinalis*), which was present in almost every plot across the 3-yr transition period. Crabgrass is a favorable forage among the weed species present in the Southeast and functions as a perennial through seedbank recruitment (Nave and Corbin, 2018; Gelley et al., 2017; Barrett, 2014; Dekker, 1997; Sorensen, 1978). Weed competition in bermudagrass required a combination of increasing defoliation and herbicide treatment in conventional treatments (Hendricks et al., 2020; Gary Bates and David McIntosh, unpublished data). In the case of pigweed (*Amaranthus* spp.), the seedbank might negate species selection without increased tillage (Brainard et al., 2011; Steckel, 2007; Dekker, 1997).

Weed control in a low-input organic setting is limited to tillage, defoliation, and prevention (Liebman and Davis, 2009). Dormancy mechanisms allow the weed seedbank to persist well beyond the 3-yr transition period (Steinbauer et al., 1955). The annual rotation underwent biannual tillage in addition to the planting of smothering species: wheat and sorghum-sudangrass (Odhiambo and Bomke, 2001; Clark, 2007). In the case of sorghum-sudangrass, allelopathy may have improved weed control (Clark, 2007, Scott and Weston, 1991; Weston et al., 1998). Tillage reset the plant community i each spring and fall, and growing annual species outcompeted weeds through vigorous growth.

The monthly harvests taken in both 2019 and 2020 may have influenced the incursion of weeds by exhausting plant nutrient reserves (Table 1.1; Quinby et al., 2020; Thinguldstad et al., 2020). In similar production settings, harvest intervals were longer and total annual harvests were fewer than in the present study (Quinby et al., 2020; Thinguldstad et al., 2020; Hendricks et al., 2020; Nave et al., 2019; Corbin et al., 2018; Bates and Beeler, 2008; Bates et al., 2010a; Bates et al., 2010b; Bates and McIntosh, 2013a; Bates and McIntosh, 2013b). However, weed competition has also been seen as a factor of cutting height rather than frequency in conventional C_3 swards (Kim and Albrecht, 2008). Crabgrass success in the perennial grass treatments may be a function of bare ground and limited cover (White et al., 1997). In a New Zealand C_3 perennial grass-legume sward, crabgrass succeeded where disturbance was more intense than normal in a temperate sod (White et al., 1997). Weed competition affects alfalfa more than perennial grasses at initial establishment. Alfalfa did not quickly establish and competed with a charged seedbank in this study, as evidenced by its trace presence in the first 2-yr of the transition period (Table 1.2). Additionally, alfalfa in the study had an incidence of leaf rust (*Uromyces striatus*) in summer 2020, likely as a consequence of a warm, wet summer (UT SPPC report, Victoria Xiong). An alternate strategy might be to use C_4 annual grasses as a smother crop during the summer before fall planting alfalfa (Forney et al. 1985).

Prevention in the study was effective at limiting artificial weed introductions to the plot. Equipment cleaning and buffer areas kept out contamination from weedy pastures. Three avenues of weed introductions in the study site were potentially Canadian geese (*Branta canadensis*), seedbank recruitment, and the spring manure applications to the tall fescue and bermudagrass monocultures.. The 30-yr field history of the site as an orchard favored a large seedbank of white clover, crabgrass, and common bermudagrass (Liebman and Davis, 2009).

Manure was turned with a tractor during the composting process, but no test on the manure was made to determine potential weed seed contamination, as suggested by Brainard et al. (2011). In practical settings, low levels of weed seed contamination are likely (Cooperband, 2002; Dekker, 1997). The soil microbiota could similar favor certain species during the establishment period as has been seen in native grasslands (Middleton and Bever, 2012).

Total Annual Forage Mass

Of the five treatments, the annual rotation produced the most total annual forage mass in 2019 (Table 1.7). However, the bermudagrass-alfalfa and bermudagrass treatments did not differ. The tall fescue, tall fescue-alfalfa treatments performed similarly to the corresponding bermudagrass and bermudagrass-alfalfa treatments. The greater and lesser performing treatments significantly differed by ~2000 kg ha^{-1} of annual forage mass. The annual rotation had actively growing forage between Nov. 2018 and Apr. 2019, during which the tall fescue, tall fescue-alfalfa and bermudagrass treatments were not actively growing. Winter wheat and Austrian winter pea are able to actively grow at low temperatures (Figure 1.1; Clark, 2007). Even with the wet, warm winter in 2019, the phenological pathway of winter wheat and Austrian pea would give these species an advantage over most perennial grass and grass-legume mixtures (Figure 1.2). Similarly, the sorghum-sudangrass and cowpea mixture were able to maintain productivity in the cooler than average, dry 2019 summer. Their relative drought tolerance allowed it to grow well in the face of the drought period during Aug. and Sep. 2019. Given re-establishment efforts in the fall resulting in subsequent successful stands, the grass-alfalfa mixtures were not limited.

In 2020 the annual rotation, tall fescue, and tall fescue-alfalfa treatments performed comparably. Weather conditions were favorable for early season productivity of these species, and regular precipitation supported continued growth further into the summer (Figure 1.2). The productivity of the tall fescue and tall fescue-alfalfa treatments was tied to the favorable weather conditions as well as the relatively competitive forage grass component present (Tables 1.1-1.4).Whereas weeds comprised the majority of the bermudagrass monoculture and mixture, tall fescue was the majority component in its respective treatments.

The University of Tennessee Beef and Forage Center regularly executes variety trials at similar testing locations in the region (Bates and Beeler, 2008; Bates et al., 2010a; Bates et al., 2010b; Bates and McIntosh, 2013a; Bates and McIntosh, 2013b). These trials seldom required postplant herbicide applications. Other than a nonselective burndown herbicide, generally glyphosate, these trials were able to successfully establish and compete against weeds. At the same research station, conventionally managed stands of tall fescue have been shown to produce variable FM between years (Bates and Beeler, 2010b). The yield penalty concept is presently debated in the organic literature, (Seufert et al., 2012; Delate and Cambardella, 2004; Badgley et al., 2006; Lammerts van Bueren and Verhoog, 2006). While the literature suggests a gradient of a penalty, it was hypothesized that the current agronomic practices and limited genetics gains in FM across species would result in similar productivity. The annual rotation, with its multiple components, when compared to conventionally managed stands of wheat and sorghum-sudangrass, had a yield penalty of 51% in 2019. A study with a sorghum-sudangrass and cowpea mixture of similar seeding rates on similar soils produced more FM in 2016 and 2017 than the combined components of annual rotation treatment (Nave et al., 2019).

All nutrients with the exception of N seemed to be satisfactory during the study. Because manure was applied to the tall fescue and bermudagrass monocultures, these treatments would have also received additional P, K, and micronutrients from the manure. Manure additionally is a source of organic matter, which may have provided additional benefits such as improved water-holding capacity and reduced soil compaction (Magdoff and van Es, 2009). Compared conventional N, organic N management was not as immediately available in the present study's perennial grass monocultures; however, additional N applications throughout the season were more than double that applied in the present study: 224 kg N ha^{-1} for bermudagrass and 168 kg N ha^{-1} for tall fescue as opposed to the 84 kg total N ha^{-1} for the both species in the present study (Bates et al., 2010b; Bates et al., 2013a). In light of the reduced N available, the low-input organic systems observed may actually be more N-efficient (kg forage kg^{-1} N applied) than the pre-existing best practices.

Legume presence did not affect the total annual forage mass between the perennial grass monocultures and their corresponding mixtures (Table 1.2, 1.7). The grass-alfalfa mixtures were sought for the purpose of biological nitrogen fixation (Quinby et al., 2020; Ledgard and Steele, 1992). Given that alfalfa populations were well-below conventional densities (<5 plants per 0.1 m^2) for a significant duration of the study, the lack of differences between each perennial grass monoculture and its respective mixture was reasonable (Tables 1.1-Table 1.7; Quinby et al., 2020; Jennings and Nelson, 2002; Jennings and Nelson, 1998). More alfalfa plants could have been present in the stand than were observed, given that 50-60 plants m^{-2} is the minimum stand for economic production (Ball et al., 2015). The annual rotation mixtures included legumes for the benefits of N fixation in addition to previously seen improvements in nutritive value (Nave et al., 2019).

Plant density and productivity have a similar relationship as diversity and productivity (He et al., 2005; Symstad et al., 1998). Annual plantings reset plant populations to maintain stands. In the perennial grass monocultures and mixtures, no additional seed was planted. Stand renovation is ecologically possible for tall fescue and bermudagrass, though replanting alfalfa is contextual to the existing plant stand (Bartholomew, 2005; Jennings and Nelson, 2002; Jennings and Nelson, 1998). Short of a complete stand failure, alfalfa's autotoxicity cannot be overcome without a time delay (Biermacher et al., 2012; Jennings and Nelson, 2002; Jennings and Nelson, 1998). In the transition period any modicum of plants above the 50-60 plants m^{-2} density would preclude replanting alfalfa (Jennings and Nelson, 2002; Jennings and Nelson, 1998). *Sclerotinia* crown rot is also a concern (Scott et al., 2014). Similarly, allelopathic crop history might preclude alfalfa, such as the case of sweet clover (*Melilotus officinalis*) and sorghum-sudangrass (Clark, 2007; Forney and Chester, 1984; Forney et al., 1985).

In C_3 swards, other authors have seen forage mass increase with harvest frequency (Kim and Albrecht, 2008). Intensity—or cutting height for defoliation—is tied to persistence in swards as a consequence of morphological structure and physiological reserves (Tracy et al., 2018; Jones and Tracy, 2017; Kallenbach et al., 2002). Kallenbach et al. (2002) took 4-6 cuts of pure alfalfa stands and determined four cuts to maximize quantity and five cuts to optimize quality. Jones and Tracy (2017) took three cuts each year of mixed orchardgrass-alfalfa stands as opposed to the present study's six cuts on analogous tall fescue-alfalfa stands. With infrequent defoliation schedules, intensity would determine forage mass and persistence relationships because plant recovery from previous defoliations would be more than sufficient (Jones and Tracy, 2017). Frequency is then better tied to persistence (Tracy et al., 2018). In C_4 swards, such as sorghum-sudangrass, bermudagrass, and crabgrass, three-cuts per growing season are recommended in the literature on the basis of plant height (Gelley et al., 2017). At the extreme end of increased harvest frequency is continuous grazing pressure exerted by continuous stocking in some production systems. Over time such systems might exhaust certain forage species (Sheaffer et al., 1988). Best practices, as evidenced by University of Tennessee variety trials, suggest two cuts for tall fescue, three cuts for bermudagrass, and four cuts for alfalfa during each of its growing season (Bates et al., 2010b; Bates and

McIntosh, 2013a; Bates and McIntosh, 2013b). For the forage wheat and sorghum-sudangrass trials, harvests occurred twice (Bates and Beeler, 2008; Bates et al., 2010a).

Average Monthly Forage Mass

Species selections differences in average monthly forage mass harvests were statistically different in 2019 with the exceptions of June and July 2019 (Table 1.8; P=0.14 and P=0.09). Within each month, the seasonal growth patterns present in the swards were not always consistent with known C_3 and C_4 grass growth curves. The exceptions observed in June and July 2019 were consistent with the re-establishment of the bermudagrass and bermudagrass-alfalfa treatments. Similarly, the warm-season annuals were established in June after harvesting the C_3 annuals. In June 2019, the young annual treatments performed comparably to the grass and grass-alfalfa mixtures out of their peak growth season (Table 1.8). As harvesting continued from April to June, the C_3 annuals decline in productivity and their competitive ability against growing season weeds (Tables 1. 3, 1.8). The termination process resets this competition in the annual rotation. In the tall fescue and tall fescue-alfalfa, growth is slowed by increasing summer temperatures and reduced soil water availability and weeds like crabgrass gradually increase in the sward. Alfalfa in mixtures did not result in changes in monthly forage mass, with the exception of May 2019 when comparing bermudagrass and bermudagrass-alfalfa.

During August and September 2019, a severe drought limited forage production across treatments. The September harvest FM was an order of magnitude less than the August harvest FM (Table 1.8). Harvesting during the drought likely limited plant recovery at the end of the growing season. The growth rate of sorghum-sudangrass is greatest in July, which was difficult to confirm in July 2019 (Nave et al., 2019; Gelley et al., 2016). The forage mass harvested each month suggests that plants were not replacing lost forage mass during the August and September 2019 period.

Differences in FM were observed throughout the entire 2020 growing season (Table 1.8). The progression of species selections producing the most FM followed conventional expectations; the annual rotation was the most productive treatment in April, the tall fescue monocultures and mixtures were comparable to the annual rotation in May, and most of the species selections were comparable in June. In May the tall fescue monoculture was significantly more productive than either the bermudagrass or the bermudagrass-alfalfa (Table 1.8). The tall fescue-alfalfa performed similarly to the bermudagrass-alfalfa, but it differ from bermudagrass in the same month. The variability of weed competition within and among treatments at the start of the growing season appears to confound the performance of relatively simple mixtures. The convergence in June 2020 appears to align with the end of the C_3 annual growth as well as the tall fescue and tall fescue-alfalfa summer slump. The increased performance of the tall fescue-alfalfa relative to bermudagrass-alfalfa in June is likely tied to the aforementioned weed competition developing in the bermudagrass-alfalfa mixtures.

In mixed C_3 – C_4 swards, the FM available over the course of the growing season has been found to be more important than total annual forage mass (Belesky et al., 2002; Mitchell et al., 1986). Southeastern producers are pressed for forage in the winter and summer (Ball et al., 2015; Mitchell et al., 1986).

Monthly harvesting to the extremes of the growing season likely limited production during the study. Tall fescue and annual rotation treatments would not be as restricted for photosynthetic resources as the C_4 bermudagrass treatments (Volenec et al., 1996).

Alfalfa was challenging to establish and maintain over the course of the study. In the best performing plot in August 2020, there were fewer than 50 stems m^{-2} (Tables 1.2, 1.8). A conventional stand on the same location of the study faced severe competition with Palmer pigweed (*Amaranthus palmeri*), but was terminated before the start of the present study.

Tall fescue was introduced to the wider market at the outset of modern agronomic practices, including systematic fertilizer and pesticide applications (Hoveland, 2009). Because of this history, the species was hypothesized to perform well within the low-input organic conditions. The relatively comparable performance between the monocultures and mixtures was a consequence of the trace alfalfa presence at the outset of the study as well as the broadleaf and leguminous weed components observed (Tables 1.2, 1.4). White clover appeared in plots and likely provided additional N to the stands. The tall fescue treatments performed comparably to tall fescue monocultures fertilized with ammonium nitrate and broiler litter in an earlier Tennessee study, though the climatic differences between the Cumberland Plateau study site and the present Nashville Basin study site must be emphasized (Corbin et al., 2018). The Plateau is cooler than the Nashville Basin, and thus tall fescue is under reduced physiological heat stress in the aforementioned study. Additionally, target N fertility was identical to the present fertility management, though losses due to leaching were possible given the spring precipitation patterns in 2019 and 2020 (Corbin et al., 2018).

Bermudagrass and bermudagrass-alfalfa plots were subject to the greater weed competition among the treatments (Table 1.3); however, the bermudagrass component was generally detected in the sward (Table 1.1). Fowler (1981) suggests that defoliation resets competition dynamics in botanically-complex C_4 swards. Crabgrass persistence was tied to a similar growth pattern as bermudagrass, but the bermudagrass persistence may have been a consequence of regular harvesting (Table 1.8; Fowler, 1981). A study of alternative N fertilization in conventional tall fescue and bermudagrass harvested five times each year on a monthly basis produced more FM than the present study (Tables 1.7, 1.8; Corbin et al., 2018). This comparative success may be due to the different warm and cool season legumes used and successfully established, as well as the limited weed competition possible under conventional sward management (Corbin et al., 2018; Quinby et al., 2020). Cool season legume presence would extend the seasonal FM for the bermudagrass-alfalfa mixtures (Hendricks et al., 2020; Quinby et al., 2020). A conventional study involving grass-alfalfa mixtures suggested a 42 day harvest frequency for tall fescue-alfalfa mixtures and a 35 day harvest frequency for bermudagrass-alfalfa mixtures (Quinby et al., 2020). For bermudagrass-alfalfa mixtures, the 28-35 day frequency is maintained as best practices in the Southeast (Hendricks et al., 2020; Thinguldstad et al., 2020). Under the monthly cutting regime, mixtures were cut 7-10 days more frequently than the recommendation (Quinby et al., 2020). This frequent cutting would have corresponding consequences for alfalfa persistence (Tables 1.2, 1.3; Quinby et al., 2020; Thinguldstad et al., 2020). This persistence problem could be exacerbated by the fertility management paradigm; without regular applications of P and

K, the low-input system could struggle to meet the needs of a better stand (Thinguldstad et al., 2020).

Earlier work in sorghum-sudangrass favors management for nutrient value given the relatively high FM of the crop (Gelley et al., 2017; Creel and Fribourg, 1981). Management for quality supercedes the relative abundance of FM. The dynamics of sorghum-sudangrass and cowpea mixtures has been examined with challenges apparent to maintaining economic value, given that cowpea was not observed to give additional FM to a mixture as compared to a monoculture (Nave et al., 2019). The relative gains in nutritive value as compared to sorghum-sudangrass monocultures are curbed by relative expenses of including cowpea (Nave et al., 2019).

Cereal grains, like winter wheat, as well as Austrian pea cover crops are often incorporated into row crop systems between cash crops (Clark, 2007; Vincent-Caboud et al., 2019; Butler et al., 2016; Reddy et al., 2003). The preference for biomass in cover cropping as well as crop phenology explains the high FM observed in the first harvests of each growing season (Table 1.8). In the present study, the C_3 annuals are planted in October of the previous year, for subsequent harvest in April, May, and June. The extreme decline in FM by June is not necessarily applicable to organic vegetable systems where the cover crop is terminated earlier (Butler et al., 2016).

Forage Nutritive Value

In 2019, CP differed among treatments for all months except June (Table 1.9; P=0.47). The CP concentration for the annual rotation represented by the winter wheat and Austrian pea mixture was consistently greater in April and May, although it did not differ from bermudagrass-alfalfa in May 2019. The similarity among the annual rotation and the tall fescue monoculture and mixture in June was associated with the relative maturity of the C_3 annual and perennial grasses. With the exception of the bermudagrass and bermudagrass-alfalfa treatments in August, CP values were higher than the thresholds set for beef heifers, steers, and lactating cows (Ball et al., 2015). The CP of the species selections were generally above thresholds for horses as well, though drought conditions and a sharp decline in CP across treatments was seen in August and September 2019 (Table 1.9; Ball et al., 2015). In comparison to a similar sorghum-sudangrass and cowpea mixture, the present study's annual rotation maintained great CP (Nave et al., 2019).

In 2020, CP did not differ among treatments in April, though differences were observed for the remainder of the growing season (Table 1.9). The active new growth present in the C_3 planted forages and weeds aligned the treatments. In May and June, this active new growth of the annual rotation was sufficient to distinguish CP concentration from tall fescue and tall fescue-alfalfa, although neither treatment differed from bermudagrass monoculture and mixture (Table 1.9). The failure to separate means in June 2020 despite a detected difference among treatments suggests that the Tukey post-hoc test was conservative in a month where statistical power was likely lacking (Table 1.9).

Weed presence improved nutritive value for the bermudagrass and bermudagrass-alfalfa treatments in months when the planted forages were not actively growing (Tables 1.2-1.3, 1.9). In addition to forage species deemed weeds merely on the basis of their origin, some of the common grassland weeds were present (e.g. crabgrass, Carolina geranium (*Geranium carolinianum*), white clover, and pepperweed (*Lepidium virginicum*) (Table 1.4). Many of these weeds have greater nutritive value, though actual animal consumption might not be commensurate (Bosworth et al., 1985; Bosworth et al., 1980). Similar weed influences on nutritive value have been seen in comparable conventional studies (Quinby et al., 2020). In bermudagrass monocultures and mixtures the high weed levels maintained nutritive value even when the bermudagrass was not in-season.

In 2019, NDF differed among treatments for all months except July (Table 1.10). In April 2019, the tall fescue monoculture was significantly more fibrous than the annual rotation or tall fescue-alfalfa mixture. Legume presence in the latter two treatments likely explains the pattern. In May 2019, the tall fescue monoculture and mixture were significantly more fibrous than the other treatments (Table 1.10). The bermudagrass monocultures and mixtures were starting active growth and the annual rotation had a higher proportion of legume material than the tall fescue-alfalfa mixtures (Table 1.2). The annual rotation was the most fibrous treatment in June 2019 as a consequence of monocarpic phenology of the C_3 annuals (Table 1.10). Additionally, the NDF in the tall fescue-alfalfa mixtures was likely enhanced by active growth by the trace amounts of alfalfa. The lack of significance in July 2019 could be explained by the re-establishment of the bermudagrass and bermudagrass-alfalfa treatments alongside the standard plantings of the C_4 annuals (Table 1.10). The drier summer likely increased the fiber content in the tall fescue monocultures and mixtures because the plants were not growing as actively. During the August 2019 drought period, the bermudagrass monoculture was more fibrous than the tall fescue mixture and monoculture (Fig 1.2, Table 1.10). In September, these differences were minimized and the only difference observed was between bermudagrass-alfalfa with greater NDF than tall fescue-alfalfa. This is likely to occur, based on the fact that C_3 species are growing more actively in mild temperatures during this period, therefore increasing its nutritive value. During the same period, the similarity among the annual rotation, bermudagrass-alfalfa mixture, and tall fescue monoculture were tied to the decline of the trace alfalfa present in both of the perennial grass-alfalfa mixtures. By the end of the 2019 growing season in September, no alfalfa was seen in either of the mixtures. The grass species present, thus determined the fiber in these mixtures. In the bermudagrass monoculture and mixture, crabgrass (*Digitaria sanguinalis*) was a major component of the observed weeds in 2019.

In 2020, NDF differences were observed among treatments from April to July. The annual rotation, given its high phenological maturity relative to the actively-growing perennial forages, was more fibrous than all other treatments in April (Table 1.10). The tall fescue and tall fescue-alfalfa were more fibrous in May and June 2020 than the bermudagrass and bermudagrass-alfalfa (Table 1.10). The annual rotation was similar to all the other treatments, likely due to the staggered active growth.

The IVDMD48 did not differ in April 2019 (Table 1.11). In every subsequent month, there were significant differences among the species selections (Table 1.11). The annual rotation was more digestible in May, July, August and September 2019, although it only differed from tall fescue monoculture in July and from bermudagrass monoculture and mixture in September (Table 1.11). The tall fescue mixtures were more digestible than the monocultures in June 2019, remaining similar for all other months. This reversal in the trend for the annual rotation is associated with the end of the C_3 annuals life history. The annual rotation had comparable digestibility during the summer months that remained consistent with 2016/2017 data on a similar sorghum-sudangrass and cowpea mixture (Table 1.11; Nave et al., 2019). The divergence of the tall fescue monocultures and mixtures might be explained by differences in the botanical composition at the transition between cool and warm season weeds, but also the trace alfalfa in the plots. Nutritive value of these forage species selections was influenced by the main species as well as the weed species present in the swards.

In 2020, digestibility was not different among treatments in April and June, but was different in May, August and September (Table 1.11). In-vitro dry matter digestibility remained high throughout these first three harvests despite the previously described differences in plant development (Table 1.11). The difference observed in May was a consequence of the 10% difference in digestibility between annual rotation and the bermudagrass monoculture (Table 1.11).

The present studied used the E+ tall fescue (c.v. KY-31). In a haying context, this hay could be suitable for maintaining most classes of livestock with reduced fear of toxicosis (Allen and Segurra, 2001; Gwinn et al., 1998). Throughout the study, tall fescue never passed the late boot developmental stage.

Sorghum-sudangrass was managed without consideration for potential dhurrin accumulation. Regardless of nutritional status, the risk of nitrate poisoning presents a risk to the end user’s livestock (Ball et al., 2015). Especially in light of the 2019 late summer-fall drought period, nitrate testing would have been important as a check on anti-quality factors, despite the relatively high quality of the forage. The addition of cowpea to sorghum-sudangrass stands has been previously shown to be beneficial to forage nutritive value, increasing both CP and digestibility (Nave et al., 2019).

Supplementation in livestock systems is often necessary to compensate for suboptimal nutritive value or fluctuating animal nutritional needs (Tilhou et al., 2018; Hafla et al., 2016; Mueller, 2016; Hafla et al., 2018). For low-input organic production, growing nutritious forage is a priority, especially given the access to pasture rule (USDA-NOP). Monthly harvest data suggest that the tall fecue, tall fescue-alfalfa, and annual rotation treatments will sufficiently meet cow-calf animal needs during the growing season. The bermudagrass and bermudagrass-alfalfa treatments will be insufficient during most of the growing season. For the C_3 annuals, winter grazing utilization is a possibility to avoid the question of supplementation, though spring FM might be limited as has been seen in cool season swards (Mueller, 2016; D'Souza et al., 1990; Baker et al., 1988; Wilman and Griffiths, 1978).

CONCLUSIONS

The present study evaluated five species selections under an organic transition program. Forage mass was maximized by the annual rotation. Nutritive value was maximized in the annual rotation, tall fescue, and tall fescue-alfalfa treatments across the growing seasons.

The fertility management regime was limited to a single application of manure to the grass monocultures, and the application was not as readily available as conventional N. With that considered, split-applications with increased quantities of N might improve future studies trying to optimize N applications in organic systems.

Future studies might consider using a three-cut system similar to commercial haying operations rather than the six-cut system used herein. This six-cut system was similar to the demands of rotational stocking, though further grazing evaluation is needed to determine whether the forage-livestock interaction inflates or decreases the yield penalty of low-input organic forages relative to conventional practices.

Weed competition in transitioning organic swards is an anecdotal concern validated by the increase in weed species over the transition period. While the organic vegetable literature promotes using ley systems as a transition phase for other cropping systems, the weed species richness in the seedbank can remain high over the transition. Some of these weeds affect the nutritive value and the FM of the stand so as to offset the predicted seasonal changes in these responses within a stand. Organic species selections could be thought to also include some of these common weeds that are acceptable in forage production systems.

Overall, an annual rotation of winter wheat and winter pea coupled with sorghum-sudangrass and cowpea was seen to produce the most forage mass in this evaluation within a low-input transitioning organic forage system. The annual rotation was also effective in terms of weed competition and nutritive value. These results however may have differed with the use of another legume such as red clover in the grass monocultures or the success of bermudagrass establishment. However, the long-term sustainability of an organic forages system over time will likely favor a perennial sod such as the tall fescue and tall fescue-alfalfa systems to prevent erosion. Tall fescue monocultures however would be limited by N requirements. Similarly, sod would be more favorable for grazing as opposed to haying.

Chapter 1 Tables and Figures

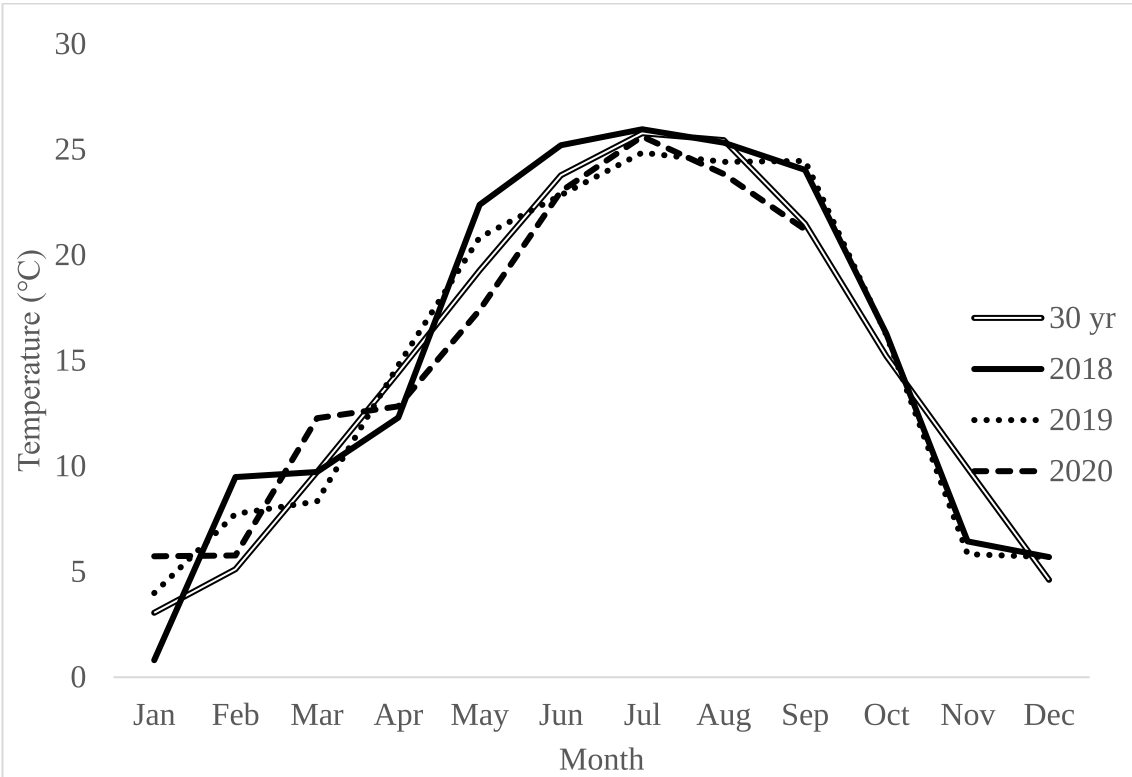

Figure 1.1 Air Temperature (℃) for Middle Tennessee AgResearch and Education Center, Spring Hill, TN, 2018-2020 including 30-year average.

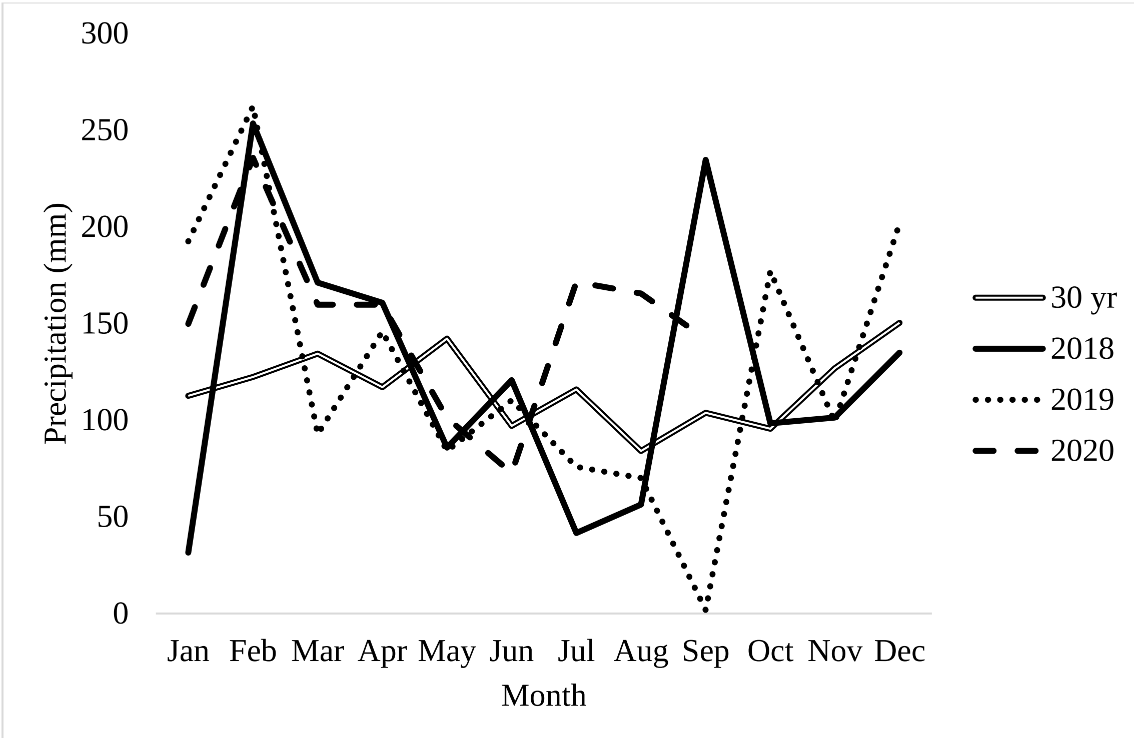

Figure 1.2 Precipitation (mm) for Middle Tennessee AgResearch and Education Center, Spring Hill, TN, 2018-2020 including 30-year average.

Table 1.1 Average forage grass proportion of five species combinations during two consecutive years under a low-input organic forage system in Tennessee.

	Forage Grass Proportion					
	------------------*g kg*$^{-1}$------------------					
2019	**April**	**May**	**June**	**July**	**August**	**September**
Annual Rotation	508.9^{B}	642.3^{A}	821.4	242.5^{B}	568.6^{A}	501^{A}
Bermudagrass	-	55^{B}	-	202.4^{B}	177.3^{B}	104.3^{B}
Bermudagrass-Alfalfa	-	138.9^{B}	-	211.5^{B}	102.1^{B}	73.6^{B}
Tall Fescue	956.5^{A}	861.1^{A}	822.3	788.3^{A}	545.3^{A}	200.6^{B}
Tall Fescue-Alfalfa	876.8^{A}	756.9^{A}	779.5	715.6^{A}	332.5^{AB}	116.3^{B}
P-value	<0.01	<0.01	0.87	<0.01	<0.01	<0.01
Standar error	23	65.9	65.1	79.5	60.7	54.8
2020						
Annual Rotation	854.4^{A}	968.1^{A}	695.5^{A}	184.3^{B}	491.5	819.4
Bermudagrass	0^{B}	125^{B}	39.8^{B}	666.8^{A}	768.5	511.6
Bermudagrass-Alfalfa	0^{B}	125^{B}	123.1^{B}	250.6^{B}	552.8	403.1
Tall Fescue	892.5^{A}	912.4^{A}	772.1^{A}	934.3^{A}	565.4	521.6
Tall Fescue-Alfalfa	712.6^{A}	794.4^{A}	624.9^{A}	908.5^{A}	374.4	357.5
P-value	<0.01	<0.01	<0.01	<0.01	0.15	0.19
Standard error	42	87.2	100.9	82.2	100.3	134.1

Means followed by the same superscript letter grouping within a column do not differ ($P \geq 0.05$).

Table 1.2 Average forage legume proportion of five species combinations during two consecutive years under a low-input organic forage system in Tennessee.

	Forage Legume Proportion					
	---------------------------------*g kg*$^{-1}$---					
2019	**April**	**May**	**June**	**July**	**August**	**September**
Annual Rotation	456.8^{A}	332.4^{A}	0	719^{A}	344.4^{A}	195^{A}
Bermudagrass	-	-	-	-	-	-
Bermudagrass-Alfalfa	-	83.9^{B}	-	27^{B}	0^{B}	0^{B}
Tall Fescue	-	-	-	-	-	-
Tall Fescue-Alfalfa	0^{B}	0^{B}	7.4	23.6^{B}	0^{B}	0^{B}
P-value	<0.01	<0.01	0.42	<0.01	<0.01	<0.01
Standar error	37.8	45	4.3	34.6	42.4	33
2020						
Annual Rotation	94.1	0	123.5	815.8^{A}	476.6^{A}	122.3^{A}
Bermudagrass	-	-	-	-	-	-
Bermudagrass-Alfalfa	5.6	20.6	85.3	547.3^{B}	117^{B}	3.3^{B}
Tall Fescue	-	-	-	-	-	-
Tall Fescue-Alfalfa	0	42	29.1	20.9^{C}	10.9^{B}	0^{B}
P-value	0.18	0.14	0.29	<0.01	<0.01	0.02
Standard error	34.5	37.5	51.4	41.1	61.1	24.5

Means followed by the same superscript letter grouping within a column do not differ ($P \geq 0.05$).

Table 1.3 Average weed proportion of five species combinations during two consecutive years under a low-input organic forage system in Tennessee.

	Weed Proportion					
	------------------------------$g\ kg^{-1}$------------------------------					
2019	**April**	**May**	**June**	**July**	**August**	**September**
Annual	34.4^{A}	25^{B}	179	39^{B}	87^{D}	308^{B}
Bermudagrass	-	945^{A}	-	798^{A}	823^{AB}	896^{A}
Bermudagrass-Alfalfa	-	777^{A}	-	762^{A}	898^{A}	927^{A}
Tall Fescue	44^{B}	139^{B}	178	212^{B}	455^{C}	800^{A}
Tall Fescue-Alfalfa	123^{B}	244^{B}	213.1	261^{B}	668^{B}	884^{A}
P-value	<0.01	<0.01	0.90	<0.01	<0.01	<0.01
Standard error	60	60	60	70	50	50
2020						
Annual	52^{C}	32^{B}	181^{B}	0^{B}	32^{B}	58
Bermudagrass	1000^{A}	875^{A}	960^{A}	333^{A}	231^{AB}	488
Bermudagrass-Alfalfa	994^{A}	755^{A}	791.6^{A}	202^{AB}	330^{AB}	594
Tall Fescue	108^{C}	88^{B}	228^{B}	66^{AB}	435^{AB}	479
Tall Fescue-Alfalfa	287^{B}	164^{B}	346^{B}	68^{AB}	615^{A}	643
P-value	<0.01	<0.01	<0.01	0.03	0.01	0.07
Standard error	40	100	110	70	100	130

Means followed by the same superscript letter grouping within a column do not differ ($P \geq 0.05$).

Table 1.4 Botanical composition on a pooled annual sum of biomass basis of of five species combinations during 2020 under a low-input organic forage system in Tennessee.

	Pooled annual sum of components				
	---------------------------------- *g kg^{-1}*----------------------------------				
	Forage Grass	**Forage Legume**	**Grass Weed**	**Legume Weed**	**Broadleaf Forb Weed**
Annual Rotation	651.1^{A}	304.7^{A}	23.6	0^{B}	20.6^{B}
Bermudagrass	429.3^{C}	-	201.8	30.2^{A}	338.6^{A}
Bermudagrass-Alfalfa	262.2^{C}	127.7^{B}	279.4	33.7^{A}	297^{A}
Tall Fescue	774^{B}	-	138.2	34.3^{A}	53.5^{B}
Tall Fescue-Alfalfa	586.6^{BC}	10.9^{B}	295.4	28.9^{A}	78.3^{B}
P-value	<0.01	<0.01	0.22	<0.01	<0.01
Standard error	71.6	29.1	76	15.1	32.2

Means followed by the same superscript letter grouping within a column do not differ ($P \geq 0.05$).

Table 1.5 Correlations (*P* = 0.05) between forage grass and legume components with respective grass, legume, and broadleaf weed components under low-input organic forage systems in Tennessee.

	Grass Weed	Legume Weed	Broadleaf Forbs
April			
Forage Grass	NS	-	-0.46 (*P*<0.01)
Forage Legume	NS	-	NS
May			
Forage Grass	NS	-	-0.64 (*P*<0.01)
Forage Legume	NS	-	0.45 (*P*<0.01)
June			
Forage Grass	NS	NS	-0.58 (*P*<0.01)
Forage Legume	NS	NS	NS
July			
Forage Grass	0.24 (*P*=0.14)	NS	-0.39 (*P*=0.01)
Forage Legume	NS	NS	NS
August			
Forage Grass	NS	NS	NS
Forage Legume	NS	NS	NS
September			
Forage Grass	0.33 (*P*=0.04)	NS	NS
Forage Legume	NS	NS	NS

NS denotes non-significant correlations ($P \geq 0.05$).

Table 1.6 Weed richness level associations of grass, legume, and broadleaf forb functional groups with five species combinations and years by Fisher's exact test under low-input organic forage systems in Tennessee.

Response Association	**Weed Species Richness**			
	Overall	**Grass**	**Legume**	**Broadleaf**
Treatment	$P = 0.06$	$P = 0.04$	$P < 0.01$	$P = 0.20$
Year	$P < 0.01$	$P = 0.19$	$P = 0.01$	$P < 0.01$

Based on Fisher's exact test ($P = 0.05$).

Table 1.7 Total forage mass (FM) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee.

Treatment	**Year**	
	Total FM (kg ha^{-1} yr^{-1})	
	2019	**2020**
Annual Rotation	7020^{A}	6501^{A}
Bermudagrass	2949^{B}	2251^{B}
Bermudagrass-Alfalfa	4863^{B}	3796^{B}
Tall Fescue	4211^{B}	3976^{AB}
Tall Fescue-Alfalfa	4052^{B}	4128^{AB}
P-value	<0.01	<0.01
Standard Error	507	574

Means followed by the same letter grouping within a column are not statistically different ($P \geq 0.05$).

Table 1.8 Average monthly forage mass (FM) of five different species combinations during two consecutive years under a low-input organic forage system in Tennessee.

	Monthly Forage Mass (FM)					
	---------- *kg ha⁻¹* ----------					
2019	**April**	**May**	**June**	**July**	**August**	**September**
Annual Rotation	2403^{A}	1245^{AB}	279	340	2433^{A}	321^{AB}
Bermudagrass	-	389^{B}	-	495	1800^{A}	266^{ABC}
Bermudagrass-Alfalfa	-	1486^{A}	-	670	2276^{A}	433^{A}
Tall Fescue	1421^{B}	1847^{A}	286	200	360^{B}	98^{C}
Tall Fescue-Alfalfa	1456^{B}	1507^{A}	180	203	551^{B}	156^{BC}
P-value	<0.01	<0.01	0.14	0.09	<0.01	<0.01
Standard error	86.6	246.6	36.2	138.5	162.5	42.5
2020						
Annual Rotation	1496^{A}	931^{ABC}	222^{AB}	503^{A}	2341^{A}	1010
Bermudagrass	104^{B}	402^{C}	149^{B}	181^{B}	926^{BC}	490
Bermudagrass-Alfalfa	144^{B}	794^{BC}	194^{AB}	399^{AB}	1627^{AB}	638
Tall Fescue	343^{B}	1886^{A}	221^{AB}	256^{AB}	579^{B}	692
Tall Fescue-Alfalfa	358^{B}	1699^{AB}	250^{A}	263^{AB}	716^{BC}	843
P-value	<0.01	<0.01	0.03	0.02	<0.01	0.1
Standard error	98	239.4	19.7	61.7	205	125.7

Means followed by the same letter grouping within a column are not statistically different ($P \geq 0.05$).

Table 1.9 Crude protein (CP) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee.

	Crude Protein (CP)					
	----------$g\ kg^{-1}$----------					
2019	**April**	**May**	**June**	**July**	**August**	**September**
Annual Rotation	189.8^{A}	181.7^{A}	157.5	217.4^{A}	108.3^{B}	144.5^{A}
Bermudagrass	-	148.1^{B}	-	155^{B}	76.7^{C}	106^{B}
Bermudagrass-Alfalfa	-	157.6^{AB}	-	182.1^{AB}	86.4^{C}	109.8^{B}
Tall Fescue	151.9^{B}	133.8^{B}	157.9	166.2^{B}	131.1^{A}	142.1^{A}
Tall Fescue-Alfalfa	146.1^{B}	133.6^{B}	161.2	171.6^{AB}	125.1^{A}	134.4^{AB}
P-value	<0.01	<0.01	0.47	0.01	<0.01	<0.01
Standard error	6.3	7.3	3.6	10.8	3.9	6.7
2020						
Annual Rotation	164.9	158.9^{A}	193.4^{A*}	258.3^{A}	107.1^{C}	144.3^{C}
Bermudagrass	178	149^{AB}	169^{B}	171^{C}	153.7^{AB}	151.5^{ABC}
Bermudagrass-Alfalfa	172.6	152.2^{AB}	189.1^{A}	211.5^{B}	138.1^{B}	147.3^{BC}
Tall Fescue	196.2	138.6^{B}	169.8^{B}	165.2^{C}	169.6^{A}	165.8^{AB}
Tall Fescue-Alfalfa	177.1	139.6^{B}	171.2^{B}	175^{C}	169.3^{A}	169.3^{A}
P-value	0.20	0.01	0.02	<0.01	<0.01	<0.01
Standard error	8.7	3.4	5.5	4.8	4.5	4.5

Means followed by the same letter grouping within a column are not statistically significant ($P \geq 0.05$).

*Mean separation for June 2020 was achieved using Fisher's LSD. This post hoc test was seleted because the conservative Tukey HSD test could not detect differences despite a significant ANOVA.

Table 1.10 Amylase neutral detergent fiber (a-NDF) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee.

Neutral detergent Fiber (NDF)						
	------------------------------------*g kg*$^{-1}$--					
2019	**April**	**May**	**June**	**July**	**August**	**September**
Annual Rotation	491.4^{B}	573.7^{B}	601.9^{A}	447.5	631.8^{ABC}	556.1^{AB}
Bermudagrass	-	509.6^{B}	-	552.5	664.2^{A}	609.7^{AB}
Bermudagrass-Alfalfa	-	535.7^{B}	-	512.1	658.2^{AB}	611.7^{A}
Tall Fescue	533.2^{A}	664.3^{A}	562.6^{B}	581.1	613.3^{BC}	574.3^{AB}
Tall Fescue-Alfalfa	501.7^{B}	675.1^{A}	539.9^{C}	592.3	592.7^{C}	553.2^{B}
P-value	0.02	<0.01	<0.01	0.12	<0.01	0.01
Standard error	8.5	18.6	7.5	38.8	11.9	12.8
2020						
Annual Rotation	554.6^{A}	459.2^{AB}	506.7^{A}	394.9^{C}	622	632.6
Bermudagrass	408.6^{BC}	409^{B}	421.4^{B}	503.9^{B}	578	624.3
Bermudagrass-Alfalfa	390.2^{C}	419^{B}	421.3^{B}	445.1^{C}	571.1	633.3
Tall Fescue	466^{B}	523.3^{A}	527^{A}	594.4^{A}	599.6	614.4
Tall Fescue-Alfalfa	451.8^{BC}	522.2^{A}	525.5^{A}	572^{A}	589.5	615.8
P-value	<0.01	<0.01	<0.01	<0.01	0.09	0.15
Standard error	13.8	15.1	8.8	13.7	12.5	6.3

Means followed by the same letter grouping within a column are not statistically significant ($P \geq 0.05$).

Table 1.11 In-vitro dry matter digestibility (IVDMD48) of five different species combinations during two consecutive years under a low-input organic forge system in Tennessee.

***In-vitro* dry matter digestibility (IVDMD48)**						
	------------------------------------*g kg^{-1}*--					
2019	**April**	**May**	**June**	**July**	**August**	**September**
Annual Rotation	808.4	740^{A}	738.4^{C}	853.1^{A}	741.1^{A}	721.8^{A}
Bermudagrass	-	646.1^{C}	-	733.1^{AB}	628.5^{C}	629.5^{B}
Bermudagrass-Alfalfa	-	645.1^{C}	-	799.1^{AB}	648.7^{C}	627^{B}
Tall Fescue	772.7	689.2^{B}	769.3^{B}	713.7^{B}	707.8^{B}	684.5^{A}
Tall Fescue-Alfalfa	770.8	671^{BC}	793.5^{A}	745.4^{AB}	698.5^{B}	686.6^{A}
P-value	0.09	<0.01	<0.01	0.02	<0.01	<0.01
Standard error	14.6	6.7	11.4	27.5	7	11.9
2020						
Annual Rotation	819.9	854.6^{A}	808.8	877.4^{A}	759.1^{A}	776.6^{A}
Bermudagrass	843.8	781.5^{B}	783.2	742.4^{C}	693.4^{B}	692.8^{C}
Bermudagrass-Alfalfa	834.8	805.8^{AB}	800.4	796^{B}	707.5^{B}	697.7^{C}
Tall Fescue	874.3	804.6^{AB}	803.2	753.1^{C}	744.5^{A}	746.7^{B}
Tall Fescue-Alfalfa	841.5	810.4^{AB}	800.3	764.5^{BC}	742.1^{A}	735.4^{B}
P-value	0.07	0.01	0.17	<0.01	<0.01	<0.01
Standard error	11.8	11.4	7.9	9.2	7.2	5.8

Means followed by the same letter grouping within a column are not statistically significant ($P \geq 0.05$).

Chapter 1 Appendix

Weeds present in a majority of of five different species combinations during three consecutive years under a low-input organic forge system in Tennessee.

Annual Rotation

Common name	**Scientific name**	**2018**	**2019**	**2020**
Bermudagrass	*Cynodon dactylon*	■	■	■
Spurge	*Euphorbia pubenticisma*			■
Crabgrass	*Digitaria sanguinalis*	■	■	■
Oxalis	*Oxalis sp.*		■	
Pepperweed	*Lepedium virginicum*		■	
Tall fescue	*Schedonorus arundinaceous*	■		
White clover	*Trifolium repens*			■

Bermudagrass

Common name	**Scientific name**	**2018**	**2019**	**2020**
Crabgrass	*Digitaria sanguinalis*	■	■	■
Galium	*Galium aparine*			■
Marestail/horseweed	*Conyza canadensis*		■	■
Orchardgrass	*Dactylis glomerata*			■
Oxalis	*Oxalis sp.*			■
Pepperweed	*Lepedium virginicum*		■	■
Spurge	*Euphorbia pubenticisma*		■	
Pigweed	*Amaranthus sp.*		■	
Tall fescue	*Schedonorus arundinaceous*	■		■
White clover	*Trifolium repens*			■
Fleabane	*Erigeron annuus*			■

Bermudagrass-alfalfa

Common name	Scientific name	2018	2019	2020
Crabgrass	*Digitaria sanguinalis*	■	■	■
Dandelion	*Taraxacum officinale*			■
Marestail	*Conyza canadensis*			■
Oxalis	*Oxalis sp.*			■
Pepperweed	*Lepedium virginicum*	■	■	■
Spurge	*Euphorbia pubenticisma*		■	
Tall fescue	*Schedonorus arundinaceous*			■
White Clover	*Trifolium repens*	■	■	■
Fleabane	*Erigeron annuus*			■

Tall fescue

Common name	Scientific name	2018	2019	2020
Bermudagrass	*Cynodon dactylon*	■	■	■
Crabgrass	*Digitaria sanguinalis*		■	
Marestail	*Conyza canadensis*		■	■
Orchardgrass	*Dactylis glomerata*		■	■
Oxalis	*Oxalis sp.*		■	■
Pepperweed	*Lepedium virginicum*	■		
White clover	*Trifolium repens*	■	■	■

Tall fescue-alfalfa

Common name	Scientific name	2018	2019	2020
Bermudagrass	*Cynodon dactylon*		■	■
Cheatgrass	*Bromus japonicus*	■		
Crabgrass	*Digitaria sanguinalis*		■	■
Dandelion	*Taraxacum officinale*			■
Orchardgrass	*Dactylis glomerata*		■	■
Oxalis	*Oxalis sp.*			■
Pepperweed	*Lepedium virginicum*	■		
White clover	*Trifolium repens*	■	■	■

CHAPTER 2:

Economic outcomes of cool and warm-season swards in transitioning organic swards

ABSTRACT

Despite the vast quantity of production and market research for forage and organic products nationally, limited work has evaluated organic forage production in the Southeast. The present study seeks to evaluate several species for optimizing forage production under low-input transitional organic conditions. This study was conducted at the Middle Tennessee AgResearch and Education Center, in Spring Hill, TN. The forage selections consisted of the following: a tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort.) monoculture, a bermudagrass (*Cynodon dactlyon* (L.) Pers.) monoculture, a tall fescue and alfalfa mixture (*Medicago sativa* L.), a bermudagrass and alfalfa mixture, and an annual rotation (winter wheat [*Triticum aestivum* L.] and winter pea [*Pisum sativum* L.] mixture rotated with a sorghum-sudangrass [*Sorghum bicolor* (L.) Moench *x Sorghum sudanese* (Piper) Stapf] and cowpea [*Vigna unguiculata* (L.) Walp.] mixture). Plots were established during the 2017-2018 growing season following a fallow orchard. Regular production measurements began in the 2019 calendar year when the plots achieved full organic certification status. The transition cost was determined by initial seed cost and by forage productivity. Developing budgets highlighted a gap in stand failure rates in the literature. On a hectare basis, tall fescue was the cheapest forage selection for the overall transition period, at \$796.48 ha^{-1}. However, on a cost per unit basis and a cost per unit of crude protein, all treatments were similar except for the bermudagrass monoculture (\$0.34 kg^{-1} forage mass and \$2.34 kg^{-1} crude protein). Given the lack of a premium during the transition period, tall fescue is the most cost-effective transition forage.

INTRODUCTION

Certified organic production is an increasing portion of the US agricultural sector (Baier, 2010; Baier, 2008; Baier, 2005; Brandao et al., 2012; Allen and Kovach, 2000). Consumer demand is increasing concurrent to an increasing focus on perceived food quality rather than on unit price (Allen and Kovach, 2000). This trend coincides with increasing disposable income as well as a societal desire for increased sustainability (Tilman et al., 2002; Tilman et al., 2001). While a majority of certified organic products focus on fruits, vegetables, and grains, there exists a demand for organic beef and dairy products (Heckman, 2019; Heckman, 2015; Brandao et al., 2012). In order to meet federal regulations, at least 35% of cattle's dry matter needs must be from grazing organic forages (Baier, 2010; Baier, 2008; Baier, 2005) while the remainder of their dry matter needs can be met with other organically produced feedstuffs. Indirectly, organically produced cattle must be raised cost-effectively on organic forages.

There are several barriers or challenges producers face when transitioning to organic forage production. The first challenge is remaining profitable while making this transition to an organic sytem. Transitioning to organic forage production requires producers to follow organic practices for three years prior to being able to use the organic designation when marketing their products (Brandao et al 2012; Baier, 2010; Baier, 2008; Badgley et al., 2006; Baier, 2005). The second challenge is managing weed and pest populations during the transition period and beyond. In some instances, weed and pest populations may temporarily increase during the transition phase resulting in lower forage yield and quality (Turner, 2012). Some of these issues may be compounded as forage producers attempt to address agronomic challenges and as they adopt new management practices (Porter, 2009). Lastly, certain input costs may increase during the transition phase as many conventional inputs will no longer be utilized. However, management plans, certification inspections, and detailed farm plans may increase costs, because they are inherent across the National Organic Program (NOP) (USDA-NOP; Baier, 2010; Baier, 2008; Baier, 2005). These requirements present economic and agronomic barriers to farmers (Brandao et al., 2012; Badgley et al., 2006) and require an extra level of management and capital allocation. Thus, it is imperative to develop cost-effective production and marketing strategies to assist producers through the transition phase and beyond (Tracy et al., 2018; Noss, 2013; Brandao et al., 2012; Schwenke, 1991).

Forage production for beef and dairy operations differs as a consequence of the product being produced. Cow-calf operations market stockers, stockering operations market feeder cattle, and feedlots market slaughter-ready cattle (Thomas, 2005) which all require a different balance of nutritional components to maintain a certain rate of growth. Dairy operations generally produce revenue from milk, milk products, and by selling bull calves. Given that these animals are lactating and milk and milk products are the primary revenue source, these animals require a higher plain of nutrition to support their biological system than beef cattle.

The aforementioned operations vary in cash flow, labor availability, and willingness to adopt certain practices because of the product being produced and marketed (Pray and Umali-Deininger, 1998; Feder and Umali, 1993). Similarly, forage resources must vary based on the needs of the class of livestock maintained on the farm (Ball et al., 2015; Baier, 2010; Baier, 2008; Baier, 2005). Perennial pasture, annual forages, or integrated crop and livestock systems may be used to maintain the nutritional needs and forage mass required to meet the biological needs of livestock, but the balance of the forage base may differ based on the class of livestock. Though there are differences among different pasture systems, pasture-based production systems can offer an economical feed supply for livestock (Gillespie and Nehring, 2014; Baker et al., 1988).

Conventionally managed forage systems have been widely studied with a considerable quantity of research to support management practices in perennial pasture, annual pasture, and integrated crop and livestock systems. However, there has been a limited much focus on organic forage production and how it influences profitability of an operation. This study seeks to determine the cost of transitioning from conventional to organic forage production for perennial forage species and annual forage species for beef and dairy cattle production systems. The optimal species selection must meet animal needs and organic certification standards, while also attempting to provide a positive net return to the operation through the transition period. Based on these criteria, the hypothesis of our study is that annual species are able to provide higher forage mass while maintaining forage nutritive value, therefore the optimal selection for an organic transitional program.

MATERIALS AND METHODS

Site Description

Field research took place at the Middle Tennessee AgResearch and Education Center in Spring Hill, TN. The station is within the limestone soils of the Nashville Basin. The site was a peach orchard for roughly 30 years before the study and had been fallow for 2 years prior to the start of the plot establishment.

Agronomic

Seed was sourced for all of the treatment species as per the requirements of the USDA Organic regulations. Certified organic and untreated seed was selected for all of the species. Certain varieties were selected on the basis of their use on working farms or University of Tennessee variety trials (e.g. KY-31 tall fescue, Cheyenne II bermudagrass) (Bates and Beeler, 2008; Bates et al., 2010a; Bates et al., 2010b; Bates and McIntosh, 2013a; Bates and McIntosh, 2013b).

Fertility management was focused on single applications of N and boron. Manure served as the most practical fertility source for a low-input organic forage system. The tall fescue and bermudagrass monocultures, lacking companion legumes, received manure in order to satisfy N requirements. Horse manure from the research station was utilized because the available bovine sources presented noxious weed contamination (*Amaranthus* spp.). Manure was applied at a rate of 84 kg ha^{-1} N in March 2019 and 2020 for tall fescue and the same rate in April 2019 and 2020 for bermudagrass. P_2O_5 and K_2O content applied in the 2019 manure applications were 72.1 kg ha^{-1} and 34 kg ha^{-1} respectively. P_2O_5 and K_2O content applied in the 2020 manure applications were 74.9 kg ha^{-1} and 27.8 kg ha^{-1} respectively. Boron was applied to the tall fescue-alfalfa and bermudagrass-alfalfa mixtures at a rate of 2 kg ha^{-1} in March of 2019 and 2020. This application followed university recommendations for alfalfa in Tennessee, as well as similar research (Quinby et al., 2020).

Site description, forage mass and crude protein analyses are included and described on Chapter 1 of this thesis. Production data for 2019 and 2020 are similarly aforementioned in Chapter 1.

Agricultural Economic measurements

Enterprise budgets were developed for each of the species evaluated. Establishment and production budgets for each of the five treatments were developed to account for the 3-year transition period (Tables 2.1-2.2). Average custom operation rates were used to calculate the cost of in-field production operations including chisel plowing, disking, planting, mowing, tedding, raking, baling, stacking and moving bales (Bowling, 2013). The treatments were priced as conventionally established. The establishment factored seeding rates assuming that seed was not treated with fungicides and pesticides as per USDA NOP (Table 2.1). Grass seed is regionally sold untreated and is thus similar to conventional operations. Seed pricing was consistent to the existing budget.

Establishment prorated in budgets assumed a stand failure rate of 15% across all perennial treatments and 2.5% for the annual treatment, given challenges establishing seeded bermudagrass and alfalfa during the study as well as the limited literature on stand failures in both conventional and organic literature (Biermacher et al., 2012; Barker et al., 2012; Griffith et al., 2011; Bartholomew, 2005). Bartholomew's (2005) synthesis suggest a range of 7-55% failure rate. Similar projects have assumed a 10% replant rate for native warm-season grasses under conventional management (Lowe et al., 2016a; Lowe et al., 2016b; Griffith et al., 2011). The establishment costs were amortized evenly across the 3-yr transition period for the perennial treatments (Table 2.2).

A series of production budgets was developed on the basis of harvest and fertility inputs (Table 2.2). Production budgets were similar to the establishment budgets, with the addition harvest costs and the omission of seed costs. The annual rotation establishment budget and production budgets both included seed costs given the need to establish crops twice annually. Manure was priced out by the value of the nitrogen ($0.70 kg^{-1} N), phosphorus ($0.68 kg^{-1} P_2O_5), and potassium ($0.68 kg^{-1} K_2O) content as well as the price of these elements in local markets. These common organic fertilizers included poultry litter, blood meal, bone meal, and manure.

The lifespan of the stands were assumed to be 3-yr, given that the transition period is 3-yr and that the current literature on alfalfa in the mid-South suggests that a 4-yr stand life is the maximum persistence expected under conventional conditions (Quinby et al., 2020; White and Lemus, 2015). For the sake of equivalent comparison, all treatment establishments were prorated over 3-yr; additionally, the literature regarding forages in organic agriculture favors incorporating grassland crops within larger production systems (Eichler-Inwood et al., 2015; Delate, 2009; Porter, 2009; Liebman and Davis, 2009; Kasperczyk and Knickel, 2006). For the sake of alternate uses, such as grain or specialty crops, the stand life is also conducive to land use conversion from forages following successful organic certification.

Boron pricing was assumed as the same as conventional sources; an OMRI-approved boron (Maxi Granular Boron 15%, Cameron Micronutrients, Virginia Beach, VA) was used. Boron prices came from Bowling (2013)($2.05 kg^{-1}). Boron application cost was considered as sprayed at a rate of 1.78 kg ha^{-1}.

This budget system assumed successful establishment, and that the forage harvested was taken as a dry hay crop in order to assess cost on both forage and crude protein bases. Haying inputs—such as baling twine—are priced out on the basis of forage mass harvested. These inputs were priced out using forage mass (FM) data from 2019 and 2020 as annual harvests. The model assumed a 1000-lb (454 kg) bale. The bales produced were converted from the annual forage mass collected in 2019 and 2020 by harvesting with a Swift silage flail chopper (Table 1.7; Swift Machine & Welding Ltd., Saskatoon, Canada). These harvests were conducted monthly from April to September. Annual averages for the production years, 2019 and 2020, are presented separately.

The baling costs were assessed on an annual basis to the total annual forage mass harvested within each replication of all treatments. The establishment year 2018 was omitted from measured harvesting in order to allow the treatments to establish.

Statistical analysis

Analysis and reporting were developed on literature recommendations (Kramer et al., 2019; Onofri et al., 2010). The experiment was laid out in a randomized complete block design of five species replicated in four plots. Plots were independent experimental units. Production costs were assessed to individual plots as per the budgets developed for their treatments as well as FM measurements made on individual plots. 2018 was omitted from analysis as an establishment year. Production years 2019 and 2020 were analyzed separately because of the re-establishment of the bermudagrass and alfalfa treatments in addition to the variability of the temperature and precipitation between the 2 years. ANOVA via PROC GLIMMIX was used to determine significance in annual FM and production cost of the treatments, and Tukey's HSD was used for means comparison (SAS v9.4, SAS Institute, Cary, NC). ANOVA were carried out on the 2 production years as well as the overall transition period. Identical analyses were carried out on the costs per kg forage and costs per unit crude protein. These analyses followed in a randomized complete block design with repeated measures of as a mixed model

ANOVA. Fixed effects included treatment within year. Random effects included block and block x treatment. The repeated measure was the production year.

RESULTS AND DISCUSSION

Weather

Weather shocks can be felt over time periods longer than the transition period (Countryman et al., 2016). Drought effects can be felt well beyond the transition period, and the ability of forage to buffer drought depends on the climatic and economic conditions before and after the transition period (Countryman et al., 2016). Weather risk might be factored into the cost of establishing annual forages, but was not fully captured in the current analysis (Shockley and Mark, 2017). Being able to run equipment in the field without damage to soil or planting in suboptimal conditions is a relevant question when an annual rotation is planted and terminated twice a year. Interactions between treatment and year were not seen, though years differed from one another as did treatments.

Total forage mass

Forage mass was reduced in association with high levels of weed competition present in the perennial grass and grass-alfalfa treatments. The weed presence was generally favorable (e.g. crabgrass, *Digitaria sanguinalis*), though pigweeds (*Amaranthus* spp.) also were present and would likely lower the market value of the hay.

The study did not assume any potential winter utilization of forage between December and March. Tall fescue and the cool season annuals would still offer some forage for winter grazing. However, such utilization would limit spring growth (Quinby et al., 2020; Baker et al., 1988; Wilman and Griffiths, 1978). Forage used as winter stockpiled forage is not necessarily available in spring; the spring growth is limited by nutrient reserves (Quinby et al., 2020; Tilhou et al., 2018; Backus et al., 2017; Volenec et al., 1996; Wilman and Griffiths, 1978).

Plot harvesting was conducted with respect to maintaining swards at a moderate intensity and with a constant monthly frequency. Defoliation intensity affects weed competition more than defoliation frequency in previous C_3 sward research (Kim and Albrecht, 2008). This defoliation regime would not be as practical for a producer growing hay, but would follow patterns of rotational stocking. Physiological recovery after harvest was likely limited by the monthly harvesting (Quinby et al., 2020; Kim and Albrecht, 2008; Volenec et al., 1996).

Suitability of certain species selections is also limited to the conditions required for equipment operation. Hay lands would generally be more level and fertile than pasturelands. In a low-input setting, N fertility was limited to biological N fixation for the mixtures and composted manure in the monocultures. N limitation associated even in transitioning fertile soils to certified organic production suggest that grass-legume mixtures would be preferable to grass monocultures, should the legumes successfully establish (Brandao et al., 2012; Delate, 2009; Delate and Cambardella, 2004; Ledgard and Steele, 1992). Compared to cropland soils, organic matter would be higher in grassland soils which would overcome the yield slump traditionally seen in transitioning systems (Mohler, 2009; Magdoff and van Es, 2009).

Establishment and Production

Tall fescue-alfalfa had the lowest establishment cost of the five treatments at \$178.29 ha^{-1}. The bermudagrass monocultures and annual rotation held the most expensive establishment costs, at \$286.84 ha^{-1} and \$293.83 ha^{-1} respectively (Table 2.1). The pattern of expenses appears commensurate with the associated seed costs and fertility inputs of all treatments.

The patterns of production costs was comparable to those seen in the establishment budgets (Table 2.1). The tall fescue-alfalfa and bermudagrass treatments differed by ~\$220 ha^{-1}, and the annual rotation was the most costly treatment in 2019 and 2020 (Table 2.1). These trends could be explained given the comparable forage mass production with differing levels of fertility inputs. The production costs patterns in 2020 correspond to the prior year, though budgets continued to be driven by the cost of harvesting hay and fertility inputs (Table 2.2).

Bermudagrass was the most expensive selection at \$0.13 kg^{-1} forage (Table 2.3). The other perennial treatments were similarly expensive on a per kg forage basis to the annual rotation. Relative productivity of these treatments, continuing fertility inputs, and the associated high seed costs, explains the similarity (Table 2.3).

The bermudagrass monoculture was more expensive, at \$0.88 kg^{-1} crude protein (CP), than the other treatments (Table 2.3). This pattern is likely explained by the generally higher CP content of the cool-season forages and legume components compared to the bermudagrass monoculture.

An opportunity in the peer-reviewed literature exists regarding stand failure in that the exact risk of stand failure has not been fully described for some forage species within most production regions, though some reports exist for dual-use species and specialty species (Corbin et al., 2018; Biermacher et al., 2012; Barker et al., 2012; Chapman et al 2008; Buxton and Wedin, 1970; Adams, 1968; Bates and McIntosh, unpublished data). Familiar introduced C_3 species have reported failure rates of 7-34% (reported in Bartholomew, 2005). Less-developed C_4 native species have failure rates ranging from 32-55% (Bartholomew, 2005; Ries and Hofmann, 1996). In a historical example, vetch (*Vicia* spp.) failed in 75% of the planting attempts (Adams, 1968). Planting errors range from timing and field conditions at planting to post-emergence competition and initial defoliation frequency (Ball et al., 2015). Bartholomew (2005) suggests that stands can be renovated for cheaper than complete replacement in low-input systems. In tall fescue and bermudagrass systems, overseeding is possible; however, the autotoxicity of alfalfa prevents overseeding above a certain plant population. These uncertainties in organic systems may limit the accuracy of the analysis, particularly if certain species selections are not reliably established in the face of weeds and soil quality.

Tall fescue is a successful grass in the southeastern United States because the species readily meets agronomic and animal needs (Hoveland, 2009). Development of the species predates intensive grassland management practices, and so tall fescue might reasonably perform well under low-input organic conditions simply because the species was already naturally selected under those conditions. Stand failure is possible in the tall fescue species, but KY-31 has a relatively low rate of failure in comparisons with other forms within the species (Rogers et al., 2014). For the Southeast, summer-active tall fescue is a common form.

Alfalfa's suitability for low-input organic systems depends on the successful establishment of the species as well as the initial soil fertility. Soil fertility at the outset of the project was sufficient for alfalfa and remained so throughout the transition period. Even in the event of a successful establishment, alfalfa would need to be replaced just after achieving certified organic status given the observed persistence of stands in conventional Tennessee and Mississippi systems (Quinby et al., 2020; White and Lemus, 2015). Given the minimal stand life of alfalfa in the Southeast, a grass mixture containing alfalfa may require a rotation where true clovers such as red (*Trifolium pratense*) and white (*T. repens*) are used for two seasons between alfalfa plantings. This post-transition planning is beyond the scope of this paper, but it is important given the knowledge gap in planning crop rotations through the transition period (Porter, 2009).

Seeded bermudagrass was selected in this study given that most commercial sprigging operations treat sprigs with prohibited substances (e.g. ahead of sale. The establishment and persistence challenges for seeded bermudagrass seen in the present study could be a consequence of weather and regional fitness. Tennessee is at the northern edge of suitable seeded bermudagrass planting areas. Winter hardiness is crucial for the subtropical species, and has been shown to be a challenge in conventional variety trials (Bates and McIntosh, unpublished data). Availability of a suitable cultivar comes to question when planning a transition, because untreated sprigs are not yet widespread in the region.

Bermudagrass and bermudagrass-alfalfa treatments came to be dominated by winter and summer cool and warm-season weeds. The crabgrass (*Digitaria sanguinalis*) that volunteered into the swards grew in similar phase to the common and seeded bermudagrass plants. In practical settings, with limited N, the crabgrass will eventually eliminate the bermudagrass through competition (Gelley et al., 2017; Fribourg et al., 1980). Though forage quantities were limited, crabgrass is preferable to other weeds such as pigweeds (*Amaranthus* spp.) or ragweeds (*Ambrosia* spp.). However, the annual rotation encountered little weed competition over the course of the study relative to the other treatments.

The species in the annual rotation—wheat, Austrian winter pea, cowpea, and sorghum-sudangrass—are effective cover crops and nutrient scavengers in conventional and organic systems (Florence et al., 2019; Büchi et al., 2018; Eichler-Inwood et al., 2015; Clark, 2007; Weston, 1996). Legume winter cover has been previously proposed to improve sustainability (Sheaffer and Seguin, 2003). Cover crop species have been seen to enhance maize yields in conventional settings, and likely supported subsequent crop success following each termination (Andraski and Bundy, 2005). The biannual tillage would be suboptimal for soil conservation outcomes, though process likely reduced weed competition in addition to the observed FM. Additionally, the two-mixture rotation may not meet certain interpretations of crop rotation requirements for the USDA-NOP (Baier, 2010; Porter, 2009; Baier, 2008; Baier, 2005).

Grass-legume compatibility is an important consideration in the transition period. The literature suggesting grass-legume mixtures as temporary grasslands between conventional and organic production highlights the benefits of biological N fixation as well as the stability of grassland ecosystems (Delate, 2009; Porter, 2009). Despite challenges in long-term legume persistence, especially in the case of alfalfa, maintaining legumes in mixtures during the 3 year transition period is an achievable—though challenging—agronomic ideal (Quinby et al., 2020; Butler and Muir, 2012; Brandao et al., 2012; Porter, 2009; Mitchell et al., 1986). The economic value of legumes relative to conventional N has been a hindrance to adoption in comparable conventional systems, but the value of legumes relative to organic N applications may subvert these earlier challenges (Corbin et al., 2018; Biermacher et al., 2012). In the case of annual forage crops, integrating cowpea into sorghum-sudangrass stands was not cost-effective in a local, contemporary study (Nave et al., 2019).

The present production cost analysis ignores the ecosystem services that perennial grasslands offer, such as: C sequestration, wildlife habitat, water quality, and erosion control (Blanco-Canqui et al., 2016; Ball et al., 2015; Wedin and Fales, 2009; Sanderson et al., 2009; Singer et al 2009). Less-intensely managed landscapes make more favorable matrix habitat for wildlife (Aoyoma and Huntsinger, 2019; Sanderson et al., 2009; Duelli and Obrist, 2003). Managing soil quality comes with good stewardship in low-input production systems (Fonte et al., 2014; Heckman, 2013; Powlson et al., 2009; Singer et al., 2009; Kasperczyk and Knickel, 2006; Cavigelli, 1998a; Cavigelli, 1998b; Bird et al., 1998). Forage species selection also matters as a consequence of ecosystem function; species vary in how they structure themselves and thus affect and effect ecosystem processes (Reich, 2014; Perkins et al., 2011). Organic regulations encourage grazing, which necessitates best management practices as well. With the potential for organic forages to be both hayed and grazed, such practices might include: keeping cattle out of waterways, rotating through paddocks, and providing water sources apart from ponds or streams (Lambert et al., 2014; Singer et al., 2009; Baier, 2010; Baier, 2008; Butler et al., 2007a; Butler et al., 2007b; Kasperczyk and Knickel, 2006; Baier, 2005).

Farm-level transition strategies require contextual knowledge of operations. In a similar understanding of ecology, transition strategies can incorporate inclusive paradigms of local knowledge (Black Elk, 2016; Heckman, 2013).

A risk in the development of low-input agronomic recommendations is that practitioners will be limited to short-term management perspectives. In low-input settings, economics supersede agronomic best practices (Goulding, 2016; Heckman, 2006; Tozer et al., 2004; Schimmelpfennig and Norton, 2003; Rigby and Craceres, 2001). Organic grasslands need to still be well-managed while also remaining cost-effective (Heckman, 2015; Farrell and Alteri, 1995). At the farm-level, a portfolio approach may be necessary (Porter, 2009; Neal et al., 2007; Mitchell et al., 1986). A farm may still need to incorporate crabgrass in heavy use areas or maize and soybean in integrated crop-livestock areas. But, transitioning existing grasslands or planting new grasslands is a broad strategy for transitioning land into certified organic production of any crop (Brandao et al., 2012; Liebman and Davis, 2009; Mohler, 2009; Delate, 2009; Porter, 2009; Kristiansen and Merfield, 2006; Kasperczyk and Knickel, 2006).

The yield penalty has been an area of concern in the wider organic literature (Seufert et al., 2012; Badgley et al., 2006; Kristiansen and Merfield, 2006; Delate, 2009; Delate and Cambardella, 2004; Lee et al., 2007). Yield penalty is considered the generally reduced productivity of an organic crop to its conventional equivalent. Concerns regarding the yield penalty are pronounced in row crops; organic forage and fodder crops are connected to meat and dairy production, but are comparable to conventional equivalents (Seufert et al., 2012; Kristiansen and Merfield, 2006; Lee et al., 2007). The concerns for N limitations and yield penalty are surmountable, especially with the incorporation of grasses and legumes into existing cropland systems (Eichler-Inwood et al., 2015; Delate, 2009; Baier, 2008; Badgley et al., 2006; Delate and Cambardella, 2004).

Population growth favors an increase in pleasure animals such as horses, and organic feedstocks will be a market of interest. Revitalized rural communities require economic sustainability in order to maintain these specialty markets (Lasley et al., 2009; Rigby and Caceres, 2001). The stability in the certified organic market is promising in making the production strategy possible. Economically efficient strategies might also improve present inequities in agricultural production (Horst and Marion, 2018). The economics of scale dissuade those without land access or capital from participating in some agricultural markets, such as grain operations or dairy operations. Grassland agriculture is a promising area for smallholders and new farmers to enter into agricultural production.

Value of hay

The value of hay is not as reliably measured as grain commodity crops given the variability of the crop and the majority of hay crops going for use on the home farm, though basic standards have been developed in commercial, regional hay markets. Standards for alfalfa hay come from the USDA, and the federal agency maintains price reports across market sectors. However, the organic market has reports for the categories of Supreme and Good quality (2019 USDA-AMS National Organic Grain and Feedstuffs Report). In the field research, all treatments were consistently between the Fair, Good, and Premium categories on the basis of crude protein (CP). Given the limited availability of data for guidelines on grass and mixed hay and the low legume composition in the mixed stands, the Good quality prices were used as the basis of pricing the value of hay per kg forage.

Protein and energy limit pasture systems for dairy animals (Muller, 2016), but as previously described in beef systems, there is an optimum point of investment in improved forage production (Tilhou et al., 2018; Doole and Romera, 2013; Wedin and Fales, 2009; Lasley et al., 2009; Singer et al., 2009; Sheaffer et al., 2009). Flexible herd sizes have been suggested as a solution to the limitations of forage seasonality (McBride and Greene, 2009).

The grass-fed marketing strategy can be seen as encompassing organic beef production because of the NOP access to pasture rule (USDA NOP, Thomas, 2005). Producers can still pursue premium returns without perceived sacrifices in forage management tools by using grass-fed marketing. The natural label is a similarly loosely-defined premium (Thomas, 2005). However, an organic forage base could be considered flexible for the purposes of dairy and horse markets in addition to feeding beef cattle. Wilman and Griffiths (1978) examined the dual use of hayfields for hay and sheep grazing. This strategy would likely be similar on a practicing organic farm. High quality 1st or 2nd cut hay would be sold into the specialty markets for horses and/or dairy animals, and cow-calf beef herds could utilize the lower quality forage present otherwise.

Stability of the grass-alfalfa mixtures is questionable given field experience with establishing alfalfa and similar challenges noted in the literature (Biermacher et al., 2012; Quinby et al., 2020). The variability of the forage might negatively affect the nutritive value of the hay and consequently the value to market sectors such as beef or dairy cattle and horses.

CONCLUSION

In the present study, idealized budgets were developed of five species selections under low-input organic production. In developing these budgets, there exists a need to develop empirical stand failure rates for forage species at a finer scale than is currently present in the literature. Estimations of useful stand life were assessed on a time scale that would be useful for organic grain and specialty crop producers. Annual production costs differed by ~\$400 ha^{-1} between the most and least expensive treatments, that being the annual rotation (\$885.80 ha^{-1}) and the tall fescue-alfalfa treatments (\$490.19 ha^{-1}). Fertility management given the presence or absence of a legume component affected costs of production, though similar levels of agronomic performance made the per-unit costs similar for most of the treatments.

All treatments had comparable value on forage and CP bases with the exception of the bermudagrass monoculture. The lack of an organic premium during the transition period will require producers to add value through alternate market strategies, such as grass-fed or all-natural labelling. The success of these labels relative to certified organic labelling warrants further investigation as organic market share increases. Increasing premiums for agricultural products with enhanced sustainability practices is necessary for economic sustainability. In the Southeast, urbanization and production challenges push producers to either increase efficiency in conventional operations, or add value within specialty markets. Given the opportunity cost of producing the several species selections above, the tall fescue monoculture might be ideal for a part-time producer, though an annual rotation will produce more forage per land area at a comparable cost.

Chapter 2 Tables and Figures

No Figures are present in Chapter 2.

Table 2.1 Establishment budgets for 5 species selections under low-input organic forage system in Tennessee on an acre basis.

		Unit	Quantity	Annual Rotation	Bermudagrass	Bermudagrass-alfalfa	Tall fescue	Tall fescue-alfalfa
Variable Expenses								
Seed	Wheat	bu	1.67	$27.56	$27.56	$27.56		
Seed	Bermudagrass	lb	15		$88.80			
Seed	Bermudagrass	lb	10			$59.20		
Seed	Alfalfa	lb	15			$46.35		$46.35
Seed	Winter Pea	lb	50	$42.50				
Seed	Sorghum-sudangrass	lb	30	$10.50				
Seed	Cowpea	lb	75	$84.75				
Seed	Tall fescue	lb	20				$30.00	$30.00
Manure		Acre	1		$69.30		$69.30	
Boron		Acre	1			$17.66		$17.66
Repair & Maintenance		Acre	1	$2.44	$1.22	$1.22	$1.22	$1.22
Fuel, Oil & Filter		Acre	1	$16.14	$8.07	$8.07	$8.07	$8.07
Operator Labor		Acre	1	$14.10	$7.05	$7.05	$7.05	$7.05
Operating Interest		%	$492.96	$5.94	$6.06	$5.01	$3.47	$3.31
Other Variable Costs		Acre	1					
		Total Variable Expenses		$203.92	$208.05	$172.12	$119.11	$113.66
Fixed Expenses								
Machinery								
Capital Recovery		Acre	1	$82.74	$41.37	$41.37	$41.37	$41.37
Other Fixed Machinery Costs		Acre	1					
Other Fixed Costs		Acre	1					
		Total Fixed Expenses		$82.74	$41.37	$41.37	$41.37	$41.37
Total Establishment Expenses				**$286.66**	**$249.42**	**$213.49**	**$160.48**	**$155.03**
Total Establishment Expenses with 15% failure rate perennial and 2.5% annual				**$293.83**	**$286.84**	**$245.51**	**$184.55**	**$178.29**

Table 2.2 Production budgets for 5 species selections under low-input organic forage system in Tennessee on an acre basis.

		Unit	Quantity	Annual Rotation	Bermudagrass	Bermudagrass-alfalfa	Tall fescue	Tall fescue-alfalfa
Prorated establishment cost					95.61	81.84	61.52	59.43
Variable Expenses								
Seed	Wheat	bu	1.67	$27.56				
Seed	Winter Pea	lb	50	$42.50				
Seed	Sorghum-sudangrass	lb	30	$10.50				
Seed	Cowpea	lb	75	$84.75				
Manure		Acre	1		$69.30		$69.30	
Boron		Acre	1			$17.66		$17.66
Repair & Maintenance (Table 3.)		Acre	1	$3.83	$2.61	$2.61	$2.61	$2.61
Fuel, Oil & Filter (Table 3.)		Acre	1	$23.45	$15.38	$15.38	$15.38	$15.38
Operator Labor (Table 3.)[4]		Acre	1	$20.49	$13.44	$13.44	$13.44	$13.44
Twine		Bale						
Operating Interest		%	$283.70	$6.39	$3.02	$1.47	$3.02	$1.47
Other Variable Costs		Acre	1					
Total Variable Expenses				$219.47	$199.36	$132.40	$165.27	$109.99
Fixed Expenses								
Machinery								
Capital Recovery (Table 3.)		Acre	1	$128.91	$87.54	$87.54	$87.54	$87.54
Other Fixed Machinery Costs		Acre	1					
Other Fixed Costs		Acre	1					
Total Fixed Expenses				$128.91	$87.54	$87.54	$87.54	$87.54
Total Production Expenses				**$348.38**	**$286.90**	**$219.94**	**$252.81**	**$197.53**
Total Establishment Expenses with 2.5% failure rate for annual				**$357.09**	**$286.90**	**$219.94**	**$252.81**	**$197.53**

Table 2.3 Cost per kg forage and cost per kg crude protein (CP) of 5 species selections under low-input organic forage systems in Tennessee.

Treatment	**Cost per kg forage**	**Cost per kg CP**
Annual Rotation	\$0.06^{B}	\$0.32^{B}
Bermudagrass	\$0.13^{A}	\$0.88^{A}
Bermudagrass-alfalfa	\$0.06^{B}	\$0.38^{B}
Tall fescue	\$0.07^{B}	\$0.44^{B}
Tall fescue-alfalfa	\$0.05^{B}	\$0.32^{B}
P-value	<0.01	<0.01
Standard Error of the Mean	\$0.01	\$0.08

Means followed by the same superscript letter grouping within a column do not differ ($P \geq 0.05$).

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VITA

Jonathan Omar Cole Kubesch was born August 30, 1995 in Middletown, Ohio. He was raised in Hamilton, Ohio, and introduced to agriculture at Good Enough Farm in Peru, Indiana. He is 1 of 6 children of Joe O.C. Kubesch and Leila Kubesch. Jonathan O.C. Kubesch graduated May 31, 2014 from Fairfield Senior High School in Fairfield, Ohio. He then attended the Ohio State University in Columbus, Ohio where he graduated with research distinction May 6, 2018 with a B.S. *cum laude* in Evolution and Ecology, with a minor of Agronomy. He worked for the Missouri Department of Conservation under Dr. Elizabeth L. Middleton on virgin prairies as part of a patch-burn grazing study in 2016. Jonathan O.C. Kubesch subsequently worked for the U.S. Geological Survey at the Badlands National Park in Interior, South Dakota under Dr. Amy J. Symstad on rangeland as part of a study regarding bison carrying capacity in a national park. His undergraduate thesis, carried out under the direction of Dr. David J. Barker, "Edaphic and morphological factors affecting running buffalo clover (*Trifolium stoloniferum*) ecology", provided evidence considered in the legal protections for that species by the U.S. Fish and Wildlife Service in public comments from several state and private conservation agencies. Jonathan O.C. Kubesch worked at the Middle Tennessee AgResearch and Education Center at Spring Hill, Tennessee from May-August 2018 before starting his graduate research assistantship under Dr. Renata L.G. Nave at the University of Tennessee—Knoxville. Under this assistantship, he pursued a master's degree in Plant Sciences with a focus in Crop Science.