POTASSIUM APPLICATION AND HARVEST REGIMEN IN ALFALFA YIELD, FORAGE NUTRITIVE VALUE, AND STAND PERSISTENCE IN THE SOUTHERN COASTAL PLAIN OF SOUTH GEORGIA.

By

BRITTA THINGULDSTAD

(Under the Direction of Jennifer J. Tucker and Jacob R. Segers)

ABSTRACT

Potassium fertilization and harvest timing can both impact stand life of alfalfa (*Medicago sativa* L.). The objective of this trial was to determine the impact of potassium fertilization and harvest regimen on forage yield, stand persistence, and nutritive value of 'Bulldog 805' alfalfa in the Southeast. Main plots were growth stage: bud stage, and 10, 30 and 50% bloom. Plots were subdivided to examine K fertilization at rates: 0, 67, 101, 134 and 168 kg K_2O ha^{-1}, in three equally-split applications throughout the season. Measurements included: total-plot yield (via mechanical harvesting), mass $shoot^{-1}$ and leaf:stem. Stand density measurements included: shoots m^{-2}, visual ground cover, and crown and stem counts. Grab samples were collected for nutritional analysis using near-infrared reflectance spectroscopy. Later maturity stages positively impacted yield and density measurements and negatively impacted nutritive value. The low levels of potassium fertilization used in this trial only affected predicted forage mineral content.

INDEX WORDS: Potassium, Alfalfa, Harvest timing

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BRITTA THINGULDSTAD

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BRITTA THINGULDSTAD

Major Professors: Jennifer Tucker
Jacob Segers

Committee: Dennis Hancock
Lawton Stewart

Electronic Version Approved:
Suzanne Barbour
Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION

Alfalfa (*Medicago sativa* L.) has gained popularity as an animal feed crop due to its superiority in yield, protein content and palatability (Simons et al., 1995). Because of this, alfalfa has the potential to provide acceptable animal gains (Ball et al., 2015). Alfalfa also provides high nutritional value during the summer months, a time which most available forage species lack nutritive value (Hoveland, 1986). Despite being introduced in Georgia in the 1800's, alfalfa production has been mostly confined to the northern United States. Development of cultivars adapted to conditions in the South have allowed alfalfa production to increase in the southern United States (Haby and Leonard, 2005). The Coastal Plains region of the southeastern United States is considered a particularly harsh environment for adequate alfalfa growth due to poor soil conditions (Haby and Leonard, 2005), hot summers, irregular freezing temperatures and inconsistent rainfall (Terrill et al., 1996). Improved pest tolerance, dormancy characteristics and tolerance to soil conditions are some of the traits exhibited in new adapted cultivars to allow increased growth in the Coastal Plains region (Brown et al., 1990).

Potassium fertilization and harvest timing can both drastically impact stand life of alfalfa. Potassium fertilization can increase yield, growth, and nutritive value of alfalfa (Collins and Duke, 1981; Grewal and Williams, 2002; and Berg et al., 2007). Potassium fertilization has been shown to maintain alfalfa stand density and can improve stand density by up to 40% (Chandler et al., 1946). Without any K fertilization, complete stand loss has been reported after 5 years (Markus and Battle, 1965). Yield responses can also be seen from increased K fertilization, but rates are dependent on soil types (Collins et al., 1986). For example, sandy soils in the southern Coastal Plains can quickly leach nutrients and have low cation exchange capacities (Kissel and Sonon, 2011). Therefore, higher K rates may be necessary to produce a positive response in alfalfa in the southern Coastal Plains. Furthermore, K can become more important as stands age, and responses may not be seen until after the establishment year (Simons et al., 1995; Berg et al., 2007; and Berg et al., 2009).

Harvest regimen may also impact alfalfa stands. Typically, harvesting at later maturity can increase yield and stand persistence, but will decrease nutritive value (Moyer et al., 1998). Stand age may affect alfalfa response to harvest regimen, and consistent defoliation at early maturity stages will cause excessive stand loss (Gasser et al., 1969). Maximum productivity and yield has been achieved between early and late bloom harvesting intervals (Gasser et al., 1969) and seasonal yield is highest in the second-year after establishment (Lissbrant et al., 2009). Nutritional composition metrics are also optimized in the early bloom stage and decline thereafter (Weir et al., 1960; and Wildman et al., 2003). Changes in leaf and stem composition may be the driving factors of decreased nutritive value in later maturity stages with lower leaf:stem ratios (Sheaffer et al., 2000). As stems become thicker and more numerous, overall stand density increases as well and weed infestation decreases (Weir et al., 1960).

Due to the recent release of high-performing alfalfa cultivars adapted to the environment of the southeastern United States, more research is necessary to find the complementary intersection between optimum fertilization input and harvest frequency in the Southeastern United States. Therefore, the objective of this trial is to determine the impact of K fertilization and harvest regimen on forage yield, nutritive value and stand persistence of alfalfa in the southern Coastal Plains.

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CHAPTER 2

LITERATURE REVIEW

Introduction

Fertilization and harvest management are critical to utilize cultivars adapted to the Southeastern US to their greatest potential, considering the harsh environment they inhabit. In the Southeast, high temperatures and humidity, coupled with low rainfall may influence appropriate harvest timing and fertilization. Current recommendations on harvest timing and nutrient management are generated from research conducted in northern climates with different alfalfa varieties. Therefore, examination of the optimum K fertilization rate and harvest timing with adapted varieties is important in the context of southeastern environments.

Bulldog 805

"Georgia Bulldog 805" was released in January 1996 (Bouton et al., 1997), and was tested experimentally as "GA-FL-77-S2" and is also called "ABT 805" in its registration papers (Bouton et al., 1997). Bulldog 805 was selected under continuous grazing pressure of beef cattle in Georgia for two summers (Bouton et al., 1997). Bulldog 805 alfalfa is advantageous in the southeast because of its high resistance to fusarium wilt, southern root-knot nematode, phytophthora root rot, spotted alfalfa aphid, and moderate resistance to anthracnose, bacterial wilt, verticillium wilt and stem nematode (Bouton et al., 1997). Its recommended uses include: grazing, hay, and silage production in the southeastern United States (Bouton et al., 1997). Stand density improvements have been recorded for Bulldog 805 over Alfagraze, 13R Supreme, Rio, ABI 700, and Florida 77 in unpublished data by Bouton and Gates, 1995 (Bouton et al., 1997).

Despite limited data on Bulldog 805, there is substantial data regarding its parent material: FL-77. Brummer and Bouton (1992) found that Florida-77 depended more on total nonstructural carbohydrates (TNC) than other grazing tolerant cultivars (such as Alfagraze and Travois) for regrowth. However, Alfagraze produced higher levels of TNC under frequent cutting conditions compared to Florida-77 (Brummer and Bouton, 1992). Florida-77 is characterized by more erect, fewer, and thicker stems, and higher dry matter yields than grazing type cultivars (Brummer and Bouton, 1991). Bulldog 805 demonstrated better survival under hay management than its parent, FL-77, with 22 plants m^{-2} compared to six plants m^{-2} and 8,998 kg ha^{-1} compared to 6,492 kg ha^{-1} seasonal yields, respectively, in the second harvest year (Bouton and Gates, 2003). However, Bouton and Gates (2003) noted that these study results might not be typical, due to the Bulldog 805 cultivar being selected in the same location as the trials were conducted, resulting in an advantage of Bulldog 805 in that environment over the parent strains.

Potassium Fertilization of Alfalfa and Its Effects

Potassium fertilization in alfalfa has been well researched and has the potential to have profound impacts on nutritional composition and many biological processes such as: plant health, yield, nodulation, N fixation, and photosynthesis (Collins and Duke, 1981; Grewal and Williams, 2002; and Berg et al., 2007). Potassium fertilization rate has been shown to impact each of these traits indicating that it should be a major concern for producers seeking to achieve maximum yield, nutritive value, and profitability from alfalfa crops.

Potassium deficiency

A review of over 2,000 studies by the International Potash Institute indicated that K is critical for plant health (Perrenoud, 1990). Plant health can influence overall production by limiting yield, nodulation, nitrogen fixation and nutritional components of alfalfa through increased disease proliferation and stunted growth from poor plant nutrition (Grewal and Williams, 2002). Approximately 70% of bacterial and fungal disease occurrences were decreased by K fertilization in plant species (Amtmann et al., 2008). Seventy-one kg K ha^{-1} was sufficient to reduce disease as evident by decreases of common leaf spot disease by approximately 2% compared to no K (Grewal and Williams, 2002). There is also some evidence that insect damages can be reduced by K application due to alterations in carbohydrate availability and subsequent insect predation (Amtmann et al., 2008). Potassium is integral in activating hormonal pathways and plasma membrane barrier functions that defend against insect and disease-related stressors (Amtmann et al., 2008).

In a field study conducted by Chandler et al. (1946), it was shown that if more than 15% of alfalfa plants exhibit K deficiency symptoms, the stand will respond to K fertilizer with increased yields. Crop yield was found to be most associated with the proportion of plants exhibiting physical K deficiency symptoms, followed by K content, and exchangeable K content in the soil (Chandler et al., 1946). Potassium fertilization also increased alfalfa survivability and stand duration by an average of 45.3% compared to stands kept deficient (Chandler et al., 1946).

Potassium Tissue Content

Potassium content in alfalfa can be affected by K fertilization rate (Lloveras et al., 2012; Markus and Battle, 1965). When K content was lower than 12.5 g K kg^{-1}, alfalfa showed yield increases of 20% with 560 kg K_2O ha^{-1} (Chandler et al., 1945). Alfalfa K content ranged from 12.4 to 22.6 g kg^{-1} between first and second cuttings and tended to be lower in first cuttings compared to second cuttings (Chandler et al., 1945). Average K content in the first sampling of plants were 12.5 g kg^{-1} and 22.2 g kg^{-1} for unfertilized and fertilized plots, respectively (Chandler et al., 1945). However, K content leveled out and was not different between fertilized and unfertilized plots at the end of the three-year study (Chandler et al., 1945). Increasing K fertilization linearly increased K content of alfalfa up to 24.6 g K kg^{-1} with the highest K treatment of 400 kg K ha^{-1} (Lloveras et al., 2012). Unfertilized control plots had approximately 7.7 g K kg^{-1} which decreased across harvest seasons, from the substantial removal of K from alfalfa (Lloveras et al., 2012). Markus and Battle (1965) reported much lower K content of alfalfa with 0.99 to 1.59 g K kg^{-1} for 83 and 333 kg K ha^{-1} treatments, respectively, for the first year of the study. After the second year, K tissue content was approximately 0.90 to 2.15 g K kg^{-1} (Markus and Battle, 1965). Potassium tissue content of alfalfa on 2 different soils (Coaticook silt loam and Greensboro loam) were positively influenced by K fertilization (Gervais et al., 1962). The 0 kg K ha^{-1} treatment had an average of 12.4 g K kg^{-1} while the 290 kg K ha^{-1} treatment had an average of 17 g K kg^{-1} (Gervais et al., 1962). Soil structure may influence K content in alfalfa, as evident by greater increases in K content in the Coaticook silt loam soils compared to the Greensboro loam soils (Gervais et al., 1962). Burmester et al., (1991) cites critical potassium content of 15 to 22 g kg^{-1}, which was not achieved after the first year of the study in unfertilized plots. Changes in K content seemed to level off after 317 kg K ha^{-1} treatment with approximately 19 to 38 g K kg^{-1} across all years. Second cutting had higher K content than the fifth cutting in all K treatments in the first two years, but in the final year, K content was greater in the fourth cut than the second cut for all K treatments (Burmester et al., 1991).

Rates and Timing of Potassium Application

Potassium rate and application timing can impact availability for use in alfalfa plants. Alfalfa response to K can vary depending on if the fertilizer is applied once a year (single rate) or spread throughout the season (split application) (Kresge and Younts, 1962; Morris and Perkins, 1965; and Lloveras et al., 2001). Potassium is considered a luxury nutrient and is absorbed quickly after application which may limit availability if only applied once (Meyer et al., 1995). Application of large amounts of K fertilization in one application can cause unbalanced plant uptake, uneven seasonal distribution of K, as well as K leaching into the environment (Kresge and Younts, 1962). Soil type might also account for some variation in yield response with K fertilization (Lissbrant et al., 2009), as well as environmental stressors throughout the year (Kresge and Younts, 1962).

Alfalfa Yield Potential

In conjunction with forage nutritive value, maintaining consistent and considerable yield is critical to remaining a competitive forage producer and producing enough available forages to sell or feed to livestock. Previous research has determined that K fertilization can greatly stimulate alfalfa growth and prospective yield potential (Gervais et al., 1962; Jouany et al., 1996; and Berg et al., 2009).

Collins et al. (1986) evaluated various single application rates of K on sandy soils and silt loam soils and found that 224 kg K ha^{-1} maximized yield response at 3,470 kg ha^{-1} on silt loam soils, whereas 448 kg K ha^{-1} maximized yield response of 2,380 kg ha^{-1} on sandy soils. Markus and Battle (1965) reported yields of 3,950 and 4,100 kg ha^{-1} $year^{-1}$ for plots without K fertilization compared to 9,780 kg ha^{-1} $year^{-1}$ for plots with 373 kg K ha^{-1} annually but added that no significant increases in yield were found over 187 kg K ha^{-1}. Simons et al. (1995) found that K fertilization did not increase yield initially but reported 3,826 kg ha^{-1} with no K application and 4,252 kg ha^{-1} with 83 kg K ha^{-1}. This could be explained because as stands age, potassium becomes more essential for forage production (Berg et al., 2007). However, Lloveras et al. (2012) reported no significant difference between K treatments of 0, 100, 200, 300, and 400 kg K ha^{-1} annually until the fourth year. In the fourth year, 0 K treatment had lower yield, likely due to the absence of adequate exchangeable potassium in the top 30 cm of the soils (Lloveras et al., 2012).

Berg et al. (2007) reported a 300% increase in total seasonal alfalfa yield between the first and second year in K fertilized plots vs. unfertilized plots when using a split application method (Berg et al., 2007). Gervias et al. (1962) found that at 135 kg K ha^{-1}, alfalfa yield differences began to stabilize, and little benefit was gained when increased to

269 kg ha^{-1} applied before seeding and after the third and sixth cutting. Lissbrant et al. (2009) reported similar results to Gervias et al. (1962), showing K fertilization of 200 kg K ha^{-1} total split over the first and last harvest averaged 3,140 kg ha^{-1} over the four replicates, four harvests, and seven years of the study. Six years after the study began, yield increases slowed and continued to show no response to split applications greater than 200 kg K ha^{-1} (Lissbrant et al., 2009). Split K fertilization at high rates (370-400 kg ha^{-1}) produced a response for several authors (Morris and Perkins 1965; Berg et al., 2007; and Berg et al., 2009) with yields of approximately 1,100 kg ha^{-1}.

Lloveras et al. (2001) studied both split and single applications and found no differences between the split or single application at a cumulative 322 kg K ha^{-1} application rate. This indicates that, in medium textured soils, yield depression would not occur at K rates up to 322 kg K ha^{-1} applied at seeding (Lloveras et al., 2001). However, K concentration in the soil was already high, and could have had some effect on this lack of response (Lloveras et al., 2001). Maximum yield was achieved by Kresge and Younts (1962) at 185 kg K ha^{-1} split applied applications with approximately 13.5 kg DM ha^{-1}. However, a treatment of 93 kg K ha^{-1} split applied early surpassed the 185 kg ha^{-1} treatment yield (Kresge and Younts, 1962). This unusual result might be due to a more efficient usage of the K by the plants (Kresge and Younts, 1962). In Georgia, both single and split applications of 187 kg K ha^{-1} maximized yield response in 4 varieties tested (approximately 6,726 – 10,089 kg ha^{-1} per year DM, averaged over 4 years; Morris and Perkins 1965).

Alfalfa Measurements

Mass shoot^{-1} exhibits a positive linear relationship to yield and can be positively influenced by K fertilization (Berg et al., 2007). Berg et al. (2009) noted significantly greater mass shoot^{-1} in 3 of 4 harvest periods and a trend in one harvest period with 400 kg K ha^{-1} having an average of 1.21 g shoot^{-1} compared to 0.41 g shoot^{-1} for unfertilized plots. However, using regression analysis, it was determined that K fertilization at high rates could limit total yield, despite increases in shoot mass (Berg et al., 2007). Lloveras et al. (2012) agreed that the highest K treatments of 300 and 400 kg K ha^{-1} had greater mass shoot^{-1} than unfertilized plots with an average of 0.96 compared to 0.74 g shoot^{-1}. Alfalfa grown in a greenhouse given 0, 0.6, or 6 mM K had similar mass shoot^{-1} initially after harvest, but after six days, 6 mM K had greater mass shoot^{-1} with the highest of 70 mg compared to 80 mg for 0.6 mM K (Li et al., 1997).

There is some evidence that foliar density improvements can also be accomplished through a single application of 71 kg K ha^{-1} when compared to K deficient plants, with an increase in leaf retention and reduction in leaf drop due to leaf spot disease (Grewal and Williams, 2002). Forty-two kg K ha^{-1} annually was sufficient to produce 90% of the maximum leaf to stem ratio when fertilized with 0 to 60, 80, and 100 kg K ha^{-1} annually (Grewal and Williams, 2002). Zero to 100 kg K ha^{-1} provided progressively higher leaf:stem, and 100 kg ha^{-1} had the numerically highest K with a ratio of 1.01 (Grewal and Williams 2002). However, there was no difference above 40 kg K ha^{-1} (Grewal and Williams, 2002).

Stand Density

Stand density can be an indicator of yield potential across several years of harvest and has been used as criterion to maintain or abandon existing alfalfa stands (Berg et al., 2007). Collins et al. (1986) determined alfalfa which received no K fertilization had more than a 20% decrease in stand density compared to alfalfa receiving K. Increasing K by 93 to 186 kg K ha^{-1} further increased stand density by 20% (Markus and Battle, 1965). Markus and Battle (1965) reported a complete elimination of the alfalfa stand within five years when fertilized with either 0 or 19 kg K ha^{-1} annually. An indirect benefit of K increasing stand density is the subsequent increase of competition among plant species with denser populations; thus, a decreased broadleaf weed and grass invasion in alfalfa plots (Collins et al., 1986; Simons et al., 1995). Potassium fertilization could potentially self-limit yield responses as increased stand density and shoots lead to increased leaf area, and increased shading (Wolf et al., 1976).

Associated with stand density, shoots m^{-2} is a more distinct measurement of stand performance. Potassium fertilization has been documented to cause significant increases in shoots m^{-2} compared to unfertilized alfalfa, which is attributed to higher forage yields (Berg et al., 2005; and Berg et al., 2007). Berg et al. (2009) reported a difference of 158 shoots m^{-2} for 0 and 400 kg K ha^{-1} comparatively. All other harvest periods and K treatments were not significant, and often 0 kg K ha^{-1} had numerically lower shoots m^{2} compared to 400 kg K. However, the 400 kg K ha^{-1} treatment had greater plants m^{-2} than the often 0 kg K ha^{-1} treatment in the second year of the study (300 vs. 52 plants m^{-2}, respectively; Berg et al., 2009). Lloveras et al. (2012) reported that poor K fertilization led to an overall decrease in stand density of 412 plants m^{-2} to 63 plants m^{-2}. Lloveras et al. (2012) credits the lack of significant findings in potassium treatment and stand density to the milder winters and increased winter survival of plants compared to studies conducted in the Midwest with harsher winters.

Alfalfa Nutritional Value

Optimum production remains at the intersection of maximum yield, stand longevity, and nutritive value which are paradoxically in conflict, but each influenced by K fertilization. Neutral detergent fiber and acid detergent fiber were both greater for 400 kg K ha^{-1} yr^{-1}, with 411 and 309 g kg^{-1}, respectively, while the 0 kg ha^{-1} yr^{-1} treatment had the lowest NDF and ADF of 268 and 368 g kg^{-1}, respectively (Lissbrant et al., 2009). Lissbrant et al. (2009) reported the highest CP content achieved in alfalfa fertilized with 0 kg K ha^{-1} yr^{-1} was 192 g kg^{-1}. Potassium treatment of 400 kg ha^{-1} yr^{-1} resulted in the lowest CP values of 180 g kg^{-1} (Lissbrant et al., 2009).

Increasing potassium fertilization numerically increased digestible dry matter from 839 kg ha^{-1} to 1,040 kg ha^{-1} for the second cut with 56 and 448 kg K ha^{-1}, respectively (Calder and MacLeod, 1967). Digestible nutrient yield was increased from 1,880 kg ha^{-1} to 2,520 kg ha^{-1} in alfalfa fertilized with 0 or 400 kg ha^{-1} yr^{-1} K, respectively (Lissbrant et al., 2009). Potassium fertilization numerically increased *in vitro* digestibility from 594 to 616 g kg^{-1} when K was increased from 56 to 448 kg ha^{-1} (Calder and MacLeod, 1967). Lissbrant et al. (2009) reported that increased K fertilization up to 400 kg ha^{-1} yr^{-1} decreased *in vitro* true dry matter disappearance by 24 g kg^{-1} and crude protein concentration by 12 kg ha^{-1}, perhaps due to the substantial increases in yield and subsequent higher shoot mass. Increasing mass per shoot will inevitably increase lignin concentration and decrease digestibility (Lissbrant et al., 2009).

Mineral composition of alfalfa was also affected by potassium fertilization which will have nutritional implications on animals fed these forages. Calcium concentration within the alfalfa decreased with increased levels of K (Gervais et al., 1962; Markus and Battle, 1965). Decreases of magnesium by 2.7 g kg^{-1}, phosphorus by 0.6 g kg^{-1}, sulfur by 0.4 g kg^{-1} and nitrogen content by 3.5 g kg^{-1} occurred with increasing K fertilization from 0 to 448 kg ha^{-1} in sandy soils (Collins et al., 1986). However, this may be attributed to a dilution effect with increasing K content in alfalfa (Collins et al., 1986), as average K concentrations in alfalfa also increase linearly with increasing potassium fertilization rates (Lloveras et al., 2001). As expected, many researchers found increasing K content in forages with increasing K fertilization (Gervais et al., 1962). Critical K level for alfalfa was found to be 17.5 - 20 g kg^{-1}, which increased over the course of the year, indicating that the plant was under increasingly stressful conditions during the course of the season (Kresge and Younts, 1962). In Georgia soils, K concentration increased from 23.2 to 43 g kg^{-1} with 0 to 333 kg K ha^{-1} (Morris and Perkins, 1965). A numerically higher K content was seen in plants with a split application of fertilizer of 41.9 compared to 39.9 g kg^{-1} with single application of the same amount of K (Morris and Perkins, 1965).

Changes in Soil Chemistry

Potassium fertilization can affect soil chemistry, specifically mineral quantity (Lloveras et al., 2012). Average K levels were approximately 35 mg kg^{-1} for control plots and 103 mg kg^{-1} for K fertilized plots (Chandler et al., 1945). High rates of K removal contributed to decreasing K levels in the soil across the harvest seasons (Lloveras et al., 2012). Unfertilized control plots decreased from 161 mg K kg^{-1} to 60 mg kg^{-1} K after 4 years (Lloveras et al., 2012). After two years of alfalfa harvests, K content was below 100 mg kg^{-1} for all treatments except 400 kg K ha^{-1} (Lloveras et al., 2012). After the third year, there was no difference in yield among treatments, and the unfertilized plots declined in K content up to 94 mg kg^{-1} (Lloveras et al., 2012). Due to variability among years in climate conditions and yield responses, it was determined that 70 to 120 mg K kg^{-1} is the desired level for yield responses in alfalfa (Lloveras et al., 2012). Only after applications of 200 kg K ha^{-1} was there an increase in soil K levels (Lissbrant et al., 2009). Both 0 kg ha^{-1} and 100 kg K ha^{-1} treatments had numerically decreasing soil K from six years of harvesting from 112 to 84 mg kg^{-1} and 109 to 101 mg K kg^{-1} (Lissbrant et al., 2009). Markus and Battle (1965) reported similar results over eight years of a study that showed decreasing K content in the topsoil from either 0 or 50 kg K ha^{-1} application but increasing K content in the soil for all other higher K treatments. In the subsoil, decreasing K content was seen in more treatments with 0, 50, and 100 kg K ha^{-1} all decreasing K content over the eight years and all other treatments increasing in K content (Markus and Battle, 1965). In those soil conditions, optimum K content in the topsoil was determined to be 40 to 80 mg K kg^{-1} and 30 to 33 mg K kg^{-1} in the subsoil (Markus and Battle, 1965). Over five years, K fertilization of 33 kg K ha^{-1} produced an increased K content response of up to 8 mg K kg^{-1}, but when 133 kg K ha^{-1} was applied at 133 kg K ha^{-1}, soil K levels increased over 104 mg kg^{-1} (Jouany et al., 1996). After five years, K content in the soil was not different between treatments, however, before then there were significant variations between years irrespective of treatments (Jouany et al., 1996). In Hartsell soils (sandy soils), initial K level was 30 mg kg^{-1} and final soil K was 38 and 81 for 112 kg K ha^{-1} and spring-applied 224 kg K ha^{-1} treatments, respectively (Burmester et al., 1991). Topsoil magnesium and calcium content of soil deceased over eight years of the study (Markus and Battle, 1965). However, subsoil Mg and Ca content was not consistent between plots over eight years (Markus and Battle, 1965). Phosphorus was unaffected between the first two years, but after six years, all P levels dropped (Lissbrant et al., 2009). Initial P was between 5 and 10 mg kg^{-1} and declined to 3 to 5 mg K kg^{-1} in the 6th harvest year (Lissbrant et al., 2009). K fertilization had no effect across six years of harvests and across each K fertilization rate of 0 to 400 kg K ha^{-1} (Lissbrant et al., 2009).

Harvest Intervals and Its Impacts on Alfalfa

It is important to recognize that climatic conditions have an important impact on appropriate harvest intervals and frequency (Langille et al., 1965); therefore, not all harvest methods are appropriate in every climate. For example, in Northern and Northwestern states where alfalfa is commonly grown, final cuttings before frost can limit the harvest season (Brink and Marten, 1989) and only three to four cuttings can be made. In the Southeast, frost can be delayed until November or December depending on year and allow six to eight cuttings every season. Typically, harvesting can be completed on a fixed frequency (i.e., two, four, or six-week intervals) or by morphological stage (i.e., bud, 10%, 30% or 50% bloom) and is chosen based on producer preference or goals for yield and quality.

Alfalfa Yield Potential

Physiological maturity stage is often expressed as an indication of nutritive value of alfalfa and used to determine the appropriate cutting time. There are several ways to determine when to harvest, among those are: by days between harvests, maturity stage and number of harvests. Harvesting more frequently will result in cutting at earlier maturity stages. Harvesting at an immature stage can have negative impacts on forage persistence and yield and harvesting at a mature stage can have negative impacts on nutritional value (Weir et al., 1960). Moyer et al. (1998) found that pre-bud and vegetative harvested stands produced 50% lower yields than pre-bloom stages or later, which can have huge implications on grazing and pasture management.

Days of growth can be as a harvest schedule with longer days between harvest typically associated with greater yields and lower digestibility. However, Mays and Evans (1973) reported an average of 28% lower yields in spring growth with a ten-week harvest schedule compared to a four, six, and eight-week harvest schedule which may have been attributed to extreme lodging. When comparing much shorter harvest intervals of 28, 35, and 42-days, 42-days maximized yields of 1,260 kg ha^{-1} while harvesting at 28 and 35-days yielded 630 kg ha^{-1} and 990 kg ha^{-1}, respectively (Kallenbach et al., 2005). Over three years, a 35-day harvest interval was superior to 25-days with 5,160 kg ha^{-1} and 4,050 kg ha^{-1}, respectively (Probst and Smith, 2011).

Gasser et al. (1969) found that harvesting between early and late bloom will produce the most forage per ha and have the highest productivity of stands. There is some indication that dry matter yield improvements stop after early bloom stage (MacLeod et al., 1972). In Georgia, Brown et al. (1988) found that there was no difference in yield when alfalfa was harvested at 10% bloom, 50% bloom, or 10% bloom with a summer rest period. Alfalfa harvested at 50% bloom yielded the greatest percentage the first three harvests at approximately 17-23% of total yield compared to 12-23% of total yield with the 10% bloom or summer rest (Brown et al., 1988). In California, seasonal yield increased with increasing maturity from 19,480 kg ha^{-1} pre-bud to 20,580 kg ha^{-1} at 50% bloom stages (Weir et al., 1960). In Arizona, alfalfa cut at the 10% bloom stage had the greatest total forage yield compared to bud stage with cumulative seasonal yields of 106,203 kg vs 112,661 kg for all plots over the harvest season, respectively (Feltner and Massengale, 1965).

In Missouri, average yield for each harvest decreased from 1,250 kg ha^{-1} to 630 kg ha^{-1} as harvest frequency increased from four and six harvests per season, respectively (Kallenbach et al., 2002). In Wisconsin, Kust and Smith (1961) experienced a 2,740 kg ha^{-1} decrease in yield for each increase in cutting frequency from three to six harvests. In Central Georgia, alfalfa cut three times the first year, four times the second year, and five times the third year, averaged 1,180 kg ha^{-1} annually when cut at bud stage for the first cutting each year, and 10% bloom for the following cuttings each year (Terrill et al., 1996). In Wisconsin, Smith and Nelson (1967) experienced higher yields with alfalfa cut three times with 776 g per 1.22 m row compared to 509 g per 1.22 m row for alfalfa cut six times. Average yields decreased as cutting frequency increased from three to six cuts and the magnitude of differences between harvest frequencies also increased after the second year (Smith and Nelson, 1967). In Tennessee, four cuts produced the highest yield at 4,980 kg ha^{-1} compared to eight cuts that only yielded 940 kg ha^{-1} due to weed pressure and stand loss (Reynolds, 1971).

Alfalfa Measurements

Cutting interval has a direct impact on mass $shoot^{-1}$ ratio. Ventroni et al. (2010) found that plants cut at the longest cutting interval (40 days) had the greatest mass $shoot^{-1}$ ratio, with an average of 0.56 g $shoots^{-1}$. The shortest cutting interval had the lowest mass $shoot^{-1}$ with 0.17 g $shoot^{-1}$ at 20-day cutting intervals (Ventroni et al., 2010). Teixeira et al. (2007) found no differences in mass per shoot with two 42, two 28 or a combination of 42 and 28-day defoliation cycles. However, shoot mass was highly correlated with shoot yield (Teixeira et al., 2007). This was due to an inverse relationship between shoot mass and the number of shoots per unit area (Teixeira et al., 2007).

Increasing leaf:stem ratio has several benefits including: increasing yield potential and increasing digestibility (Sheaffer et al., 2000). When harvesting at bud stage vs late flower, Sheaffer et al. (2000) found a decrease in leaf concentration from 540 g kg^{-1} to 401 g kg^{-1}. Stem yield increases linearly through maturity, but leaf yield will increase and plateau at around early bloom stages (Kilcher and Heinrichs, 1974). Leaf ratio was consistently greater in bud stage harvest regimes compared to 10% bloom or greater and was also higher during the summer months (Luckett and Klopfenstein, 1970).

Changes in leaf:stem ratio appear to have the greatest effect on overall herbage quality (Sheaffer et al., 2000). Digestibility decreases with decreasing leaf:stem ratio, since an increase in stem concentration results in higher lignin content (Sheaffer et al., 2000). Increased leaf:stem ratio was associated with higher leaf CP with 216 g kg^{-1} compared to 192 g kg^{-1} (Sheaffer et al., 2000). Kilcher and Heinrichs (1974) reported that CP in stems reached a maximum of 18% during the vegetative stage and fell to below 8% at the full bloom stage. *In vitro* true digestibility and CP were both significantly and consistently lower in stem fractions compared to leaf fractions across all harvests and seasons (Fick and Holthausen, 1975).

Survival and Stand Persistence

Harvest interval and frequency have a profound impact on the overall survivability of alfalfa stands. Rate of plant mortality influences the productive life of alfalfa (Teixeira et al., 2007). Waiting until mid-bloom stages significantly increases the survival of alfalfa, particularly in the first and second harvests (MacLeod et al., 1972). Pre-bud, or immature cutting, is routinely linked to massive stand damage and loss in persistence in alfalfa (Gasser et al., 1969). Such frequent defoliation can also cause stand loss from increased weed competition in the pasture. Weed infestation is more prominent in pastures defoliated at vegetative and pre-bud stages (Moyer et al., 1998). Weir et al. (1960) reported a 1% weed infestation in alfalfa cut at 35 and 42-day intervals, compared to 23% and 36% weed composition in 21 and 28-day harvest intervals, respectively. Probst and Smith (2011) found that when alfalfa was harvested at 25-day intervals the percent stand (69.5% averaged over four years) was lower than 30, 35, and 40- day harvest intervals. Percent stand decreased over 35% from years one through four at the 25-day harvest interval, compared to 2.1% decrease in stand at 35-day harvest intervals (Probst and Smith, 2011). Sheaffer and Marten (1990) described results of the lowest percent stand with four cuttings (the last October 15th) with 7% stand density compared to three cuts (last cut on the first of September) with 42% remaining stand density.

Plant density is self-limiting, as plant population approached 450 plants m^{-2}, all yields decreased dramatically, likely due to increased competition between plants (Lamb et al., 2003). Mays and Evans (1973) showed that 'Dupuits' alfalfa at 10-week harvest intervals resulted in 10 plants m^{-2} compared to 20 plants per m^2 with a six-week harvest interval, this is likely due to the late harvesting dates and potential frost damage over four years. Alfalfa without a fourth cutting had the highest stand density (28 plants m^{-2}) compared to all other treatments (Mays and Evans, 1973). Ventroni et al. (2010) found that shoots m^{-2} had the greatest influence on forage yield when compared to height $shoot^{-1}$ and mass $shoot^{-1}$ at defoliation intervals of 20 and 40 days in year one and defoliation frequencies of 30 and 40 days in year two. Reynolds (1971) found a significant positive correlation (r^2 = 0.974) between forage yields and plant density at the end of the previous season. Teixeira et al. (2007) found no differences in plant population from four defoliation treatments including 42-day grazing cycles, 28-day grazing cycles and 42 then 28 and 28 then 42-day grazing cycles. However, there were severe reductions in stand density in all treatments over two years from 130 plants m^{-2} to 60 plants m^{-2} (Teixeira et al., 2007). The decrease in stand density was accompanied by an increase in shoots $plant^{-1}$ from approximately six plants m^{-2} to 13 plants m^{-2} for all defoliation treatments (Teixeira et al., 2007). Observations of increased weed pressure in plots with increased defoliation could be the cause of decreased stand population (Teixeira et al., 2007).

Kallenbach et al. (2002) reported stand density of 265 plants m^{-2} at the beginning of the study, and then regardless of treatments found stand density to decrease to 42 plants m^{-2} after three years. An initial difference between plots harvested six times and those harvested four to five times was noticed but the difference eventually decreased (Kallenbach et al., 2002). Bélanger et al. (1992) agreed with the results of Kallenbach et al. (2002) reporting a general decrease of stand density across all treatments but found a difference in the harvests two years after the beginning of the trial. Plant density decreased at a greater rate with plots that were harvested at early bloom and the third harvest was during the critical fall rest period compared to after the critical fall rest period with 46 and 60 plants m^{-2}, respectively (Bélanger et al., 1992). Reynolds (1971) did report a difference between plots cut six times compared to two, three and four cuts with an average difference of 36 plants m^{-2} and 62 plants m^{-2}, respectively. Alfalfa was more vigorous at three harvests compared to six, with an average of 6.53 more plants per quadrat (Smith and Nelson, 1967). Rimi et al. (2014) noted an 11% increase in plants m^{-2} in plots harvested at early flower compared to those harvested at early bud.

Alfalfa Nutritional Value

Growth stage at harvest has a large impact on alfalfa nutritional value. There is some evidence that CP content increases as maturity increases, until the early bud stage when it plateaus, and eventually declines with advanced maturity (Kalu and Fick, 1983). More frequent cutting, resulting in earlier maturity stage at harvest, increased CP content (Polmonari et al., 2014; Kust and Smith, 1961). MacLeod et al. (1972) found that daily CP losses are up to 3.2 g kg^{-1}, calculated using the total CP and DM content and dividing by the harvest interval in days. However, maximizing protein content at harvest with early maturity stages may lower yields and decrease seasonal protein yield (Weir et al., 1960; Smith and Nelson, 1967). If alfalfa is harvested at a vegetative or pre-bud state too frequently, weed infestation will decease CP content of the stand, up to 20 g kg^{-1} (Moyer et al., 1998). Wildman et al. (2003) found the highest CP values for 10% bloom harvest with a bud harvest at the second harvest with 226 g kg^{-1} CP compared to the 10% bloom harvest, 50% bloom harvests and bud harvests with 215 g kg^{-1}, 213 g kg^{-1} and 208 g kg^{-1} CP, respectively.

Kallenbach et al. (2005) found that nutritive value was maximized with alfalfa harvested every 28 days compared to 35 and 42-day harvest intervals at 30% NDF averaged over five years. NDF was lower in alfalfa cut at the 10% bloom stage treatment compared to 50% bloom and bud stage harvests (Wildman et al., 2003). The lowest ADF values were seen with pre-bud 21-day harvest intervals with 323 g kg^{-1} ADF as compared to 28-day and 35-day harvest interval that had 316 g kg^{-1} and 315 g kg^{-1} ADF, respectively (Palmonari et al., 2014). Kallenbach et al. (2002) found similar results where alfalfa harvested more frequently (up to six times) had lower NDF and ADF values than those harvested less frequently. As stem proportion increases with increasing maturity, NDF and ADF content increases because of the high concentration of these fractions in stem material, and low concentration in leaf material (Kalu and Fick, 1983); Therefore, increased leaf content, and lower maturity stage, results in lower NDF and ADF (Sheaffer et al., 2000). The highest stem yield, and lowest nutritive value, was observed in alfalfa harvested at late bloom compared to early bloom and mid-bud harvests (Sheaffer et al., 2000). Greatest seasonal production of TDN was at the 10% bloom stage with 10,940 kg ha^{-1} (Weir et al., 1960).

Dry matter disappearance (DMD) was significantly higher for alfalfa harvested every three weeks with an average of 58% compared to an average of 54% for five-week alfalfa, respectively (Romero et al., 1987). Luckett and Klopfenstein (1970) indicated that bud stage harvesting had the highest DMD at 70.3% compared to an average of 68% for 10% and full bloom systems. *In vitro* digestibility drastically decreases as alfalfa matures and then begins to sharply increase (Calder and MacLeod, 1967) and is highest at early bud stages compared to bud and early bloom stages (Romero et al., 1987). Macleod et al., (1972) found that *in vitro* dry matter daily losses are about 0.77% per day. Four harvests yielded an average of 70.1% *in vitro* digestible dry matter yield (IVDDDM) compared to three cuts with 67.4%; however, over four years, it reduced the persistence of alfalfa so much that the IVDDM became equal after three harvests (Brink and Marten, 1989).

Conclusion

Harvest interval and frequency influences yield, nutritive value and persistence of alfalfa stands and has a profound impact on producer's profitability. Climate is a large factor in determining an appropriate harvesting schedule, but consideration should be given to the inverse relationship between quality and quantity. While many producers strive to increase yields and total forage available to sell, quality must remain a priority. Frequent harvesting positively influenced quality, but too frequent harvesting decreased yield and overall persistence for the following years. Infrequent harvesting has increased yields and persistence across years but had substantial negative impacts on quality.

Potassium fertilization linearly improves plant health, nutritive value and yield until maximum plant potential is achieved. Along with an appropriate harvest schedule, long term K fertilizer additions may increase alfalfa performance, provide greater quality and have a positive influence on morphological development.

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CHAPTER 3

POTASSIUM APPLICATION AND HARVEST REGIMEN IN ESTABLISHED ALFALFA AFFECTS YIELD, NUTRITIVE VALUE, AND STAND PERSISTENCE IN THE SOUTHERN COASTAL PLAIN[1]

[1]Thinguldstad, Britta, J.J. Tucker, J.R. Segers, Dennis Hancock, and Lawton Stewart. To be submitted to *Crop Science*

Abstract

Potassium fertilization and harvest timing can both impact the yield and stand life of alfalfa (*Medicago sativa* L.), and these impacts are further influenced by climatic conditions. Yet, nutrient management and harvest recommendations for alfalfa are generated from research largely conducted in more moderate climates. The objective of this trial was to determine the impact of K fertilization and harvest regimen on alfalfa stand persistence, forage yield and nutritive value in the southeastern USA. This two-year study was conducted at the Coastal Plain Experiment Station in Tifton, GA on a two-year-old stand of 'Bulldog 805' alfalfa planted in fall 2015 using a split plot design, with main plots being harvest stages bud, and 10, 30 and 50% bloom and split plots of K fertilization at rates of 0, 67, 101, 134, and 168 kg ha^{-1}, which were split applied three times across the season. At each harvest, plots were visually assessed to determine alfalfa cover and confirm percent bloom prior to harvest. Fifty shoots were collected to evaluate leaf:stem ratio and mass $shoot^{-1}$. Grab samples were collected for nutritional analysis using near-infrared reflectance spectroscopy (NIRS). Potassium treatment only influenced mineral content of forages. In harvest periods one through five, calcium and magnesium were highest in the 0 kg K ha^{-1} treatment ($P < 0.03$ and $P < 0.01$, respectively). Growth stage affected all parameters except for leaf:stem ($P < 0.32$). Yield was greater for 50% bloom than bud and 10% bloom in harvest period five ($P < 0.01$), but trends were not all the same. In several harvest periods, neutral detergent fiber (NDF) and acid detergent fiber (ADF) content increased ($P < 0.01$) and crude protein content decreased ($P < 0.01$) with increasing maturity stage. Potassium treatment and harvest timing can affect yield, nutritive value, and stand persistence of alfalfa.

Introduction

With the development of new varieties suited for the southeastern climate, there has been an increase in interest to produce alfalfa (*Medicago Sativa* L.) in the southeastern USA. Soil conditions, humidity, high temperatures and poor rainfall distribution make the southeastern USA a challenging location to grow alfalfa. However, alfalfa is a high-quality perennial legume with the potential to provide exceptional animal production while fixing nitrogen for increased soil benefits. Potassium fertilization and harvest regimen both influence the success of an alfalfa stand (Berg et al., 2009; and Gasser et al., 1969); however, these recommendations need to be examined further in the context of southeastern environments.

Potassium is a critical nutrient for many biological functions and affects overall plant performance (Grewal and Williams, 2002). Deficiencies of K are associated with increased disease, decreased photosynthetic ability, and reduced carbohydrate availability, all of which can negatively influence yield potential in alfalfa (Amtmann et al., 2008; Peoples and Koch 1979; and Cooper et al., 1967). Soils in the southern Coastal Plain are often low in K due to low cation-exchange capacity (CEC; Sonon et al., 2014). Since alfalfa plants are luxury consumers of K, splitting K applications across the season may better distribute the nutrient through the growing season. Pinpointing the minimum effective fertilization rate for optimum growth can reduce input costs for producers and extend stand persistence.

Harvest frequency is another critical component to stand health. Too frequent defoliation can damage the stand and decrease longevity (MacLeod et al., 1972) as well as limit yield potential. Increased harvest intervals decrease digestibility (Palmonari et al., 2014). Finding the optimum harvest timing for quality and yield can be difficult. While cold climates and dormancy ratings of alfalfa in the north can limit production at the end of a harvesting season, extreme temperatures common to the Southeast with little rainfall can slow alfalfa growth in the summer (Brown et al., 1990). Longer growing seasons, later frost, and semi to non-dormant alfalfa varieties can enable later harvesting in the region. However, mild winters without harvests may reduce carbohydrate reserves due to shading of regrowth, hindering photosynthetic ability (Teixeira et al., 2007a).

Maintaining proper nutrient levels in alfalfa can be critical in established stands because for each ton of forage harvested, approximately 27 kg K_2O is removed from the soil (Snyder, 2003). Simons et al. (1995) reported no difference in yield among K treatments in the first year of harvests on a three-year-old stand but saw increasingly significant yield differences after the first harvest year. This suggests that K can become more critical for yield as the nutrients are removed during harvesting (Simons et al., 1995). In an established stand of two-year-old alfalfa in northern Alabama, topdressing K increased stand longevity and yield (Burmester et al., 1991). However, there was no increase in yield with applications greater than 224 kg K ha^{-1}, which was the recommended rate (Burmester et al., 1991). Collins et al. (1986) reported the highest yields (2,380 kg ha^{-1} per cutting) with the 448 kg K ha^{-1} treatment yielding compared to 0 kg K ha^{-1} (1,130 kg ha^{-1} per cutting) on a two-year-old alfalfa stand. However, impacts on stand density were not observed above 224 kg K ha^{-1}, which had 35.1 plants m^{-2} compared to 15.3 plants m^{-2} with 0 kg K ha^{-1} (Collins et al., 1986). Berg et al. (2007) began data collection on a four-year-old stand of alfalfa and noted that by the end of the seventh production year, K fertilization played a greater role in forage yield. Potassium fertilization of 400 kg K ha^{-1} increased plant populations by 28% on average and produced an average positive response of 94 shoots m^{-2} (Berg et al., 2007). Berg et al. (2009) reported no differences of plants m^{-2} on a four-year-old stand with 400 kg K ha^{-1} in the first year, but in the second year, there were significant differences in all four harvests between the 0 and 400 kg K ha^{-1} K treatments. Shoots $plant^{-1}$ demonstrated similar results with no difference in the first year, but plots fertilized with 400 kg K ha^{-1} had lower shoots $plant^{-1}$ in the first, third and fourth harvest compared to 0 kg K ha^{-1} in the second year (Berg et al., 2009).

Along with K fertilization, established stands may also be affected by harvest timing. Lissbrant et al. (2009) reported the highest seasonal yields in the second-year of alfalfa stands and decreasing yield thereafter, regardless of harvest or K treatment. Harvest timing was found to have an impact on alfalfa shoot DM yield in a two-year-old stand with 10,972 kg ha^{-1} for 28 day growing cycles compared to 21,038 kg ha^{-1} for 42 day growing cycles (Teixeira et al., 2007b). However, defoliation treatment had no effect on plant population over the harvest seasons in the established stand (Teixeira et al., 2007b).

Both K fertilization and harvest frequency may affect stand density, leaf:stem, mass $shoot^{-1}$, yield, and digestibility parameters. The southeastern climate and soil types in the southern Coastal Plain present a unique challenge when determining sufficient K fertilization rates and maximum harvest frequency to optimize yield and nutritive value in alfalfa. Therefore, the objective of this trial was to determine the impact of K fertilization and harvest regimen on stand persistence, forage yield, and nutritive value on an established stand of alfalfa in the southern Coastal Plain.

Materials and Methods

Study Location and Establishment

The experiment was conducted at the University of Georgia's Coastal Plain Experiment Station (31°30'00.7"N, 83°31'18.1"W) in Tifton, GA on a two-year-old stand of 'Bulldog 805' alfalfa (Athens Seed Co., Athens, GA) planted at 22 kg ha^{-1} pure live seed fall of 2015 at a soil depth of 1.27 cm. Soils were characterized as Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults), well drained, with a 2 to 5% slope with rapid or moderately rapid permeability (USDA 2017). Plots were planted in 35.6 cm row spacing into Tifton-85 bermudagrass using a no-till 2007 Pasture Pleaser Tye drill (AgCo, Duluth, GA). Bermudagrass was subsequently killed out before the initiation of the study using Clethodim at a rate 168 g a.i. ha^{-1} (Select MAX; Valent, Valent USA Corporation, Walnut Creek, CA). Data collection began in April of 2017. The main plot comprised of 16 plots measuring 14 m^2 that were randomly assigned using a split block design. Main plots were growth stage: bud, and 10, 30 and 50% bloom stage. Plots were further subdivided into 2.79 m^2 plots to examine K fertilization at rates: 0, 67, 101, 134, and 168 kg ha^{-1} muriate of potash (0-0-60). These rates were split applied three times throughout the season: before the first cutting (April in 2017 and March in 2018), ten days after the second cutting (June in 2017 and 2018), and ten days after the second to last cutting (September in 2017 and October in 2018). These rates are lower than current recommendations for these soils and were chosen to determine if decreasing current recommended K rates would be beneficial. Each plot was an experimental unit and was replicated four times.

Plot Management

At the initiation, mid-point and conclusion of the study, soil tests were conducted, and plots fertilized in accordance with UGA soil recommendations (Kissel and Sonon, 2011). In April of 2017 all plots were fertilized with phosphorus at 84 kg ha^{-1} (MAP 12-61-0, Haifa; Haifa North America, Altamonte Spring, FL) and boron at 2.2 kg ha^{-1} (Boron 10%; CNI Liquid, CNI AgriMinerals, Albany, GA). Additional soil samples were collected at the end of each harvest season. In 2018 all plots were fertilized with boron at 3.36 kg ha^{-1}.

Scouting for insect pests occurred weekly throughout the growing season for alfalfa weevil [(*Hypera postica* (Gyllenhal) (Coleoptera: Curculionidae)]; cowpea aphid [(*Aphis craccoivora)* (Koch) (Hemiptera: Aphidoidea]; potato leafhopper [*Empoasca fabae* (Harris) (Hemiptera: Cicadellidae)]; three-cornered alfalfa leaf hopper [*Spissistilus festinus* (Say) (Hemiptera: Membracidae)]; and fall armyworm [*Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)]. In September 2017, zeta-cypermetherin (Mustang Maxx; FMC Corporation, Philadelphia, PA) and Chlorantraniliprole (Prevathon; Corteva Agriscience, Wilmington, DE) were applied to plots at rates of 28 g a.i. ha^{-1} and 100 g a.i. ha^{-1} to control the three-cornered alfalfa leaf hopper and fall armyworm, respectively. In February 2018, lambda cyhalothrin (Lambda Star; Nufarm Americas Inc., Burr Ridge, IL) was applied at a rate of 34 g a.i. ha^{-1} to control cowpea aphids. In May, June, August, and October of 2018 dimethylcyclopropane carboxylate (Mustang Maxx; FMC Corporation, Philadelphia, PA) was applied to plots at a rate of 28 g a.i. ha^{-1} to control the three-cornered alfalfa leaf hopper and the alfalfa weevil. Malathion (Malathion 5EC;

Drexel Chemical Company, Memphis, TN) was applied in July of 2018 at 1.4 kg a.i. ha^{-1} to control fall armyworms.

Grass weeds were controlled in April, May, and July of 2017 and June and August in 2018 using clethodim (Select MAX; Valent, Valent USA Corporation, Walnut Creek, CA) at a rate of 168 g a.i. ha^{-1}. Sethoxydim (Poast; BASF Corporation, Research Triangle Park, NC) was used in March of 2018 to control grass weeds, at a rate of 0.34 kg a.i. ha^{-1}.

Plot borders were maintained weekly. A fence was constructed in June of 2018 to surround the plots at approximately two meters from all plot edges to reduce potential damage by endemic wildlife in the area.

Weather

The harvest season was from May 1, 2017 through November 29, 2017 and April 6, 2018 through November 9, 2018. Weather data was collected from the UGA weather station in Tifton, Georgia and reported for the duration of the harvest season (UGA-AEMN, 2018). There was considerable variability in average precipitation across years. In the first year, precipitation totaled 72 cm (Table 2.1), while 2018 had 100 cm rainfall (Table 2.1). Average maximum and minimum temperatures were nearly equal for 2017 and 2018 (29°C and 18°C for 2017 (Table 2.1); 30°C and 19°C for 2018 (Table 2.1), respectively). The 100-year averages for maximum and minimum temperature were similar to 2017 and 2018 (29°C and 16°C, respectively). Total precipitation for 2017 was lower than the 100-year average of 75 cm, while 2018 had an average of 25 cm higher precipitation than the 100-year average (Table 2.1).

Measurements

At each harvest, plots were visually assessed to determine percent alfalfa ground cover. Percent bloom was confirmed at each harvest to verify growth stage, based on the procedure described by Mueller and Fick (1989). Fifty shoots were collected from each plot at 2.5 cm from the ground and split into two bundles of 25 shoots. Twenty-five shoots were weighed and individually measured for length using a meter stick to determine average height for mass shoot^{-1} calculation. The second bundle of 25 shoots were used for leaf:stem and all leaves were removed from the stems and placed in separate bags (stems included apical buds and flowers) and then weighed. Mass shoot^{-1} and leaf:stem samples were then dried at 60°C for 72 hours and weighed. Shoots m^{-2} was calculated by dividing yield m^{-2} by mass shoot^{-1}. Yield was determined using a Swift Forage Plot Harvester IV (Thompson, 1972) by harvesting the whole plot. A tripod was set up and a hanging scale attached (Intercomp, Medina, MN). All forage harvested from each plot was put onto a 1.4-m^2 tarp and hung from the hanging scale to record plot yield. A 200-g grab sample was taken from each plot for nutritional analysis. Grab samples were then weighed, dried in a forced air oven at 60°C for 72 hours and reweighed to determine dry matter concentration. Samples were ground in a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen and prepared for lab analysis. Stand density was assessed before the first and at the last harvest each year using three 0.1 m^2 quadrats randomly placed in the plot and counting the apparent individual crowns and associated stems within each quadrat. Soil samples were taken before and after each harvest season in each plot to determine nutrient removal at the topsoil (0-15 cm) and subsoil (15-30 cm) level. Soil samples from each plot were analyzed at the University of

Georgia Agricultural and Environmental Services Labs: Soil, Plant and Water Laboratory in Athens, Georgia. Soil samples were analyzed using Mehlich-1 procedure (Mehlich, 1953). In November and December, after the final harvest, tissue samples were collected from each plot. Approximately 15 cm from the top of all plants within a plot were removed, weighed, dried, and ground through a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen. Samples were then sent to the University of Georgia Agricultural and Environmental Services Labs: Soil, Plant and Water Laboratory (Athens, GA) and analyzed for plant tissue K content.

Forage Analysis

Approximately five grams of each ground grab sample was scanned using near-infrared spectroscopy (NIRS) using a NIRSystems 6500 (FOSS, Hilleroed, Denmark) analyzed with the alfalfa hay equation developed by the NIRS Forage and Feed Testing Consortium (Hillsboro, WI) to determine crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, in-vitro true dry matter digestibility (IVTDMD48), total digestible nutrients (TDN), estimated dry matter intake (DMI), relative forage quality (RFQ), calcium (Ca), phosphorus (P), potassium (K) and magnesium (Mg). Calibration statistics for 2018 Legume Hay NIR equations were as follows: NDF, SEC = 1.95, R^2 = 0.95; SECV = 2.04; ADF, SEC = 1.55, R^2 = 0.93; SECV = 1.63; CP, SEC = 0.70, R^2 = 0.95; SECV = 0.76, where SEC = standard error of calibration and SECV = standard error of validation, in g kg^{-1} on a DM basis. A subset of samples (*n* = 152) were used to validate the NIRS results via comparison of samples analyzed using wet chemistry. Samples were analyzed for dry matter (DM) and ash content (AOAC, 2000), NDF (Van Soest et al., 1991) and ADF (AOAC, 2000) using an ANKOM 2000 analyzer (ANKOM Technology, Macedon, NY; Mertens, 2002), in vitro true dry matter digestibility as described by Promerleau-Lacasse et al. (2019), and CP content using a Leco combustion analyzer (model FP628, Leco Corporation, Saint Joseph, MI).

Statistical Analysis

Data were analyzed in SAS v9.4 (Cary, NC) using PROC MIXED with a denominator degrees of freedom correction using a Kenward-Rogers adjustment to generate standard errors and *F* statistics for each model. The lowest Bayesian's Information Criterion was used from the [AR 1] covariance structure to ensure the best fit. Block was considered a random effect. Potassium treatment, growth stages and year were considered fixed effects. A Tukey-Kramer adjustment ($P < 0.05$) was applied to the LSMEANS to compare means at a significant difference of $P < 0.05$.

Results and Discussion

Potassium Treatment

Potassium treatment had no significant effect on yield, mass shoot^{-1}, leaf:stem, shoots m^{-2}, percent alfalfa ground cover, crown and stem counts or K content of tissue samples ($P > 0.05$; data not shown). At the start of the study, soils were in the medium range of K in the topsoil and subsoil and had high topsoil P based on UGA soil test recommendations for alfalfa maintenance (Kissel and Sonon, 2011). The recommended K fertilization level was 224 kg K_2O ha^{-1} (Kissel and Sonon, 2011). Our highest treatment was 168 kg K ha^{-1}. Therefore, K treatments were not high enough to elicit a response in our soils already containing moderately sufficient K. End of trial tissue samples indicated that K was deficient (Table 2.2); K content was approximately half of those reported by Burmester et al. (1991) with similar treatments (Table 2.2). In the second year, top soils maintained medium K and were classified as very high in P. Using the UGA soil test recommendations for alfalfa maintenance, fertilization of 168 kg K ha^{-1} was required, which was within the study boundaries. Following reports by Lloveras et al. (2012) and Markus and Battle (1965), topsoil and subsoil K were considered deficient after the first year in unfertilized plots in this study, and the 67 kg K ha^{-1} plots were deficient in subsoil K at the end of the first year (Figures 2.1 and 2.2). Potassium content was not different in the topsoil samples across the two years, but subsoil samples were lower in K content at the conclusion of the trial (P < 0.01; Table 2.3). Unfertilized plots had significantly lower K content than all other fertility rates in topsoil and subsoil samples across two years (except 0 and 67 kg ha^{-1} treatments were not different in subsoil samples; $P < 0.01$; Figures 2.1 and 2.2). Topsoil samples were higher in magnesium in the middle of the study compared to the end of the study ($P = 0.02$). However, subsoil samples were lower ($P < 0.01$) at the end of the season compared to the beginning of the season similar to Markus and Battle (1965) who found decreasing Mg and Ca due to leaching in the soil over the course of the study on Nixon loam soils (Table 2.3). Soil P was much greater than those of Lissbrant et al. (2009) who reported soil P of 9 to 13 mg P kg^{-1} while soils in this study ranged from 30 to 50 mg P kg^{-1} (data not shown). The authors predicted differences in yield and field data between the 0 and 168 kg ha^{-1} treatments but did not observe them, possibly due to otherwise sufficient nutrient availability. Additionally, K might not have affected stand density due to low winter kill in the plot area and easier survivability (Lloveras et al., 2012). In both 2017 and 2018, temperatures were not low enough to produce significant winter kill (less than -3°C) and the lowest temperature was 9.2°C in 2017 (Hancock et al., 2009; Table 2.1) Berg et al. (2005) also did not find differences between stand density and K treatment. However, Berg et al. (2007) found incrementally increasing responses to K fertilization up to the seventh year of production. Despite being a second-year stand in this study, differences in treatment may be clearer following more prolonged K deficiency. Previous fertilization techniques in the study site were sufficient to establish the stand and decrease lasting effects of subsequent K deficiency.

Potassium treatment did not affect metrics of nutritive value (i.e., CP, fiber content and digestibility; data not shown) but did affect NIRS-predicted mineral content of the alfalfa (Table 2.5). In harvest periods one through five, calcium and magnesium were highest in the 0 kg K ha^{-1} treatment ($P < 0.03$ and $P < 0.01$, respectively; Table 2.5), similar to results of Gervais et al. (1962) and Collins et al. (1986), respectively. Phosphorus remained generally unchanged between K treatments. As expected, K concentration was lowest for the 0 kg K ha^{-1} treatment ($P < 0.01$; Table 2.5). Lloveras et al. (2001) also reported increases of K concentration with increasing K fertilization. However, that linear response was not observed in the current study, and K concentration was positively influenced with K fertilization at any rate.

Growth Stage

There was a magnitude difference of year in all yield and field data for harvest intervals. Year two was consistently higher in yield, percent ground cover, shoots m^{-2} and nutritive value parameters, which was similar to results by Lissbrant et al. (2009). This was likely due to the greater stand density and ground cover. For most harvest periods, alfalfa ground cover, shoots m^{-2}, and mass $shoot^{-1}$ increased as alfalfa maturity increased from bud stage to 50% bloom ($P = 0.02$; $P < 0.04$; and $P < 0.01$, respectively; Table 2.6). These variables might have been affected by stand age, as the plant matures it is better able to compete for nutrients, grows larger, and becomes more established. Typically, with increased shoots m^{-2} and ground cover, shoot mass decreases per plant to accommodate the same space with more shoots (Teixeira et al. 2007a). Stem counts in 2018 confirmed that there were greater stems as the season progressed, and greater stem counts with later growth stages ($P < 0.01$; Table 2.7). Conversely, mid-season crowns were less numerous in 2018 than 2017, particularly with bud stage harvest treatment which could be evidence of the more intense harvest timing decreasing stand density ($P < 0.01$; Table 2.8). Berg et al. (2005) found an increased mass $shoot^{-1}$ associated with increased alfalfa yield, which was not seen in this study. Perhaps differences in mass $shoot^{-1}$ were not seen because the study site was planted on 36-cm rows and other authors found that wide row spacing may have allowed greater light interception at crown level and could facilitate greater shoot production (Ventroni et al., 2010). A difference in magnitude could have been associated with greater days between harvest in year one. On average, days between harvest were 37 in 2017 and 30 in 2018. Previous authors (Palmonari et al., 2014; and Kallenbach et al., 2005) have found that increasing days between harvest decreases forage nutritive value. In both 2017 and 2018, as growth stage increased, days between harvest also increased with the highest of 36 days for 50% bloom, while bud stage was on average approximately 30 days across 2017 and 2018 growing seasons.

There was no consistent yield difference across harvests within each time-period. Overall differences between bud, 10%, 30%, and 50% tended to be grouped by the earlier two (bud and 10% bloom) and later two (30% and 50% bloom) growth stage treatments (Table 2.9). Morphological differences between 30 and 50% bloom are small and can be difficult to distinguish. This may be why there was little difference between earlier growth stages and later growth stages. Additionally, rapid changes were observed in bloom presence, and this could have altered bloom percentage at harvest during the summer months. Greater lodging in the 30% and 50% bloom stage could have lowered ability to capture total yield with the harvester. Brown et al. (1990) reported increased leaf senescence in later maturity stages up to 50% as a result of the hot conditions in the Coastal Plain, which indicated no yield advantage for 50% over 10% bloom.

Growth stage had an effect on all forage nutritive value parameters. Though, some variability was seen throughout the growing season, CP, TDN, IVTDMD48, and RFQ generally decreased as maturity increased, congruent with several other authors (Gasser et al., 1969; and Kalu and Fick, 1983; Table 2.10). Consequently, NDF, ADF, and lignin increased as maturity increased similar to Kallenbach et al. (2002) and Sheaffer et al. (2000) (Table 2.11). Mineral status of alfalfa was not clearly affected by growth stage. Potassium decreased as maturity increased, which could be a function of storage location of K in the plant (Lissbrant et al., 2009; Table 2.12).

Conclusion

Low levels of K fertilization did not influence alfalfa yield, nutritive value or stand persistence and higher rates are still recommended to produce a positive response. Harvesting at later maturity stages tended to increase yield but also increased fiber content and lowered digestibility. Crown and stem counts both increase throughout the season as maturity increased, suggesting that this well-established stand was making up for smaller shoots by increasing in shoot quantity, particularly when harvested at later maturity stages. To optimize both quantity of alfalfa produced and maintain adequate nutritive value, 10% bloom remained the best growth stage to harvest and fertilizing with less than the current recommended K rate did not negatively affect alfalfa over the two-year lifetime of this trial.

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TABLES AND FIGURES

Table 2.1. Average maximum and minimum temperature and total rainfall for April through November in 2017 and 2018 at the University of Georgia, Tifton Campus Animal and Dairy Science Farm collected from the UGA Automated Environmental Monitoring Network (UGA-AEMN, 2018).

Month	Maximum Temperature [°C]			Minimum Temperature [°C]			Total Precipitation (cm)		
	2017	2018	100-Yr Avg	2017	2018	100-Yr Avg	2017	2018	100-Yr Avg
April	27.3	23.3	25.4	13.9	11.1	12.1	9.8	7.0	7.0
May	28.9	30.0	29.3	16.3	18.9	16.5	6.7	17.6	8.0
Jun	29.9	32.2	32.0	20.4	21.7	20.2	13.0	15.0	11.0
Jul	32.3	31.8	32.8	22.4	22.4	21.5	12.4	14.7	14.0
Aug	32.5	32.4	32.7	22.3	22.1	21.3	13.5	24.2	13.0
Sep	30.1	32.9	30.7	18.9	22.1	19.0	9.4	6.1	9.0
Oct	26.7	27.5	26.3	15.3	16.7	13.0	5.3	7.0	6.0
Nov	22.0	23.2	21.2	9.2	15.1	7.7	1.7	8.5	7.0

Table 2.2. Least square means for potassium content of alfalfa at each growth stage taken by tissue sample in 2018 at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

Growth Stage	**K (g kg^{-1})**
Bud	19.7[b†]
10% bloom	32.8[a]
30% Bloom	29.3[a]
50% bloom	29.6[a]
SE	1.52

[†]Means followed by different letters are different ($P < 0.05$).

Table 2.3. Least square means for topsoil content of pH, calcium (Ca), magnesium (Mg) and potassium (K) at the mid-point and conclusion of a two-year study at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Time	Sample Category	
		Topsoil	Subsoil
pH	Mid-Point	6.1[b†]	5.8[b]
	Conclusion	6.7[a]	6.2[a]
	SE	0.03	0.04
	P - Value	< 0.01	< 0.01
Calcium (mg kg^{-1})	Mid-Point	1106[a]	639[a]
	Conclusion	1082[b]	581[b]
	SE	39.6	37.5
	P-Value	0.03	< 0.01
Magnesium (mg kg^{-1})	Mid-Point	162.5[b]	89.4[a]
	Conclusion	170.7[a]	84.0[b]
	SE	5.92	3.65
	P-Value	0.02	< 0.01
Potassium (mg kg^{-1})	Midpoint	53.1	30.7[a]
	Conclusion	54.8	27.3[b]
	SE	2.73	2.35
	P-Value	0.42	< 0.01

†Means followed by different letters are different ($P < 0.05$).
‡Initiation topsoil samples: pH = 5.8; calcium = 744 mg kg^{-1}; magnesium = 107.2 mg kg^{-1}; potassium = 42.17 mg kg^{-1}
§Initiation subsoil samples: pH = 5.5; calcium = 498 mg kg^{-1}; magnesium = 64.56 mg kg^{-1}; potassium = 39.42 mg kg^{-1}

Table 2.4. Least square means for topsoil and subsoil content of pH, calcium (Ca), and magnesium (Mg) analyzed by potassium treatment of a two-year alfalfa study at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Category	Potassium Treatment (kg ha^{-1})					SE	*P*-Value
		0	67	101	134	168		
pH	Topsoil	6.4	6.4	6.5	6.4	6.4	0.05	0.15
	Subsoil	5.92	6.0	6.1	5.9	6.0	0.06	0.11
Calcium (mg kg^{-1})	Topsoil	1042	1077	1237	1031	1084	53.9	0.03
	Subsoil	561	597	699	579	615	43.0	0.02
Magnesium (mg kg^{-1})	Topsoil	160.7	165.5	184.3	157.5	164.9	7.90	0.07
	Subsoil	80.5	84.4	97.0	83.4	87.9	4.69	0.05

†Means within row followed by different letters are different ($P < 0.05$).

Table 2.5. Least square means for NIRS-predicted (Ca), phosphorus (P), potassium (K), and magnesium (Mg) content of alfalfa by potassium treatment separated by harvest period and averaged over the 2017 and 2018 growing seasons at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period						
K Treatment	1	2	3	4	5	6	7
				Ca (g kg^{-1})			
0	15.3[a†]	16.1[a]	15.2[a]	15.1[a]	15.3[a]	18.5	7.1
67	14.6[ab]	15.5[ab]	14.3[b]	14.2[b]	14.4[b]	17.7	6.5
101	14.6[b]	15.3[ab]	14.5[b]	14.0[b]	14.6[b]	17.5	6.5
134	14.5[b]	15.2[b]	14.2[b]	14.1[b]	14.3[b]	16.9	6.6
168	14.5[b]	15.4[ab]	14.2[b]	13.9[b]	14.4[b]	17.3	6.6
SE	0.16	0.21	0.19	0.17	0.14	0.45	0.23
P-Value	0.01	0.04	0.00	< 0.01	< 0.01	0.23	0.19
				P (g kg^{-1})			
0	3.07	2.98	2.83	2.69	2.89	2.78[b]	3.16
67	3.23	3.09	2.91	2.72	2.91	2.91[a]	3.22
101	3.20	3.02	2.96	2.73	2.91	2.90[a]	3.14
134	3.22	3.10	2.98	2.76	2.92	2.93[a]	3.26
168	3.20	3.13	2.99	2.77	2.95	2.92[a]	3.31
SE	0.068	0.040	0.044	0.034	0.024	0.036	0.045
P-Value	0.47	0.06	0.06	0.52	0.38	0.02	0.08
				K (g kg^{-1})			
0	22.5[b]	22.1[b]	20.6[b]	19.7[b]	19.6[b]	14.8[b]	11.9[c]
67	24.5[a]	23.8[a]	23.5[a]	22.7[a]	22.7[a]	17.8[a]	14.8[b]
101	24.9[a]	24.1[a]	24.3[a]	23.3[a]	23.5[a]	18.0[a]	15.4[ab]
134	24.7[a]	24.3[a]	24.2[a]	23.7[a]	23.3[a]	17.5[a]	15.8[ab]
168	24.8[a]	24.6[a]	24.5[a]	23.8[a]	23.7[a]	17.9[a]	16.5[a]
SE	0.42	0.39	0.56	0.50	0.54	0.70	0.48
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01
				Mg (g kg^{-1})			
0	3.36[a]	3.83[a]	3.54	3.62[a]	3.94[a]	4.58[a]	5.46[a]
67	3.17[ab]	3.64[ab]	3.24	3.31[b]	3.55[b]	4.31[ab]	5.07[b]
101	3.08[b]	3.46[b]	3.26	3.21[b]	3.52[b]	4.24[ab]	4.78[b]
134	3.13[b]	3.56[b]	3.19	3.22[b]	3.52[b]	4.23[ab]	4.83[b]
168	3.10[b]	3.61[b]	3.24	3.18[b]	3.47[b]	4.18[b]	4.74[b]
SE	0.047	0.053	0.091	0.075	0.074	0.094	0.108
P-Value	0.01	< 0.01	0.06	< 0.01	< 0.01	0.02	< 0.01

[†]Means followed by different letters are different within column ($P < 0.05$).

Table 2.6. Least square means for mass $shoot^{-1}$, percent alfalfa cover, and shoots per m^2 by growth stage of alfalfa separated by harvest period and averaged over the 2017 and 2018 growing seasons at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
			Mass $shoot^{-1}$ (g $shoot^{-1}$)				
Bud	1.4	0.9[b]	1.1[ab]	1.1	0.8[b]	1.0[b]	1.1[a]
10% Bloom	1.2	0.1[ab]	1.1[ab]	1.1	0.9[a]	0.9[b]	0.9[b]
30% Bloom	1.3	1.1[a]	1.2[a]	1.0	1.1[a]	1.2[a]	1.1[a]
50% Bloom	1.5	1.2[a]	1.0[b]	1.0	0.9[ab]	1.3[a]	0.1[ab]
SE	0.10	0.04	0.05	0.04	0.05	0.06	0.05
P-Value	0.32	< 0.01	< 0.01	0.38	< 0.01	< 0.01	< 0.01
			Shoots m^{-2}				
Bud	109.3	116.4	139.6[ab]	116.1	123.0	135.4	119.1[ab]
10% Bloom	141.3	150.0	172.6[a]	112.4	94.8	142.5	137.1[ab]
30% Bloom	128.7	99.6	112.9[b]	146.9	103.7	151.2	93.4[b]
50% Bloom	125.6	104.1	151.2[ab]	167.9	149.9	93.0	156.9[a]
SE	9.84	19.77	12.75	14.60	15.10	26.91	16.95
P-Value	0.22	0.27	0.01	0.07	0.11	0.44	0.04
			Alfalfa Cover (%)				
Bud	61[b]	76	81	80	67	78	77
10% Bloom	75[ab]	79	81	78	78	75	69
30% Bloom	77[a]	73	75	78	70	74	81
50% Bloom	78[a]	76	78	76	78	80	86
SE	3.6	4.1	1.9	3.6	4.2	3.6	4.5
P-Value	0.02	0.83	0.10	0.93	0.17	0.64	0.05

[†]Means followed by different letters are different within column ($P < 0.05$).

Table 2.7. Least square means for early-season, late-season, and final alfalfa crown counts and mid-season, late-season and final alfalfa stem counts for the 2017 and 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

Growth Stage	2018 Crown Counts Crowns m^{-2}			2018 Stem Counts Stems m^{-2}		
	Early	**Late**	**Final**	**Mid**	**Late**	**Final**
Bud	20.7[†]	24.5	32	122.2[a]	89.6[b]	162.5
10% Bloom	18.75	21.1	26.5	90.1[b]	120.0[a]	145.1
30% Bloom	18	22.2	32.5	95.0[b]	103.3[ab]	162.6
50% Bloom	19.25	25.4	30	113.9[ab]	106.8[ab]	189.6
SE	1.77	2.28	4.24	8.01	6.09	22.6
P-Value	0.76	0.53	0.64	< 0.01	< 0.01	0.59

[†]Means followed by different letters are different within column ($P < 0.05$).

Table 2.8. Least square means for mid-season alfalfa crown counts for the 2017 and 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

Growth Stage	Mid-Season Crown Counts Crowns m^{-2}	
	2017	**2018**
Bud	42.5[a†]	20.7[c]
10% Bloom	32.0[b]	25.5[bc]
30% Bloom	20.8[c]	25.2[bc]
50% Bloom	23.8[c]	24.3[bc]
SE	2.19	
P-Value	< 0.01	

[†]Means followed by different letters are different ($P < 0.05$).

Table 2.9. Least square means for yield separated by harvest period and total cumulative yields by growth stage of alfalfa and averaged over the 2017 and 2018 growing seasons at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period							Cumulative Yield (kg ha^{-1})
Growth Stage	1	2	3	4	5	6	7	
	Yield (kg ha^{-1})							
Bud	1393†	937	1489^{ab}	1199	827^{b}	1296	1337	8477
10% Bloom	1595	1472	1818^{a}	1176	861^{b}	1247	1067	9236
30% Bloom	1670	1038	1270^{b}	1437	1012^{ab}	1139	1062	8628
50% Bloom	1678	1170	1406^{ab}	1589	1273^{a}	1071	1516	9703
SE	84.5	191.2	107.0	112.9	68.0	133.5	134.5	278.4
P-Value	0.07	0.23	0.02	0.08	< 0.01	0.63	0.09	0.07

†Means followed by different letters are different within column ($P < 0.05$).

Table 2.10. Least square means for crude protein (CP), total digestible nutrients (TDN), relative feed quality (RFQ) and in-vitro true dry matter digestibility (IVTDMD48) by growth stage of alfalfa separated by harvest period and averaged over the 2017 and 2018 growing seasons at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
	CP (g kg^{-1})						
Bud	247[a†]	221[c]	229[a]	227[a]	240	244[a]	256
10% Bloom	223[b]	229[bc]	234[a]	224[a]	239	237[ab]	270
30% Bloom	221[b]	257[a]	212[b]	226[a]	235	231[b]	270
50% Bloom	206[c]	238[b]	210[b]	201[b]	232	242[ab]	272
SE	2.4	2.1	3.7	3.8	2.6	2.3	4.9
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	0.18	< 0.01	0.13
	TDN[1] (g kg^{-1})						
Bud	685[a]	680[a]	651[a]	666[a]	654[b]	703[a]	724
10% Bloom	665[b]	680[a]	646[a]	646[ab]	674[a]	677[b]	722
30% Bloom	670[ab]	686[a]	601[b]	642[bc]	661[b]	663[b]	722
50% Bloom	660[b]	657[b]	640[a]	622[c]	676[a]	677[b]	708
SE	5.1	4.1	5.0	6.1	3.3	4.4	4.7
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.13
	RFQ[2]						
Bud	193[a]	175[ab]	150[ab]	165[a]	155[b]	204[a]	226
10% Bloom	157[b]	181[a]	153[a]	147[b]	174[a]	179[b]	237
30% Bloom	163[b]	183[a]	118[c]	146[b]	163[bc]	168[b]	223
50% Bloom	154[b]	160[b]	138[b]	131[b]	171[ac]	178[b]	213
SE	5.1	4.5	3.7	4.4	2.7	4.3	6.9
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.12
	IVTDMD48 (g kg^{-1})						
Bud	827[a]	811[b]	787[a]	812[a]	816[ab]	846[a]	878[a]
10% Bloom	797[b]	814[ab]	790[a]	797[a]	823[a]	821[b]	854[b]
30% Bloom	801[b]	823[a]	759[b]	801[a]	812[b]	800[c]	845[b]
50% Bloom	788[b]	799[c]	779[a]	768[b]	822[ab]	833[b]	853[b]
SE	4.7	3.9	6.3	6.9	3.7	4.4	5.3
P-Value	< 0.01	0.02	< 0.01	< 0.01	0.11	< 0.01	< 0.01

[†]Means followed by different letters are different within column ($P < 0.05$).

[1]TDN: Predicted total digestible nutrients = (NFC × 0.98) + (CP × 0.87) + (FA × 0.97 × 2.25) + [NDF_n × ($NDFD_p$ ÷ 100)] – 10

[2]RFQ: Estimated relative forage quality = DMI (% of BW) × TDN (% of DM) / 1.23

Table 2.11. Least square means for acid-detergent fiber (ADF), neutral-detergent fiber (NDF), and lignin by growth stage of alfalfa separated by harvest period and averaged over the 2017 and 2018 growing seasons at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

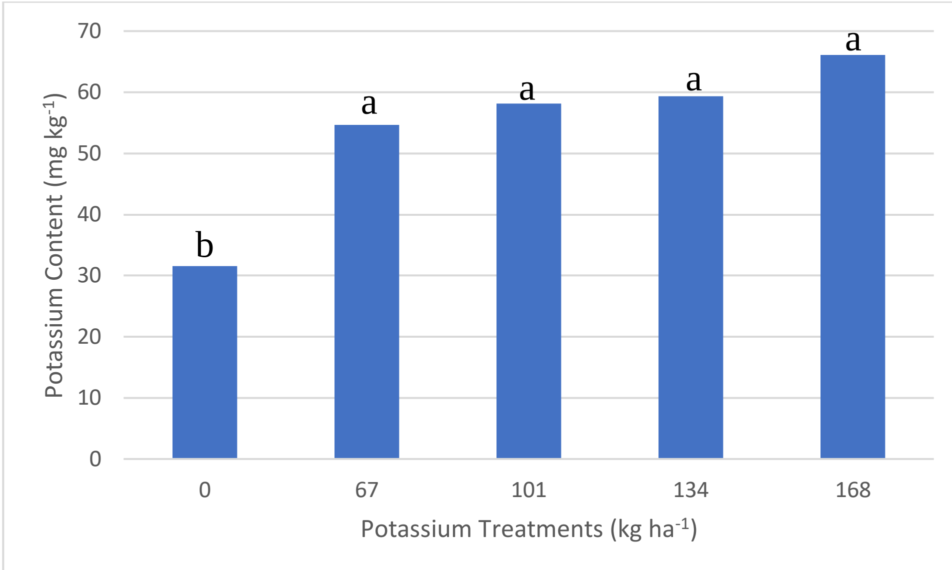
	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
				NDF (g kg^{-1})			
Bud	$390^{b†}$	394^{b}	447^{b}	405^{b}	439^{a}	354^{b}	331^{ab}
10% Bloom	434^{a}	376^{b}	438^{b}	450^{a}	398^{b}	386^{a}	310^{b}
30% Bloom	418^{ab}	383^{b}	513^{a}	458^{a}	414^{b}	412^{a}	325^{ab}
50% Bloom	428^{a}	430^{a}	458^{b}	472^{a}	$401^{\mathbf{b}}$	394^{a}	349^{a}
SE	7.6	7.1	7.3	6.8	4.6	7.4	7.7
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.03
				ADF (g kg^{-1})			
Bud	$300^{b†}$	297^{b}	347^{b}	305^{b}	319^{a}	268^{c}	235
10% Bloom	340^{a}	290^{b}	348^{b}	340^{a}	296^{c}	292^{b}	241
30% Bloom	329^{a}	294^{b}	394^{a}	342^{a}	312^{ab}	315^{a}	251
50% Bloom	336^{a}	330^{a}	348^{b}	365^{a}	299^{bc}	286^{bc}	263
SE	6.0	5.7	6.5	7.0	4.0	5.7	7.2
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.09
				Lignin (g kg^{-1})			
Bud	57^{c}	73	68^{c}	84^{ab}	77^{a}	61^{d}	84^{a}
10% Bloom	67^{b}	74	80^{b}	83^{b}	70^{b}	71^{c}	46^{c}
30% Bloom	70^{ab}	73	95^{a}	89^{a}	72^{b}	84^{b}	48^{c}
50% Bloom	74^{a}	71	92^{a}	88^{ab}	74^{b}	93^{a}	66^{b}
SE	1.3	1.5	0.9	1.2	0.9	1.7	1.4
P-Value	< 0.01	0.71	< 0.01	0.02	< 0.01	< 0.01	< 0.01

[†]Means followed by different letters are different within column ($P < 0.05$).

Table 2.12. Least square means for NIRS-predicted calcium (Ca), phosphorus (P), potassium (K), and magnesium (Mg) by growth stage of alfalfa separated by harvest period and averaged over the 2017 and 2018 growing seasons at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

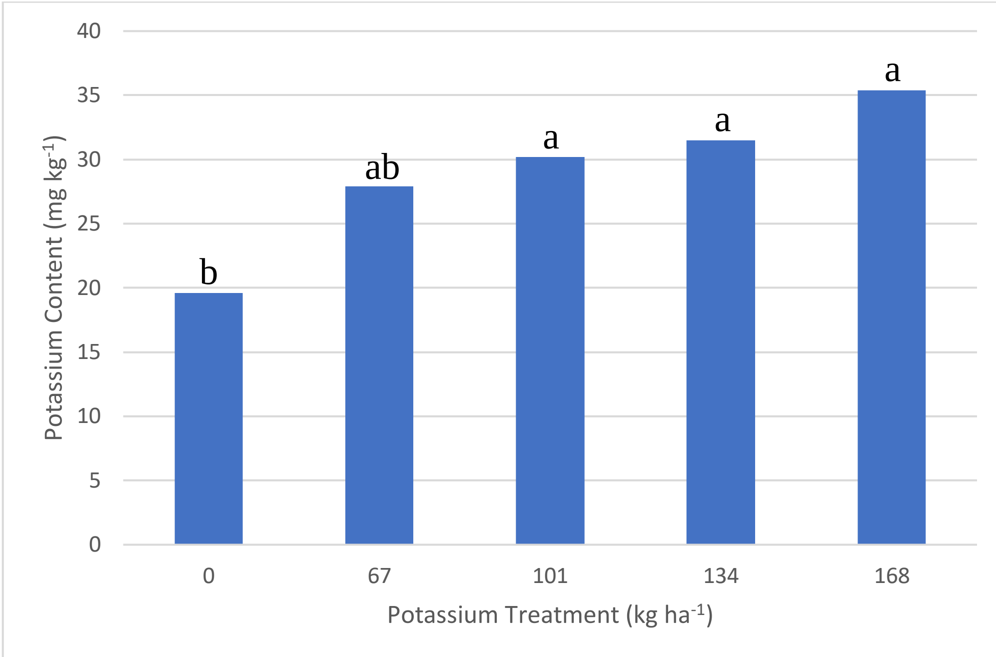
	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
				Ca (g kg^{-1})			
Bud	$14.7^{b\dagger}$	15.5	14.0^{b}	14.0	14.9	14.7^{c}	17.0^{a}
10% Bloom	13.6^{c}	15.7	14.9^{a}	14.3	14.7	15.4^{c}	3.1^{b}
30% Bloom	15.1^{ab}	15.7	14.9^{a}	14.6	14.3	18.8^{b}	3.2^{b}
50% Bloom	15.2^{a}	15.1	14.1^{b}	14.1	14.5	21.4^{a}	3.3^{b}
SE	0.13	0.19	0.17	0.16	0.18	0.45	0.24
P-Value	< 0.01	0.14	< 0.01	0.07	0.22	< 0.01	< 0.01
				P (g kg^{-1})			
Bud	3.49^{a}	2.86^{b}	3.27^{a}	2.71^{b}	3.01^{a}	2.96^{a}	2.79^{c}
10% Bloom	3.24^{b}	2.95^{b}	3.27^{a}	2.84^{a}	2.94^{ab}	2.91^{a}	3.24^{b}
30% Bloom	3.12^{b}	3.20^{a}	2.70^{b}	2.72^{b}	2.90^{bc}	2.90^{a}	3.37^{ab}
50% Bloom	2.90^{c}	3.23^{a}	2.51^{c}	2.67^{b}	2.82^{c}	2.79^{b}	3.48^{a}
SE	0.061	0.035	0.040	0.031	0.027	0.032	0.048
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
				K (g kg^{-1})			
Bud	27.9^{a}	21.6^{c}	28.6^{a}	20.7^{b}	25.5^{a}	19.4^{a}	11.2^{c}
10% Bloom	24.3^{b}	23.1^{b}	23.2^{b}	24.1^{a}	22.6^{b}	18.6^{ab}	17.7^{a}
30% Bloom	23.0^{bc}	24.0^{b}	23.1^{b}	23.2^{a}	22.4^{b}	16.9^{b}	15.9^{b}
50% Bloom	22.0^{c}	26.3^{a}	18.9^{c}	22.6^{ab}	19.6^{c}	13.8^{c}	14.7^{b}
SE	0.53	0.45	0.51	0.59	0.61	0.68	0.56
P-Value	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01
				Mg (g kg^{-1})			
Bud	3.27^{a}	3.66^{ab}	3.25^{b}	3.30	3.49	3.99^{c}	4.45^{b}
10% Bloom	2.90^{b}	3.45^{b}	3.63^{a}	3.43	3.62	3.89^{c}	5.00^{ab}
30% Bloom	3.25^{a}	3.71^{a}	3.16^{b}	3.38	3.51	4.37^{b}	5.03^{ab}
50% Bloom	3.35^{a}	3.66^{ab}	3.14^{b}	3.13	3.78	4.99^{a}	5.43^{a}
SE	0.041	0.058	0.082	0.084	0.084	0.083	0.148
P-Value	< 0.01	0.05	< 0.01	0.14	0.15	< 0.01	< 0.01

†Means followed by different letters are different within column ($P < 0.05$).



abcMeans followed by different letters are different (P < 0.05).
†Initiation topsoil samples: potassium = 42.17 mg kg^{-1}

Figure 2.1. Topsoil potassium content by potassium treatment collected across a two-year alfalfa evaluation at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.



[abc]Means followed by different letters are different ($P < 0.05$).
†Initiation subsoil samples: potassium = 39.42 mg kg^{-1}

Figure 2.2. Subsoil potassium content by potassium treatment collected across a two-year alfalfa evaluation at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

CHAPTER 4

EFFECTS OF POTASSIUM APPLICATION AND HARVEST REGIMEN IN FIRST-YEAR ALFALFA YIELD, NUTRITIVE VALUE, AND STAND PERSISTENCE IN THE SOUTHERN COASTAL PLAIN[1]

[1]Thinguldstad, Britta, J.J. Tucker, J.R. Segers, Dennis Hancock, and Lawton Stewart. To be submitted to *Crop Science*

Abstract

Potassium fertilization and harvest timing can both impact stand life of alfalfa (*Medicago sativa* L.). In the southern Coastal Plain, high temperatures and humidity often influence harvest timing and fertilization. Current nutrient management and harvest recommendations are generated from research conducted in northern climates with different varieties. The objective of this trial is to determine the impact of K fertilization and harvest regimen on stand persistence, forage yield and nutritive value of 'Bulldog 805' alfalfa during the establishment year. This study was conducted at the Coastal Plain Experiment Station in Tifton, GA on a first-year stand of 'Bulldog 805' alfalfa planted fall 2017. Plots were randomly assigned using a split plot design, with main plots being harvest stages bud and 10, 30 and 50% bloom and split plots of K fertilization rates of 0, 67, 101, 134, and 168 kg ha^{-1}, which were split applied three times across the season. At each harvest, plots were visually assessed to determine alfalfa cover and confirm percent bloom prior to harvest. Fifty shoots were collected to evaluate leaf:stem and mass $shoot^{-1}$ ratio. Grab samples were collected for nutritional analysis using near-infrared reflectance spectroscopy. Potassium treatment had no substantial biological effect on any evaluated parameter. Growth stage at harvest affected all parameters except for shoots m^{-2}. In several harvest periods, yield, leaf:stem and mass $shoot^{-1}$ increased with increasing maturity stage ($P < 0.01$). Crude protein (CP) decreased as maturity increased ($P < 0.04$). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) increased with increasing maturity stage at harvest in several harvest periods ($P < 0.01$). Consideration of potassium fertilization and harvest regimen is critical to alfalfa performance.

Introduction

Potassium is one nutrient that is critical for seedling vigor and root development and plays a significant role in site selection of alfalfa (Hancock et al., 2009). It is therefore important to maintain K levels throughout the harvest season, particularly in sandy soils with high leaching potential characteristic of the southern Coastal Plain (Sonon et al., 2014). Potassium fertilization can directly affect profitability and fertilizing in the first year of the stand can influence yield and dictate a profitable outcome in the future (Haby and Leonard, 2005). Lloveras et al. (2001) reported higher total dry matter yields for the 332 kg K ha^{-1} treatment than 0 kg K ha^{-1} treatment (87,600 kg ha^{-1} and 85,000 kg ha^{-1}, respectively, over 4 years). Fertilization with 187 kg K ha^{-1} maximized yield responses of 8,967 kg ha^{-1} on average over nine years of the study and was the minimum amount of K needed to maintain stand longevity (Markus and Battle, 1965).

Harvest timing can impact future alfalfa growth and affect yield, nutritive value and stand persistence. In the southern Coastal Plain, it is recommended that stands are not cut until they reach the 25% bloom stage for the first harvest in the establishment year to increase crown and root development (Hancock et al., 2009). Earlier harvests may decrease stand longevity and density (Hancock et al., 2009). Kust and Smith (1961) did not note any differences in yield across two, three, and four cuttings per year in the first harvest year of alfalfa in Wisconsin. However, plots cut late in the fall during the first year had lower yields the following spring (Kust and Smith, 1961). Smith and Nelson (1967) observed descending seasonal yields for three, four, five, or six cuts in the season. Crude protein (CP) dropped significantly in plots cut at early bud stage compared to 10% bloom after three harvest seasons (Weir et al., 1960). Wildman et al. (2003) assessed a one-year stand of alfalfa in Louisiana harvested at a fixed harvest schedule and found that short duration between harvests (less than 35 days) had a severe impact on stand density after one year. However, yield and digestibility differences were not consistently different between maturity stages of bud, 10%, and 50% bloom (Wildman et al., 2003). Across eight growth stages in the establishment year, Bélanger et al. (1992) reported the lowest seasonal yield total in two treatments with bud stage harvests. However, these treatments also had the greatest CP and in vitro digestibility among harvests (Bélanger et al., 1992).

Both K fertilization and harvest frequency may affect stand density, leaf:stem, mass shoot^{-1}, yield, and digestibility parameters. The southeastern climate and soil types in the southern Coastal Plain present a unique challenge when determining sufficient K fertilization rates and appropriate harvest frequency to optimize yield and nutritive value in alfalfa. Therefore, the objective of this trial was to determine the impact of K fertilization and harvest regimen on stand density, forage yield, and nutritive value on a newly established stand of alfalfa in the southern Coastal Plain.

Materials and Methods

Study Location and Establishment

The experiment was conducted at the University of Georgia's Coastal Plain Experiment Station (31°30'00.4"N, 83°30'58.3"W) in Tifton, GA on a first-year stand of 'Bulldog 805' alfalfa planted at 22 kg pure live seed fall 2017. Soils were characterized as Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults), well drained, with a 2 to 5% slope with rapid or moderately rapid permeability (USDA, 2017). Plots were planted in 18 cm row spacing at a depth of 1.27 cm. Data collection began in spring 2018. The main plot comprised of sixteen plots that measured 42 m^2 and were randomly assigned using a split block design. Main plots were growth stage: bud, and 10, 30 and 50% bloom stage. Plots were further subdivided into 8.36 m^2 plots to examine K fertilization at rates: 0, 67, 101, 134 and 168 kg K ha^{-1}. Potash was split applied three times throughout the season: before the first cutting (March), ten days after the second cutting (May), and ten days after the second to last cutting (October). These rates are lower than current recommendations for these soils and were chosen to determine if decreasing current recommended K rates would be beneficial. Each plot was an experimental unit and was replicated four times. Soil samples were conducted in November of 2017 and plots were fertilized with 78 kg P_2O_5 ha^{-1} (MAP 12-61-0, Haifa; Haifa North America, Altamonte Spring, FL) and 3.4 kg boron ha^{-1} (Boron 10%; CNI Liquid, CNI AgriMinerals, Albany, GA) based on UGA soil test recommendations (Kissel and Sonon, 2011). Soil samples were analyzed using the Mehlich-1 procedure (Mehlich, 1953).

Scouting for insect pests occurred weekly throughout the growing season for alfalfa weevil [(*Hypera postica* (Gyllenhal) (Coleoptera: Curculionidae)], cowpea aphid [(*Aphis craccoivora)* (Koch) (Hemiptera: Aphidoidea]; potato leafhopper [*Empoasca fabae* (Harris) (Hemiptera: Cicadellidae)], three-cornered alfalfa leaf hopper [*Spissistilus festinus* (Say) (Hemiptera: Membracidae)], and fall armyworm [*Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)].

In January, lambda cyhalothrin (Lambda Star; Nufarm Americas Inc., Burr Ridge, IL) was used to control cowpea aphids at a rate of 34 g a.i. ha^{-1}. In May, June, August, and October, zeta-cypermetherin (Mustang Maxx; FMC Corporation, Philadelphia, PA) was applied to plots at a rate of 28 g a.i. ha^{-1} to control the three-cornered alfalfa leaf hopper and fall armyworm. In July, Malathion (Malathion 5EC; Drexel Chemical Company, Memphis, TN) was applied at 1.4 kg a.i. ha^{-1} to control fall armyworms.

Broadleaf weeds were controlled in January and March of 2018 using imazethapyr (Pursuit; BASF Corporation, Research Triangle Park, NC) at a rate of 0.006 kg a.i. ha^{-1}. Clethodim (Select MAX; Valent, Valent USA Corporation, Walnut Creek, CA) was used in June and August to control grass weeds at a rate of 168 kg a.i. ha^{-1}.

Plot borders were maintained weekly. Plots were reset prior to study initiation at approximately ten cm on March 8, 2018 due to variability in height and bloom across all plots. At this time, all plots were at or near 25% bloom to minimize early stunting of the newly-established stand and minimize any effects on subsequent data collection (Hancock et al., 2009).

Weather

The harvest season was from April 19th through October 23rd, 2018. Weather data was collected from the UGA weather station in Tifton, Georgia and reported for the duration of the harvest season (UGA-AEMN, 2018). Average daily temperature was 31°C as a high and 21°C as a low which was similar to 100-year averages of 29°C and 16°C (Table 3.1). Total rainfall for the 2018 harvest season was 100 cm which was 25 cm greater than the 100-year average (Table 3.1).

Measurements

At each harvest, plots were visually assessed to determine ground cover. Percent bloom was confirmed at each harvest to verify growth stage, based on the procedure described by Mueller and Fick (1989). Fifty shoots were collected from each plot at 2.5 cm from the ground and split into two bundles of 25 shoots. Twenty-five shoots were weighed and individually measured for length using a yard stick for mass $shoot^{-1}$ calculation. The second bundle of 25 shoots were used for leaf:stem and all leaves were removed from the stems and placed in separate bags (stems included apical buds and flowers) and then weighed. Mass $shoot^{-1}$ and leaf:stem samples were then dried at 60°C for 72 hours and weighed. Shoots m^{-2} was calculated by dividing yield m^{-2} by mass $shoot^{-1}$. Yield was determined using a Swift Forage Plot Harvester IV (Thompson, 1972) by harvesting the whole plot. A tripod was set up and a hanging scale attached (Intercomp, Medina, MN). All forage harvested from each plot was put onto a 1.4-m^2 tarp and hung from the hanging scale to record plot yield. A 200-g grab sample was taken from each plot and used for nutritional analysis. Grab samples were then weighed, dried in a forced air oven at 60°C for 72 hours, to determine dry matter concentration and ground in a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen and prepared for lab analysis. Stand density was assessed before the first, in the middle (June), and at the last harvest each year using three 0.1-m^2 quadrats randomly placed in the plot and counting the apparent individual crowns and associated stems within the quadrat. Soil samples were taken before and after each harvest season in each plot to determine nutrient removal at the topsoil (0-15 cm) and subsoil (15-30 cm) level. Soil samples were analyzed in the University of Georgia Agricultural and Environmental Services Labs: Soil, Plant and Water Laboratory in Athens, Georgia.

Forage Analysis

For nutritive analysis, approximately five grams of each ground grab sample was scanned using near-infrared reflectance spectroscopy (NIRS) with a NIRSystems 6500 (Hilleroed, Denmark) analyzed with the alfalfa hay equation developed by the NIRS Forage and Feed Testing Consortium (Hillsboro, WI) to determine crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, in-vitro true dry matter digestibility (IVTDMD48), total digestible nutrients (TDN), estimated dry matter intake (DMI), relative forage quality (RFQ), calcium (Ca), phosphorus (P), potassium (K), and magnesium (Mg). Calibration statistics for 2018 Legume Hay NIR equations were as follows: NDF, SEC = 1.95, R^2 = 0.95; SECV = 2.04; ADF, SEC = 1.55, R^2 = 0.93; SECV = 1.63; CP, SEC = 0.70, R^2 = 0.95; SECV = 0.76, where SEC = standard error of calibration and SECV = standard error of validation, in g kg^{-1} on a DM basis.

Statistical Analysis

Data were analyzed in SAS v9.4 (SAS Institute, Cary, NC) using PROC MIXED with a denominator degrees of freedom correction using a Kenward-Rogers adjustment to generate standard errors and *F* statistics for each model. The lowest Bayesian's Information Criterion was used from the [AR 1] covariance structure to ensure the best fit. Block was considered a random effect. Potassium and growth stages were considered fixed effects. A Tukey-Kramer adjustment ($P < 0.05$) was applied to the LSMEANS to compare means at a significant difference of $P < 0.05$.

Results and Discussion

Potassium Treatment

Potassium treatments did not affect ($P > 0.05$) any evaluated parameters except for: leaf:stem, and NIRS-predicted Ca content and Mg content. Topsoil and subsoil K content was approximately 95 kg K ha^{-1} and 119 kg K ha^{-1}, respectively. Topsoil and subsoil phosphorus content were 63 kg ha^{-1} and 113 kg ha^{-1}, respectively. For these levels, the recommended rate was 224 kg K_2O ha^{-1} (based on UGA soil test recommendations for alfalfa maintenance; Kissel and Sonon, 2011); however, our highest treatment was 168 kg K ha^{-1}. Therefore, the lower than recommended K rates were not high enough to produce a response in most variables. Perhaps calcium and magnesium content may have shown a response due to antagonistic effects of these minerals (Syed-Omar, 1991). Additionally, as a first-year stand, differences due to K fertilization may not be as obvious, and continued deficiency might show results similar to other authors (Lloveras et al., 2001; Markus and Battle, 1965). Leaf:stem was influenced by K treatment, only in harvest period two with the greatest ratio in the 0 kg K ha^{-1} treatment ($P = 0.01$; Table 3.2). NIRS-predicted calcium and magnesium content was only affected in harvest period two ($P = 0.03$; data not shown). Both Ca and Mg were higher ($P = 0.04$ and $P = 0.02$, respectively) in 0 kg K ha^{-1} treatment than 101 kg K ha^{-1} treatment (15.2 g Ca kg^{-1} vs 13.9 g Ca kg^{-1}, respectively; 4.33 g Mg kg^{-1} vs 3.94 g Mg kg^{-1}, respectively).

These results are similar to those reported by Gervais et al. (1962) and Collins et al. (1986).

Growth Stage

Growth stage at harvest affected all variables except shoots m^{-2}. Yields generally increased with increasing maturity (Table 3.3), but this was not consistently true throughout the year. In harvest period five, in particular, yield decreased ($P < 0.04$) with increasing maturity stages. During the beginning of this harvest period there was a substantial amount of rain (corresponding to bud stage harvest) followed by a few weeks of no rain and high temperatures (corresponding to 30% and 50% bloom harvests). This could have contributed to yield losses experienced in the later maturing harvests. Overall yield increased throughout the season until harvest period three, and then sharply declined. Harvest period three, in June, had an explosion of weed growth which was reflected in the total yields. Extensive hand weeding was used to decrease weed growth and caused a subsequent decrease in total yield following harvest period three (Table 3.3) and a decrease in shoots m^{-2} ($P < 0.01$; data not shown). Reynolds (1971) also indicated weed infestation and resulting stand loss, particularly in the earlier maturity stages. A corresponding seasonal decrease in leaf:stem occurred, potentially due to the negative linear relationship between yield and leaf:stem (Sheaffer et al., 2000). Within harvest period one, three, six and seven, yield and leaf:stem trends were the same between growth stages with later maturity stages having greater leaf:stem ratios ($P < 0.01$; Table 3.3 and Table 3.4). These results are similar those of Kilcher and Heinrichs (1974) who found linearly increasing leaf:stem until early bloom where it plateaued. However, after the 10% bloom stage, greater leaf:stem ratio continued to be observed in the study, contrasting previous reports (Kilcher and Heinrichs, 1974; Luckett and Klopfenstein, 1970). Crown counts remained relatively stagnant throughout the season among growth stages; however, stem counts seemed to reverse their trend late in the season (Table 3.5). During mid-season, stem counts were greater ($P < 0.01$) in bud stage than 10% and 30% but lower ($P < 0.01$) than 30% and 50% later in the season. This may be attributed to the earlier growth stage harvests beginning to reduce persistence after initial establishment of alfalfa. Percent alfalfa cover numerically increased throughout the harvest season which may have resulted in greater plant competition and lowered yields as the season progressed (Lamb et al., 2003; Table 3.4). Mass shoot^{-1} was affected by growth stage. In several harvest periods (one, three, six and seven) mass shoot^{-1} was greater in later maturity stages ($P < 0.01$; Figure 3.1). These results are comparable to Ventroni et al. (2010) who saw a greater response of mass shoot^{-1} with later maturity stages.

Nutritive value parameters were similar to those of previous reports (e.g., Kalu and Fick, 1983; Kallenbach 2002). As maturity increased, CP generally decreased ($P < 0.05$; Table 3.6). However, there was a decline in CP between harvest periods two and three for all growth stages, likely the result of increased weed pressure (Moyer et al., 1998). Digestibility (IVTDMD48), TDN, and RFQ tended to decrease as maturity increased (Table 3.7), similar to reports by Calder and MacLeod (1967), Romero et al. (1987), and Kallenbach (2002). Days between harvest may have also contributed to differences in nutritive value. On average, 50% bloom had 29 days between harvest across the season, while bud stage was approximately 24 days on average. Palmonari et al. (2014) and Kallenbach et al. (2005) also found a decrease in digestibility with greater days between harvest. NIRS-predicted mineral status of alfalfa remained relatively unchanged throughout the season, but P and K tended to slightly decline towards the end of the season (Table 3.8). Following K treatment applications, a numerical decline in NIRS-predicted K content was seen over time (Table 3.8).

Conclusion

Alfalfa maintenance requires attention to harvest timing and fertilization. This study indicated that current recommendations for K fertilization in the Coastal Plains are valid, and lower rates did not produce a positive response. Harvest timing is important for stand survival, yield, and nutritive value. While growth stage had no consistent effect on yield, lower stem counts late in the season indicated that early maturity stage harvests decrease stand persistence. Additionally, nutritive value was higher in the earlier maturity stages. Because there was no yield benefit to harvesting at later maturity stages, and nutritive value was greater at earlier maturity stags, 10% bloom remains the optimum time to harvest in order to optimize nutritional value and negate a decline in stand persistence particularly in a first-year stand. Assumptions that higher rates of K fertilization like those currently recommended would produce a positive response in yield and nutritive value was not realized in this study.

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Table 3.1. Average maximum and minimum monthly temperature and total rainfall for April through November in 2018 at the University of Georgia, Tifton Campus Animal and Dairy Science Farm collected from the UGA Tifton Automated Environmental Monitoring Network (UGA-AEMN, 2018).

Month	**Maximum Temperature [°C]**		**Minimum Temperature [°C]**		**Total Precipitation (cm)**	
	2018	**100-Yr Avg**	**2018**	**100-Yr Avg**	**2018**	**100-Yr Avg**
Apr	23.3	25.4	11.1	12.1	7.0	7.0
May	30.0	29.3	18.9	16.5	17.6	8.0
Jun	32.2	32.0	21.7	20.2	15.0	11.0
Jul	31.8	32.8	22.4	21.5	14.7	14.0
Aug	32.4	32.7	22.1	21.3	24.2	13.0
Sep	32.9	30.7	22.1	19.0	6.1	9.0
Oct	27.5	26.3	16.7	13.0	7.0	6.0
Nov	23.2	21.2	15.1	7.7	8.5	7.0

Table 3.2. Least square means of leaf:stem of alfalfa for potassium treatment separated by harvest period for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

K Treatment ($kg\ ha^{-1}$)	**Harvest Period**						
	1	2	3	4	5	6	7
				Leaf:stem			
0	1.9[†]	1.3[a]	1.2	1.1	1.0	1.0	1.0
67	1.9	1.1[ab]	1.2	1.0	1.0	1.0	1.1
101	1.9	1.1[b]	1.1	1.1	1.0	1.0	1.1
134	1.9	1.1[b]	1.1	1.1	0.9	0.9	1.0
168	2.0	1.1[ab]	1.1	1.1	0.9	0.9	1.0
SE	0.08	0.06	0.10	0.06	0.05	0.50	0.04
P-Value	0.74	0.01	0.81	0.98	0.71	0.67	0.95

[†]Means followed by different letters are different ($P < 0.05$).

Table 3.3. Least square means of yield separated by harvest period and total cumulative yields by growth stage of alfalfa for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period							
Growth Stage	1	2	3	4	5	6	7	Cumulative Yield (kg ha^{-1})
	Yield (kg ha^{-1})							
Bud	731^{c†}	836^{ab}	1931^{b}	805	717^{a}	329^{c}	462	5811^{ab}
10% Bloom	869^{c}	758^{b}	1410^{c}	822	414^{b}	635^{b}	481	5389^{b}
30% Bloom	2247^{a}	1193^{a}	2534^{a}	1246	304^{b}	635^{b}	623	8782^{a}
50% Bloom	1495^{b}	1103^{ab}	2311^{a}	992	482^{b}	872^{a}	625	7880^{ab}
SE	171.8	163.7	116.8	261.7	64.9	82.7	72.2	712.5
P-Value	< 0.01	0.02	< 0.01	0.58	< 0.01	< 0.01	0.07	0.02

†Means followed by different letters are different within column ($P < 0.05$).

Table 3.4. Least square means of leaf:stem and percent alfalfa separated by harvest period for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
				Leaf:Stem			
Bud	1.5[b]	1.3[a]	1.0[b]	1.0[b]	0.9	0.9[b]	0.8[b]
10% Bloom	1.5[b]	1.1[b]	1.0[b]	1.2[a]	1.0	1.1[a]	1.0[a]
30% Bloom	2.7[a]	1.1[b]	1.2[ab]	1.0[b]	1.0	0.6[c]	1.2[a]
50% Bloom	1.9[b]	1.1[b]	1.5[a]	1.1[a]	0.9	1.2[a]	1.2[a]
SE	0.10	0.06	0.08	0.05	0.05	0.04	0.05
P-Value	< 0.01	0.03	< 0.01	< 0.01	0.39	< 0.01	< 0.01
				Alfalfa Cover (%)			
Bud	58	56[b]	66	61	64[a]	61	67
10% Bloom	58	57[b]	69	68	64[a]	57	66
30% Bloom	49	60[ab]	76	58	50[b]	65	69
50% Bloom	60	72[a]	72	70	62[a]	70	71
SE	7.2	6.8	4.5	5.7	5.0	5.5	4.9
P-Value	0.37	0.02	0.35	0.25	< 0.01	0.25	0.79

[†]Means followed by different letters are different ($P < 0.05$).

Table 3.5. Least square means for early-season, mid-season and late-season alfalfa crown counts and mid-season, and late-season alfalfa stem counts for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

Growth Stage	Crown Counts Crowns m^{-2}			Stem Counts Stems m^{-2}	
	Early	**Mid**	**Late**	**Mid**	**Late**
Bud	27.0[†]	20.3	28.3[a]	110.7[a]	76.0[b]
10% Bloom	19.0	20.4	22.3[ab]	86.0[b]	87.3[ab]
30% Bloom	23.5	23.4	21.3[b]	78.0[b]	103.0[a]
50% Bloom	20.8	23.0	25.0[ab]	94.1[ab]	110.0[a]
SE	1.95	1.16	2.19	4.97	6.77
P-Value	0.06	0.10	0.02	< 0.01	< 0.01

[†]Means followed by different letters are different ($P < 0.05$).

Table 3.6. Least square means of crude protein (CP), total digestible nutrients (TDN), relative feed quality (RFQ) and in-vitro true dry matter digestibility (IVTDMD48) of alfalfa separated by harvest period for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
				CP (g kg^{-1})			
Bud	235[a†]	222[b]	220[b]	239[ab]	214[ab]	192[c]	272[ab]
10% Bloom	227[a]	233[b]	218[b]	244[a]	228[a]	257[a]	277[a]
30% Bloom	215[b]	257[a]	240[a]	225[bc]	204[bc]	254[a]	252[b]
50% Bloom	216[b]	255[a]	216[b]	214[c]	188[c]	223[b]	264[ab]
SE	3.3	3.8	4.4	4.3	5.4	6.5	5.4
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.04
				TDN[1] (g kg^{-1})			
Bud	769[a]	717[ab]	677	711[a]	690[a]	686[c]	756[a]
10% Bloom	735[b]	703[b]	693	715[a]	690[a]	709[b]	739[a]
30% Bloom	744[b]	726[a]	676	666[b]	661[b]	732[a]	720[ab]
50% Bloom	705[c]	718[ab]	697	683[b]	692[a]	721[ab]	691[b]
SE	4.1	4.2	5.4	4.1	3.6	4.7	5.8
P-Value	< 0.01	< 0.01	0.06	< 0.01	< 0.01	< 0.01	< 0.01
				RFQ[2]			
Bud	269[a]	185[ab]	163	191[a]	170[a]	161[b]	266[a]
10% Bloom	212[b]	176[b]	175	207[a]	177[a]	219[a]	275[a]
30% Bloom	219[b]	193[a]	167	156[b]	143[b]	233[a]	197[b]
50% Bloom	182[c]	192[ab]	172	161[b]	162[a]	211[a]	191[b]
SE	5.0	4.5	5.4	4.2	3.8	7.0	9.6
P-Value	< 0.01	0.04	0.37	< 0.01	< 0.01	< 0.01	< 0.01
				IVTDMD48 (g kg^{-1})			
Bud	898[a]	821	794[b]	845[a]	815[a]	795[c]	876[a]
10% Bloom	862[b]	820	825[a]	856[a]	826[a]	848[ab]	871[a]
30% Bloom	861[b]	831	804[ab]	805[b]	778[b]	850[a]	821[b]
50% Bloom	834[c]	829	824[a]	803[b]	796[b]	821[bc]	818[b]
SE	4.1	5.1	6.4	5.4	4.7	6.6	8.2
P-Value	< 0.01	0.18	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

[†]Means followed by different letters are different ($P < 0.05$).

[1]TDN: Predicted total digestible nutrients = (NFC × 0.98) + (CP × 0.87) + (FA × 0.97 × 2.25) + [NDF_n × ($NDFD_p$ ÷ 100)] – 10

[2]RFQ: Estimated relative forage quality = DMI (% of BW) × TDN (% of DM) / 1.23

Table 3.7. Least square means of neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin of alfalfa separated by harvest period for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

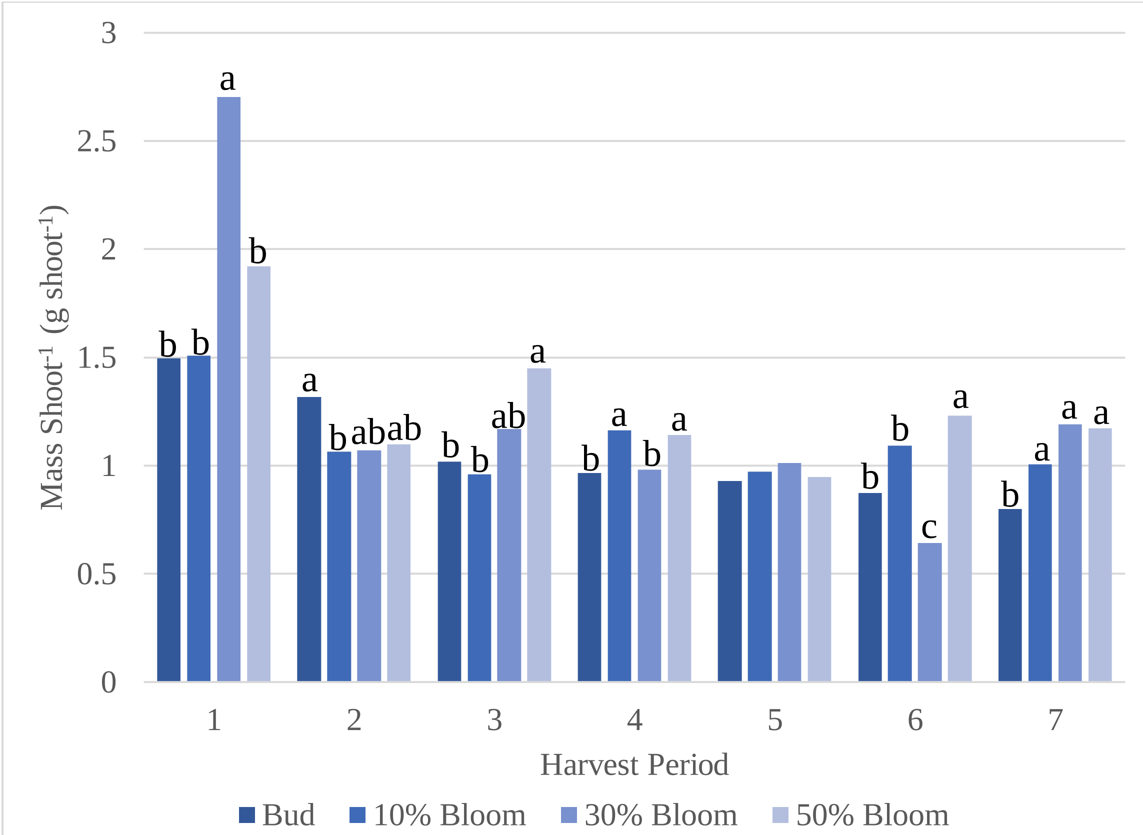
	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
				NDF (g kg^{-1})			
Bud	320^{c†}	398^{b}	420^{ab}	406^{b}	437^{ab}	442^{a}	299^{b}
10% Bloom	373^{b}	437^{a}	433^{ab}	371^{c}	414^{b}	340^{b}	284^{b}
30% Bloom	369^{b}	402^{b}	406^{b}	452^{a}	475^{a}	320^{b}	368^{a}
50% Bloom	416^{a}	395^{b}	446^{a}	454^{a}	439^{ab}	347^{b}	368^{a}
SE	5.1	6.5	8.1	7.8	9.6	8.3	10.1
P-Value	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01
				ADF (g kg^{-1})			
Bud	249^{c}	289^{b}	309	275^{b}	312^{ab}	307^{a}	212^{b}
10% Bloom	292^{b}	320^{a}	325	270^{b}	290^{b}	253^{b}	211^{b}
30% Bloom	288^{b}	290^{b}	312	328^{a}	333^{a}	231^{b}	267^{a}
50% Bloom	325^{a}	291^{b}	320	324^{a}	305^{b}	251^{b}	293^{a}
SE	4.5	4.5	6.2	6.1	6.5	6.6	8.4
P-Value	< 0.01	< 0.01	0.27	< 0.01	< 0.01	< 0.01	< 0.01
				Lignin (g kg^{-1})			
Bud	54.1^{c}	80.3	87.9^{ab}	71.0	64.9^{b}	84.8^{a}	47.8^{c}
10% Bloom	69.9^{b}	79.3	88.8^{ab}	76.2	66.1^{b}	51.6^{b}	44.4^{c}
30% Bloom	76.3^{a}	80.3	85.0^{b}	69.6	83.0^{a}	51.4^{b}	77.6^{a}
50% Bloom	80.4^{a}	74.4	97.0^{a}	65.1	83.1^{a}	62.2^{b}	62.2^{b}
SE	3.93	2.27	2.38	2.74	1.21	2.58	2.25
P-Value	< 0.01	0.14	0.04	0.08	< 0.01	< 0.01	< 0.01

†Means followed by different letters are different ($P < 0.05$).

Table 3.8. Least square means of NIRS-predicted calcium (Ca), phosphorus (P), potassium (K), and magnesium (Mg) of alfalfa separated by harvest period for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

	Harvest Period						
Growth Stage	1	2	3	4	5	6	7
				Ca (g kg^{-1})			
Bud	13.4^{c†}	15.1^{b}	16.1^{a}	13.5^{ab}	13.8	12.9^{b}	12.8^{c}
10% Bloom	14.9^{a}	16.4^{a}	14.2^{c}	12.7^{b}	13.6	13.4^{b}	15.1^{a}
30% Bloom	14.1^{b}	13.4^{c}	15.2^{b}	13.5^{ab}	12.7	14.3^{ab}	13.9^{b}
50% Bloom	15.4^{a}	12.1^{c}	13.4^{c}	14.3^{a}	13.1	15.4^{a}	14.9^{a}
SE	0.21	0.22	0.22	0.21	0.38	0.35	0.21
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	0.23	< 0.01	< 0.01
				P (g kg^{-1})			
Bud	4.0^{a}	3.2^{c}	3.2^{b}	3.2^{b}	3.2^{a}	2.6^{c}	3.1^{b}
10% Bloom	3.9^{b}	3.8^{a}	3.7^{a}	3.4^{a}	3.0^{a}	3.1^{a}	3.5^{a}
30% Bloom	3.7^{c}	3.7^{ab}	3.5^{ab}	3.1^{b}	2.7^{b}	3.0^{ab}	2.8^{c}
50% Bloom	3.8^{c}	3.6^{b}	3.1^{b}	3.2^{b}	2.5^{b}	2.8^{bc}	3.5^{a}
SE	0.04	0.05	0.10	0.04	0.05	0.05	0.03
P-Value	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
				K (g kg^{-1})			
Bud	33.7^{a}	24.3^{b}	24.7^{c}	28.4^{b}	33.4^{a}	26.1^{a}	23.3^{a}
10% Bloom	30.1^{b}	28.0^{a}	31.5^{a}	29.0^{b}	30.7^{ab}	25.6^{a}	23.3^{a}
30% Bloom	28.7^{c}	25.9^{b}	22.4^{d}	32.3^{a}	28.6^{bc}	22.6^{b}	20.1^{b}
50% Bloom	30.2^{b}	29.2^{a}	27.6^{b}	33.5^{a}	26.2^{c}	20.9^{b}	24.1^{a}
SE	0.39	0.55	0.50	0.65	0.91	0.50	0.55
P-Value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
				Mg (g kg^{-1})			
Bud	3.0^{c}	4.1^{b}	3.7	3.8^{ab}	3.4	3.1^{b}	3.9^{bc}
10% Bloom	3.6^{ab}	4.8^{a}	3.7	3.9^{a}	3.4	3.8^{a}	4.4^{a}
30% Bloom	3.5^{b}	4.2^{b}	4.1	3.5^{b}	3.2	4.1^{a}	3.8^{c}
50% Bloom	3.8^{a}	3.5^{c}	3.8	3.6^{ab}	3.3	4.1^{a}	4.1^{b}
SE	0.05	0.05	0.10	0.10	0.09	0.15	0.07
P-Value	< 0.01	< 0.01	0.08	0.03	0.39	< 0.01	< 0.01

†Means followed by different letters are different ($P < 0.05$).



[abc]Different letters within graph represent significant differences at ($P < 0.05$).

Figure 3.1. Least square means for mass shoot^{-1} of alfalfa separated by harvest period for the 2018 growing season at the University of Georgia Animal and Dairy Science Farm in Tifton, Georgia.

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

Alfalfa production has increased due to availability of varieties selected for success in the southeastern USA. Potassium fertilization and harvest regimen both influence the success of an alfalfa stand; however, previous recommendations have been based on northern varieties and climates and need to be further examined in the context of the southern Coastal Plains. The objective of this research was to determine the impact of K fertilization and harvest regimen on forage yield, nutritive value, and stand persistence of alfalfa in the southern Coastal Plain. Two experiments were conducted in two sites with a two-year old established stand and a fall-established first-year stand.

Potassium treatments of 0, 67, 101, 134, and 168 kg ha^{-1} were lower than the recommended rate of 224 kg K_2O ha^{-1} for our soils. Burmester et al. (1991) and Collins et al. (1986) both found that 224 kg K_2O ha^{-1} produced the greatest yield response in alfalfa, but fertilization beyond that rate was not beneficial. In either experiment, no significant response was seen with yield, mass shoot^{-1}, shoots m^{-2}, alfalfa cover, crude protein, IVTDMD48, or TDN. Potassium treatment elicited more responses in the established stand than the first-year stand. Perhaps continued nutrient removal and K depletion in soils produced a greater response between treatments. Maintaining adequate nutrient status in the soil is critical to establishing a long-lived perennial and maintaining high yields (Hancock et al., 2009; Simons et al., 1995).

Growth stages of bud, 10%, 30% and 50% bloom interacted with nearly all parameters in both locations. There was considerable variability within year and between years in the first 2-year experiment which likely resulted from weather and pest pressure differences. Wildman et al. (2003) also reported similar inconsistencies between bud, 10%, and 50% bloom growth stages. Yield declined in both locations throughout the season and appeared to increase with later maturity stages. Over two years in the established stand, mass shoot^{-1} had no strong trends, but the first-year stand had clearly greater mass per shoot when maturity increased. Alfalfa ground cover was lower in the first-year stand compared to the two-year stand. No trends in ground cover were seen across the harvest season in the established stand—which is likely the result of it being an existing vigorous stand. In the first-year stand, alfalfa cover increased throughout the season, indicating it was likely successfully establishing a root system and continuing to proliferate. Crown and stem counts were inconsistent throughout the season. However, in both experiments, bud stage appeared to have greater crown and stem counts in the middle of the season and lower at the end of the season which may indicate that harvest timing beginning to decrease stand persistence as seen by other authors (Gasser et al., 1969; Brink and Marten, 1983).

Positive nutritive value metrics (CP, IVTDMD48, TDN, and RFQ) tended to decrease as maturity increased and negative nutritive value metrics (NDF, ADF, and lignin) increased in both locations. Both Wildman et al. (2003) and Palmanari et al. (2014) reported decreasing CP with increasing maturity of alfalfa. Further, as lignin becomes more prevalent with increasing maturity, NDF and ADF increase and digestibility decreases (Kallenbach et al., 2002; Sheaffer et al., 2000). Brink and Marten (1983) reported increasing digestibility with lowered maturity. However, long term harvesting at early maturity stages caused stand thinning (Brink and Marten, 1983).

The results of this study indicate that to preserve long-term stand density, maintain adequate yields, and optimize nutritive value, 10% bloom should continue to be used as the target growth stage in the Coastal Plains, agreeing with Wildman et al. (2003). Additionally, K fertilization below the current recommendations will not produce a positive response. Future analyses including the carbohydrate content of the roots in the established stand may further delineate differences in potassium deficiency below the ground. Continued data collection of the first-year stand may also provide a greater comparison of alfalfa growth and yield potential, especially between the two row-spacings in these studies.

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APPENDIX A

ROOT CARBOHYDRATE ANALYSIS

Introduction

Potassium Treatment

Potassium may influence mass shoot^{-1}, leaf stem^{-1}, and stand density by altering shoot growth which is determined by carbohydrate reserves in the roots (Li et al., 1997). During regrowth of shoots, root starch concentrations decreased from 226 mg g^{-1} to 100 mg g^{-1} in plants fertilized with 6.0 mM K (Li et al., 1997). Plants receiving no K had much lower root starch levels, which still decreased as shoots regrew from 75 mg g^{-1} to 50 mg g^{-1} (Li et al., 1997). Plants receiving 6.0 mM K had 60 mg g^{-1} root sugars that declined to 30 mg g^{-1} compared to 30 mg g^{-1} declining to 20 mg g^{-1} for plants receiving no K (Li et al., 1997). Root TNC concentrations were 72 mg plant^{-1} to 22 mg plant^{-1} following defoliation for plants fertilize with 6.0 mM K (Li et al., 1997). Plants receiving no fertilization had 18 mg TNC plant^{-1} and did not change significantly from defoliation (Li et al., 1997). Taproot starch was greater in plants fertilized with 400 kg K_2O ha^{-1} yr^{-1} compared to those with no K fertilization (200 μg starch mg^{-1} vs. 175 μg starch mg^{-1}, respectively; Berg et al., 2009). Fertilized and unfertilized plants both decreased following defoliation but those fertilized with K remained higher in starch concentration than unfertilized plants (Berg et al., 2009). Taproot sugar concentrations were lower throughout the study for those that were fertilized with K compared to those not fertilized (Berg et al., 2009).

Harvest Regimen

Changes in root reserves following excessive and repetitive defoliation can have profound impacts on alfalfa stand persistence and density. Longer regrowth periods, especially during the summer, allows the plant to take advantage of increased solar radiation and photosynthetic potential, further increasing yields (Teixeira et al., 2007a). Alfalfa root weights were doubled in plants harvested twice compared to four times, and etiolated regrowth was 0.543 g DM per crown compared to 0.211 g DM per crown for four cuts (Langille et al., 1965). Total available carbohydrate (TAC) level is a reflection of carbohydrate reserves available for regrowth for the plant and can influence survivability and persistence (Kust and Smith, 1961). If alfalfa is repeatedly cut at an immature stage, the subsequent decrease in root carbohydrate levels will weaken the plant and increase plant mortality (Smith, 1991). Total available carbohydrates reflected better regrowth and nutritional composition with alfalfa harvested twice with 37.5% TAC compared to three or four harvests with 33.9% and 32.8% TAC, respectively (Langille et al., 1965). Root carbohydrate concentration decreased 2.35% and persistence was negatively affected by decreasing harvest interval and increasing frequency of harvests from three cuts to four cuts (Brink and Marten, 1989). When alfalfa was not cut an additional time in autumn in Wisconsin, TAC levels were 30.5%, compared to 19.0% TAC when an additional cutting was made in fall (Kust and Smith, 1961). Alfalfa cut three times compared to six times during the first year experienced an average of 1.00 g higher average dry weights and an average of 7.35% higher TAC at the end of the season (Kust and Smith, 1961). Those cut six times were weakened and produced 41% less dry weight forage the second harvest year compared to alfalfa cut three times (Kust and Smith, 1961). In Arizona, TAC levels were also slower to increase in alfalfa harvested at full bloom stages compared to bud or 10% bloom (Feltner and Massengale, 1965). Alfalfa with the lowest TAC ratings at the full bloom stage also had the highest incidence of disease which indicates that low TAC levels could have caused an increase in stand depletion via higher disease proliferation (Feltner and Massengale, 1965).

Total nonstructural carbohydrates (TNC) and starch are highest in the fall, with TNC at approximately 400 mg g^{-1} and starch concentrations averaging approximately 348 mg g^{-1} (Li et al., 1996). TNC and starch steadily decline through the spring until shoot regrowth resumed (Li et al., 1996; Teixeira et al., 2007a). Frequent defoliation consistently decreased overall starch content with levels barely over 13% DM maximum for 28-day defoliation compared to 42-day (Teixeira et al., 2007a). In the spring, taproot starch concentrations decreased to less than 5% in the 28-day harvest treatment, compared to an increase of starch of 10-20% in plants defoliated every 42 days (Teixeira et al., 2007a). Total starch and TNC was reduced with a third harvest compared to two in Canada (Dhont et al., 2002). This reduction in TNC caused about 35% dry matter loss in the roots throughout the winter period which could lead to a loss in other root constituents (Dhont et al., 2002). Teixeira et al. (2007a) reported sugar concentration ranging from 4% in the spring and 12% in the autumn. Sugar concentration was more than cut in half between first and second sampling dates with 9% and 4%, in 28 days (Teixeira et al., 2007a). Sucrose concentrations were consistently lower in roots that had been harvested twice vs three times in the growing season (Dhont et al., 2002).

Mild winters in southern locations may contribute to changes in root carbohydrate levels. In Oklahoma, carbohydrate levels in alfalfa roots continued to decline as expected throughout the winter (Hamdani and Todd, 1989). However, plants cut in August had a quicker decline in root carbohydrates than those cut in October, suggesting that later cutting may be more beneficial in environments where photosynthetic activity and growth can occur in the beginning of winter (Hamdani and Todd, 1989). This could be due to shading from regrowth in plots not cut in October, which increases demand on carbohydrate reserves in the roots (Hamdani and Todd, 1989). In Tennessee, eight cut systems had the lowest percent carbohydrate with an average of approximately 15%, compared to four cuts with an average of approximately 25% (Reynolds, 1971). However, there was a low correlation between carbohydrate concentration and yield for the next harvest year, affirming that mild temperatures and leaf material present through the winter may reduce the dependence on carbohydrate reserves and lessen the changes in productivity from variation in carbohydrates (Reynolds, 1971). Rimi et al. (2014) stated water soluble carbohydrates (WSC) were 34% higher in plants harvested at early flower compared to early bud in the first year, but that was reversed in the second year. Alfalfa harvested at early flower had 23% lower WSC than those harvested at early bud stage (Rimi et al., 2014).

Materials and Methods

At the end of the final season, a destructive harvest was performed on all plots from experiment one to determine true crown and stem counts and collect roots for carbohydrate analysis. A 0.5 x 1-m steel square frame was manufactured to attach to a three-point hitch on a tractor (Figure A.1). The bottom edge of the square was sharpened to resemble a blade cut through the soil. Approximately 227 kg was added as tractor weights to the back of the square frame to keep it weighted in the soil. Starter trenches were dug at the beginning of each row at the desired depth of approximately 1-m and the cutter was placed in the trench and dragged to the end of the row, resulting in the roots being cut. Three-0.1 m^2 quadrats were placed in each plot and roots were excavated within quadrats, counted and stems associated each crown counted. Roots were then removed from each plot, washed in water, frozen on ice, hammer-milled (No. 10 Hammer Mill, CS Bell Company, Hillsboro, OH), vacuum sealed in a FoodSaver (Sunbeam Products, Boca Raton, FL) and frozen at -18°C. The roots were driven to Athens, Georgia, freeze dried, and ground to pass through a 1-mm screen in a Wiley Mill (Thomas Scientific, Swedesboro, NJ) for carbohydrate analysis using a procedure adapted from Hunt et al. (2005).

Results

Results are currently being analyzed at the UGA Forage Testing Laboratory.

Figure A.1. A steel frame constructed to fit a three-point tractor hitch to cut alfalfa roots at approximately one meter for carbohydrate analysis at the University of Georgia Animal and Dairy Science farm in Tifton, Georgia.

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