Proceedings of the 60th
Southern Pasture and Forage Crop Improvement
Conference
2006
# Proceedings of the 60th Southern Pasture and Forage Crop Improvement Conference

## Year 2006

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The breeding program on forage legumes at Auburn University has focused mainly on breeding and utilization of sunn hemp (*Crotalaria juncea* L.) and utilization of sericea lespedeza (*Lespedeza cuneata* (Dumont de Courset) G. Don) in recent years. In addition to those two species, breeding on vetches (*Vicia* spp), crimson clover (*Trifolium incarnatum* L.), red clover (*Trifolium pratense* L.), and white clover (*Trifolium repens* L.) is being conducted.

Sunn hemp has as base chromosome number (n) 8, it belongs to the Family *Fabaceae*, Tribe *Crotalarieae*. It is a fast growing species that is a widely grown green manure in the tropics, where it is also grown as a fiber and animal fodder crop (Purseglove 1981). It is a legume adapted to a wide range of environmental conditions and soil types. Furthermore, it tolerates droughts and can grow in low fertility soils. Sunn hemp produces high biomass yields, fixes N and is resistant to several nematodes (McSorley 1999).

Measurements of neutral detergent fiber (NDF) and acid detergent fiber (ADF) of sunn hemp leaves indicate that their forage quality is acceptable for lactating cows. NDF values of leaves 6 to 12 WAP ranged between 244 to 373 g kg\(^{-1}\) and ADF values ranged between 189 and 289 g kg\(^{-1}\). Stems were not found to be suitable for feeding lactating cows. NDF values of stems 6 to 12 WAP ranged from 660 to 783 g kg\(^{-1}\) and ADF values ranged from 543 to 653 g kg\(^{-1}\) (Mansoer et al. 1997).

Plants flower commonly late in the Fall in response to short days. In the southeast, mild Falls allow plants to set a few pods but the seeds are not fully developed by the time plants are killed by a frost. Consequently, no seed production has taken place with exception of small scale operations in South Texas (Cook and White, 1996). However, the possibility of an early frost with the subsequent reduction in seed yield limits seed production in the continental USA. Shortage of inexpensive seed has prevented sunn hemp from being a commonly grown crop. There is the need to make sunn hemp a more cost effective crop by developing a cultivar that can produce seed in our area. A breeding program aimed at developing cultivars selected to produce seed under the climatic conditions of Alabama has been conducted at Auburn University. A locally selected cultivar grows less, therefore has lower biomass yield but it has the added value of producing seed.

It has been reported that sunn hemp seeds contain five pyrrolizidine alkaloids. Pyrrolizidine alkaloids ingested in sufficient amount can be toxic to animals and birds. Research at Auburn in cooperation with other institutions has shown that trichodesmine and junceine were the only pyrrolizidine alkaloids present in the seeds of nine populations that originated in different parts of the world (Ji et al. 2005). Furthermore, seed of the breeding population has been fed to broiler chicken to determine its effects.
on the birds. Seeds fed at a contaminant or an ingredient level did not affect bird mortality (Hess et al. 2006).

Sericea lespedeza (SL) is a long-lived species well adapted to most of the southeastern U.S. that can provide much needed forage during the summer in the Southeast region. Up to now, the main use of this plant has been in soil conservation and soil mine reclamation because it builds organic matter in the soil (Kalburtji et al. 1999). Recent research has indicated SL forage can control gastrointestinal parasites (GIP) in small ruminants.

Infection with gastrointestinal parasites (GIP), particularly *Haemonchus contortus*, is a major limiting factor to economic small ruminant production in the southern USA. Recent reports (Mortensen et al. 2003) indicate that anthelmintic resistance in goats has become highly prevalent in the southern USA. Grazing forages high in tannins has been shown to reduce numbers of parasite eggs in sheep and goat feces in a number of studies (Athanasiadou et al. 2000, Min et al. 2004).

Research on the effect of SL forage on GIP in goats (Min et al. 2004) has shown that animal grazing on SL alone or grazing on SL alternating every 2 weeks with fescue-crabgrass reduced total fecal egg output based on fecal egg counts (FEC, parasite eggs per gram of feces) and fecal output, rate of larva development (larvae per 10g of feces), and animal worm burden compared to those animals grazing on crabgrass alone.

The anthelmintic potential of SL hay (cultivar AU Grazer) has also been investigated. SL hay was evaluated by feeding goats either SL or bermudagrass (BG) hay diets. Feeding SL hay to goats reduced parasite FEC and increased packed cell volume (PCV) compared with BG hay (Shaik et al. 2004, 2006). Furthermore, SL hay reduced numbers of both abomasal (*Hemonchus contortus, Ostertagia circumcinta*) and small intestinal (*Trichostrongylus colubriformis*) nematodes compared with goats fed BG hay and a lower percentage of ova in feces from SL-fed goats developed into infective (L3) larvae (Shaik et al. 2006). Additional work by Dykes et al. (2006) confirmed the effects of SL on goats. Similar work has been conducted with sheep where FEC were reduced up to 98% (Lange et al. 2005). Thus, SL hay could reduce pasture contamination from GIP larvae and could be replace pharmaceutical anthelmintics. These results indicate that SL has a great potential use in organic agriculture.

Literature Cited


Forage Breeding Workgroup

Shedding a little light on bahiagrass: Bahiagrass Breeding at UF

**Significance:**

Bahiagrass is one of the predominant pasture grasses utilized by the beef cattle industry in the southern parts of Georgia and Alabama, and throughout Florida. Its popularity is attributed to its tolerance of low soil fertility, establishment by seed, persistence under grazing, long-lived stands and good disease and nematode resistances. It is used as a pasture, hay, seed or sod crop. Although bahiagrass is native to South America, it has proved to be remarkably adapted to the southern Coastal Plain and, particularly, to our Florida environment. This species is estimated to cover at least 6.0 million acres throughout the southeastern United States.

The variety ‘Pensacola’ dominates the bahiagrass acreage in the southeastern U.S. In Florida, an estimated 60% of the bahiagrass acreage is planted in Pensacola, about 25% in ‘Argentine’, 10% in ‘Tifton 9’, and 5% in ‘Paraguay 22’. A new bahiagrass, ‘AU Sand Mountain’, recently released from Auburn University, has out-yielded Pensacola and Argentine varieties in several Florida variety trials; however, it is less productive than Tifton 9 and is not expected to impact bahiagrass acreage in Florida.

Strong support from the beef cattle industry in the southeastern U.S. has prompted a Florida-wide UF/IFAS and USDA-ARS emphasis on bahiagrass variety development. The team approach emphasizes plant improvement in seedling vigor and establishment, cold tolerance, reduced photoperiod sensitivity, seasonal distribution of forage production, forage quality, and insect, nematode and disease resistance.

**Rationale:**

The bahiagrass breeding program focuses on three areas of bahiagrass improvement; diploid breeding, tetraploid breeding, and the evaluation of newly imported germplasm.

**Diploid Breeding**

The first focus area is based on the selection for leaf tissue tolerance to frosting, early spring and late fall forage growth, and improved rooting in a “Pensacola”-type (diploid) bahiagrass. At present, there are several forage and turfgrass populations in various stages (years) of selection for these desirable traits. We have termed these “PCA” cycles for “photoperiod and cold adapted”. These cycles have been grown, alternating between Marianna and Ona, FL selecting over wide environments to improve cold tolerance and photoperiod response. In addition to those physiological traits, progress has been made in selecting for
resistance to the dollar spot fungus, rooting/stolon mass, and more rapid germination of the seed. PCA Cycle 4 is now in trials at the Range Cattle Research and Education Center at Ona, the Coastal Plain Experiment Station at Tifton, at the North Florida Research and Education Center at Marianna, the Agronomy Forage Research Unit near Gainesville, and is also being evaluated at Mississippi State University for winter survival. Breeder’s seed increases of PCA Cycle 4 have been established at two locations in Florida.

Tetraploid Breeding
The second area of focus in our forage and turf breeding program involves bahiagrass similar in appearance to Argentine, Paraguay and Paraguay 22 or the tetraploid bahiagrass types. A survey of nearly 1200 Florida cattlemen, taken at cattlemen meetings and field days across the state, indicated that about 80% of the ranchers prefer the ‘Argentine-type’ bahiagrass. This robust plant germinates quickly and spreads rapidly to cover new land within the first year of establishment. Breeding improvement has been limited with Argentine and Paraguay 22 due to the chromosome number and type of reproduction (apomixis) in the plant. We recently imported new germplasm from Argentina to use in our tetraploid crossing program. In addition, to the new acquisitions, we have been able to successfully use chemicals on “Tifton 9” to create new tetraploid lines. These lines are being crossed with the new materials from Argentina, and several other tetraploid types that have desirable features for forage and turf. We hope that the new developments in tetraploid germplasm will allow us to actively breed new strains of bahiagrass with the desirable attributes that cattlemen seem to prefer in Argentine bahiagrass.

New Germplasm Evaluation
The third area of focus involves the evaluation of other bahiagrass plant introductions and new closely-related *Paspalum* species. Seed has been obtained for plant accessions from the National Plant Germplasm System and from other scientists working with *Paspalum* species in Australia, Uruguay and Argentina. These materials are being evaluated at a number of locations in Florida in various environments to better determine where they are best suited. Some of these new species have shown superior winter growth and better seasonal forage distribution, compared to bahiagrass. Selection has been directed at winter survival, frost tolerance, forage yield, forage quality, seasonal forage distribution, seed production, and persistence under grazing.

The overall goal of the Bahiagrass Program is to supply the livestock producer, sodsman and home owner with a selection of different bahiagrass, and possibly other *Paspalum* cultivars, that fit well for a variety of uses.
**Impact:**

Anticipated outcomes of this project include the development and eventual release of more productive cultivars of bahiagrass and other *Paspalum* species that should be useful in:

1. Minimizing the need for conserved forage or winter grazing for livestock in the southern Coastal Plain
2. Improving forage quality of bahiagrass-based pasture systems
3. Sod-based rotation systems as short-duration, hay crops
4. Utility turf application
5. Attenuating agricultural nutrient losses to the environment

**Collaborators:**

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5. USDA-ARS, Brooksville Subtropical Agricultural Research Station, Brooksville, FL
6. University of Georgia, Tifton, GA
7. USDA-NRCS, Gainesville, FL
8. Graduate students, Univ. of Florida, Agronomy Dept., Gainesville, FL
9. USDA-ARS, Crop Genetics and Breeding Research Unit, Coastal Plain Experiment Station, Tifton, GA
10. Facultad de Ciencias Agrarias, Universidad Nacional del Nordeste, c.c. 308, 3400 Corrientes, Argentina
11. Mississippi State University, Starkville, MS
12. Texas A&M University, Overton, TX
13. Louisiana State University, Rosepine, LA

Funding for this effort has been provided by a number of small grants and cultivar royalties through The Florida Foundation Seed Producers, Inc. This research is being performed under University of Florida, IFAS, Florida Agricultural Experiment Station, Research Project QUN/AGR-03854.
The perennial grass breeding program at Tifton, Georgia has a long history. Drs. Glenn Burton and Wayne Hanna, with collaborators, developed a significant number of forage and turf cultivars over the past 60-plus years. Work is continuing in areas of forage and turf improvements for the South. Forage improvement of bermudagrass and bahiagrass continues within the Crop Genetics and Breeding Research Unit of USDA/ARS. Recently, a new effort has begun within the unit toward developing perennial grass crops as feedstocks for bio-energy in the Southeast.

An emphasis beginning three years ago in the forage breeding program was to evaluate and reestablish the 600 plus forage bermudagrass (Cynodon spp.) plant introduction nursery. Accessions in this nursery have been accumulated from Africa, Asia, Europe, and the United States and from previous breeding efforts over the past 60 years. It is from this material that Dr. Burton screened and crossed material with high digestibility, fall armyworm tolerance and high yields to produce hybrids such as Coastal, Tifton 44 and Tifton 85. A reevaluation of the material was begun by assessing phenotypic traits such as plant height, leaf width and length, coarseness of stems as well as ploidy levels by use of a flow cytometer. The entire nursery was re-established first in pots in the greenhouse then by replanting at a new location in the spring of 2004. These plots underwent further evaluation for traits such establishment rate, stolon number and length (Table 1). From the entire collection a core collection of 170 genotypes was developed using clustering analysis of fourteen phenotypic traits and ploidy levels (Anderson, 2005). The core collection is currently being evaluated for in vitro digestibility, fall armyworm resistance, shade tolerance and chemical attributes. Amplified fragment length polymorphisms (AFLP) have indicated great amounts of genetic variability that may be used for development of molecular markers to assist breeding for important traits.

Synthetic seeded breeding lines and a vegetatively propagated hybrid bermudagrass are being evaluated for release along with a fast germinating bahiagrass. Seeded forage bermudagrass with cold tolerance continue to be goals for forage improvement within the breeding program. Agronomic studies that involve fertilization rates and sod based rotations are also underway.

A greater emphasis has been placed on evaluating perennial grasses as feedstocks for conversion to bio-energy or bio-fuels. The sugar-based fermentation conversion of ligno-cellulosic plant material to ethanol has been researched extensively over the past few decades. The premise is to convert as much of the dry matter cellulose and hemi-cellulose as possible to hexoses and pentoses. Highly efficient cellulases and hemi-cellulases are being commercially developed, however, complex cell-wall structures that have cellulose and hemi-
cellulose bound to lignin restrict access of these enzymes. For that reason, it is necessary to evaluate germplasm for traits that make conversion more efficient, then breed or engineer plants with lower lignin or with cell-wall structures more amenable to decomposition. Digestion by rumen microbes correlates very well with desirable traits for conversion to ethanol (Table 2) (Anderson et. al., 2005). Thermo-chemical processes such as pyrolysis and gasification are also methods of converting ligno-cellulosic plant material to useable energy. In this case high biomass yields combined with lower ash and silicon content are desireable. A multi-species test has been established to determine comparative biomass yields, nutrient cycling, and carbon sequestration. Napiergrass (Pennisetum purpureum), giant reed (Arundo donax), and bermudagrass are among the species under evaluation as potential dedicated crops for bio-energy in the Southeast.

References:


Table 1: Means of 23 phenotypic traits within 11 major clusters from cluster analysis of full bermudagrass germplasm collection at Tifton, GA, taken during the summer of 2003.

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Table 2. Percent dry weight (DW) loss, and free sugars released in filtrate after pretreatments with commercial esterase and cellulase for bermudagrass and napiergrass genotypes at 4 and 8 weeks of age compared to *in vitro* dry matter digestibility (IVDMD).

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<tr>
<th>Genotype</th>
<th>Age</th>
<th>% DW loss†</th>
<th>Xylose (mg/g)†</th>
<th>Glucose (mg/g)†</th>
<th>IVDMD-leaf‡</th>
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<tr>
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<td>41</td>
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<td>58.74</td>
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<td>Tifton 85 (B)</td>
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<td>Tifton 44 (B)</td>
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<td>15.9</td>
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†Values are the sum of subsequent incubations with esterase for 24 h and then cellulase for 72 h.
‡48 hour rumen digestion, 48 pepsin digestion
The mission of the Dale Bumpers Small Farms Research Center (DBSFRC) is to develop scientific principles and technologies that enhance the profitability and sustainability of small farms in the mid-South region. These farmers are at particular risk from increased costs of production, declining receipts, and potential loss of a way of life. We are studying agroforestry as a means to ameliorate this risk through commodity diversification.

Crop monoculture has been a paradigm of modern U.S. agriculture. Unlike tropical or semi-arid regions, where agroforestry is widely practiced, the U.S. has been very slow in adopting agroforestry practices because of the lack of scientific, socio-economic, and traditional support systems associated with conventional agriculture. Further, conventional agriculture has a large database that may not apply to agroforestry systems because of unforeseen competitive interactions for soil water, nutrients, and light. The design of agroforestry systems is complex, governed by species, site conditions, spatial and temporal factors, and producer budget and objectives. Poor understanding of these factors constrains the design, establishment, management, and adoption of agroforestry systems. It might be appropriate to say that livestock producers are as uneasy with the prospect of tree farming as tree farmers are with cattle production.

Despite these deficiencies, the conversion of marginal crop and pasture land to tree crops is becoming increasingly attractive as an economically rational use of land resources (Grado et al., 2001; Harwell and Dangerfield, 1991). Profitability (gross value of production less cash expenses) of cow-calf production in the southern U.S. was positive only seven of 17 years from 1982 through 1999 (USDA-ERS, 2001), while the U.S. softwood timber supply situation appears to be entering a growth phase with pine stumpage prices in the South projected to increase 1.5% annually for the next several years. About 22 million acres in the South, much of it marginal crop and pastureland, could yield a greater economic return when planted with pine to create silvopastures (Haynes, 1990). Loblolly pine is well suited for agroforestry because it grows rapidly on sites with low inherent soil fertility and minimal fertilizer inputs (Schultz, 1997).

Overstory trees can simultaneously complement or constrain understory forage production and quality. Trees can favorably alter the understory microclimate (Feldhake, 2001) and protect forage by reducing evapotranspiration during drought (Frost and McDougald, 1989), minimizing deleterious interactions of heat stress and
high light intensity on photosynthesis of C3 species (Lin et al., 1999), and reducing radiation frost damage (Feldhake, 2002) compared to unshaded forage. Conversely, trees can reduce forage production through shade, competition for soil water and nutrients, and allelopathy (Clason and Sharrow, 2000; Garrett and McGraw, 2000). The objective of this paper is to highlight selected studies at the DBSFRC on physiological constraints and growth dynamics of loblolly pine-based agroforestry, including research limitations, concerns, and research needs.

**Forage responses to spacing early in the tree rotation**

We conducted a study to determine if row spacing affected yield, quality, and botanical composition of minimally managed forage in loblolly pine early (5-6 yr after planting) in the tree rotation (Burner and Brauer, 2003). Plots were located in alley middles in each of eight tree spacing configurations: 4 x 8’, 4 x 12’, 4 x 16’, 2 row (4 x 8’) + 24’, 3 row (4 x 8’) + 32’, 4 row (4 x 8’) + 40’, 5 row (4 x 8’) + 48’ wide, and control (no trees). The first three configurations were ‘rectangular’ configurations, and the last four were ‘multiple-row’ configurations. Tree rows were planted in an east-west orientation. As expected, forage yield was low (880 lb/acre/yr) with no fertilizer inputs. Row spacing affected the yield, quality, and botanical composition of pasture five to six years in the rotation especially at densities exceeding 340 trees per acre (TPA). Botanical composition shifted from predominantly cool-season (tall fescue) to warm-season (bermudagrass and Panicum) grasses between annual spring and fall harvests, respectively, which caused seasonal differences in several yield and quality traits. Forage yield generally increased, but quality and minerals (crude protein, IVDMD, Ca, and P) tended to decrease with alley spacing. Forage minerals, except for Cu and Na, met or exceeded needs of growing and finishing beef cattle, while crude protein concentration (8.4%) was marginally adequate. The tendency for increased forage quality in pine-shaded alleys would be offset by low yield, necessitating rotational grazing.

Trees should be planted in rows no closer than 16’ for best forage yield, quality, and equipment access. Minimal management will limit forage productivity, animal stocking rate, and possibly tree growth, and might require that livestock be supplemented with protein and minerals. Further, tall fescue might not be sustainable with minimal management. While we do not necessarily recommend a no-input approach as a best management practice, resource-limited producers may be unable to impose high-input strategies on marginal sites.

Another study was conducted in separate plots of the same pine stand to assess the effects of tree density and configuration (multiple-row vs. rectangular) on forage yield with fertilizer inputs (Brauer et al., 2004). Forage in May and September averaged about 7,000 and 4,000 lb/acre in the control, respectively. Forage yields were lower in pine alleys than the control. At comparable TPA, forage yield tended to be greater in multiple-row configurations with wide (40 to 48’) alleys than rectangular configurations (8 x 8’ or 12 x 12’). Tall fescue was the dominant species in all configurations in May, and in 4 x 8’ and 8 x 8’ configurations in September.
Bermudagrass was the dominant species in September in the control. Tall fescue and bermudagrass were co-dominant in September in 12 x 12', 4 row (4 x 8') + 40' and 5 row (4 x 8') + 48' configurations. Forage yield was inversely related to tree canopy cover in May ($r^2 = 0.96$) and September ($r^2 = 0.90$). Forage yield in summer (i.e., June to September) was related to productivity of the bermudagrass. Annual forage production in this study was 22 and 81% greater for multiple-row than rectangular configurations at tree densities of 300 and 680 TPA, respectively. The differences in forage production suggest that multiple-row configurations are preferable to rectangular configurations for forage production. Other research also has shown that the 2-row multiple-row configuration is practical for producing sawtimber without sacrificing the area allocated for forage production (Ares and Brauer, 2003).

**Influence of alley crop environment on orchardgrass and tall fescue forage**

A study was conducted to determine whether the alley environment differentially affected persistence, forage yield, and quality of two shade tolerant forage grasses (Burner, 2003). The experiment was conducted for 3 yr on orchardgrass, tall fescue, and a 1:1 orchardgrass - tall fescue mixture in 16'-wide alleys of 10-yr-old loblolly pine and shortleaf pine, and an unshaded control at Booneville, AR. Loblolly pine was 5' taller and had twice the canopy cover as shortleaf pine (52 and 25% canopy cover, respectively). Averaged across harvests, orchardgrass persisted better in loblolly pine alleys (72% stand) than in the control (44% stand), while tall fescue persisted better in the control (30% stand) than in loblolly pine (13% stand). Persistence in shortleaf pine alleys was intermediate for both grasses. Yields of orchardgrass and the mixture did not differ in pine alleys (1150 lb/acre), and were usually greater than tall fescue yields ($\leq$ 620 lb/acre). Across treatments, forage yield in pine alleys was about 70% of that in the open. Crude protein was higher in loblolly pine alleys (17.2%) than in the control (14.1%). In a related study, orchardgrass had a lower concentration of total nonstructural carbohydrate in alley cropped than control forage, while water soluble carbohydrate and digestibility did not differ (Burner and Belesky, 2004). The introduction of livestock into this system could affect species persistence due to preferential grazing of orchardgrass. For example, orchardgrass did not persist well in conifer-shaded swards grazed by sheep in West Virginia (Belesky et al., 2001). Producers should consider using orchardgrass monocultures or mixtures with tall fescue for pine alleys in the mid-south U.S.

**Forage nitrogen recovery in a meadow and loblolly pine alley**

Forage should be managed differently in conventional and agroforestry systems, but managers have scarce data on which to base their decisions. We conducted experiments to measured forage N fertilizer recovery at two sites: an unshaded meadow and a shaded alley in 10-yr-old loblolly pine (Burner and MacKown, 2005; Burner and MacKown, 20XX). Tall fescue was the predominant forage species. Fertilizer N was broadcast as split-applications at six rates (90 lb/acre increments
from 0 to 450 lb/acre/yr). The meadow and pine alley had sufficient forage yield for rotational livestock production. Cumulative forage yield in the meadow was much more responsive to added N than pine alley forage, but average cumulative fertilizer N recoveries were only 38% and 12%, respectively. The proportion of total forage as tall fescue was favored at rates ≥ 180 lb/acre, but these rates increased concentrations of forage nitrate in the pine alley to potentially harmful levels for grazing ruminants (> 2300 ppm nitrate-N). Cumulative forage N use efficiency (CNUE) was 23 and 10 lb dry weight per lb supplied N for the meadow and pine alley, respectively. Cumulative N acquisition efficiency, not cumulative N conversion efficiency, appeared to be the primary driver of low CNUE in the pine alley. Low CNUE could be caused by low energy levels in alley cropped forage (Burner and Belesky, 2004). The apparent increase in crude protein in pine alley vs. meadow forage appeared to be a mechanistic response to decreased specific leaf weight. A shallow fragipan, low available soil P (< 6 ppm), and depletion of soil water in July to September (both sites), and low solar irradiance (pine alley), were likely contributors to low fertilizer N recovery and forage productivity. Because of poor forage yield response, low CNUE, risk of nitrate toxicity to ruminant livestock, and substantial accumulation of soil mineral N (55 to 210 lb/acre) in pine alleys fertilized with > 180 lb N/acre/yr, only maintenance levels of fertilizer N (< 90 lb/acre/yr) should be applied to similar sites. For these same reasons, yearly applications of fertilizer N > 270 lb/acre/yr are not recommended for meadows similar to the study site.

Conclusions

Pine alleys can be used for rotational livestock grazing, but management and planning are needed to assure there is an adequate supply of quality forage. Loblolly pine grows well on poor sites as long as there is no standing water, and trees will respond to fertilization when soil nutrients are deficient. Growers should select suitable sites and plant trees at appropriate stocking levels to maximize the grazing potential until the first thinning, while at the same time assuring that tree density meets long term production objectives.

Orchardgrass appears to be at least as competitive, if not more so, than tall fescue in pine alleys despite being at its extreme southwestern range limit in western Arkansas. Tall fescue may not be a sustainable alley crop except under minimal tree competition in wide alleys, but it may be possible to develop tall fescue cultivars with enhanced shade or drought tolerance. Producers using orchardgrass in pine alleys should consider establishing the sward after three to five seasons of tree growth to take advantage of protective shade. It is not clear whether these two forages differ in shade or drought tolerance. We are conducting research to try to separate relative impacts of shade and soil water on tall fescue because one or both of these factors decrease concentrations of forage energy levels needed to drive nutrient accumulation and assimilation. Alley cropped forage can have roughly the same yield and quality as conventional pasture if the level of tree competition is regulated through appropriate planting design, periodic pruning and thinning, and control of animal stocking rates. Special attention should be paid to forage nitrate
because N fertilization of shaded forage can foster nitrate accumulation. We are currently studying N recovery of grass and tree components to better understand the competitive interactions between these system components.

The integration of pines, forage, and livestock on the same land unit requires more management and thought than monoculture production. Are the benefits of commodity diversification through agroforestry sufficient to offset management costs? Can a farm be more economically and biologically sustainable if agroforestry methods are implemented? We believe the answer to both questions is “yes”.
References


Introduction

The Appalachian Region is 23% larger than the state of California and encompasses parts of 11 states including all of West Virginia. While there are some highly productive agricultural regions within Appalachia, most of it is marginally productive, hilly and difficult to farm (Barnes, 1938; Proctor and White, 1962). Agricultural production is mainly from small farms averaging 60 ha with 40% of that land area occupied by woodlands (USDA 1999). The dominant form of agriculture, on an area basis, is the production of perennial forage grazed by beef cattle. This form of agriculture does not generate enough income to support a family on an average farm, thus off-farm jobs are the norm.

Conversion of pasture and woodlands to silvopasture production systems has the potential to increase farm income in an ecologically sustainable manner. Silvopastures diversify farm income by growing trees for wood or other useful products and forage for animal production within the understory. Silvopastoral systems provide forages with an environment where both solar radiation and temperature vary spatially on a daily and seasonal time scale. The economic success of silvopastoral systems requires proper management of the solar radiation resource.

Forage growth does not have a simple relationship to light environment. Some C3 plants appear to use diffuse radiation more efficiently than direct beam radiation (Sinclair et al., 1992; Healey et al., 1998) so that in a humid, cloudy environment the amount of field-of-view open to reflective clouds is more critical than in sunny, arid regions. Tree shade induces changes in light intensity and quality that can cause morphological changes in forage grasses such as increased leaf elongation, reduced specific leaf weight and reduced tillering which in turn affects forage quality (Devkota and Kemp, 1999; Monaco and Briske, 2000; Burner, 2003; Belesky 2005). Timing of daily exposure to solar radiation is also important since it affects plant carbohydrate content, thus energy value as animal feed (Ciavarella et al., 2000; Mayland et al., 2000).

This paper reports how forage performance was related to Photosynthetically Active Radiation (PAR) spatially and temporally for several silvopasture research
projects at the USDA-ARS Appalachian Farming Systems Research Lab, Beaver, WV and in cooperation with Virginia Tech, Blacksburg, VA.

Materials and Methods

PAR

Photosynthetically active radiation (PAR) was measured for all experiments using 1 m long LI-COR LI-191-SB line quantum sensors (LI-COR inc., Lincoln, NE). Sensors were mounted horizontally about 25 cm above the ground to prevent shading by forages. Data from the sensors were collected using Campbell Scientific 21X data loggers (Campbell Scientific, Logan, UT) with measurements made every 10 seconds and averaged hourly. Sensors were moved between sites throughout the growing season for 7-10 day measurement periods with up to 16 sensors used at any given time depending on spatial requirements. Sensors were placed close together in an open field once early and late each summer for calibration. Automated weather stations were used to measure open-site PAR continuously throughout the growing season for estimation of silvopasture PAR during periods without quantum sensors at a given site.

Yield

Forage yield was measured for 5 different silvopasture experiments.

1) Black locust (Robinia pseudoacacia L.) rows planted in a steep pasture watershed
Plots, .7 X 4 m were clipped in 3 or 6 week intervals during 2001, 2002 and 2003. Trees were in row 12 m apart oriented SE to NW. Plots were parallel to tree rows at varying distance from trees. Pasture was dominated by tall fescue (Festuca arundinacea Schreb.) and white clover (Trifolium repens L.).

2) Black walnut (Juglans nigra L.) and honey locust (Gleditsia triacanthos L.) rows planted on a hillside pasture
Plots with each tree species contained rows oriented SE to NW that varied in tree density with harvest strips placed to give three treatments, closed overstory, afternoon shade, and no shade most of the day. Strips were .53 X 2.44 m and harvested every 5 weeks during 2002 and 2003. Pasture was dominated by tall fescue.

3) Forage planted in a mixed density northern conifer stand composed of mostly white pine (Pinus strobus L.) and red spruce (Picea rubens Sarg.). Twelve plots with varying shade were identified and 4, 0.1 m² samples were harvested from each every time the forage reached 20 cm during 2000, 2001 and 2002. The area was grazed by sheep after each clipping. Pasture was dominated by orchardgrass (Dactylis glomerata L.), perennial ryegrass (Lolium perenne L.) and white clover.

4) Forage planted in a thinned mixed hardwood forest.
Grazing paddocks for sheep were established in a thinned second growth mature hardwood forest dominated by oak (Quercus spp.). Paddocks were planted with perennial ryegrass and white clover. Open pasture paddocks for
comparison were dominated by orchardgrass and white clover. Pastures were grazed in a 6 week rotation with yield samples taken before grazing. This work started in 2002 and is ongoing as new paddocks are still being created.

5) Forage-containing pots placed in-ground within a forest clearing and on a gradient within a north side forest edge.

The research was done adjacent to and within the north edge of a 400 by 30 m group selection clear-cut of a second growth hardwood forest (Quercus spp), made four years prior to the experiment. The long axis of the clearing was oriented east-west and was wide enough that the base of the region near and within the north edge received no shading from the south side throughout the growing season. The remaining forested area had achieved a closed canopy of over 25 m in height. Mowing had allowed the site to develop a low canopy within the clearing and forest edge of mixed low forbs and grasses with some bare ground patches which increased in area with distance into the forest. Pots with orchardgrass, 15 cm in diameter with bottoms removed were placed into the ground within a shade gradient going from forest edge to 10 m into the forest along the north edge. Pots in the cleared area were designated as “O”, 2 m within the forest as “Eo”, 10 m within the forest as “Ew” and 35 m within the forest “W” for a deep forest comparison. Selected pots were harvested and all others clipped whenever grass reached 20 cm.

Results

1) Forage yield was not statistically different between harvest strips relative to distance from black locust tree rows. This is in spite of a nearly 5 fold difference in total daily PAR on sunny days between the sites under tree canopies compared to mid alley. The major difference in forage across the site was more clover in the mid alley compared to under black locust. Because of row orientation the forage under the black locust received sunlight early and late in the day when the mid alley was shaded, thus coupled with diffuse radiation and sun flecks, the forage under the trees effectively experienced a longer growing day than other harvest strip sites.

2) In the black walnut and honey locust silvopasture the sites receiving shading in the afternoon yielded higher than sites with full sun or mottled shade most of the day. A similar trend was evident both in 2002 and 2003 even though 2002 was a very dry summer and 2003 was a very wet one. Under closed tree canopies black walnut restricted PAR about 15% more than honey locust. During the dry summer of 2002 forage yield was higher in association with black walnut compared to honey locust but yields during the wet 2003 summer were similar under the two tree species.

3) Within the conifer silvopasture yield decreased with PAR although there were plot site limitations such as shallow rocky soil that complicated the relationship. At the best yielding sites 20-30% of maximum PAR produced over 60% of a largely unshaded site’s yield. One factor limiting yield in a conifer silvopasture is that forage does not receive as much PAR in spring and autumn compared to a deciduous tree silvopasture thus PAR is more restricted during what is usually optimal growth periods for C3 forages. Also, since at this site the
trees were not in north-south rows, the forage had a shortened day in which high PAR levels could be incident since the horizon was blocked and eliminated 2 hours of direct beam radiation both in the morning and evening.

4) Forage yield in the grazed hardwood silvopasture was about half the yield from the open pasture. While PAR was also about half, the yield difference cannot be attributed primarily to the reduction in PAR. The open pasture had been managed as pasture for many decades with additions of lime and fertilizer. The silvopasture site had shallower, rocky soils that had been established in forage in 2001 so these forest soils were not optimal for forage production. Lambs did perform as well in the silvopasture as the open pasture, however, larger paddocks were required in the silvopasture for replication of animal units.

5) In the forests edge pot study, forage yield increased with PAR. By late summer the O treatment and Eo received essentially the same amount of daily PAR since the changing solar angle allowed direct beam radiation to penetrate under the tree foliage canopy (Figure 1). Maximum differences in PAR between treatments happened about 3.5 weeks before and after summer solstice. This was the period when trees were fully leafed out and the sun angle was most vertical. The two years were very different during summer with 2003 being much cloudier (Table 1). The comparison of PAR data from the two years demonstrates the importance of expressing PAR as true values rather than percent since percent of maximum received in the open is very different than percent of maximum possible with no cloud cover (Table 1).

Summary

Levels of unobstructed PAR vary widely between regions of the country, time of year and between years with different prevailing weather patterns. For this reason comparisons between silvopasture systems, which are complex by nature and often limited in PAR interception, need evaluation relative to absolute PAR and not relative indices such a percent shade. The relationship between PAR and forage productivity will differ between thinned forests with a newly established forage on a forest soil and long-established pasture with planted trees. Forages respond differently within confer silvopastures where spring and autumn have lower levels of PAR compared to summer due to larger tree shadows cast by a low sun angle compared to deciduous-tree silvopastures where spring and autumn PAR levels are higher than during summer since the trees have no leaves and produce little shade. The spatial growth patterns for forages are affected also by tree spacing since in thinned forests environments, high PAR day length is limited by horizon obstruction by trees but in north-south tree row silvopastures forage under trees may have a longer day length than at mid-alley locations. What is evident from a variety of experiments at our location and others is that it is possible to produce high quality forages within a variety of silvopasture configurations and the factors determining design characteristics will depend on soils, long-term site weather and economics.
Figure 1. Modeled maximum PAR and measured PAR for the open (O), within forest edge near the open (Eo), 8-10 m within the forest (Ew), and 35 m within the forest (W). Each point represents the average of 10 days.

Table 1. Summer solstice (7-week average) actual and relative PAR.

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<th>Ew</th>
<th>W</th>
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Belesky D.P. 2005 Dactylis glomerata growing along a light gradient I. Dry matter production and partitioning in plants established in spring or late summer. Agroforestry Systems 65:81-90


INTRODUCTION

Silvopastoral grazing includes grazing of naturally established forests or woodlands as well as man-made plantations and orchards. Many areas around the world have large tracts of land which are grazed by ruminants. This land is generally characterized as rugged having a steep slope that prevents its use for production of cereal grains or other arable crops, or other environmental factors limits its ability to produce crops other than forage. During the establishment period of reforestation, a considerable amount of non-woody vegetative growth can occur and compete with the seedlings for nutrients. This competition can be detrimental to seedling survival and hamper growth. This competition is generally eliminated by controlled burning, herbicides or grazing. This can provide an opportunity for ruminant production to control the vegetative competition and if managed correctly has the potential to increase the short-term net returns of otherwise idle land.

Although new interest in combining trees and livestock has been aroused, such a system has been known to be profitable for many years. John H. Peterson Jr. (1987) reported on the following excerpt from Stephenson (1954) describing the cattle husbandry practices of 1783-84 North Carolina backwoods:

With the most careless handling, domestic cattle have increased with the greatest rapidity. It is nothing uncommon for one man to own 100 or more head of horned cattle; some count their herds by the thousands, all running loose in the swamps. By penning up the calves, and throwing out a little corn every day to the dams, the milch cows have been accustomed to come up to the dwelling-house from time to time to be milked. . . . Out of the woods one head with another is sold to the cattle-handlers at 3 to 6 Spanish dollars; and to the owner, has been at so little trouble and expense, this is almost clear gain.

Producers near forested areas still rely on the forest to provide vegetation and shelter for cattle even though drastic changes in management have evolved since the early settlement of the nation.

Orchards and nut bearing plantations can also provide opportunities for combining livestock and trees. Removal of the forage by livestock would increase nutrient recycling, eliminate the operating expense of mechanical harvesting of the forage and provide additional income. It is uncertain as to what species of trees,
forages and livestock may best compliment one another. In addition, little information exists for the interactions that may occur as a result of intensively managed grazing.

OVERVIEW OF PRODUCTIVITY IN SILVOPASTORAL SYSTEMS

Combining cattle and trees to develop a more productive setting is not new to the agriculture industry. For years small family farms have grazed their cattle under the canopy of mature timber stands and wooded areas are still utilized to provide shelter. However, the myth that grass can not be grown under walnut, oaks and other timber species to support adequate gains or grazing days is still held by several to be fact. Recently, researchers have been investigating alternative methods, grazing being one of the more prominent, for controlling forage and brush growth in timber plantations to reduce potential fire hazard and to eliminate competition for moisture and soil nutrients. Further, investigations of systems that combine ruminants and silviculture are helping to identify complimentary management practices.

Forage Productivity in Silvopastoral Systems

Although forage productivity varies largely in these studies, a strong correlation can be seen between light intensity and forage production in pine - forage stands. This relationship is not as prevalent in nut tree - forage systems. The increased forage production observed within nut-tree plantations is likely a result of the tree spacing utilized within pine and nut bearing stands. This relationship may also be explained by the difference in canopy light transmission or the density of the canopies. The canopy structure of walnut and pecan plantings probably allow more light to reach the forage canopy than pine canopies. The accumulation of material under the canopies and the given forage species commonly studied may additionally explain a portion of the variation between the pine and deciduous stands. Accumulation of pine needles may increase the amount of vegetation shaded out when compared to deciduous stands. Most of the research involving pine stands utilizes warm season species which in general are more sensitive to lowered irradiance while cool-season forages are commonly grown with nut trees. This is primarily a result of geographical location. The increases in forage production within silvopastoral systems span across a variety a species such as the variety of southern pines, the Northwest firs as well as the mesquite of Texas. East and Felker (1993) observed a 152% increase in green panic yields under mesquite canopies when compared to adjacent open areas. These responses illustrate the opportunity over a range of climates, species of trees and forages for the implementation of silvopastoral systems.

Shade and Forage Quality Interactions

The effect shade stress has upon forage quality also varies. Kephart and Buxton (1993) illustrated that reduction of ambient sunlight to 37 and 70 % of full intensity resulted in increased nitrogen concentration, decreased neutral detergent fiber, enhanced degradability by in vitro dry matter digestibility while cell-wall composition remained constant. Garrett and Kurtz (1983) presented data suggesting forage
digestibility of fescue and orchardgrass was enhanced by shade from walnut canopies (54.5 %, 49.5 %, 56.5 % and 54.0 % for shaded fescue, open fescue, shaded orchardgrass and open orchardgrass respectively). These data coincide with Smith’s (1942) findings in which forage quality under black walnuts was greater than adjacent open areas. Green panic, plains bristlegrass, and Virginia wildrye crude protein content was found to be significantly greater when grown with mesquite when compared with adjacent open areas while no difference in dry matter digestibility was observed (East and Felker, 1993). Balocchi and Phillips (1997) also reported herbage crude protein content was greater under the canopy of *Pinus radiata* agreeing with Kephart and Buxton’s and East and Felker’s findings. Their findings also indicated a depression for in vitro dry matter digestibility as modified acid-detergent fiber increased with shade stress disagreeing with Kephart and Buxton’s and Garrett and Kurtz’s data. This response may, however, be a resultant defense tactic of the forage to grazing pressure which was not present in the other two studies. Wolters (1973) working with longleaf pine stands in Louisiana additionally revealed that forage crude protein was greater under the canopy when compared to the open. Wilson (1996) observed similar responses with tropical grasses in which 50% shade increased both dry matter and nitrogen yield when compared to forages grown in full sun. This work also showed that shade increased the amount of live material present by 4%. Other research coincides with the conclusion that shade improves nitrogen content of herbage (Wong and Wilson, 1980; Walgenbach and Marten, 1981). Research conducted at the University of Missouri has tested a variety of forage species and their response to 0, 50, and 80% shade (Lin, 1997). The responses for yield, %ADF, %NDF, and %CP were measured in this study to identify species that could be incorporated into an agroforestry system. These data revealed that C-4 grass yields were greatly suppressed by shade in spring-early summer and summer-fall periods while tall fescue and orchardgrass were not significantly altered by 50% shade. Forage %NDF and %ADF was not altered or slightly increased due to shading for most species observed in this study. Crude protein percentage of most cool-season grasses was increased as the degree of shading increased while legumes were unaffected coinciding with previous research. Increased forage quality within silvopastoral systems would greatly enhance the acceptance of these practices as individual animal performance would be expected to be increased as a result of greater nutrient digestibility and utilization.

**Livestock Performance under the Canopy**

Cattle and sheep are the two primary species utilized in silvopastoral systems. In some instances emphasis is also placed upon the grazing wildlife within the area. Sheep are utilized quite heavily in the Northwest fir plantings while cattle are the predominant animals grazed in the southern pine plantations.

Animal performance is generally dependent upon two parameters. The first is forage availability and the second forage quality. In order to meet the animal's genetic potential for growth, lactation, calving percentage, or any other performance measurement, ample high quality forage is required.
Animal performance has not been shown to be depressed by the presence of timber given forage availability is not limiting. Quigley et al. (1984) demonstrated that continuous grazing of a Ponderosa pine-Bunchgrass range resulted in increased performance over a 10-year period when compared to deferred rotational grazing. Gains of cattle grazing an Eucalypt plantation in Brazil were approximately 0.5 kg (Couto et al., 1994). Calves grazing pecan orchards for herbage control had average daily gains of 0.42 kg. When management strategies changed and more emphasis was placed on maintaining higher quality forage, calf gains were approximately 0.60 kg per day (Mitchell and Wright, 1991). Walnuts planted in pastures provided a 22 % increase in steer gains for bluegrass pastures in Tennessee (Neel, 1939). Gains for calves grazing in young ponderosa stand were similar to those of Mitchell and Wright averaging 0.61 kg over the six-year grazing study. Calf performance was slightly higher in a longleaf pine stand over a ten year study period irrespective of grazing intensity with daily gain averaging 0.79 kg (Pearson and Whitaker, 1974). However, percentage calf crop decreased from 82% for light grazing pressure to 70% for heavy intensity. Cow and calf performance on southern pine areas has also been shown to respond to grazing management. These studies further illustrate the potential for combining cattle and timber as animal performance appears to be similar to open pasture grazing.

Tree Growth-Grazing Interactions

Little data exists explaining the impact grazing has on tree performance. The majority of the research has investigated the affects of grazing on tree regeneration. There appears to be no conclusion as to whether grazing is detrimental during this period. Evidence does exist for increased seedling damage by cattle due to trampling and browse damage by sheep, however, the conflict arises as to the actual seriousness of this damage.

When trees such as Virginia pine are used for Christmas tree production, damage can be substantial if trees are not protected from grazing (Pearson et al., 1990). On the other hand, sheep grazing had no effect on height or diameter growth of Douglas fir trees from four years of age through eight (Sharrow et al., 1992). A second study conducted by Sharrow and co-researchers (1996) illustrated no depression in either height or diameter growth in an agroforestry system involving grazing by sheep when compared to the control forest setting. An earlier study conducted by the same researchers revealed a significant improvement in both diameter and height growth of four to six year old firs (Sharrow et al., 1989). Grelen and co-workers (1985) examined the results of grazing a slash pine stand from establishment through 18 years of age. No differences for height growth were observed between ungrazed, lightly or heavily grazed stands for five and 18 year measurements. The study did indicate an increase in the number of planted trees lost for the heavily grazed areas when compared to the ungrazed planting. Interestingly, the heavily grazed areas were significantly larger in diameter than the ungrazed (19.05 cm versus 17.02 cm for grazed and ungrazed respectively). This could be attributed to a decrease in nutrient competition between forage and trees, a decrease in tree-tree competition since survival was lower or a combination of the two. Lastly, no differences were observed for total volume
production. Couto and co-workers (1994) observed similar results with Eucalpyt trees in which grazing did not hinder the diameter or height growth. Lewis (1985) observed similar responses in which grazing bahiagrass under a pine canopy increased tree height growth after 8 years by 1.4 m. The published research suggests that grazing will not depress tree growth and may improve performance possibly allowing for a shortened rotation by eliminating vegetative competition.

**Physical Properties of Forest Soils Following Gazing**

A large concern with forest grazing is the impact on soil properties. Forest soils tend to be very fragile and in general highly erodable. The majority of the forested areas are sloping hillsides and when disturbed can begin to lose topsoil quickly. Almost all research conducted to the present suggests that grazing compacts forest soils to moderate depths (41 cm) and over a sustained length of time can compact the soil to 0.9 m in depth (Linnartz et al., 1966; Rhoades et al., 1964; Duvall and Linnartz, 1967).

Agroforestry systems are in general different than grazing on forest soil and native vegetation found within the timber stands. Silvopastoral systems are in general a more intense management system. Improved forage varieties are planted to maximize herbage production to support grazing. Currently, grazed pastures may be planted with widely spaced trees to maintain productivity of both tree and vegetation. In general, the soil characteristics are different under these systems as they will already be compacted as is the case with previously grazed pastures. In addition, more precautions may be taken to prevent soil erosion from the use of sod forming grasses. Bezkorowajnyi, Gordon and McBride (1993) conducted a study in which they examined the effects of cattle grazing on the performance of trees planted into already grazed pastures. Their results illustrated that compaction to depths of 19.5 cm were greater in grazed areas when compared to ungrazed fields. These effects were seen after three months of grazing. However, no differences were seen in the first months indicating the potential for short duration grazing systems. Further, they applied three levels of compaction (low, medium or high) to potted seedlings and observed shoot growth of poplar cuttings was reduced for medium and high compaction levels. They additionally observed that root length growth was enhanced as compaction increased. Short duration grazing of seedlings during establishment, therefore, may stimulate root mass development without sacrificing shoot growth and photosynthesis capacity. Additional studies investigating grazing – soil interactions are needed to aid in the development of proper management of silvopastoral systems.

**RECENT SILVOPASTORAL RESEARCH EFFORTS IN MIDWEST**

Research conducted by the University of Missouri agroforestry group continues to address the management of the silvopastoral systems. Lehmkuhler et al. (1998) investigated implementation of managed grazing versus continuous grazing management on animal, forage and tree responses for one area of a black walnut plantation in southern Missouri. Using a high stocking rate and short grazing period, they observed an increase in forage availability and a tendency for improved quality
under the managed grazing system in comparison to the continuous system agreeing with previous research. When botanical composition was investigated, continuous grazing resulted in a larger percentage of dead material comprising the samples which was interpreted as a reduced efficiency of forage utilization while the rotationally grazed paddocks had higher amounts of clovers and grass. These forage productivity factors help explain trends in performance improvements for rotationally grazed cattle. Tree growth, both diameter and height, were not affected by grazing.

In a second trial conducted at the same location, these researchers investigated the response to varying the stocking density (Lehmkuhler et al., 1999). Initial stocking rates of 4.9 or 9.9 animals/ha for six weeks followed by 4.9 animals/ha for two weeks using rotational grazing management were investigated. Increased stocking rates resulted in reduced performance of Holstein heifers which agrees with other research. Forage availability and quality varied little between the two stocking rates. When forage availability was expressed as a quantity of live forage, it was determined that forage availability was below calculated intake levels five of the eight weeks. The researchers concluded that the use of total forage availability is not as accurate at predicting performance as is using live forage availability.

How does one go about establishing a silvopasture? One approach is to establish forage under the canopy of trees and thin the stand as necessary to maintain enough light transmission to support adequate forage production. The alternative is to establish seedlings into existing pastures. The challenge with this approach for existing cattle operations is the loss of grazing acres. The forage would need to be harvested mechanically rather than grazed or the seedlings would need to be protected from grazing animals. Lehmkuhler et al. (2003) investigated methods of protection for newly planted seedlings of red oak, honey locust, pecan and black walnut. Protection methods investigated were a foliar application of denatonium benzoate, a single strand of electrified poly-wire or no protection. Pastures were grazed for eight weeks each of two years. Use of foliar deterrent was not an effective strategy to prevent seedling damage while the electric fence protecting nearly all trees from damage. Cattle grazed in pastures with trees gained similarly to those in pastures without trees indicating. Though an investment is required in temporary fencing, this management strategy allows continued utilization of the grazing area during the establishment phase of the silvopastoral system. Additionally, the use of electrical fencing systems compliment managed grazing using rotational or strip grazing.

**SUMMARY**

Silvopastures allow for diversity of the landscape and production systems. Several factors must be considered when designing this type of system including forage response to shade and grazing pressure, tree performance when animal pressure is present, soil characteristics, as well as the animal utilized. Grazing pine stands appear to have no detrimental effects on tree performance, however, little information exists detailing the responses of grazing deciduous nut bearing trees. Livestock performance may be impacted depending upon the type of animal utilized in relation to the species of
trees in the silvopastoral system. However, in most instances, proper management allows for complementation of woody biomass and livestock production.

Reference:


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Fermentation Characteristics of Round-Bale Silages
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Introduction

Making round-bale silage is an attractive option for many producers. From one relatively inexpensive harvesting machine one can make either hay or silage, depending on weather or need. It provides a means of making a silage that is transportable and saleable while maintaining an anaerobic environment in the process of transferring that silage to the buyer. So the potential exists for selling silage over a greater hauling distance than is possible for silage from other silo types. A further advantage of round-bale silage is that it is easy for the producer to create an inventory by field or harvest, setting aside for example the highest quality bales for the livestock that can best utilize that quality.

While there are a lot of advantages, a major concern is the quality of fermentation that one gets from baled silage. There certainly is anecdotal evidence of fermentation problems: clostridial or butyric acid silages, moldy bales and even contamination with listeria. Are these the result of ensiling long forage particles at low densities? Do the layers of plastic film used affect these problems? Will the use of stationary knives at the baler pickup to cut the forage in smaller pieces improve density and fermentation? This paper will review the literature to attempt to answer these questions and provide some practical recommendations to help ensure a good fermentation in round-bale silage.

Ensiling Basics

Preservation by ensiling depends on three factors: anaerobic (oxygen-free) environment, fermentation acids (lactic and acetic acids), and low pH. Failure to achieve one or more of these factors may compromise silage quality.

An anaerobic environment is the most essential element for silage preservation. It is created by sealing the crop and allowing plant respiration to remove any oxygen trapped within the crop. This usually occurs within a few hours of a bale being wrapped. There are two main reasons why an oxygen-free environment is important. One, many aerobic spoilage microorganisms (particularly molds and yeasts) can grow at low pH (< 4.0) so that a good fermentation can slow down but not stop the growth of molds. Two, an anaerobic environment is also critical for the efficient growth of the lactic acid bacteria (LAB) that ferment the crop.

Lactic acid bacteria typically account for just a small percentage of the microorganisms on the crop when bales are wrapped. However, once the crop becomes anaerobic, the lactic acid bacteria are extremely good competitors and will usually become the
dominant microorganisms within hours or days depending on moisture content. The LAB grow on plant sugars, producing primarily lactic acid as well as acetic acid, ethanol and other products. Lactic acid is a good inhibitor of the bacteria that cause listeriosis (*Listeria monocytogenes*). Acetic acid is a good inhibitor of yeasts and molds. However, concentrations of acetic acid are rarely high enough to prevent mold growth.

The production of lactic and acetic acids lowers crop pH. A low pH reduces the activity of plant enzymes and inhibits growth of undesirable anaerobic bacteria. The most important of these are the clostridia. These bacteria produce butyric acid and amines from fermentation of sugars or lactic acid and amino acids, respectively. Such fermentations cause losses of dry matter (DM) and reduce silage intake by ruminants. In addition, low pH makes lactic and acetic acids more inhibitory to sensitive microorganisms, for example increasing the effect of acetic acid on mold growth.

**Keys to Dealing with Detrimental Microorganisms**

**Clostridia.** Clostridial bacteria are anaerobic bacteria like the lactic acid bacteria. However, they are typically slower than the LAB and cannot grow at as low a pH as LAB. So the key to controlling these bacteria is to drop the pH sufficiently. The critical pH to reach is a function of the crop and its DM content (Fig. 1). At the same DM content, a lower pH is needed to prevent clostridial growth in grasses than in legumes. A crop like whole-plant corn has abundant sugars for fermentation, and pH is usually below 4.0, which why corn silage rarely has butyric acid. Grasses and legumes have highly variable sugar contents dependent on stage of growth, weather, and harvest conditions. Because of this, field wilting prior to making silage is the common means in the U.S. for preventing clostridial fermentation. If the crop has a low sugar content, then the crop has to be drier to prevent clostridial activity.

**Yeast and molds.** Some yeasts grow anaerobically, producing ethanol, but these yeasts are not usually a major concern. The biggest concern is aerobic spoilage caused by yeasts that grow aerobically on lactic acid and by molds. When silage is exposed to air, yeasts that consume lactic acid are generally the first aerobic microorganisms to grow, using up lactic acid, raising silage pH, and then allowing all of the other spoilage microorganisms to grow. While molds can grow at low pH, they are much slower than other aerobic microorganisms so that when you see molds on the silage surface, it indicates that oxygen has been present for some time. Because many yeasts and molds can grow at low pH, the key to stopping them is keeping oxygen out. In practical terms, that means doing a good job of wrapping, handling wrapped bales carefully, and routinely monitoring and patching wrapped bales.

**Listeria.** *Listeria monocytogenes* has been isolated from wrapped round-bale silages. Most reported cases have been in cool-season grass silages in northern Europe. However, that may be more a function of the number of scientists there who have looked for listeria. I do expect that listeria can be present in our bale silages. Listeria are aerobic bacteria and do not grow below pH 4.5 to 5.0. Listeria generally are found in spoiled silage where oxygen has been present and pH is high. This is another good
reason not to feed spoiled silage. Like the situation with yeasts and molds, the key is keeping oxygen out. If there are no visible molds, the likelihood of a significant listeria population is greatly reduced.

**How Does Fermentation in Round-Bale Silage Compare with That in Other Silo Types?**

There are several reasons why one might expect a poorer fermentation in round-bale silage relative to silage from other silo types. Lactic acid bacteria are on the outside of plant particles and do not have a means for moving around. The sugars that they grow on must diffuse from the inside of plant cells to them. Therefore one might expect that access to sugars may be more limited in round-bale silage compared with other silo types where the crop is finely chopped. Expected densities in bale silage typically range from 10 to 14 lbs. DM/ft$^3$. These densities are similar to those in bag silos, but below those in tower silos and well-packed bunkers or piles. A lower density might also contribute to few sugars diffusing to the LAB. Finally, wrapped bales have the largest surface to volume ratio of all silo types. This makes wrapped round-bale silage potentially most susceptible to oxygen getting into the silage during storage, negatively affecting preservation.

A number of studies have compared wrapped bale silage with silage from another silo type. Nicholson et al. (1991) ensiled alfalfa (average DM content of 39%) from the same fields into wrapped bales (4 layers of film) or a bag silo. Core samples found a more rapid and extensive fermentation in the bag silage as indicated, for example, by pH (Fig. 2). At 60 d, there were more water-soluble carbohydrates (WSC) in the bale silage (6.6 vs. 4.4% DM) than the bag silage. The differences in remaining sugars and degrees of fermentation suggest that a significant portion of the WSC was not available to the LAB. In a subsequent study (Nicholson et al., 1992), alfalfa was harvested at two DM contents (27 and 40%) in bales and bags. Again, fermentation was faster and attained a lower pH in the bag silage. At the end of 60 d, butyric acid was beginning to accumulate in the bale silage at both DM contents.

Other studies have shown smaller differences than the two Canadian studies above. For example, McCormick et al. (1998) in Louisiana compared the ensiling of annual ryegrass using wrapped bales (4 layers of film) with bag silos. Alternate windrows were ensiled for each silage type. Over two years, DM contents were similar, 34 vs. 36%, respectively. The average pH was higher in the bale silage (4.80 vs. 4.53). Concentrations of various fermentation products were not significantly different; however, there was a trend for the bale silage to be lower in lactic acid and higher in acetic acid.

The somewhat higher pHs in baled silage suggest that greater wilting may be necessary to avoid clostridial fermentation. Huhnke et al. (1997) sampled bales from four different Oklahoma farms ensiled at a wide range of moisture contents. The forage was primarily...
annual ryegrass with varying amounts of legume (1 to 50%). The pH values from that study are shown in Fig. 3. The high pHs generally are from outer cores with spoilage present. Only six samples had significant levels of butyric acid. There is a trend with the well-fermented silages of increasing pH (or less fermentation) in drier bales as would be expected. Superimposed on the data in Fig. 3 is the line from Fig. 1 for grasses, indicating the critical pH to avoid clostridial activity. For moisture contents below 60% (or DM > 40%), pH values are generally below the line, indicating a clostridial fermentation would be unlikely. Under wetter conditions most of the points are above the line. While few samples had butyric acid, the level of fermentation in annual ryegrass at DM < 40% under Oklahoma conditions appears to be insufficient to prevent clostridial activity.

In Wisconsin, alfalfa is the dominant forage ensiled in wrapped bales. For other silo types, clostridial fermentation is unlikely in our alfalfa silages when the crop is wilted to 35% DM or higher. However, our typical recommendations are to wilt to 40% DM or higher in making wrapped bale silage to avoid clostridial activity based on experience. So a reasonable rule of thumb for the minimum DM content to ensile wrapped bales of a particular forage would be to add at least 5 percentage units to the minimum DM content to prevent clostridial silage in other silo types.

**Layers of Plastic**

Several factors may be causing the reduced fermentation observed in wrapped round-bale silage: the numbers of layers of plastic film, chop length and density. A greater number of layers would be expected to keep the silage more anaerobic leading to a more efficient fermentation and reduced visual evidence of molds.

Hancock and Collins (2006) compared 2, 4 and 6 layers of film in two trials with alfalfa in Kentucky. There were two DM contents in the first trial (50 and 63%) and one in the second (39% DM). After 5 mo storage, there were few significant differences in fermentation. The pH was higher under the 2 layer treatment (5.81) at 63% DM compared with the other two treatments (4.79). Differences in fermentation products were few and did not follow any consistent increasing or decreasing pattern with the number of layers. However, there was evidence of greater oxygen transfer across the plastic in the 2 layer treatments. Bale temperatures were higher in the 2 layer treatments during storage, and NDFs were significantly higher in the 2 layer treatments in two of the three DM contents. Hancock and Collins concluded that 2 layers were inadequate for preservation of alfalfa wrapped bale silage for 5 mo storage whereas 4 and 6 layers were similarly effective.

This work confirms a number of studies in northern Europe and Japan in more moderate climates (Muck and O’Kiely, 2002). In longer term studies (9 to 11 mo) in these areas of the world, increasing the number of layers from 2 to 4 layers substantially reduced losses and incidence of visible mold whereas increasing from 4 to 6 layers had little effect on quality. For example, Forristal et al. (1999) found in Irish conditions with a
9-mo storage that the average area of visible mold declined from 21.5% to 1.7% to 0.7% with 2, 4 and 6 layers respectively.

A concern about applying these results to the Southeast is the effect of your climate on plastic integrity. The higher temperatures and intensity of solar radiation could reduce the effectiveness of the polyethylene film. Paillat and Gaillard (2001) found that the service life of polyethylene stretch film in a tropical climate (Reunion Island, 21° S latitude) was reduced on average 30% to 50% (dependent on the stretch rate, altitude) compared to that in a temperate climate (France), and thus additional layers may be necessary for good preservation.

Overall, it would appear that the number of layers of polyethylene film has a relatively small effect on fermentation. However, the number of layers does affect the amount of oxygen that diffuses into the bale during storage and consequently the amount of spoilage and visible molding that occurs. Two layers of film are inadequate for preservation. Four and six layers have performed similarly in temperate climates, but it would seem prudent to use six layers for long-term (> 9 mo) storage in the Southeast.

**Chop Length**

Cutting systems have become available on round balers, typically consisting of stationary knives that provide a theoretical length of cut between 1.5 to 6 in. depending on the model. These systems could potentially improve fermentation by the shorter particle sizes and by increasing density.

There are relatively few studies on these systems. Han et al. (2006) studied the effect of bale chamber pressure and chop length on the ensiling of pearl millet in wrapped round bales in two trials (23 and 42% DM) in Kentucky. Long forage was compared with a 6 in. chop length. The chopped forage produced heavier bales (7 to 11%), but DM densities were not significantly different. Fermentation was only marginally affected by chop length across the two trials after 8-mo storage. The pH values were not different statistically different (P > 0.05) in either trial. Lactic acid in the trial with a wetter crop was the only fermentation product with a significant difference in the two trials, being higher in the shorter chop length. The chopped pearl millet silage did have less WSC remaining in the silage, suggesting more of the sugars were available to the lactic acid bacteria.

Borreani and Tabacco (2006) in Italy compared a 3.7 in. chop length with long alfalfa in three trials, one with two different DM contents. Chopping increased density in a fixed chamber baler by approximately 4% across all trials. In the wetter trials (35 and 38% DM), chopping did not affect the rate of decline or final (140 d) pH values of the silages. At 49% DM, the rate but not final pH was improved by chopping. The greatest effects on pH occurred at 61% DM with a 0.3 pH unit reduction in the final silage from chopping. Lactic acid was reduced by chopping in the wettest silage and acetic acid increased by chopping in the driest silage. Otherwise there were no significant effects of chopping on
these principal fermentation products. In the two wettest silages, dry matter recovery was increased from chopping by approximately 1 percentage unit.

These limited results suggest that chopping is not having a large effect on fermentation. The biggest effects appear to be under dry conditions (> 50% DM), permitting a more extensive fermentation.

Density

A higher density might be expected to improve fermentation by increasing the contact between forage particles and helping to express plant juices, making plant sugars more readily available to the lactic acid bacteria. Again, research in this area is limited.

Han et al. (2004) carried out two trials (41 and 48% DM) on alfalfa in Kentucky comparing densities of approximately 12.5 vs. 10.5 lbs. DM/ft³ by varying baler chamber pressure. In the wetter trial, there was a trend toward lower pH, higher lactic acid and lower acetic acid in the high density treatment, but the effects were not significant (P > 0.05). In the drier silage, pH was significantly lower (4.8 vs. 5.1) and acetic acid significantly higher (3.3 vs. 2.0% DM) in the high density treatment. Other factors such as temperature during storage, DM recovery and mold score were unaffected by density.

More recent work from the same group (Han et al., 2006) studied bale chamber pressure on pearl millet silage at two DM contents (23 and 42%). In the wetter silage, pH was reduced by high density (8.7 vs. 5.4 lbs. DM/ft³), but in the drier silage the effect of density (11.9 vs. 9.0 lbs. DM/ft³) was not significant. Lactic acid was increased by high density in the wetter silage but there was no effect in the drier silage. Acetic acid was not affected by density in either trial. The lack of fermentation effects in the drier trial may have been due to the excellent fermentations that occurred (average pH 4.15; lactic acid, 6.4% DM; acetic acid, 0.8% DM), precluding an effect of density.

Overall, it appears that increasing density modestly improves silage fermentation but not consistently. This inconsistency may be due to the supply of sugars for the lactic acid bacteria. Where sugar concentrations limit fermentation, increasing density may allow for more sugars to reach the lactic acid bacteria, improving fermentation. If the crop has abundant sugars, increasing density appears to have no effect on fermentation.

Summary

High quality silage can be made with wrapped round bales, but fermentation is somewhat restricted relative to fermentation in other silo types. Research on the number of layers of plastic, chopping the forage at baling, and bale density suggests that each factor can play a minor role in affecting fermentation. However, no one factor stands out as being solely responsible for reduced fermentation in wrapped bale silage. The practical effect of the more restricted fermentation in bale silage is that crops
should be ensiled at least 5 percentage units drier than recommended for ensiling in bag, pile or bunker silos to avoid clostridial fermentation.

References


Figure 1. The pH below which the growth of *Clostridium tyrobutyricum* ceases as a function of the DM content of the crop (based on Leibensperger and Pitt, 1987).
Figure 2. The pH of alfalfa-grass silage made by wrapped round bales or bag silo (Nicholson et al. (1991)).
Figure 3. The pH values of wrapped bale silage (annual ryegrass with varying amount of legume) sampled at four Oklahoma farms as related to bale moisture content (Huhnke et al., 1997). The line is the critical pH for clostridial growth on grass silage, taken from Fig. 1.
Bale silage production has seen increases in both popularity and technical advancements in recent years. In the Mississippi-Louisiana area where high rainfall and humidity limit successful hay production, bale silage production has grown from less than one percent of dairies in 1995 to more than 30 percent in 2005 (Walz et al., 2005). In addition, several of the larger (more than 200 cows) cow-calf operations in the area have adopted the technology. Factors other than the problematic drying conditions prevalent in the region which have driven baleage use are: wide availability of machinery such as tedders, rakes, balers, and wrappers specifically designed for bale silage, high costs of hay barn construction, research data to support the efficacy of bale silage production, and ready access to custom producers. Recent reports from Europe (Borreani and Tabacco, 2006) and Puerto Rico (Gonzalez and Rodriguez, 2003) indicate that bale silage technology is finding new users in other regions where hay production is difficult. The objectives of this report are 1) to provide research evidence that will refute several myths associated with bale silage production and 2) to provide practical guidelines for producing bale silage from forages typically grown in the Gulf Coast region of the United States.

Bale silage technology is based on the idea that wilted forage may be baled and covered with some form of plastic to limit oxygen entry, thereby reducing proliferation of undesirable microorganisms such as yeasts, molds, clostridial bacteria. In the absence of oxygen, a restricted lactic fermentation takes place and the end result is a forage conservation product that remains relatively stable for 8-12 months. One of the first myths perpetuated by some is that large bale silage may be successfully stored in bags, tubes, or stacks because the oxygen stored within any of these containers is not sufficient to cause excess respiration. In the mid to late nineteen eighties, these were the primary structures/methods used for making baleage, but results were often less than stellar.

In 1990, Straub and coworkers reported on a series of bale silage experiments conducted at the University of Wisconsin and the USDA/ARS Dairy Forage Research Center. Alfalfa was mowed and conditioned with a 3.7m mower conditioner and left in the windrow until forage moisture was reduced to approximately 60-65% moisture. Storage systems evaluated during the four-year storage period were bale bags, a triangular stacking system, and an end-to-end storage system. In the final three years of the study a stretch plastic bale wrapping machine was added which used 1.5 mil white stretch wrap plastic. In
year 1, plastic damage from rodents was evident on all systems. In addition, considerable molding and moisture accumulation was evident in bags and both stacking systems. All treatments were considered failures. In the second year, the end to end system was replaced with a bale wrapping system using a four-ply wrap of 1.5 mil sheeting applied in a single wrap. The bale wrapping system produced high quality baleage with little evidence of molding except at the plastic lap. The stacked bales had considerable external mold with a foam-like appearance, but the internal quality was acceptable. The bagged bales exhibited both external and interior mold and were discarded. Dry matter losses were least for wrapped bales (4.3%) and greatest for bales in bags (7.3%). Bale bags were discontinued after the second year due to difficulty in sealing bags and moldiness. In the third and fourth years of the study, the bale stacking system was compared to bale wrapping. Propionic acid (1%) was added to bale exteriors to retard mold on bales in the stacking system. In year three, the stacking system was successful, but in year four the stacked baleage was moldy and unfit for feeding. Problems with the stacks were attributed to failures with sealing the structure and bales squatting and turning over. Alfalfa wrapped in stretch film made high quality bale silage in both years and the authors concluded that the stretch wrap plastic system was the only bale silage technique that consistently provided acceptable results.

Florida researchers (Cromwell, et al., 1994) compared the stretch wrap system to plastic bale bags and multiple bale plastic tubes for bermudagrass bale silage production. Bale bags were found unacceptable because of their high cost (6-8 dollars/bag) and excessive labor required to load and seal bales. Bales stored in the plastic tube system exhibited considerable mold, and a large portion of the forage was not eaten by cattle. Wrapped bales all produced high quality baleage provided plastic integrity was maintained throughout the summer.

Subsequent to this research, we conducted a study at the Southeast Research Station to evaluate the several bale silage systems for ryegrass baleage production (McCormick, et al., 2002). Treatments were: 1) bale tube 2), Flexibagger bale tube, 3) stretch wrap bales stored on side and 4) stretch wrapped bales stored on end. Results from the six-month storage period are provided in
Table 1. Storage system affects on ensiling characteristics of ryegrass round bale silage.

<table>
<thead>
<tr>
<th>Storage System</th>
<th>Dry matter, %</th>
<th>Initial bale wt, lb</th>
<th>Final bale wt, lb</th>
<th>Shrink, %</th>
<th>pH</th>
<th>Lactic acid, %</th>
<th>Acetic acid, %</th>
<th>Bale temp, F</th>
<th>Mold score¹</th>
<th>Bales fed, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrap-end</td>
<td>45.0</td>
<td>1322</td>
<td>1308</td>
<td>5.4</td>
<td>4.75a</td>
<td>2.13</td>
<td>0.84</td>
<td>80.9a</td>
<td>1.00a</td>
<td>100.0</td>
</tr>
<tr>
<td>Wrap-side</td>
<td>41.9</td>
<td>1502</td>
<td>1500</td>
<td>4.6</td>
<td>4.70a</td>
<td>2.64</td>
<td>1.32</td>
<td>74.5a</td>
<td>1.42a</td>
<td>100.0</td>
</tr>
<tr>
<td>Flexi-bagger</td>
<td>44.7</td>
<td>1514</td>
<td>1400</td>
<td>11.4</td>
<td>5.33b</td>
<td>2.2</td>
<td>1.24</td>
<td>99.2b</td>
<td>2.50b</td>
<td>80.0</td>
</tr>
<tr>
<td>Stuffer</td>
<td>44.1</td>
<td>1390</td>
<td>1370</td>
<td>4.2</td>
<td>5.36b</td>
<td>1.75</td>
<td>1.15</td>
<td>83.4a</td>
<td>3.60c</td>
<td>0.0</td>
</tr>
</tbody>
</table>

¹ Visual score on bale exterior where 1 = no visible mold and 5 = extensive mold. Values in a row with different letters differ statistically (P < 0.05).

The Flexi-bagger system utilized heavy three-ply bags which were “stretched” by steel fingers so that the plastic collapsed back tightly on the bales. The objective of this system was to eliminate air and reduce molding. The data clearly indicate that the flexi-bag tube system was superior to the stuffer tube, but bales did experience considerable heating at feed-out and moldiness remained a problem, though not as severe as with the loose tube system. Plastic quality on the end-stored bales was superior to all treatments and bale configuration remained unchanged from initial wrapping. Plastic on the ends of individually wrapped bales overlap many more times than on the sides forming a protective layer which may have inhibited interior moisture condensation thereby eliminating mold. These data indicate that wrapped bales should be stored on end for long-term storage. A follow up study compared three individual wrappers as to effectiveness in ryegrass bale silage production. There were no differences in storage losses or nutritive value for three-point hitch, turn table, or turn table with bale pick up individual wrap systems (McCormick et al., 2002). Although the author is unaware of any direct evaluations between bale silage produced with individually wrapped bales and the “in line” wrappers, recent research from Arkansas indicates these new “stretch tube wrappers” are suitable for making high quality orchard grass and wheat bale silage (Rhewin et al., 2005). Further, the efficacy of these new stretch wrappers that form tubes by applying stretch film to the sides of the bales is supported by the fact that five of six custom producers in the southern Mississippi/Louisiana area employ this technology. The in-line wrappers are faster and require less plastic than the machines that wrap individual bales completely. The research discussed above clearly demonstrates that preformed bags, preformed tubes, and bale stacks are not methods of choice for bale silage production. Stretch-wrap either applied
individually as a complete wrap on the sides to form a tube has proven to be the most economical and effective means of producing round bale silage.

Probably no assertion has caused producers more ensilage disasters, particularly with immature annual ryegrass, than the proclamation of some wrapper representatives that “you can bale right behind the cutter”. An abundance of research indicates that the optimum wilting time varies with crop species, drying conditions, mechanical conditioning, windrow thickness, and ground moisture. Certainly, more important than how long the forage has been left to dry is the final dry matter achieved prior to baling. Early studies by Australian researchers (Valentine et al, 1984) compared ryegrass-clover-turnip mixtures baled at 27, 37, or 47% dry matter (DM). These studies were carried out with bale bags so storage losses were high. None the less, bales stored at the higher DM concentration experienced substantially lower storage losses than the high moisture bales. An analysis of 84 ryegrass baleage crops in Britain revealed that DM contents ranged from 21.5 to 29.7 in the years from 1984 to 1987 (Haigh, 1990). The author concluded that forage must be wilted to at least 28% DM to maintain ammonia N content below 10% of total N, minimize butyric acid concentrations, and optimize animal performance. In more recent work (Huhnke, et al., 1997) ryegrass and legume-grass silages ranging in initial DM contents from 35 to 75% were evaluated. After six months in storage neither apparent DM losses nor forage quality were affected by initial moisture content. Bates and co-workers (1989) from the University of Florida studied the affect of moisture content on bermuda grass and perennial peanut baleage production. They ensiled 5-week old bermudagrass directly after cutting (27.4% DM ) and after a 3.5-hour wilt (48.8 % DM). Dry matter losses were nearly four times as high for direct cut forages compared to wilted bermudagrass (11.7 vs 2.9%). Moreover, ammonia N represented over 14% of total N compared to 7.7% for wilted forage indicating superior fermentation and retention of protein quality. High moisture contents in perennial peanuts yielded even more undesirable bale silage. The authors concluded that legumes, because of their inherent lack of water soluble carbohydrates and high buffering capacity may require storage at higher DM concentrations than for grasses. Subsequent research dealing with moisture affects on alfalfa bale silage production indicates that DM ranges from 50-80 percent make acceptable baleage, particularly when four or more layers of stretch wrap are applied (Undersander and Wood, 1999; Han et al.; 2004). Given the bulk of this research, most immature forages will require at least a 4-hour wilt period for successful fermentation. The table below gives the average time required to wilt forages grown at the Southeast Research Station to 40-60 % DM (forage conditioned with a flail type conditioner and left in 4 ft windrows until baling).
Table 2. Approximate wilt times for various bale silage crops grown in Louisiana.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Avg</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual ryegrass</td>
<td>48</td>
<td>12-96</td>
</tr>
<tr>
<td>Bermudagrass</td>
<td>4</td>
<td>1-24</td>
</tr>
<tr>
<td>Crabgrass</td>
<td>24</td>
<td>4-30</td>
</tr>
<tr>
<td>Bahiagrass</td>
<td>4</td>
<td>1-24</td>
</tr>
<tr>
<td>Sorghum</td>
<td>48</td>
<td>24-72</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>24</td>
<td>4-30</td>
</tr>
</tbody>
</table>

It’s worth noting that the high moisture content in 4 ft height sorghum is very difficult to bring below 65% within a 48 hour period. The heavy nature of the crop precludes tedding therefore it often must be baled at moistures somewhat higher than recommended. Nevertheless, the high plant sugar content and low buffering capacity usually allow it to ferment acceptably and produce good quality bale silage (McCormick et al., 2004).

As implied from the tabular data above, we have studied bale silage production on a wide range of annual and perennial forages grown in Louisiana. However, we have spent more time studying factors contributing to successful baleage production for annual ryegrass than any other forage. The reasons for this are simple. Annual ryegrass is the most widely grown winter annual in Louisiana. It is easily established and in south Louisiana the growing season stretches from early October through mid-May. In plot tests, tonnage harvested often exceeds five tons of dry matter per acre. Forage quality is excellent when the plant is immature, but by the time the plant can be harvested as hay (Late April to mid May) the plant is seeded out and often contain less than 10% protein and more than 40% ADF. Most producers in the area graze ryegrass from early December through the winter and then make one or two baleage cuttings in the spring. More and more dairymen are setting aside ryegrass acreage solely for bale silage production. In good years they are able to make 3 to 4 cuttings beginning in December and ending in May. Listed below are recommendations for ryegrass baleage production based on our research and that of many other scientists.

Best Management Practices for Ryegrass Bale Silage Production

1) Select a recommended, late maturing ryegrass variety (unless ryegrass is over-seeded on summer hay fields).
2) Clip or graze uniformly to 3-4 inches and apply 50-75 unit of N fertilizer.
3) Harvest at boot to early heading stage of maturity.
4) Wilt forage until dry matter is in the 40-60% range.
5) Reduce bale size compared to conventional hay (usually 4x4 or 4x5 ft).
6) Use plastic or untreated sisal twine.
7) Wrap within 2 hours of baling.
8) Use a minimum of four layers of stretch film and at least six layers for long-term storage or on bales outside the optimum moisture range.
9) Use bale handlers on individual bales and minimize handling of wrapped bales prior to feed-out.
10) Store bales on a clean, well drained area.
11) Consider use of inoculants on low sugar crops.
12) Separate cuttings and core-sample for forage quality analysis.

Ryegrass managed as described above often contains 40-50% dry matter at baling and contains more than 20% protein and less than 30% ADF. For most beef cattle operations we recommend allowing the ryegrass to mature to the full bloom stage which generally yields a product containing 12-16% protein and 34-38% ADF. At the later stage, yield is often 10-20% greater.

In the table below we have listed the average forage quality of annual ryegrass and other forages grown for optimum yield and quality at the Southeast Research Station. Also included are producer sample averages for Mississippi and Louisiana bale silage crops analyzed at the Southeast Research Station Forage Quality Lab (McCormick et al., 2005; Walz et al., 2005).

| Table 3. Quality analysis of producer and research samples at the Southeast Res. Station. |
|---------------------------------|-----------------|-----------------|-----------------|
| Crop ¹                          | Dry matter, %   | Protein, %      | NDF, %          |
|                                 | Producers       | Station         | Producers       | Station         |
| Ryegrass                        | 44.8            | 40.1            | 14.9            | 19.2            | 64.6            | 61.4            |
| crabgrass/signalgrass          | 47.7            | 43.1            | 10.8            | 19.9            | 65.3            | 61.3            |
| sorghum/millet                 | 37.5            | 28.8            | 9.8             | 13.1            | 73.1            | 68.5            |
| bermudagrass                   | 48.9            | 44.9            | 9.3             | 13.0            | 73.6            | 73.2            |
| Bahiagrass                     | 55.5            | 50.2            | 9.2             | 12.9            | 72.4            | 68.9            |

¹ Producer averages based on 117 ryegrass, 4 crabgrass, 4 sorghum, 8 bermudagrass, and 10 bahiagrass bale silage producer samples submitted in 2004.

Although the above sample analyses appear reasonably good for producer samples, the range in quality was substantial. For example, dry matter and protein ranged from 17.9 to 69.4% and 7.1 to 24.8%, respectively for ryegrass producer samples.

In summary, the bale silage concept has evolved tremendously during the last twenty five years. Technological advances such as balers with knives for chopping forages, combined baler-wrapper machines, improvements in stretch plastics, and improved equipment for conditioning and tedding forages promise to enhance the effectiveness of the bale silage forage conservation system. More research is needed to address the nutritional advantages and liabilities of
bale silage. Producers are also interested in determining the optimum time to harvest, morning or evening. Is interseeding legumes in summer perennial pastures a feasible means of improving baleage quality? Do the brown mid-rib sorghum and millet genotypes possess advantages when stored as baleage? How can we effectively reduce molds and deterioration in high DM baleages? Why do there appear to be more problems properly producing ryegrass bale silage from fields fertilized with poultry litter than commercial fertilizers? There is obviously much to learn and many questions to answer, but the future for the bale silage system appears bright (particularly in places like Louisiana where the skies are often cloudy).

References


Despite some production issues associated with preservation of forages as round-bale silage, potential benefits with respect to minimizing DM loss and preserving forage quality compared with traditional hay preservation systems are well documented. Less information is available regarding the feeding value of forages preserved in this manner. This paper attempts to address issues associated with the utilization of round-bale silage by its ultimate consumer, the ruminant animal. Primary emphasis is placed on utilization of energy and protein because the compositional differences between forages preserved in different manners predominantly affect animal performance by altering the nature of these two components.

Potential Concerns

There are some potential nutritional concerns when dealing with round bale silage that are not generally applicable to hay feeding. Most of these are associated with failure to achieve a rapid fermentation. Because of potential variation in forage maturity, DM and water-soluble carbohydrate content, chop length, packing density, wrapping efficiency, and many other factors, the quality of fermentation in round bale silage production is quite variable. In situations in which low pH and/or anaerobic conditions are not achieved, a variety of potential animal health concerns can arise. Growth of molds and fungi can result in abortion, as can growth of Bacillus species, all of which are facilitated by aerobic conditions in poorly-preserved silage (Sargison, 1993). Similarly, high pH and presence of oxygen can allow the multiplication of Listeria monocytogenes, responsible for several clinical diseases in cattle, sheep, and horses (Sargison, 1993). Additionally round bale silage has been implicated in some cases of bovine and equine botulism. Although Clostridium botulinum is an obligate anaerobe, its growth is suppressed at lower pH values (Sargison, 1993).

Energy Consumption

The ability to support a given level of animal production from round bale silage will predominantly be a function of the quantity of energy the animal derives from the silage. In turn, this energy supply is primarily dependant on two factors: voluntary intake and digestibility. Voluntary forage intake is a complex phenomenon, affected by numerous factors. Primary factors to consider when evaluating fermented feeds include fiber concentrations, particle size, as it relates to passage rate, and potential intake inhibitors such as high levels of NH₃-N or butyric acid.
**Voluntary Intake**

Relatively few studies have compared the voluntary intake of forage preserved as hay compared with round bale silage. McCormick et al. (1998) reported similar DM intakes by lactating Holstein cows for ryegrass preserved as hay compared with round bale silage. However, theirs was a systems analysis: consequently, forages were harvested at the boot stage for silages and at the bloom stage for hay. These maturity differences and the ensuing differences in chemical composition resulted in greater amounts of grain feeding for cows consuming hay. Thus, the best comparison of the two systems in their study is afforded by their measure of feed efficiency (lb FCM/lb DMI), which was 12.5% greater for the round bale silage system. Interestingly, intake of chopped haylage reported by McCormick et al. (1998) was about 15% greater than for the other two systems, presumably as a consequence of the smaller particle size, as only minor differences were noted in the chemical composition of the two fermented forages. This suggests that opportunities may exist to increase voluntary intake of forage preserved as round bale silage. This rationale formed part of the basis for a study evaluating the effects of pre-ensiling maceration on utilization of orchardgrass/white clover silages (Charmley et al., 1999). However, in that study, voluntary intake of macerated round bale silage by growing steers was not different than intake of conventionally-conditioned round bale silage. This lack of difference could relate to differences in chemical composition of the two round bale silages, consequent to higher DM concentrations in the macerated silages. Despite the absence of intake effects, gain:feed ratios were improved by about 25% with maceration. In another study, Charmley and Firth (2004) compared intakes by cattle consuming round bale silage that was harvested in long form, or coarsely sliced with a cutting assembly attached to their round baler. Again, no difference was detected in voluntary intake, perhaps because they achieved only minor differences in mean particle length with this approach. Though evaluating conventional silages (preserved in stave silos) rather than round-bale silages, Petit et al. (1985) found no difference due to conservation method (silage vs. hay) in DM intake by steers for alfalfa, timothy, or mixed legume/grass forage. In that study, only minor differences were detected in the chemical composition of the forages due to conservation method. Recently, Han et al. (2004) reported greater voluntary DM intake by steers consuming alfalfa preserved as round bale silage as compared with alfalfa hay harvested from the same field. These differences in intake reflected the greater fiber and lower crude protein concentrations in the hay, which were attributed to greater respiratory and leaf shatter losses in the hay conservation system. In a report by Oshita et al. (2004), non-lactating Holstein cows ate about 15% more DM when consuming round bale alfalfa silage than when consuming long-stem alfalfa hay of similar chemical composition. However, the silage was chopped to a nominal length of 40 mm before being fed to the cows.

Other studies have compared voluntary intake of round bale silage with other, more conventional types of silage systems. Interestingly, Charmley and Firth (2004) reported greater intakes by steers consuming round bale timothy
silage as compared with flail-harvested silage, despite smaller mean particle size for the latter system. They suggested that the greater degree of wilting for the round bale silages was the most likely explanation, and others (Gordon et al., 1999) have reported increasing voluntary intake with increasing baleage DM concentrations. Charmley and Firth (2004) found numerically, but not statistically greater voluntary intake by cattle consuming round bale vs. precision-chopped silages. Conversely, Petit et al. (1993) reported lower intakes of round-bale grass silage compared with silage harvested with either a cylinder-type or self-loading forage harvester. In that study, the DM concentration was greatest with the round bale silage, as was the ultimate silage pH. Likewise, Nicholson et al. (1991) found poorer fermentation in bale-, as compared with chopped, bagged alfalfa silage (higher pH, lower lactic acid in bales) coupled with lower voluntary intakes.

Taken together, the above reports suggest that, if hay and silage are both well-preserved and of similar chemical composition and particle size, little difference would be expected in voluntary intake. However, improvements in maintenance of forage quality with baled silage systems relative to hay systems would be expected to translate into parallel improvements in voluntary DM intake. Effects of various silage systems on voluntary intake are largely mediated through effects on the quality of fermentation achieved. Variability in achieving rapid acidification in round bale silage is likely a primary cause for the variability in intake responses in the literature. Furthermore, potential may exist to enhance voluntary intake of round bale silage through pre- or post-ensiling processing to reduce particle size.

Digestibility

Although digestibility measures account for only a fraction of the dietary energy lost by animals, this fraction represents the major source of variation in energy utilization when comparing forage conservation systems. Although changes in silage fermentation characteristics will manifest as changes in ruminal fermentation characteristics, it is unlikely that such shifts will typically have a major influence on the utilization of energy. In support of this argument, calorimetric studies with growing steers (Gordon et al., 1999) have shown that, even when comparing fermentation stimulants with fermentation inhibitors or wilted (45% DM) with unwilted (19% DM) silages, the major differences in energy utilization were accounted for by changes in digestibility, as opposed to changes in urinary energy, methane energy, or efficiency of ME use.

Oshita et al. (2004) were able to produce alfalfa round bale silage very similar in chemical composition to a commercially-procured alfalfa hay. Although DM digestibility was not significantly affected by preservation method, digestibilities of NDF, ADF, and cellulose were all greater with the ensiled product. As with their intake responses, Petit et al. (1985) found no differences in digestibilities when comparing hay- and conventional silage-preservation systems for three different forage types. Han et al. (2004) had greater DM digestibility with round bale alfalfa silage than for alfalfa hay. The lower
digestibility for the hay in that study was likely a consequence of the greater fiber concentrations in the hay, due to pre-storage DM loss through leaf shatter and respiration. Petit et al. (1993) reported a trend toward greater digestibility of gross energy for round bale silage compared with conventionally stored silage harvested by either of two approaches. However, this trend occurred in the presence of lower voluntary intake, confounding our interpretation. In the study by Charmley and Firth (2004), digestibilities were nearly 8 percentage units greater for round bale silage than for either flail-harvested or precision-chopped silage, even in the presence of greater intakes for the round-bale silage treatment.

Thus, digestibility values, like intake values, are ultimately driven by the ability of a given conservation system to maintain high forage quality. However, because of the negative effect of increasing intake on digestibility, the apparent digestibilities measured in vivo can exhibit the opposite trend of what one may expect based strictly on chemical composition. In such cases, use of in situ measures of degradation can help separate inherent differences in digestibility from different preservation methods from effects of intake, per se. For example, in the studies by Charmley et al. (1999), intakes of macerated round bale silage were substantially greater than intakes of macerated, precision-chopped silage. Digestibilities of all measured components were considerably less for the macerated, round bale silage. In situ DM disappearance data from this study showed that there were no inherent differences in the degradation rates or effective degradation values as a result of the different preservation systems, leading to the conclusion that the differences in digestibility were strictly a function of intake differences. Petit and Tremblay (1992) found a much larger fraction of DM in the potentially degradable pool ('A' + 'B' fractions) and, consequently, a substantially greater effective DM degradability for grass conserved as silage (round bale or heap silage) as compared with hay. This increase in effective degradability was observed despite a 50% average decrease in the measured degradation rate of the potentially degradable DM fraction with the silages.

Protein Characteristics

The primary differences in the nitrogenous fractions between forage conserved in round bale silage vs. hay systems are shifts in the overall concentration of crude protein and shifts in the composition of the N fractions, particularly through proteolysis and deamination. In situations in which excessive heating occurs (in either hay or silages), protein availability can decrease through formation of Maillard reaction products. Though silage conservation methods will typically allow us to retain higher crude protein concentrations relative to hay, a larger portion of the crude protein will be in the form of NPN, ultimately increasing the degradable protein fraction. In situ protein degradation data from Petit and Tremblay (1992) can be used to highlight the importance of such changes. Using the NRC (1996) Level I Model and estimates of DM and CP disappearance from the in situ analysis of Petit and Tremblay (1992), one can generate
estimates of energy and metabolizable protein-limited gains. Using the nutrient requirements for a 272 kg growing steer consuming forage at 2.4% of body weight, and effective degradability estimates generated by Petit and Tremblay (1992) for a 2%·h⁻¹ passage rate, their hay, containing 19.5% CP would be predicted to provide sufficient metabolizable protein to support 0.86 kg/d gain, yet only enough energy to support a gain of 0.68 kg/d. Conversely, because of the high degree of degradable protein in the round bale silage, consumption of an equivalent amount of this forage would be predicted to have sufficient energy to support a gain of 1.12 kg/d, yet would supply enough metabolizable protein for only 0.62 kg/d gain. Thus, switching from hay to round bale silage in this instance, with the exclusion of any supplements, would be anticipated to result in lower gains, despite the increase in available energy. In such cases, animals would be expected to respond to dietary supplementation with undegraded protein sources. Such a response was documented by Rouzbehan et al. (1996) when growing steers, consuming grass/clover round bale silage were supplemented with fish meal. Quantitative knowledge of ruminal protein degradation characteristics is essential for calculation of proper diets to optimize growth, especially for animals consuming diets high in degradable protein.

Effects of Additives

Generally, researchers evaluating use of additives for round bale silage have reported some benefits, particularly for retarding growth of mold and yeasts. However, there seems to be some consensus that potential effects of additives are minor in comparison to potential effects of factors such as DM content, forage species, maturity, and wrapping strategy (Bates et al., 1989; Keller et al., 1998). Chaudhry et al. (2001) improved the storage quality and voluntary intake of round bale silage prepared from mature Rhodes grass hay through the use of pre-ensiling NaOH treatment. No benefits were observed from using NaOH on young grass silage, nor were benefits seen from CaO treatment or treatment with inoculant derived from ruminal microorganisms from Rhodes grass-fed cattle. With round bale silages prepared from forage pea or field bean forages (Fraser et al., 2001), inoculation with L. plantarum improved lactic acid concentrations and decreased pH, NH₃-N, and acetic acid concentrations in the silages. However, the authors also noted decreased N retention in growing lambs in response to inoculation. These results suggest that inoculation may have resulted in some increase in proteolysis without concomitant deamination, as NH₃-N concentrations were lower with inoculation. Nowak et al. (2004) failed to detect any effects of L. plantarum/E. faecium inoculants on ruminal or small intestinal protein disappearance of perennial ryegrass round bale silage. However, they also failed to elicit significant effects on the chemical composition or fermentation characteristics of the silage. In a summarization of twenty-two experiments with round bale grass silage Haigh et al. (1996) found that use of inoculants significantly increased lactic acid and decreased butyric acid concentrations. However, little benefit was seen in silage DM intake or live weight gain when the silages were fed to growing lambs. Alternatively, Meeske et al.
(2002) reported minor effects on fermentation characteristics of round bale oat silage in response to inoculation with *L. plantarum/S. faecium/P. acidilactici*, yet found increased silage intake and milk production of lactating Jersey cows consuming the silages. Because of this apparent disconnect between silage fermentation characteristics and animal responses, evaluation of potential benefits of round bale silage additives should incorporate animal feeding studies whenever possible.

**Literature Cited**


Introduction

One of the most common problems faced by hay producers is how to manage hay production schedules around unfavorable weather. This problem is particularly frustrating throughout the spring and early summer when the probability of rainfall events is high. Inevitably, some wilting forage crops are damaged by unexpected rainfall events each year, and producers often inquire about the effects of unexpected rain damage, and what impact this may have on subsequent animal performance. In truth, the scope of the problem is considerably more complex than direct damage to wilting forage crops via leaching, reactivated respiratory processes, and/or leaf shatter. Common consequences of uncooperative weather also may include: i) spontaneous heating and/or combustion that occurs when producers try to complete baling operations of incompletely wilted forage prior to an oncoming rainfall event; ii) a combination of rain damage and spontaneous heating that may occur with multiple rainfall events or prolonged unstable weather; and iii) excessively mature forage that results from delaying haymaking operations until weather is more favorable. Producers are often unaware or unconcerned about the last consequence, but maturity effects on forage quality can be every bit as severe as spontaneous heating and/or rain damage.

Effects of Maturity on Forage Quality

Generally, the effects of maturity on forage quality are well known to most producers; more than any other factor, the maturity level of the forage at the time of harvest determines the quality of the hay. Generally, the ratio of leaf and stem tissues declines as forages mature. This results in greater concentrations of fiber components, such as NDF, ADF, and lignin, but lower concentrations of CP, digestible dry matter, and energy. Figure 1 illustrates the effect of growth stage on the concentration of NDF for tall fescue forage (Ball et al., 2002). Between the late-boot and soft dough stages of growth, NDF increased by about 12 percentage units from 53 to 65%. A similar response can be expected for other southern forages, such as bermudagrass (Table 1). This is important for several reasons. First, as concentrations of NDF increase, the digestibility (Figure 1) of these same forages decreases concomitantly. Secondly, higher concentrations of NDF are frequently associated with poorer voluntary intakes by livestock consuming forage-based diets. This is especially important when the livestock class consuming the forage has high nutrient demands, such as those of dairy or stocker cattle. Finally, and most importantly, these concepts are important because they illustrate that there is always a cost associated with delaying harvest because of potential rainfall events, and these costs result in a forage of lower nutritional value that will not be consumed as readily by livestock.

Effects of Rainfall on Dry Matter Loss and Forage Quality

Overview. Rainfall applied to wilting forages will leach soluble nutrients (primarily sugars) from hay, resulting in DM loss, increased concentrations of fiber components, and decreased energy density within the forage. Leaching losses are a function of the forage species, the DM content of the forage at the time the rainfall event occurs, the sugar content of the forage,
and the number, amount, intensity, and/or duration of the rainfall event or events. Plant sugars are assumed to be 100% digestible; therefore, leaching causes the loss of the most digestible components of the forage. Rain also can reactivate respiration by plant enzyme systems and other microorganisms associated with the forage plants (Rotz and Muck, 1994). This causes additional plant sugars to be consumed, resulting in additional DM loss and further reductions in the nutritional value of the forage. Significant losses of DM also can occur directly as a result of leaf shatter, especially if the hay crop is a legume. In addition, any rainfall during the wilting process may lead to additional tedding and raking operations that result in even more leaf shatter before the forage is dry enough to bale. However, since the production of legume hays is less common in the southeastern US than in many other parts of the country, the concepts of leaf shatter and rain damage to wilting legume forages will not be discussed further.

**Losses of DM from Wilting Orchardgrass Forages.** Recently, studies conducted at the University of Arkansas evaluated losses of DM and changes in nutritive value for wilting orchardgrass and bermudagrass forages (Scarborough et al., 2005) damaged by rainfall delivered from a rainfall simulator. From 0 to 76 mm (0 to 3 inches) of simulated rainfall were applied to both forages in single rainfall events in 12.5-mm (0.5-inch) increments. Rainfall was applied to orchardgrass when the moisture content of the forage was very high (67.4%), ideal for baling (15.3%), and excessively dry (4.1%).

Losses of DM for the orchardgrass were low (< 2%) if rainfall occurred when the forage moisture content was high (67.4%), but increased substantially if rainfall occurred when the forage was dry (Table 2). Losses of 10.7% of total plant DM occurred when 76 mm of rainfall were applied to excessively dry (4.1%) forage. At an ideal moisture for baling (15.3%), maximum losses were only slightly lower, reaching 8.8% of DM. Regardless of the moisture content of the forage, DM losses for dry forages increased with the amount of rainfall in curvilinear patterns, but losses were disproportionally large at rainfall increments of 13, 25, and 38 mm, and tended to level off as cumulative rainfall increased beyond these levels.

For bermudagrass (Table 3), rainfall treatments were applied immediately after mowing (76.1%), at the approximate midpoint of the wilting period (40%), and when the forage moisture content was ideal for baling (13.0%). There was essentially no DM loss when the forage was wet, but drier forages lost measurable DM with increased rainfall. Greater losses of DM occur in drier forages because plant cells lose their integrity, and can no longer regulate the movement of soluble compounds in or out of the cell. Unlike orchardgrass, maximum DM losses for bermudagrass were quite limited; the forage that was ideal for baling (13.0%) lost a maximum of 2.1% of total plant DM. Perhaps these differences can be explained on the basis of the sugar content of each grass. Perennial cool-season grasses, such as orchardgrass, have much higher concentrations of water-soluble plant sugars and other compounds than bermudagrass or other warm-season perennial grasses. Therefore, orchardgrass has the potential for more DM loss through leaching. Figure 3 illustrates the comparison of DM losses for bermudagrass and orchardgrass when both forages were wilted to an ideal moisture content for baling; DM losses for orchardgrass were at least four times greater than observed for bermudagrass after the rainfall amount reached 51 mm.

**Changes in Nutritive Value for Grasses.** The summary of nutritive value for rain-damaged orchardgrass forages (Table 2) demonstrates that relatively wet (67.4%) forage was affected only minimally. Drier forages (4.1 or 15.3% moisture) exhibited more undesirable changes in response to simulated rainfall. Theoretically, fiber components (NDF, ADF, and lignin) are not water soluble; therefore, their concentrations should increase as soluble plant
sugars are leached away during the application of simulated rainfall. Generally, our results supported this premise; concentrations of these fiber components increased in curvilinear patterns by as much as 7.8, 9.9, and 3.74 percentage units, respectively.

For bermudagrass (Table 3), changes in nutritive value followed patterns that were similar to those observed for orchardgrass, except that the magnitude of the responses was generally smaller. Maximum increases in NDF, and ADF in response to 76 mm of simulated rainfall were only 2.9 and 2.2 percentage units, respectively, and were observed for forage wilted to 40.0% moisture prior to the rainfall event. For bermudagrass that was dry enough for baling (13.0%), respective increases in NDF and ADF in response to 76 mm of simulated rainfall were only 1.3 and 1.1 percentage units. While the nutritive value of bermudagrass remained relatively stable in response to simulated rainfall, it should not be assumed that rain-damaged forages are as palatable, and they may not be consumed as readily by livestock.

**Rainfall Effects on Tall Fescue and Subsequent Intake by Steers**

Recently, another series of experiments were completed at the University of Arkansas that assessed the effects of naturally occurring rainfall and subsequent spontaneous heating during storage on the nutritive value of wilting tall fescue forage (Turner et al., 2003), and subsequent effects on voluntary intake and digestibility by growing steers (Turner et al., 2004). Tall fescue was baled at slightly above the recommended moisture content (22.5%), at an ideal moisture for baling (16.4%), and when it was excessively dry (9.9%) without rain damage. In addition, tall fescue was baled at 24.6% moisture after a 23-mm rainfall event, and at 9.3% moisture following three rainfall events totaling 71 mm. The tall fescue was mowed in late-May at the heading stage of growth. At baling, a 23-mm rainfall event increased (P < 0.01) the concentration of NDF by 4.9 percentage units compared to all hays baled without rain damage (72.0 vs. 67.1%), while digestibility was suppressed by 1.8 percentage units (63.6 vs. 61.8%). After three rainfall events totaling 71 mm, NDF was further increased (P < 0.01) to 76.4%, which was an increase of 8.7 percentage units over hay baled at an ideal 16.4% moisture; however, the associated reduction in digestibility was only 3.2 percentage units. Generally, the effects of a single 23-mm rainfall event were not excessive, especially compared to the rapid changes in nutritive value that may occur as a result of delaying harvest (see Figure 1). However, substantial increases in NDF were observed in hay that was subjected to three rainfall events totaling 71 mm.

After storage, there were few differences in nutritive value between bales that incurred modest spontaneous heating, rain damage, or both (Table 5). This strongly suggests that the practice of baling hay when slightly wet in order to avoid an unexpected shower offers little nutritional (chemical) advantage over waiting to bale until after the rainfall event; however, waiting out the shower will likely require additional raking and tedding operations. Spontaneous heating is highly dependent on the moisture content of the hay. Therefore, producers may have difficulty evaluating what is marginally wet, and the potential for serious depressions in nutritive value as a result of excessive spontaneous heating is quite high.

The voluntary intakes of these fescue hays (Table 6) were identical for hays baled without rain damage, regardless of whether they incurred modest spontaneous heating or not. It is important to note that the levels of spontaneous heating in these hays were very modest because of the relatively low moisture levels (< 25%) at baling, the small rectangular bale packages, and a period of relatively cool weather that occurred within two weeks of baling. More intense heating would be expected if these hays had been packaged as large round bales. Hays that were damaged by rain or rain and modest spontaneous heating were not consumed as well
by steers. Depressions (P = 0.01) in daily voluntary hay intake, relative to those baled without rain damage, were 0.17% of bodyweight for hay receiving 71 mm of rain prior to baling, and 0.25% of bodyweight for hay receiving a single 23-mm rainfall event coupled with modest spontaneous heating. Therefore, there was about a 10% reduction in voluntary hay intake in any forage damaged by at least one soaking rain. Coefficients of apparent digestibility for DM, OM, and NDF were greater (P ≤ 0.03) for hays damaged by rainfall events; this may have been related to total tract retention times that were numerically, but not statistically (P > 0.10), longer than observed for hays not damaged by rain.

**Recommendation**

Given the uncertainty of the weather, specific recommendations are difficult. For tall fescue, results of experiments at the University of Arkansas indicate that the damage created by a single rainfall event of approximately 25 mm is not excessive, particularly when compared to the consequences of spontaneous heating, or the rapid negative changes in forage quality that occur when harvest is delayed. This suggests that producers could be more aggressive during the late-spring with fairly limited risk. Orchardgrass and legumes may be more susceptible to rain damage, and may need to be managed more conservatively. In contrast, the quality characteristics of bermudagrass (and likely other perennial warm-season grasses) are only affected minimally by rainfall events; however, this may be less important because weather patterns usually become more stable during summer months. Although there are relatively few studies assessing the impacts of rain damage on voluntary intake of hay by livestock, these studies suggest that a 10% reduction in response to a soaking rain may serve as a good ‘rule of thumb’ until additional studies provide more information.
References


Table 1. Fiber characteristics of ‘Coastal’ bermudagrass (adapted from NRC, 1989).

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Table 2. Effects of crop moisture content and amount of rainfall on the nutritive value of wilting orchardgrass hay. Orchardgrass forage was harvested on 18 June 2001, which was the second harvest of the growing season. Simulated rainfall was applied at a rate of 76 mm/h (adapted from Scarbrough et al., 2005).

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<sup>a</sup> Moisture content of the forage when the simulated rainfall was applied.

<sup>b</sup> Highest order effect of rainfall amount: NS, nonsignificant (P > 0.05); L, linear; Q, quadratic; C, cubic; and Qu, quartic.
Table 3. Effects of crop moisture content and amount of rainfall on the nutritive value of wilting bermudagrass hay. Bermudagrass was harvested on 30 August 2001. Simulated rainfall was applied at a rate of 76 mm/h (adapted from Scarbrough et al., 2005).

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<sup>a</sup>Moisture content of the forage when the simulated rainfall was applied.

<sup>b</sup>Highest order effect of rainfall amount: NS, nonsignificant (P > 0.05); L, linear; Q, quadratic; C, cubic; and Qu, quartic.
Table 4. Effects of natural rainfall on the nutritive value of endophyte-infected tall fescue hay at baling. Rainfall events were naturally occurring, and bales were packaged as conventional rectangular bales in Fayetteville, AR during May 2000.a

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<th>ADIN % of N</th>
<th>NDF % of DM</th>
<th>ADF % of DM</th>
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<th>Digestibility&lt;sup&gt;c&lt;/sup&gt;</th>
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<td>7.1</td>
<td>66.3</td>
<td>37.6</td>
<td>4.81</td>
<td>64.1</td>
</tr>
<tr>
<td>b</td>
<td>16.4</td>
<td>0</td>
<td>0</td>
<td>8.2</td>
<td>8.3</td>
<td>67.7</td>
<td>38.3</td>
<td>5.12</td>
<td>62.9</td>
</tr>
<tr>
<td>c</td>
<td>9.9</td>
<td>0</td>
<td>0</td>
<td>7.9</td>
<td>8.0</td>
<td>67.3</td>
<td>38.1</td>
<td>4.98</td>
<td>63.9</td>
</tr>
<tr>
<td>d</td>
<td>24.6</td>
<td>23</td>
<td>1</td>
<td>8.4</td>
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<td>e</td>
<td>9.3</td>
<td>71</td>
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<td>76.4</td>
<td>42.6</td>
<td>5.52</td>
<td>59.7</td>
</tr>
</tbody>
</table>

**Contrasts**

1) one rainfall event (d) vs. no rain (a, b, c) NS<sup>d</sup> NS < 0.01 < 0.01 0.02 0.08
2) multiple rainfall events (e) vs. no rain (a, b, c) 0.09 NS < 0.01 < 0.01 0.01 < 0.01
3) one rainfall event (d) vs. multiple events (e) NS NS < 0.01 < 0.01 NS 0.09
4) ideal moisture (b) vs. excessively dry (c) NS NS NS NS NS NS NS

---

<sup>a</sup> Adapted from Turner et al. (2003).
<sup>b</sup> Number of rainfall events contributing to the total rainfall prior to baling.
<sup>c</sup> Determined by 48-h ruminal incubation in situ.
<sup>d</sup> NS, nonsignificant (P > 0.10)
Table 5. Effects of natural rainfall during wilting and spontaneous heating during storage on the nutritive value of endophyte-infected tall fescue hay. Rainfall events were naturally occurring, and bales were packaged as conventional rectangular bales and stored for approximately six weeks in small stacks at Fayetteville, AR during 2000.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crop Moisture at Baling</th>
<th>Total Rainfall Amount</th>
<th>Number of Rainfall Events\textsuperscript{b}</th>
<th>Maximum Internal bale temperature \textsuperscript{c}</th>
<th>CP % of DM</th>
<th>ADIN % of N</th>
<th>NDF % of DM</th>
<th>ADF % of N</th>
<th>Lignin % of N</th>
<th>Digestibility % of DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>22.5</td>
<td>0</td>
<td>0</td>
<td>49.8</td>
<td>8.9</td>
<td>10.4</td>
<td>74.5</td>
<td>43.4</td>
<td>5.89</td>
<td>59.8</td>
</tr>
<tr>
<td>b</td>
<td>16.4</td>
<td>0</td>
<td>0</td>
<td>40.0</td>
<td>8.2</td>
<td>6.4</td>
<td>70.5</td>
<td>41.1</td>
<td>6.20</td>
<td>62.9</td>
</tr>
<tr>
<td>c</td>
<td>9.9</td>
<td>0</td>
<td>0</td>
<td>42.8</td>
<td>7.9</td>
<td>7.6</td>
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<td>39.7</td>
<td>5.83</td>
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<td>23</td>
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<td>50.8</td>
<td>8.6</td>
<td>15.5</td>
<td>78.5</td>
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<td>31.4</td>
<td>7.7</td>
<td>13.0</td>
<td>76.0</td>
<td>44.0</td>
<td>6.83</td>
<td>59.7</td>
</tr>
<tr>
<td>SEM</td>
<td>1.3</td>
<td>0.44</td>
<td>1.20</td>
<td>0.71</td>
<td>0.51</td>
<td>0.386</td>
<td>0.75</td>
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</tbody>
</table>

\textbf{Contrasts}

1) all damaged hays (a, d, e) vs. no damage (b, c) \textsuperscript{d} NS < 0.01 < 0.01 < 0.01 NS < 0.01

2) rain damaged (d, e) vs. no rain (a, b, c) \textsuperscript{d} NS < 0.01 < 0.01 < 0.01 0.06 < 0.01

3) spontaneous heating (a, d) vs. minimal heating (b, c, e) \textsuperscript{d} 0.07 0.01 < 0.01 < 0.01 NS < 0.01

4) spontaneous heating and rain damage (d) vs. heating only (a) \textsuperscript{d} NS 0.02 < 0.01 NS NS NS

\textsuperscript{a} Adapted from Turner et al. (2003).

\textsuperscript{b} Number of rainfall events contributing to the total rainfall prior to baling.

\textsuperscript{c} Determined by 48-h ruminal incubation in situ.

\textsuperscript{d} NS, nonsignificant (P > 0.10)
Table 6. Effects of natural rainfall during wilting and spontaneous heating during storage on the voluntary intake, in vivo apparent digestibility, and total tract retention time for growing steers consuming endophyte-infected tall fescue hay. Rainfall events were naturally occurring, and bales were packaged as conventional rectangular bales and stored for approximately six weeks in small stacks at Fayetteville, AR during 2000.\(^a\)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Moisture at Baling</th>
<th>Total Rainfall Amount</th>
<th>Maximum Internal bale temperature °C</th>
<th>Intake % of BW</th>
<th>Digestion Coefficients %</th>
<th>Total Tract Retention Time h</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>22.5 %</td>
<td>0 mm</td>
<td>49.8</td>
<td>2.28</td>
<td>2.10</td>
<td>51</td>
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<tr>
<td></td>
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<td></td>
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<td></td>
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</tr>
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<td></td>
<td></td>
<td></td>
<td>56</td>
</tr>
<tr>
<td>B</td>
<td>9.9 %</td>
<td>0 mm</td>
<td>42.8</td>
<td>2.31</td>
<td>2.10</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>C</td>
<td>24.6 %</td>
<td>23 mm</td>
<td>50.8</td>
<td>2.04</td>
<td>1.85</td>
<td>57</td>
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<td></td>
<td></td>
<td>64</td>
</tr>
<tr>
<td>D</td>
<td>9.3 %</td>
<td>71 mm</td>
<td>31.4</td>
<td>2.15</td>
<td>1.92</td>
<td>53</td>
</tr>
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<td></td>
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<td>59</td>
</tr>
<tr>
<td>SEM</td>
<td>1.3</td>
<td>0.057</td>
<td>0.062</td>
<td>1.70</td>
<td>1.63</td>
<td>1.82</td>
</tr>
</tbody>
</table>

**Contrasts**

1) all damaged hays (a, c, d) vs. no damage (b) 0.05 0.09 0.09 0.05 0.01 NS\(^c\)

2) rain damaged (c, d) vs. no rain (a, b) 0.01 0.01 0.03 0.02 0.01 NS

3) spontaneous heating (a, c) vs. minimal heating (b, d) NS NS NS NS NS 0.06 NS

\(^a\) Adapted from Turner et al. (2004).

\(^b\) Determined with Yb as an external marker.

\(^c\) NS, nonsignificant (P > 0.10).
Figure 1. Relationship between concentrations of NDF and digestibility (%) for KY-31 tall fescue (adapted from Ball et al., 2002). Source: C. S. Hoveland and N. S. Hill, University of Georgia.

Figure 2. Losses of DM in response to simulated rainfall for vegetative orchardgrass (OG) and bermudagrass (BER) hays damaged by rainfall at ideal moisture concentrations for baling (adapted from Scarbrough et al., 2005).
## Financial Statement
### 2004 - 2005

59th Southern Pasture and Forage Crop Improvement Conference
Philadelphia, Mississippi

<table>
<thead>
<tr>
<th></th>
<th>Income</th>
<th>Expense</th>
<th>Balance</th>
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<tbody>
<tr>
<td>Previous Balance</td>
<td>$3,568.20</td>
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<tr>
<td>Pearl River Resort</td>
<td></td>
<td>500.00</td>
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<tr>
<td>FedEx/Kinkos</td>
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<td>174.22</td>
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<td>Interest on account</td>
<td>17.09</td>
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**Current Balance (as of 5/10/05)**

$2,911.07

Respectfully submitted,

M. W. Alison
Secretary-Treasurer, SPFCIC
Resolution Approved 2005 Business Meeting

The membership of the 59th Southern Pasture and Forage Crop Improvement Conference mourn the passing of our friend and colleague, Carroll G. Chambliss of the University of Florida and Florida Cooperative Extension Service. We will miss his active participation in the Southern Pasture and Forage Crop Improvement Conference and his dedicated service to forage-based livestock production.

BE IT THEREFORE RESOLVED that we express our sympathy and condolences to the relatives of Carroll Chambliss.
WHEREAS, the membership of the 59th Annual Southern Pasture and Forage Crop Improvement Conference has gleaned much information and great benefits from their participating in the 2005 conference, and

WHEREAS, such information and benefits could not have been realized without the friendly, hospitable, and concerted efforts of the staff and administration of Mississippi State University,

THEREFORE, BE IT RESOLVED that the 59th SPFCIC expresses its grateful appreciation to the staff, faculty and administration of Mississippi State University for their gracious hospitality, imaginative programming, well-planned and executed tour, which was of interest to the membership, and

THAT special recognition be extended to Mississippi State University, Mississippi Agriculture and Forestry Experiment Station, and Mississippi Cooperative Extension Service, and to Dr. Clarence Watson, Associate Director, MAFES for welcoming SPFCIC to Mississippi.

SPECIAL RECOGNITION is also extended to the following individuals who served on local arrangements committee: Richard Watson, Chair, David Lang, Mike Collins, Terry Kiser, Blair McKinley, Angelica Chapa, Bisoodat Macoon, F. T. (Butch) Withers, Rick Evans, and Dawn McGinley;

TO OUR HOSTS, Jack and Cheryl Evans of the E.E. Ranch and the Carrol-Leflour-Montgomery Cattleman’s Association;

TO OUR SPONSORS, Samuel Roberts Noble Foundation, Pennington Seed Company, Dow AgriSciences, and Mississippi Forage and Grassland Council;

To Conference Chair-elect John Caddell, Immediate Past President Gary Bates, and Secretary-Treasurer Wink Alison;

To Session Chairmen John Andrae, Tom Terrill, Ann Blount, and Glen Aiken, and to all who made conference presentations.

AND, in Memoriam, the membership of the 59th Southern Pasture and Forage Crop Improvement Conference mourn the passing of our friend and colleague, Carrol G. Chambliss, Chairman of the 2005 Conference, of the University of Florida and Florida Cooperative Extension Service. We will miss his active participation in the Southern Pasture and Forage Crop Improvement Conference and his dedicated service to forage-based livestock production.

BE IT THEREFORE RESOLVED that we express our sympathy and condolences to the relatives of Carrol Chambliss.

2005 Resolutions Committee
Monte Rouquette, Jr., Chairman
Gary Bates
John Stuedemann