Compatibility, Yield, and Quality of Perennial Warm-Season Grass-Legume Mixtures

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(ABSTRACT)

The lack of consistent summer pasture supply is a major limitation to livestock production in the mid-Atlantic region. Perennial warm-season grasses might provide a solution if managed for high quality. Experiments were conducted on separate well-established stands of Caucasian bluestem and 'Cave-in-Rock' switchgrass at the Kentland Farm near Blacksburg, VA. Stages of grass maturity at harvest simulating pasture and hay systems were tested. Six interseeded legume species and two grass monoculture checks, one with 56 kg N/ha applied in spring and after each harvest, the other with no N, were imposed as sub-plots. Legume species included alfalfa, red clover, sericea lespedeza, annual lespedeza, Illinois bundleflower, and purple prairieclover. Inter-seeded legumes provided small yet improved yield and forage quality of perennial warm-season grasses in the legume-establishment year. In the year following establishment, grass mixtures with alfalfa, red clover, and, for switchgrass, sericea lespedeza yielded as much forage as N-fertilized grasses. Alfalfa and red clover altered the distribution of yield of the grasses, and may not be as compatible with perennial warm-season grasses as sericea lespedeza in the long-term. Interseeded legumes improved yield and quality significantly in terms of increased crude protein and lowered fiber concentrations in both, Caucasian bluestem and switchgrass in the second year.

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Table of Contents

List of Tables

List of Figures

INTRODUCTION

Many years Virginia experiences short periods of drought, especially in mid-summer. High temperatures and low precipitation are detrimental to production of cool-season forages. Lack of productivity of cool-season pastures during the summer months often results in overgrazing. This overgrazing weakens the plants, thereby reducing subsequent productivity and persistence. It also denudes some areas of vegetation, thereby increasing the potential for weed establishment and for erosion and nutrient runoff from these sites when rains return. If producers had other inexpensive summer feeding options, cool-season grass pastures could be "rested" during this "summer slump" and remain more vigorous and persistent.

Stocking rates on most Virginia farms are often conservative because of the anticipated summer slump in cool-season grass production. This typically results in understocking of spring pasture and thus underutilization of grass growth that could be used to produce animal gain or milk. If a more consistent pasture forage supply could be depended upon on Virginia livestock farms, producers could more confidently increase their stocking rates, thereby increasing their profitability.

Tall-growing perennial warm-season grasses produce 65 to 75% of their yields in mid-summer, which could provide forage during this period of reduced cool-season forage production (Jung et al., 1978). While perennial warm-season grasses, such as switchgrass (*Panicum virgatum* L.) and Caucasian bluestem [*Bothriochloa caucasia* (Trin) C.E. Hubbard], have proven to be consistently productive when grown where adequate soil depth is present to allow them to express their rooting potential, their nutritional quality has been marginal. With typical management, switchgrass crude protein (CP) concentration is often less than 10%, and cell wall content (neutral detergent fiber) frequently exceeds 70%. Thus, nutritional value of perennial warm-season grasses as they are often managed is insufficient to maintain high rates of gain or milk production. Legume inter-seeding, a common practice in cool-season grass stands, might improve the forage quality of perennial warm-season grass stands.

Pasture-based dairy farms are growing in number as this method of dairying becomes recognized as a profitable method. However, consistent summer pasture supply is one of the major limitations to pasture-based dairying. If their forage quality was maximized, perennial warm-season grasses might provide a solution to this dilemma.

Methods to effectively establish and manage switchgrass and Caucasian bluestem for yield and persistence have been well characterized in Virginia. The potential of these species to provide a dependable pasture forage supply during summer months warrants investigation of options to enhance their forage quality. The purpose of this project was to address the potential of managing switchgrass and Caucasian bluestem for higher forage quality by introducing legumes. The following hypotheses were tested:

1- The potential to no-till legumes into existing perennial warm-season grass stands.

2- The ability of legumes to improve yield and quality of perennial warm-season grasses.

3- The compatibility of legumes with perennial warm-season grasses.

LITERATURE REVIEW

Distribution and Adaptation

Prior to the dominant presence of European immigrants on the North American continent, there were millions of acres of perennial warm-season grasses on unforested land. With the introduction of intensive cropping and heavy, continuous stocking by cattle, the presence of these native warm-season grasses declined dramatically (McKenna, 1988). Switchgrass is one of the native grasses that has recently received increasing attention because of its vigorous summer growth. Caucasian bluestem is an introduced perennial warm-season grass that has also gained prominence.

Switchgrass, offers great potential for use in pasture, hay, and range (Eberhart and Newell, 1959). Switchgrass is one of the dominant species of the true or tall grass prairies and flood plains of the Great Plains, and has been viewed as a desirable species since the early 1900’s (Lyon and Hitchcock, 1904). Switchgrass is distributed from Canada to Central America and from the Atlantic coast to Nevada. Usually found in large bunches, switchgrass spreads by thick, scaly, creeping rhizomes. The inflorescence is a large open panicle (Hitchcock, 1951).

Switchgrass is adapted to a wide range in soil pH (4.9 to 7.6), precipitation (40 to 260 cm/year), and average annual temperature (17 to 26 degrees C) (Duke, 1978). Switchgrass, exhibits C4 photosynthesis and therefore is able to decrease transpiration and maintain photosynthesis during hot and dry days. As a consequence of C4 photosynthesis, switchgrass tolerates water stress and gives high yields during the summer slump (Trocsanyi, 1990). Based on habitat and morphological characteristics, "upland" and "lowland" ecotypes have been described. Upland ecotypes are 0.9 to 1.5 m tall, semi-decumbent, fine-stemmed, early maturing, and found naturally on loamy or sandy soils. Lowland types are 0.6 to 3.0 m tall, robust, coarse, thick-culmed, with large, wide panicles, longer leaves, and shorter rhizomes than upland types, and are found primarily on fine textured soils (Cornelius and Johnston, 1941; Eberhart and Newell, 1959; Porter, 1966).

Caucasian bluestem, also known as Old World bluestem, originated in Russia. It was sent to the United States in 1929 by the Botanic Garden at Tiflis, Georgia, USSR (Harlan, 1952). Caucasian bluestem produces nearly all of its herbage between 1 June and 31 August, compared to 42% during this period for 'Alta' tall fescue (*Festuca arundinacea* Schreb.) (Forwood et al., 1988). The carrying capacity of Caucasian bluestem from June through August is generally two to three times higher than that of tall fescue, partially due to the abundant new tiller growth of Caucasian bluestem that occurs throughout the summer (Forwood et al., 1988). Like all warm-season grasses, Caucasian bluestem utilizes the C4 pathway for photosynthesis and therefore is able to tolerate water stress. It is a leafy bunchgrass with fine stems, short-growing (~ 1m tall), and has bluish-purple seedheads and leaf blades (Ball et al., 1996). The major use of Caucasian bluestem is pasture and hay.

Defoliation Management Effects on Yield, Persistence, and Quality of Switchgrass and Caucasian Bluestem

Switchgrass yielded an average of 3.7 Mg dry matter (DM) /ha from late June to August at low fertility levels in Pennsylvania (Griffin and Jung, 1981). In Missouri, switchgrass yields averaged 8.3 Mg DM/ha and 5.2 Mg DM/ha with two cuttings per year over a three year period when cutting height was 8 cm and 23 cm, respectively. Corresponding yields of Caucasian bluestem were 8.4 and 5.3 Mg DM/ha, respectively (Anderson and Matches, 1983). In Iowa, George and co-workers (1990) evaluated yield and quality of 'Cave-in-Rock', 'Pathfinder', and 'Blackwell' switchgrass cultivars. Yields were determined by cutting herbage at a 20-cm height. Spring herbage DM yield of Cave-in-Rock (1.78 Mg/ha) exceeded that for Pathfinder and Blackwell by 0.43 and 0.55 Mg/ha, respectively.

In Pennsylvania, Jung and co-workers (1990) studied perennial warm-season grass responses to N. They evaluated differences among six grass species and among cultivars of big bluestem (*Andropogon gerardii* Vitman), switchgrass, and indiangrass (*Sorghastrum nutans* L.). The stubble height left at the first harvest was approximately 7 cm for the short growing grasses and 15 cm for the others, and that left at the second harvest was 5 cm for all grasses. Mean DM yields of 'New Jersey 50' switchgrass over 4 years was 10.1 Mg/ha/yr, which was significantly higher than mean yields of all other entries. Yields for other switchgrass varieties ranged from 8.0 to 8.5 Mg/ha. The variety 'Cave-in-Rock' was not included in their trial. Mean yields of big bluestems ranged from 5.4 to 6.1 Mg/ha. Mean DM yield of forage from all warm-season grasses was 2.1 Mg/ha higher when N was applied than when it was not applied.

A 20-cm residual cutting height has been recommended to maintain switchgrass stand productivity (Balasko et al., 1984; Jung et al., 1985). Trocsanyi (1990) studied the influence of cutting management on yield and canopy characteristics of switchgrass in Virginia. Switchgrass was subjected to several cutting treatments, including four dates of first harvest, and two cutting heights (20 versus 30 cm). She concluded that early June harvest with a cutting height that does not remove growing points, results in sufficient regrowth of switchgrass, which could supply forage for animal production during the summer slump. A cutting height of 20 cm decreased vigor of switchgrass, especially if plants were harvested at the end of June.

Switchgrass has few basal leaves to provide photosynthate; therefore the plant is dependent on energy reserves for regrowth. Nonstructural carbohydrates are often considered the primary source of reserve energy for regrowth (Anderson et al., 1989). Anderson and co-workers evaluated the interactions of meristem removal, tiller development, and nonstructural carbohydrate reserves on regrowth of switchgrass in Nebraska. They concluded that basal and axillary tiller (or growing points) removal in switchgrass resulted in a substantially greater decline in total nonstructural carbohydrates than defoliation that did not remove the growing points. George and co-workers (1989) reported that multiple, 6-cm defoliations of switchgrass in spring generally resulted in slower recovery of TNC concentrations than 15-cm or 20-cm defoliations. They suggested that greater removal of growing points and leaf area would require greater TNC reserves to support initiation of basal and axillary meristem regrowth and development of new leaf area. Belesky and Fedders (1995) further studied the relationship between canopy morphology and defoliation regimes. Canopy morphologies were represented by flaccidgrass (*Pennisetum flaccidum* Griseb.), switchgrass, bermudagrass (*Cynodon dactylon* L.), and Caucasian bluestem. Flaccidgrass and switchgrass represented the erect or tall-growing grasses, and bermudagrass and Caucasian bluestem represented the low-growing grasses. They found that early and continued clipping was detrimental to yield of erect-growing grasses. In contrast, when Caucasian bluestem was frequently defoliated, tiller populations increased and formed a dense ground cover.

Caucasian bluestem, with its indeterminate growth habit and abundant basal leaves, may be more adaptable to continuous grazing than switchgrass (Anderson and Matches, 1983). Also, Caucasian bluestem appears to have a lower energy requirement than native warm-season grasses. Basal leaves make Caucasian bluestem less dependent on stored TNC for regrowth (Finch, 1973; Forwood et al., 1988). In Oklahoma, a study was conducted on grazing effects on the total nonstructural carbohydrate pools in Caucasian bluestem. Christiansen and Svejcar (1987) concluded that Caucasian bluestem survived continuous heavy grazing over three consecutive seasons, reinforcing indeed the hypothesis of Anderson and Matches in 1983.

The forage quality of switchgrass has been reported to be adequate for mature brood cows, however, the high proportion of stem tissue present at maturity (63%) limits the quality of the whole plant (Griffin and Jung, 1981; Panciera, 1982). In Iowa, CP concentration was greater in Cave-in-Rock than in Pathfinder or Blackwell, 143 g/kg compared to 139 and 136 g/kg, respectively (George et al., 1990). In Missouri and Oklahoma, digestibility and CP concentration of switchgrass and Caucasian bluestem decreased with time between harvests (Anderson and Matches, 1983; Taliaferro et al., 1984; Forwood et al., 1988). Anderson and Matches (1983) speculated that animal voluntary intake of both species might be increased by grazing at vegetative stages. The forage quality of Caucasian bluestem is considered to be better than that of switchgrass (Forwood et al., 1988).

In Nebraska, Anderson et al. (1988) studied forage quality and performance of yearlings grazing switchgrass strains. When grazing began at the boot stage, gains of yearlings were substantially less than when grazing began prior to the boot stage. They concluded that forage quality (in vitro dry matter digestibility or IVDMD and CP) declined rapidly as plants matured to the heading stage and confirmed Anderson and Matches' suggestion that grazing should begin prior to the boot stage. In Oklahoma, performance of steers grazing Caucasian bluestem was reported to be excellent (Coleman and Forbes, 1997). Average daily gains varied between 0.55 to 0.81 kg/day depending on the grazing pressure applied.

Wolf and Fisher (1996) established guidelines on how to manage switchgrass for grazing and hay harvest in Virginia. They recommended that grazing begin in late May when there are about 45 cm of growth. Cattle should graze to leave a 30-cm stubble; controlled grazing is the best management. About 5 weeks of rest should be allowed for regrowth. For hay harvest, they recommended the first harvest be at late boot stage, around June 15 to June 25. Cutting at 20 to 25 cm benefits regrowth. Leaving nodes on the stems in the stubble allows for axillary tiller formation. These tillers provide leaf area and energy for faster regrowth. A second hay cut can be expected in mid August.

Guidelines on how to manage Caucasian bluestem for grazing and hay harvest in Virginia have been established as well (Wolf et al., 1995). They recommended that grazing begin between June 5 and 10 at about 20 cm of growth and that cattle graze to leave 8 to 10 cm stubble. For hay harvest, they recommended taking the first hay harvest at the late boot stage (between June 15 to 25), a second hay cut in August, and a third 2 weeks before the first frost date. Cutting at 8 to 10 cm was recommended to benefit regrowth.

Limitations of Use of Switchgrass and Caucasian Bluestem

Wolf and co-workers at Virginia Tech have characterized the yield potentials, fertility requirements, and establishment requirements and methods for switchgrass and Caucasian bluestem (Wolf et al, 1996; Wolf and Fiske, 1995). Many Virginia producers have established these species in the last 10 years. However, slow establishment and high establishment costs have caused many producers to manage their warm-season grass stands quite conservatively, for fear of damaging stands that took significant investment in time and money to establish. This conservative management has often taken the form of infrequent harvest, which results in mature, stemmy growth that is of moderate to low forage quality. Legumes are commonly seeded with cool-season grasses to improve forage quality and distribution of yield. A thorough investigation of management techniques that might enhance the forage quality of perennial warm-season grasses is needed. Introduction of legumes together with manipulation of frequency of defoliation may hold the key to producing higher quality forage from warm-season grasses.

Introducing Legumes into Cool-Season Grasses to Improve their Quality

The benefit of including legumes in mixture with grasses has long been recognized. Introducing legumes in pastures and hay fields improves forage quality and lowers the cost of production (Brown and Munsell, 1943). Legumes provide proteins that grasses lack and increase dry matter yield by fixing atmospheric nitrogen and converting it into a soluble inorganic form that can be absorbed into plant tissues. Several investigators have reported that legumes exert a beneficial effect by increasing the protein content of the non-legume component of the mixture (Wagner, 1954). Legume-grass mixtures produce more forage than pure stands of grasses receiving no or moderate amounts of N fertilizer (Barnett and Posler, 1983; Carter and Sholl, 1962; Dobson et al., 1976; Jones et al., 1988). In Minnesota, Heichel and Henjum (1991) reported that forage legumes in mixture with grass are virtually self-sufficient for N and can concurrently transfer considerable N to the companion grass. Swards of reed canarygrass (*Phalaris arundinacea* L.) with alfalfa (*Medicago sativa* L.), birdsfoot trefoil (*Lotus corniculatus* L.), red clover (*Trifolium pratense* L.), or ladino clover (*T. repens* L.) were evaluated for stand composition, dry matter productivity, N fixation, and N transfer. Alfalfa in mixture with grass fixed the most N per season. The proportion of legume in the stand was significantly correlated to seasonal dry matter productivity. West and Wedin (1985) characterized the relationship between N fixation, alfalfa DM yield, and percentage alfalfa in mixture with orchardgrass (*Dactylis glomerata* L.) in Iowa. Grass DM yield alone averaged 4.0 Mg/ha, compared to 6.2 Mg/ha when mixed with alfalfa. The percentage of alfalfa in the mixture averaged 34%. The amount of N fixed was directly related to alfalfa DM yield and perhaps to percentage of alfalfa.

In Virginia, alfalfa was successfully no-till planted into tall fescue sod in the fall. Adding phosphorus to encourage early seedling development and spraying with paraquat to reduce the competition for water, light, and P from the existing fescue sod benefited alfalfa establishment (Bryant, 1983). Studies with no-till alfalfa conducted by Wolf et al. (1983) indicated that carbofuran, an insecticide, increased stand, yield, and percentage of alfalfa in the year of establishment. No-till planting of alfalfa and red clover is recommended for improving the nutritive value and seasonal production of endophyte-infected tall fescue (Hoveland et al., 1996,1997). ‘Alfagraze’ alfalfa was no-till planted in September of 1996 using paraquat herbicide and vinclozolin insecticide. Grass suppression was beneficial in no-till planting of alfalfa in northern Georgia. In 1997, ‘Redland III’ red clover was no-till planted in September using paraquat herbicide, vinclozolin fungicide, and nutrients (56 kg P_2O_5/ha and 56 kg K_2O/ha). Fungicide, grass suppression and nutrient application increased red clover forage yield significantly (Hoveland et al., 1997).

Previous Work with Warm-Season Grass-Legume Mixtures

The advantages of cool-season legumes in cool-season pasture and hayland planting have been well documented, but there is little information on mixing legumes with warm-season grasses in the mid-Atlantic region. Iowa researchers successfully established several cool-season legume species into established stands of switchgrass via both broadcast seeding and no-till drilling, with red clover performing the best (Blanchet et al., 1995; Gettle et al., 1996). Ten forage legumes and a legume mixture were no-till inter-seeded into established ‘Cave-in-Rock’ switchgrass in Iowa in early April. Legumes included biennial ‘Polara’ white-flowered sweetclover (*Melilotus alba* Medik.) and ‘Madrid’ yellow-flowered sweetclover (*Melilotus officinalis* Lam.), ‘Norcen’ and ‘Fergus’ birdsfoot trefoil, ‘Apollo Supreme’ and ‘Alfagraze’ alfalfa, 'Mammoth' and

‘Redland II’ red clover, ‘Emerald’ crownvetch (*Coronilla varia* L.), common hairy vetch (*Vicia villosa* Roth.), and a 50:50 mixture of Norcen trefoil and medium red clover. Excellent legume establishment occurred for all legumes by June. The alfalfa cultivars and hairy vetch had the highest percentage establishment. Gettle et al. (1996) successfully established the same species of cool-season legumes by frost-seeding into established switchgrass. Red clover establishment was greater than for most other legumes in both years of the experiment. This method would save the cost of planting.

George et al. (1995) reported improved forage yields and seasonal distribution of forage supply by renovating switchgrass pastures with cool-season legumes. In the year after legume establishment, the red clover mixture produced the highest upper canopy (> 20 cm) total season DM yield (8.78 Mg/ha) compared to switchgrass with 240 kg N/ha which produced only 3.41 Mg/ha. The alfalfa mixture produced 5.21 Mg/ha. Jung et al. (1985) measured performance of switchgrass and bluestem cultivars in mixture with red clover, ladino clover, alsike clover (*T. hybridum* L.), birdsfoot trefoil, and bigflower vetch (*Vicia grandiflora* L.). They reported that the introduction of legumes, especially red clover, into mixed swards by over-seeding was not difficult when warm-season grasses provided less than 75% ground cover. Introducing these legumes into warm-season grass pastures by over-seeding increased the yield of these pastures. Red clover contributed 20% of the total estimated forage in swards of Caucasian bluestem, in spring of 1978, and ranged from 15 to 28% of the total forage for different strains of switchgrass. Red clover composition was significantly higher than birdsfoot trefoil composition in both switchgrass and Caucasian bluestem.

Several native warm-season legume species including purple prairieclover (*Petalostemon purpureus* L.), roundhead lespedeza (*Lespedeza capitata* Michx.), and Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacMill., B. Robins. & Fern.] worked well when seeded with switchgrass in Kansas (Posler et al., 1993). Forage yields of grass-legume mixtures were significantly higher than yields of grass alone. Yields of switchgrass mixed with purple prairieclover, roundhead lespedeza and Illinois bundleflower averaged 5.2, 5.6, and 5.5 Mg DM/ha, respectively, over two years. Forage yields of switchgrass alone averaged 2.5 Mg DM/ha. Although the inclusion of legumes had no effect on forage digestibility, CP concentrations of warm-season legume-grass mixtures were higher than that of switchgrass alone. No attempt was made to introduce these legumes into an established warm-season grass stand. Annual and perennial (sericea) lespedeza are warm-season legumes that might be compatible with warm-season grasses. Both cool-and warm-season legumes need to be tested for their compatibility with warm-season grasses under Virginia conditions.

Description of Legumes

<u>Cool-season legumes</u>:

Alfalfa is a cool-season perennial with a distinct taproot and trifoliate leaves. It is an erect-growing plant with leafy stems arising from large crowns at the soil surface. Flowers of the varieties grown in the South are normally some shade of purple (Ball et al., 1996). Alfalfa's many benefits have earned it the reputation as "queen of forages". It was chosen for this experiment because of its high nutritional value, its adaptability to a wide range of soils and growing conditions, and its drought tolerance. Alfalfa not only benefits the grass but also the soil by adding high levels of N, improving soil tilth, and reducing soil erosion. No-till establishment of alfalfa has been reported to be successful (Bryant, 1983; Wolf et al., 1983; Hoveland, 1996).

Red clover is a cool-season, short-lived perennial with a taproot system with many secondary branches. It is an erect-growing, leafy plant with hairy leaves marked with a white “V”. Its flowers are clustered into large pinkish-violet heads. Red clover is a good source of nitrogen and is also drought tolerant (Ball et al., 1996). Red clover is extensively grown alone or in combination with grasses for hay and pasture in the northeastern, north-central, and southeastern United States. Red clover is successfully established in the upper South and northern USA without herbicide treatment of the sod. Red clover seeding vigor is much better than alfalfa, making it a better competitor with grasses (Hoveland, 1997).

Warm-season legumes:

Annual lespedeza (*Lespedeza striata* L.) is a warm-season annual with a taproot, trifoliate leaves, and pink to purple flowers. Its forage quality is excellent, and it is drought tolerant (Ball et al., 1996). Annual lespedeza germinates in the spring, grows throughout the summer, then makes seed and dies in the autumn. Dry matter yields are modest, but forage quality is excellent. It is tolerant of infertile and/or acid soils and is a good reseeder (Ball, 1997).

Sericea lespedeza (*Lespedeza cuneata* L.) is a warm-season perennial. It is an erect-growing, leafy, deep-rooted, and drought-tolerant plant (Ball et al, 1996). Sericea can grow on acid, high aluminum soils where alfalfa cannot. The potential of low-tannin sericea varieties to furnish low-cost grazing for steers makes it attractive in many situations (Schmidt et al., 1985).

Illinois bundleflower is a native warm-season perennial. It is upright and deep-rooted. It is found throughout the plains and prairies of the United States. Bundleflower is both winter hardy and drought resistant and grows on a wide range of soil types. Illinois bundleflower appears to have potential for pasture and range inter-seeding (Dovel et al., 1990).

Purple prairieclover is a native warm-season perennial. Reproduction is from underground stems and seed. The flowers are cone type growing at the tip of each stem, occuring from July to September. Purple prairieclover starts growing in the spring on the plains and prairies of the United States. The plant is high in protein value and is eaten by all livestock (Ball, 1997).

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MATERIALS AND METHODS

Soil and Location

The experiments were conducted on separate well-established stands of Caucasian bluestem and Cave-in-Rock switchgrass at the Kentland Farm near Blacksburg, VA, located at 37° 11' N°80° 25' W at 610 m elevation. The soil was a Groseclose loam (clayey, mixed, mesic Typic Hapludult). Switchgrass was used for four years as an establishment experiment; there was no harvest management prior to this experiment. Cave-in-Rock switchgrass was seeded in 1986 using a no-till drill at a rate of 4.5 kg/ha of pure live seed (McKenna and Wolf, 1990). Caucasian bluestem was drilled in 20-cm rows at a depth of 2.5 cm at 1.8 kg/ha of pure live seed, in 1985 (McKenna and Wolf, 1991). There was no harvest management on the Caucasian bluestem stand prior to this experiment. Both switchgrass and Caucasian bluestem were a mature established stand prior to this experiment. Legume species were no-till drilled into established grass stands. Soil samples were taken each year. Soil pH was determined on 1:1 (v/v) soil-water slurries and Mehlich I extractable nutrients were determined according to procedures outlined by the Council on Soil Testing and Plant Analysis (1980). Soil P and K were maintained at medium to high levels for both experiments, and pHs were 6.8 and 6.2 for switchgrass and Caucasian bluestem, respectively. The sites were prepared by burning dead warm-season grass residue in early April 1998.

Treatments

Two treatment factors were imposed on the well-established warm-season grass stands beginning in April 1998. One factor was defoliation management, either "hay" (reproductive) or simulated rotational "grazing" (vegetative). The other factor was legume/N treatments, including six interseeded legume species, and two grass monoculture checks, one with 56 kg N/ha applied in spring and after each harvest, the other with no N. The six legume species included ‘Choice’ alfalfa, ‘Cinammon’ red clover, ‘AU-Lotan’ sericea lespedeza, ‘Marion’ annual lespedeza, Illinois bundlflower, and purple prairieclover no-till seeded at 17, 7, 22, 17, 17, and 11 kg/ha, respectively, on 19 April 1998 using a Marliss no-till drill. The experimental designs were split-plots. The Caucasian bluestem and switchgrass experiments had three and four replications, respectively, with defoliation management as main plots and legume/N treatment as sub-plots.

Harvest dates for Caucasian bluestem harvested under "grazing" management were 15 June, 28 July, and 19 October in 1998; and 17 May, 8 July, 18 August, and 12 October in 1999. "Hay" management harvests occurred on 9 July and 14 September in 1998; and on 1 June, 28 July, and 14 September in 1999. For switchgrass, grazing harvests were 15 June and 11 August in 1998; and 30 April, 28 June, 18 August, and 13 October in 1999. Hay harvests occurred on 9 July and 14 September in 1998; and 17 May, 28 July, and 23 September in 1999.

At every harvest, a 1 x 6m swath of forage was cut from the center of each 2x6m plot with a flail harvester to estimate yield. Residual height of cutting was 7 cm for Caucasian bluestem and 20 cm for switchgrass except for the first grazing and hay harvest of switchgrass in 1999 when residual height was 10 cm. In 1998, harvested forage was weighed fresh, and a representative subsample was weighed fresh, dried at 65 degree C in a forced-air oven, and weighed dry to determine dry matter yield. This same subsample was ground to pass a 1mm screen and analyzed for crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) concentrations (AOAC, 1970; Goering and Van Soest, 1970).

At each harvest, two randomly placed 0.25 m^2 quadrats where hand-clipped at 7 cm above ground level for Caucasian bluestem and 20 cm above ground level for switchgrass, and composited into one sample per plot to determine botanical composition. Samples were hand-separated into “grass”, “legume”, and “weed” in the first year (establishment year for legumes). Due to some volunteer legume encroachment in 1999, a “legume-weed” category was added to discount its effect on measures of yield and forage quality. Species components were dried at 65°C and weighed to determine component percentages in the mixtures. In 1999, the “grass”, “legume”, and “weed” components were recombined, ground to pass a 1mm screen, and analyzed for forage quality.

In 1999, 2 to 3 weeks after each harvest, two random 0.25 m^2 quadrats were used to count legume and Caucasian bluestem plant density and switchgrass tiller density.

Data Analyses

Experiments and years were analyzed separately, since 1998 was an establishment year and 1999 was a full production year. Data for total season yield, season average botanical composition, and season average forage quality were analyzed by ANOVA, with defoliation management as main plots and legume/N as subplots. Individual harvest data including yield, botanical composition, and forage quality were analyzed as split-plots in time using ANOVA procedures. Legumes/N treatments were main plots and harvest dates were sub-plots. ANOVA procedures were used to detect treatment effects ($p<0.05$), and means were separated using LSD ($p<0.05$).

Results and Discussion

Weather Data

Growing season precipitation deviated considerably from 30-yr averages during the 2 years of the experiment (Table 1). In 1998, rainfall was well above average from April to through June and again in August, but considerably below average in July. In 1999, rainfall in April and May was slightly above average, well below average in June and August, but well above average in July and September. Temperatures were generally above average in 1998 and 1999 (Table 2).

Caucasian Bluestem-Legume Mixtures

Year 1: Yield and Species Composition

During the legume establishment year, legumes did not increase the yield of Caucasian bluestem compared to unfertilized Caucasian bluestem. Nitrogen-fertilized Caucasian bluestem had 50% greater total season yield than all Caucasian bluestem-legume mixtures, for which yield did not differ from Caucasian bluestem with no nitrogen (Fig.1). Legume composition was greatest for Caucasian bluestem mixtures with red clover, alfalfa, or sericea lespedeza, averaging 14% over the season (Fig.1). Annual lespedeza averaged only 7% over the season. Illinois bundleflower and purple prairieclover did not establish, therefore no results will be reported for these legumes. The competitive ability of the seedlings and their ability to perennate in an established grass sward, could have been the problem for these legumes. Establishment and survival of Illinois bundleflower into an established kleingrass pasture was successful using a pasture drill method and a broadcasting method, as well as a grass suppression treatment

(Dovel et al., 1990). Dovel reported that due to higher than usual rainfall, conditions for establishment of Illinois bundleflower, were very favorable. Indeed, another possible explanation could be that the amount of water received in 1998 was not sufficient to sustain these plants.

Hay management of Caucasian bluestem (2 harvests) yielded 27% more total DM than grazing management (3 harvests). Defoliation management did not affect legume composition. Cutting the Caucasian bluestem-legume mixtures twice during the legume establishment year produced an average of 12 Mg/ha of DM yield, as opposed to 8.8 Mg/ha when cut three times (Fig. 2). There was no defoliation management by legume/N treatment interaction for yield or legume composition. There was a significant harvest within defoliation management by legume/N treatment interaction ($P < 0.05$) for legume composition. The interaction was due to the delayed appearance of the warm-season legumes during the establishment year, especially sericea lespedeza (Fig. 3 and 4).

Year 1: Forage Quality

Caucasian bluestem mixtures with alfalfa or red clover or sericea lespedeza had slightly higher CP concentration than Caucasian bluestem alone ($P = 0.09$) (Fig. 5). Caucasian bluestem-legume mixtures had 6% lower neutral detergent fiber (NDF) concentrations than N-fertilized Caucasian bluestem (Fig. 6). Legume/N treatment had no effect on acid detergent fiber (ADF) concentrations during the establishment year. Acid detergent fiber concentrations were 9% greater for hay compared to grazing management. Defoliation management had only a slight effect on NDF concentrations ($P = 0.09$) and no effect on CP concentrations. There were no defoliation management by legume/N treatment interactions for CP, ADF or NDF.

Year 2: Yield and Species Composition

In year 2, mixtures of Caucasian bluestem with alfalfa or red clover had similar total season yield to N-fertilized Caucasian bluestem, which averaged 16.2 Mg DM/ha over the season (Fig. 7). Nitrogen-fertilized Caucasian bluestem yielded 250% more than unfertilized Caucasian bluestem. Season average legume composition was greatest for Caucasian bluestem mixtures with alfalfa, red clover, or sericea lespedeza, averaging 80, 60, and 40%, respectively (Fig. 7). Annual lespedeza averaged only 7% over the season. It may not have reseeded itself, or the Caucasian bluestem may have been too competitive.

Simulated rotational grazing of Caucasian bluestem (four harvests) yielded 26% more forage over the season than hay harvest management (three harvests) (Fig.8). One possible explanation may be the response to N application for the N-fertilized treatment. Caucasian bluestem under the grazing treatment was cut 4 times in the second year, therefore 3 x 56 kg N was applied for a total of 168 kg N. Under a hay treatment, the grass was cut 3 times, with 2 x 56 kg N (112 kg N). This could also be explained by Belesky and Fedders' suggestion (1995) that Caucasian bluestem, when frequently defoliated, produces more tillers and thus, increases its herbage. This suggests that Caucasian bluestem may be more adaptable to grazing. Defoliation management did not affect legume composition; however there were significant harvest within defoliation management by legume/N treatment interactions for both total season yield and season average legume composition (Fig. 9, 10, 11, and 12). Interseeded cool-season legumes substantially altered the yield distribution of Caucasian bluestem in the second year. The cool-season legumes were in higher proportion in spring-early summer, and N-fertilized Caucasian bluestem produced the most late summer-fall forage (Fig. 9, 10, 11 and 12). Early in the season, only alfalfa and red clover were growing, therefore only those legumes alone were cut in the first couple harvests. By the end of the summer, the N-fertilized Caucasian bluestem has received more N fertilization, which could explain the most late summer-fall forage.

Year 2: Plant Density

Plant density data were collected in the second year to better explain species composition and the competition and/or compatibility between grass and legumes. N-fertilized Caucasian bluestem plant density was higher than that of red clover or sericea lespedeza. At the first hay harvest (June 1st), alfalfa had a density 45% greater than that of red clover. There was no difference among treatments at later hay harvests (Fig. 13 and 14). There was a significant legume/N treatment by harvest interaction within defoliation management for legume plant density in year 2. This was due to the absence of warm-season legumes at the first harvests and a high population of annual lespedeza at the final grazing harvest (Fig. 15). Annual lespedeza may have had an adverse effect on total yield when Caucasian bluestem was harvested under simulated rotational grazing; its numerous plants may have competed with the grass. Legume plant density at individual hay harvests reflected the legume percentage for botanical composition, with more cool-season legumes early in the season and more sericea lespedeza later in the season (Fig. 16).

Year 2: Forage Quality

Legumes significantly improved forage quality during the second year (Fig. 17). Season average CP concentrations were highest with Caucasian bluestem mixed with alfalfa (170 g/kg DM), which is 63% higher than that of unfertilized Caucasian bluestem and 53% higher than that of N-fertilized Caucasian bluestem. This clearly shows the N contribution from alfalfa, which averaged 80% of the mixture. Red clover or sericea lespedeza mixed with Caucasian bluestem were second highest, averaging 115 g CP/kg DM. Red clover and sericea lespedeza averaged 60 and 40% of the sward, respectively. The annual lespedeza-Caucasian bluestem mixture had similar CP concentration to that of N-fertilized and unfertilized Caucasian bluestem alone and N-fertilzed Caucasian bluestem was significantly higher than unfertilized Caucasian bluestem. Acid detergent fiber and NDF concentrations were significantly lower with alfalfa (320 and 470 g/kg DM, respectively), or red clover (350 and 570 g/kg DM, respectively, Fig. 18) mixtures compared to the warm-season legume-Caucasian bluestem mixtures and Caucasian bluestem alone. However, sericea and annual lespedeza mixtures with Caucasian bluestem had similar ADF concentrations to that of red clover-Caucasian bluestem and those of N-fertilized and unfertilized Caucasian bluestem. The sericea mixture had a similar NDF concentration to those of red clover and annual lespedeza mixtures with Caucasian bluestem. The annual lespedeza-Caucasian bluestem mixture had NDF concentration that was similar to those of N-fertilized and unfertilized Caucasian bluestem. Defoliation management did not affect the forage quality of Caucasian bluestem-legume mixtures (Fig. 19) and there were no defoliation management by legume/N treatment interactions for any of the quality data; however there were significant legume/N treatment by harvest within defoliation management interactions (Fig. 20, 21, 22, & 23). The forage quality of Caucasian bluestem-legume mixtures is very impressive. Moreover, quality did not decrease with time between harvests. This was not the case in previous work done in Missouri and Oklahoma where digestibility and crude protein concentration of switchgrass and Caucasian bluestem decreased with time between harvests (Anderson and Matches, 1983; Taliaferro et al., 1984; Forwood et al., 1988).

Switchgrass-Legume Mixtures

Year 1: Yield and Species Composition

During the establishment year, N-fertilized switchgrass had 31% greater total season yield than all switchgrass-legume mixtures, for which yield did not differ from switchgrass with no N (Fig. 24). Season average legume composition was greatest for switchgrass mixtures with annual lespedeza, averaging 6% (Fig. 24). Mixtures of switchgrass with alfalfa or red clover or sericea lespedeza averaged 3%. Defoliation management did not affect total DM yield production or legume composition; however, total season yield of forage harvested under hay management was numerically higher than forage harvested via simulated rotational grazing (Fig. 25). There were no legume/N treatment by defoliation management interactions for yield or legume composition.

Evidence of an interaction between harvest within defoliation management and legume treatment occurred as legume percentage increased at the later harvests (Fig. 26).

Year 1: Forage Quality

During the establishment year, simulated rotational grazing produced forage with 20% greater CP concentration than hay management (Fig. 28). Legume/N treatments did not affect quality of switchgrass in the legume establishment year (Fig. 27 & 29). There were significant legume/N treatment by harvest within defoliation management interactions for CP and NDF concentrations, since there were no legumes present at the first two harvests. CP concentrations increased and NDF concentrations decreased at the later harvests when legumes were present.

Year 2: Yield and Species Composition

In year 2, mixtures of switchgrass with alfalfa, red clover or sericea lespedeza had similar total season yield to N-fertilized switchgrass, averaging 10 Mg DM/ha over the season (Fig. 30). Nitrogen-fertilized switchgrass yielded 300% more forage than unfertilized switchgrass (Fig. 30). Legume composition was greatest for switchgrass mixtures with alfalfa, red clover, or sericea lespedeza, averaging 60% (Fig. 30). The switchgrass-annual lespedeza mixture averaged 22% legume. As in the Caucasian bluestem experiment, cool-season legumes substantially altered yield distribution of switchgrass in the second year (Fig. 31 and 32). Defoliation management did not affect total DM yield or legume composition of switchgrass-legume mixtures (Fig. 33). There was a significant harvest within defoliation management by legume/N treatment interaction for legume composition (Fig. 34 and 35). Cool-season legumes were in higher proportion early in the season; red clover declined by late season, but alfalfa persisted. Annual lespedeza was generally low, especially under grazing harvests. Sericea lespedeza averaged more than 50% when present and may be the most compatible legume.

As in previous experiments in Iowa, both alfalfa and red clover had the highest percentage establishment (Blanchet et al., 1995; Gettle et al., 1996; Jung et al., 1985). Cool-and warm-season legumes improved forage yield and seasonal distribution of forage supply in switchgrass the year after establishment. Cutting at 20 cm stubble height for switchgrass may have reduced the amount of yield produced as indicated by Anderson and Matches in Missouri (1983).

Plant Density

Annual lespedeza, especially ‘Marion’ variety, has excellent natural reseeding ability and produced a dense stand in year 2. When mixed with switchgrass, annual lespedeza produced an average of 3244 plants/m^2 over the season. The reason why annual lespedeza was more dense in switchgrass, is probably because switchgrass does not form a dense cover as Caucasian bluestem does. Even though annual lespedeza growth was dense, it was mostly below the 20 cm residual height, which explains the difference between the density data expressed as counts and the composition data expressed as percentages (Fig. 36 and 37). Tiller density of switchgrass was higher with switchgrass mixed with alfalfa as compared to the switchgrass-red clover mixture in the first grazing harvest. Unfertilized and N-fertilized switchgrass had the highest tiller density at the second and third grazing. Nitrogen-fertilized switchgrass had the highest tiller density at the second hay harvest and was similar to those of annual lespedeza-switchgrass mixtures and unfertilized switchgrass at the third hay harvest (Fig. 38 and 39).

Year 2: Forage Quality

As in the Caucasian bluestem experiment, legumes significantly improved forage quality in the second year. Crude protein concentrations were highest in switchgrass mixtures with alfalfa or red clover, averaging 160 g/kg DM over the season, followed by sericea lespedeza (130 g/kg DM) which was not significantly different from annual lespedeza (110 g/kg DM, Fig. 40). These concentrations reflect the species composition, which averaged 60% for alfalfa, red clover, or sericea lespedeza. The 22% annual lespedeza contributed as well to the CP concentration of switchgrass. Warm-season legumes improved CP concentrations as in Posler's experiment in Kansas (1993). Acid detergent fiber concentrations were lowest in switchgrass mixtures with alfalfa or red clover, averaging 295 g/kg DM over the season (Fig. 41). Mixtures of switchgrass with sericea or annual lespedeza had ADF concentrations similar to those of N-fertilized and unfertilized switchgrass, averaging 335 g/kg DM over the season (Fig. 41). Neutral detergent fiber concentrations were lowest in switchgrass mixtures with alfalfa or red clover, averaging 475 g/kg DM over the season, followed by sericea and annual lespedeza, averaging 570 g/kg DM over the season. Nitrogen-fertilized and unfertilized switchgrass had the highest concentrations, averaging 630 g/kg DM over the season (Fig. 41). Defoliation management did not affect forage quality (Fig. 42) and there were no defoliation management by legume/N treatment or harvest within defoliation management by legume/N treatment interactions for any quality parameter (Fig. 43, 44, 45, and 46). As in Caucasian bluestem experiment, the time at which switchgrass-legume mixtures were harvested did not affect forage quality.

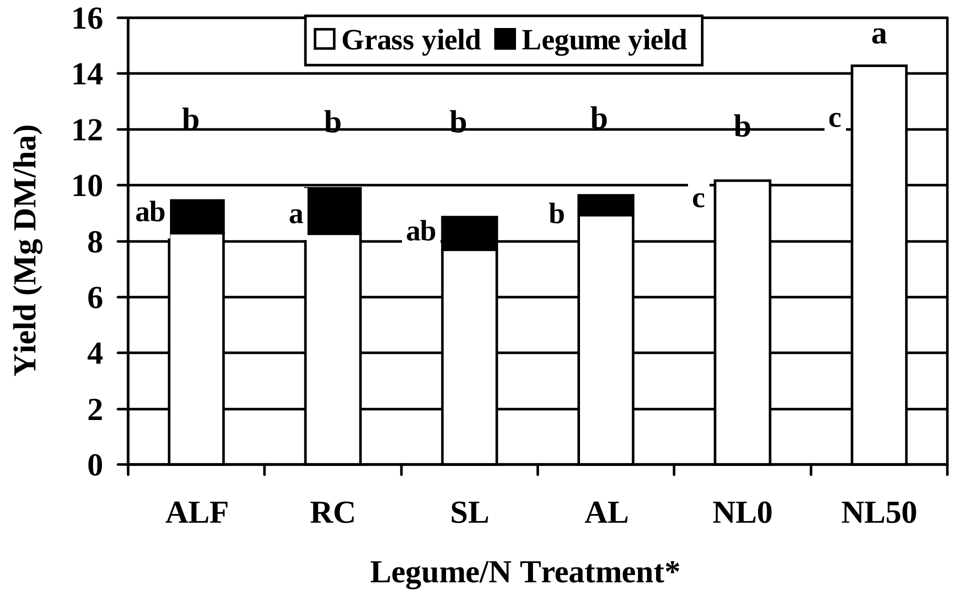
Table 1. Monthly precipitation and departures from 30-year averages at the Virginia Tech Kentland Farm, Whithorne, VA.

	1998		1999	
Month	Precipitation	Departure	Precipitation	Departure
	----------------------------Millimeters----------------------------			
January	148.84	90.93	99.56	41.65
February	64.77	-2.79	52.57	-14.97
March	119.12	41.65	63.50	-13.97
April	126.74	54.61	81.78	9.65
May	148.84	52.07	109.22	12.45
June	92.20	4.57	24.13	-63.50
July	49.27	-50.29	153.16	53.59
August	154.94	71.37	55.11	-28.45
September	28.70	-47.24	116.84	40.89
October	61.97	-22.86	43.18	-41.66
November	21.84	-43.43	53.34	-10.92
December	65.53	-3.81	45.72	-22.86
Total	**1082.80**	**144.78**	**898.14**	**-38.10**

Table 2. Monthly average temperatures from 1998 through 1999 and departures from 30-year averages at the Virginia Tech Kentland Farm, Whithorne, VA.

	1998		1999	
Month	**Avg.**	**Dep.**	**Avg.**	**Dep.**
	----------------------------Degrees Celsius------------------------			
Apr.	11.4	-16.8	12.1	-16.2
May	17.2	-16.3	14.8	-18.6
June	20.5	-17.1	19.6	-17.9
July	22.2	-17.4	23.6	-15.9
Aug.	21.5	-17.4	21.5	-17.4
Sept.	20.4	-14.9	17.3	-18.1

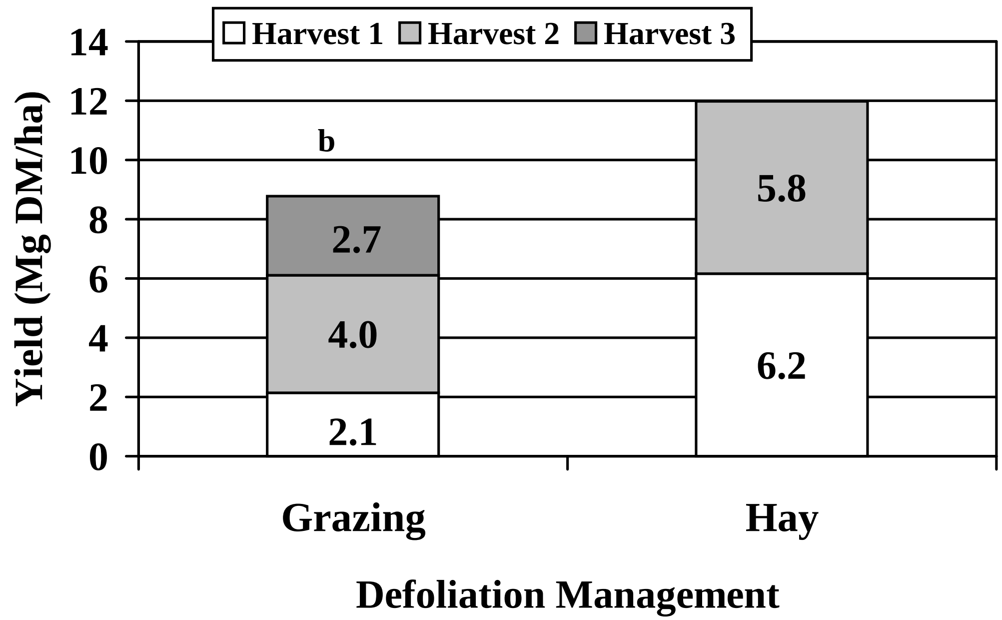
Figure 1. Total season DM yield and season average legume composition of Caucasian bluestem-legume mixtures averaged across two defoliation management regimes in 1998.



*ALF = Alfalfa, RC = Red clover, SL = Sericea lespedeza, AL = Annual lespedeza, NL0 = No legume, 0 N, NL50 = No legume, 56 kg N/ha in spring and after each harvest.

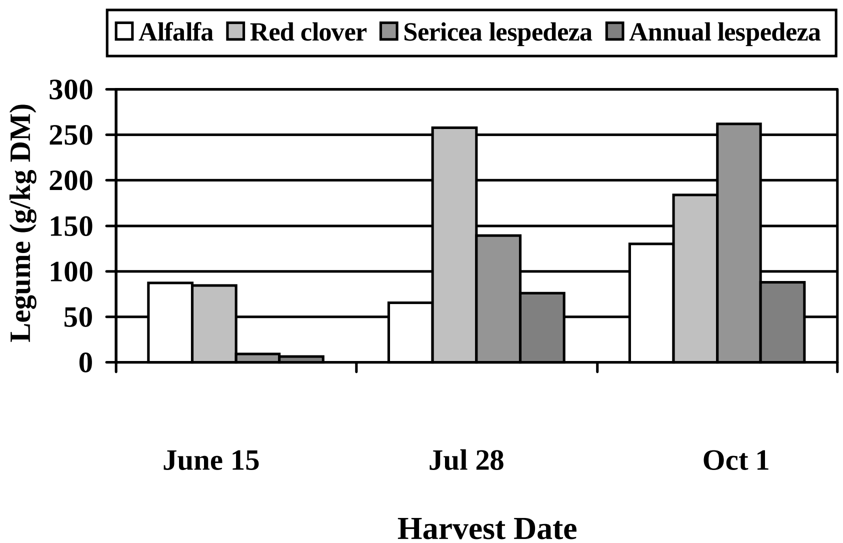
** Letters above the bars show significant differences for total yield, letters on the top left side of bars show significant differences for species composition. Same letters are not significantly different (P< 0.05).

Figure2. Total season DM yield of Caucasian bluestem-legume mixtures harvested under simulated rotational grazing or hay management averaged across six legume/N treatments in 1998.



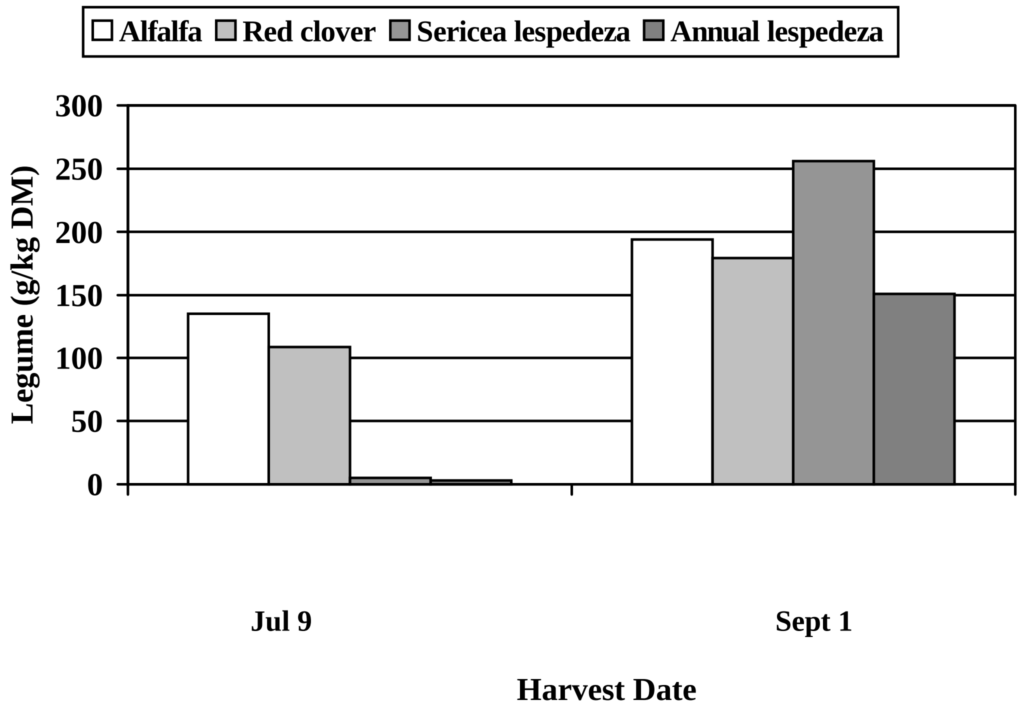
***** Means were separated using LSD (p<0.05).

Figure 3. Legume proportion in Caucasian bluestem-legume mixtures harvested under simulated rotational grazing in 1998.



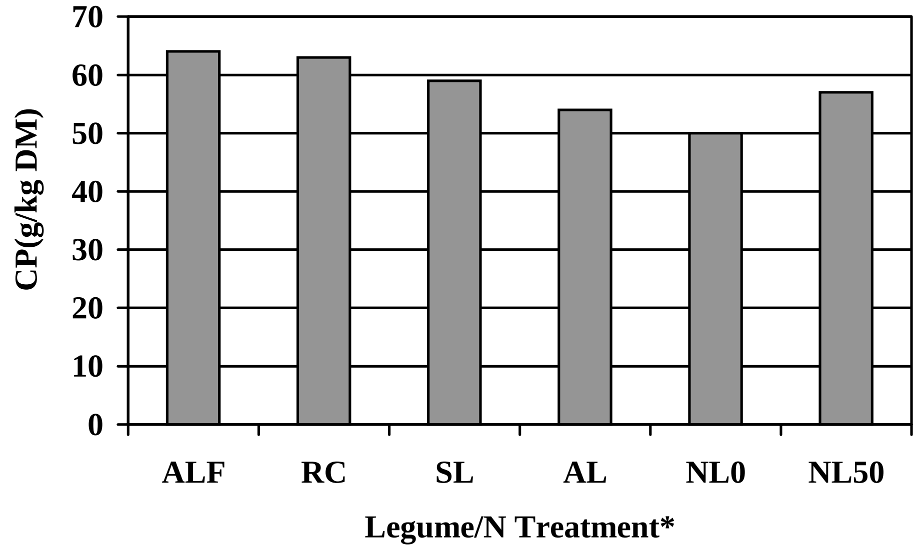
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P=0.001).

Figure 4. Legume proportion in Caucasian bluestem-legume mixtures under hay management in 1998.



*There was a significant interaction between harvest within defoliation management and legume/N treatment (P=0.001).

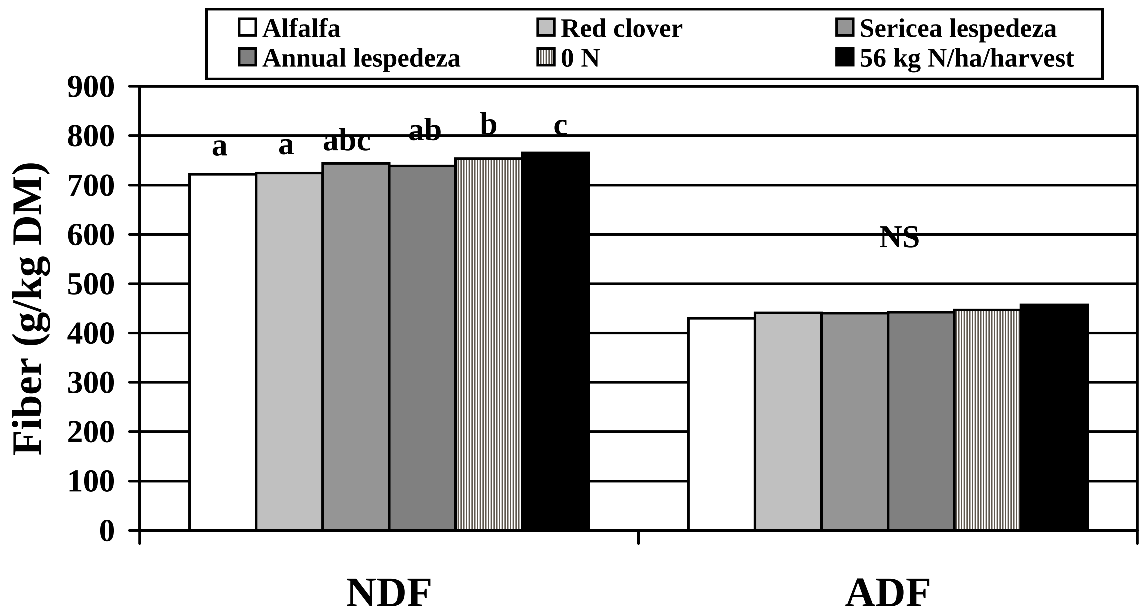
Figure 5. Season average crude protein concentrations in Caucasian bluestem-legume mixtures averaged across two defoliation management regimes in 1998.



* ALF = Alfalfa, RC = Red clover, SL = Sericea lespedeza, AL = Annual lespedeza, NL0 = No legume, 0 N, NL50 = No legume, 56 kg N/ha in spring and after each harvest.

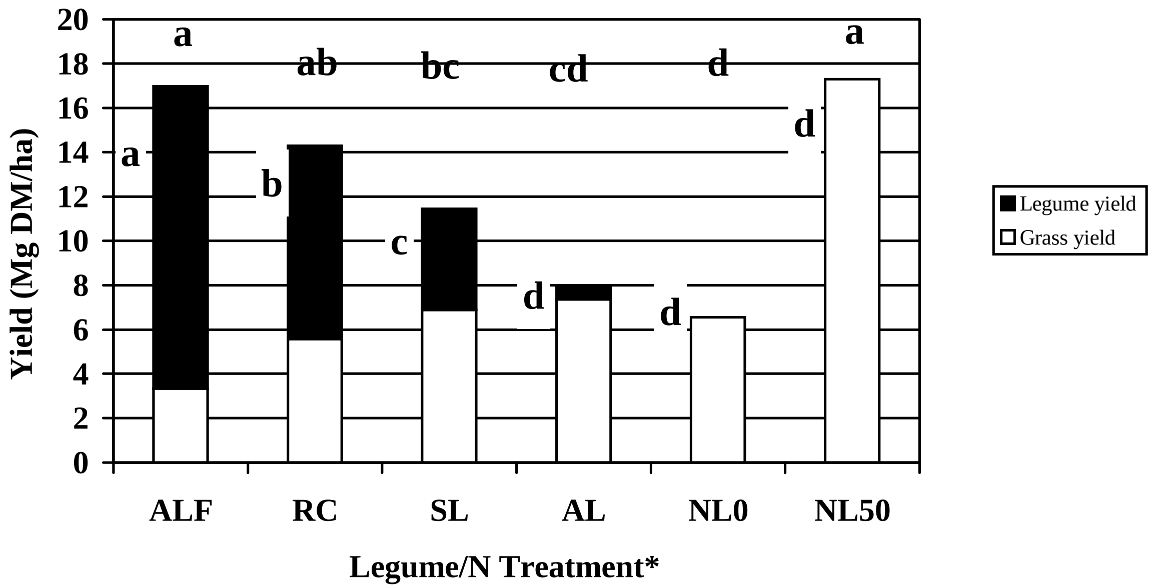
** Means were separated using LSD (P<0.05). Legume/N Treatment had a slight effect on CP concentrations (P=0.09).

Figure 6. Season average fiber concentrations in Caucasian bluestem-legume mixtures averaged across two defoliation management regimes in 1998.



* Means were separated using LSD (P<0.05).

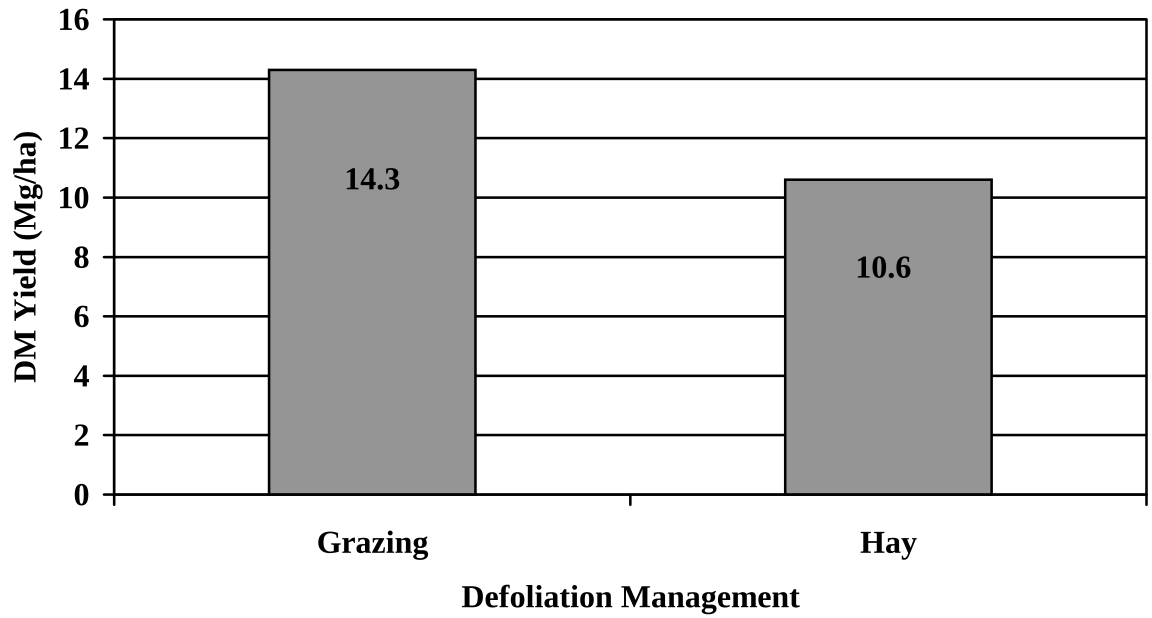
Figure 7. Total season DM yield and season average legume composition of Caucasian bluestem-legume mixtures averaged across two defoliation management regimes in 1999.



* ALF = Alfalfa, RC = Red clover, SL = Sericea lespedeza, AL = Annual lespedeza, NL0 = No legume, 0 N,
NL50 = No legume, 56 kg N/ha in spring and after each harvest

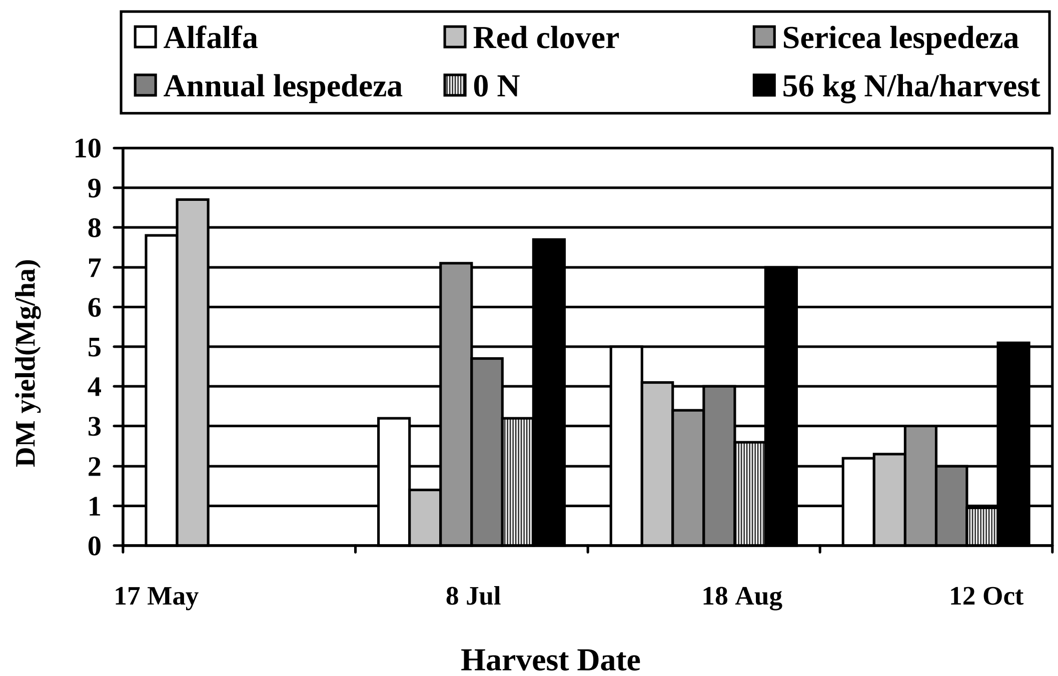
** Letters above the bars show significant differences for total yield, letters on the top left side of bars show significant differences for species composition. Same letters are not significantly different (P< 0.05).

Figure 8. Total season DM yield of Caucasian bluestem-legume mixtures harvested under simulated rotational grazing or hay management averaged across six legume/N treatments in 1999.



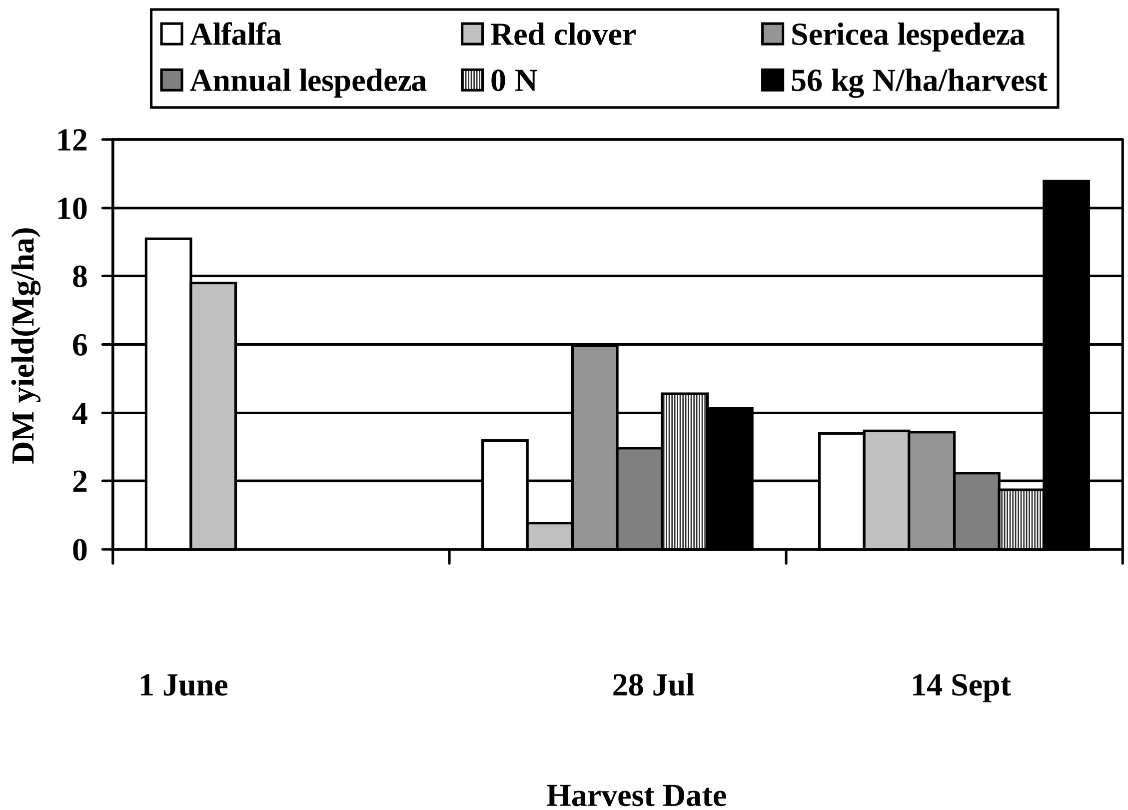
*Means were separated using LSD (P<0.05). Defoliation management had a slight effect on DM yield (P=0.07). Even though statistically speaking it is a small difference, biologically, it represents an important difference.

Figure 9. Individual harvest DM yields for Caucasian bluestem-legume mixtures harvested under simulated rotational grazing in 1999.



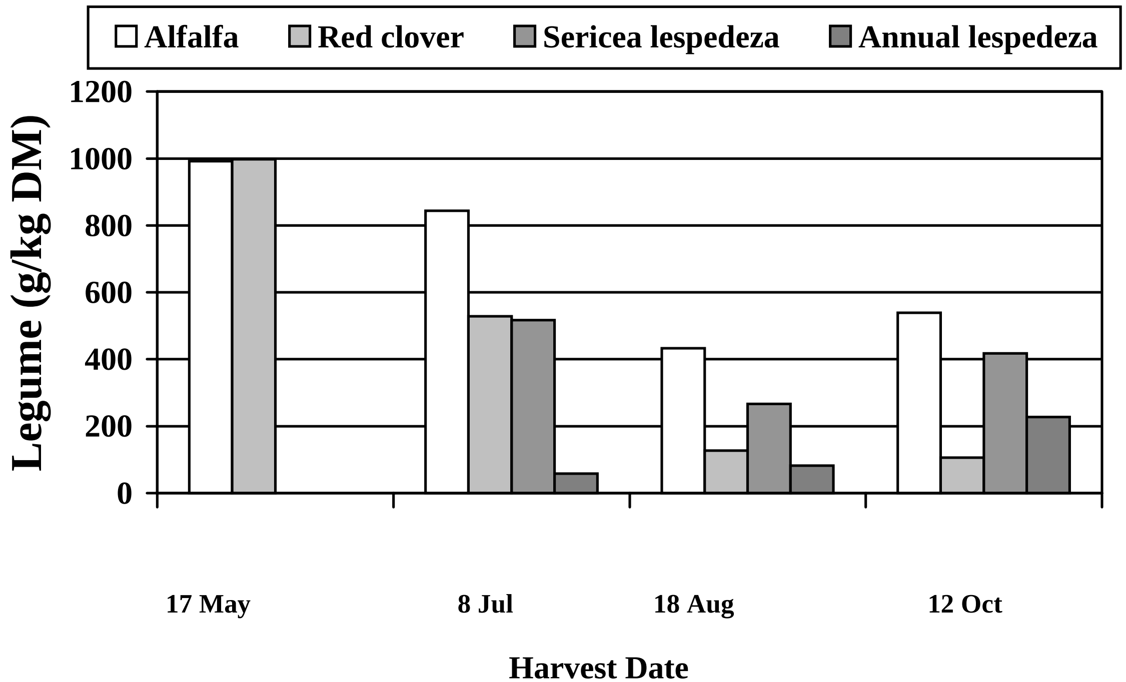
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P=0.01).

Figure 10. Individual harvest DM yields for Caucasian bluestem-legume mixtures under hay management in 1999.



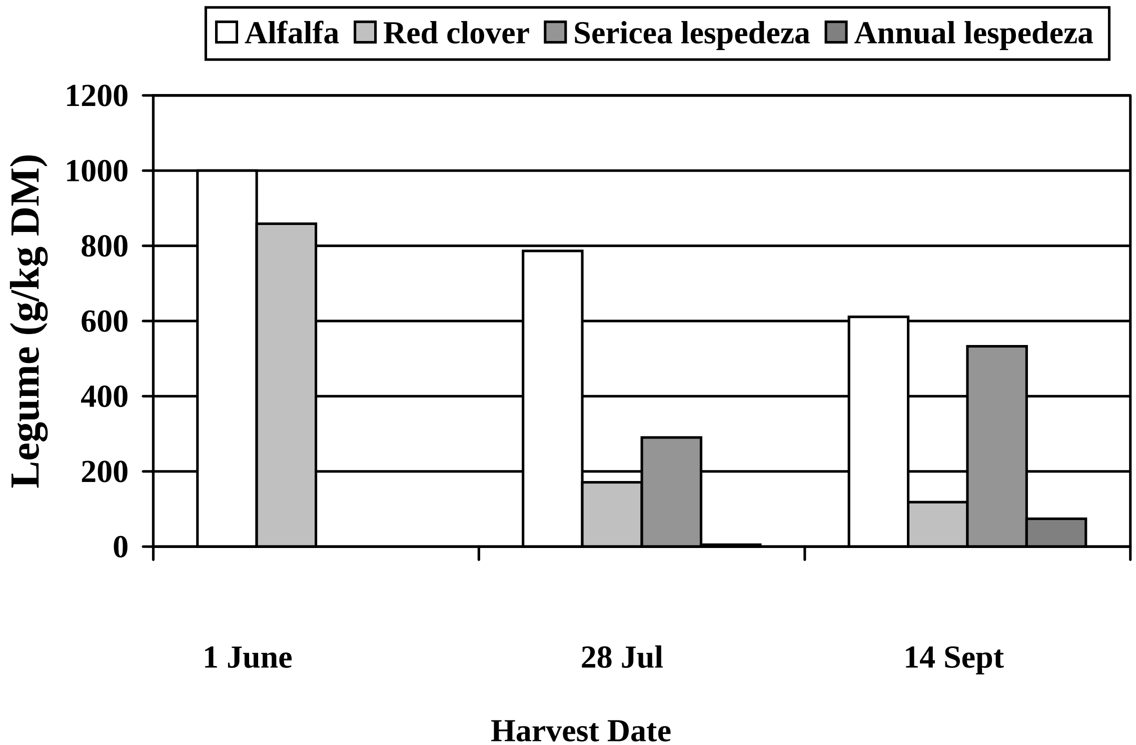
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P=0.01).

Figure 11. Individual harvest legume proportion in Caucasian bluestem-legume mixtures under simulated rotational grazing in 1999.



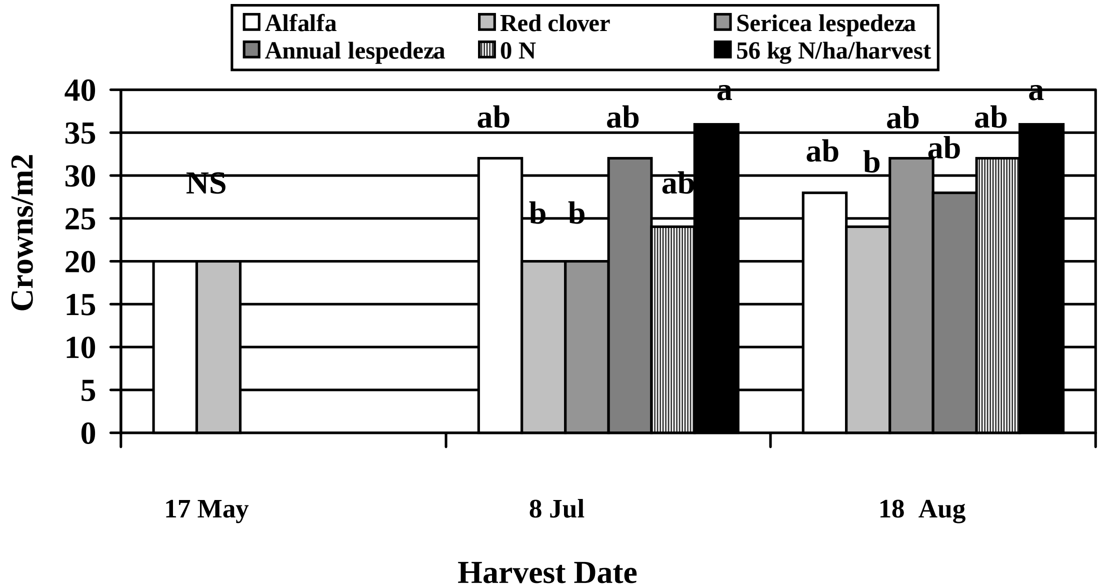
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001).

Figure 12. Individual harvest legume proportion in Caucasian bluestem-legume mixtures under hay management in 1999.



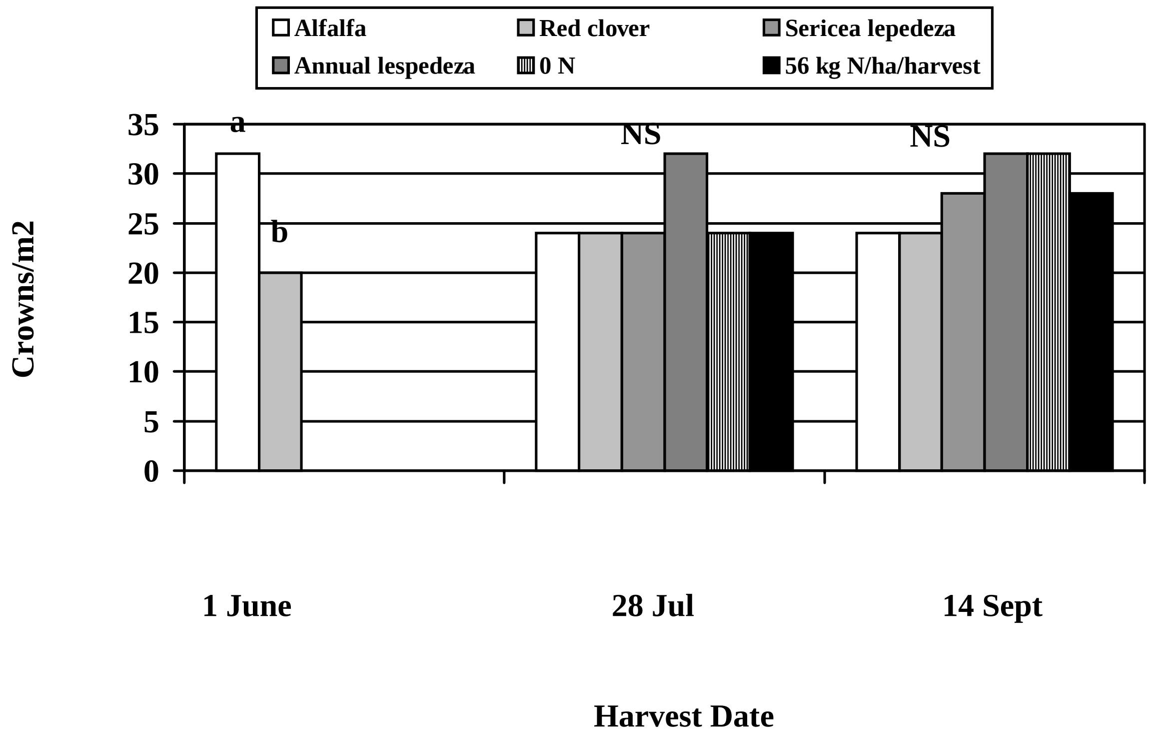
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001).

Figure 13. Caucasian bluestem crown density under simulated rotational grazing in 1999



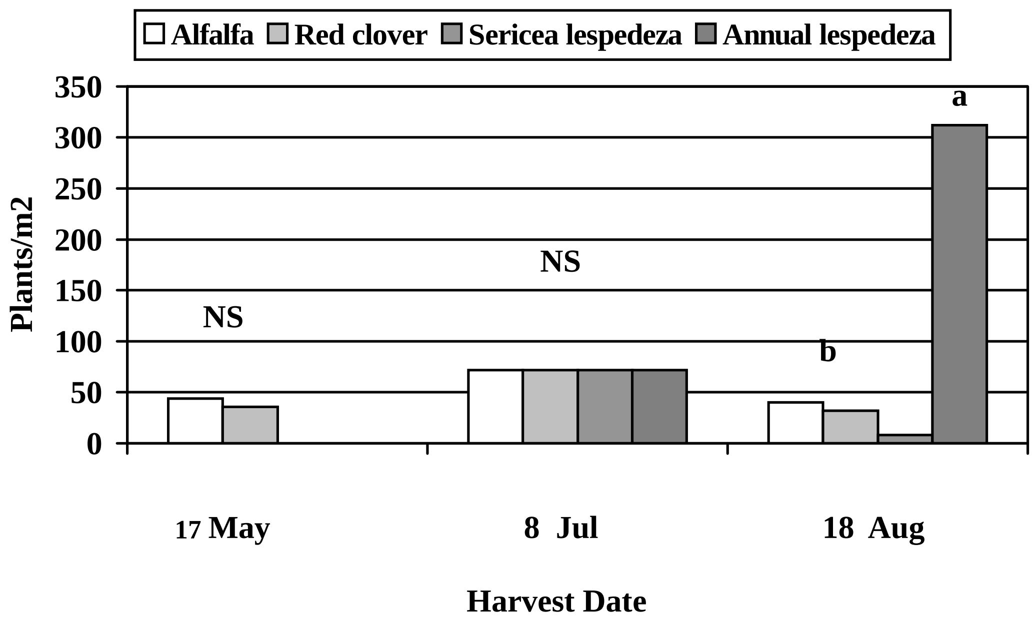
***Each date is a separate statistical analysis, means were separated using LSD, same letters are not significantly different (P<0.05).**

Figure 14. Caucasian bluestem crown density under hay management in 1999



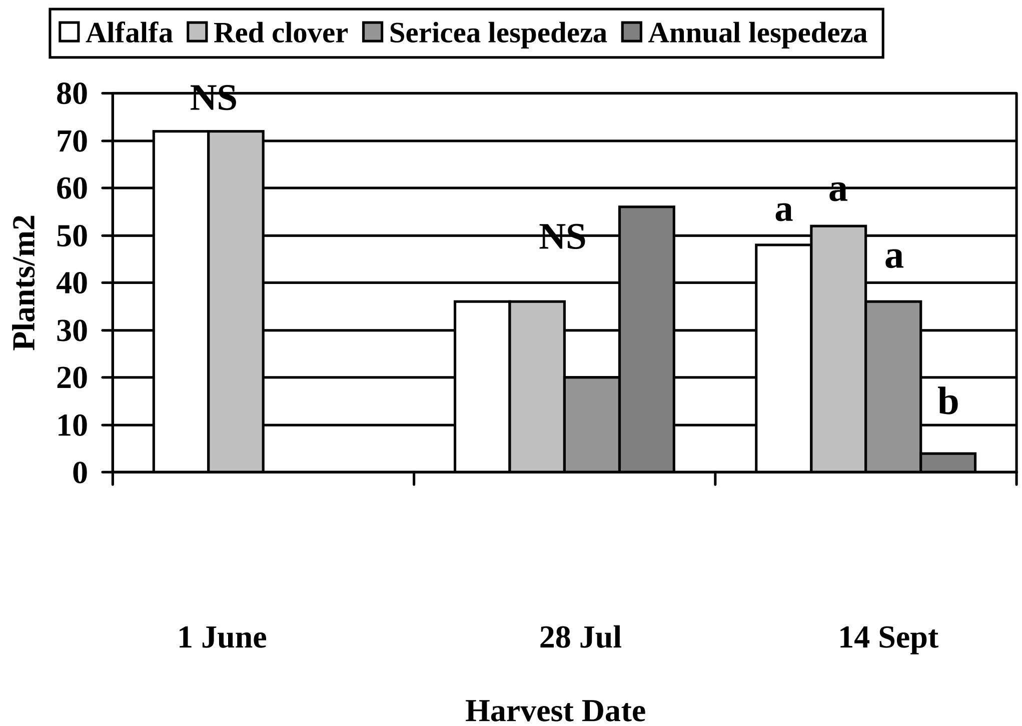
*****Each date is a separate statistical analysis, means were separated using LSD, same letters are not significantly different (P<0.05).

Figure 15. Legume plant density in Caucasian bluestem-legume mixtures under simulated rotational grazing in 1999.



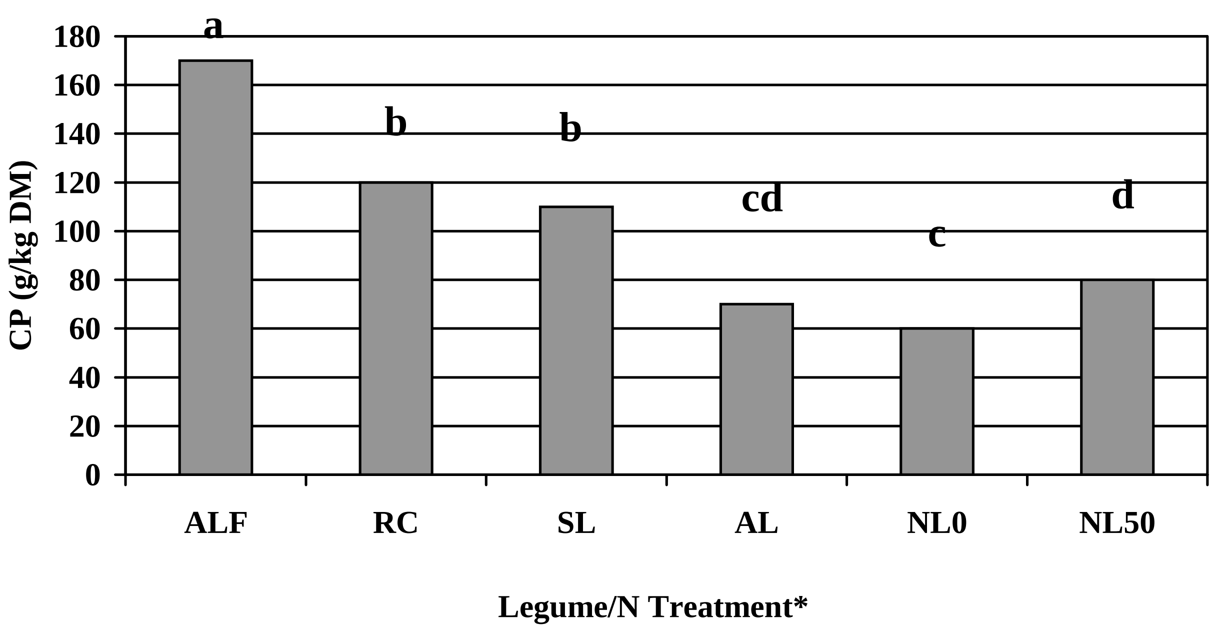
*Each date is a separate statistical analysis, means were separated using LSD, same letters are not significantly different (P<0.05).

Figure 16. Legume plant density in Caucasian bluestem-legume mixtures under hay management in 1999.



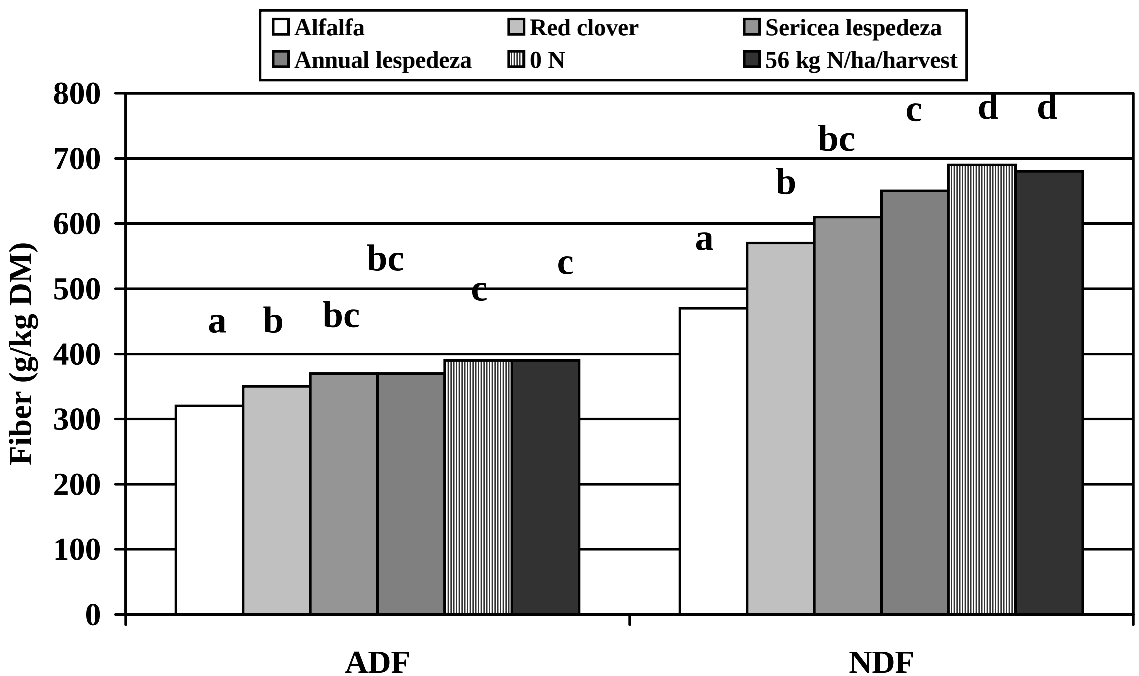
*Each date is a separate statistical analysis, means were separated using LSD, same letters are not significantly different (P<0.05).

Figure 17. Season average crude protein concentrations in Caucasian bluestem-legume mixtures averaged across two defoliation management regimes in 1999.



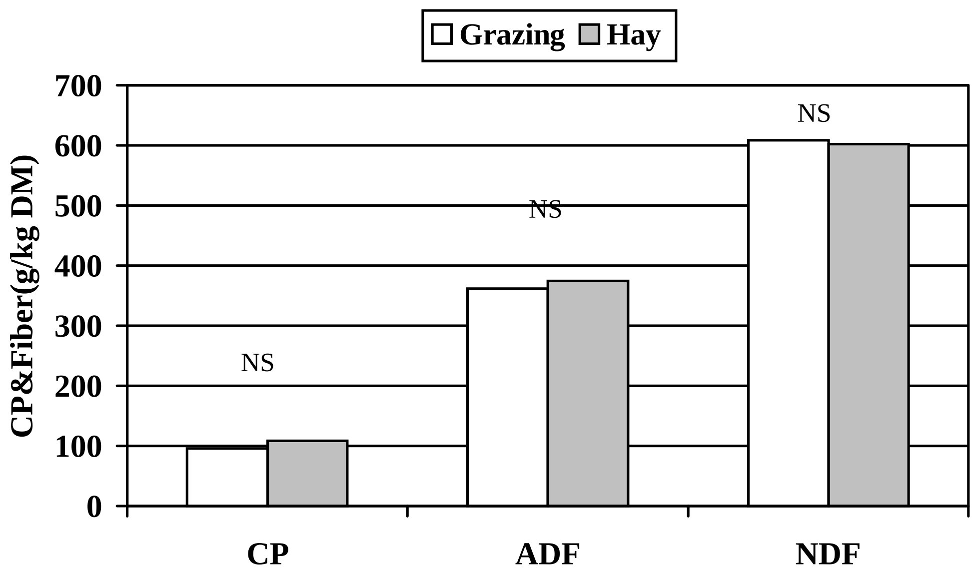
*ALF = Alfalfa, RC = Red clover, SL = Sericea lespedeza, AL = Annual lespedeza, NL0 = 0 N, NL50 = 56 kg N/ha in spring and after each harvest.
** Means were separated using LSD, same letters are not significantly different (P< 0.05).

Figure 18. Season average fiber concentrations in Caucasian bluestem-legume mixtures averaged across two defoliation management regimes in 1999.



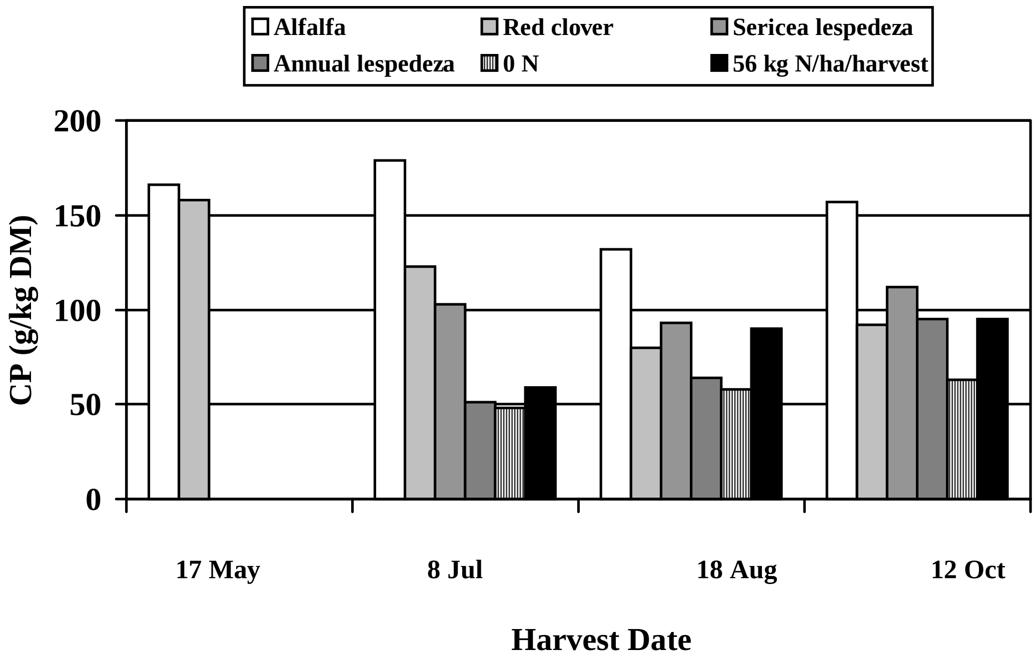
* ADF and NDF are two separate analyses. Means were separated using LSD, same letters are not significantly different (P<0.05).

Figure 19. Total season crude protein and fiber concentrations in Caucasian bluestem-legume mixtures via simulated rotational grazing or hay management in 1999.



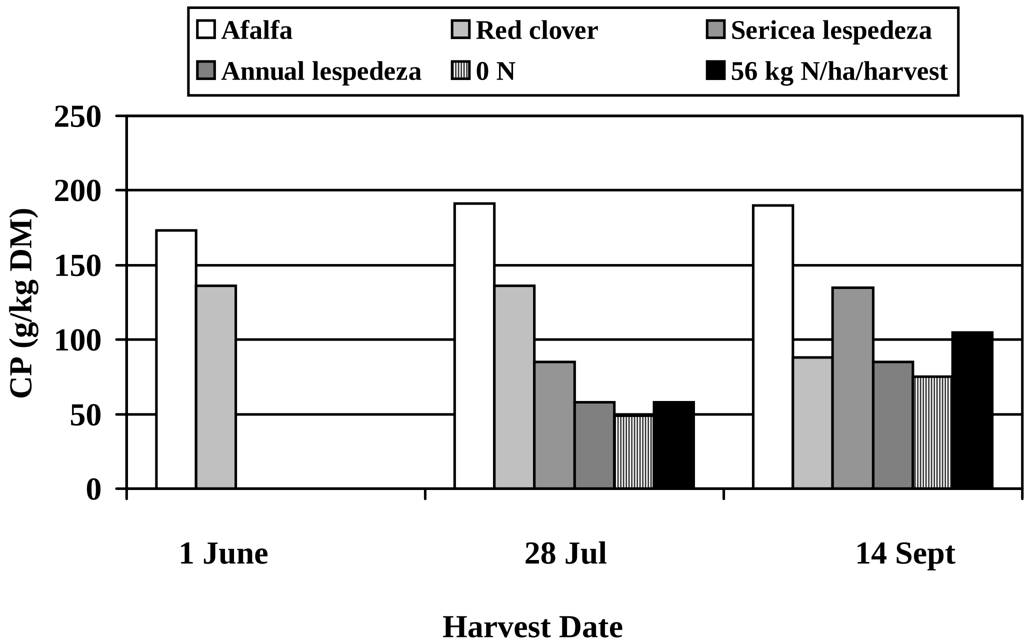
* CP, ADF, and NDF are 3 separate analyses. Means were separated using LSD (P<0.05).

Figure 20. Individual harvest crude protein concentrations in Caucasian bluestem-legume mixtures under simulated rotational grazing in 1999.



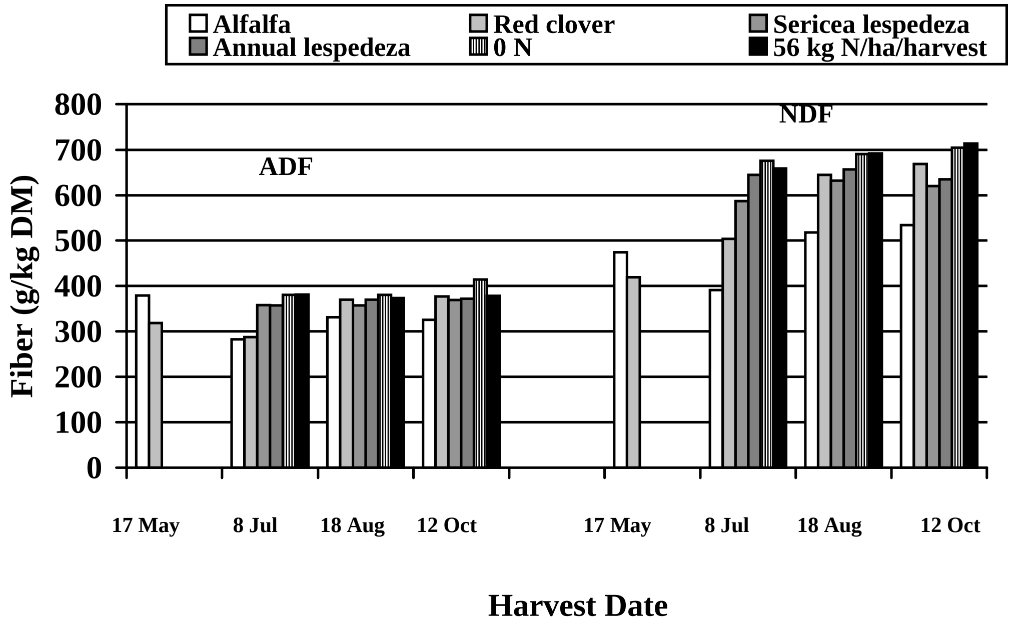
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001).

Figure 21. Individual harvest crude protein concentrations in Caucasian bluestem-legume under hay management in 1999.



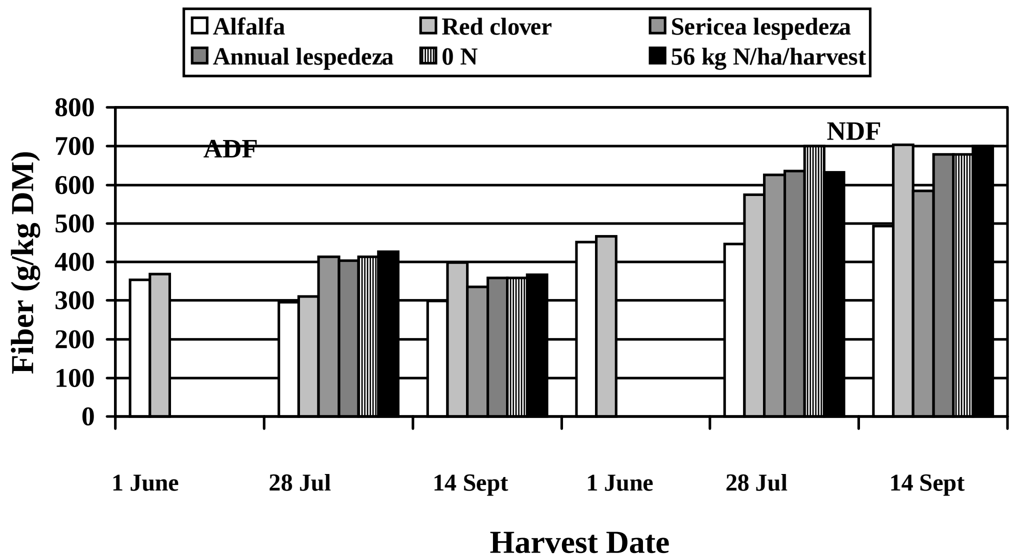
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001).

Figure 22. Individual harvest fiber concentrations in Caucasian bluestem-legume mixtures under simulated rotational grazing in 1999.



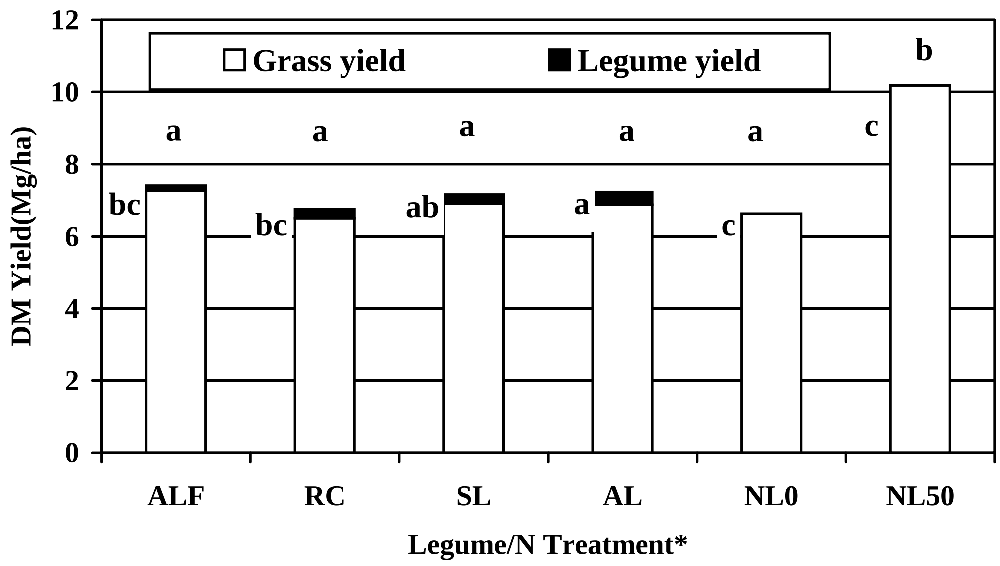
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001) for both ADF and NDF.

Figure 23. Individual harvest fiber concentrations in Caucasian bluestem-legume mixtures under hay management in 1999.



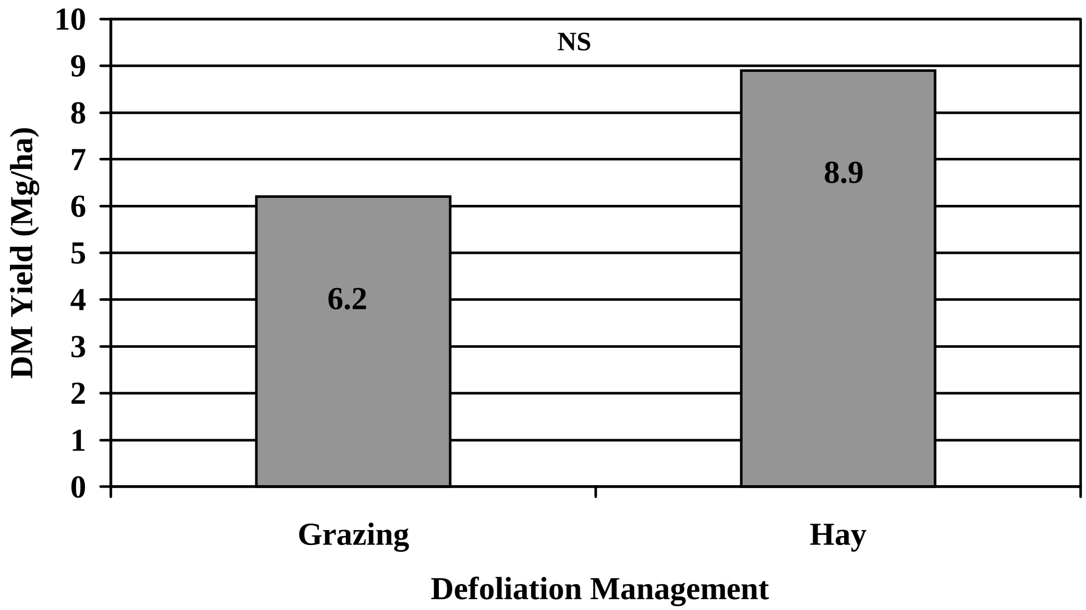
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001) for both ADF and NDF.

Figure 24. Total season DM yield and season average legume composition of switchgrass-legume mixtures averaged across two defoliation management regimes in 1998.



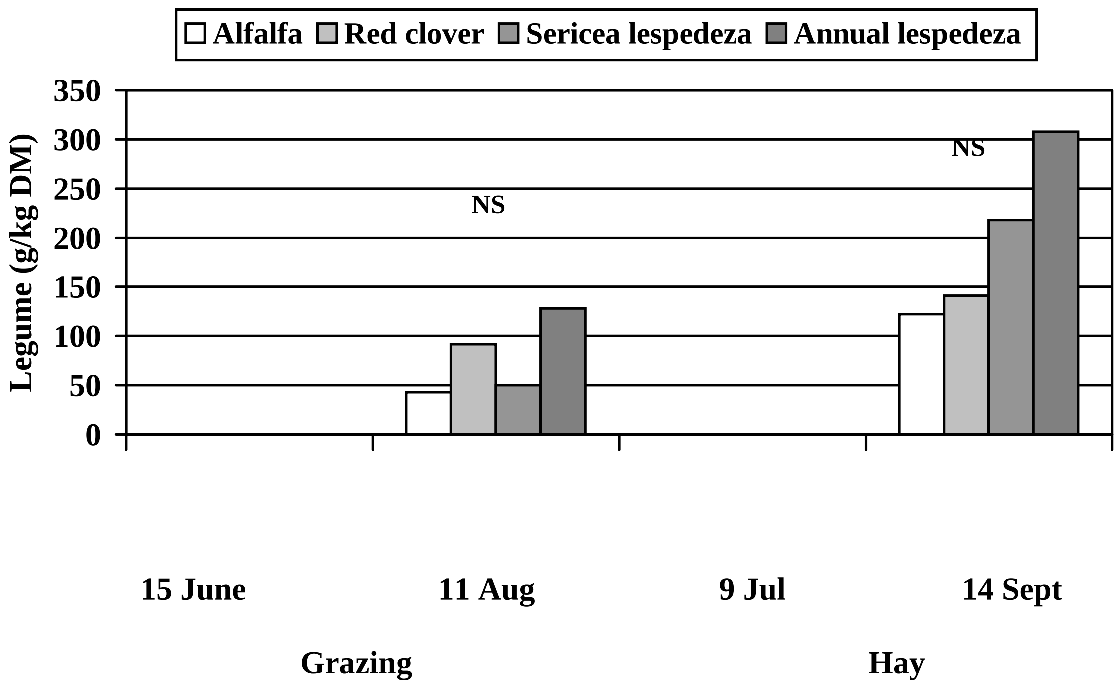
* ALF = Alfalfa, RC = Red clover, SL = Sericea, AL = Annual lespedeza, NL0 = 0 N, NL50 = 56 kg N/ha in spring and after each harvest
** Letters above the bars show significant differences for total yield, letters on the top left side of bars show significant differences for species composition. Same letters are not significantly different (P< 0.05).

Figure 25. Total season DM yield of switchgrass-legume mixtures Harvested via simulated rotational grazing or hay management in 1998.



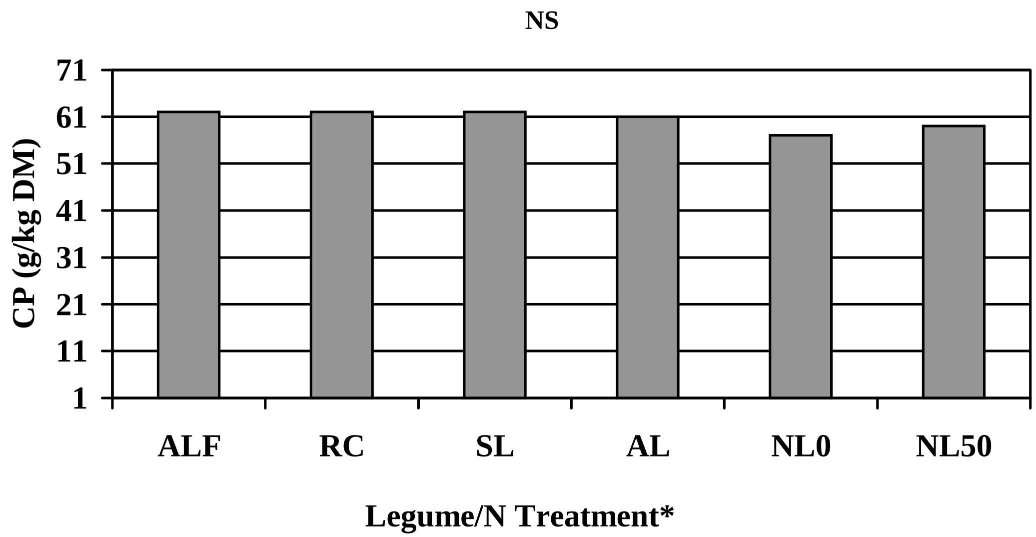
* Means were separated using LSD (P<0.05).

Figure 26. Legume proportion in switchgrass-legume mixtures harvested via rotational grazing or hay management in 1998.



*Each date is a separate analysis. Means were separated using LSD (P<0.05).

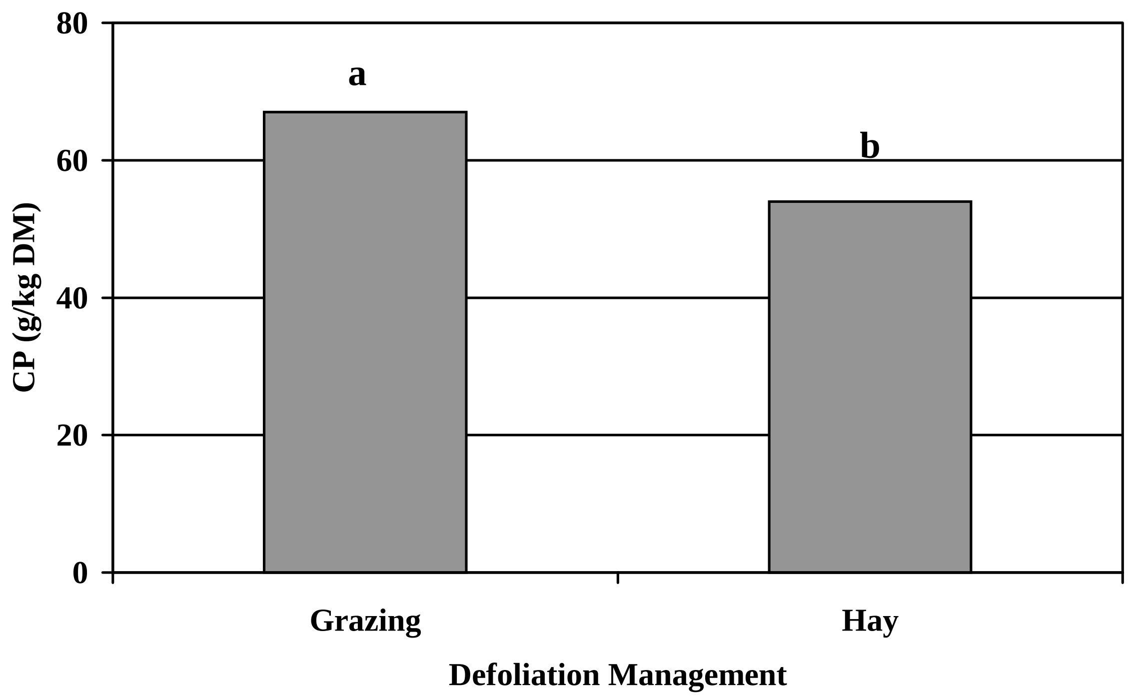
Figure 27. Season average crude protein concentrations in switchgrass-legume mixtures averaged across two defoliation management regimes in 1998.



* ALF = Alfalfa, RC = Red clover, SL = Sericea lespedeza, AL = Annual lespedeza, NL0 = 0 N, NL50 = 56 kg N/ha in spring and after each harvest.

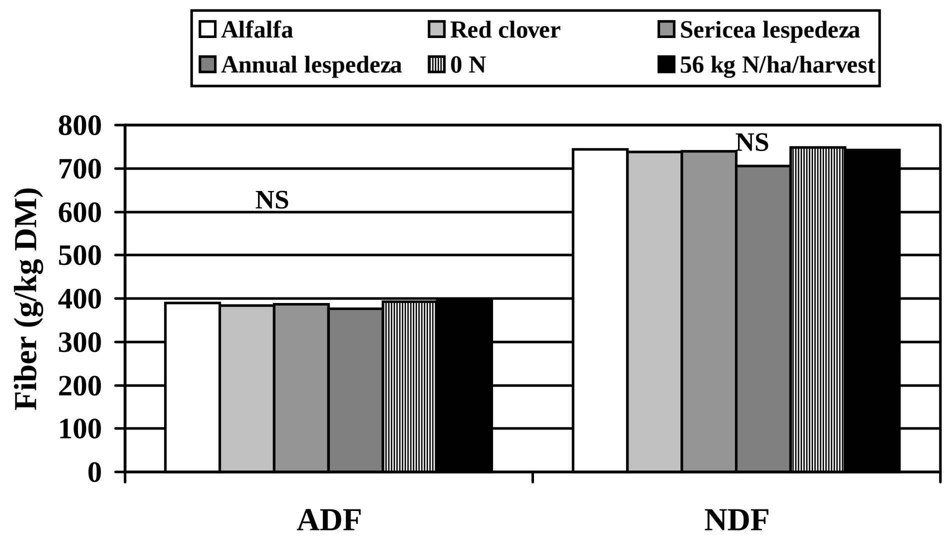
**Means were separated using LSD, ($P < 0.05$).

Figure 28. Season average crude protein concentrations in switchgrass-legume mixtures harvested via simulated rotational grazing or hay management in 1998.



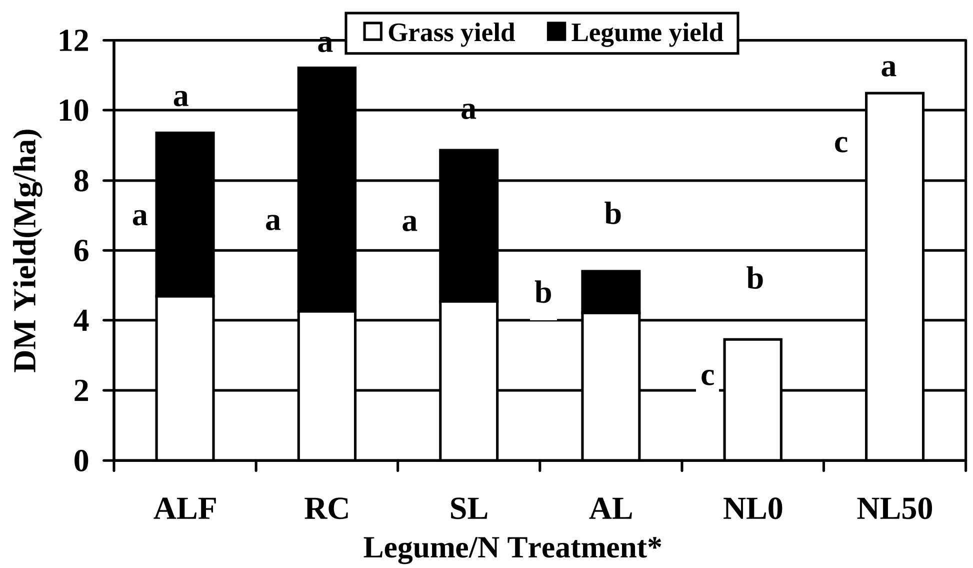
*Means were separated using LSD (P<0.05). Same letters are not significantly different.

Figure 29. Season average fiber concentrations in switchgrass-legume mixtures averaged across two defoliation management regimes in 1998.



*ADF and NDF are 2 separate analyses. Means were separated using LSD (P<0.05).

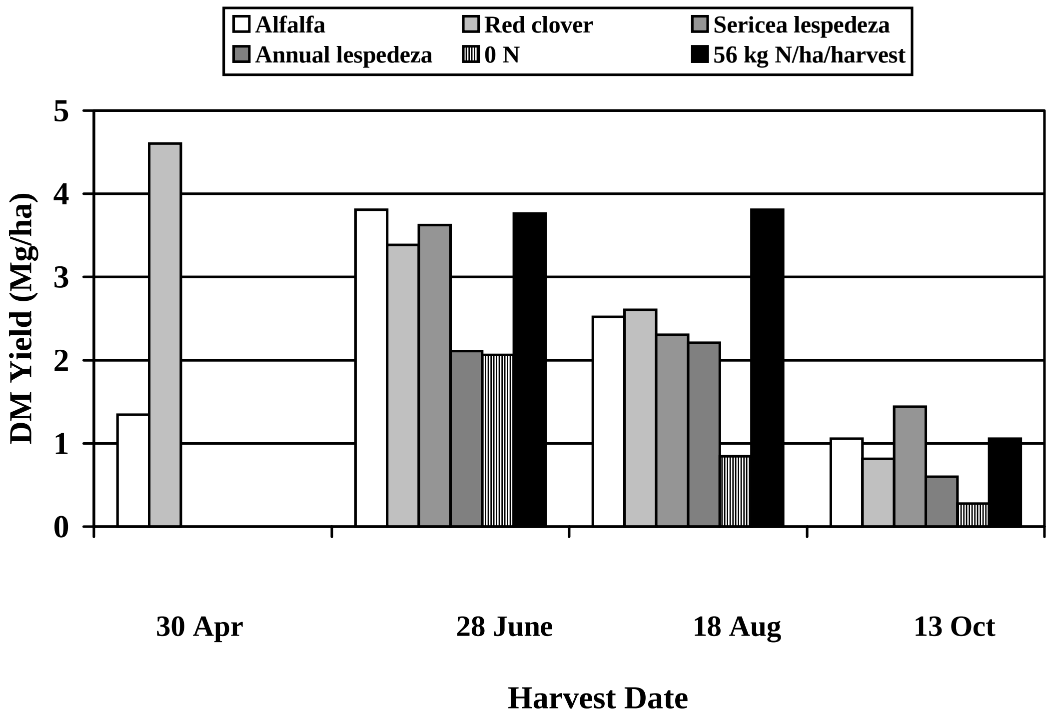
Figure 30. Total season DM yield and season average legume composition of switchgrass-legume mixtures averaged across two defoliation management regimes in 1999.



*ALF = Alfalfa, RC = Red clover, SL = Sericea lespedeza, AL = Annual lespedeza, NL0 = 0 N, NL50 = 56 kg N/ha in spring and after each harvest.

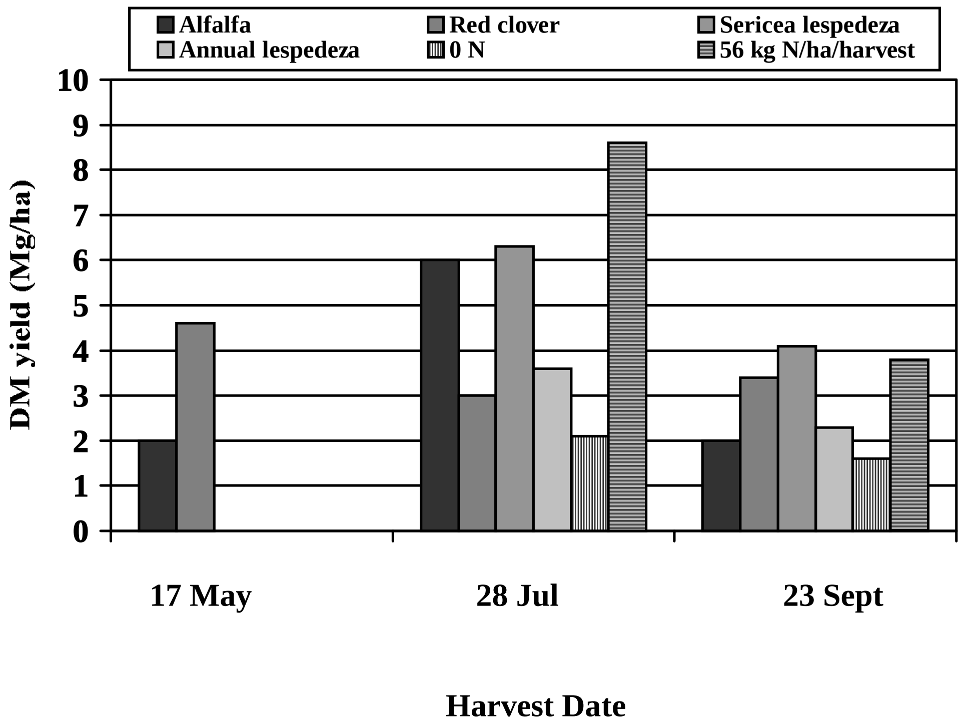
** Letters above the bars show significant differences for total yield, letters on the top left side of bars show significant differences for species composition. Same letters are not significantly different ($P < 0.05$).

Figure 31. Individual harvest DM yields for switchgrass-legume mixtures under simulated rotational grazing in 1999



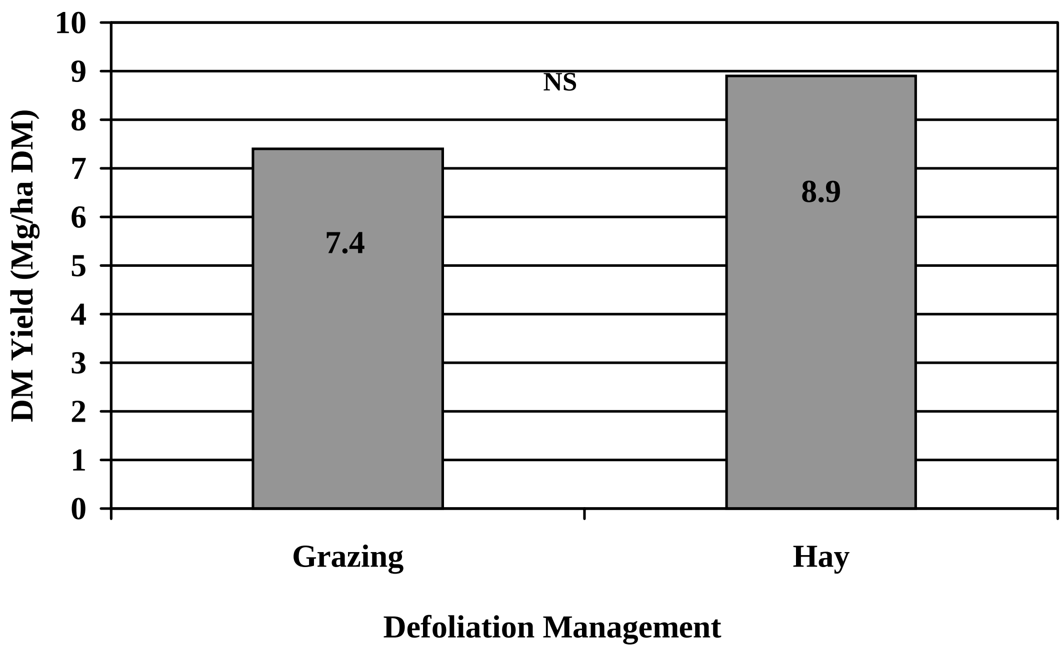
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001).

Figure 32. Individual harvest DM yields of switchgrass-legume mixtures under hay management in 1999.



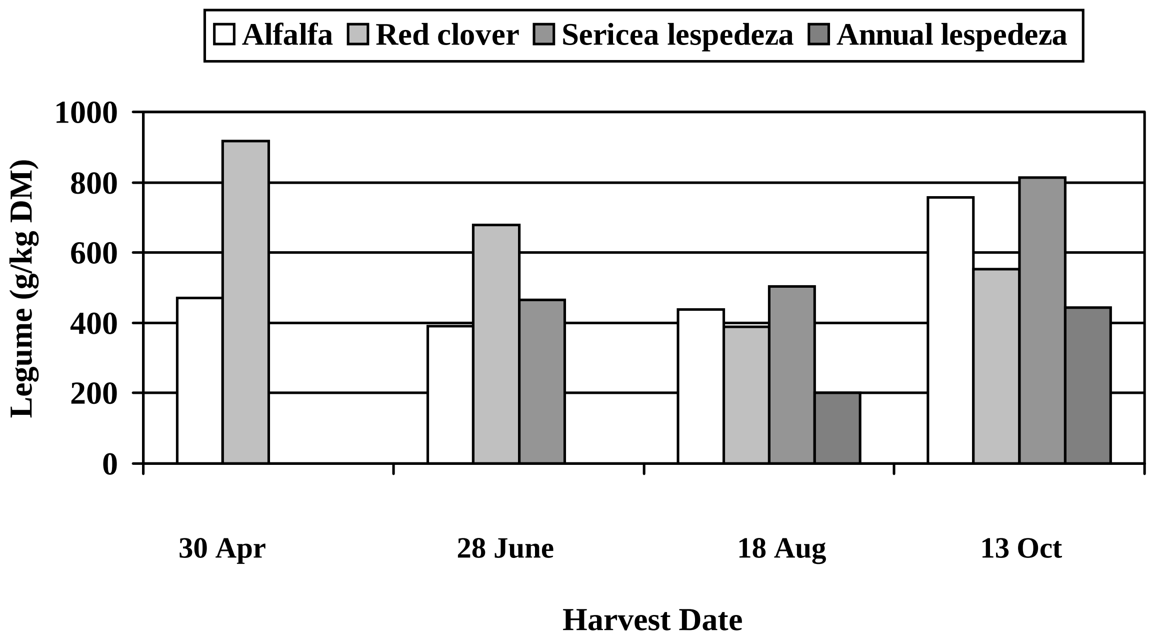
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P<0.0001).

Figure 33. Total season DM yield of switchgrass-legume mixtures harvested via simulated rotational grazing or hay management in 1999.



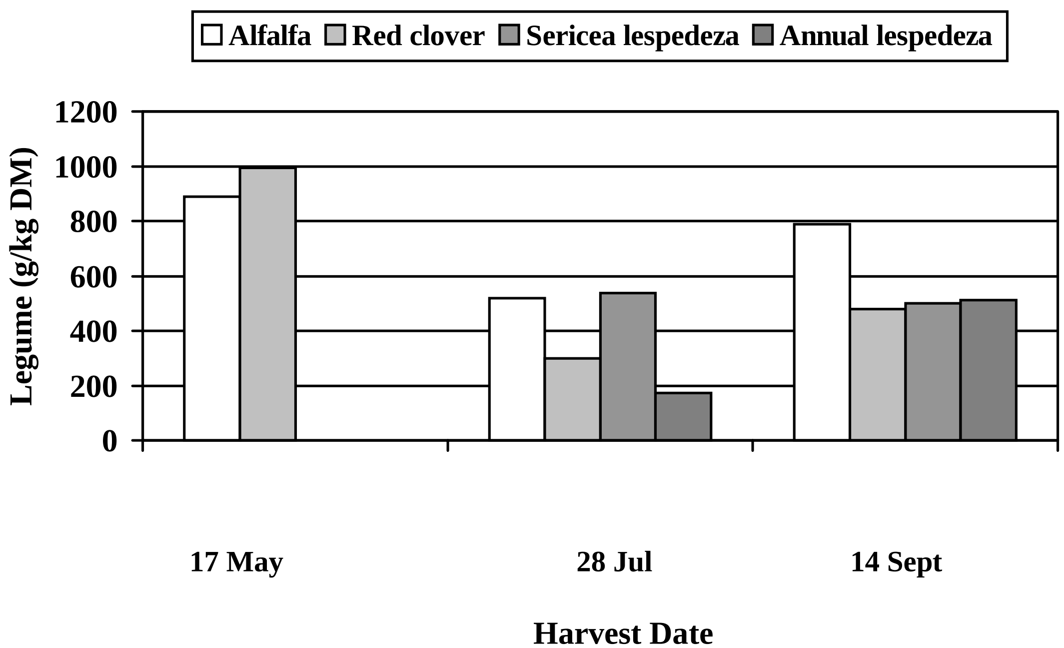
*Means were separated using LSD (P<0.05).

Figure 34. Legume proportion in switchgrass-legume mixtures harvested under simulated rotational grazing in 1999.



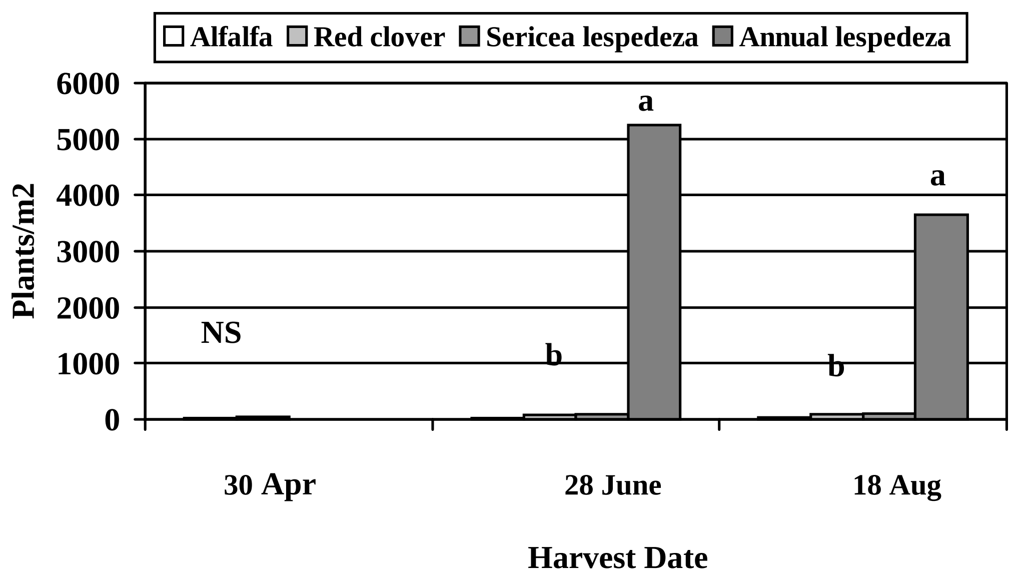
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P=0.0002).

Figure 35. Legume proportion in switchgrass-legume mixtures harvested under hay management in 1999.



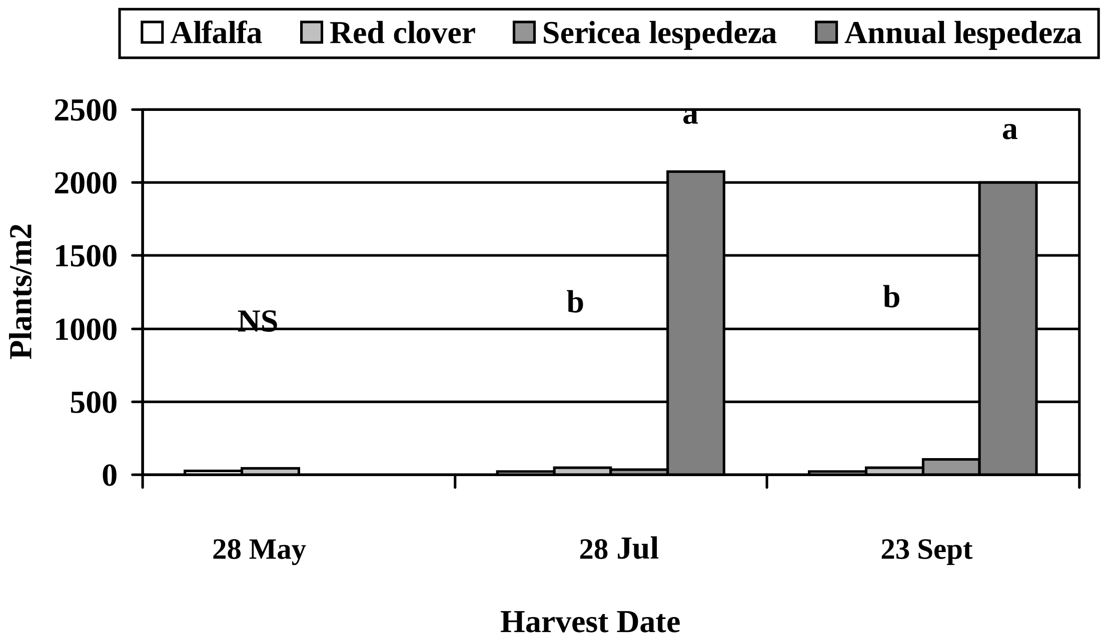
*There was a significant interaction between harvest within defoliation management and legume/N treatment (P=0.0002).

Figure 36. Legume plant density in switchgrass-legume mixtures under simulated rotational grazing in 1999.



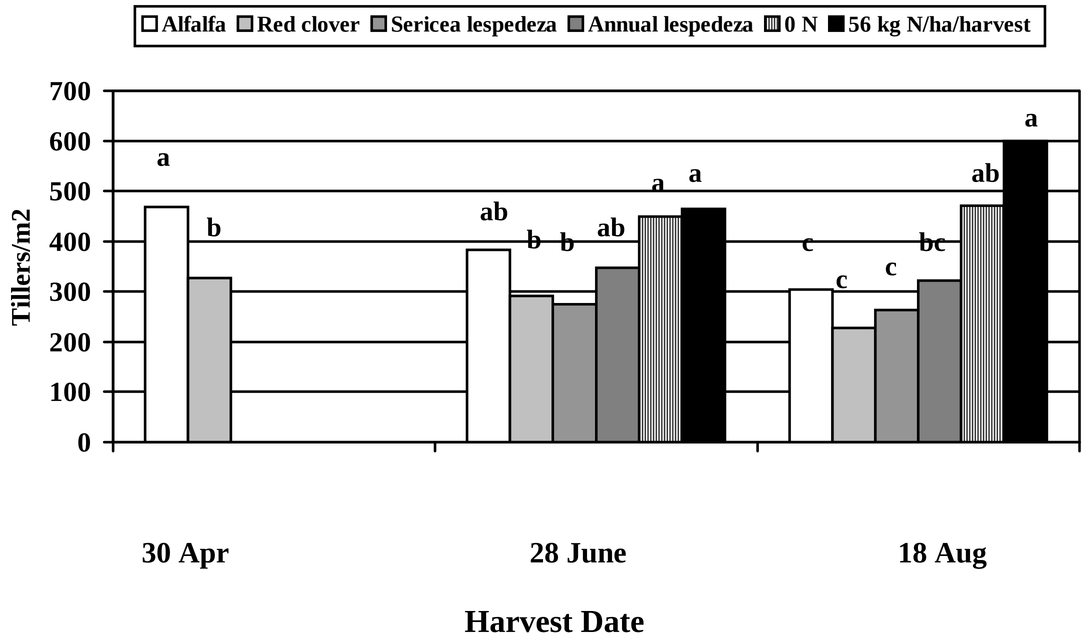
* Each date is a separate analysis. Means were separated using LSD (P<0.05). Same letters are not significantly different.

Figure 37. Legume plant density in switchgrass-legume mixtures under hay management in 1999.



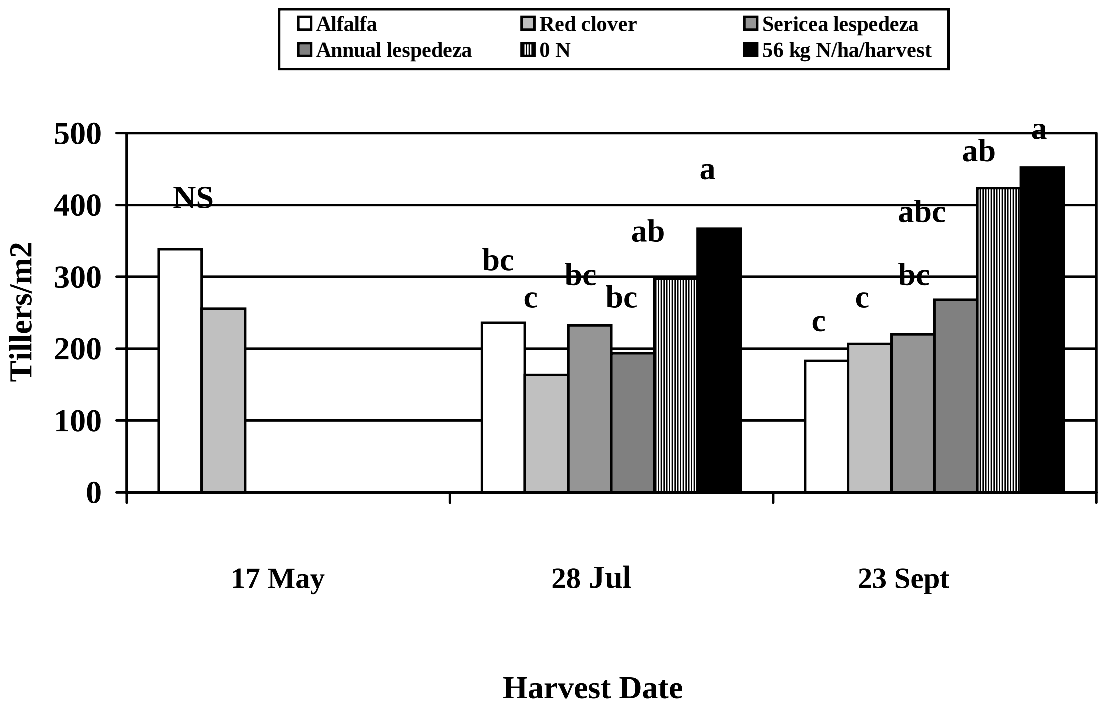
* Each date is a separate analysis. Means were separated using LSD (P<0.05). Same letters are not significantly different.

Figure 38. Switchgrass tiller density under simulated rotational grazing in 1999.



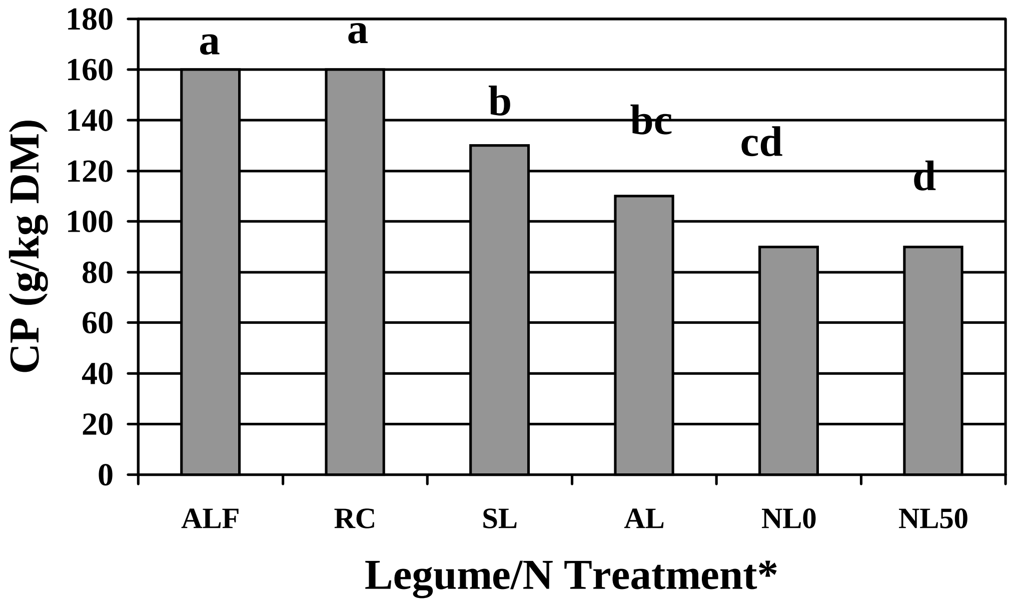
* Each date is a separate analysis. Means were separated using LSD (P<0.05). Same letters are not significantly different.

Figure 39. Switchgrass tiller density under hay management in 1999.



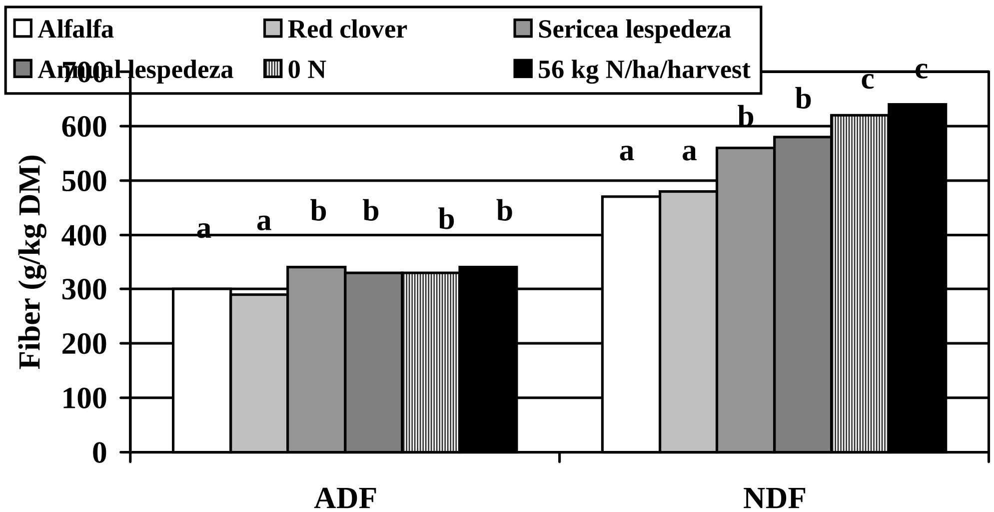
* Each date is a separate analysis. Means were separated using LSD (P<0.05). Same letters are not significantly different.

Figure 40. Season average crude protein concentrations in switchgrass-legume mixtures averaged across two defoliation management regimes in1999.



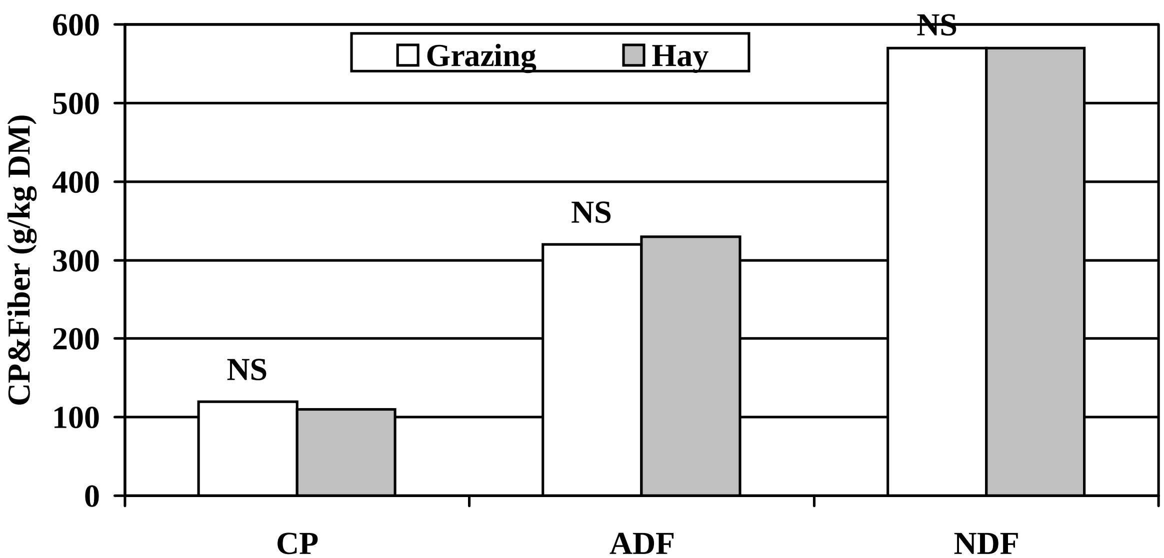
* ALF = Alfalfa, RC = Red clover, SL = Sericea lespedeza, AL = Annual lespedeza, NL0 = 0 N, NL50 = 56 kg N/ha in spring and after each harvest.
** Means were separated using LSD, same letters are not significantly different ($P < 0.05$).

Figure 41. Season average fiber concentrations in switchgrass-legume mixtures averaged across two defoliation management regimes in 1999.



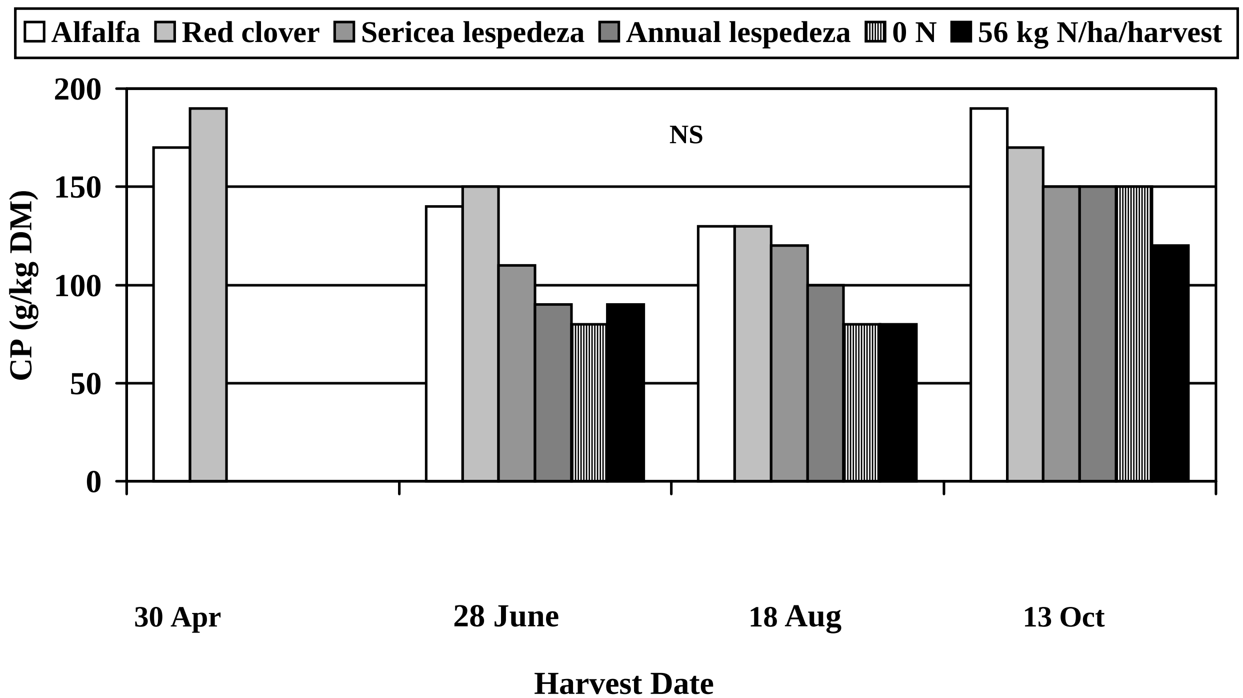
* ADF and NDF are 2 separate analyses. Means were separated using LSD, same letters are not significantly different (P<0.05).

Figure 42. Season average crude protein and fiber concentrations averaged across six legume/N treatments in switchgrass-legume mixtures via simulated rotational grazing or hay management in 1999.



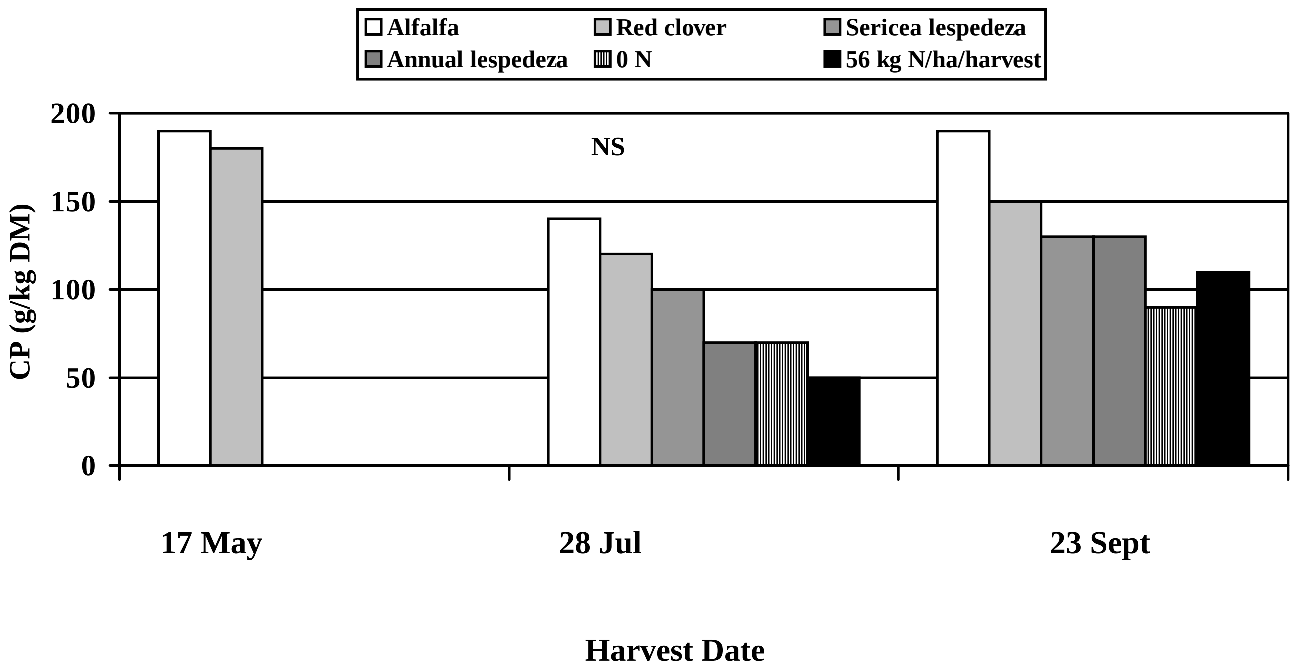
*CP, ADF, and NDF are 3 separate analyses. Means were separated using LSD (P<0.05).

Figure 43. Crude protein concentrations in switchgrass-legume mixtures harvested under simulated rotational grazing in 1999.



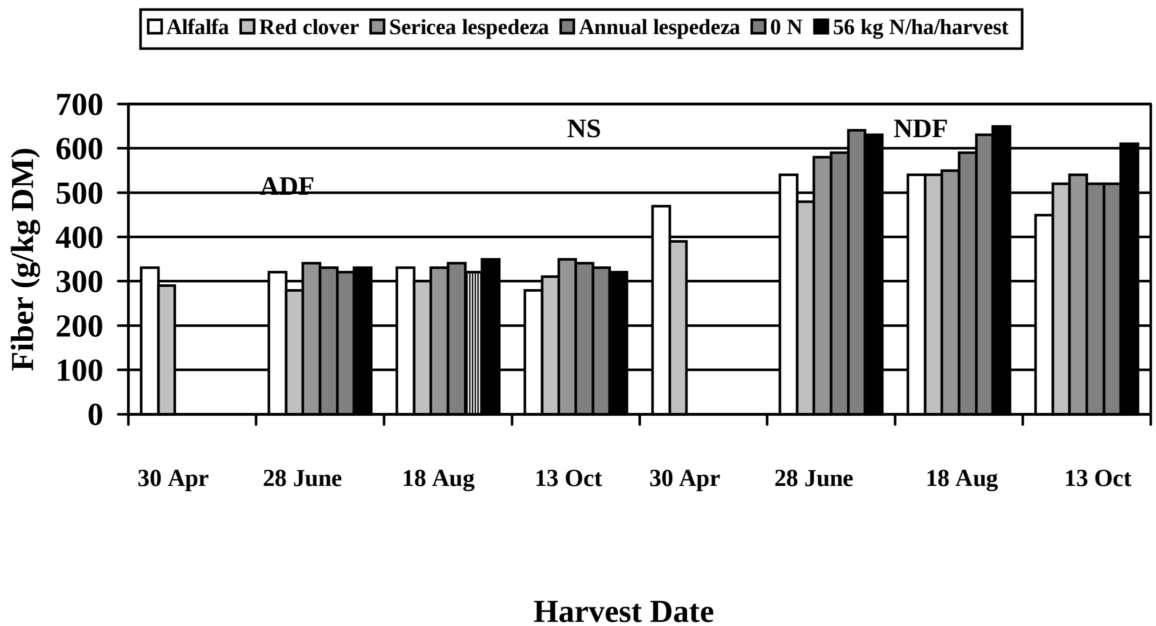
*No significant harvest within defoliation management by legume/N treatment interaction (p<0.05).

Figure 44. Crude protein concentrations in switchgrass-legume mixtures harvested under hay management in 1999.



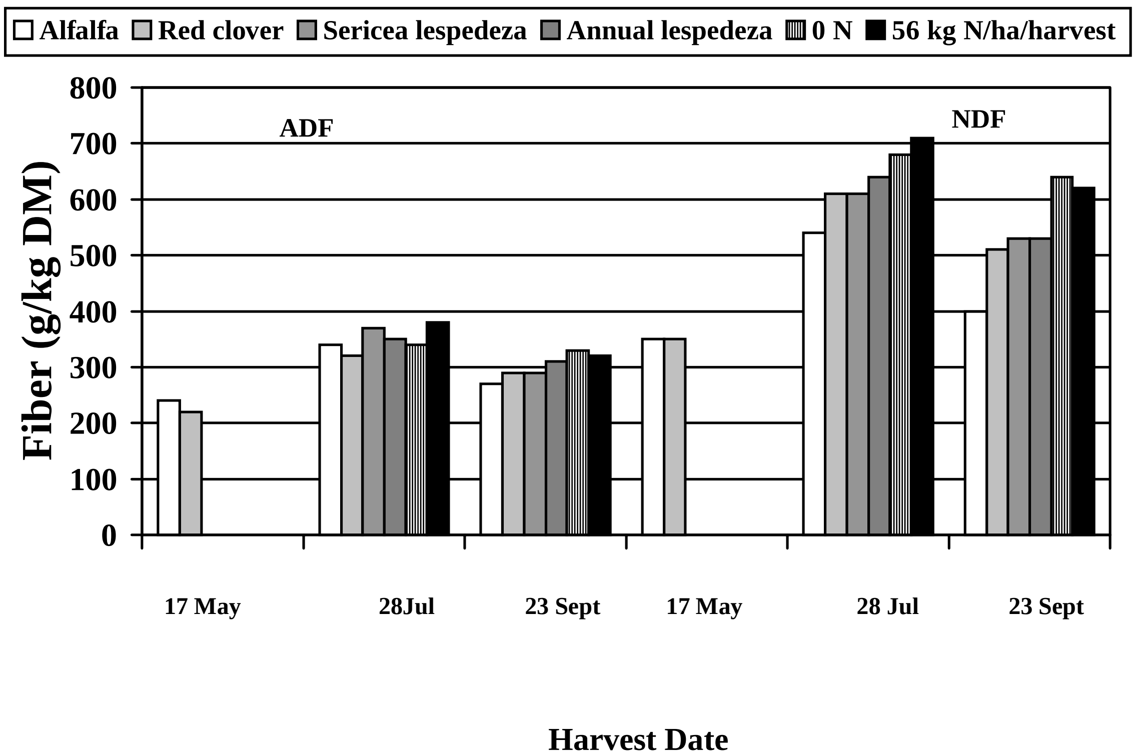
*No significant harvest within defoliation management by legume/N treatment interaction ($p<0.05$).

Figure 45. Fiber concentrations in switchgrass-legume mixtures harvested under simulated rotational grazing in 1999.



*No significant harvest within defoliation management by legume/N treatment interaction (p<0.05).

Figure 46. Fiber concentrations in switchgrass-legume mixtures harvested under hay management in 1999.



*No significant harvest within defoliation management by legume/N treatment interaction (p<0.05).

Summary and Conclusions

During the legume establishment year, inter-seeded legumes had minimal impact on yield and quality of Caucasian bluestem and switchgrass. Yields of both Caucasian bluestem and switchgrass were highly responsive to nitrogen fertilization.

In year 2, inter-seeded legumes contributed significantly to both yield and quality of the grass-legume mixtures. For Caucasian bluestem, mixtures with alfalfa or red clover yielded as much as nitrogen-fertilized grass. For switchgrass, mixtures with alfalfa, red clover, or sericea lespedeza yielded as much as N-fertilized grass. Inter-seeded cool-season legumes altered the distribution of production for both Caucasian bluestem and switchgrass. Only alfalfa and red clover were cut at the first vegetative and reproductive harvests, because they had vigorous growth at the beginning of the season. Indeed, cool-season legumes were in higher proportion in early summer, but the N-fertilized grasses produced the most late summer-fall forage.

By the end of the second year, sericea lespedeza appeared to be the most compatible legume with warm-season grasses. Sericea lespedeza growth was consistent throughout the season. Its proportion during the second year was 40% in Caucasian bluestem compared to 80% and 60% for alfalfa and red clover, respectively. In mixture with switchgrass, sericea lespedeza averaged 50% of the stand during the year after legume establishment. The warm-season legume appears to be more suited in mixture with warm-season grasses. This could be explained by the early emergence of the cool-season legumes, and possibly, their competition on the emergence of the warm-season grasses.

Density data shows that annual lespedeza may not be compatible with perennial warm-season grasses. Its dense but below cutting height growth may adversely affect the grass growth and forage production. However, it might be different under grazing conditions. Cattle do not graze uniformely and tend to be selective of legume plants. Therefore, grass could be favored in a real grazing situation.

Inter-seeded legumes significantly improved quality of the grass-legume mixtures. For Caucasian bluestem, mixtures with alfalfa had the highest CP concentration, averaging 170g/kg DM over the season. The sericea lespedeza Caucasian bluestem mixture had similar CP concentration to that of the red clover (110 g/kg DM). Acid detergent fiber concentrations were lowest in grass mixtures with cool-season legumes. However, grass mixtures with sericea or annual lespedeza had similar ADF concentrations to that of red clover. Neutral detergent fiber concentrations were lowest in grass mixtures with the cool-season legumes, with sericea lespedeza similar to red clover. Highest fiber concentrations were in the grasses alone.

No-till establishment of cool and warm-season legumes into perennial warm-season grasses was successful for alfalfa, red clover, sericea lespedeza, and annual lespedeza. Alfalfa and sericea lespedeza may be the most compatible legumes to grow with perennial warm-season grasses.

Caucasian bluestem and switchgrass-legume mixtures produced substantial yields from May-June to October. Caucasian bluestem’ lower energy requirement and tolerance to close grazing, makes it more attractive for a grazing system. Moreover, its yield and high quality persist from mid-June to late fall.

Introduction of legumes into these grasses increased yield and quality during late spring-early summer to mid-summer; however, N fertilization worked better in late summer-early fall. The potential of legumes to reduce N fertilization, maintain yield, and improve quality, may present the most cost-effective solution for summer pasture in Virginia.

A third year of data collection is necessary to determine the long-term compatibility of cool-and warm-season legume-grass mixtures. Cool-season legumes may hurt warm-season grasses. Caucasian bluestem and switchgrass-legume mixtures should also be tested under real grazing conditions before making any recommendations to producers.

Vita

Meriem El Hadj was born in Algiers, Algeria on February 1, 1973. She is the daughter of Messaoud and Yamina Boussaid.

She received her Baccalaureat of Science degree from Descartes High School in Algiers in 1992. She started her Bachelor of Science degree in the department of Amenagement du Territoire et Protection de l'Environnement at the University of Science and Technology of Bab-Ezzouar in Algiers. She completed her Bachelor of Science degree in Environmental Sciences at Virginia Polytechnic Institute and State University in Blacksburg, Virginia in 1998.

In the summer of 1998, she enrolled in the Master's program in Crop and Soil Environmental Sciences at Virginia Polytechnic Institute and State University.

The author is married to Selim El Hadj.