Forage Systems for the Southeastern United States:

Crabgrass and Crabgrass-Lespedeza Mixtures

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By

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ABSTRACT

Crabgrass is a warm-season annual species that has the potential to provide high-quality summer forage for ruminants in the transition zone between subtropical and temperate regions of the United States. Growing annual lespedeza in association with crabgrass may be beneficial due to nitrogen transfer from the legume to the grass. The objectives of the research reported in this thesis were to (1) determine the effects of pH on establishment and growth of crabgrass; and (2) evaluate the effects of lespedeza seeding rate and N fertilization treatment on the yield, botanical composition, and nutritive value of crabgrass-lespedeza mixtures. A greenhouse study was conducted using three soil pH levels of 4.8, 5.5, and 6.3. Crabgrass germination and root and shoot yields were not affected by soil pH values. A field study was conducted to evaluate the influence of six lespedeza seeding rates (0-28 kg ha^{-1}) and two N fertilization treatments (140 kg total N ha^{-1} or zero N) on crabgrass-annual lespedeza mixtures. In most cases, increasing lespedeza seeding rate increased lespedeza in the sward. However, lespedeza rate had limited effect on yield and nutritive value of the mixture. Nitrogen fertilization increased crabgrass in the sward and total yield by as much as 46%. Responses of nutritive value parameters to N fertilization were variable and appeared linked to weather factors. *In vitro* true digestibilities ranged from 750 to 875 g kg^{-1}, and were largely unaffected by N fertilization and seeding rate The results of these studies indicate that

crabgrass could provide moderate amounts of highly digestible forage while growing on acidic soils commonly found in the southeastern United States. Annual lespedeza may be grown in association with crabgrass, but limited improvement in yield and nutritive value were found for this practice.

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For the one person in my life

who knows the drill

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INTRODUCTION

The transition zone for forage production lies between the temperate and subtropical regions of the U.S., and includes Arkansas, Kentucky, Missouri, North Carolina, South Carolina, Tennessee; northern portions of Mississippi, Alabama, and Georgia; and southern portions of Illinois, Indiana, Ohio, West Virginia, and Virginia (Burns and Bagley, 1996). Tall fescue is the primary forage base for more than 9 million brood cows in this region (NASS, 2005). Growth of cool-season grasses in the transition zone is restricted during the summer months by high temperature and intermittent summer rainfall. Including a warm-season species in forage systems can provide a more uniform distribution of forage during the grazing season (Burns and Bagley, 1996; Burns et al., 2004).

Soils in the transition zone tend to be acidic in nature (Ball et al., 2002; Burns et al., 2004). Over half of the soils tested in a survey of hay and pasture fields in ten southern states had a pH value below 6.0 (Ball et al., 2002). In the same survey, 46% of soils tested had low levels of P, and 33% had low levels of K; but, only 66 and 28% of hay and pasture fields, respectively, received fertilizer on a yearly basis. In general, warm-season grasses are tolerant of soil acidity, making them well-suited to forage systems in this region (Robinson et al., 1993).

Use of warm-season grasses which can be managed to reseed themselves can be advantageous to forage producers. Burns et al. (2004) reported that pastures in the Southeast USA generally include a majority (> 60%) of species such as crabgrass (*Digitaria* species) and foxtails (*Setaria* species) in the summer months. Managing volunteer stands of summer annual grasses could provide high quality forage during the summer months (Teutsch et al., 2005a).

Many producers in the Southeast cannot justify the cost of lime and fertilizer applications on rented land with short-term leases. Use of a species adapted to lower fertility situations that may exist could improve productivity in these fields. Nitrogen fertilization is essential to the optimal production of most warm-season grasses, including crabgrass (Fribourg, 1974, Teutsch et al., 2005b). One possibility to reduce N fertilizer inputs is to use a grass-legume mixture that contains at least 25% legume (George et al., 2000; Rohweder et al., 1977).

Warm-season legumes should be used with warm-season grasses because of close similarities in adaptation, seasonal distribution, and time of maturity (George et al., 2000). Annual lespedeza (*Kummerowia stipulacea* and *Kummerowia striata*) may be particularly useful when grown in mixture with warm-season grasses in the Southeast because it is very well-adapted to the region, easily established, tolerant of acidic and low fertility soils, and can be managed to volunteer through reseeding (Ball et al., 2002; Brink and Fairbrother, 1988; McGraw and Hoveland, 1995). Use of warm-season species such as crabgrass and annual lespedeza in mixture could provide high quality forage throughout the summer months in the transition zone.

CHAPTER 1: REVIEW OF LITERATURE

Crabgrass (*Digitaria* species, L.) and annual lespedeza (*Kummerowia stipulacea* and *Kummerowia striata*, L.) are warm-season forages that are productive in the transition zone (Ball et al., 2002). These two species may be well-adapted for use in mixture to increase yield, nutritive value, and forage quality of pastures in the southeastern United States (Brink and Fairbrother, 1988; Lomas et al., 2003; McGraw and Hoveland, 1995; Posler et al., 1993). The objective of the following sections is to summarize relevant past work on crabgrass, annual lespedeza, and the use of grass-legume mixtures.

CRABGRASS

Crabgrass (*Digitaria* species, L.) is a C_4 annual grass that is adapted to temperate and tropical regions (Mitich, 2005; Uva et al., 1997). The species possesses a prolific growth habit which makes it highly invasive in crops and turf (Piper, 1916; Uva et al., 1997). Its possible use as a forage has often been overlooked due to the common perception of the grass as a weed (Peters and Dunn, 1971). However, its commonplace occurrence as a species of opportunity in pastures throughout the South combined with its high forage quality give it the potential to be utilized in year-round grazing systems to fill in the summer slump in forage production of cool-season species in the transition zone (Ball et al., 2002; Burns et al., 2004; Dalrymple, 1976; Moser et al., 2004; Redfearn and Nelson, 2003; Sistani et al., 2003; Teutsch et al., 2005b). Crabgrass can also be used in systems for disposal of livestock waste where its ability to use large amounts of nutrients from the soil has made it useful in management of effluents

(Dalrymple, 1994a). In conservation sites and areas that are at high risk of erosion, it can provide adequate and rapid cover (Dalrymple, 2002).

Origin and History

Crabgrass is believed to have originated in southern Africa (Ball et al., 2002). Many *Digitaria* seeds have high nutritional values and the grains were grown for food for centuries (Mitich, 2005). The grass was used as forage in Europe before settlers from central Europe inadvertently brought it to the United States in hay. In 1849, the United States Patent Office [predecessor to the United States Department of Agriculture (USDA)] put forth crabgrass as a forage species (Dalrymple, 1994a; Larson, 2001; Mitich, 2005), and Hitchcock (1935) reported that *Digitaria* species could be successfully utilized as forage.

‘Red River’ Crabgrass

‘Red River’ crabgrass [*Digitaria ciliaris* (Retz.) Koel] was introduced as a forage cultivar in 1988, and is the only available improved variety of crabgrass (Alderson and Sharp, 1995; Dalrymple, 2001; Teutsch, 2002). ‘Red River’ crabgrass grows in a semi-prostrate to upright manner, is stoloniferous, and self-pollinated (Alderson and Sharp, 1995; Dalrymple, 2001). The variety stays green and lush for the full season when managed correctly, and is largely unbothered by pests or diseases (Dalrymple, 1994d). The cultivar can produce up to 11000 kg DM ha^{-1} when conditions are optimal (Dalrymple, 2001; Teutsch, 2002). ‘Red River’ generates adequate seed for propagation of the cultivar at yields of approximately 100 kg ha^{-1} or higher, and its seeds cycle through dormancy rapidly (Dalrymple, 1994d; Dalrymple, 2001).

Seed Dormancy and Germination

Crabgrass begins to germinate within a few weeks following frosts (when soil temperatures begin to be consistently at or above 16°C), and will germinate throughout the late spring and summer (Dalrymple, 1975a). Some germination from seeds present in the soil will generally occur following each rain when soil temperature remains above 16°C, or until stands fill in (Anonymous, 2002; Teutsch, 2002). Peters and Dunn (1971) reported that crabgrass seed has primary dormancy which prevents germination until certain environmental conditions are present that initiate a response in the seed that “breaks” dormancy. Crabgrass germination has been increased as much as 40% by allowing the seed to age at least from the time of harvest in the fall until the following spring (Anonymous, 2002). It has also been reported that aging crabgrass seed for two years before planting aids percentage and uniformity of germination (Dalrymple, 1998).

Germination of crabgrass is influenced by soil water potential (due to its influence on availability of soil water), temperature, and their interaction. Data have indicated that crabgrass will emerge at soil water potentials between -30 and -100 kPa with little difference in emergence rate when temperatures ranged between 15 and 25°C, and higher emergence rates at higher water potentials when temperatures were above 25°C (King and Oliver, 1994). Temperatures near 25°C led to higher overall emergence regardless of soil water potential (King and Oliver, 1994).

Morphology

Crabgrass seedlings grow in an upright manner with linear leaves that are generally 10 times as long as they are wide (Uva et al., 1997). Both seedlings and mature plants often have rough hairs on the sheath and leaf (Peters and Dunn, 1971). Crabgrass plants have no auricle, but do have a membranous ligule that has a serrated appearance. Leaves on mature plants may grow to lengths of 20 cm and widths of 14 mm. Crabgrass stems may grow to lengths of 1 m. Mature plants often demonstrate a prostrate growth habit. The mature crabgrass plant has a fibrous root system. In some cases, coronal roots may be present along stems that have rooted at the node (Peters and Dunn, 1971; Uva et al., 1997).

With optimum temperatures and adequate moisture and nutrients, crabgrass plants often produce many leaves (Dalrymple, 1975a). Uva et al. (1997) reported that, in late summer, mature crabgrass leaves often have a purplish coloration. This coloration seems to be natural in mature crabgrass plants and is generally not an indication of disease or nutrient deficiency.

Crabgrass plants begin tillering after production of 4-5 leaves (Buchholtz, 1954; Hitchcock, 1935). One plant can produce as many as 700 tillers (Mitich, 2005). Crabgrass plants will often produce tillers until they have filled in the space between each other at which point tillering is greatly reduced (Peters and Dunn, 1971).

The inflorescence of the crabgrass plant consists of 2-5 branches with 2 rows of spikelets on each branch and 1 seed in each spikelet (Hitchcock, 1914; Uva et al., 1997). The branches of the panicle occur from a whorl at the top of the stem leading to a finger-like arrangement. Seeds are approximately 2.4 mm in length (Buchholtz, 1954).

Diseases and Pests

Crabgrass is subject to some fungal spotting on leaves and stems (Dalrymple, 1994d). The armyworm is the most realized pest of crabgrass, and grasshoppers and some other insects also bother it occasionally (Ball et al., 2002; Pitman et al., 2004).

Growth Requirements and Adaptation

Photoperiod

Peters and Dunn (1971) found that crabgrass plants which germinated in May produced more tillers than those which germinated in June, and plants germinated in the spring produced many more tillers than plants which germinated later in the summer, leading to the conclusion that photoperiod is one factor that has a direct influence on the number of tillers produced by a crabgrass plant. Photoperiod also initiates the curbing of vegetative growth in crabgrass plants in the autumn months (Peters and Dunn, 1971). Peters and Dunn (1971) showed that crabgrass plants grown at the same temperatures developed vegetatively when allowed 18 hours of light, but stopped vegetative growth when only given 10 hour light periods. Dalrymple (1994a) reported that 12 hours or more of light per day were optimal for crabgrass production.

Temperature

Optimum temperatures for crabgrass growth lie in the range between 27-38°C (Dalrymple, 1994b). Soil temperatures should be above 20°C at depths of 5-10 cm for optimum crabgrass growth (Dalrymple, 1994a; Peters and Dunn, 1971). Temperature has a profound effect on emergence of crabgrass. King and Oliver (1994) reported that crabgrass will not emerge at 10°C. Crabgrass emerged at faster rates at the higher temperature of 30°C, but total numbers of plants emerged were lower than at 25°C. Crabgrass has no winter survival and is usually killed by the first hard frost (-2.2-0°C) (Dalrymple, 1975a; Piper, 1916).

Water

Dalrymple et al. (1994) reported that crabgrass produced 67 kg DM cm^{-1} water between April and October in Arkansas. In Oklahoma, the grass produced 50 kg DM cm^{-1} water between April and September (Dalrymple et al., 1994). Crabgrass has shown good tolerance to drought

(Ball et al., 2002). Although yields are limited during periods of moisture stress, the grass generally survives and will rapidly resume growth when adequate moisture becomes available or if irrigation is used (Bates, 1978; Dalrymple, 1976). Rainfall levels between 610 and 1500 mm are optimal for crabgrass growth and production (Dalrymple, 1994a). However, low soil moisture can slow crabgrass growth resulting in a higher leaf to stem ratio and increased forage quality (Coleman et al., 2004; Teutsch et al., 2005a). Crabgrass yields increase with moisture levels that are consistently adequate, and humid conditions are favorable for the species; but it will not grow well and may not survive on soils with excessive moisture for extended periods of time (Piper, 1916; Pitman et al., 2004).

Soils and Soil Fertility

Crabgrass prefers well-drained soils that do not crust, and the species does not perform well on soils with high clay and/or silt contents (Dalrymple, 1975a; Dalrymple, 1994c). Like many warm-season grasses, crabgrass responds well to nitrogen fertilization, especially if moisture conditions are favorable (Dalrymple, 1976; Jung et al., 1990; Teutsch et al., 2005b). Dalrymple (1975b) found yields of 2700, 3100, 4870, 6840, and 7910 kg DM ha^{-1} for N rates of 0, 34, 68, 134, and 268 kg ha^{-1}, respectively (applied in late May). Teutsch et al. (2005b) also found that increasing rates of nitrogen application increased DM yields of crabgrass up to 342 kg N applied ha^{-1}. However, when maximum yields were achieved, there was potential for dangerous levels of nitrate to accumulate in the crabgrass (Teutsch and Tilson, 2004; Teutsch et al., 2005b). Recommended rates between 110 and 250 kg N ha^{-1} applied as 65-90 kg N ha^{-1} at seeding and 45-65 kg N ha^{-1} following each subsequent harvest significantly reduce risks of nitrates accumulating to toxic levels, increase potential for nitrogen to be applied when moisture is available, and generally maximize economic potential (Teutsch and Tilson, 2004; Teutsch et al., 2005b).

General recommendations are to apply phosphorus and potassium fertilizers to crabgrass at rates suggested for other summer annual grasses after taking soil tests to determine needs (Dalrymple, 1994a; Teutsch, 2002). Sistani et al. (2003) found that crabgrass removed phosphorus from a highly phosphorus-enriched soil more effectively than five ryegrass cultivars tested. However, there is a lack of research data available on the response of crabgrass to phosphorus and potassium.

Limited research and anecdotal reports indicate that crabgrass will grow over a wide range of soil pH values, but no research data is available evaluating the pH requirement of crabgrass grown as a forage (Buchanan et al., 1975; Dalrymple, 1994a). Dalrymple (1994a) stated a soil pH range from 6.0 to 7.2 should be targeted, while Teutsch (2002) reported a narrower span of 6.0 to 6.5 is optimum. In a study attempting to find ways to decrease the competitiveness of crabgrass as a weed, Buchanan and coworkers (1975) reported that crabgrass was tolerant of low soil pH, and maximum shoot growth occurred between soil pH of 5.2 and 5.6; but the authors offered very little numerical data to support their conclusions.

In another study of crabgrass as a weed, Pierce et al. (1999) used either $CaCO_3$ or $MgCO_3$ to adjust soil to pH levels ranging from 4.8 to 7.8 and recorded the effect of these treatments on germination and root and shoot dry weights. The researchers reported that there were no significant differences in germination over the soil pH range of 4.8 to 7.8 when $CaCO_3$ was used as the soil amendment, but there was a significant decrease in crabgrass germination at soil pH levels above 6.8 when $MgCO_3$ was the liming material used. Pierce and coauthors (1999) suggested this effect may have been caused by a low Ca:Mg ratio. Shoot dry matter of crabgrass decreased as soil pH increased from 4.8 to 7.8 (Pierce et al., 1999). However, the rate of yield decrease was greatest at pH levels from 6.0 to 7.8. These researchers also found that root dry weight increased with increasing soil pH levels in the range from 4.8 to 5.3. Largest root dry weights were measured when soil pH levels were between 5.3 and 5.8 and 5.8 and 6.3 for soils amended with $MgCO_3$ and $CaCO_3$, respectively (Pierce et al., 1999). In the ranges of 5.8 to 7.8 for soils limed with $MgCO_3$ and 6.3 to 7.8 for soils limed with $CaCO_3$, crabgrass root dry weights declined as pH increased (Pierce et al., 1999).

Management

Broadcast planting of crabgrass is appropriate from mid-winter to early spring, but there is some indication that it is best to wait as late as possible (Dalrymple and Flatt, 1994a). Crabgrass may be overseeded into winter crops and then incorporated with some form of soil disturbance. It is recommended that crabgrass be seeded in late spring after soil temperatures have reached at least 16°C (Teutsch, 2002). Although crabgrass has been shown to emerge from soil depths of 0 to 5 cm (Dalrymple and Flatt, 1996; Peters and Dunn, 1971), the recommended planting depth is between 0.6 and 1.3 cm (Teutsch, 2002). It is best to seed crabgrass into a well-prepared seedbed (Teutsch, 2002). Recommended seeding rates for crabgrass range from 2-7 kg of live seed ha^{-1} for both broadcast and row-planted stands (Dalrymple, 1998; Teutsch, 2002). Crabgrass must generally be mixed with some larger substance such as sand, fertilizer, sawdust, or granulated lime for seeding with conventional drills due to the extremely small and light nature of the crabgrass seed (Dalrymple, 1994a).

The prolific seeding capability of crabgrass allows it to be managed as a reseeding annual (Redfearn and Nelson, 2003). In 1996, Dalrymple and Flatt reported a stand that had been in production for over 24 years without any replanting. Allowing a crabgrass stand to go to seed at least once during the growing season will generally produce enough of a seed bank in the soil for the stand to voluntarily re-establish itself the next growing season (Teutsch, 2002). Light soil disturbance (such as dragging, allowing cattle onto the pasture, or shallow disking) should be used in late winter or early spring (before optimum germination time) to improve seed contact with the soil which will consequently improve germination rate and uniformity. Reports indicate that crabgrass production following tillage can be increased as much as from 600% compared with production following no tillage (Dalrymple, 2003). Tillage should be not be deeper than 8-10 cm in depth (Voigt and Sharp, 1995). It has been shown that deeper tillage may result in decreased stands or stands that are slower to establish (Dalrymple and Flatt, 1996). With proper management each year, crabgrass seed banks can develop in the soil to a point where there is almost always enough germinable seed to produce an adequate stand each growing season with minimal tillage management.

Crabgrass is generally cut for hay at late boot to early head stage, or at a height of 46-61 cm. (Piper, 1916; Teutsch, 2002). It should be grazed when it has reached 15-20 cm, to a residual height of 8-10 cm. The grass will usually reach grazable height within 35-60 days following germination (Teutsch, 2002). Rotational stocking should be used for best results (Dalrymple, 2003).

Production Characteristics

Dalrymple (1975c) reported that crabgrass seed has a weight of 0.0003 kg $(cm^3)^{-1}$ and there are approximately 2,092,545 seeds kg^{-1}. Each crabgrass plant produces approximately

150,000 seeds, and yields are generally around 56 kg seed ha^{-1} (Dalrymple, 1976; Mitich, 2005). Crabgrass seeds have an average crude protein content of 12% (Dalrymple and Flatt, 1992).

Crabgrass seasonal DM yields ranging from 3300 to 12320 kg ha^{-1} have been measured (Dalrymple et al., 1994; Teutsch et al., 2005b). Crabgrass yield increases with stage of maturity, although nutritive value and forage quality may show concurrent decreases (Ball et al., 2002; Bosworth et al., 1980; Coleman et al., 2003; Dalrymple and Mitchell, 1991). Residual height left following grazing or harvest for hay also has effect on yield of subsequent cuttings or grazings (Dalrymple and Mitchell, 1991). Crabgrass that is growing in a mixed stand with other grasses has been shown to increase in percentage in the stand when the mixture is cut frequently and residual height is kept at 10 cm or above (Aiken et al., 1995; Dalrymple, 2002).

Crabgrass has been shown to have forage quality equal to or higher than many warm-season grasses such as pearl millet or bermudagrass (Ball et al., 2002; Bosworth et al., 1980; Dalrymple and Flatt, 1994b; Pitman et al., 2004). Bosworth et al. (1980) found *in vitro* dry matter digestibility (IVDMD) of crabgrass at boot stage to be 72% as compared to 60% for pearl millet. Dalrymple (1994d) reported that the forage cultivar ‘Red River’ crabgrass had a crude protein (CP) concentration of 15% and IVDMD of 73% compared with 15 and 64% for ‘Midland’ bermudagrass grown under the same conditions. Dalrymple (1976) has also reported that crabgrass is more palatable than many other warm-season grasses (Johnsongrass, indiangrass, ‘Ermelo’ weeping lovegrass, ‘Midland’ bermudagrass, and several bluestems).

Coleman et al. (2003) reported neutral detergent fiber (NDF) values of 628, 645, and 672 g kg^{-1} for crabgrass hay harvested at vegetative, boot, and mature stages, respectively. These authors also reported acid detergent fiber (ADF) figures for crabgrass hay harvested at the three stages of 374, 380, and 401 g kg^{-1} DM, respectively. The ADF numbers of immature crabgrass were comparable to those found in mature alfalfa (Ball et al., 2002; Coleman et al., 2003). Neutral detergent fiber and ADF digestibilities were 573, 587, and 582, and 562, 589, and 583 g kg^{-1} for crabgrass hay harvested when vegetative, at early boot, and mature, respectively (Coleman et al., 2003). These numbers show that stage of maturity had limited effect on the nutritive value of the crabgrass in this study.

Stage of maturity at harvest of crabgrass hay also had limited effect on intake, passage rate, and retention and rumination times (Coleman et al., 2003). Digestible organic matter intake of goats eating crabgrass hay harvested at boot stage was 12.3 g kg^{-1} body weight (BW) compared with 13.2 g kg^{-1} BW eaten of crabgrass hay harvested at maturity (Coleman et al., 2003). Total mean retention times were 55.8 hrs for the hay harvested at boot stage and 49.5 hrs for the mature hay, while total rumination times were 406 and 390 min, respectively (Coleman et al., 2003).

Stage of harvest has significant effect on nutritive value and forage quality parameters of crabgrass (Ball et al., 2002; Bosworth et al., 1980). *In vitro* dry matter digestibility percentages reported by Bosworth et al. (1980) were 79, 72, and 63 for crabgrass cut at vegetative, boot, and head stages, respectively. The same study found that crabgrass had crude protein (CP) percentages of 14, 8, and 6 when harvested while still vegetative, when booting, or when heading, respectively. Percentage of phosphorus in crabgrass decreased from 0.43 to 0.17 as the plant matured from vegetative to heading stage, and this caused it to fall short, at advanced maturity, of fulfilling the requirements of a high-demand ruminant of approximately 0.3% P (the study was fertilized with 19 kg P ha^{-1}) (Bosworth et al., 1980). Percentages of Ca and Mg present in crabgrass were not affected by stage of maturity, but K significantly decreased as crabgrass aged. However, crabgrass was consistently able to meet the requirements of ruminants for Ca, Mg, and K (Bosworth et al., 1980). Bosworth et al. (1980) found that the K/(Ca + Mg) ratio of crabgrass declined with increasing maturity of the species and was maintained below levels associated with danger of grass tetany at all stages of crabgrass growth.

ANNUAL LESPEDEZA

Korean and striate lespedezas (*Kummerowia stipulacea* and *Kummerowia striata*, L.) are summer-annual legumes commonly known as annual lespedeza. In the transition zone of the United States, these species produce most of their growth during mid-summer (July and August) (Cassida, 1999). The species are particularly useful for producing quality forage in low-input systems (Sollenberger and Collins, 2003).

Origin and History

Both types of annual lespedeza originated in eastern Asia and are well-adapted to the southeastern part of the United States (Clewell, 1966). Thomas C. Porter first discovered striate lespedeza in the United States in Georgia in 1846. The species is believed to have been brought to America from China in shipments of tea (Henson, 1957). Reports show that the plant was commonly found by the mid to late nineteenth century, with some indication that it may have been spread heavily during the Civil War by military movements (Lamont, 1994). The earliest records of its being promoted as a hay crop come from 1880 (Piper, 1916).

Korean lespedeza was first brought to North America in 1919 where it was grown at a USDA experimental farm in Virginia (McGraw and Hoveland, 1995). Clewell (1966) reported that both *Kummerowia striata* and *Kummerowia stipulacea* have been commonly planted since

1925, and both are important and widely adapted forage crops in the southeastern United States (Brink and Fairbrother, 1988; Clewell, 1966).

The annual lespedezas were widely used in the United States in the early-mid 1900s with peak production being in the late 1940s (Cassida, 1999; McGraw and Hoveland, 1995; Roberts, 1999). Following World War II, production of annual lespedeza declined due to increased availability of soil amendments needed to grow higher-producing legumes, such as alfalfa and the clovers, and a rise in the lespedezas' susceptibility to bacterial wilt and other diseases (Davis et al., 1994; McGraw and Hoveland, 1995; Roberts, 1999). Annual lespedeza has high potential for continued future use by managers who wish to diminish costs and/or inputs by using the species to lessen the need for fertilizers and lime, to help prevent erosion, and to provide quality forage (Sollenberger and Collins, 2003; Zachariassen and Power, 1991).

Distinguishing Characteristics

Korean and striate lespedezas' primary differences are in growth habit, leaf shape, age to maturity, and placement of seeds on plants (Henning et al., 1997). Striate lespedeza has a more prostrate growth pattern than Korean, and the leaves of striate are narrower. Striate lespedeza carries its seeds at the joint of leaf to stem, while Korean lespedeza's seeds are carried at the end of the branches where the leaves turn forward following anthesis, reducing seed shatter (Henning et al., 1997; Roberts, 1999). Korean lespedeza often flowers up to three weeks earlier than striate, and is better suited to the more northern regions of the annual lespedezas' zone of adaptation due to its ability to produce seed before frost which will be available for voluntary seeding the following spring (Cassida, 1999).

Morphology

Annual lespedeza plants are generally 10 to 15.5 cm in height with leafy trifoliates and fine stems (Ball et al., 2002; Radford et al., 1968). Stands may be spreading or erect, depending on density (Piper, 1916). Annual lespedezas have short taproots and pink or purple flowers which appear from late summer to early fall (McGraw and Hoveland, 1995).

Germination and Early Establishment

The seed of annual lespedeza does not germinate well immediately after its production. Middleton (1933) reported that large seed (seed which would not pass through mesh with 1.4 mm holes) had less hard seed and higher rates of germination. Emergence of annual lespedeza is slow, but establishment is often easier than for many other small-seeded legumes (Beuselinck and McGraw, 1994; Cassida, 1999; McGraw and Hoveland, 1995; Roberts, 1999). Successful seedling growth is aided by suppressing competition from grasses and other dominant species (McGraw and Hoveland, 1995; Piper, 1916).

Diseases and Pests

Bacterial wilt (*Xanthomonas campestris* pv. Lespedezae [Ayers et al.] Dye), and tar spot are the primary diseases that affect annual lespedezas, particularly in the northern regions of the species' adaptation (Ball et al., 2002; Jost, 1998; Sollenberger and Collins, 2003). Powdery mildew (*Microsphaera diffusa* C. & P.) and southern blight (*Sclerotium rolfsii* Sacc.) have a lesser impact, and are generally more troublesome to annual lespedeza grown in the South (Ball et al., 2002; Jost, 1998; Sollenberger and Collins, 2003). Annual lespedezas are known hosts for root-knot, sting, soybean cyst, and tobacco stunt nematodes (McGraw and Hoveland, 1995;

Sollenberger and Collins, 2003). Striate lespedeza is more resistant than Korean to disease (Ball et al., 2002; Cassida, 1999; Roberts, 1999). Insect damage is generally minimal in annual lespedeza (Ball et al., 2002; Cassida, 1999; McGraw and Hoveland, 1995; Sollenberger and Collins, 2003).

Growth Requirements and Adaptation

Photoperiod

Both annual species require daylengths of at least 13-14 hours to grow and are short-day flowering (Beuselinck and McGraw, 1994; Nakata, 1952; Smith, 1941). If annual lespedezas are attempted to be grown under the colder climates of northern latitudes, they generally exhibit reproductive setback due to delayed onset of shorter days, and frost may annihilate the plants prior to seed maturity (Davis et al., 1994; McGraw and Hoveland, 1995; Nakata, 1952; Piper, 1916). In Alabama, Duggar (1935) found that lespedezas required between 103 and 109 days to begin blooming, while in a greenhouse study Zachariassen and Power (1991) reported that modern lespedeza cultivars needed 105 days to reach full maturity.

Temperature

Optimal temperature for annual lespedeza growth has been shown to be near 30-32°C (Masiunas and Carpenter, 1984; Zachariassen and Power, 1991). In a greenhouse study, shoot dry weights of lespedeza grown for 105 days were 2.10, 7.84, and 10.10 g pot^{-1} for soil temperatures of 10, 20, and 30°C, respectively (Zachariassen and Power, 1991). Zachariassen and Power (1991) also found that annual lespedeza requires a growth period of more than 100 days in combination with higher temperatures to achieve maximum growth. At 84 days after planting, the lespedeza shoot dry weight at the 30°C soil temperature treatment was only 49% of the growth achieved at 105 days after planting, indicating that 51% of lespedeza's growth at 30°C occurred in the last 20% of the growing period (Zachariassen and Power, 1991).

Annual lespedeza seedlings exhibit the most cold hardiness of the various stages of annual lespedeza growth, helping ensure the crop's survival if emerging plants are caught in a late-spring frost. Susceptibility to chilling and/or freezing injury increases in lespedeza with increasing age (Tysdal and Pieters, 1934). Annual lespedeza has no winter survival and limited cold tolerance once mature (McGraw and Nelson, 2003). Tysdal and Pieters (1934) found that a period of 16 hours or longer of temperatures averaging near -4°C would kill lespedeza.

Water

At soil temperatures of 30°C, Zachariassen and Power (1991) reported that annual lespedeza had an average daily water use rate of 41.7 ml pot^{-1} day^{-1} (initial soil mass was 1.1 kg pot^{-1}). These authors also reported high water-use efficiencies of 2.5, 2.3, and 2.3 g DM produced L^{-1} H_2O for annual lespedeza grown at soil temperatures of 10°C, 20°C, and 30°C, respectively, when the plant was allowed to use the full growing season (approximately 105 days).

Soil Fertility

The optimal pH range for lespedeza is between 5.5 and 6.0, and pH levels below 5.0 are associated with less than optimal stand establishment and decreased growth (Cassida, 1999; Roberts, 1999; Voigt and Mosjidis, 2002). Levels of soil pH above 7.2 are also considered deleterious (Sollenberger and Collins, 2003). Striate lespedeza has been reported to be more tolerant of acid soil and less tolerant of alkaline soil than Korean lespedeza, but both are tolerant of moderately acid soils (McGraw and Hoveland, 1995; Voigt and Mosjidis, 2002). Researchers in Japan reported a relative total yield of annual lespedeza grown on soil with a pH level of 5.0

that was 124% of the yield of lespedeza grown on soil with a pH level of 7.0, (Jo et al., 1980). In the same study, annual lespedeza plant nitrogen concentration did not differ between plants grown at the two different soil pH levels.

In contrast to results of Jo et al. (1980), Vanderford (1940) found an increase in yield of annual lespedeza from 7.4 to 21.4 g pot^{-1} as soil pH level increased from 4.7 to 7.0. Vanderford (1940) suggested these increases in growth were caused by enhanced availability of soil nutrients to the plants as evidenced by increased removal of Ca, N, and P in plant materials. Calcium, N, and P removed by annual lespedeza increased by 0.024, 0.340, and 0.041 g pot^{-1}, respectively, as pH increased from 4.7 to 7.0 (Vanderford, 1940). In management guides, others indicate that liming will increase the growth of annual lespedeza but offer no data to support these statements (Cassida, 1999; Henning et al., 1997; McGraw and Hoveland, 1995; Roberts, 1999).

Annual lespedeza requires no nitrogen fertilization due to its symbiotic relationship with *Rhizobium* bacteria (Wei et al., 2002). Lespedeza's fixation has been reported to range from 56 to 168 kg N ha^{-1} year^{-1} (Ball et al., 2002).

Nitrogen fertilizer may be applied to grasses grown in mixture with annual lespedeza. It is recommended that rates not exceed 34 kg ha^{-1} in order to insure that the grass does not out-compete the legume, but if grazing pressure is heavy, 35-100 kg N ha^{-1} may be tolerated (Cassida, 1999; Henning et al., 1997; Jost, 1998; Roberts, 1999). Nitrogen generally does not need to be applied to grass-legume mixtures where the legume is 25% or more of the stand (Donohue and Heckendorn, 1994). Nitrogen should not be applied to annual lespedeza and cool-season grass mixtures in early spring in order to avoid intense competition from the grass (Roberts, 1999). Roberts (1999) reported that applying 67 or 135 kg N ha^{-1} to annual lespedeza-tall fescue stands decreased the percentage of legume in the stand from 71% when no N was applied to 43% for the 67 kg N ha^{-1} treatment and 34% for the 135 kg N ha^{-1} treatment (mid-August harvest).

Annual lespedeza reportedly tolerates low fertility soils, including those low in phosphorus, due to its pronounced capability to extract phosphorus from the soil (Ball et al., 2002; McGraw and Hoveland, 1995). However, both striate and Korean types respond well to appropriate levels of fertilizer, especially phosphorus (Henning et al., 1997). Offutt et al. (1966) found that using phosphorus and potassium fertilizers together significantly increased seed and hay yields of annual lespedeza. Hay yields increased from 3315 kg ha^{-1} when no phosphorus or potassium was applied to 4077 kg ha^{-1} when 40 kg ha^{-1} each of P_2O_5 and K_2O were added. Hay yields increased even further to 4838 kg ha^{-1} when 80 kg ha^{-1} each of P_2O_5 and K_2O were applied (Offutt et al., 1966). Seed yield increased from 479 kg ha^{-1} when no P_2O_5 and K_2O were added to 664 kg ha^{-1} and 786 kg ha^{-1} for P_2O_5 and K_2O treatments of 40 kg ha^{-1} each or 80 kg ha^{-1} each, respectively (Offutt et al., 1966).

Use of recommended rates of fertilization for cool-season grass pastures (i.e. 67-112 kg N ha^{-1}, 45-134 kg P_2O_5 ha^{-1}, and 45-269 kg K_2O ha^{-1}) on forage mixtures containing annual lespedezas may cause competing species to overtake lespedeza growth under moisture and temperature conditions that are not stressful to the competing species (Donohue and Heckendorn, 1994). Increases in the stem/leaf ratio, which correspond with decreases in forage quality, may come as a result of fertilization with recommended or higher levels of P_2O_5 and K_2O (Ball et al., 2002; McGraw and Hoveland, 1995). Offutt and coworkers (1966) found this to be true. Although they found hay yields to be increased by 1523 kg ha^{-1} when 80 kg ha^{-1} each of P_2O_5 and K_2O were applied compared to none applied, there was a concurrent reduction in leafiness in the hay of 3.3% (Offutt et al., 1966).

Management

Recommended seeding rates for annual lespedeza range from 16 to 40 kg ha^{-1}, with lower rates often used when drilling, and seeding into mixtures, or overseeding pastures in late winter (Cassida, 1999). Recommended seeding time is February-April throughout the zone of annual lespedeza's adaptation (or when daylengths have reached at least 13-14 hours) (Ball et al., 2002; McGraw and Hoveland, 1995; Piper, 1916). Lespedeza seed can be broadcast or drilled. If broadcast into established forages, good soil contact is needed; so spreading early in the year to allow freezing and thawing to incorporate the seed, or using grazing animals or light disking or dragging is suggested (Cassida, 1999; Jost, 1998; Sollenberger and Collins, 2003). Recommended drilling depth for lespedeza is 0.6-1.3 cm (Jost, 1998). Inoculation of lespedeza seed with the correct bacteria is strongly suggested to ensure that maximum nitrogen fixation occurs (Duggar, 1934; NifTAL and FAO, 1984).

Annual lespedeza can be used for grazing or hay production, and will not cause bloat due to presence of tannins which act as protein precipitants in the rumen (Ball et al., 2002). Stocker cattle have shown gains of 0.8 kg d^{-1} in late summer grazing annual lespedeza in Arkansas (stocking rate = 2.7-3.7 animal units ha^{-1}) (Cassida, 1999). Hay produced from annual lespedeza is reported to have quality only slightly less than alfalfa and of sufficient worth to support dairy heifers and calves during winter months (Roberts, 1999). Lespedeza cures quickly due to the low moisture content of its fine stems, but this also means extra care must be taken to prevent excessive loss of leaf material (Cassida, 1999; Stitt, 1934). Lespedezas can be harvested or grazed 1-3 times per growing season. Davis et al. (1994) found that annual lespedeza harvested one time in late August when plants had reached approximately 30% bloom produced 8015 kg

ha^{-1} as compared to a total season yield of 4075 kg ha^{-1} when the forage was harvested once in July and once in October. Cutting the lespedeza only once for herbage also produced the highest amounts of seed for harvest or re-establishment of the stand (Davis et al., 1994). Defoliation management of annual lespedeza requires that residual leaf area remain, because lespedeza maintains very limited root carbohydrate reserves for regrowth (Beuselinck and McGraw, 1994).

Annual lespedeza can easily be managed for reseeding. Allowing a lespedeza stand to grow to full maturity during the late summer or early fall months will generally produce enough seed to re-establish a stand the following spring (Beuselinck and McGraw, 1994). If it is more advantageous to obtain a final hay cutting or grazing than to allow a lespedeza stand to go to seed, overseeding may be used to ensure a good stand of annual lespedeza in the following year.

Annual lespedeza can be managed for a more prostrate growth habit by mowing just the tops of the plants early in the season (Henning et al., 1997; Jost, 1998). When lespedeza is cut for hay it often grows more upright than when it is harvested by grazing (Henning et al., 1997). The inherently more prostrate growth habit of striate lespedeza causes it to be more useful for pasture than Korean (Cassida, 1999).

Production Characteristics

McGraw and Hoveland (1995) reported that the annual lespedezas commonly produce 200-300 kg ha^{-1} of seed under typical conditions. There are approximately 519,200 seeds kg^{-1}, and 78% pure live seed (PLS) is required in certified annual lespedeza seed (Roberts, 1999). Korean lespedeza seed has a weight of 0.0006 kg $(cm^3)^{-1}$ while striate weighs 0.0004 kg $(cm^3)^{-1}$ (Roberts, 1999). Drought and disease will often decrease seed production dramatically. Planting annual lespedeza in rows has been reported to increase seed production and ease of seed harvest.

Stage of maturity at harvest of annual lespedeza affects yield. Yield increases with maturity of the stand. However, as annual lespedezas grow, they may be very leafy at the top and appear to have high yield when in actuality many leaves near the ground have senesced (Gray and Reynolds, 1970). Leafiness and yield have been shown to be negatively related in annual lespedeza, as increased yield generally comes as a result of increased stem mass (Gray and Reynolds, 1970). Lespedeza harvested at early bloom showed an increase in total yield of 1527 kg ha^{-1} over plants harvested while still at vegetative stage, but a decrease in leaf yield of 7% (Gray and Reynolds, 1970).

Crude protein concentration of lespedeza generally is within the range of 10-16%, while total digestible nutrients (TDN) usually fall within 58-62% (Ball et al., 2002; Cassida, 1999). Brink and Fairbrother (1988) reported CP concentrations as high as 18%. Stage of maturity at harvest or grazing has a profound effect on percentage of CP and TDN. The National Research Council (1984) reported TDN percentages of 59, 55, 50, 47 and CP percentages of 16.4, 15.5, 14.5, and 13.4 for lespedeza collected fresh at late vegetative stage, harvested for hay at early bloom stage, harvested for hay at mid-bloom stage, and harvested for hay at full bloom stage, respectively. Stems contain approximately half as much protein as leaves, and leafiness of lespedeza plants and crude protein concentration are positively correlated (Gray and Reynolds, 1970; Roberts, 1999).

Annual lespedeza generally has ADF, NDF, and relative feed value (RFV) concentrations of 35-40%, 45-55%, and 98-127%, respectively. These values are comparable to alfalfa at mid-bloom (Ball et al., 2002). *In vitro* digestible dry matter (IVDDM) concentrations between 50.0 and 68.5 % have been reported for annual lespedeza (Brink and Fairbrother, 1988).

GRASS-LEGUME MIXTURES

Using legumes in mixtures with grasses in pastures and hayfields has been shown to increase yields, nutritive value, and forage quality and decrease necessity for nitrogen fertilization (Albrecht and Hall, 1995; Ball et al., 2002; George et al., 1995; Posler et al., 1993). Benefits to animal performance with the addition of legumes have also been reported. These benefits have primarily been attributed to the generally superior nutritive value and forage quality of legumes (as compared with most grasses at similar stages of maturity) (Ball et al., 2002; Mitchell et al., 1986; Wagner, 1954). Selecting grasses and legumes that are well-adapted to the region and soil conditions where they will be grown, have a similar maturity, and have similar morphological characteristics is vital to the success of the mixture (Nelson and Moser, 1995; Posler et al., 1993; George et al., 2000).

Nitrogen Transfer

One of the primary benefits of growing legumes in mixture with grasses is the transfer of fixed N to the grass (George et al., 1995; Miller and Heichel, 1995). Legumes such as red clover and alfalfa can produce 85-225 and 165-280 kg N ha^{-1} yr^{-1}, respectively, of which an average of 31 and 26%, respectively, is transferred to a grass growing in mixture with the legume (Ball et al., 2002; Miller and Heichel, 1995). West and Abdullah (1987) reported that white clover and Korean lespedeza mixed with bermudagrass produced dry matter yields equivalent to those produced with 16 and 13 kg N fertilizer ha^{-1}, respectively, in a two year study conducted in Arkansas. In another study, dry matter yields were equivalent to those produced with 53 and 26 kg N fertilizer ha^{-1} when white clover and Korean lespedeza were grown in mixture with bermudagrass, respectively (West and Abdullah, 1987).

The quantity of N transferred from legumes to grasses grown in association with them is dependent upon inoculation practices and relative quantity of symbiotic bacteria, the strength of the legume stand, management of the mixture, and environmental stresses (Mathews et al., 2004). There is limited evidence of direct transfer of N from the roots of living legumes to the roots of grasses growing in mixture with them (Mathews et al., 2004; Miller and Heichel, 1995). However, transfer primarily occurs through the decomposition of dead plant parts (including nodules) of the legume, either independently of or associated with the death of the entire plant (Miller and Heichel, 1995; Vance et al., 1988; Whitehead, 2000). Indirect transfer may also occur in grazed mixtures through intake of legumes by livestock and ensuing deposition of N through excreta (Mathews et al., 2004; Whitehead, 2000). In mixtures with perennial legumes, it has been shown that very little N is transferred in the first six months to one year of the association due to time required for decay of legume plant parts and nodules (Mathews et al., 2004; Miller and Heichel, 1995). This highlights the potential need for N fertilization in annual grass-legume mixtures at rates recommended for the grass component.

Warm-Season Grass/Warm-Season Legume Mixtures

Cool-season legumes have often been mixed with warm-season grasses, and some of the expected benefits of legume-grass mixtures have been realized (Blanchet et al., 1995; Brink and Fairbrother, 1988; Gettle et al., 1996; Griffith, 1977; Mitchell et al., 1986; West and Abdullah, 1986). However, due to differences in timing of establishment, maturity, and harvest; and differences in adaptations to temperature, varying amounts of moisture, and other environmental conditions; cool-season legumes are often not well-suited to grow in mixture with warm-season grasses. Using a warm-season legume in mixture with a warm-season grass may show increased yield and quality in summer pastures and hayfields that lead to advancements in animal performance (Brink and Fairbrother, 1988; Posler et al., 1993). Brink and Fairbrother (1988) found that the warm-season legumes alyceclover (*Alysicarpus vaginalis*) and aeschynomene (*Aeschynomene amerciana*) had similar or higher yield, nutritive value, and forage quality as alfalfa (*Medicago sativa*) in the second harvest of the growing season; and phasey bean (*Macroptilium lathyroides*), while having a lower quality than alfalfa, had 3-4 times the yield of alfalfa in the second harvest. The authors concluded these warm-season legumes may be valuable grown in association with warm-season grasses. Other researchers reported that including the native warm-season prairie legumes purple prairieclover (*Dalea purpurea*), roundhead lespedeza (*Lespedeza capitata*), leadplant (*Amorpha canescens*), Illinois bundleflower (*Desmanthus illinoensis*), catclaw sensitive brier (*Schrankia nuttallii*), and cicer milkvetch (*Astragalus cicer*) in various mixtures with the native warm-season grasses switchgrass (*Panicum virgatum*), sideoats grama (*Bouteloua curtipendula*), and indiangrass (*Sorghastrum nutans*) increased yields and CP concentrations in all mixtures (except for switchgrass-leadplant in both years for yield and 1986 for CP, respectively) (Posler et al., 1993).

Warm-season legume/grass mixtures have been shown to perform better in late summer. West and Abdullah (1986) showed that Korean lespedeza-bermudagrass mixtures increased in yield in late summer while white clover-bermudagrass mixtures were decreasing in yield due to differences in adaptation to temperature. Wagner (1954) reported benefits of increased production over the entire season without the danger of applying nitrogen fertilizer during hot, dry conditions.

Researchers in Kansas grew Korean lespedeza in mixture with ‘Red River’ crabgrass and assessed the availability of forage from the mixture and the performance of animals during and following grazing of the mixture (Lomas et al., 2003). Lomas et al. (2003) fertilized 10 pastures with ‘Red River’ crabgrass already established in them with N, P, and K; no-till drilled 21 kg Korean lespedeza ha^{-1} into 5 of the pastures; and applied additional N to the remaining 5 pastures. They found that the pastures seeded with Korean lespedeza yielded similar to that from the pastures fertilized with additional N. The authors also found that stocker steers grazing all 10 pastures showed no differences in performance during or following grazing (Lomas et al., 2003). Cattle grazed all pastures for 120 days. Average daily gains, during the finishing period, were 0.92 and 0.98 kg head^{-1} day^{-1} for steers on pastures seeded with Korean lespedeza and pastures where additional N was applied, respectively. Average daily gains, during the finishing period, were 1.64 and 1.66 kg head^{-1} day^{-1} for steers that had previously grazed pastures seeded with Korean lespedeza and pastures where additional N was applied, respectively (Lomas et al., 2003).

CONCLUSION

There is potential for warm-season legume-grass mixtures to provide high-quality forage during the summer months in the transition zone of the United States (Brink and Fairbrother, 1988). Crabgrass and annual lespedeza grown together may provide an excellent choice for the low fertility, acidic soils that are commonly found in pastures throughout the southeastern United States (Ball et al., 2002; Lomas et al., 2003; McGraw and Hoveland, 1995). More information on the establishment and utilization of this mixture is need.

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CHAPTER 2

YIELD, BOTANICAL COMPOSITION, AND NUTRITIVE VALUE OF CRABGRASS-LESPEDEZA MIXTURES AS AFFECTED BY LESPEDEZA SEEDING RATE AND NITROGEN FERTILIZATION

Abstract

Crabgrass (*Digitaria* species, L.)-annual lespedeza (*Kummerowia stipulacea*, L. and *Kummerowia striata*, L.) mixtures could provide high quality summer forage in the southeastern United States. This study was designed to evaluate the effects of six lespedeza seeding rates (0-28 kg ha^{-1}) and two N fertilization treatments (140 kg total N ha^{-1} or no N) on the yield, botanical composition, and nutritive value of crabgrass-lespedeza mixtures. At both harvests, lespedeza in the sward was less when N was applied. At the second harvest lespedeza in the sward increased with seeding rate, with the exception of the N fertilization treatment in Trial 1. Lespedeza seeding rate had no effect on total yield of the crabgrass-lespedeza mixtures. In contrast, N increased season total yield by 46, 21, and 42% in Trials 1, 2, and 3, respectively. These mixtures produced season total yields averaging 6500 and 8700 kg ha^{-1}, for the no N and N treatments, respectively. Concentrations of IVTD ranged from 750-875 g kg^{-1} and were affected minimally by lespedeza seeding rate and N fertilization. The results of the current study indicate that addition of annual lespedeza to crabgrass swards had limited effects on dry matter yield and nutritive value, while N fertilization increased yields regardless of lespedeza seeding rate. These results may have been influenced by above average precipitation during the two growing seasons when this study was conducted, and should therefore be confirmed in a year with average or below average precipitation.

Introduction

Crabgrass (*Digitaria* species, L.) is a warm-season (C_4) annual grass that is commonly found throughout the transition zone (Uva et al., 1997). The species originated in southern Africa, and was transported to the United States in hay carried over by settlers from Europe (Dalrymple, 1994). Crabgrass is tolerant of low fertility, acidic soils, and drought (Aleshire and Teutsch, 2005; Ball et al., 2002) and often makes up > 60% of the summer forage in pastures in the southeastern United States. In addition, it possesses nutritive values equal to or higher than other commonly used warm-season grasses (Ball et al., 2002).

Korean and striate lespedezas (*Kummerowia stipulacea*, L. and *Kummerowia striata*, L., respectively) are summer-annual legumes that are both commonly referred to as annual lespedeza. Both types originated in Asia and are well adapted to the climate of the mid-Atlantic region of the United States (Ball et al, 2002; Brink and Fairbrother, 1988). Like crabgrass, annual lespedeza is well adapted to the low fertility, acidic soils commonly found in the southeastern United States (Ball et al., 2002).

Grass-legume mixtures increase yield and forage quality, and improve animal performance, while decreasing N inputs (Posler et al., 1993). When selecting grasses and legumes to grow in association, it is vital to choose species that are both well-adapted to region and soil conditions where they will be grown, have similar maturity, and have similar morphological characteristics (Posler et al., 1993). Crabgrass and annual lespedeza are both well-adapted to acidic, low fertility soils; produce their primary growth in the summer months (July and August); and have morphologies that can be managed to minimize the effects of competition. Although these species may grow well together, limited research has evaluated this mixture (Lomas et al., 2003). The objective of this study was to assess the effects of N fertilization and lespedeza seeding rate on the dry matter yield, botanical composition, and nutritive value of crabgrass-annual lespedeza mixtures.

Three Trials Using Six Lespedeza Seeding Rates With or Without N Fertilization

‘Red River’ crabgrass [*Digitaria ciliaris* (Retz.) Koel] (Dalrymple, 2001) and ‘Legend’ annual striate lespedeza (*Kummerowia striata*) (USPTO, 2005) were established in 2.7 x 6m plots on 24 June 2003 (Trial 1), 11 May 2004 (Trial 2), and 12 May 2004 (Trial 3), at the Southern Piedmont Agricultural and Research Extension Center near Blackstone, VA (37.09N, 77.99W). The soil series were a Dothan-Norfolk complex (Dothan: fine-loamy, kaolinitic, thermic Plinthic Kandiudults; Norfolk: fine-loamy, kaolinitic, thermic Typic Kandiudults) for Trials 1 and 2, and a Wedowee sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) for Trial 3. Initial soil pH values and nutrient concentrations are given in Table 2.1. A cultipacker-type seeder was used to plant into a conventionally-prepared seedbed. Crabgrass seeding rate was 3.4 kg ha^{-1} for all plots, and lespedeza seeding rates were 0, 5.6, 11.2, 16.8, 22.4, and 28 kg ha^{-1}. Plots received either 140 kg N ha^{-1} (84 kg N ha^{-1} at seeding and 56 kg N ha^{-1} following the first harvest) or no N fertilization. All plots had 112 kg ha^{-1} P_2O_5 and 336 kg ha^{-1} K_2O applied prior to seeding. Broadleaf weeds were controlled in Trials 2 and 3 using Basagran [sodium salt of bentazon (3-(1-methylethyl)-1 *H*-2,1,3-benzothiadiazin-4(3-one 2,2-dioxide)] herbicide at a rate of 0.84 kg ai ha^{-1} + 1.25 ml COC L^{-1} H_2O on 09 June 2004. No weed control was required in Trial 1. Plots were harvested on 20 August and 26 September 2003, 19 July and 13 September 2004, and 20 July and 24 September 2004 for Trials 1, 2, and 3, respectively. A self-propelled sickle-bar type forage harvester was used to cut a 1.2 x 6 m strip to a 10 cm residual height through the center of each plot. Targeted harvest stage was when crabgrass had reached late boot. Dry matter and botanical composition were determined by collecting subsamples from each plot, separating them into crabgrass, lespedeza, and “other”, and drying them for 5 days in a forced-air oven at 60° C. After drying, botanical components from each plot were recombined and ground to pass through a 2 mm and 1 mm screen using Wiley (Thomas Scientific, Swedesboro, NJ) and Cyclone sample mills (Udy Corporation, Fort Collins, CO), respectively.

Neutral detergent fiber (NDF), in vitro true digestibility (IVTD), neutral detergent fiber digestibility (NDFdig) and crude protein (CP) were determined using near infrared spectroscopy. WINISI II software was used to select a calibration data set for wet chemistry (Infrasoft International, Port Matilda, PA). Neutral detergent fiber and IVTD determinations were conducted using the ANKOM filter bag system (ANKOM Technologies, 2002), and NDFdig was calculated from NDF and IVTD values. Total N was determined using a modified Kjeldahl procedure (Technicon Auto Analyzer II, Industrial Method 334-74W/B, Tarrytown, NY), and crude protein was calculated as total N x 6.25.

The experimental design was a randomized complete block with a two-factor (lespedeza seeding rate and N fertilization vs. no applied N) factorial treatment arrangement and four replications. Data were analyzed using the general linear model procedure from SAS (SAS Institute, Cary, NC). Fisher’s protected least-significant-difference test was used to separate means when appropriate. Regression analysis was performed on raw data using Sigma Plot 9.0 (Systat, Point Richmond, CA). Data were analyzed first across trials, and if significant trial by treatment interactions were found, data were then analyzed by trials.

Rainfall and Temperature Data for 2003 and 2004 Crabgrass Growing Seasons

The wettest growing season on record occurred in 2003. Between May and September (the crabgrass growing season) of 2003, rainfall exceeded 30 year averages by 508 mm (Fig. 2.1). In 2004, precipitation was 291 mm above normal during the crabgrass growing season (Fig. 2.1). Average temperatures for the crabgrass growing season were 1.3°C below and 0.5°C above 30-year average temperatures for 2003 and 2004, respectively.

Lespedeza Seeding Rate and N Fertilization Effects on Crabgrass-Lespedeza Mixtures

Significant trial by treatment interactions ($P < 0.05$) were found by analysis of variance combined over trials; therefore, all yield, botanical composition, and nutritive value data are presented by trial. Where treatment interactions were found they are presented; otherwise only main effects are discussed.

Yield of Crabgrass-Lespedeza Mixtures

Fertilization with N increased DM yields of both harvests and over the entire season for all trials ($P < 0.03$) with the exception of the second harvest of Trial 3 (Fig. 2.2). Total yield for the growing season was 46%, 21%, and 42% less for the no N treatment for Trials 1, 2, and 3, respectively. Averaged over N treatments, lespedeza seeding rate did not affect DM yield ($P > 0.10$), with the exception of the first harvest of Trial 1 ($P = 0.04$) (Fig. 2.3). Rainfall delayed the second harvest for Trials 2 and 3 resulting in more mature forage and higher yields for these harvests when compared to Trial 1 (Blaser, 1986).

Botanical Composition of Crabgrass-Lespedeza Mixtures

First Harvest. There was a significant N x seeding rate interaction for the percentage of lespedeza in the sward at the first harvest for Trial 1 ($P < 0.002$), but not for Trials 2 and 3 ($P > 0.26$). When no N was applied in Trial 1, the abundance of lespedeza increased linearly as seeding rate increased (Fig. 2.4). When N was applied in Trial 1, increasing lespedeza seeding rate did not increase the proportion of lespedeza in the sward ($P > 0.05$) (Fig. 2.4). Averaged over lespedeza seeding rate, percentages of lespedeza present in the mixture in the first harvest were 1.6 and 9.4% higher when no N was applied in Trials 2 and 3, respectively ($P < 0.02$) (Fig. 2.5). Increasing lespedeza rate had no effect on the amount of lespedeza in the sward at the first harvest in Trials 2 and 3 (data not shown). Although analysis of variance indicated that the relative contribution of both crabgrass and other components differed for lespedeza seeding rate in the first harvest of Trial 1, no consistent trend could be observed (Figs. 2.6 and 2.7). In Trials 2 and 3, lespedeza seeding rate did not impact crabgrass and other components in the sward (Figs. 2.6 and 2.7). Nitrogen treatment had no effect on crabgrass in the stand in the first harvest in any trial (data not shown). Nitrogen fertilization did increase other components in the sward for the first harvest in Trial 1 only (Fig. 2.8). This increase was likely due to the fact that the majority of the other components were summer annual grass weeds such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and goosegrass [*Eleusine indica* (L.) Gaertn.], which responded well to nitrogen fertilization.

Second Harvest. A significant N x seeding rate interaction for the presence of both crabgrass and lespedeza in the sward was found for the second harvest of all trials ($P < 0.05$). Crabgrass decreased in abundance in a linear manner in plots with no N fertilization in Trial 1 and in a quadratic manner in Trial 3, as lespedeza seeding rate increased (Fig. 2.9). No relationship was found for Trial 2 (Fig 2.9). Lespedeza seeding rate had no effect on crabgrass in the stand when N was applied in any trial (Fig. 2.9). However, increasing the rate of lespedeza seeded did increase the amount of lespedeza in the stand for the second harvest in all trials, with the exception of the N treatment in Trial 1 (Fig. 2.10). This increase was greater for plots that did not receive any N fertilization (Fig. 2.10). Nitrogen fertilization increased the other component in Trials 2 and 3 ($P < 0.001$), which consisted primarily of summer annual grass weeds (Fig. 2.11). Lespedeza seeding rate had no effect on the percentage of other components in the stand in the second harvest of Trials 2 and 3 (data not shown).

Nutritive Value of Crabgrass-Lespedeza Mixtures

Neutral Detergent Fiber. Nitrogen fertilization affected NDF concentrations in the first harvest for Trials 1 and 3 ($P < 0.004$), but differences were minimal (< 20 g kg^{-1}) (Fig. 2.12). At the second harvest, mixtures in plots receiving no N had lower concentrations of NDF in Trials 1 and 3, while the opposite was true for Trial 2 (Fig. 2.12, but the magnitude of these differences was small (< 25 g kg^{-1}). Second harvest NDF concentration decreased linearly with lespedeza rate in Trial 2 only (Fig. 2.13), but lespedeza seeding rate explained only 17% of the variation in NDF values. Although NDF was higher at the second harvest, the average NDF at the second harvest was approximately 600 g kg^{-1}, which compares favorably with the NDF of other commonly used warm-season grasses and is consistent with results found in studies done with crabgrass grown alone (Ball et al., 2002; Teutsch et al., 2005).

***In vitro* True Digestibility.** *In vitro* true digestibilities ranged from 810 to 854 g kg^{-1} for the first harvest and were not affected by N fertilization or lespedeza seeding rate (data not shown). Second harvest IVTD concentrations increased with N fertilization for Trials 1 and 3 and decreased for Trial 2 (Fig. 2.14). Despite the effect of seeding rate on IVTD in the second harvest of Trial 2 indicated by analysis of variance, no consistent trend could be discerned from the data (Fig. 2.15). *In vitro* true digestibility values were lower in the second harvest of Trials 2 and 3 as compared to Trial 1 because of the advanced maturity of the sward caused by delayed harvest due to weather conditions (Blaser, 1986; Coleman et al., 2004). Teutsch et al. (2005) found similar IVTD concentrations when crabgrass was allowed to reach seed maturity to simulate natural reseeding of volunteer stands.

Neutral Detergent Fiber Digestibility. First harvest NDFdig values ranged from 693 to 758 g kg^{-1} and were not affected by N fertilization or seeding rate (data not shown). Second harvest NDFdig increased with N fertilization in Trials 1 and 3, but not in Trial 2 (Fig. 2.16). Lespedeza seeding rate had no effect second harvest NDFdig (data not shown). These results are similar to those of Teutsch et al. (2005) who also found that final harvest NDFdig values tended to increase with N fertilization.

Crude Protein. First harvest CP increased by a relative percentage of 18.7 with N fertilization in Trial 1 only (Fig. 2.17). In the second harvest, N fertilization increased CP concentrations in Trials 1 and 3, but decreased it in Trial 2 (Fig. 2.17). Other researchers have also found increases in CP concentrations when N was applied to grass-legume mixtures (Baylor, 1974). Crude protein increased linearly with lespedeza seeding rate in Trials 1 and 2, but not in Trial 3 (Fig. 2.18). However, lespedeza seeding rate accounted for only 15 and 30% of the differences found in CP in Trials 1 and 2, respectively (Fig. 2.18).

Nitrogen Fertilization Effects on Crabgrass-Lespedeza Mixtures

Nitrogen fertilization increased crabgrass and decreased lespedeza in the sward. Other components in the sward were primarily grass weeds, and their presence was either not affected or increased by N fertilization. The increasing trend in the grass component of the sward observed in this study was consistent with the observations of other researchers (Barker and Collins, 2003; Baylor, 1974; McGraw and Nelson, 2003). Yield was increased by N fertilization regardless of lespedeza seeding rate, and these findings also agree with earlier research (Baylor, 1974).

Responses of nutritive value parameters to N fertilization were variable and were likely influenced by rainfall. For instance, above average rainfall received in 2003 and 2004 (Fig. 1) combined with N fertilization would be expected to accelerate the growth of the sward leading to an increased stem:leaf ratio and increased fiber contents resulting in decreased forage quality. Responses that may have been caused by this type of interaction were observed in Trials 1 and 3, but not in Trial 2.

The high presence of other components, particularly in the second harvest (Fig. 2.11), may also have affected the results found for Trial 2. The other components were primarily summer annual grass weeds. This higher presence of grass weeds in the plots receiving N fertilization in Trial 2 may have contributed to the decreased nutritive value seen in the second harvest of those plots.

Nitrogen fertilization of grass-legume mixtures is recommended when the legume component makes up < 25-30% of the sward on a dry matter basis (Barker and Collins, 2003; Donohue and Heckendorn, 1994). However, in Trial 3 of the current study, yields were increased by N fertilization even when lespedeza made up > 40% of the sward. This was likely due to limited transfer of fixed N from the annual lespedeza to the crabgrass. Transfer of N from legumes to grasses occurs primarily through decay of plant parts and nodules, and it has been reported that little N transfer occurs in the first six months to one year after establishment (Miller and Heichel, 1995). Stout et al. (1997) found that the application of N increased the yield of annual mixtures.

Results from the current study and past research indicate that application of N fertilizer may be needed to optimize yield of crabgrass-annual lespedeza mixtures, even when the percentage of annual lespedeza in the stand is higher than 30%. This would be especially true if this mixture were grown in a double cropping system with a nitrophilic winter annual grass such as annual ryegrass or small grains. An alternative could be the use of a winter annual grass-legume mixture to complete the N cycle, however no research has documented N cycling in this type of a forage system.

Lespedeza Seeding Rate Effects on Crabgrass-Lespedeza Mixtures

Overall, increasing the rate of lespedeza seeded tended to increase the amount of lespedeza present in the sward, particularly when no N was applied. However, seeding rate of lespedeza had limited effect on yield and nutritive value of the crabgrass-lespedeza mixture. In contrast, previous studies have found that adding legumes to a grass stand increased both yield and quality (George et al., 2000; Mitchell et al., 1986; Posler et al., 1993). This contradiction between the current study and earlier research may be due to limited N transfer in the current study because of the relative short duration of the crabgrass-annual lespedeza growing season.

Above average precipitation that occurred in the current study may have also decreased the relative contribution of annual lespedeza in the stand. While both species used in the mixture are considered to be drought tolerant, crabgrass responds to moisture stress by halting its growth until soil moisture is restored. Crabgrass will rapidly resume its production when adequate moisture becomes available (Dalrymple, 1976). In contrast annual lespedeza is more likely to continue growth during short-term drought stress (Ball et al., 2002; Dalrymple, 1994). This indicates that in dry years or years with average amounts of rainfall, the growth of annual lespedeza may be favored, increasing its contribution to the overall sward. In such seasons, larger amounts of lespedeza present in the sward could potentially have greater impact on both the yield and nutritive value of crabgrass-lespedeza mixtures.

Conclusion

In the southeastern United States, many forage producers contend with acidic soils low in fertility and a summer slump in the production of cool-season forage species. Crabgrass and annual lespedeza are well-adapted to the less productive soils found in this region. Earlier research has demonstrated that, with proper management, crabgrass has potential to provide moderate amounts of forage with high levels of digestibility (Teutsch et al., 2005). The results of the current study indicate that addition of annual lespedeza to crabgrass stands did not increase yield or nutritive value. However, the application of N fertilizer to crabgrass-annual lespedeza mixtures did increase yield. This study should be repeated in years with average and below average rainfall. In addition more work is needed to determine the optimal rate and timing of N applications for crabgrass-annual lespedeza mixtures.

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Table 2.1. Initial soil pH values and plant available nutrient concentrations.

Trial (Year)	Soil Series	pH[a]	P[b]	K	Ca	Mg
			---------------------------kg ha^{-1}------------------------			
1 (2003)	Dothan-Norfolk Complex	6.6	32 (High[c])	48 (Medium)	268 (Low+)	80 (High-)
2 (2004)	Dothan-Norfolk Complex	6.9	107 (Very High)	116 (High)	477 (Medium-)	88 (High)
3 (2004)	Wedowee sandy loam	5.8	32 (High)	75 (Medium)	247 (Low+)	59 (Medium)

[a] Soil solution pH (1:1 soil:water (wt/wt)) (McLean, 1982)

[b] Mehlich 1 extraction (Fixen and Grove, 1990)

[c] Soil test recommendations for Virginia (Donohue and Heckendorn, 1994)

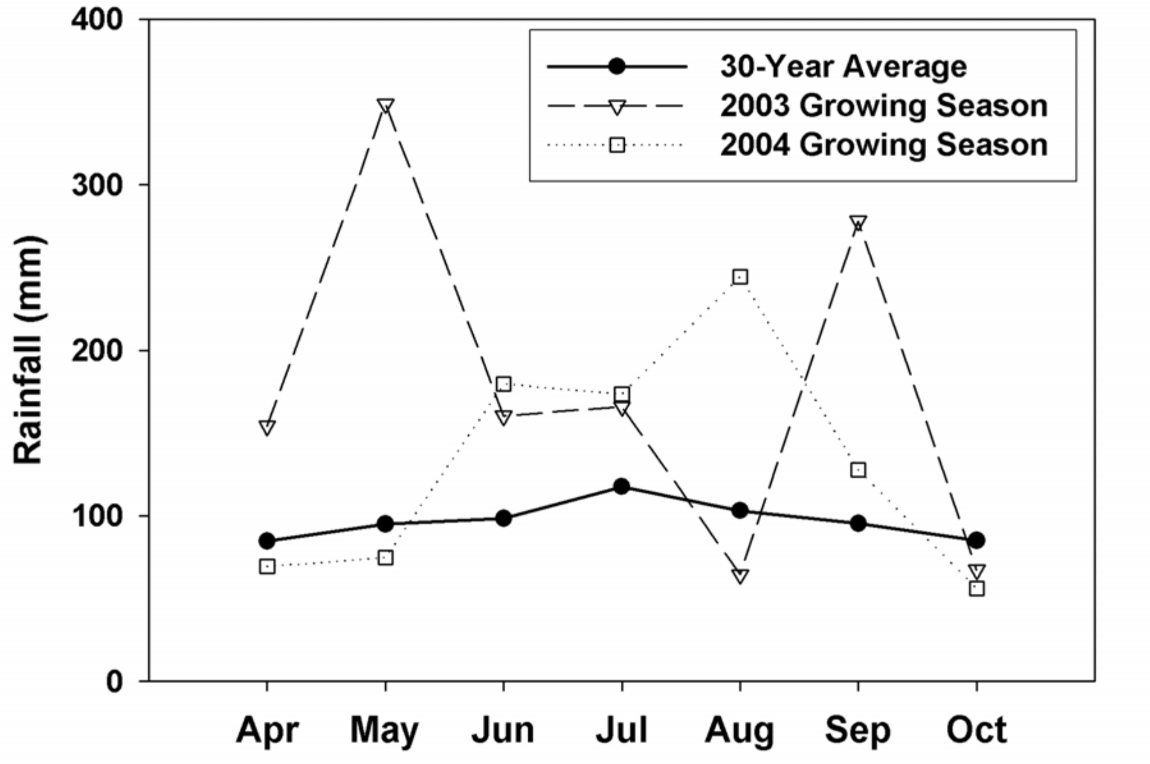

Fig. 2.1. Precipitation for the 2003 and 2004 growing seasons at the Southern Piedmont Agricultural Research and Extension Center, Blackstone, VA.

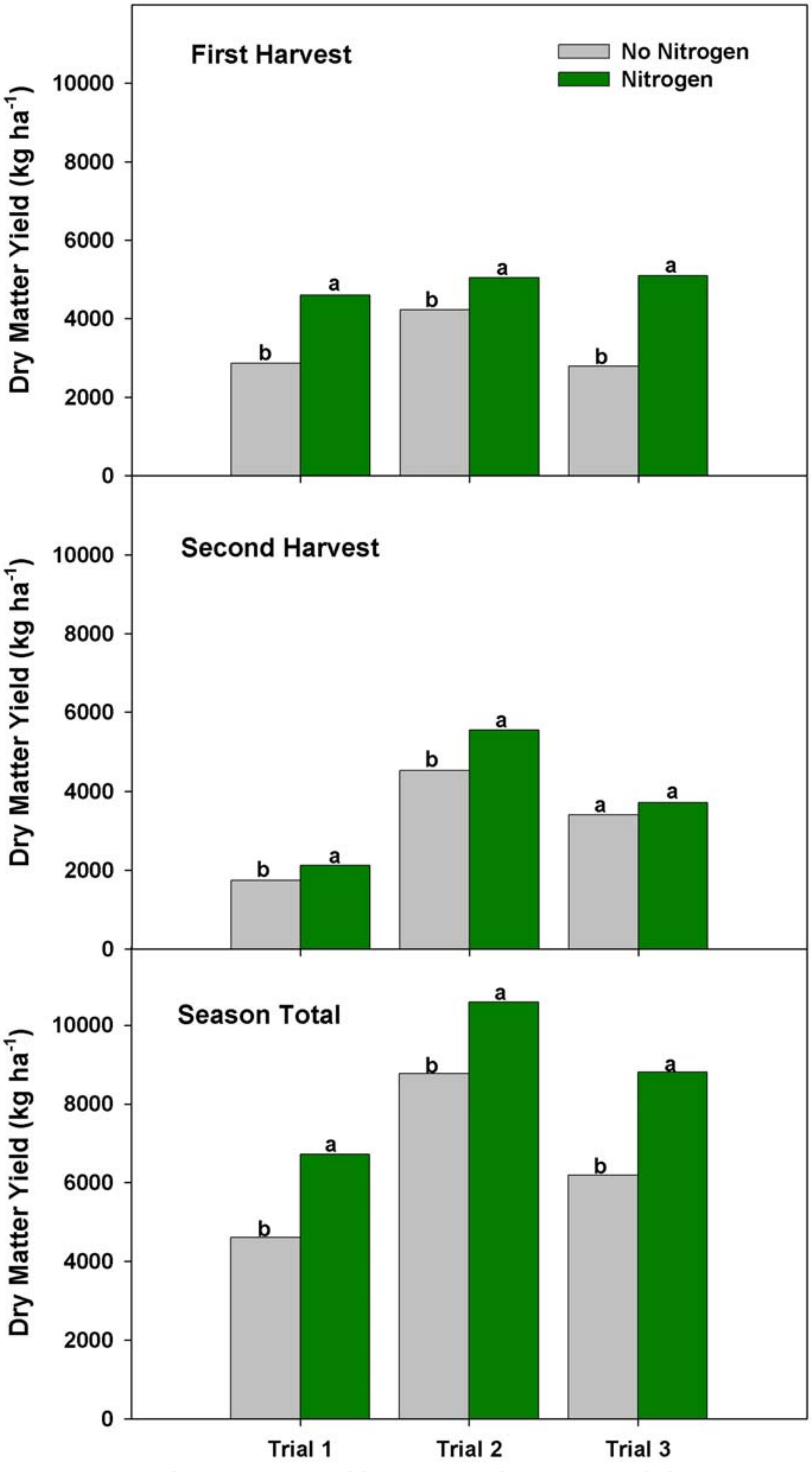

Fig. 2.2. First harvest, second harvest, and season total dry matter yields of crabgrass-lespedeza mixtures in three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

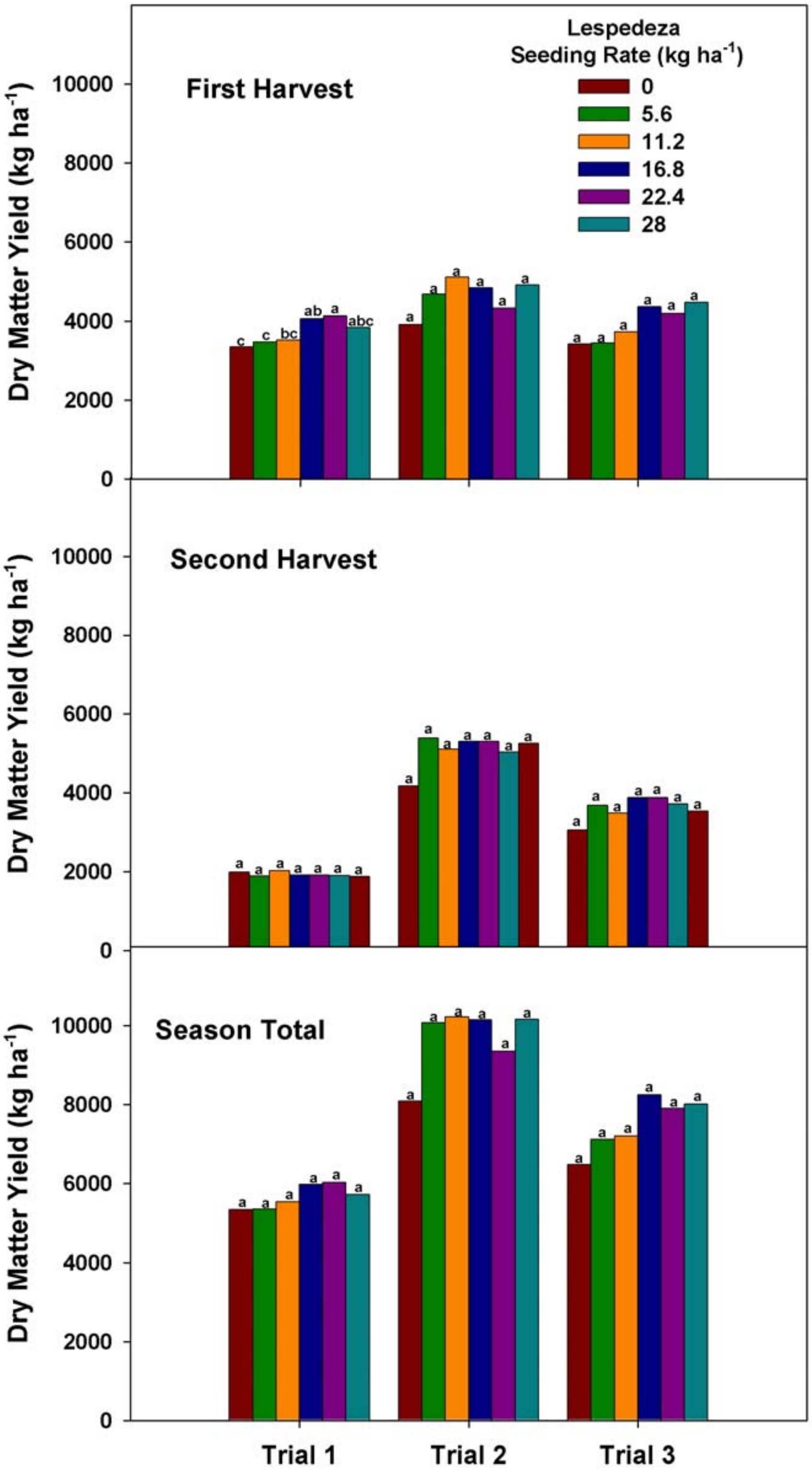

Fig. 2.3. First harvest, second harvest, and season total dry matter yields of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

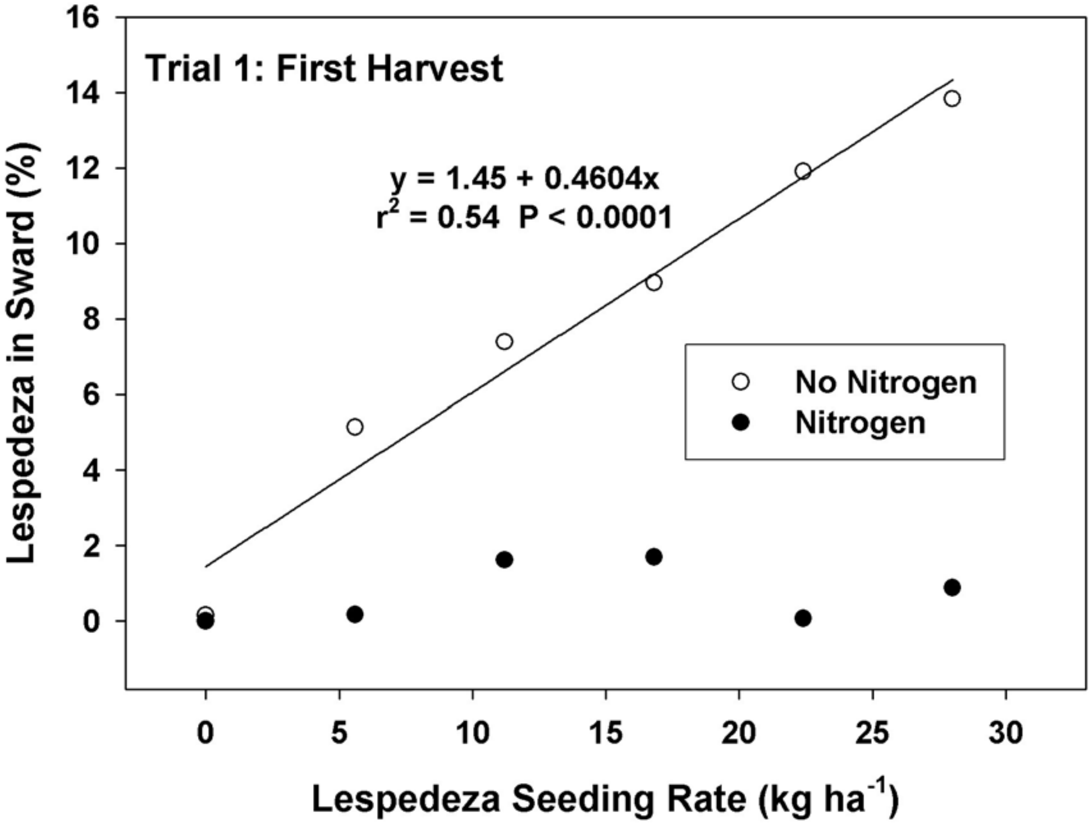

Fig. 2.4. Percentage of lespedeza present in the sward in the first harvest of Trial 1 as influenced by nitrogen fertilization and lespedeza seeding rate.

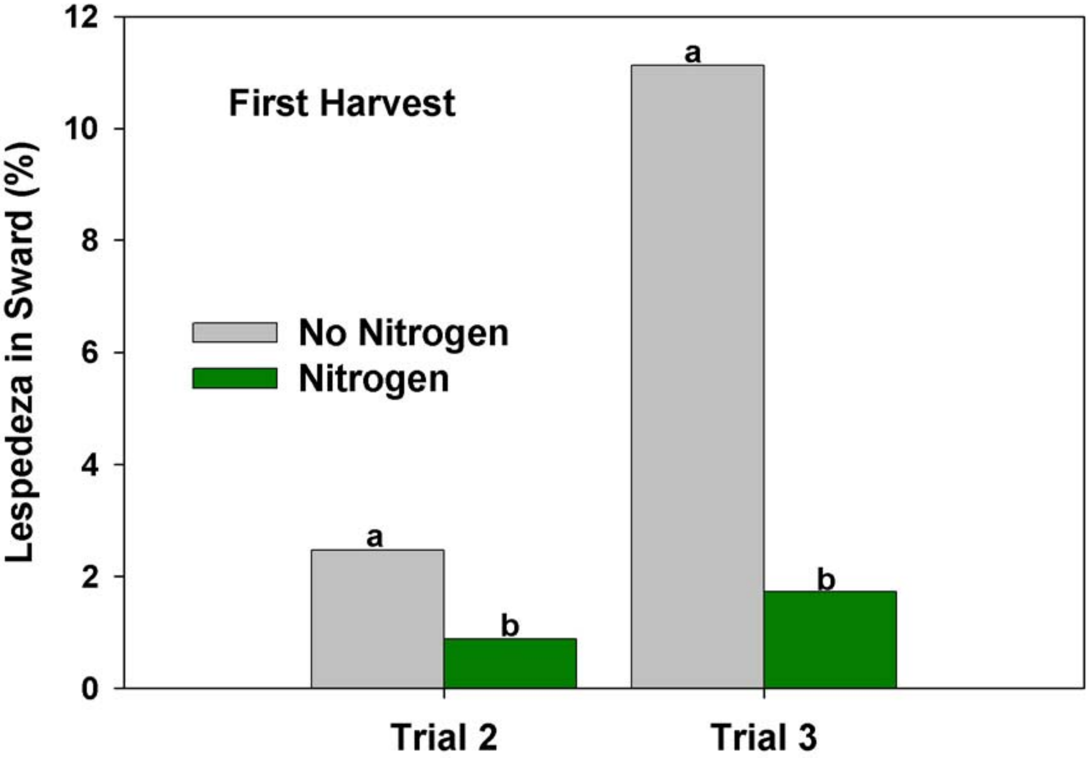

Fig. 2.5. Percentage of lespedeza present in the sward in the first harvest of Trials 2 and 3 as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

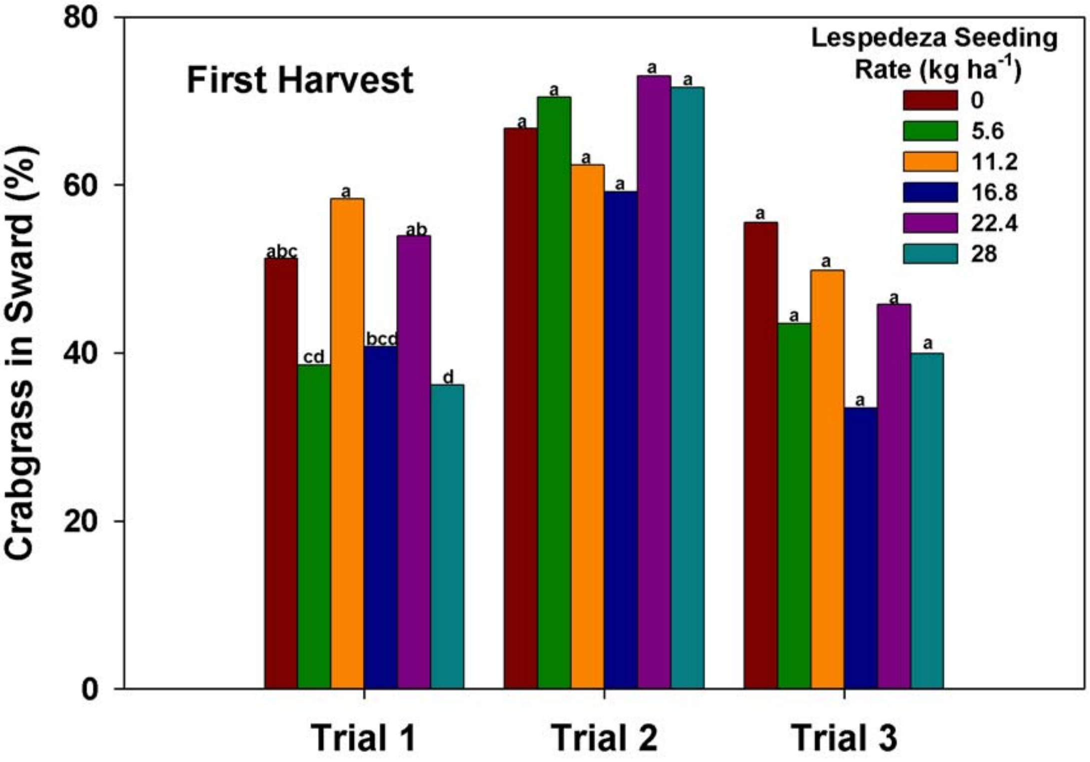

Fig. 2.6. Percentage of crabgrass in the sward in the first harvest of three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

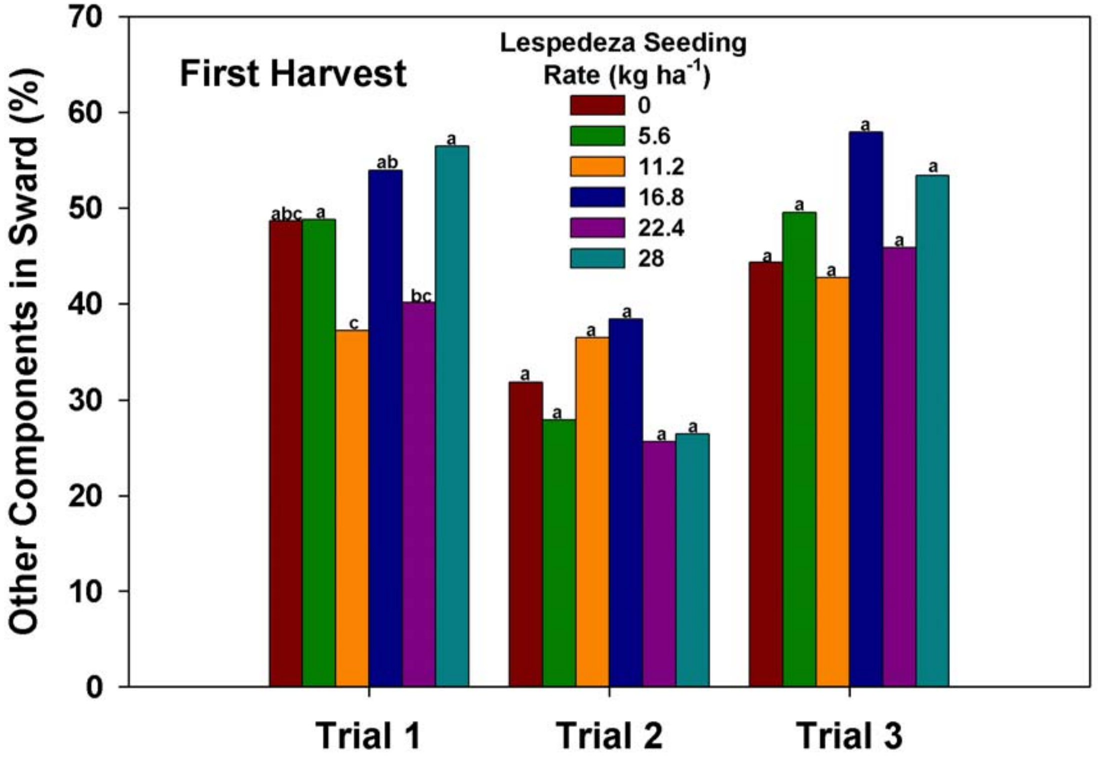

Fig. 2.7. Percentage of other components[†] in the sward in the first harvest of three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

[†] Other components primarily consisted of grass weeds [i.e. barnyardgrass (*Echinochloa crus-galli*), goosegrass (*Eleusine indica*), etc.].

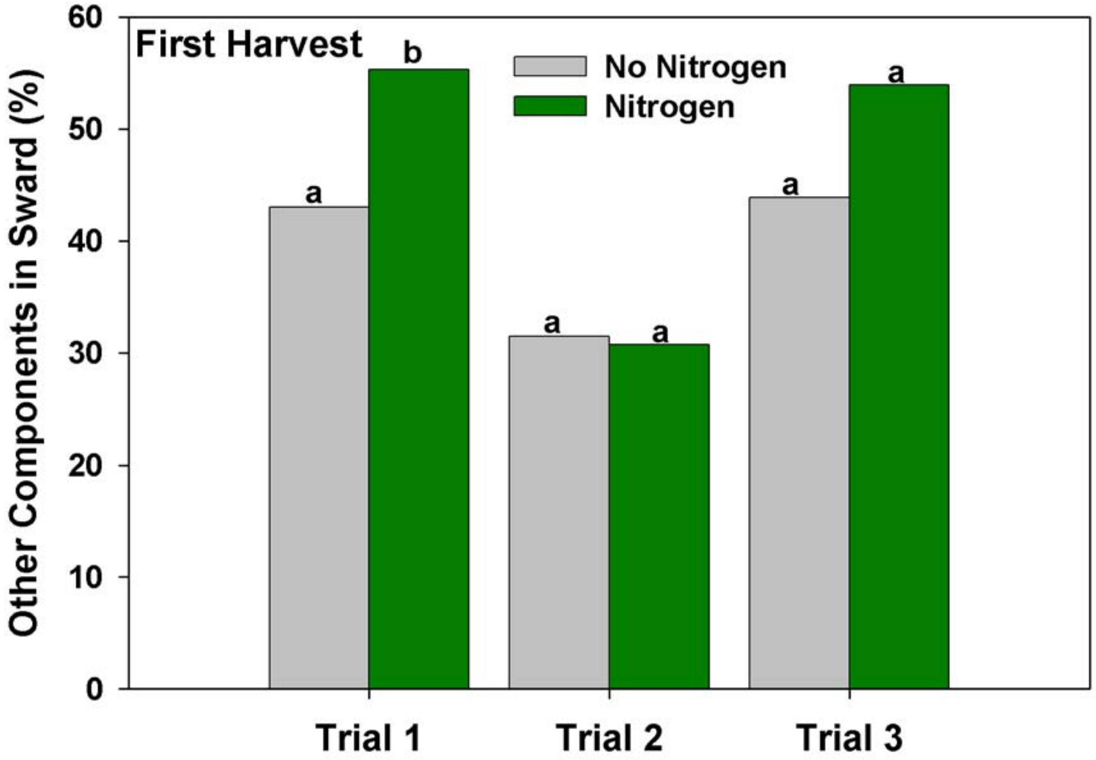

Fig. 2.8. Percentage of other components in the sward in the first harvest of three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

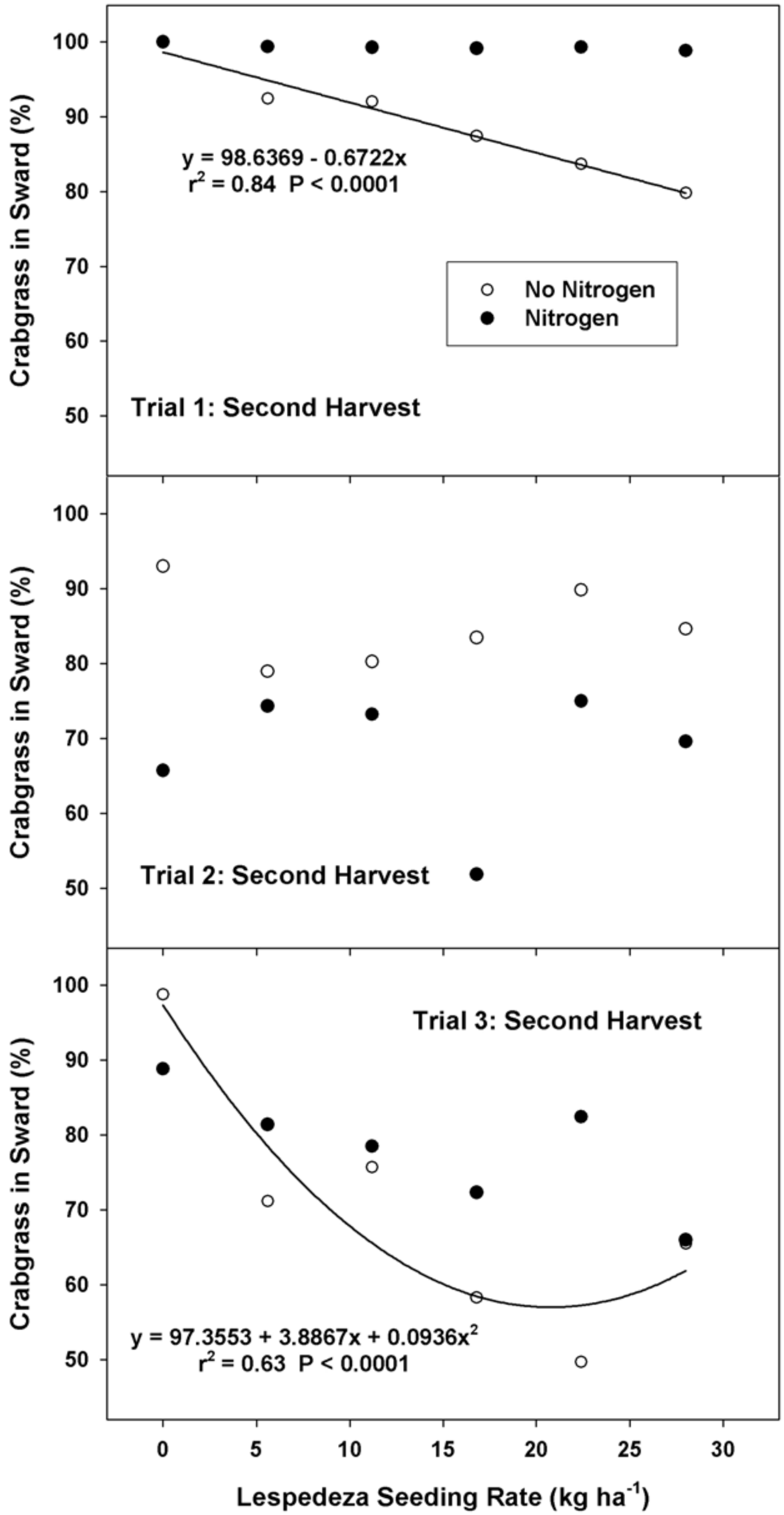

Fig. 2.9. Percentage of crabgrass present in the sward in the second harvest of three trials as influenced by nitrogen fertilization and lespedeza seeding rate.

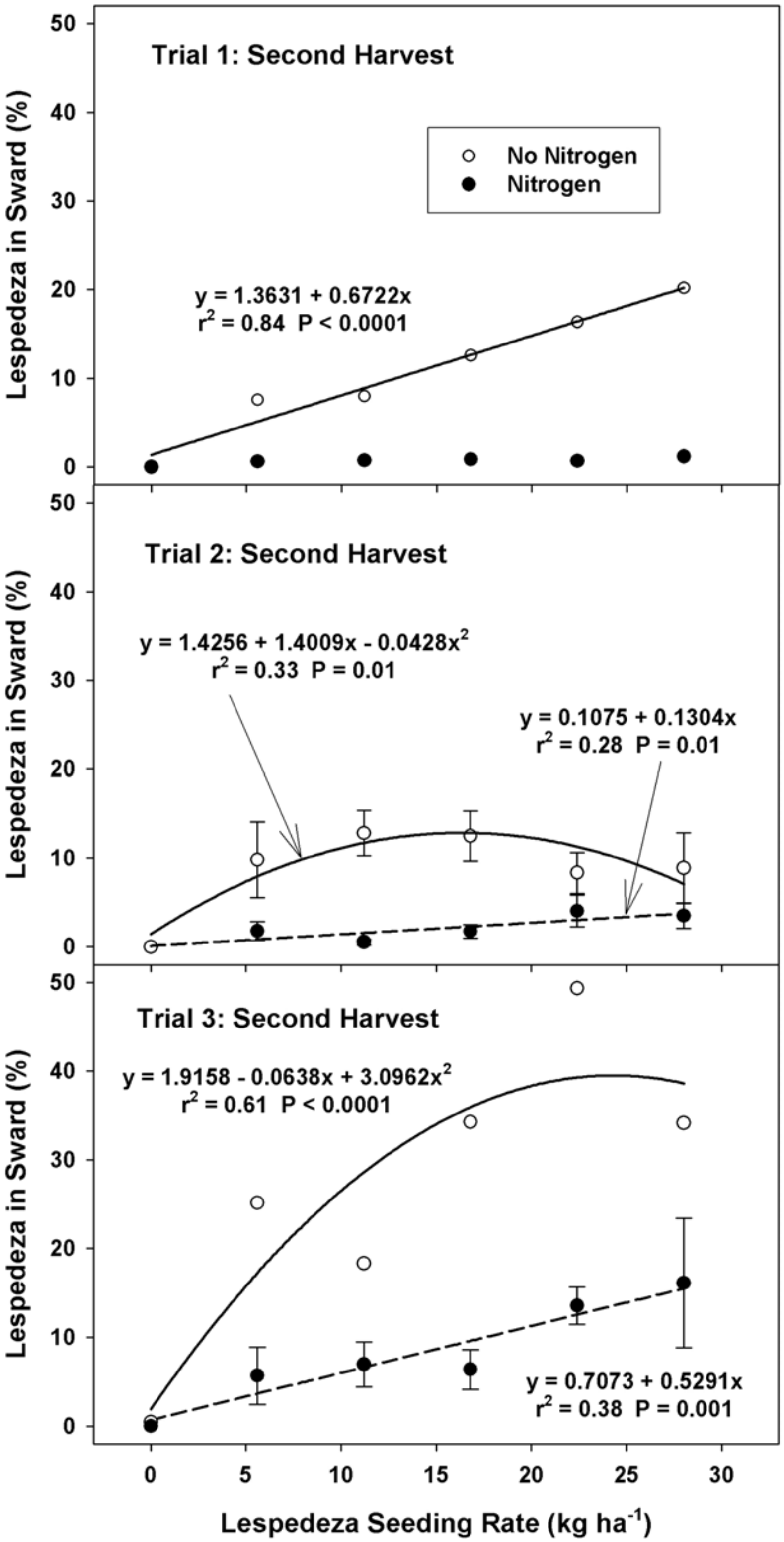

Fig. 2.10. Percentage of lespedeza present in the sward in the second harvest of three trials as influenced by nitrogen fertilization and lespedeza seeding rate.

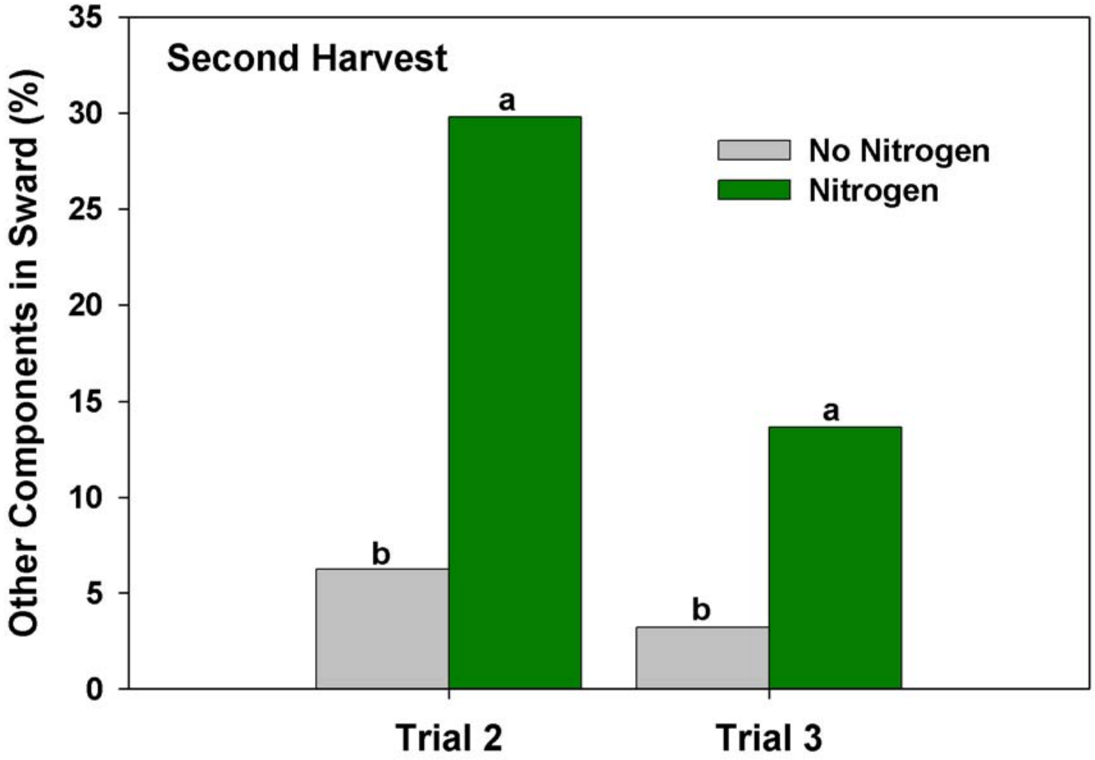

Fig. 2.11. Percentage of other components present in the sward in the second harvest of Trials 2 and 3 as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

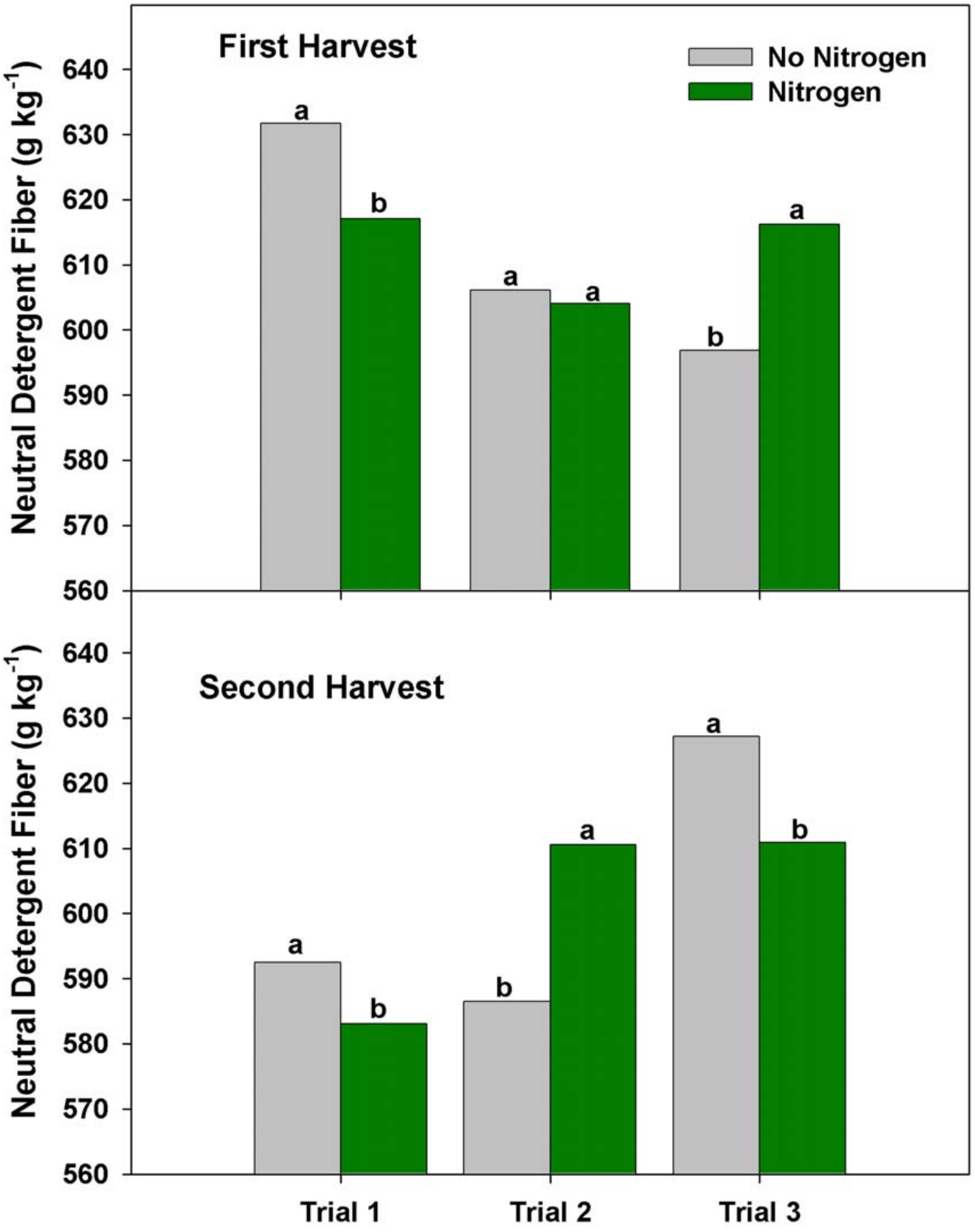

Fig. 2.12. First and second harvest neutral detergent fiber content of crabgrass-lespedeza mixtures in three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

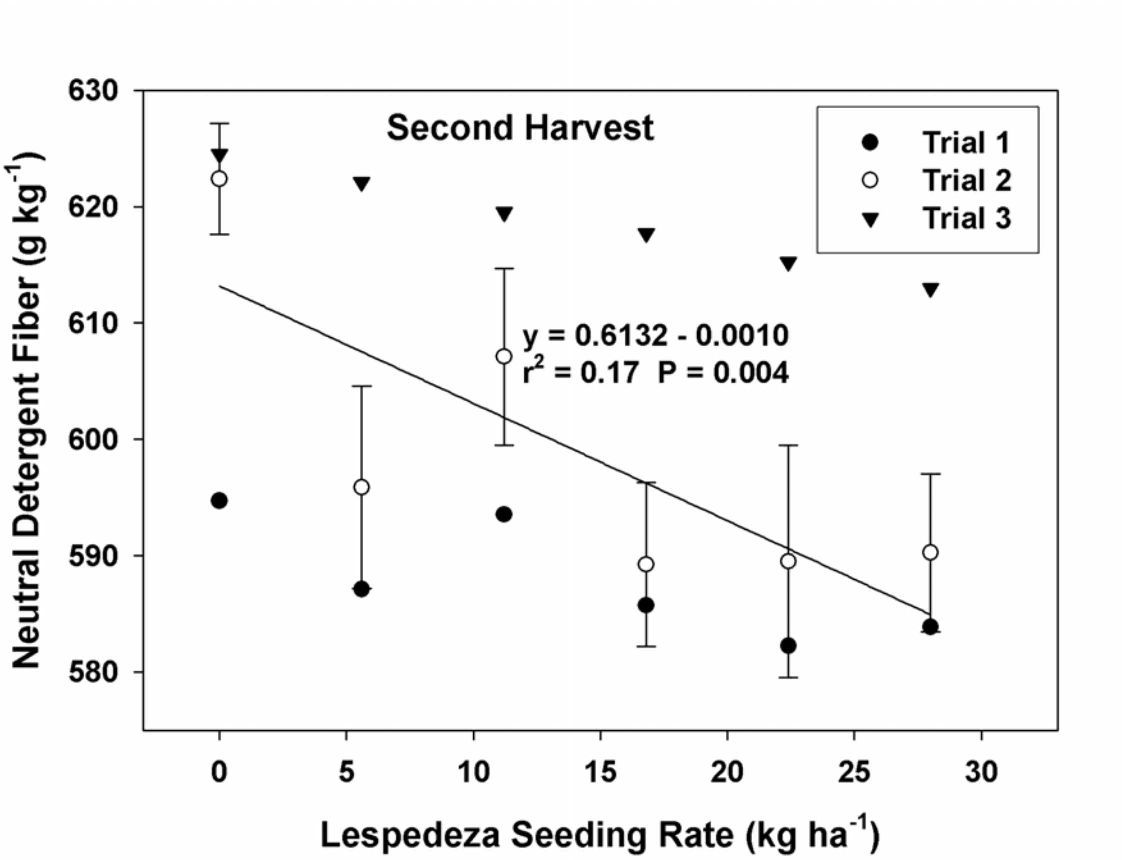

Fig. 2.13. Second harvest neutral detergent fiber content of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

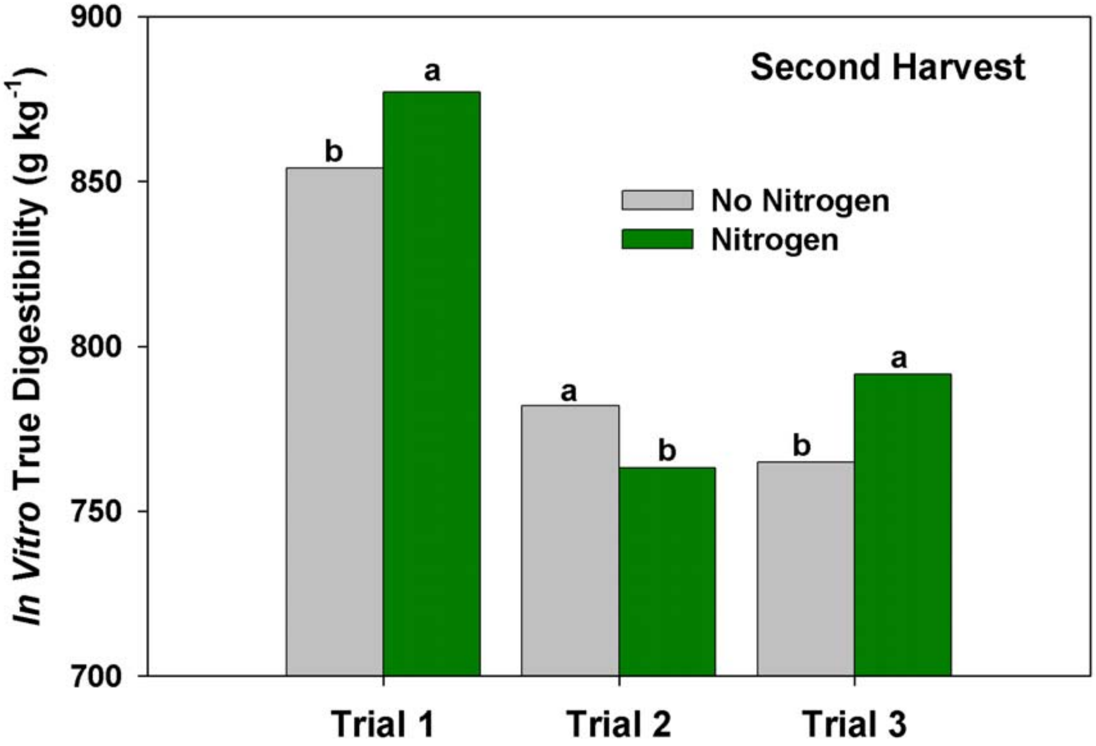

Fig. 2.14. Second harvest *in vitro* true digestibility of crabgrass-lespedeza mixtures in three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

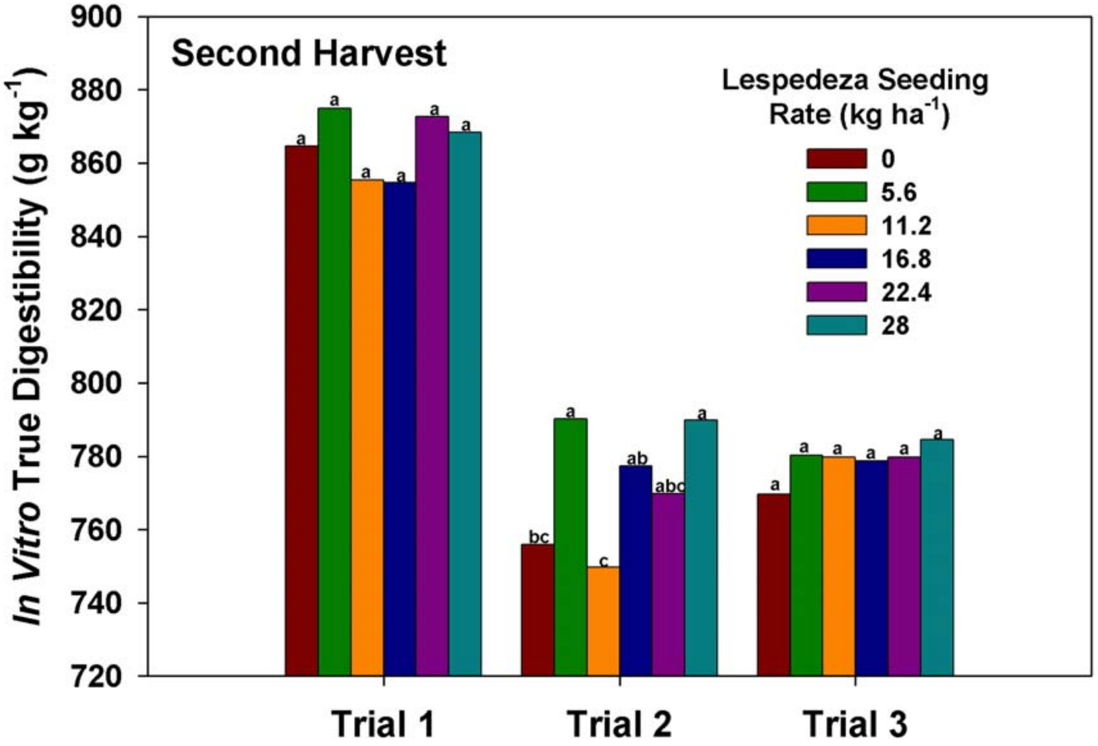

Fig. 2.15. Second harvest *in vitro* true digestibility of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate averaged over nitrogen fertilization.

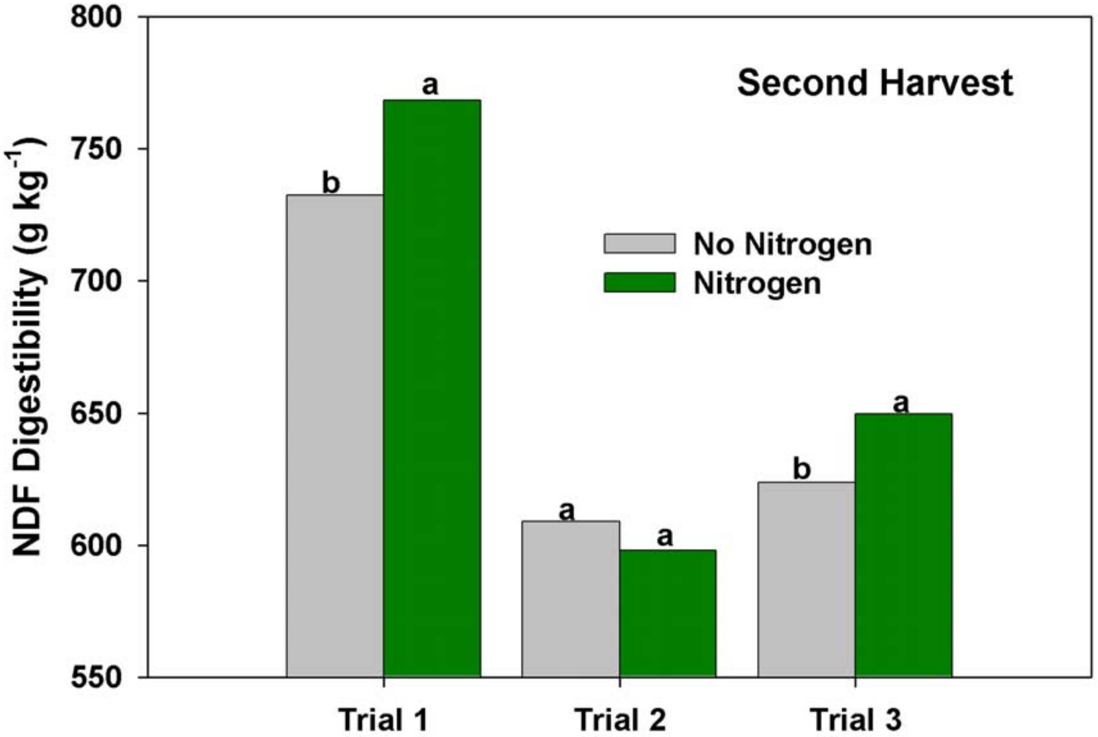

Fig. 2.16. Second harvest neutral detergent fiber digestibility of crabgrass-lespedeza mixtures in three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

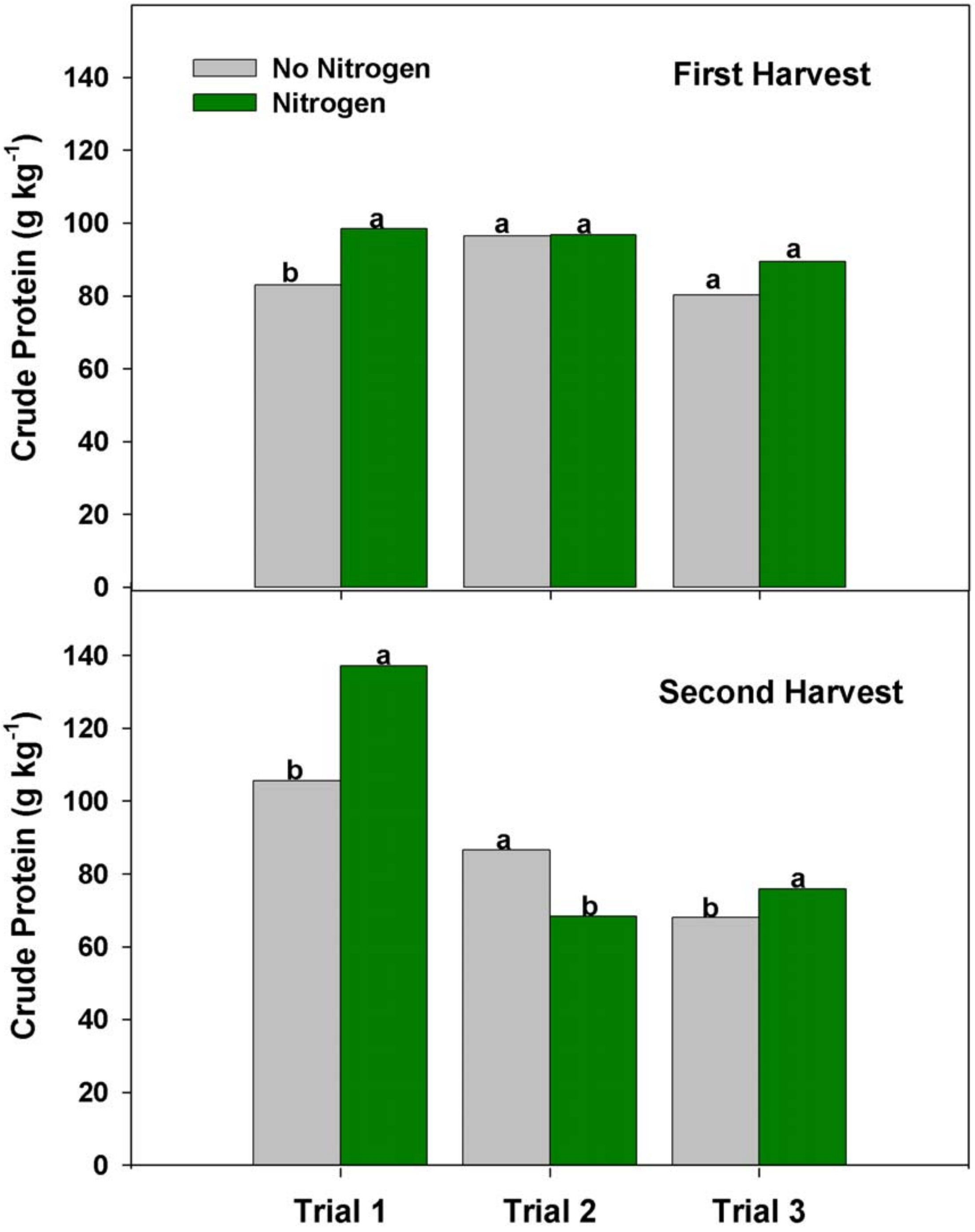

Fig. 2.17. First and second harvest crude protein content of crabgrass-lespedeza mixtures in three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

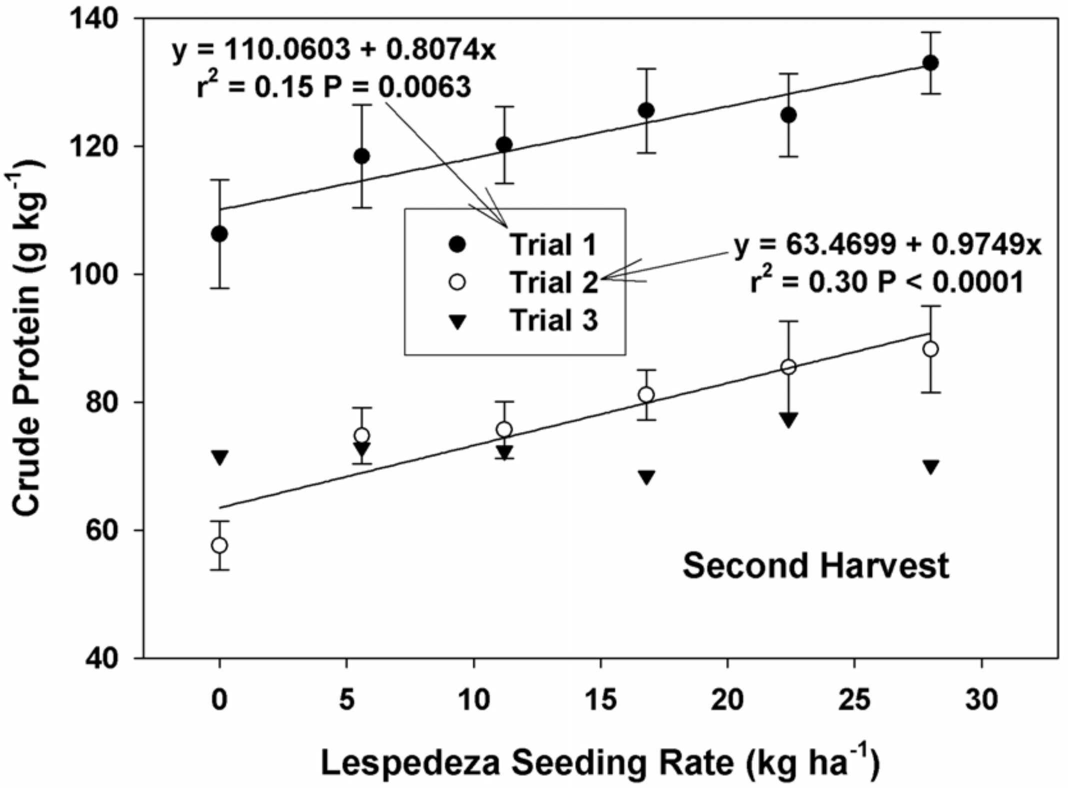

Fig. 2.18. Second harvest crude protein content of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).
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CHAPTER 3

SOIL pH EFFECTS ON THE SHOOT AND ROOT YIELD OF CRABGRASS

Abstract

Recent research indicates that crabgrass (*Digitaria* species) could provide high-quality summer forage for ruminant livestock in the mid-Atlantic region. Limited data are available documenting the soil pH requirements of crabgrass grown as forage. A greenhouse study was designed to determine the effect of soil pH value on the germination and yield of crabgrass. Treatments consisted of three pH levels, 4.8, 5.5, and 6.3. Pots 20 cm across and 22 cm deep containing 4.5 kg of air-dried soil were seeded at a density of 25 seeds pot^{-1} and thinned to 14 plants pot^{-1} after germination was complete. Two harvests three to four weeks apart were taken. Within the range of 4.8 to 6.3, soil pH had no effect on crabgrass germination, shoot yields, or root mass in either harvest. These data indicate that crabgrass has potential to produce summer forage on acidic soils commonly found within the southeastern United States.

Introduction

Crabgrass (*Digitaria* species) is a warm-season annual grass believed to have originated in southern Africa (Ball et al., 2002). The grass was used as forage in Europe before settlers unintentionally brought it to the United States (Dalrymple, 1994). In 1849, the United States Patent Office (predecessor to the USDA) introduced the use of crabgrass as a forage species (Dalrymple, 1994; Larson, 2001). Crabgrass is commonly found throughout the transition zone between the temperate and subtropical regions of the United States, with its primary production occurring in the summer months (July and August) (Dalrymple, 1994; Uva et al., 1997).

Crabgrass possesses a prolific growth habit and is well known for its reseeding capabilities (Piper, 1916) (Fig. 3.1). It is considered to be tolerant of drought and able to establish and grow on soils with low fertility (Uva et al., 1997). These characteristics and the fact that crabgrass is often an invasive species in lawns, gardens, and crop fields have caused it to be viewed as a weed (Peters and Dunn, 1971) (Fig. 3.2). However, crabgrass has nutritive values equal to or higher than other commonly used warm-season grasses. Dalrymple (1994) reported that the forage cultivar ‘Red River’ crabgrass had a crude protein (CP) concentration of 15% and *in vitro* dry matter digestibility (IVDMD) of 73% compared with 15 and 64% for ‘Midland’ bermudagrass grown under the same conditions. In addition, many of the characteristics that allow crabgrass to thrive as a weed, such as its prolific seeding and spreading morphology, may make it well adapted as a summer pasture species (Ball et al., 2002).

In the southern United States, soils tend to be acidic in nature (Ball et al., 2002; Burns et al., 2004). A survey of hay and pastureland in ten southern states showed that more than half of tested soils had a pH value below 6.0 (Ball et al., 2002). Warm-season grasses are, in general, tolerant of acidic soil conditions (Robinson et al., 1993). Limited research and anecdotal reports indicate that crabgrass will grow over a wide range of soil pH values, but no research data are available evaluating the soil pH requirement of crabgrass grown as forage (Buchanan et al., 1975; Dalrymple, 1994; Pierce et al., 1999). The objective of this study was to determine the effect of varying initial soil pH levels on germination, shoot yield, and root yield of an improved crabgrass cultivar.

Repeated Trial with Three Soil pH Values

A Cecil sandy loam soil (fine, kaolinitic, thermic Typic Kanhapludults) was obtained from a wooded area at the Southern Piedmont Agricultural Research and Extension Center, Blackstone, VA (37.09N latitude, 77.99W longitude). This soil had an initial pH value in water of 4.3 (soil:water = 1:1 (wt/wt)) (McLean, 1982). One hundred sixty-three kg soil was divided into three portions (54 kg) for pH adjustment. Pre-experimental tests with small amounts of soil and $Ca(OH)_2$ indicated that 0.27 and 0.70 g $Ca(OH)_2$ kg soil^{-1} were required for raising soil pH values to approximately 5.7 and 6.4, respectively. The three 54 kg portions of soil received 14.3, 38.0, and 61.5 g of $Ca(OH)_2$, respectively. A rotary cylinder mixer was used to mix all treatments (Fig. 3.3). In order to stabilize soil pH, all soil mixtures underwent three wetting and drying cycles in which soil was spread into a thin layer, wetted to field capacity using deionized water in sprinkling cans (Fig. 3.4), allowed to air-dry, and remixed. Total equilibration time was 72 hours. Final soil pH values for the three treatments were 4.8, 5.5, and 6.3 (Table 3.1).

A Mehlich 1 extraction of the soil indicated that phosphorus and potassium levels were deficient (Table 3.1). Recommended fertilizer rates for establishment of summer annual grasses were 84, 134, and 134 kg ha^{-1} each of N, P_2O_5, and K_2O, respectively (Donohue and Heckendorn, 1994; Teutsch, 2002). Four times the recommended amount of P_2O_5 was applied to account for significant rates of P fixation, and the small soil volumes of the pots. Laboratory grade $Ca(NO_3)_2$, $Ca(H_2PO_4)_2$, and KCl were the respective fertilizer sources. All fertilizers were added to the soil during the last mixing. After the first harvest, an additional 84 kg N ha^{-1} was applied as $Ca(NO_3)_2$ dissolved in 200 mL deionized water/pot.

Plastic pots 20 cm across and 22 cm deep were lined with a 1.5 mil thick autoclave bag to prevent loss of water and leaching of nutrients. A polyethylene air tube was placed in each pot to prevent localized anaerobic conditions and allow water to infiltrate through all soil evenly (Fig. 3.5). Four and one-half kg air dried soil was placed in each pot and wetted to achieve 80% field capacity using deionized water. Following wetting, 25 ‘Red River’ crabgrass [*Digitaria ciliaris* (Retz.) Koel] seeds were planted in each pot at a depth of 0.6 cm (Dalrymple, 2001). Trial 1 was planted on 18 June 2004, and Trial 2 was planted on 25 June 2004. Within each trial, two pots were seeded for each treatment with four replications for a total of 24 pots trial^{-1}.

All pots were weighed daily and watered with deionized water to maintain soil moisture at approximately 80% field capacity. Seedling counts were conducted every other day until germination was complete. Shoot yields were determined by clipping plants to a 10 cm residual height when crabgrass had reached the late boot stage. First harvest was on 26 July 2004, and 2 August 2004, for Trials 1 and 2, respectively. Second harvest was on 12 August 2004, and 27 August 2004, for Trials 1 and 2, respectively. After shoots were harvested, one randomly chosen pot for each treatment was selected from each replication for determination of root dry weight. Soil was carefully washed away from the roots (Fig. 3.6). Shoots and roots were dried in a forced air oven for 5 days at 60° C.

The experimental design was a randomized complete block with three pH levels as treatments (4.8, 5.5, and 6.3) and four replications, and the study was run twice. Data were analyzed using the general linear model procedure from SAS (SAS Institute, Cary, NC.). No significant trial by treatment interactions were found for germination, shoot weight, and root weight, and there were no significant differences in the response of these factors to pH. Standard error values were calculated with the standard error option in means statement to illustrate differences in shoot and root weights between the first and second trials.

Impact of Soil pH Value on Germination

Soil pH value at planting had no effect on crabgrass germination at any stand count date ($P > 0.30$). Mean germination averaged across trials for the last counting date was 19, 19, and 18 plants pot^{-1} for pH values of 4.8, 5.5, and 6.3, respectively. These data indicate that a satisfactory stand of seeded crabgrass can be obtained over a wide range of soil pH values. Research is needed to confirm these findings in the field.

Impact of Soil pH Value on Shoot Growth

Soil pH value at planting had no effect on crabgrass shoot yields in either harvest ($P > 0.05$) (Fig. 3.7). Buchanan and coworkers (1975) also found that crabgrass was tolerant of low levels of soil pH. In contrast to the current study, Pierce et al. (1999) reported that shoot dry matter of crabgrass decreased as soil pH increased from 4.8 to 7.8. However, the rate of yield decrease was greatest at pH levels from 6.0 to 7.8, which were primarily outside of the range used in the current study. In the current study, shoot weight at the second harvest was approximately half the DM of the first harvest.

Other research has shown that crabgrass yield increased as rate of nitrogen fertilization increased on soils with pH values above 6.0 (Aleshire et al., 2004; Dalrymple, 1975). Although data from the current study indicate that crabgrass yield was not impacted by soil pH values, more research is needed to determine if the nitrogen response seen in previous work is similar for soils with more acid pH values, i.e. near 5.0.

Impact of Soil pH Value on Root Growth

Soil pH value at planting had no effect on crabgrass root yields in either harvest. ($P > 0.50$) (Fig. 3.8). An extensive rooting system is vital for moisture and nutrient acquisition during establishment and production (Frank et al., 1996; Masters et al., 2004). These data indicate crabgrass produced an extensive root system over a wide range of soil pH levels under the conditions of this experiment. Root DM increased by approximately 50% from the first to the second harvest.

Conclusion

In the southeastern United States, there is a need for warm-season forages to fill the summer production slump of cool-season grasses. Our data indicate that crabgrass shoot and root growth was insensitive to soil pH values ranging from 4.8 to 6.3. This demonstrates the potential of crabgrass as a forage for low-fertility grasslands commonly found in this region of the United States. These findings could be especially important to producers who have short-term leases on pastureland that prohibit investment in lime applications; and to help prevent over-application of lime which can lead to deficiencies in minerals such as P, K, and Mg and subsequent decreases in yield (Mathews et al., 2004). Results of this greenhouse study must be confirmed in the field.

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Table 3.1. Soil pH value and nutrient concentrations before and after the addition of lime and fertilizer.

Treatment	pH[a]	P[b]	K	Ca	Mg
		---------------------------kg ha^{-1}-------------------------			
Initial	4.3	5 (Low[c])	36 (Low)	137 (Low-)	29 (Low)
1	4.8	125 (Very High)	128 (Medium)	668 (Low+)	45 (Low)
2	5.5	221 (Very High)	213 (High-)	1381 (Medium+)	57 (Low+)
3	6.3	264 (Very High)	193 (Medium+)	1992 (High)	63 (Low+)

[a] Soil solution pH (1:1 soil:water (wt/wt)) (McLean, 1982)

[b] Mehlich 1 extraction (Fixen and Grove, 1990)

[c] Soil test recommendations for Virginia (Donohue and Heckendorn, 1994)

Fig. 3.1. Seed produced by crabgrass at the Southern Piedmont Agricultural Research and Extension Center, Blackstone, VA.

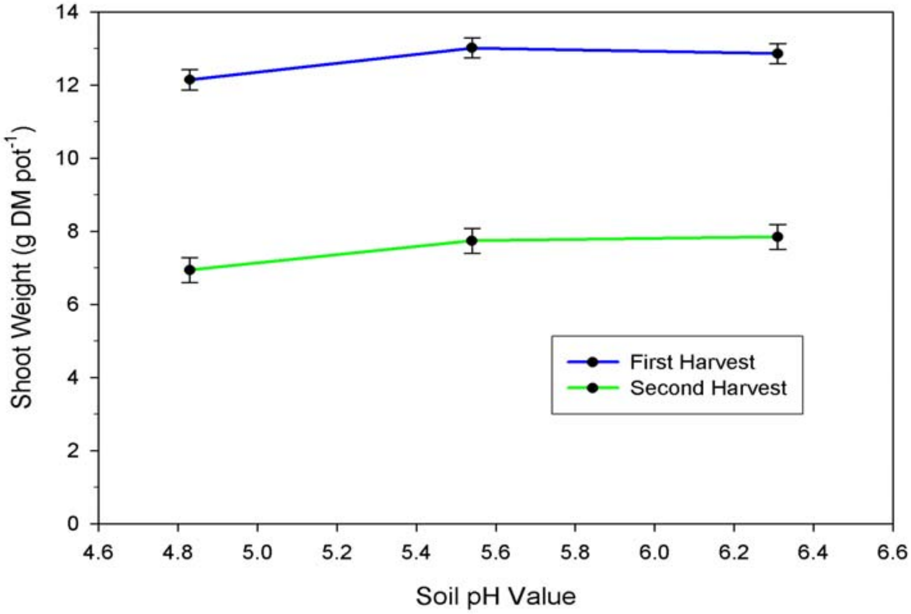
Fig. 3.2. Crabgrass growing in a sidewalk in its role as an invasive weed.

Fig. 3.3. Soil and amendments being thoroughly mixed in rotary cylinder mixer.


Fig. 3.4. Deionized water being added to soil during one of the three wetting and drying cycles used to amend soil pH.

Fig. 3.5. Plastic pots lined with polyethylene autoclave bags with an air tube added for aeration prior to filling with soil.

Fig. 3.6. Roots being washed free of soil after the first harvest.



Fig, 3.7. First and second harvest shoot yields averaged over trials as a function of soil pH value.

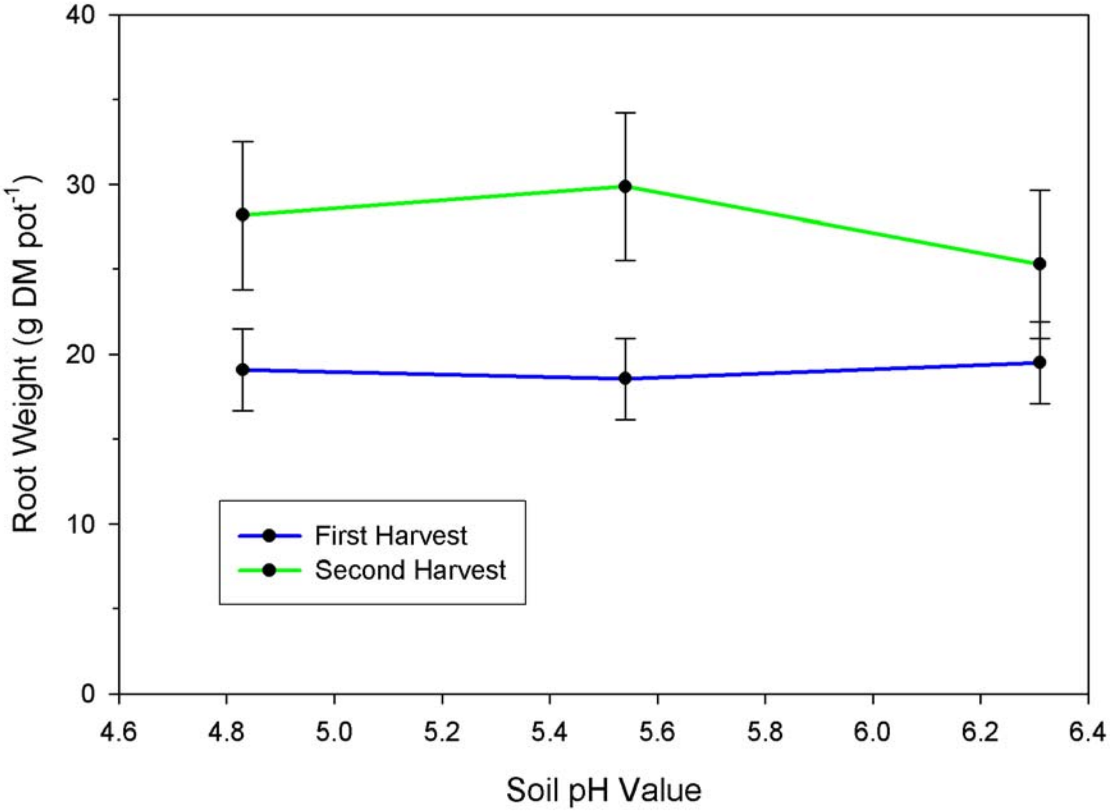


Fig. 3.8. First and second harvest root yields averaged over trials as a function of soil pH value.

CHAPTER 4

SUMMARY AND CONCLUSIONS

The transition zone between subtropical and temperate regions of the United States is dominated by low-fertility, acidic soils. The characteristic warm temperatures and intermittent rainfall during the summer months lead to a slump in production of cool-season forages. Use of warm-season forages, such as crabgrass and annual lespedeza, which are well-adapted to the soils and climate of this region, could provide high quality summer grazing.

The greenhouse portion of this research evaluated the effects of soil pH on the germination and root and shoot yield of crabgrass. The results indicated that crabgrass was unaffected by soil pH values between 4.8 and 6.3. These findings contrasted statements by Pierce et al. (1999) that increasing soil pH decreased root and shoot yields of crabgrass. However, the largest decreases in yield reported by Pierce et al. (1999) were found when soil pH was between 6.0 and 7.8, which are outside the range of the current study and most pastureland in the southeastern United States.

The field component of this research evaluated the effect of N fertilization and lespedeza seeding rate on dry matter yield, botanical composition, and nutritive value of crabgrass-annual lespedeza mixtures. Past research has reported that growing legumes in mixture with grasses increases the yield and forage quality of the stand (George et al., 2000; Mitchell et al., 1986; Posler et al., 1993). In contrast, the results of the current study indicated that growing lespedeza in mixture with crabgrass had limited beneficial effect on the yield and nutritive value of the sward. In addition, responses of nutritive value parameters of the crabgrass-annual lespedeza mixtures used in this research to N fertilization were varied and appeared linked to weather factors. Nitrogen fertilization did increase yield by as much as 46%. Under the conditions of the current study, little benefit may be realized from adding lespedeza to crabgrass stands, and, if the mixture is used, N fertilization may be appropriate.

Future research on crabgrass-lespedeza mixtures that evaluates the association in years without excessive moisture is needed. The above average rainfall received throughout the duration of the field study conducted for this project undoubtedly impacted the results. Research is also needed to determine an optimal rate and application timing for N fertilization of crabgrass-annual lespedeza mixtures. Field research to confirm greenhouse data on the response of crabgrass to soil pH and the interaction of soil pH with N fertilization should also be conducted.

Previous research combined with the current work indicates that crabgrass can provide moderate amounts of highly digestible forage while growing on acidic soils. While annual lespedeza may be grown in association with crabgrass, limited improvement in yield and nutritive value may indicate that the cost associated with overseeding lespedeza into crabgrass stands may not be justified.

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APPENDIX A

FIGURES

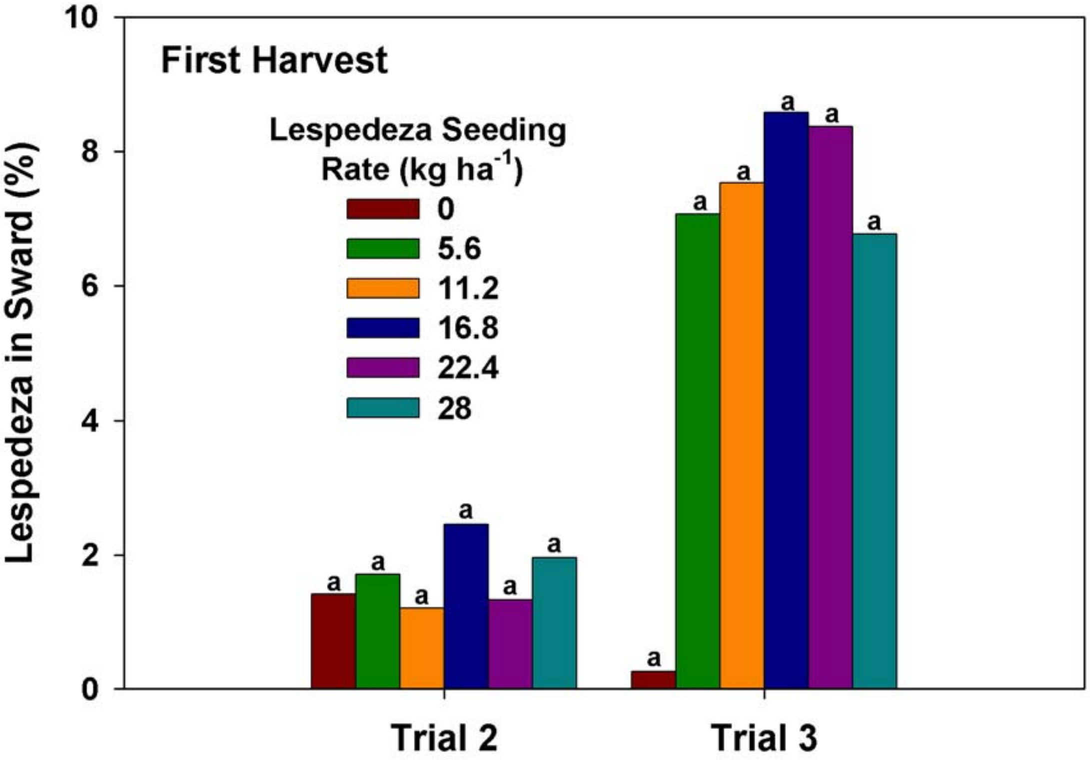

Fig. A.1. Percentage of lespedeza in the sward in the first harvest of Trials 2 and 3 as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

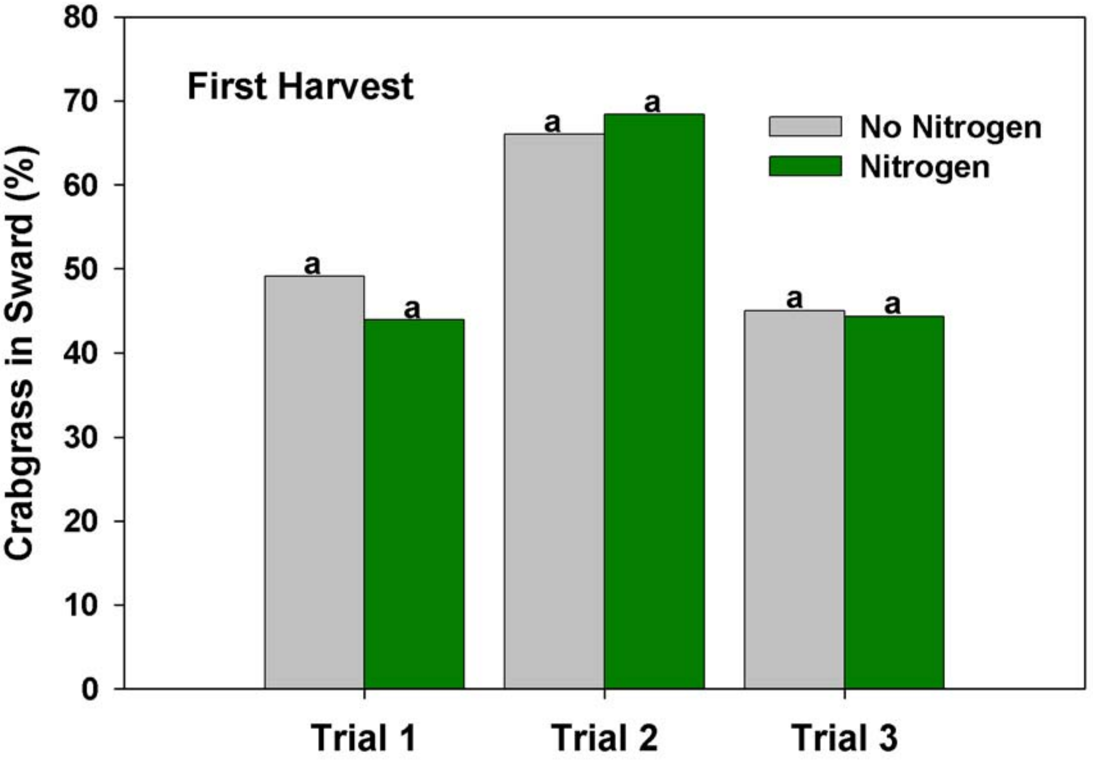

Fig. A.2. Percentage of crabgrass present in the sward in the first harvest of three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

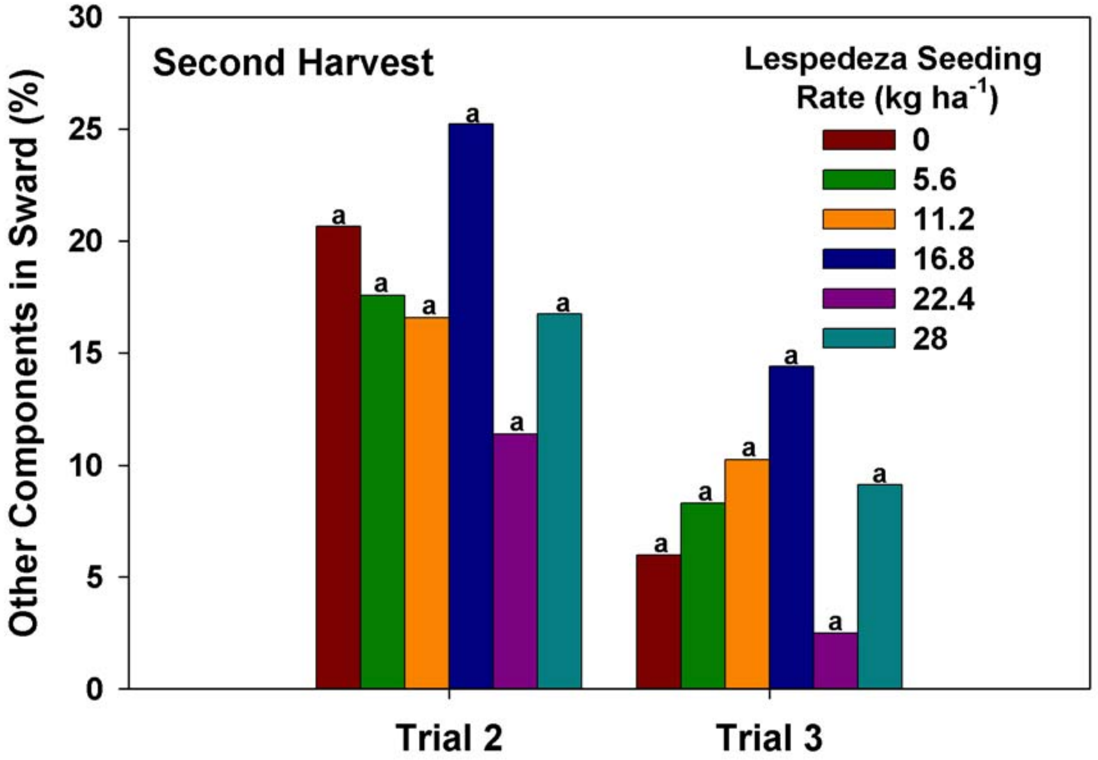

Fig. A.3. Percentage of other components in the sward in the second harvest of Trials 2 and 3 as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

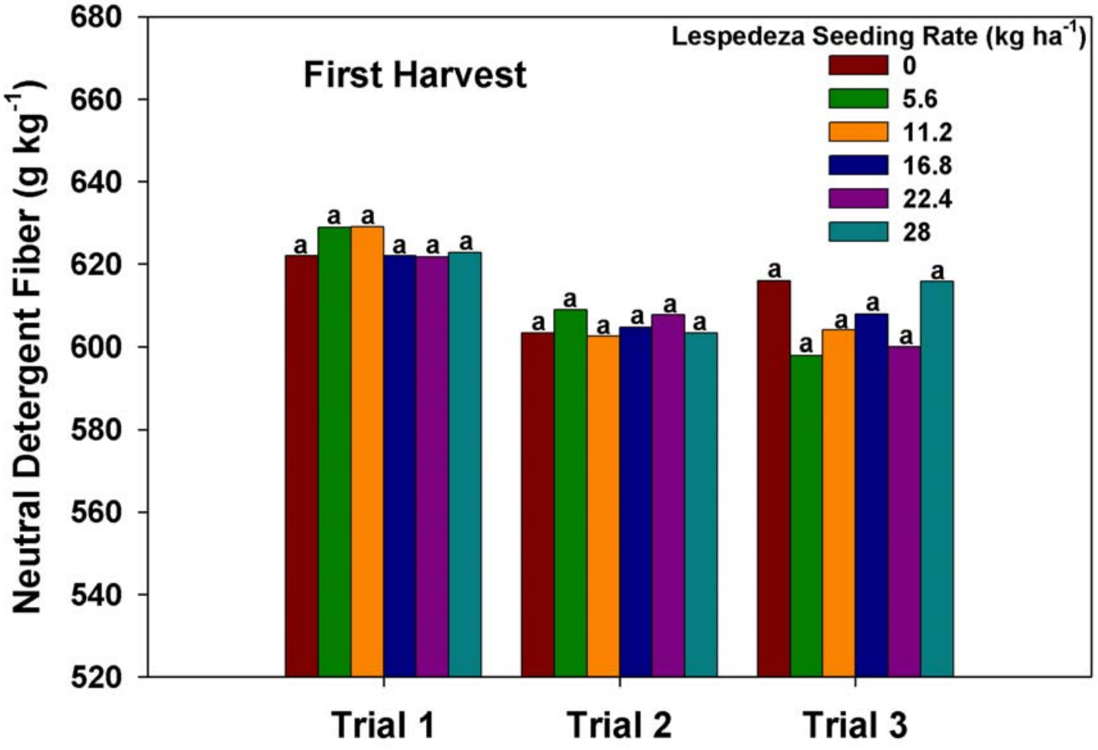

Fig. A.4. First harvest neutral detergent fiber content of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

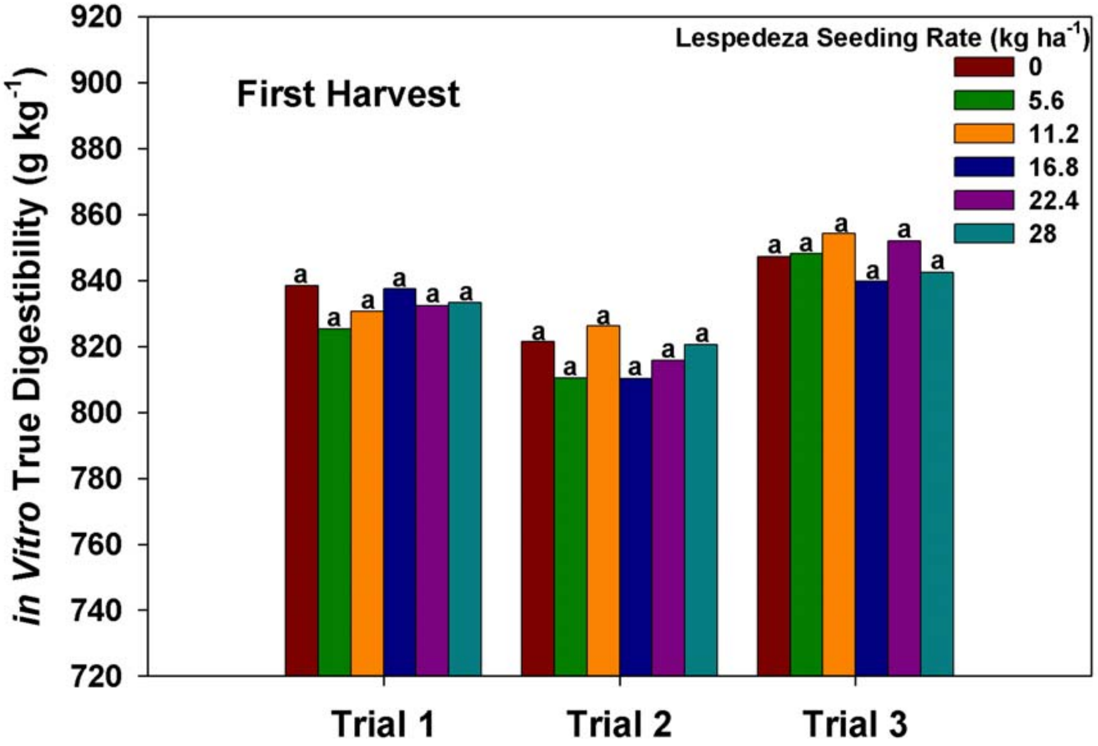

Fig. A.5. First harvest *in vitro* true digestibility of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

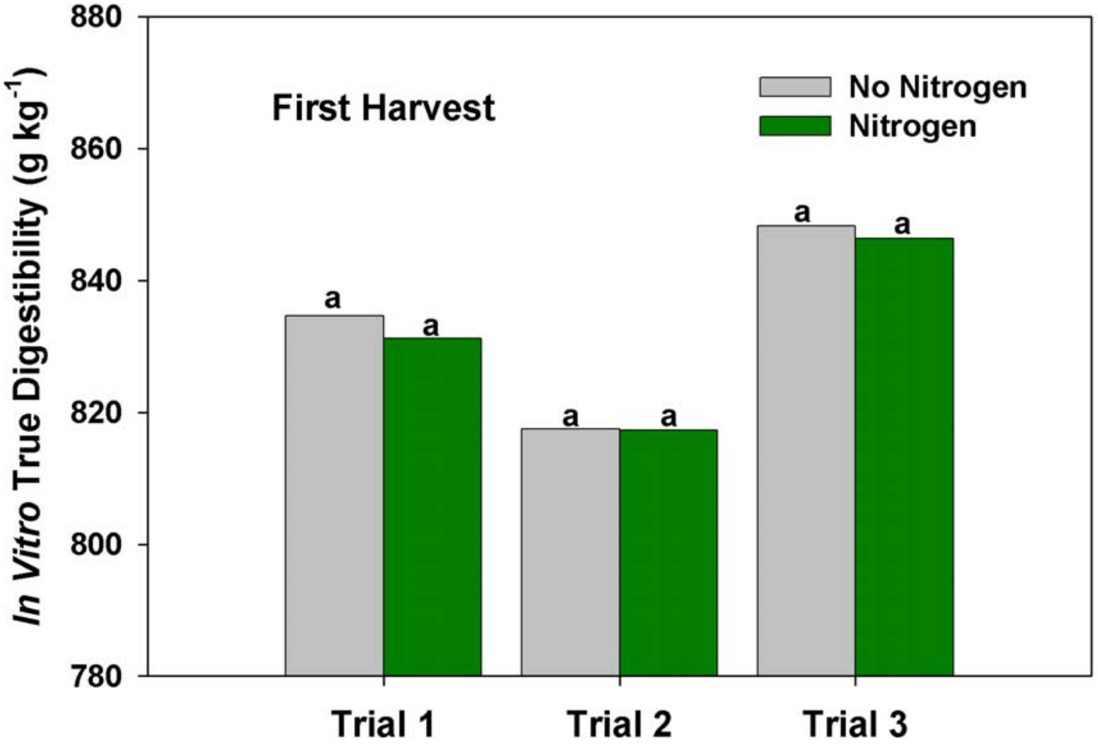

Fig. A.6. First harvest *in vitro* true digestibility of crabgrass-lespedeza mixtures in three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

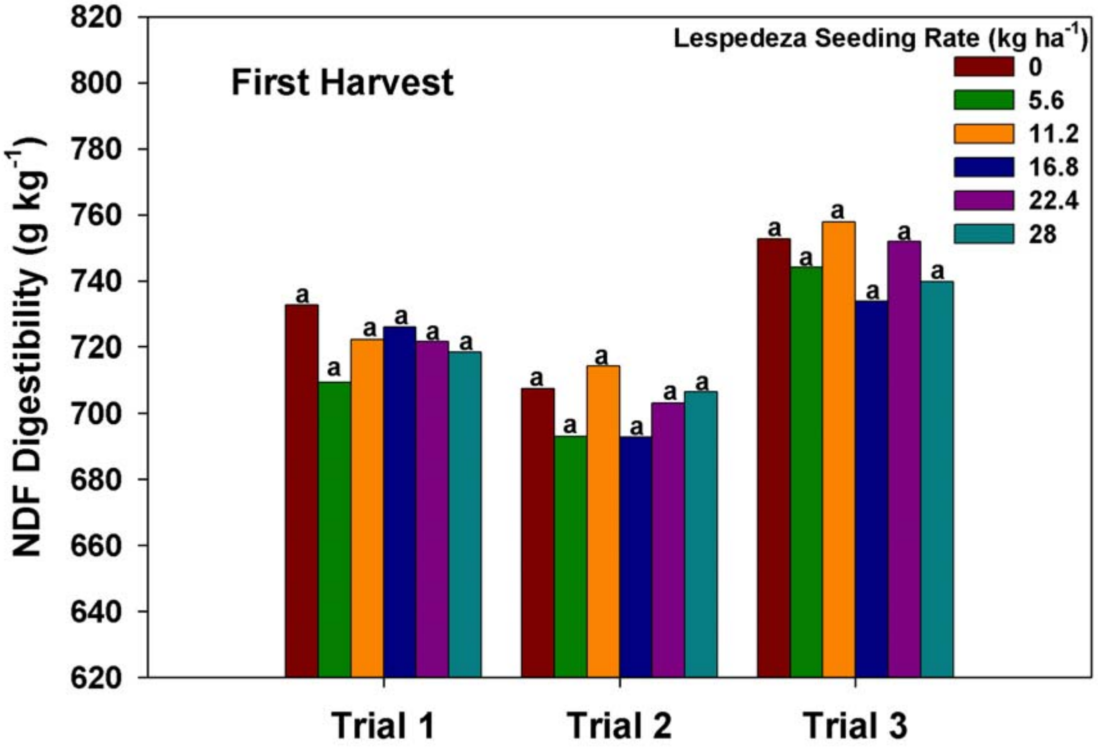

Fig. A.7. First harvest neutral detergent fiber digestibility of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

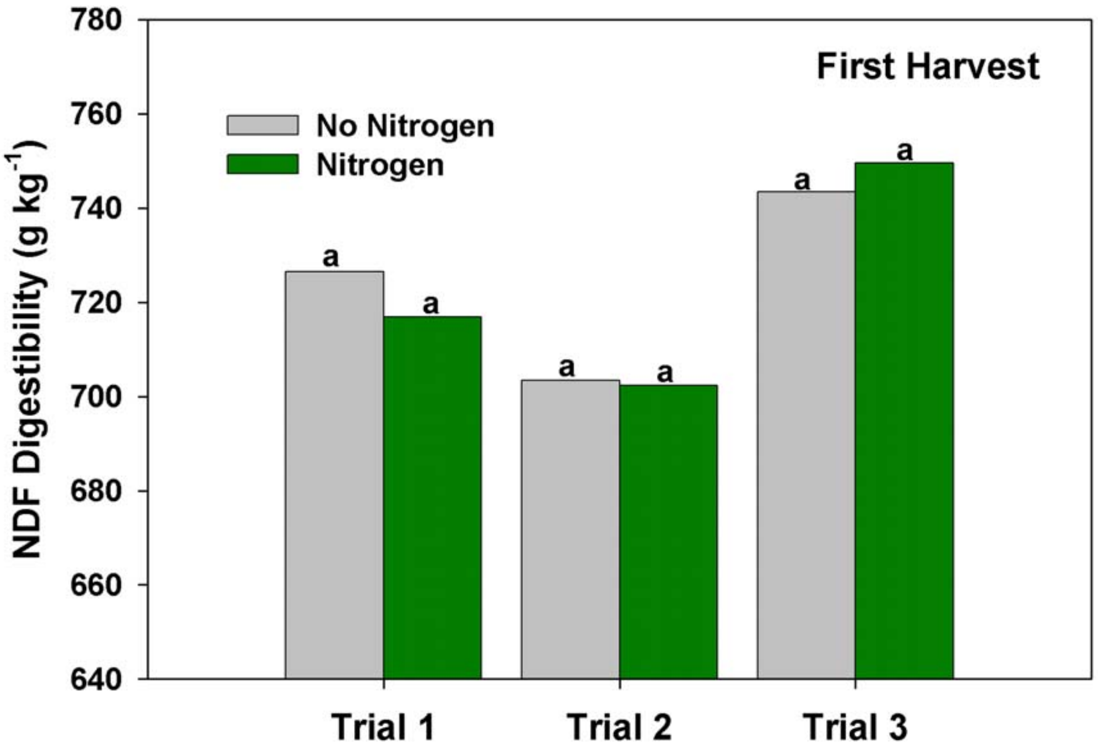

Fig. A.8. First harvest neutral detergent fiber digestibility of crabgrass-lespedeza mixtures in three trials as influenced by nitrogen fertilization (averaged over lespedeza seeding rate).

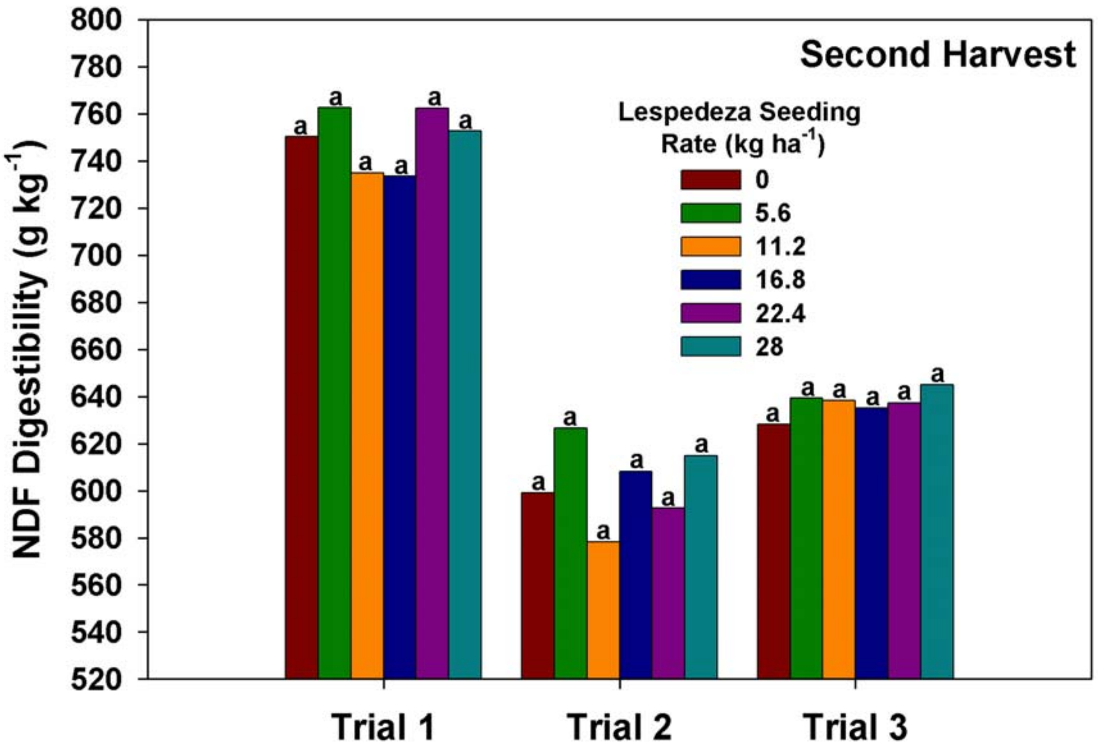

Fig. A.9. Second harvest neutral detergent fiber digestibility of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

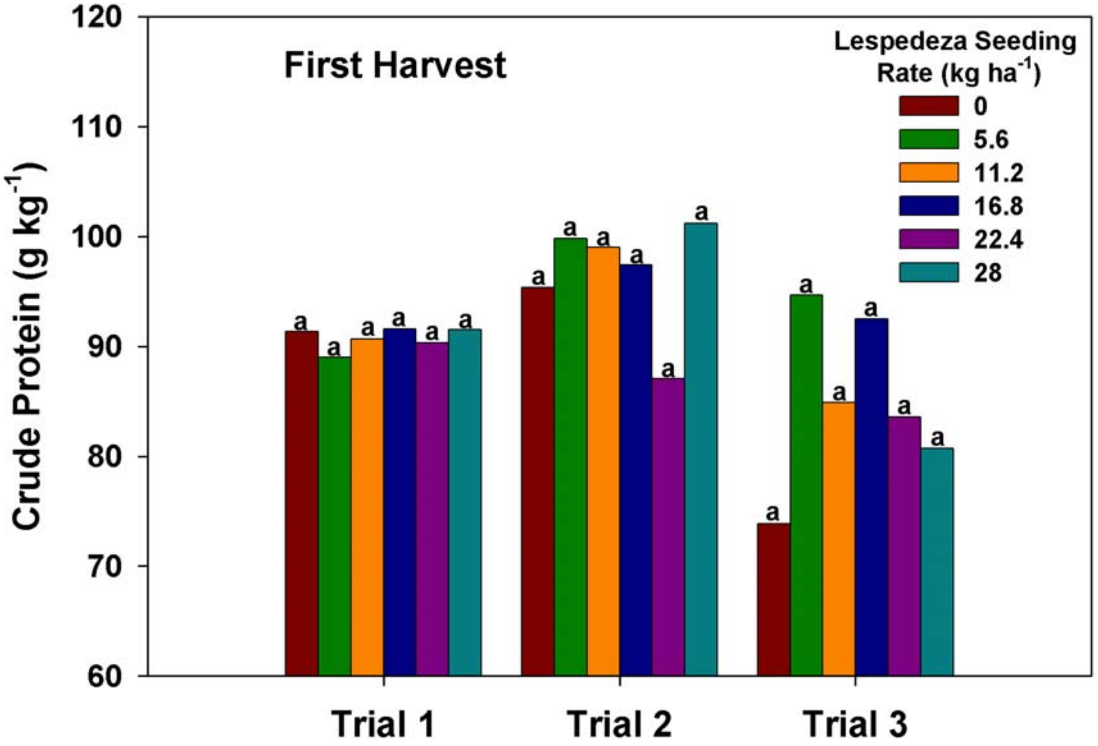

Fig. A.10. First harvest crude protein content of crabgrass-lespedeza mixtures in three trials as influenced by lespedeza seeding rate (averaged over nitrogen fertilization).

VITA

Emily Browning Aleshire was born in 1981 in Harrisonburg, VA, to John Fredric and Ollie Susan James Aleshire. She is the younger sister of Mollie Elizabeth Aleshire. She was raised in Luray, VA, where she was home-schooled throughout elementary and high school, and received a diploma from Abeka Video School in 1999. She attended Berea College in Berea, KY, and graduated in 2003 with a B.S. in Agriculture and Natural Resources. Following completion of her undergraduate degree, she returned to Virginia to pursue an M.S. degree in Crop and Soil Environmental Sciences at Virginia Polytechnic Institute and State University in Blacksburg.

EDUCATION:

Masters of Science in Crop and Soil Environmental Sciences, August 2005
Virginia Polytechnic Institute and State University, Blacksburg, Virginia
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Cumulative GPA 3.7

Bachelors of Science in Agriculture and Natural Resources, May 2003
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Cumulative GPA 3.5

Relevant Coursework Taken During Undergraduate Program:

Intro to Global Agriculture
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Plant Science
Introduction to Biology
Advanced Livestock Systems
Nutritional Studies
General Chemistry I-II
Applied Statistics
Forest and Wildlife Management
Farm Resource Management
Forage and Row Crop Production
Animal Science
Animal Reproduction and Breeding
Nutritional Physiology and Biochemistry
Organic Chemistry I-II
Information Acquisition and Analysis

Relevant Coursework Taken During Graduate Program:

Soils
Advanced Crop Physiology
Forage Crop Ecology
Weed Science
Soil Fertility and Management
Plant Physiology and the Environment
Grasslands Science
Statistics in Research I-II

EXPERIENCE:

Agricultural Research and Extension Center, May 2003 to July 2005
Virginia Agricultural Experiment Station, Blackstone, Virginia

- Managed forage research program and undergraduate labor as a graduate assistant.
- Designed, implemented, and analyzed trials (used Excel, SAS, and Sigma Plot).

Educational Farm, August 1999 to May 2003
Berea College, Berea, Kentucky

- Student supervisor of crops and maintenance operation, 2002 to 2003.
- Worked daily with activities of cattle, sheep, goat, and hog operations.

Tobacco Seed Production and Research Facility, January 2002 and 2001
F.W. Rickard Seeds, Inc., Winchester, Kentucky

- Performed laboratory operations concerned with tobacco leaf and seed research.
- Designed equipment for broadcasting growing medium additive onto seeding flats.

AWARDS:

- Second Place: Robert F. Barnes Graduate Education Award, Crop Science Society of America, October 2004.
- Aaron Ashley Memorial Award, Department of Agriculture and Natural Resources, Berea College, April 2003.
- Martin Aaron Wilson Rising Senior Dairy Interest Award, Department of Agriculture and Natural Resources, Berea College, April 2002.
- Undergraduate Research Award, Berea College, Fall 2000.
- Martin Aaron Wilson Rising Sophomore Dairy Interest Award, Department of Agriculture and Natural Resources, Berea College, April 2000.

PUBLISHED ARTICLES:

- Aleshire, E.B. and C.D. Teutsch. 2005. Soil pH effects on the shoot and root yield of crabgrass. Online. Forage and Grazinglands.

PUBLISHED ABSTRACTS:

- Aleshire, E.B. and C.D. Teutsch. 2004. Assessing the forage potential of crabgrass-lespedeza mixtures. American Society of Agronomy Annual Meetings, Seattle, WA.
- Aleshire, E.B. and C.D. Teutsch. 2004. Assessing the forage potential of crabgrass at varying pH levels. American Society of Agronomy Annual Meetings, Seattle, WA.
- Teutsch, C.D. and E.B. Aleshire. 2004. Nitrogen rate and application timing effects on the yield and nutritive value of crabgrass. American Forage and Grassland Council Conference, Roanoke, VA.
- Teutsch, C.D., W.M. Tilson, and E.B. Aleshire. 2004. Performance of seeded bermudagrass cultivars in the northern transition zone. American Forage and Grassland Council Conference, Roanoke, VA.