Management and productivity of corn and alfalfa intercropping systems in the Southern U.S.

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DEDICATION

To those that have inspired me to be a better version of myself

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ABSTRACT

Agronomic intercropping systems involve growing grasses, legumes and row crops simultaneously in the same area to increase productivity, nutritive value, and economic viability. The purpose of this study was to determine the potential yield and nutritive value of corn (*Zea mays* L.) when intercropped with alfalfa (*Medicago sativa* L.) and crabgrass [*Digitaria sanguinalis* (L.)] to be used in silage production. These species were in a combination of corn (C), alfalfa (A), alfalfa + corn (AC), and alfalfa + corn + crabgrass (ACC) and was throughout the growing season of 2022 to 2024 at the Middle Tennessee Research and Education Center (MTREC) Spring Hill, TN. Samples were collected for forage mass (FM) and nutritive value. Alfalfa yield did not differ within the 2 growing seasons, but it differs within treatment ($P < .05$). The proportion of alfalfa was higher in 2023 than 2024 ($P < .05$). Crabgrass proportion was higher in 2024 than 2023 ($P < .05$). Corn yield was higher in 2023 than it was in 2024 ($P < .05$). Overall FM was greater in 2024 than in 2023. Alfalfa improved the crude protein (CP) content of the mixture while crabgrass improved neutral detergent fiber (NDFd).

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INTRODUCTION

Corn Production

The first cultivation and use of corn (*Zea mays* L.) was around 10,000 years ago by the natives of southern Mexico. The corn grown today comes from Balsas teosinte (*Zea mays parvighumis*), a wild grass. The spread of corn has reached as far north as southern Maine before the Europeans arrived in the Americas (Corn | History, Cultivation, Uses, & Description | Britannica, 2023).

Currently, corn is one of the most valuable grain crops in Tennessee. The total average area of corn grown for grain in Tennessee ranged from 283,000 to 364,000 ha since 1970, while corn grown for silage has remained consistent at about 56,000 ha over the same time span. This amounts to one-fourth of the total average of corn acreage grown in Tennessee in 1930, but increased yields have tended to offset reduced acreage (Flinchum, 2001). The total acreage of corn grown has increased to 404 thousand ha in 2021 and a weight of corn has increased from 2.3 to 11.4 tons/ ha (Flinchum, 2001) (USDA/NASS 2021 State Agriculture Overview for Tennessee, 2021). Corn production is highly valued among crops in Tennessee at $636 million (Zhou et al., 2022).

Corn is very palatable and readily digestible by monogastric and ruminant animals. Corn is low in fiber but has about 75% starch on a dry matter (DM) basis, and starch is nearly 100% digestible form of energy for livestock feed (Loy & Lundy, 2019a). For ruminants, corn silage is an economical source of fiber and energy. It is comprised of 25 to 35% starch and 40 to 50% neutral detergent fiber (NDF) (Tharangani et al., 2021). The nutritive value of corn silage can be affected by hybrid, crop density, growing condition, degree of maturity, the moisture of the crop when harvested and the condition when it was ensiled. The roughage quality can be decided by different physical characteristics such as average particle size and density responsible for the fermentation and aerobic stability (Silva et al., 2015). Some factors that encourage farmers to produce corn silage include its lower harvest cost, minimal risk of production, and high yield per hectare (Ferraretto et al., 2018).

However, growing corn for silage production also has negative effects. The removal of the whole stalk for corn silage can reduce soil N, P, K by twice the amount, three times, and as much as ten times the amount respectively (Moore et al., 2014), when compared to 25% or more of N, P, K if the corn stalk remined (Wilts et al., 2004) . Due to corn silage having low crude protein (CP) concentration, the addition of N fertilizer is essential. One way to economically add N to the system is to intercrop corn with a forage legume that has a higher CP content like alfalfa (*Medicago sativa*) (Allen et al., 2003).

Intercropping Systems

Alfalfa is commonly known as the "Queen of the forages" due to its high productivity and high nutritive value as a feed source (Barnes, 1980). Alfalfa is a forage legume and is one of the most used crops worldwide and utilized to support the production of many classes of livestock. Alfalfa's genetic variability causes it to be flexible in adapting to a wide array of conditions from extreme heat- to cold temperatures, drought conditions, and salinity (Alla et al., 2013). It can also decrease the presence of weeds and pests, while reducing soil erosion and nutrient loss (Osterholz et al., 2020).

Crabgrass (*Digitaria* spp.) is an annual warm-season C4 grass, which when used as a forage has high nutritional value (Sosinski et al., 2022). Crabgrass is normally known for being a weed due to its rapid growth rate and its ability to regrow year after year, due to its capability to self reseed (Teutsch et al., 2005a). Furthermore, it is very tolerant to drought, with higher quality of forage compared to most common summer annual grasses that can be established in a variety of soil pH. When crabgrass is mixed with a legume it could possibly improve soil N, improve yield, and decrease the cost of fertilizers (Aguerre et al., 2023a).

Cover crops can be defined as crops grown for the sole purpose of ground coverage, that can protect the soil from nutrient loss and erosion (Reeves, 1994). Cover crops are a sustainable option to increase biomass following row crop, a form of pest and weed management, and soil conservation (Snapp et al., 2005). For cover crops to be effective they must be easy to establish, grow rapidly, have enough ground coverage, provide sufficient DM, not attract pathogens, be easy to terminate and, ultimately, they should be economically feasible (Belfry & Van Eerd, 2016). Corn, when compared to other crops, requires a great amount of N to maximize growth and productivity, and as a result, concern has grown among farmers about the cost fluctuation when applying N fertilizers that are processed using petroleum (Larson et al., 1998).

To reduce the use of fossil fuel to make N fertilizers, a sustainable way of adding natural N to the soil is to have a living mulch system (Clark, 2008). Living mulch is a type of live plant-based cover that is grown between the main-crop rows throughout production (Price, 2012). Legumes used as living mulch can provide sufficient N to reduce synthetic N fertilizer input (Coombs et al., 2017). Alfalfa used as a living mulch can be beneficial by enhancing the organic matter, carbon, and the function of microbes found in the soil (Steenwerth & Belina, 2008) and improving N fixation in the soil (Sainju et al., 2002). According to Quinby et al. (2020), when alfalfa is added to a forage mixture, it reduces the accumulation of alfalfa yield year after year. It was suggested that, despite its role as a living mulch, to minimize the loss of forages, improving management practices such as the use of herbicides, adjusting planting density, optimizing row spacing, and increasing fertilizer application, may be beneficial.

Intercropping systems are the combination of two or more crop species grown simultaneously within the same growing season. They can be grown in alternate rows, wide strips, or overseeded (Martin & Sauerborn, 2013). In an intercropping system, several combinations of plants can be used, such as annual plants intercropped with annual plants, annual with perennial plants, or perennial with perennial plants. The advantages of intercropping systems include increased production, better use of environmental resources, reduction of pathogens and weeds, improved stability and uniformity of yield, improved soil fertility and increased soil N (Mousavi & Eskandari, 2011), improved land use efficiency, and increased plant diversity. Intercropping grasses with legumes is reported to increase forage productivity and nutrient value (La Guardia Nave & Corbin, 2018a).

Time is an additional factor highlighting the benefits of intercropping. Since plants mature at different times, there is reduced competition for nutrients within an intercropping system. This leads to more efficient utilization of resources, as plants require different nutrients at various stages of their life cycles, both at separate times and in differing amounts. (Gebru, 2015).

Intercropping systems focusing on forage production such as a legume grown with a grain can improve resource utilization and increase the yield of all crops involved (Patel et al., 2021). Alfalfa and corn silage also have complementary nutritional characteristics that can benefit livestock. Growing and feeding alfalfa with corn silage can improve the economic and environmental sustainability of livestock and crop production (de Souza & Ferreira, 2017). Globally, the agricultural practice of intercropping has been increasingly adopted as a more sustainable agricultural system (Mazzafera et al., 2021).

Objective

Our objective was to determine the productivity, nutritive value, weed suppression capacity and economic viability of intercropped combination of corn with alfalfa or alfalfa/ crabgrass. We hypothesized that the system would increase corn productivity and total area use efficiency while reducing cost and increasing systems sustainability.

CHAPTER 1:

Management and productivity of corn and alfalfa intercropping systems in the Southern U.S.

ABSTRACT

Corn (*Zea mays* L.) can be used to feed both livestock and humans, and whether a monoculture or intercropped with other forages can increase feed potential and nutrient composition for livestock in the Southern US. The objective of this study was to determine the forage mass (FM) nutritive value of corn when grown by itself and intercropped with alfalfa (*Medicago sativa* L.) and crabgrass [*Digitaria sanguinalis* (L)]. The intercropping systems evaluated were alfalfa (A), corn (C), alfalfa + corn (AC), and alfalfa + corn + crabgrass (ACC) and were evaluated from 2022 to 2024 at the Middle Tennessee Research and Education Center (MTREC) Spring Hill, TN. Samples were collected during this period for forage yield, forage quality, and corn silage yield. Sample collection of alfalfa, height measurements of corn were collected one month after germination, and monthly during the summer. Weight and nutrient values were obtained from these samples, and the nutrient content was analyzed using near-infrared spectroscopy. The measurements included total plot forage mass (FM), crude protein (CP), neutral detergent fiber digestibility (NDFd), and in vitro true dry matter digestibility (IVTDMD). Field experiments that were conducted showed that alfalfa yield did not differ within the 2 growing seasons. In 2023 had a higher proportion of alfalfa than 2024 (**P** < .05), and in 2024, showed an increase in crabgrass compared to 2023 ($P < .05$). Corn silage yield was higher in 2023 than it was in 2024 ($P < .05$). Overall forage mass (FM) was greater in 2024 than in 2023. Alfalfa increased the crude protein (CP) content of the mixture while crabgrass made the mixture have a higher neutral detergent fiber (NDFd).

INTRODUCTION

In the USA, corn (*Zea mays* L.) is one of the major crops that is grown domestically. Its total use is approximately 52% for animal feed, 37% fuel and beverage, and 11% devoted to the development of food products (Rose et al., 2010). Corn is one of the best sources of metabolizable energy, easily digestible and palatable among monogastric and ruminant animals (Loy & Lundy, 2019b). Corn has a low protein content relative to other feed stuff. Legumes are often added to the feed to increase feed protein content (Manafi, 2017). For ruminants, protein is very important, and alfalfa forage can provide a large quantity of protein (Olszewska et al., 2020).

Alfalfa (*Medicago sativa*) is an important forage species in the US. It is adapted to and can be produced on a wide range of soils and in many climates and is known as the "Queen of the forages" because it is high-yielding (Fehr et al., 1980). Alfalfa is a legume, which means it has the capability to fix N, and reduce the need for synthetic N fertilizer (Solomon et al., 2011). Additionally, alfalfa can increase forage mass and crude protein content when mixed with other grasses (Beck et al., 2016).

A mixed or intercropping system is a type of cropping system where two or more crops are established simultaneously (Smith & Carter, 1998). Intercropping perennial legumes and grasses has several advantages, such as improving soil quality and productivity through nutrient cycling, increasing crop yield (Zhang et al., 2007), better land use efficiency (Dhima et al., 2007), increasing water and nutrient usage (Javanmard et al., 2009), and improving the control of pests and diseases (Sun et al., 2018).

The objective of this study was to determine the productivity, and nutritive value of intercropped alfalfa, corn, and crabgrass. We hypothesized the system would increase corn productivity and total area use efficiency while increasing systems sustainability.

MATERIALS AND METHODS

Site Description

This study was conducted at the Middle Tennessee AgResearch and Education Center (MTREC) in Spring Hill, TN ($35^{0}71$'N,$86^{0}94$'W). The soil for the experiment site located in field #38C is classified as Huntington silt loam, depressional phosphatic phase; Braxton silty clay loam, eroded sloping phase; and Maury silt loam, eroded gently sloping phase. Initial soil samples were collected at 15 cm depth on 9 September 2022 and sent to the University of Tennessee Soil, Plant, and Pest Center laboratory for analysis (Hanlon and Savoy,2007). In 2022, soil characteristics were pH 6.1, phosphorus (P) 63 kg ha^{-1} (high), potassium (K) 140 kg ha^{-1} (medium), calcium (Ca) 2016 kg ha^{-1} (sufficient), and magnesium (Mg) 215 kg ha^{-1} (sufficient).

The experimental period occurred from September 2022 to September 2024, and the experimental design used was a randomized complete block design (RCBD) with 5 treatments and 4 replications (n=20). The treatments were as follows: 1) alfalfa (cv. Evermore) grown as a monoculture (A); (2) corn silage grown as monoculture (C); (3) alfalfa (cv. Evermore) grown as living mulch and intercropped with corn silage (AC); (4) alfalfa (cv. Evermore) grown as living mulch and intercropped with corn silage and crabgrass (cv. Mojo) (ACC); (5) corn silage and crabgrass for weed suppression cv. Mojo) (CC). Individual plots measured 7.3m x 9.1m.

On 31 August 2022, an alfalfa germination test was performed. On 1 September 2022, the field site was prepared by using a John Deere 4255 with complete cab (John Deere, Waterloo, Iowa) and a Massey Ferguson disk harrow (Massey Ferguson, Hesston KS). The ground was rolled on 14 September 2022, using a John Deere 750 (John Deere, Yanmar, Japan) and 1.7 cm Brillion cultipacker (Landoll Corporation, Marysville, KS). The ground was then plowed using a John Deere 5325 (John Deere, Augusta, Georgia, USA) and a lane plow (John Lane, Homer Township, Illinois). The field was smoothed and leveled with a John Deere 5325 (John Deere, Augusta, Georgia, USA) and made in house 12.7 cm tiller box that ran perpendicular to the initial tillage passes, and finally followed using John Deere 750 (John Deere, Yanmar, Japan) and 5' Brillion cultipacker (Landoll Corporation, Marysville, KS).

On 11 September 2023, the ground was tilled using John Deere 5325 (John Deere, Augusta, Georgia, USA) and John Deere 660 tiller (Howard, United Kingdom), then it was rolled to smooth the ground using John Deere 2355 (John Deere, Baden-Wurttemberg, Germany) and 10' John Deere cultipacker (John Deere, Grovetown, Georgia). The following day the lanes were plowed using a John Deere 5325 (John Deere, Augusta, Georgia, USA) and a lane plow (John Lane, Homer Township, Illinois). On 15 September 2022, and 14 September 2023, alfalfa (Evermore) was sown using a John Deere 2355 (John Deere, Baden-Wurttemberg, Germany) and a Hege 100 series plot drill (Hege Company, Waldernburg, Germany, F.R.) with a spacing of 17 cm and a seeding rate of 22 kg ha^{-1}.

On 16 March 2023, fertilizer was applied to the alfalfa plots by hand. The plots with alfalfa received Potash (K) 212 kg ha^{-1}, Boron (B) 2.2 kg ha^{-1} while, the plots with no alfalfa received Potash (K) 89 kg ha^{-1}. On 7 November 2023, the plots were sprayed with 2-4, DB 200 (2 L ha^{-1}), and Jette 80/20 (1 L/ 378 L water) using a John Deere 750 (John Deere, Yanmar, Japan) and a 190 L plot sprayer (Willmar Fabrication, Benson, MN). On 27 February 2024, the same application of fertilizer was done as mentioned before.

On 18 April 2023, a John Deere 5325 (John Deere, Augusta, Georgia, USA) with a 4-row John Deere 1750 planter (John Deere, Christiansburg, Virginia) was pulled through the plots to mark where rows would be. The plots were then sprayed for initial burndown with glyphosate (4.4 kg ha^{-1}); 2, 4-D Amine (0.9 kg ha^{-1}); and Preference 1.4 L/ 378 L using a John Deere 2355 (John Deere, Mannheim, Baden-Wurttemberg, Germany) and a home-made hooded sprayer.

On 3 May 2023, and 13 May 2024 corn varieties Beck's 6886 VR (2023) and cv. Dynagrow D58VC65RIB (2024) were intercropped with alfalfa at a depth of 3 cm and a density of 79,040 seeds ha^{-1}. The planting was done using a New Holland TS100 (New Holland, Basildon, England) and a John Deere 1750 4-row planter (John Deere, Christiansburg, VA). Concurrently, crabgrass (Mojo) was sown at a density of 3.2kg ha^{-1} using John Deere 2355 (John Deere, Baden-Wurttemberg, Germany) a Hege 1000 series plot drill (Hege Company, Waldernburg, Germany, F.R.).

On 4 May 2023, the plots were sprayed with Python (73 ml ha^{-1}), Gramoxone (3500 ml ha^{-1}), Zidua SC (290 ml ha^{-1}), and Preference (1420 ml/ 378 l). This was done using the John Deere 2355 (John Deere, Mannheim, Baden-Wurttemberg, Germany) and a home-made hooded sprayer.

On 16 March 2023 and 27 February 2024, an application of fertilizers Potash (K) and Boron (B) was applied by hand on the site. The soil test recommended K (213 kg ha^{-1}) and B (2.2 kg ha^{-1}) fertilizers which were portioned into different bags to be applied to the plots that had alfalfa. The plots that didn't have alfalfa received K (90 kg ha^{-1}). A handful of fertilizer was spread onto the plot every few steps until the bag was empty, ensuring an even distribution.

Alfalfa and Crabgrass Measurements

In both years, forage samples were collected monthly from 6 May 2023 to 21 August 2023 and from 5 May 2024 to 28 August 2024. Total above ground dry matter (DM) and forage mass (FM) were measured at each sampling date in each plot by randomly placing a 0.1 m^2 Pvc square over the sample area and hand-clipping the forage within the 0.1 m^2 quadrat.

Collected samples were also used to estimate botanical composition and forage nutritive value. Samples were separated into botanical components (alfalfa, crabgrass, and weeds). After drying, samples were weighed to determine the total DM, FM and the botanical composition and recombined for the determination of nutritive value. Samples were then ground using the Wiley Mill Grinder (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co., Philadelphia, PA) using a 1 mm screen, and the passed through a Cyclone mill (FOSS Cyclotec, Eden Prairie, MN) to decrease the particle size (McIntosh et al., 2022). Before analysis, the samples were placed in individual foil tins and dried for an additional 30 min in a forced air oven at 55^{o}C to reach consistent moisture for scanning. The samples were scanned in small ring cups on NIRS technology (Unity Spectrastar XL-R instrument Unity Scientific, Milford, MA) to determine crude protein (CP), neutral detergent fiber (NDF), and *in vitro* true dry matter digestibility 48h (IVTDMD48). Equations for the forage nutritive value analysis were standardized and checked for accuracy with the 2021 Mixed Hay Equation developed, provided, and licensed by NIRS Forage and Feed Consortium (NIRSC, Berea, KY). The Global H and neighbourhood statistical test were analyzed for accuracy across a prediction, in which all forage samples fit the equation with the ($H < 3.0$) and are reported accordingly (Murray & Cowe, 2004). The units of measurements for nutritive value analyses are presented at 100% DM across the entire data set.

Corn measurements

Corn height was measured one month after planting and subsequently once a month after that. The corn height was measured using a two-meter (2 m) ruler to determine the growth of the corn stand within the different intercropping plots. Before harvest three (3), corn stands were selected from various locations within each plot and measured from soil to the tip of the highest tassel. Also, these 3 selected stocks were used to measure ear height. This was done measuring from the soil to the base of the lowest ear of corn.

On 21 August 2023, corn silage yield was determined by harvesting the three center rows of each plot using a John Deere 4255 (John Deere, Waterloo, Iowa), with a New Holland 790 (New Holland, Lancaster, Pennsylvania), New Holland TS100 (New Holland, Basildon, England) and Lucknow TMR mixer (Helm Welding Limited, Lucknow, Ontario, Canada).

On 28 August 2024, an RCI 36A research forage harvester (RCI Engineering, Michigan, USA) was used to harvest 2 selected beds from each plot. Samples were taken by hand and placed in a bag to weigh the wet forage mass. The samples were then placed in a drier at 60 ^{0}C for 72 h to reach a constant weight. The dry weight was then used to calculate the average DM t ha^{-1}.

Statistical Analysis

Data from the characteristics of the corn, alfalfa, crabgrass, nutritive value variables, intercropping forage mass, and silage herbage mass were evaluated using the PROC MIXED producer and means, adjusted for Tukey's method for least square means separation in SAS (SAS for Windows V 9.4, SAS Institute, Cary, NC, USA). The response variables were plant population, ear length, stand height, forage mass, CP, NDF, and IVTDMD, respectively, by month. The treatment was considered a fixed effect, and replicate was considered a random effect.

RESULTS AND DISCUSSION

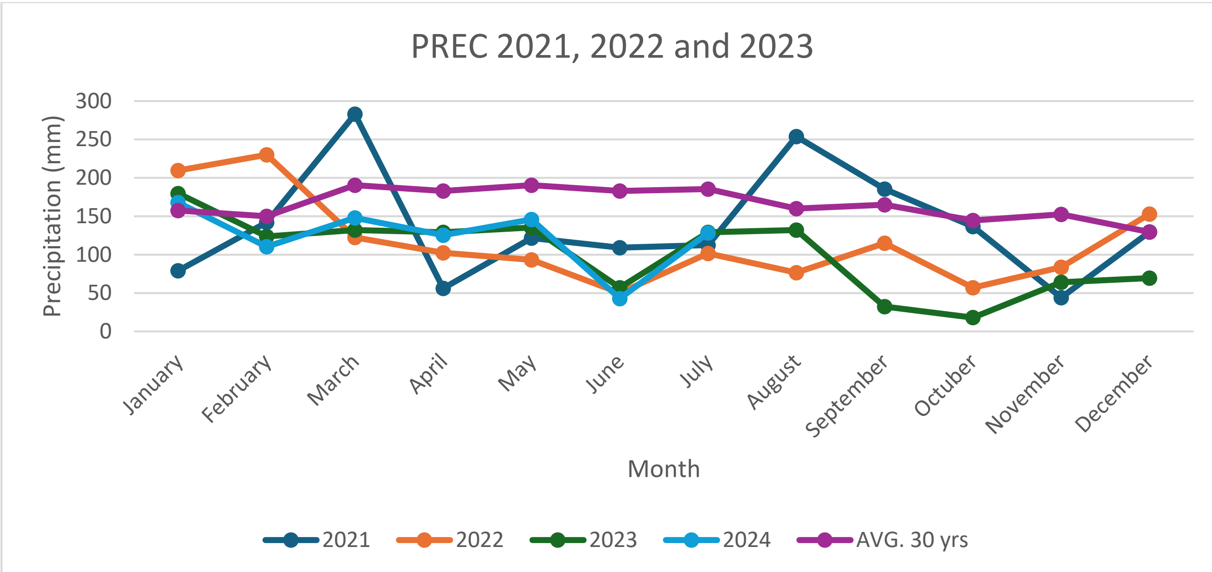
Weather

Figure 1 demonstrates the precipitation and temperature from 2021 to 2024 and averaged with thirty years data. In 2021, the average temperature from May to August was 22.9 ^{0}C, which was 0.4 ^{0}C below the average 30-yr temperature. Precipitation for the same period was 16.9% below the 30-yr average. In 2022, the average temperature from May to August was 24.6 ^{0}C, which was 1.3 ^{0}C above the average 30-yr temperature. Precipitation for the same period was 55.3% below the 30-yr average. In 2023, the average temperature from May to August was 22.8 ^{0}C, which was 0.5 ^{0}C below the average 30-yr temperature. Precipitation for the same period was 37% below the 30-yr average. In 2024, the average temperature from May to August was 1 ^{0}C, which was above the average 30-yr temperature. Precipitation for the same period was 41.2% below the 30-yr average.

Corn silage, alfalfa and forage yield

Table 1. shows the yield of alfalfa differences with treatment (P = 0.0324). There were differences in total alfalfa yield among the 3 treatments, Treatment A had the highest yield because this was just alfalfa grown as a monoculture, while the lowest yield was recorded from intercropping ACC.

As mentioned before, alfalfa was first developed in the fall of 2022, which meant that it developed as a monocrop, and had the time to establish deep roots and grow better, with higher yield. Results from Nordquist & Wicks, (1974) showed that planting date can also affect the yield of alfalfa, stating that fall seeding produces higher yield than spring seeding. Results from Berti et al., (2021), suggest that the forage yield for alfalfa was high in the first year because it was seeded in the fall and not in the spring. This did differ from my results which showed no



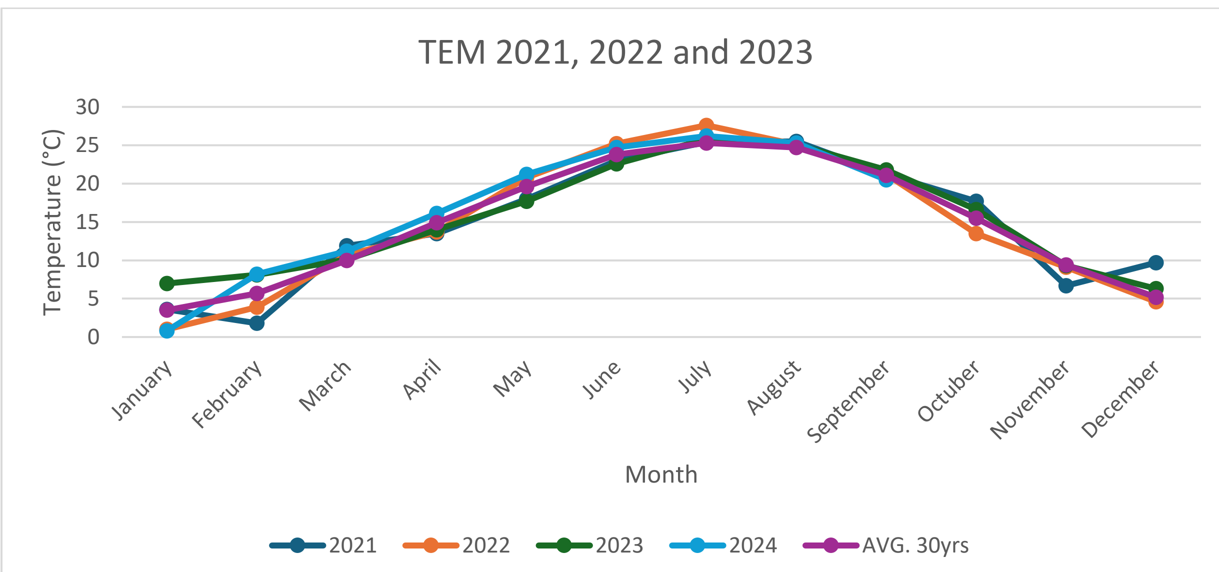


Figure 1 Precipitation and Temperature for Middle Tennessee AgResearch and Education Center, Spring Hill, TN, 2021-2024 including 30- year average.

Table 1 Alfalfa yield affected by treatment across two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S.

Treatment	Alfalfa
	-------------- (kg DM ha^{-1}) --------------
A	2905 ^{A}
AC	2381 ^{AB}
ACC	1982 ^{B}
SEM	204.2

Means within a column with a common uppercase letter no differ among treatment ($P < .05$)
SEM = Standard Error Mean. A = alfalfa alone, AC = alfalfa and corn intercropped, ACC = alfalfa, corn and crabgrass intercropped

difference in alfalfa yield between the two-growing seasons (P = 0.2968), this is why it is not shown in the table.

Canopy shade from the corn can allow some sunlight to penetrate through the leaves. The intensity from the sunlight is reduce and is called moderate shade (Dewi et al., 2022). Results from Pang et al., (2019), reports that some forage grass and legumes when grown under moderate canopy may have non-significant decrease in biomass or no decrease when compared to plants that receive direct sunlight. Our results demonstrates that treatment AC even though had a decrease in alfalfa yield, it did not differ from treatment A (2381 kg DM ha^{-1}). Treatment ACC did differ from treatment A because crabgrass was added and competition for nutrients arose. Crabgrass being a warm-season annual grass, which has a high nutritional value (Sosinski et al., 2022), can grow rapidly during the warmer months and out compete cool-season plants for water and nutrients.

Figure 2 shows corn silage had an interaction both by treatment and by year (P <.0001). In the first year's harvest (2023), corn alone (C) had an average mass of 20 DM t ha^{-1}, which was significantly higher than the other treatments. The weather during the time of planting had adequate precipitation, which allowed the corn to germinate and grow optimally. During the same period, the intercropping treatments AC and ACC did not differ (8 DM t ha^{-1} and 9 DM t ha^{-1} respectively). When corn receives water at critical times of its growth, it produces more FM. Corn is a plant that requires a substantial amount of water during certain times of growth, 37 days after planting (V6 to V8), water requirements increase at 90 to 94 days after planting (dough stage), and 110 days after planting (maturity) (Endale et al., 2008).

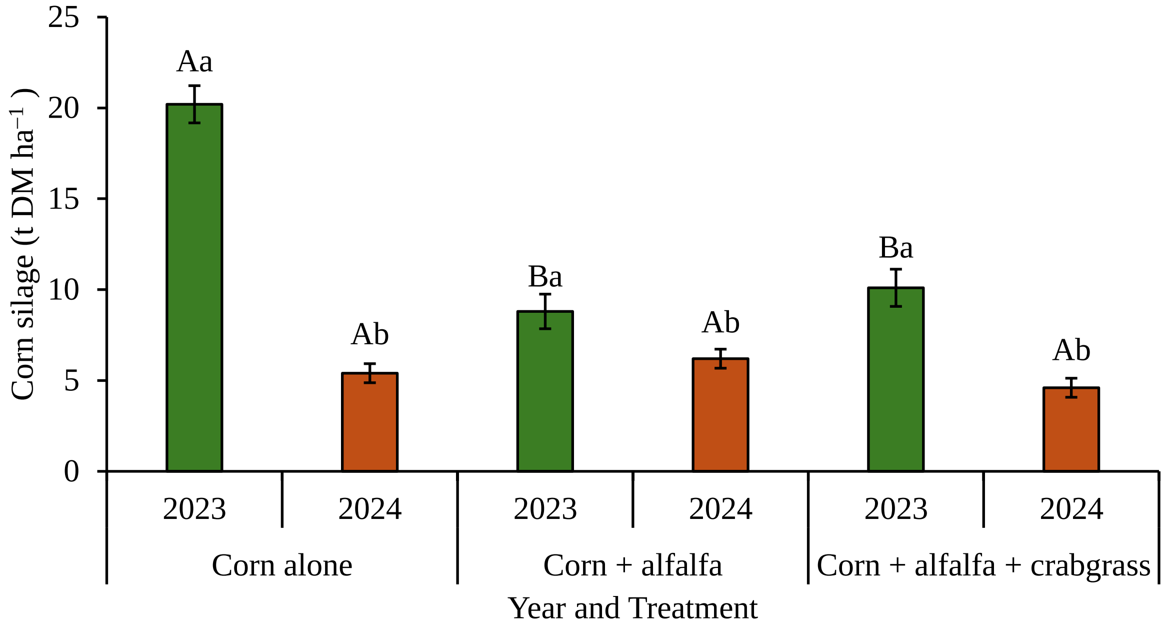


Figure 2 Corn yield affected by treatment × year interaction during two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S. Means with a common uppercase letter do not differ among treatments. Means with a common lowercase letter do not differ between years within each treatment.

In 2024, there were no significant differences between treatments C, AC, and ACC (5 t DM ha $^{-1}$, 6 t DM ha $^{-1}$ and 4 t DM ha $^{-1}$ respectively). Being that 2024 was drier than 2023, there wasn't much soil moisture, and this caused the corn to not develop adequately. The soil in the South-eastern USA has low water retention and lower organic matter, which can be easily compacted (Radcliffe & West, 2000). It was reported that shortening of the meristem can reduce leaf growth (Granier et al., 2000), plant height, and tassel articulation, which, in turn, reduces corn yield (Aslam et al., 2015). Limited soil moisture can disrupt the signal between the legume and its relationship with soil Rhizobium, negatively impacting root nodulation and N fixing (Dollete et al., 2024), this leads to reduced cell expansion and division, smaller leaf size, and decreased elongation of stems and roots, which limits water uptake (Kaushal & Wani, 2016).

Within the two growing seasons (2023 and 2024), there were also differences. This could be the result of the weather being that 2024 was a drier year than 2023. Also, there was greater competition for resources since there were more crabgrass and weeds in 2024 than in 2023.

There was a significant difference of 18% FM between the two years. In 2023 there was approximately 2,600 kg DM ha $^{-1}$ of FM that was collected. This is the accumulation of alfalfa, corn, crabgrass, and weeds. **Table 2** showed that even though alfalfa had a higher proportion in 2023 than in 2024, there were no differences in FM, which can be explained by the increase in the crabgrass proportion resulting in similar FM. In 2024, the results show that the FM was about 3000 DM kg ha $^{-1}$ which was an 18% increase from the previous year. **Table 3** indicates a notable increase in crabgrass growth from 2023 to 2024, which corresponds with the overall rise in FM. Crabgrass can reseed itself and the 2023 harvest occurred when crabgrass had matured with seed heads. The harvesting could have caused these seeds to disperse and lay dormant in the

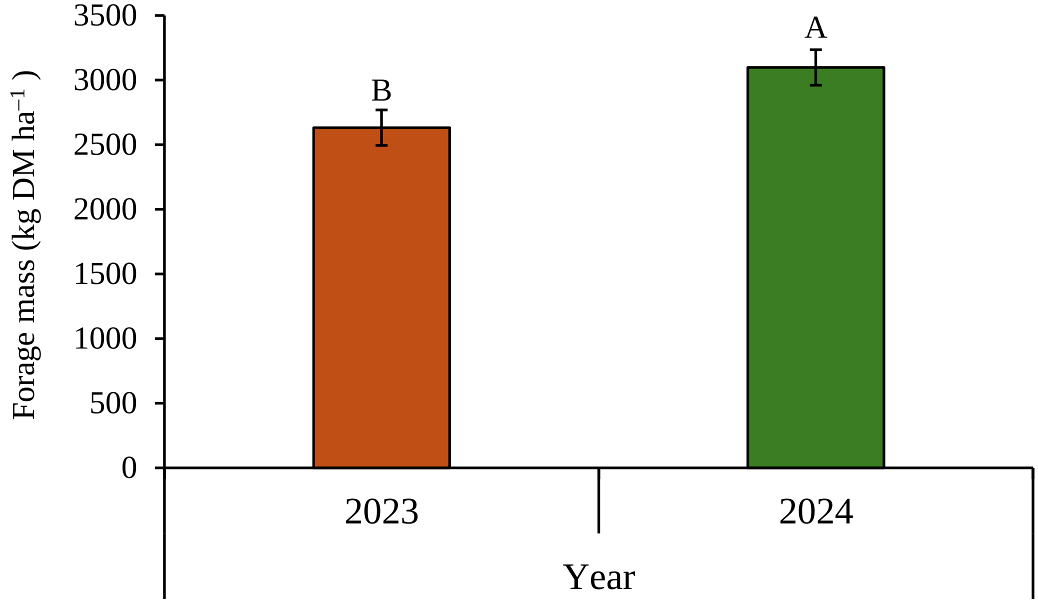


Figure 3 The average forage mass (FM) that was collected for the two seasons (2023 and 2024). The average FM was 2865 DM kg ha^{-1} (SEM = 137.3) and was affected by year (P = 0.0295).

soil seed bank. The first rain of May 2024 allowed these seeds to germinate, and this soil moisture decreased the loss of N in the soil (Teutsch et al., 2005a). The increase in crabgrass proportion in turn increased the FM.

Botanical composition

Table 2 shows the botanical composition of alfalfa by treatment and within 2 years (2023 to 2024) which shows significant differences (P = 0.0205). There was an interaction of treatment and year (P < .05). In 2023, A had a 97% alfalfa proportion and did not differ from AC and ACC which had a 97.7% and 97.0% respectively (P < .05). Apart from ACC 2024, all plots had a high proportion of alfalfa. In 2024 there were no significant differences between A and AC which had a composition percentage of 85.5% and 85.2% respectively (P < .05). Meanwhile, ACC only had 53.7% alfalfa, which is to be expected.

Aponte et al., (2019), observed that the second production year of alfalfa and grass mixtures have a proportion of approximately 50%, suggesting that as the grass ages, it starts to outcompete the alfalfa. When corn is intercropped with a legume (alfalfa), this in turn has a high soil coverage that increases solar absorption and reduces the growth of weeds (Bilalis et al., 2010). In the first growing season, the conditions were favorable to alfalfa growth and since crabgrass was nearly established, it grew a little slower. However, in 2024 environmental conditions were favorable for crabgrass, allowing it to grow and compete with alfalfa. There was also precipitation which resulted in quick crabgrass establishment and growth. Table 1 showed that there was no significant difference in alfalfa yield between the 2 growing seasons, which meant the proportion of alfalfa did not decrease but the proportion of weeds and crabgrass had increased.

Table 2 Alfalfa proportion by treatment × year interaction during two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S.

Treatment	Year 2023	Year 2024	SEM
	------------------- Alfalfa (%) -------------------		
A	97.7 ^{Aa}	85.5 ^{Aa}	3.921
AC	97.7 ^{Aa}	85.2 ^{Aa}	3.921
ACC	97.0 ^{Aa}	53.7 ^{Bb}	3.931
SEM	0.879	6.963	

Means within a column with a common uppercase letter does not differ among treatments ($P < .05$)
Means within a row with a common lowercase letter no differ among years ($P < .05$).
SEM = Standard Error Mean. A = alfalfa alone, AC = alfalfa and corn intercropped, ACC = alfalfa, corn and crabgrass intercropped

In 2023, there was good weed suppression with the proportion of weeds representing only 1.5% of the plots. This was due to the intercropping system of alfalfa and corn coverage and establishment during the first year, protecting the soil and blocking the sun light which stopped weeds from growing. Corn canopy can absorb 80 to 90% of photosynthetically active radiation (PAR), leaving the remaining PAR for alfalfa (Patel et al., 2021). This effectively prevents any PAR from being available to support weed growth. In 2024, the weed proportion was higher at 9.7%, this was the result of the increase of crabgrass that became a weed in the plots that did not have crabgrass as a treatment.

Meanwhile, the crabgrass proportion also showed differences between the years. In 2023 the presence of crabgrass was low (3.0%) because crabgrass did not establish well and was outcompeted by alfalfa (**Table 3 and 4**). In the second season (2024), crabgrass had a higher proportion at 46.2%. Kruk et al., (2006), explained that the presence of a canopy cover decreases the photon flux across all wavelengths compared to full daylight, significantly influencing the physiology and growth of weeds. Teutsch et al., (2005), observed that while crabgrass is an annual, morphologically it can spread like a perennial and can reseed itself, leading to regrowth each year.

Table 4. Shows the weed proportion differences within treatments (P = 0.0198). There were differences in the proportion of weeds within treatments, with ACC showing a lower weed proportion than A and AC. When crabgrass was present, it outcompeted weeds during the entire growing season, resulting in 100% effectiveness. Treatment A and AC had approximately 8%. weeds, and although alfalfa can provide a good canopy that can block out most of the light while also fixing N, it could not compete with all the weeds during the warmer months. Alfalfa being a

Table 3 Weed and crabgrass proportions affected by year during two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S.

Year	Weed	Crabgrass
	---------------------- (%)	----------------------
2023	1.5 ^{B}	3.0 ^{B}
2024	9.7 ^{A}	46.2 ^{A}
SEM	1.31	7.05

Means within a column with a common uppercase letter no differ among years ($P < .05$)
SEM = Standard Error Mean.

Table 4 Weed proportion affected by treatment across two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S.

Treatment	Weed
	-------------- (%) --------------
A	8.3 ^{A}
AC	8.5 ^{A}
ACC	0 ^{B}
SEM	1.94

Means within a column with a common uppercase letter no differ among treatment ($P < .05$)
SEM = Standard Error Mean. A = alfalfa alone, AC = alfalfa and corn intercropped, ACC = alfalfa, corn and crabgrass intercropped

cool-season perennial legume means that during the summer they grow slower (Sharavdorj et al., 2021), allowing for warm-season weed species to compete.

The 2024 growing season was dryer than 2023, and dryer soil meant that alfalfa shoots would increase in growth (Wissuwa & Smith, 1997). Results from Hartwig & Ammon, (2002), show that using a herbicide either pre or postemergence controls the competition between the living mulch and the main crop. It was also shown that the living mulch suppresses weed production. Sanderson et al., (2012), observed that grass-legume mixture reduced the invasion of weeds, especially alfalfa, which showed a greater reduction in weeds than other legumes.

Nutritive value

Table 5 states that alfalfa alone (A) in 2023 had a CP content of 19.1%. Alfalfa is a legume and known to have a high protein content for livestock. The intercropping treatments AC and ACC showed an increase of CP in 2023, but it did not differ from the A ($P < 0.5$). Corn alone (C) recorded the lowest CP content (5.8%), which did differ from the other treatments ($P < 0.5$). Corn being be a cereal grain means that its composition would be higher in carbohydrates (starch) (Makizadeh et al., 2020), which would provide more energy. From the result of this intercropping system, evidence suggests that even with the introduction of crabgrass to this intercropping system, the CP content remains high. This might be because, despite being a grass, crabgrass has a higher CP content to other warm – season grasses (Aguerre et al., 2023).

In 2024, the results state that treatment A had a CP content of 17.7% and this did not differ from treatment ACC with a CP content of 16.9%, but AC did differ from A and ACC (P < 0.5). The results also showed that corn grown as a monoculture had the lowest content of CP which differ from the other treatments. **Table 3** shows that in 2024 there was a significant

Table 5 Crude protein content (CP) for each treatment and for the 2 seasons (2023 and 2024) and their interaction (P = 0.0044).

Treatment	Year		SEM
	2023	2024	
	---------------- Crude protein (%) ----------------		
Alfalfa alone	19.1 ^{Aa}	17.7 ^{Ab}	0.36
Corn alone	5.8 ^{Ba}	4.9 ^{Ca}	0.36
Corn + alfalfa	19.3 ^{Aa}	15.4 ^{Bb}	0.36
Corn + alfalfa + crabgrass	19.4 ^{Aa}	16.9 ^{Ab}	0.36
SEM	0.36	0.36	

Means within a column with a common uppercase letter no differ among treatments (*P* < .05)
Means within a row with a common lowercase letter no differ among years (*P* < .05).
SEM = Standard Error Mean. A = alfalfa alone, C = corn alone, AC = alfalfa and corn intercropped, ACC = alfalfa, corn and crabgrass intercropped.

increase in the proportion of crabgrass. This increase out competed the proportion of alfalfa, which, when samples were collected had a higher proportion of crabgrass than alfalfa which reduced the overall CP content.

In 2024, showed that treatments A, AC and ACC had an overall decrease in CP content, and this differed from 2023, while treatment C did not differ among the two seasons. **Table 1**, states that there was no difference in FM of alfalfa between the two seasons, but a reason which could cause a reduction in CP is harvesting time. Berti et al., (2021b) explained that in North Dakota and Minnesota, CP was influenced by harvest date and could depend on temperature and moisture. **Figure 1** shows that during the growing season of 2024 it was drier than 2023.

Table 6 shows the percentage of lignin (LIG) present in the plants during the two seasons. This table shows that the LIG was affect by treatment and year ($P < 0.0015$ and $P < 0.0258$ respectively).

LIG in one of the most abundant biopolymer on the globe (Liu et al., 2018). It is complex and found in the cell walls of plants and it provides structural support, defense, water transport (Xie et al., 2018), and environmental stress tolerance (Choi et al., 2023).

Table 6 shows that in 2023, treatment C had the lowest amount of LIG (2.9%), this differed from the other treatments (A, AC, ACC). Lignin is indigestible by the microorganisms of the rumen (Berti et al., 2021a), and it increases as the plant matures (Quinby et al., 2021). In 2024, treatments A and ACC did not differ, treatment AC differed from all the treatments. Treatment C had the lowest percentage of LIG (2.6%).

In 2024, there was a decrease in LIG between the years but was significant for treatments A. C and ACC. There was a longer frost in the spring of 2024 compared to 2023, indicating that the air and soil temperature remained cooler later in the spring of 2024, which lead to alfalfa

Table 6 Lignin (LIG) content as affected by treatment x year interaction during two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S.

Treatment	Year		SEM
	2023	2024	
	---------------- LIG (%) ----------------		
A	8.8^{Aa}	8.4^{Aa}	0.23
C	2.9^{Ba}	2.6^{Ca}	0.23
AC	8.7^{Aa}	7.3^{Bb}	0.23
ACC	9.0^{Aa}	8.8^{Aa}	0.23
SEM	0.23	0.23	

Means within a column with a common uppercase letter no differ among treatments ($P < .05$)
Means within a row with a common lowercase letter no differ among years ($P < .05$).
SEM = Standard Error Mean. A = alfalfa alone, C = corn alone, AC = alfalfa and corn intercropped, ACC = alfalfa, corn and crabgrass intercropped

remaining dormant longer. This resulted in the alfalfa being more mature in 2023 than in 2024. Also Spandl & Hesterman, (1997) stated that since alfalfa is a legume, it has a higher amount of LIG than cool-season grasses, it even has more LIG than many warm-season grasses (Jung et al., 1997).

The NDFd for 2023 shows no significant difference between treatments A, AC and ACC (43.2, 43.9 and 42.7% respectively), while C had the highest concentration of NDFd (48.9%). Table 6 shows that in 2023 the LIG content was high in treatments A, AC and ACC, and higher the LIG content the less digestible is the forage.

Corn being a C4 grass has more fiber than a legume which makes it more digestible. Having less crabgrass in 2023 than 2024, this led to higher N being in the soil that changed the leaf – stem ratio and decreased digestibility (Teutsch et al., 2005b). Also, results from Noller & Rhykerd, (2015) states the N rates in the soil can increase the NFD (nitrate-from nitrogen) concentration, which decreases the plant and NDF digestibility.

In 2024, treatments A and ACC had the lowest NDFd and differed from treatments C and AC. Due to the significant increase of crabgrass throughout the entire experimental site in 2024 than 2023 (**Table 3**), this had increased the NDFd for this system. When grass is added to a legume stand, it can increase the NDFd of that intercropping system (Ball et al., 2021). It was also noted in **Table 5**, that the CP content had decrease from 2023 to 2024, and Traxler et al., (1998) noted that s decrease in CP corresponds with an increase of in NDFd, which aligns with our results.

Between the 2 growing seasons (2023 and 2024), there was no significant difference among years or treatment except for treatment AC which differed. This could be the result of having corn in the treatment and a high amount of crabgrass that affected the entire experimental site. This high amount of grass increased the NDFd of this treatment.

Table 8. The IVTDMD percentage was not affected by treatment, this is why it is not shown on the table. IVTDMD is a method used to estimate the digestibility of feed by simulating the conditions in the rumen of an animal (Lopez-Marnet et al., 2021). The digestibility is then calculated based on the amount of DM that is broken down during the process (Altman et al., 2022). In 2023, Table 8 shows that there was a higher percentage of IVTDMD than 2024. Even though there was more concentration of LIG in 2023 than 2024 (Table 6), and NDFd was higher in 2024 than 2023 (**Table 7**).

Results shown from Aguerre et al., (2023b), states that legume as a monoculture and crabgrass-legume mixture has an increase in IVTDMD. These results were also similar to those obtained from Nave & Corbin, (2018b) with crabgrass and a legume mixture. However, results from Brown et al., (2018) show that cool-season legumes have a higher lignin content than grasses and normally have lower digestible fiber; but, this was not the case in our study.

Table 7 Neutral detergent fiber digestibility (NDFd) content as affected by treatment x year interaction during two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S.

Treatment	Year		SEM
	2023	2024	
	---------------- NDFd (%) ----------------		
A	43.2^{Ba}	44.8^{Ba}	1.35
C	48.9^{Aa}	48.5^{Aa}	1.35
AC	43.9^{Bb}	50.6^{Aa}	1.35
ACC	42.7^{Ba}	43.7^{Ba}	1.35
SEM	1.35	1.35	

Means within a column with a common uppercase letter no differ among treatments (*P* < .05)
Means within a row with a common lowercase letter no differ among years (*P* < .05).
SEM = Standard Error Mean. A = alfalfa alone, C = corn alone, AC = alfalfa and corn intercropped, ACC = alfalfa, corn and crabgrass intercropped

Table 8 In vitro true dry matter digestibility (IVTDMD) proportions were affected by year during two consecutive years, 2023 and 2024, in Spring Hill, TN, U.S.

Year	IVTDMD
	------------------------ (%) ------------------------
2023	74.0^{A}
2024	72.4^{B}
SEM	0.47

Means within a column with a common uppercase letter no differ among years (*P* < .05).
SEM = Standard Error Mean.

CONCLUSION

Alfalfa when intercropped with corn did not improve corn productivity. When crabgrass was added to the mixture it improved the overall FM. Our results show that alfalfa being a legume has a high quantity of lignin that reduces digestion, but when crabgrass was added to the mixture this improved the overall nutritive value of the intercropped mixture. Corn has a lower concentration of CP, but when added to the mixture, improved forage quality.

Environmental and seasonal factors play an important role in this system. Drought is a major problem when managing an intercropping system. During these trying times an irrigation system should be implemented to reduce the loss of FM. Adding crabgrass to alfalfa and corn stands that are already established can increase FM and nutrient composition during the summer periods.

REFERENCES

Aguerre, M. J., Peña, O. M., Velasquez, C., & Ferreira, G. (2023a). Nutritional Composition and In Vitro Ruminal Digestibility of Crabgrass (Digitaria sanguinalis (L.) Scop.) in Monoculture or Interseeded with Cowpea (Vigna unguiculata (L.) Walp) and Lablab (Lablab purpureus (L.) Sweet). *Animals*, *13*(14), Article 14. https://doi.org/10.3390/ani13142305

Aguerre, M. J., Peña, O. M., Velasquez, C., & Ferreira, G. (2023b). Nutritional Composition and In Vitro Ruminal Digestibility of Crabgrass (Digitaria sanguinalis (L.) Scop.) in Monoculture or Interseeded with Cowpea (Vigna unguiculata (L.) Walp) and Lablab (Lablab purpureus (L.) Sweet). *Animals*, *13*(14), Article 14. https://doi.org/10.3390/ani13142305

Alla, W. A. H., Bakheit, B. R., Elwafa, A. A.-, & El-Nahrawy, M. A. (2013). Evaluate of some varieties of alfalfa for forage yield and its components under the New Valley conditions. *Journal of Agroalimentary Processes and Technologies*.

Allen, M. S., Coors, J. G., & Roth, G. W. (2003). Corn Silage. In *Silage Science and Technology* (pp. 547–608). John Wiley & Sons, Ltd. https://doi.org/10.2134/agronmonogr42.c12

Altman, A. W., Vanzant, E. S., McLeod, K. R., & Harmon, D. L. (2022). In Vitro Measurements of True Digestibility and Products of Digestion Using Multiple Cultivars of Non-Extracted and CBD-Extracted Industrial Hemp Biomass (Cannabis sativa). *Frontiers in Animal Science*, *3*. https://doi.org/10.3389/fanim.2022.915916

Aponte, A., Samarappuli, D., & Berti, M. T. (2019). Alfalfa–Grass Mixtures in Comparison to Grass and Alfalfa Monocultures. *Agronomy Journal*, *111*(2), 628–638. https://doi.org/10.2134/agronj2017.12.0753

Aslam, M., Maqbool, M. A., & Cengiz, R. (2015). *Drought Stress in Maize (Zea mays L.)*. Springer International Publishing. https://doi.org/10.1007/978-3-319-25442-5

Ball, D., Collins, M., Lacefield, G., Martin, N., Mertens, D., Olson, K., Putnam, D., Undersander, D., & Wolf, M. (2021). *Understanding forage quality*.

Barnes, D. K. (1980). Alfalfa. In *Hybridization of Crop Plants* (pp. 177–187). John Wiley & Sons, Ltd. https://doi.org/10.2135/1980.hybridizationofcrops.c9

Beck, P., Hess, T., Hubbell, D., Gadberry, M. S., Jennings, J., & Sims, M. (2016). Replacing synthetic N with clovers or alfalfa in bermudagrass pastures. 2. Herbage nutritive value for growing beef steers. *Animal Production Science*, *57*(3), 547–555. https://doi.org/10.1071/AN15046

Belfry, K. D., & Van Eerd, L. L. (2016). Establishment and Impact of Cover Crops Intersown into Corn. *Crop Science*, *56*(3), 1245–1256. https://doi.org/10.2135/cropsci2015.06.0351

Berti, M. T., Cecchin, A., Samarappuli, D. P., Patel, S., Lenssen, A. W., Moore, K. J., Wells, S. S., & Kazula, M. J. (2021a). Alfalfa Established Successfully in Intercropping with Corn in the Midwest US. *Agronomy*, *11*(8), Article 8. https://doi.org/10.3390/agronomy11081676

Berti, M. T., Cecchin, A., Samarappuli, D. P., Patel, S., Lenssen, A. W., Moore, K. J., Wells, S. S., & Kazula, M. J. (2021b). Alfalfa Established Successfully in Intercropping with Corn in the Midwest US. *Agronomy*, *11*(8), Article 8. https://doi.org/10.3390/agronomy11081676

Bilalis, D., Papastylianou, P., Konstantas, A., Patsiali, S., Karkanis, A., & Efthimiadou, A. (2010). Weed-suppressive effects of maize–legume intercropping in organic farming.

International Journal of Pest Management, *56*(2), 173–181. https://doi.org/10.1080/09670870903304471

Brown, A. N., Ferreira, G., Teets, C. L., Thomason, W. E., & Teutsch, C. D. (2018). Nutritional composition and in vitro digestibility of grass and legume winter (cover) crops. *Journal of Dairy Science*, *101*(3), 2037–2047. https://doi.org/10.3168/jds.2017-13260

Choi, S. J., Lee, Z., Kim, S., Jeong, E., & Shim, J. S. (2023). Modulation of lignin biosynthesis for drought tolerance in plants. *Frontiers in Plant Science*, *14*. https://doi.org/10.3389/fpls.2023.1116426

Clark, A. (2008). *Managing Cover Crops Profitably (3rd Ed.)*. DIANE Publishing.

Coombs, C., Lauzon, J. D., Deen, B., & Van Eerd, L. L. (2017). Legume cover crop management on nitrogen dynamics and yield in grain corn systems. *Field Crops Research*, *201*, 75–85. https://doi.org/10.1016/j.fcr.2016.11.001

Corn | History, Cultivation, Uses, & Description | Britannica. (2023, January 6). https://www.britannica.com/plant/corn-plant

de Souza, J. E. B., & Ferreira, E. P. de B. (2017). Improving sustainability of common bean production systems by co-inoculating rhizobia and azospirilla. *Agriculture, Ecosystems & Environment*, *237*, 250–257. https://doi.org/10.1016/j.agee.2016.12.040

Dewi, R. K., Suliansyah, I., Anwar, A., Syarif, A., & Rahmah, M. (2022). Effect of shading on plant growth of 4 varieties of hybrid corn. *IOP Conference Series: Earth and Environmental Science*, *1097*(1), 012011. https://doi.org/10.1088/1755-1315/1097/1/012011

Dhima, K. V., Lithourgidis, A. S., Vasilakoglou, I. B., & Dordas, C. A. (2007). Competition indices of common vetch and cereal intercrops in two seeding ratio. *Field Crops Research*, *100*(2), 249–256. https://doi.org/10.1016/j.fcr.2006.07.008

Dollete, D., Lumactud, R. A., Carlyle, C. N., Szczyglowski, K., Hill, B., & Thilakarathna, M. S. (2024). Effect of drought stress on symbiotic nitrogen fixation, soil nitrogen availability and soil microbial diversity in forage legumes. *Plant and Soil*, *495*(1), 445–467. https://doi.org/10.1007/s11104-023-06348-1

Endale, D. M., Schomberg, H. H., Fisher, D. S., Jenkins, M. B., Sharpe, R. R., & Cabrera, M. L. (2008). No-Till Corn Productivity in a Southeastern United States Ultisol Amended with Poultry Litter. *Agronomy Journal*, *100*(5), 1401–1408. https://doi.org/10.2134/agronj2007.0401

Fehr, W. R., Hadley, H. H., American Society of Agronomy, & Crop Science Society of America (Eds.). (1980). *Hybridization of crop plants*. American Society of Agronomy : Crop Science Society of America.

Ferraretto, L. F., Shaver, R. D., & Luck, B. D. (2018). Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. *Journal of Dairy Science*, *101*(5), 3937–3951. https://doi.org/10.3168/jds.2017-13728

Flinchum, W. (2001). *Corn Production in Tennessee*.

Gebru, H. (2015). A Review on the Comparative Advantages of Intercropping to Mono-Cropping System. *Journal of Biology*.

Granier, C., Inzé, D., & Tardieu, F. (2000). Spatial Distribution of Cell Division Rate Can Be Deduced from that of p34cdc2 Kinase Activity in Maize Leaves Grown at Contrasting

Temperatures and Soil Water Conditions1. *Plant Physiology*, *124*(3), 1393–1402. https://doi.org/10.1104/pp.124.3.1393

Hartwig, N. L., & Ammon, H. U. (2002). Cover crops and living mulches. *Weed Science*, *50*(6), 688–699. https://doi.org/10.1614/0043-1745(2002)050[0688:AIACCA]2.0.CO;2

Javanmard, A., Dabbagh Mohammadi Nassab, A., Nasab, M., Javanshir, A., Moghaddam, M., & Janmohammadi, H. (2009). Forage yield and quality in intercropping of maize with different legumes as double- cropped. *Journal of Food, Agriculture and Environment*, *7*.

Jung, H. G., Mertens, D. R., & Payne, A. J. (1997). Correlation of Acid Detergent Lignin and Klason Lignin with Digestibility of Forage Dry Matter and Neutral Detergent Fiber. *Journal of Dairy Science*, *80*(8), 1622–1628. https://doi.org/10.3168/jds.S0022-0302(97)76093-4

Kaushal, M., & Wani, S. P. (2016). Plant-growth-promoting rhizobacteria: Drought stress alleviators to ameliorate crop production in drylands. *Annals of Microbiology*, *66*(1), 35–42. https://doi.org/10.1007/s13213-015-1112-3

Kruk, B., Insausti, P., Razul, A., & Benech-Arnold, R. (2006). Light and thermal environments as modified by a wheat crop: Effects on weed seed germination. *Journal of Applied Ecology*, *43*(2), 227–236. https://doi.org/10.1111/j.1365-2664.2006.01140.x

La Guardia Nave, R., & Corbin, M. D. (2018a). Forage Warm-Season Legumes and Grasses Intercropped with Corn as an Alternative for Corn Silage Production. *Agronomy*, *8*(10), Article 10. https://doi.org/10.3390/agronomy8100199

La Guardia Nave, R., & Corbin, M. D. (2018b). Forage Warm-Season Legumes and Grasses Intercropped with Corn as an Alternative for Corn Silage Production. *Agronomy*, *8*(10), Article 10. https://doi.org/10.3390/agronomy8100199

Larson, J. A., Roberts, R. K., Tyler, D. D., Duck, B. N., & Slinsky, S. P. (1998). Nitrogen-Fixing Winter Cover Crops and Production Risk: A Case Study for No-Tillage Corn. *Journal of Agricultural and Applied Economics*, *30*(1), 163–174. https://doi.org/10.1017/S1074070800008142

Liu, Q., Luo, L., & Zheng, L. (2018). Lignins: Biosynthesis and Biological Functions in Plants. *International Journal of Molecular Sciences*, *19*(2), Article 2. https://doi.org/10.3390/ijms19020335

Lopez-Marnet, P.-L., Guillaume, S., Jacquemot, M.-P., Reymond, M., & Méchin, V. (2021). High throughput accurate method for estimating in vitro dry matter digestibility of maize silage. *Plant Methods*, *17*(1), 89. https://doi.org/10.1186/s13007-021-00788-5

Loy, D. D., & Lundy, E. L. (2019a). Chapter 23—Nutritional Properties and Feeding Value of Corn and Its Coproducts. In S. O. Serna-Saldivar (Ed.), *Corn (Third Edition)* (pp. 633–659). AACC International Press. https://doi.org/10.1016/B978-0-12-811971-6.00023-1

Loy, D. D., & Lundy, E. L. (2019b). Nutritional Properties and Feeding Value of Corn and Its Coproducts. In *Corn* (pp. 633–659). Elsevier. https://doi.org/10.1016/B978-0-12-811971-6.00023-1

Makizadeh, H., Kazemi-Bonchenari, M., Mansoori-Yarahmadi, H., Fakhraei, J., Khanaki, H., Drackley, J. K., & Ghaffari, M. H. (2020). Corn processing and crude protein content in calf starter: Effects on growth performance, ruminal fermentation, and blood metabolites. *Journal of Dairy Science*, *103*(10), 9037–9053. https://doi.org/10.3168/jds.2020-18578

Manafi, M. (2017). *Poultry Science*. BoD – Books on Demand.

Martin, K., & Sauerborn, J. (2013). Origin and Development of Agriculture. In K. Martin & J. Sauerborn (Eds.), *Agroecology* (pp. 9–48). Springer Netherlands. https://doi.org/10.1007/978-94-007-5917-6_2

Mazzafera, P., Favarin, J. L., & Andrade, S. A. L. de. (2021). Editorial: Intercropping Systems in Sustainable Agriculture. *Frontiers in Sustainable Food Systems*, *5*. https://www.frontiersin.org/articles/10.3389/fsufs.2021.634361

McIntosh, D., Anderson-Husmoen, B. jo, Kern-Lunbery, R., Goldblatt, P., Lemus, R., Griggs, T., Bauman, L., Boone, S., Shewmaker, G., & Teutsch, C. (2022). Guidelines for Optimal Use of NIRSC Forage and Feed Calibrations in Membership Laboratories (Second Edition). *Book*. https://trace.tennessee.edu/utk_planpubs/100

Moore, E. b., Wiedenhoeft, M. h., Kaspar, T. c., & Cambardella, C. a. (2014). Rye Cover Crop Effects on Soil Quality in No-Till Corn Silage–Soybean Cropping Systems. *Soil Science Society of America Journal*, *78*(3), 968–976. https://doi.org/10.2136/sssaj2013.09.0401

Mousavi, S. R., & Eskandari, H. (2011). A General Overview on Intercropping and Its Advantages in Sustainable Agriculture. *Journal of Applied Environmental and Biological Sciences*, *1*, 482–486.

Murray, I., & Cowe, I. (2004). Sample Preparation. In *Near-Infrared Spectroscopy in Agriculture* (pp. 75–112). John Wiley & Sons, Ltd. https://doi.org/10.2134/agronmonogr44.c5

Noller, C. H., & Rhykerd, C. L. (2015). Relationship of Nitrogen Fertilization and Chemical Composition of Forage to Animal Health and Performance. In D. A. Mays (Ed.), *ASA, CSSA, and SSSA Books* (pp. 363–394). American Society of Agronomy, Crop Science

Society of America, Soil Science Society of America. https://doi.org/10.2134/1974.foragefertilization.c17

Nordquist, P. T., & Wicks, G. A. (1974). Establishment Methods for Alfalfa in Irrigated Corn [1]. *Agronomy Journal*, *66*(3), 377–380. https://doi.org/10.2134/agronj1974.00021962006600030012x

Olszewska, M., Grzegorczyk, S., & Grabowski, K. (2020). *THE YIELD AND NUTRIENT CONTENT OF MIXTURES ALFALFA WITH COCKSFOOT*.

Osterholz, W. R., Renz, M. J., & Grabber, J. H. (2020). Alfalfa establishment by interseeding with silage corn projected to increase profitability of corn silage–alfalfa rotations. *Agronomy Journal*, *112*(5), 4120–4132. https://doi.org/10.1002/agj2.20312

Pang, K., Van Sambeek, J. W., Navarrete-Tindall, N. E., Lin, C.-H., Jose, S., & Garrett, H. E. (2019). Responses of legumes and grasses to non-, moderate, and dense shade in Missouri, USA. I. Forage yield and its species-level plasticity. *Agroforestry Systems*, *93*(1), 11–24. https://doi.org/10.1007/s10457-017-0067-8

Patel, S., Bartel, C. A., Lenssen, A. W., Moore, K. J., & Berti, M. T. (2021). Stem Density, Productivity, and Weed Community Dynamics in Corn-Alfalfa Intercropping. *Agronomy*, *11*(9), Article 9. https://doi.org/10.3390/agronomy11091696

Price, A. (2012). *Weed Control*. BoD – Books on Demand.

Quinby, M. P., Nave, R. L. G., Sulc, R. M., Castillo, M. S., Bates, G. E., Schneider, L. G., & McIntosh, D. W. (2021). Comparison of alfalfa mixed with tall fescue and bermudagrass on forage accumulation, botanical composition, and nutritive value. *Crop Science*, *61*(5), 3746–3774. https://doi.org/10.1002/csc2.20461

Radcliffe, D. E., & West, L. T. (2000). *Southern Cooperative Series Bulletin*. http://soilphysics.okstate.edu/S257/book/mlra136/

Reeves, D. W. (1994). Cover Crops and Rotations. In *Crops Residue Management*. CRC Press.

Rose, D. J., Inglett, G. E., & Liu, S. X. (2010). Utilisation of corn (Zea mays) bran and corn fiber in the production of food components. *Journal of the Science of Food and Agriculture*, *90*(6), 915–924. https://doi.org/10.1002/jsfa.3915

Sainju, U. M., Singh, B. P., & Whitehead, W. F. (2002). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil and Tillage Research*, *63*(3), 167–179. https://doi.org/10.1016/S0167-1987(01)00244-6

Sanderson, M. A., Brink, G., Ruth, L., & Stout, R. (2012). Grass–Legume Mixtures Suppress Weeds during Establishment Better than Monocultures. *Agronomy Journal*, *104*(1), 36–42. https://doi.org/10.2134/agronj2011.0130

Sharavdorj, K., Jang, Y., Byambadorj, S.-O., & Cho, J.-W. (2021). Understanding seed germination of forage crops under various salinity and temperature stress. *Journal of Crop Science and Biotechnology*, *24*(5), 545–554. https://doi.org/10.1007/s12892-021-00101-9

Silva, M. S. J. da, Jobim, C. C., Poppi, E. C., Tres, T. T., & Osmari, M. P. (2015). Production technology and quality of corn silage for feeding dairy cattle in Southern Brazil. *Revista Brasileira de Zootecnia*, *44*, 303–313. https://doi.org/10.1590/S1806-92902015000900001

Smith, M. A., & Carter, P. R. (1998). Strip Intercropping Corn and Alfalfa. *Journal of Production Agriculture*, *11*(3), 345–353. https://doi.org/10.2134/jpa1998.0345

Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., Nyiraneza, J., & O'Neil, K. (2005). Evaluating Cover Crops for Benefits, Costs and Performance within Cropping System Niches. *Agronomy Journal*, *97*(1), 322–332. https://doi.org/10.2134/agronj2005.0322a

Solomon, J. K. Q., Macoon, B., Lang, D. J., Parish, J. A., & Vann, R. C. (2011). A Novel Approach to Grass–Legume Management. *Crop Science*, *51*(4), 1865–1876. https://doi.org/10.2135/cropsci2010.10.0598

Sosinski, S., Castillo, M. S., Kulesza, S., & Leon, R. (2022). Poultry litter and nitrogen fertilizer effects on productivity and nutritive value of crabgrass. *Crop Science*, *62*(6), 2537–2547. https://doi.org/10.1002/csc2.20815

Spandl, E., & Hesterman, O. B. (1997). Forage Quality and Alfalfa Characteristics in Binary Mixtures of Alfalfa and Bromegrass or Timothy. *Crop Science*, *37*(5), 1581–1585. https://doi.org/10.2135/cropsci1997.0011183X003700050029x

Steenwerth, K., & Belina, K. M. (2008). Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Applied Soil Ecology*, *40*(2), 359–369. https://doi.org/10.1016/j.apsoil.2008.06.006

Sun, T., Li, Z., Wu, Q., Sheng, T., & Du, M. (2018). Effects of alfalfa intercropping on crop yield, water use efficiency, and overall economic benefit in the Corn Belt of Northeast China. *Field Crops Research*, *216*, 109–119. https://doi.org/10.1016/j.fcr.2017.11.007

Teutsch, C. D., Fike, J. H., & Mac Tilson, W. (2005a). Yield, Digestibility, and Nutritive Value of Crabgrass as Impacted by Nitrogen Fertilization Rate and Source. *Agronomy Journal*, *97*(6), 1640–1646. https://doi.org/10.2134/agronj2005.0047

Teutsch, C. D., Fike, J. H., & Mac Tilson, W. (2005b). Yield, Digestibility, and Nutritive Value of Crabgrass as Impacted by Nitrogen Fertilization Rate and Source. *Agronomy Journal*, *97*(6), 1640–1646. https://doi.org/10.2134/agronj2005.0047

Tharangani, R. M. H., Yakun, C., Zhao, L. S., Ma, L., Liu, H. L., Su, S. L., Shan, L., Yang, Z. N., Kononoff, P. J., Weiss, W. P., & Bu, D. P. (2021). Corn silage quality index: An index combining milk yield, silage nutritional and fermentation parameters. *Animal Feed Science and Technology*, *273*, 114817. https://doi.org/10.1016/j.anifeedsci.2021.114817

Traxler, M. J., Fox, D. G., Van Soest, P. J., Pell, A. N., Lascano, C. E., Lanna, D. P., Moore, J. E., Lana, R. P., Vélez, M., & Flores, A. (1998). Predicting forage indigestible NDF from lignin concentration. *Journal of Animal Science*, *76*(5), 1469. https://doi.org/10.2527/1998.7651469x

USDA/NASS 2021 State Agriculture Overview for Tennessee. (2021). https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=TENNESSEE

Wilts, A. R., Reicosky, D. C., Allmaras, R. R., & Clapp, C. E. (2004). Long-Term Corn Residue Effects. *Soil Science Society of America Journal*, *68*(4), 1342–1351. https://doi.org/10.2136/sssaj2004.1342

Wissuwa, M., & Smith, S. E. (1997). Morphological and Physiological Characteristics Associated with Tolerance to Summer Irrigation Termination in Alfalfa. *Crop Science*, *37*(3), cropsci1997.0011183X003700030003x. https://doi.org/10.2135/cropsci1997.0011183X003700030003x

Xie, M., Zhang, J., Tschaplinski, T. J., Tuskan, G. A., Chen, J.-G., & Muchero, W. (2018). Regulation of Lignin Biosynthesis and Its Role in Growth-Defense Tradeoffs. *Frontiers in Plant Science, 9*. https://doi.org/10.3389/fpls.2018.01427

Zhang, L., van der Werf, W., Zhang, S., Li, B., & Spiertz, J. H. J. (2007). Growth, yield and quality of wheat and cotton in relay strip intercropping systems. *Field Crops Research*, *103*(3), 178–188. https://doi.org/10.1016/j.fcr.2007.06.002

Zhou, X. V., Larson, J. A., Sykes, V. R., Ashworth, A. J., & Allen, F. L. (2022). Long-term conservation agriculture effects on corn profitability in West Tennessee. *Crop Science*, *62*(3), 1348–1359. https://doi.org/10.1002/csc2.20727

VITA

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