AN AGROECOLOGICAL APPROACH TO PASTURE AND HAYFIELD NITROGEN FERTILIZATION

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March 20, 2017

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Chapter 1

A Historic Perspective of Fertilization Practices on Pastures and Hayfields

Introduction

Fertilization practices of pastures and hayfields have changed drastically over the centuries. When commercial fertilizers were initially being developed, pastures and hayfields were not fertilized regularly because it was not economically viable to do so. As the commercial fertilizer industry grew and our knowledge of fertilization practices increased, the benefits of fertilizing pastures and hayfields became evident. As with other crops, the addition of fertilizers to pastures and hayfields, whether manures or commercial, can lead to negative impacts on the environment. Due to these negative impacts, producers must follow Best Management Practices (BMPs) pertaining to fertilizer applications. BMPs are developed to be economically viable, environmentally sound, and socially acceptable. Florida BMPs require producers to follow University of Florida IFAS recommendations for crop fertilization. For fertilization recommendations to be meaningful to producers, it is important to understand how producers are currently fertilizing pastures and hayfields. This paper focuses on pasture and hayfield fertilization from a historical perspective. It also presents findings from an assessment of current fertilizers trends for pastures and hayfields in Florida. Finally, the paper examines future challenges and opportunities of pasture and hayfield fertilization.

Early Fertilizers Prior to Commercial Fertilizers

The concept of fertilizing crops is quite old even though modern commercial fertilizers are a relatively recent development. We do not know for certain when people started using fertilizers, such as manures and ash. It was reported that fertilizers (manures) were used as early as the Neolithic period, 6,000 BC (Bogaard et al., 2013). The use of manure as an early fertilizer was documented in early AD. For example, in the Christian Bible New Testament, Luke 13:8, “And he answered him, ‘Sir, let it alone this year also, until I dig around it and put on manure.” It took people thousands of years to move from experimenting with manures, ashes, mud/muck, marl, green manures and legumes to developing modern commercial fertilizers.

Foundation of the P and K Commercial Fertilizer Industry

Justus von Liebig, a German chemist, is credited with laying the foundation for the modern fertilizer industry. Liebig’s work focused on plant nutrient needs. Liebig recommended adding artificial fertilizers to the soil to supply nutrients to plants (Galloway et al, 2013). John Lawes, an English agricultural scientist, was also instrumental in the development of the commercial fertilizer industry. He founded the Rothamsted Experimental Station in England (the world’s oldest continuous agricultural research station). In 1842, Lawes patented a process of treating bones with sulfuric acid to produce superphosphate of lime and opened the first commercial fertilizer factory in the world.

The potassium (K) fertilizer industry developed concurrently with the development of the phosphorus (P) fertilizer industry. Liebig recommended the use of ash in 1840 as a source of K. With the discovery of K salt deposits in Germany, its use as a fertilizer increased. The US was dependent on German K until WWI. Potassium shipments from Germany were impeded by the British blockade. Alternative K sources were in the US were identified. There were 128 plants producing K by the end of the war. Sources included kelp, wood ash, lake brine, alunite, cement dust, sugar-beet waste, blast furnace dust, to name a few (Gwynn, 1996). Additional K deposits were identified in New Mexico by 1931. Potassium fertilizers derived from chemical processes were not commonly practiced until 1963, when it made economic sense to do so (Russell and Williams, 1977).

Development of Nitrogen Fertilizers

In 1774, Joseph Priestley discovered ammonia and nitrous oxide. In 1785, Henry Cavendish produced nitric acid by passing an electric current through a jar of air over water. The work of Priestley and Cavendish led to the commercial production of ammonia by Döbereiner in 1823. The process required platinum as a catalyst but it was not efficient (Galloway et al, 2013). About 1900, the cyanamide process was developed in Germany. In 1901, Frank and Freudenberg showed that calcium cyanamide released ammonia when applied to soil. They patented calcium cyanamide as a fertilizer. Many others experimented with the electric arc process but most were not economically viable. In 1905, the first nitrate fertilizer (calcium nitrate) was developed using the electric arc process in Norway (Russel and Williams, 1977). For years, the electric arc process remained the focus of efforts to fix atmospheric N_2. In 1909, Fritz Haber filed his first patent for a cool electric arc process for fixing N. Haber continued to improve this process under a contract with BASF who paired him with Carl Bosch. Together, they worked through chemical and mechanical difficulties to build a plant that could commercially produce ammonia (Travis, 2015). The first plant was built in 1913 in Germany (Russel and Williams, 1977). This plant produced 20 tons of ammonia per day, which was converted to ammonium sulfate (Travis, 2015).

In the US, Nitrate Plant No. 1 (Haber-Bosch) and Nitrate Plant No. 2 (cyanamide process) were built in Alabama between 1916 and 1918. Nitrate Plant No. 1 failed, due to an incomplete understanding about the Haber-Bosch process. The first successful ammonia plant was built in 1921, in New York. Prior to 1921, much of the commercially available N fertilizers came from Chile in the form of sodium nitrate (Russel and Williams, 1977). Due to the relatively short supplies of Chile saltpeter, as they called it, nations were racing to develop economical and practical ways to fix atmospheric N_2. Military interests were also a consideration. Nitrate was needed for munitions. Chile had few harbors that would be easy to control. A country that could fix their own nitrogen (N) would have an advantage if war were to break out (Travis, 2015).

Advances in production methods and equipment lead to the increase in ammonia production. Wartime need for munitions compelled the expansion of the N fertilizer industry, since nitrate is an integral component of munitions. When WWII was over, the ammonium nitrate supplies were shifted to farms for use as fertilizer (Russel and Williams, 1977). Urea fertilizers were developed in 1920 in Germany. The first production in the US began in 1930. By 1975, urea was the leading nitrogen fertilizer in the world.

Nitrogen fertilizers continued to evolve post WWII, with the development of ammonium phosphate and others. The industry also began focusing on improved handling of these materials through the production of granulated fertilizers. When routine soil testing became available, it was found that N-P-K compound fertilizers were not sufficient to meet the crop needs since nutrient ratios were fixed and could not be adjusted to meet crop demands based on soil test results. Bulk blending was developed. Bulk blending is defined as “physically mixing, without chemical reaction, of two or more dry fertilizer materials to produce complete mixtures on a custom basis” (Russel and Williams, 1977).

Development of Enhanced Efficiency Fertilizers

Urea is the most popular N fertilizer in the world. A drawback of using urea fertilizer is the loss of N through ammonia volatilization, especially when it is not incorporated into the soil. When urea is applied to the soil, urease enzyme hydrolyzes urea to ammonium. This reaction causes soil pH to rise around the fertilizer granule. The rise in pH can cause ammonium to be converted to ammonia which leaves the soil as a gas (Figure 1-1). Urea hydrolyzes into ammonia quickly under conditions supporting high biological activity, such as warmth and moisture (Byrnes and Freney, 1995). Also, ammonia volatilizes more readily in alkaline soils or when ammonium ions are in high concentration compared to the exchange capacity of the soil (Cornforth and Chesney, 1971). Nitrification is the process by which ammonium is converted to nitrate in the soil. Primarily two types of bacteria are involved in this process: Nitrosomonas and Nitrobacter (Figure 1-2). Excess nitrates in the soil can leach, leading to water quality issues.

For the past several decades, the rate of nutrient release from fertilizers has been studied in order to increase nitrogen use efficiency (NUE). Nitrogen use efficiency is defined as the proportion of applied N that is utilized by the plant and contained in the crop harvested biomass, crop residue and N that is incorporated into the soil organic matter or inorganic N pools. By increasing NUE, less applied N is susceptible to loss through volatilization, leaching or denitrification (Cassman et al., 2002). Increasing NUE saves the farmer money and decreases negative impacts on the environment.

$$CO(NH_2)_2 + H^+ + H_2O \xleftrightarrow{\text{Urease}} 2NH_4^+ + HCO_3^-$$

$$\downarrow$$

$$NH_4^+ + HCO_3^- \rightarrow NH_3 + CO_2 + H_2O$$

Figure 1-1. Urea Hydrolysis and Ammonia Volatilization Reactions

$$2NH_4^+ + 3O_2 \xrightarrow{\text{nitrosomonas}} 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 \xrightarrow{\text{nitrobacter}} 2NO_3^-$$

Figure 1-1. Nitrification Reactions

Enhanced efficiency fertilizers (EEFs) have an agronomic, economic and/or environmental benefit over conventional water-soluble fertilizers. There has been some confusion about what constitutes an EEF. In 2013, the Association of American Plant Food Control Officials defined Enhanced Efficiency Fertilizers as “fertilizer products with characteristics that allow increased plant uptake and reduce the potential of nutrient losses to the environment (e.g., gaseous losses, leaching, or runoff) when compared to an appropriate reference product,” (Hatfield and Venterea, 2014). The AAPFCO doesn’t officially recognize a difference between slow release and controlled release products (Carson and Ozores-Hampton, 2014). Enhanced Efficiency Fertilizers can be in the form of slow-release nitrogen, such as manures and other organic materials or chemically altered fertilizers such as urea formaldehyde, although some have designated EEFs to refer to inorganic fertilizer products, and/or primarily N fertilizers.

Nitrogen EEFs use different technologies to improve efficiencies. For example, some N products use a physical barrier to control the N release rate, such as sulfur-coated or polymer-coated urea. Additionally, N stabilizers can be added to urea fertilizer to inhibit urease activity or nitrification. Nitrification inhibitors have been studied since the late 1870s when Herman Hellriegel and Hermann Wilfarth discovered the nitrification process (Galloway, et al., 2013). In 1924, urea formaldehyde was patented and introduced as the first slow release fertilizer (Timilsena et al., 2015). A breakthrough came in 1967 with the patenting of a sulfur coating process by Glenn Blouin and Donald Rindt (Azeem et al., 2014). Around the same time, Hansen with Archer Daniels Midland was granted a patent for the first polymer coated urea product (Hansen, 1965).

Sulfur coated urea products can be very effective as a controlled-release fertilizer. The urea granule is coated with sulfur and wax. Sulfur is a relatively cheap material and is an essential plant nutrient. The nitrogen release rate from sulfur-coated urea is dependent on temperature, soil moisture, microbial activity, as well as the sulfur and wax coating thicknesses. It has been reported that 1/3 of the granules release relatively quickly while 2/3 release relatively slowly. This is due to imperfections in the sulfur and wax coatings (Timilsena et al., 2015). This release pattern is sometimes desirable when plant nutrients are needed immediately and more slowly with time.

Sulfur coated urea can be encapsulated in a polymer coating which improves the controlled release characteristics over using sulfur alone (Azeem et al., 2014).

Polymer-coated urea products release N more slowly and evenly than sulfur-coated products. However, current polymer coatings are typically not biodegradable and thus, accumulate in the soil. Research shifted to focus on urea coatings that could be made from low cost, biodegradable materials. Controlled-release products with coatings made of starch, lignin and cellulose are relatively cheap and biodegradable but have been shown to have inferior controlled release characteristics as compared to polymer coated urea products (Azeem et at., 2014). Research continues to focus on improving controlled release fertilizers in order to increase NUE for improved crop yields and decrease negative environmental impacts.

Urease and nitrification inhibitors are referred to as N stabilizers and have also been extensively studied over the past few decades. Urease is the catalyst in the first step of urea hydrolysis. This microbe-derived enzyme catalyzes the reaction to form ammonium from the urea. Urease inhibitors have been studied for potential use in agriculture and in pharmaceuticals. NBPT (N-(N-Butyl) Thiophosphoric Triamide) is the best studied urease inhibitor and has been commercially available (commonly marketed as Agrotain®) since the 1990s (Upadhyay, 2012).

Nitrification is the process of converting ammonium to nitrate. In 1878, Warington pioneered work on nitrifying bacteria and found that carbon disulfide inhibits nitrification. Many other chemicals and heavy metals have been evaluated as nitrification inhibitors (Rodgers, 1986). There are several nitrification inhibitors marketed today but not all of them perform as advertised. The two most common nitrification inhibitors that have been shown to perform well are nitrapyrin (marketed as N-Serve) and dicyandiamide (marketed as Guardian). Nitrification inhibitors, when used alone, have been shown to cause increased ammonia volatilization by increasing ammonium ions in the soil (Cornforth and Chesney, 1971).

Forage Crops

Florida's most abundant warm season, perennial grasses for pastures and hayfields are bahiagrass (*Paspalum notatum* Flügge*)* and bermudagrass (*Cynodon dactylon* L.). Bahiagrass is native to subtropical South America. In 1913, the Bureau of Plant Industry introduced "common" bahiagrass to Florida and cultivated it at the Florida Agricultural Experiment Station. A new bahiagrass cultivar was identified by E.H. Finlayson in 1938 near Pensacola, Florida (Newman et al. 2014). This variety was named Pensacola bahiagrass and served as the parent material for other improved varieties. Current recommended bahiagrass varieties for Florida include: Pensacola, Argentine, Tifton 9, UF Riata, and TifQuik.

Common bermudagrass (likely from India or Africa) was introduced in 1751 in Savannah, Georgia by Governor Henry Ellis. By the early 1800s, it was widely distributed in the southern US (Mitich, 1989; Hanna et al., 2011). For many years, bermudagrass was considered a noxious weed and still is when it is growing where it is not desired such as row crop fields, hayfields, pastures and lawns. In 1928, researcher, James Stevens began working with bermudagrass by collecting and starting a bermudagrass nursery in Tifton, GA (Hanna et al., 2011). This nursery helped gather breeding stock that later was used to create the improved varieties that are currently grown and used in hayfields and pastures. Recommended varieties of bermudagrass for Florida include: Coastal, Alicia, Russell, Jiggs and Tifton 85.

Chapter 2

An Assessment of Fertilization Practices and Nitrogen Sources for use in Florida Hayfields

Introduction

Agroecology, as defined currently, is an ecological approach to agriculture that views agricultural areas as ecosystems and is concerned with the ecological impact of agricultural practices (Merriam-Webster). Production practices of agroecology meet a triple bottom line, which includes:

- economic – needs to be profitable to the farmer,
- environmental – impacts of nutrients, pesticides, tillage practices,
- social – impacts on human population and societal benefits of agriculture.

Agroecology, as a science, has evolved since the concept was first introduced in 1928. The term first was defined by Bensin, a Russian agronomist, as using ecological research methods on commercial crop plants. From the 1930s through the 1950s, the US experienced great intensification of agriculture. Agricultural production was focused on maximizing yields. The practices were non-ecological and focused on chemical input-intensive, monocultures. Agronomic output was the emphasis in the term agroecology during this period (Wezel et al., 2009).

In the 1962, Rachel Carson's book, *Silent Spring*, fueled the Environmental Movement (Wessel, 2014) that eventually helped to bring about the establishment of the Environmental Protection Agency (EPA) by President Nixon. This movement started applying ecology to agriculture. It initially focused on pesticides in the environment but it has since expanded to include all impacts that farming can have on the environment (Wezel et al., 2009).

World N use, globally per year, increased rapidly until 1960. From there, the trend slowed but continued increasing until 1988, when N use reached its maximum (Frink et al, 1999). Nutrient inputs, specifically N and P, have come under scrutiny for negative impacts on the environment (Stewart et al, 2005). Fertilizer use philosophies shifted to increasing fertilizer use efficiency (FUE) by soil testing prior to application, use of split applications, development of more efficient fertilizers such as controlled-release, and other management practices such as proper irrigation techniques and grazing methods.

Nitrogen in the Environment

Losses of Nitrogen (N) from agricultural fields typically occurs through volatilization, denitrification, soil erosion, runoff, and leaching (Motavalli et al., 2008). Nitrogen fertilizer losses should be minimized for environmental, as well as economic reasons. The greatest N loss globally is due to leaching, erosion, and runoff. Nitrogen that leaches or runs off into waterways can disrupt water nutrient cycles and thus impair waterways by increasing available nutrients and stimulating algal and weed growth. It has been reported that 60% of US coastal rivers and bays have been degraded by nutrient pollution (Motavalli et al., 2008).

Urea, when applied, is rapidly converted to ammonium by urease enzyme, which is supplied by microbes (Fig. 2-1). Depending on soil and environmental conditions, ammonium can then be either converted to nitrate through the nitrification process or via ammonia volatilization. Ammonia volatilization is affected by soil pH, buffer capacity, environment, surface crop residue, N source, and N placement. Nitrates are soluble in soil solution and thus mobile in the soil profile. Rainfall and irrigation leaches nitrates down past the root zone and into groundwater. Denitrification occurs under anaerobic conditions. Anaerobic bacteria obtain necessary oxygen from nitrite and nitrate in the soil. This reaction releases N gases (N_2 and N_2O) into the atmosphere (Havlin et al., 2014).

Perennial grasses have dense, deep root systems and thus can capture more N in the soil, as compared to annual crops (Jordan et al., 2007). If N fertilizers are applied to well-managed hayfields in such a way to minimize volatilization and leaching, NUE can be improved significantly.

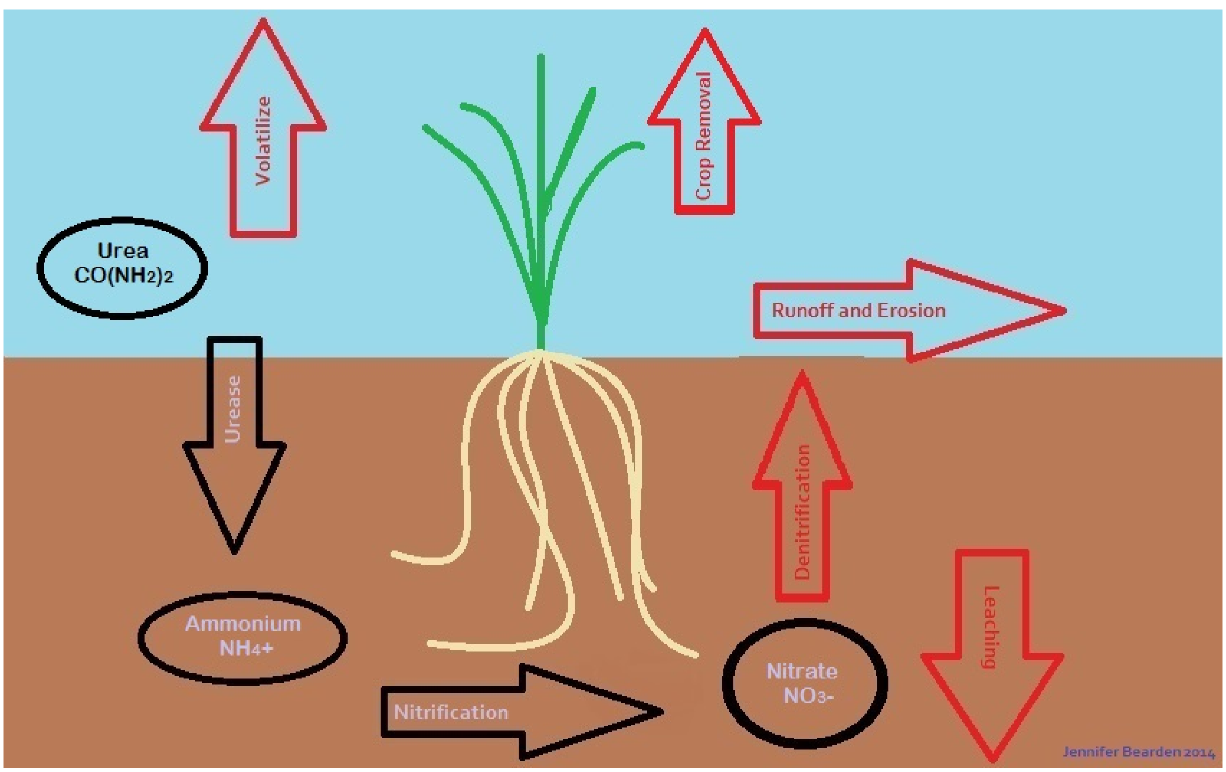

Figure 2-1. Nitrogen Cycle

Putting Fertilizer Philosophies into Practice: The 4Rs

An innovative, research-based approach to fertilizer BMPs is to apply fertilizers considering the 4Rs – Right Rate, Right Time, Right Place, and Right Source. The 4Rs (Rate, Time, Place and Source) are interlinked in nutrient management and must be considered together (Mikkelsen, 2011; Majumdar, 2013). The 4R Nutrient Stewardship concept was developed through cooperation among the International Plant Nutrition Institute, the Fertilizer Institute, the International Fertilizer Industry Association, and the Canadian Fertilizer Institute. General fertilizer recommendations are a good start to nutrient management but fall short, since most production systems are complex and not uniform farm to farm. The 4Rs concept is based on concrete principles in chemistry, biology, physics and economics (Mikkelsen, 2011). They provide a global framework to guide fertilization decisions, whereas the fertilizer BMPs are regional and crop specific practices that farmers can implement on their farms. The 4Rs can be generalized and applied to any crop (Majumdar et al., 2013).

Florida BMPs are developed and adopted by Florida Department of Agriculture and Consumer Services (FDACS). FDACS defines agriculture BMPs as “practical, cost-effective actions that agricultural producers can take to conserve water and reduce the amount of pesticides, fertilizers, animal waste and other pollutants entering our water resources” (*Agriculture Best Management Practices*, 2017).

Right rate - The right rate concept is straightforward. The objective is to provide just enough nutrients to meet realistic yield goals (Mikkelsen, 2011). In practice, this starts with a soil test to determine current plant available nutrient levels in the soil. The UF/IFAS fertilizer recommendation will be based on the plant available nutrients in the soil and the plant nutrient demand. The nutrient sources and their predicted use efficiencies should also considered. Enhanced efficiency fertilizers and slow release fertilizers will slowly release nutrients to the crop, whereas water-soluble fertilizers will be readily available at application. Lastly, nutrients will be removed (exported) or recycled on the farm and this must be considered as well. More nutrients are recycled on grazed pastures, whereas hayfields have more nutrients exported, therefore hay fields will require more nutrient inputs to offset the nutrient exports coming off the farm as hay. If the hay is being used on farm, then the nutrients from this hay will be recycled on the farm in pastures with livestock. Also, when hay and feeds are brought into pastures with livestock, nutrients are being put into the system. The current rate according to IFAS recommendations for hay fields subject to multiple cuttings per year is 80 lbs/acre N in early spring (plus P and K according to soil test) and then apply 80 lbs N/acre (plus 40 lbs K_2O/acre) after each cutting except after the last cutting in the fall (Mylavarapu et al., 2015).

Right time - Nutrients should be available when plants are actively taking up nutrients from the soil. This will be dependent on plant species, variety, planting date, and management, as well as soil characteristics such as soil nutrient supply and soil type. Also, predictable weather patterns affect the timing of fertilizer applications. Periods of high rainfall should be avoided because nutrient leaching losses will be higher. Farm logistics also impacts timing. Equipment availability and other farm duties sometimes make the timing application of fertilizers difficult. Split applications of water-soluble sources help to decrease nutrient losses, but it is not always logistically possible. When split applications are not possible, enhanced efficiency fertilizers can be an appropriate choice (IPNI, 2009). Timing then focuses on matching the peak uptake of the crop with the peak release of the fertilizer.

Right place - Nutrients must be in the root zone of plants for uptake to occur. For perennial pastures, fertilizers are applied on the soil surface rather than incorporated into the soil subsurface. This affects how fertilizers become available to plants and how nutrients become susceptible to losses. The goal of fertilizing pastures and hay fields should be to optimize the amount of nutrients that are available to the plant in the root zone but to decrease nutrient losses due to leaching and run-off.

Right source - The goal is choosing a source that will provide plant available nutrients when the plants are actively taking up nutrients while minimizing nutrient losses to the environment. Producers are limited to sources based on what is commercially available, as well as available application equipment (Majumdar, 2013). Currently, the main commercially available N sources to producers in Northwest Florida are urea, ammonium nitrate, ammonium sulfate, UAN, controlled release fertilizers (polycoated urea and inhibitor additives with urea) and slow release fertilizers (biosolids and manures/litters). It is important to consider timing of applications when choosing a source.

Enhanced Efficiency Fertilizers as a Right Source

The ultimate goal of any fertilization program is to meet crop nutrient demands when plants are taking up nutrients and growing. Appropriate timing of fertilizer application will decrease N losses to the environment while promoting optimal yield. Enhanced Efficiency Fertilizers should be chosen with timing and nutrient release rate in mind. The ideal release pattern should follow the nutrient uptake pattern of the crop (Timilsena, 2015).

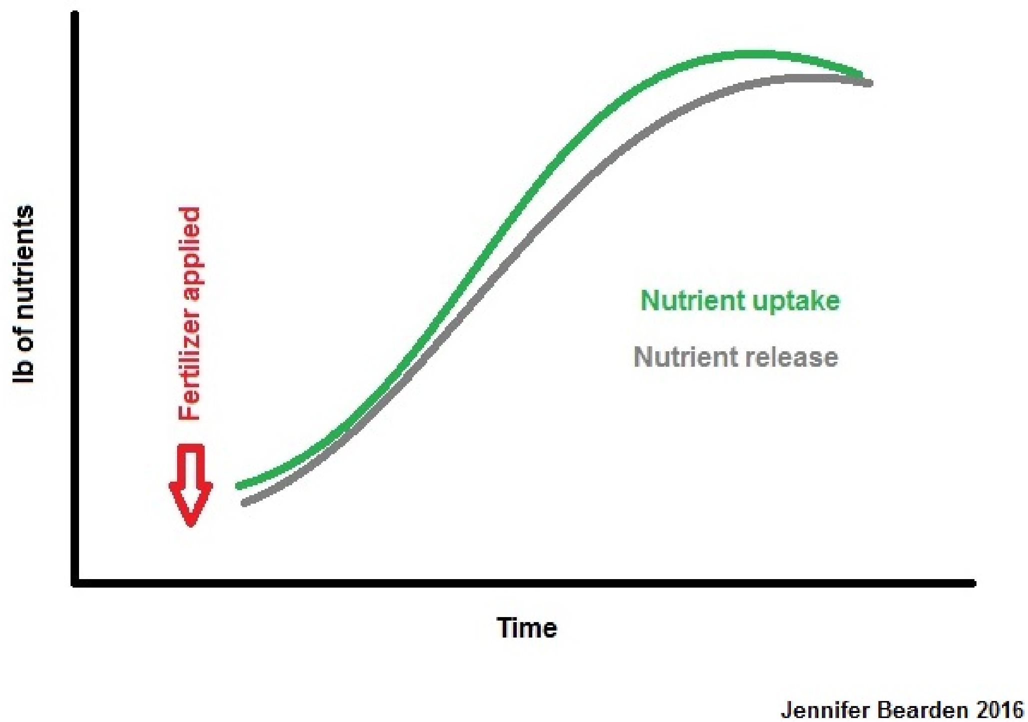

Figure 2-3. Release Pattern of ideal EEF

Enhanced Efficiency Fertilizers (EEFs) include controlled-release mineral fertilizers and slow-release fertilizers such as biosolids, animal manures, compost, and wood ash. The use in high value crops are justified economically but the price had been limiting their use on major crops (Fixen and West, 2002). In recent years, the price has become more affordable, allowing farmers to consider EEFs as a nutrient source. Meanwhile, slow-release waste products are available but producers are unsure of the biological and economic benefit of the different available materials.

Nitrogen Fertilizer Survey

Agroecology is a three-legged stool. It addresses agriculture through economics, environment and society. In essence, farmers, extension agents, specialists/researchers should look at all farming practices and evaluate them based on these three, sometimes opposing forces. Best Management Practices (BMPs) must be environmentally sound as well as economically feasible and socially acceptable. Florida Department of Agriculture and Consumer Services (FDACS) adopts BMPs by rule for different types of commodities and agricultural operations. The BMPs are developed with input from UF IFAS and are based on sound, scientific principles.

According to NASS, Florida had 290,000 harvested acres of hay in 2015. Concerns exist regarding N losses to the environment due to poor fertilization practices on hayfields in Florida. To enable more meaningful recommendations, we surveyed hay producers and fertilizer companies in Florida. The goals were 1) to identify forms of N fertilizers currently available to hay producers across the state, 2) determine whether or not producers use soil testing, and 3) determine how producers fertilize their hayfields.

Methods

Two surveys were developed to address Florida N fertilizer use on hay fields. One survey was developed for fertilizer company representatives. This survey was conducted to determine what forms of N are available to producers, including enhanced efficiency fertilizers, and to capture the opinions of salespeople on the fertilization of hay fields in Florida. The survey consisted of nine questions (Appendix 1). A second survey was developed for hay producers (Appendix 3). It also consisted of nine questions pertaining to hay field fertilization practices. Both surveys were conducted by phone and was approved by UF Institutional Review Board. Ten companies responded to the first survey, while eight producers responded to the second survey.

Results and Discussion

The results of the fertilizer company survey showed that a wide array of N fertilizers are available to hay producers including urea, ammonium nitrate, ammonium sulfate, and calcium nitrate. Seventy percent of surveyed companies offered a controlled-release product and 40% offered Class AA Biosolids. Ninety percent of the salespeople were of the opinion that most hay producers did not over-fertilize their hay fields. Also, 70% of salespeople were of the opinion that a majority of hay producers (>50%) soil test at least every three years. Most fertilizer companies sell to other industries, and hay producers make up less than 25% of their business. In conclusion, fertilizer companies supply a commodity to meet the demand of the consumer. They offer a variety of N forms, including EEFs. Fertilizer company representatives hold the opinion that hay producers are good land stewards and tend to follow BMPs, such as routine soil testing.

The results of the producer survey confirmed that bermudagrass and bahiagrass are the most commonly used forages for hay production in Florida. Sixty-three percent of producers surveyed grew bermudagrass and 75% grew bahiagrass for hay (some producers grew both). Acreages reported ranged from 17-450 with the average being 169 acres of hay production. All producers reported applying a balanced fertilizer, based on soil test results for the first application. All producers reported either closely following IFAS fertilization recommendations or applying less than the recommended rate. Reported rates for the first application ranged from 48-84lbs/acre N. Rates for applications following each cutting ranged from 26-80lb/acre N. The UF IFAS recommended rates for hay production are 80 lbs N/acre in the spring, followed by 80 lbs N/acre following each cutting, for both, bermudagrass and bahiagrass (Mylavarapu et al., 2015). Twenty-five percent of producers reported soil testing annually. Another 25% of producers reported soil testing every 2-3 years. The remaining 50% reported soil testing every other year. None of the six bahiagrass producers tissue tested for phosphorus levels prior to fertilizing, as recommended by IFAS. Two of the eight producers (25%) reported using an EEF. One producer used biosolids and one used poultry litter. All producers indicated that they did not regularly apply urea as their N source.

Conclusions and Implications

Fertilizer companies surveyed were from across the state of Florida. Although not inclusive of all Florida fertilizer companies, the survey did represent the different regions of the state from Northwest to South. Respondents for the producer survey proved to be more difficult to obtain. Producers were reluctant to complete the survey if their farms were in areas where environmental concerns have led to either mandatory BMP compliance or voluntary BMP compliance, and areas that are under Basin Management Action Plans. This led to a low response rate as well as areas in the state not being represented by the producer survey.

Producers and fertilizer company representatives reported that producers were not over-applying fertilizers on hay fields. According to the FDACS BMPs for Florida Vegetable and Agronomic Crops manual (2015), hay producers are required to soil test annually. Only 25% met this BMP. Even though EEFs were available, 75% of hay producers surveyed did not use them. The underutilization of EEFs is likely due to low return on investment that hay generally brings and the high cost of some EEFs like polymer-coated urea.   The low response rate by producers may have also skewed the reported number of producers using EEFs. A greater effort to better capture the responses of producers is needed. An anonymous online survey may work better to make producers more comfortable answering fertilization questions. Providing incentives for responses is also a good way to increase response rates.

Acknowledgements

I would like to thank Ed Jennings, Regional Specialized Livestock Agent in Pasco County for help in contacting hay producers in his region in Florida.

Chapter 3

Looking to the Future: Challenges and Opportunities for Forage Producers

We are faced with challenges and opportunities to improve agricultural practices and inputs. Agriculture as an industry is faced with feeding a growing population with fewer resources all, while also protecting the environment from agricultural activities. It is a daunting task but the industry is innovative. Research and development of new crop varieties that more efficiently utilize nitrogen fertilizers (see Appendix 3 for recommended improved varieties), equipment and materials focuses on increasing efficiency without negatively impacting the environment.

Precision Agriculture

Precision agriculture has been around for decades. It uses intensive data and information to make more efficient use of farm inputs such as fertilizers, herbicides, seeds and fuel. Data can be collected by analyzing the growing conditions such as soil for nutrients available, pH and moisture. Information such as crop herbicide tolerances and nutrient demands are also important when using software to analyze data and make treatment decisions. Precision agriculture leads to improved production, as well as maintaining acceptable environmental quality standards. Precision agriculture includes data collection, analysis, computer processing, field positioning, yield monitoring, remote sensing and sensors. Data is collected by satellites, aircraft, tractors and hand-held devices (Mulla, 2013). Farms have been adopting this technology for years and will continue to adopt more advances in the future. Like with fertilizers, this technology comes with a price. The return on investment must be there for the technology to be of value to the farmer.

Pastures and hay fields currently may benefit from soil sensing equipment to create maps that guide variable rate application of lime products and fertilizers. This technology saves money by applying just the right amount of nutrients that each zone/grid in the field needs. A new technology in forage and hay production is yield and moisture monitoring. Yield maps can help identify unproductive areas in the fields. This allows for closer inspection of these depressed areas, in order to correct issues and increase productivity (Long et al., 2016). As this technology becomes more readily available and affordable, it will be adopted by a much larger number of producers.

Enhanced Efficiency Fertilizers of the Future

Much work is being directed at producing effective controlled release products that are environmentally friendly. These new products will follow the agroecological principles of being economically viable to produce and use, environmentally sustainable, and socially acceptable. Enhanced efficiency fertilizers face future challenges. First, models to predict nutrient release are required, in order to match nutrient release with nutrient uptake. This will increase NUE and decrease N losses to the environment. Improved methods to evaluate the economic return on the use of EEFs on pasture and hayfields is needed. Also, the environmental benefits of using EEFs on pastures and hayfields should be quantified, in order to justify incentive and cost-share programs (Motavalli et al., 2008).

Management Decisions

Rotational Stocking – Although recommended for decades, many producers still do not understand the impact that rotational stocking has on the health of the pastures and soils. Stocking rate and grazing management are critically important to pasture grass performance and soil quality. As stocking rates increase, nutrients are redistributed by animals across the pasture, especially into congregation areas.

Grazing management can help distribute recycled nutrients more evenly across pastures. Rotational stocking with high stocking rates for short periods of time can better distribute nutrients more evenly as compared to continuous stocking systems or even rotational stocking for longer periods of time. Rotational stocking also encourages increase pasture plant root growth both in length and density, which allows the grass to take up water and nutrients during times of stress. Congregation areas under shade and near water should not be included in the soil sampling for the whole field for a fertilizer recommendation. These areas will have higher nutrients as compared to the rest of the pastures (Dubeux et al., 2007). If you sample these areas, your soil test results will be higher than represented by rest of the pastures and you will likely not apply enough nutrients to the other parts of the pastures based on these results.

Legume/Grass Mixtures – The concept of using legumes to fix dinitrogen, in order to supply their own N has been in practice for hundreds of years, long before the science was understood. In 1948, Worthen recommended the use of legumes for fertilizing low-value crops (Worthen, 1948). Legumes are excellent forages and actually can make high quality hay. During agricultural intensification, cropping shifted to monocultures because they are easier to manage. Legume/grass pastures can make it difficult to manage pests especially weeds. Legume/grass mixtures can; however, supply adequate nutrition either through grazing or hay consumption. There are limits to the amount of available soil N inputs from legume/grass pastures. This decreases the potential N losses to the environment (Ledgard, 2001). Mixed legume/grass pastures require lower N fertilizer inputs. When managed properly through rotational stocking, these pastures can be cost effective and environmentally friendly, compared to our traditional management systems.

Conclusions

The development of the fertilizer industry led to readily available commercial fertilizers for application on farmland, including pastures and hayfields. Research has shown benefits from the addition of fertilizers to pastures and hay fields, so farmers began relying upon readily available commercial fertilizers to increase yields. Misapplication of fertilizers has negative environmental impacts. These negative impacts resulted in the introduction of the 4Rs and BMPs, such as soil testing, split applications, and the use of EEFs. Currently, EEFs still cost more than synthetic, water-soluble fertilizers. Pastures and hay fields continue to be fertilized with fertilizers that are readily available and cost effective. Based upon surveys, producers are generally doing a good job of not over-applying fertilizers.

Future improvements will keep pushing forage systems to be even more efficient. Precision agriculture applications, such as soil mapping, variable rate fertilizer applications, hay yield monitors and moisture monitors will continue to be adopted by producers as they become more available and affordable. New EEF advancements will focus on better coating processes that are environmentally friendly and allow for more controlled and predictable release of nutrients. Along with new innovations, a return to some tried and true management methods will also increase efficiencies, while decreasing negative impacts on the environment. Adding legumes to perennial grasses is one way to return to a more sustainable, low-input system that decreases N losses to the environment. Also, using rotational stocking will increase pasture and soil health by increased root length and density and increase soil organic matter. Agriculture will continue to be an innovative and ever changing industry, focusing on economic, social and environmental impacts of producing food and fiber.

Literature Cited

Agriculture Best Management Practices. Retrieved on March 11, 2017 from: http://www.freshfromflorida.com/Divisions-Offices/Agricultural-Water-Policy/Agricultural-Best-Management-Practices

Bogaard, A., R. Fraser, T.H.E. Heaton, M. Wallace, P.Vaiglova, M.Charles, and E. Stephan. 2013. Crop manuring and intensive land management by Europe's first farmers. PNAS. 110:12589-12594.

Byrnes, B.H. and J.R. Freney, J.R. 1995. Recent developments on the use of urease inhibitors in the tropics. Fertilizer Research 42:251-259.

Cassman, K.G., A.R. Dobermann, and D.T. Walters. 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. Agronomy & Horticulture – Faculty Publications. Paper 356.

Cornforth, I.S.and H.A.D. Chesney. 1971. Nitrification inhibitors and ammonia volatilization. Plant and Soil, 34:497-501.

Dictionary and Thesaurus | Merriam-Webster. (n.d.) Retrieved October 22, 2016, from http://www.merriam-webster.com/

Fixen, P.E. and F.B. West. 2002. Nitrogen fertilizers: meeting contemporary challenges. A Journal of the Human Environment. 31:169-176.

Frink, C., P. Waggoner, and J. Ausubel. 1999. Nitrogen fertilizer: retrospect and Prospect. Proceedings of the National Academy of Sciences. 96:1175-1180.

Galloway, J., A. Leach, A. Bleeker, and J. Erisman. 2013. A chronology of human understanding of the nitrogen cycle. Philosophical Transactions of the Royal Society B. 368:20130120

Gwynn, J. W. 1996. History of potash production from the Salduro salt marsh (Bonneville Salt Flats). Tooele County: Utah Geological Survey, Survey Notes. 28:1-3.

Hanna, W., B. Anderson, and D. Hancock. 2011. The history of the development of forage bermudagrass: I. the early days. Georgia Cattlemen. July 2011.

Hansen, L. 1965. Granular fertilizer having a plurality of coatings and the process of making. US Patent 3223518 A. Date issued:14 December.

Havlin, J., S. Tisdale, W. Nelson, and J. Beaton. 2014. Soil fertility and fertilizers: an introduction to nutrient management. 8th ed. Pearson Inc. Upper Saddle River, NJ.

International Plant Nutrition Institute. (2009) The Global “4R” nutrient stewardship framework. http://www.ipni.net/ipniweb/portal/4r.nsf/0/BAB4157B488871A385257DF100739D94/$FILE/The%20Global%204R%20Nutrient%20Stewardship%20Framework.pdf. (Retrieved 10/21/2016).

International Plant Nutrition Institute. Image. (2014) http://www.ipni.net/ipniweb/portal/4r.nsf/article/4r-nutrient-stewardship-communications-guide-and-illustrative-diagrams. (Retrieved 10/21/2016).

IPNI. 2013. 4R plant nutrition manual: A manual for improving the management of plant nutrition, 1st Rev. Ed., (T.W. Bruulsema et al. ed.), International Plant Nutrition Institute, Norcross, Ga, USA.

Jordan, N., G. Boody, W. Broussard, J. Glover, D. Keeney, D., McCown, B., G. McIsaac et al. 2007. Sustainable development of the agricultural bio-economy. Science. 316:1570-1571.

Ledgard, S.F. 2001. Nitrogen cycling in low input legume-based agriculture, with emphasis on legume/grass pastures. Plant and Soil. 228: 43-59.

Long, E.A., Q.M. Ketterings, D. Russell, F. Vermeylen, and S. DeGloria. 2016. Assessment of yield monitoring equipment for dry matter and yield of corn silage and alfalfa/grass. Precision Agriculture. 17:546-563.

Majumdar, K., A. Johnston, S. Dutt, T. Satyanarayana, and T. Roberts. 2013. Fertiliser best management practices, concept, global perspectives and application. Indian Journal of Fertilisers. 9:14-31.

Mikkelsen, R.L., (2011) The “4R” nutrient stewardship framework for horticulture. HortTechnology. 21:658-662.

Mitich, L. W. (1989). History and taxonomy of bermudagrass. In Proceedings of the 41st Annual California Weed Conference. pp. 181-187.

Montgomery, E. G. 1918. Productive farm crops. Second edition revised. Lippincott, Philadelphia PA. p 338-341.

Mulla, D.J. 2013. Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. Biosystems Engineering. 14:358–371.

Mylavarapu, R., D. Wright, and G. Kidder. 2015. UF/IFAS standardized fertilization recommendations for agronomic crops. SL129. EDIS. http://edis.ifas.ufl.edu/ss163.

Newman, Y., J. Vendramini, and A. Blount. 2014. Bahiagrass (*Paspalum notatum*): overview and management. SS-AGR-332. EDIS. http://edis.ifas.ufl.edu/ag342

Rodgers, G.A. 1986. Nitrification inhibitors in agriculture. Journal of Environmental Science and Health. Part A: Environmental Science and Engineering. 21:701-722.

Russell, D. and G. Williams. 1977. History of chemical fertilizer development. Soil Science Society of America Journal. 41: 260-265.

Stewart, W M., D.W. Dibb, A.E. Johnstonand T.J. Smyth. 2005. The contribution of commercial fertilizer nutrients to food production. Agronomy Journal; 97:1-6.

Timilsena, Y. P., R. Adhikari, P. Casey, T. Muster, H. Gill, and B. Adhikari. 2015. Enhanced efficiency fertilisers: a review of formulation and nutrient release patterns. Journal of the Science of Food and Agriculture. 95:1131–1142.

Travis, A.S. 2015. The synthetic nitrogen industry in World War I: its emergence and expansion. Springer Briefs in Molecular Science. Springer, New York, NY.

Upadhyay, L.S.B. 2012. Urease inhibitors: a review. Indian Journal of Biotechnology. 11:381-388.

Wessel, G. M. 2014. Rachel Louise Carson (May 27, 1907 - April 14, 1964). Mol. Reprod. Dev., 81: Fm i. doi:10.1002/mrd.22295.

Wezel, A., S. Bellon, T. Doré, C. Francis, D. Vallod et al. 2009. Agroecology as a science, a movement and a practice. A review. Agronomy for Sustainable Development. 29:503-505.

Worthen, E.L. 1948. Farm soils, their management and fertilization. 4th ed. Wiley and Sons, New York, NY.

Appendix 1

Fertilizer Company Survey Script

Hi,

I am Jennifer Bearden, UF IFAS Okaloosa County Extension agent. I am working on a master's degree through the UF IFAS Agroecology program under Dr. Cheryl Mackowiak. My final project is on Enhanced Efficiency Fertilizer Use in Florida Hayfields. I'm contacting fertilizer salespersons to obtain information on fertilizer sources, availability, and use across the state. Participation in the study is completely voluntary. You can choose not to answer any question. You will not be identified in the project. Your response will be combined with responses from other participants across the state. The results of this study will be used to demonstrate how hay producers are currently fertilizing their hayfields. Results may be used to secure grant funds to further research hayfield fertilization. The survey should only take 10-15 minutes to complete. If you have any questions regarding this study, you can contact me at (850) 689-5850. Please direct any questions or concerns about the your rights as a participant to the IRB02 office, PO Box 112250, University of Florida, Gainesville, FL 32611-2250; ph (352) 392-0433.

For the purpose of this project, Enhanced Efficiency Fertilizers (EEFs) include controlled-release mineral fertilizers and slow-release fertilizers such as biosolids, animal manures, compost, and wood ash.

1. What percent of your clients produce some hay?
    a. <25%
    b. 25 – 50%
    c. 50 – 75%
    d. >75%

2. What forms of nitrogen fertilizers do you currently offer

    urea,

    ammonium nitrate,

    ammonium sulfate

3. Do you offer controlled-release fertilizers? If so what kinds?

4. Do you offer Class AA biosolids?

5. Are you interested in supplying any fertilizer alternatives (biosolids, compost, wood ash, others)? If so, which ones?

6. In your opinion, what percent of hay producers:

- Under-fertilize hayfields (<25%) (25-50%) (50 – 75%) (>75%)
- Over-fertilize hayfields (<10%) (<25%) (25-50%) (50 – 75%), (>75%)

7. In your opinion, what percentage of your hay producers routinely (every 3 years or more) soil test? (<25%), (25-50%) (50 – 75%) (>75%)

8. In your opinion, do the majority of your hay producers apply fertilizers according to:

    a. Soil report and consultation with your company or other service?

    b. Soil report and UF IFAS recommendations?

    c. Their own experience?

9. What can IFAS research and extension do to better support you and your hay producers?

Thank you for your time.

Appendix 2

Hay Producer Survey Script

Hi,

I am Jennifer Bearden, UF IFAS Okaloosa County Extension agent. I am working on a master's degree through the UF IFAS Agroecology program. My final project is on Enhanced Efficiency Fertilizer Use in Florida Hayfields. I'm contacting hay producers to obtain information regarding fertilization practices in Florida hayfields. Participation in the study is completely voluntary. You can choose not to answer any question. You will not be identified in the project. Your response will be combined with responses from other participants across the state. The results of this study will be used to demonstrate how hay producers are currently fertilizing their hayfields. Results may be used to secure grant funds to further research hayfield fertilization. The survey should only take 10-15 minutes to complete. If you have any questions regarding this study, you can contact me at (850) 689-5850. Please direct any questions or concerns about the your rights as a participant to the IRB02 office, PO Box 112250, University of Florida, Gainesville, FL 32611-2250; ph (352) 392-0433.

For the purpose of this project, Enhanced Efficiency Fertilizers (EEFs) refer to controlled-release mineral fertilizers and slow-release fertilizers, such as biosolids, animal manures, compost, and wood ash.

1. What grass hay species do you grow?
2. What is your total acreage in hay production?
3. How much N-P-K do you apply with each hay cutting and on average, how many hay cuttings per year?

4. Do you feel that you are under-fertilizing, over-fertilizing or have it about right?
5. How often do you soil test for bermudagrass?
6. How often do you soil test and tissue test for bahiagrass?
7. Do you use EEFs (coated N or biosolids)? If so, which ones?
8. If not, what would motivate you to use EEFs?
9. What can IFAS research and extension do to better support you as a hay producer?

Thank you for your time!

Appendix 3

UF | IFAS Extension
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Forage Demo Garden
Variety Guide

BAHIAGRASS (*Paspalum notatum*)

UF-Riata – This cultivar was selected from Pensacola for its longer period of forage production extending the grazing period from early spring to late fall. UF-Riata was released in 2007 by the University of Florida.

Tifton-9 – This cultivar was also selected from Pensacola for greater seedling vigor and higher yields. It was released in the late 1980s by the Georgia Coastal Plain Experiment Station (Tifton Campus).

TifQuik – This cultivar is a recently released variant of Tifton-9. It has greater seedling vigor and quicker stand formation. It was also released by the Georgia Coastal Plain Experiment Station (Tifton Campus).

AU Sand Mountain – This cultivar was released by Auburn University. It was selected from Pensacola. It is more cold hardy than the other varieties of bahiagrass. In Northwest Florida, the yield is between Pensacola and Argentine.

Argentine – This cultivar was introduced from Argentina in 1944. It has a wider leaf blade than Pensacola. It is less cold tolerant. It produces slightly higher yields in late summer and early fall than Pensacola.

Pensacola – This cultivar also originated from Argentina. It was first identified in the 1938 by E.H. Finlayson, Extension Agent in Pensacola. He saw the potential for this grass as a pasture and land conservation grass. This cultivar is now the most common cultivar of bahiagrass grown in Florida. It is also the parent grass of our improved cultivars.

BERMUDAGRASS (*Cynodon dactylon*)

Tifton 85 – This cultivar is a hybrid between a bermudagrass (Tifton 68) and stargrass. It was released in 1993 by the Coastal Plain Experiment Station (Tifton Campus). It is a high yielding, more digestible bermudagrass than Coastal.

Russell – This cultivar was jointly released by Auburn University and Louisiana State University in 1994. It is more cold hardy than Coastal. It is high yielding but less digestible than Tifton 85. It holds up very well under grazing conditions.

Alicia – This cultivar was marketed by a Texas company. It has yields similar to Coastal but is less digestible and susceptible to leaf-spot.

Jiggs – This cultivar was released from a private company in Texas. It performs well in poorly drained soils but is less cold hardy than other cultivars.

Coastal – This cultivar was released in 1943 and was the first hybrid forage bermudagrass. It was bred on the Georgia Coastal Plain Experiment Station. It is the standard by which other bermudagrasses are measured.

PERENNIAL PEANUT

UF Peace – This is a new cultivar released recently from the University of Florida. This cultivar is comparable to Florigraze in yield.

UF Tito – This is another new cultivar recently released from the University of Florida. It also has comparable yield to Florigraze but is more competitive against bermudagrass weeds than UF Peace.

Arbrook – This cultivar has a more erect growth habit as compared to Florigraze.

Florigraze – This cultivar has a prostrate growth habit.

Ecoturf – This cultivar is primarily used in landscapes.

LIMPOGRASS (*Hemarthria altissima*)

KenHy – This cultivar is higher in digestibility, more persistent and higher yielding than Floralta. This new cultivar is a very recent release by the University of Florida and the Florida Foundation Seed Producers, Inc.

GibTuck – This cultivar is also more persistent and higher yielding than Floralta and is also a brand new release by the University of Florida and the Florida Foundation Seed Producers, Inc.

Floralta – This cultivar was released in 1984. It is more cold tolerant than Bigalta and more persistent under grazing conditions.

Bigalta – This cultivar was one of the original cultivars introduced in the 1970s and 80s. It is only recommended for mechanical defoliation and light grazing. It is less cold tolerant than Floralta.