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BIOMASS PRODUCTION BY FESCUE AND SWITCHGRASS ALONE AND IN MIXED SWARDS WITH LEGUMES

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ABSTRACT

As much as 60 million hectares are available in the U.S. for possible conversion to the production of biomass to supply renewable energy. Information is needed on species and production systems for supplying this biomass. Two field experiments were conducted between 1989 and 1993. One study evaluated biomass production and composition of switchgrass (Panicum virgatum L.) grown alone and with bigflower vetch (Vicia grandiflora L.) and the other assessed biomass productivity and composition of tall fescue (Festuca arundinacea Schreb.) grown alone and with perennial legumes. Switchgrass received 0, 75 or 150 kg ha^{-1} of N annually as NH_4NO_3 or was interseeded with vetch. Tall fescue received 0, 75, 150 or 225 kg ha^{-1} of N annually or was interseeded with alfalfa (Medicago sativa L.) or birdsfoot trefoil (Lotus corniculatus L.). Over a four year period, dry matter (DM) yields from 'Kanlow' switchgrass averaged 9.0 Mg ha^{-1} with no N fertilization and increased to 14.7 Mg ha^{-1} when 150 kg ha^{-1} of N was applied. Vetch shoot and root tissue contained 79 kg N ha^{-1} at anthesis but delayed the commencement of switchgrass growth in spring and reduced tiller numbers considerably resulting in switchgrass yields no greater than those from the unfertilized control. 'Kanlow' produced an average of 14.7 Mg ha^{-1}. Switchgrass biomass had high concentrations of fiber, 77% NDF, and concentrations of N well below 1%. Equal concentrations of cellulose and hemicellulose together comprised more than 90% of the total fiber yield of switchgrass. Tall fescue yielded an average of 10 Mg ha^{-1} annually with 225 kg ha^{-1} of N but only 4.0 Mg ha^{-1} without N fertilization. The efficiency of use of the applied N was similar for the two species, near 30 kg DM kg^{-1} N, the difference in yield was attributable to much greater switchgrass yields without N fertilization. Tall fescue mixtures with birdsfoot trefoil that were harvested less frequently produced 9.2 Mg ha^{-1} per year of biomass DM and were as productive as pure grass stands receiving 150 kg ha^{-1} of N annually. Alfalfa mixtures were less productive, equivalent to pure stands with 75 kg ha^{-1} of N. Tall fescue biomass averaged 62% NDF, considerably less than the average for switchgrass and had much higher concentrations of N, 1.8%. The results of two field experiments indicate that, under these soil and climatic conditions, production systems based on N-fertilized switchgrass were the most productive. Without any vegetation control on the vetch component, vetch mixtures with switchgrass do not appear to be a viable means of meeting the N needs of switchgrass. Biomass yields of tall fescue are below those possible from switchgrass at this location.

Abbreviations - Chapter 1

Y	= Years
R	=Replicates
N	=Nitrogen treatments
CV	=Cultivars
TYLD	=Total sward yield (Mg ha^{-1})
DF	=Degrees of freedom
TNIT	=Total seasonal nitrogen yield (Mg ha^{-1})
TNDF	=Total seasonal neutral detergent fiber yield (Mg ha^{-1})
TADF	=Total seasonal acid detergent fiber yield (Mg ha^{-1})
TCEL	=Total seasonal cellulose yield (Mg ha^{-1})
THC	=Total seasonal hemicellulose yield (Mg ha^{-1})
TADL	=Total seasonal acid detergent lignin yield (Mg ha^{-1})
NDAVG	=Weighted seasonal average neutral detergent fiber concentration (%)
ADAVG	=Weighted seasonal average acid detergent fiber concentration (%)
NAVG	=Weighted seasonal average nitrogen concentration (%)
CAVG	=Weighted seasonal average cellulose concentration (%)
HCAVG	=Weighted seasonal average hemicellulose concentration (%)
ADLAVG	=Weighted seasonal average acid detergent lignin concentration (%)

Abbreviations - Chapter 2

YR	=Year
CV	=Cultivar
N	=Nitrogen fertilization treatment
HAR	=Developmental Stage (Harvest)
DF	=Degrees of Freedom
NIT	=Nitrogen concentration
NDF	=Neutral detergent fiber concentration
ADF	=Acid detergent fiber concentration
ADL	=Acid detergent lignin concentration
AIA	=Acid insoluble ash concentration
CEL	=Cellulose concentration
HCEL	=Hemicellulose concentration

Abbreviations - Chapter 4

DF	= Degrees of freedom
YR	= Years
R	= Replicates
MGT	= Harvest management treatments
N	= Nitrogen fertilization treatments
CV	= Tall fescuc cultivars
SWDYLT	= Total biomass yield (Mg ha^{-1})
GRYLT	= Tall fescue biomass yield (Mg ha^{-1})
LEGYLT	= Legume biomass yield (Mg ha^{-1})
THC	= Total seasonal hemicellulose yield (Mg ha^{-1})
WDYLDT	= Weed biomass yield (Mg ha^{-1})
PEWEED	= Percentage of invading species in biomass DM (%)
NITYT	= Total seasonal nitrogen yield (Mg ha^{-1})
NDFYT	= Total seasonal neutral detergent fiber yield (Mg ha^{-1})
ADFYT	= Total seasonal acid detergent fiber yield (Mg ha^{-1})
CELYT	= Total seasonal cellulose yield (Mg ha^{-1})
ADLYT	= Total seasonal acid detergent lignin yield (Mg ha^{-1})
NITGY	= Yield of nitrogen in grass biomass (Mg ha^{-1})
NDFYG	= Yield of NDF in grass biomass (Mg ha^{-1})
ADFYG	= Yield of ADF in grass biomass (Mg ha^{-1})
CELYG	= Yield of cellulose in grass biomass (Mg ha^{-1})
ADLYG	= Yield of ADL in grass biomass (Mg ha^{-1})
NITCT	= Weighted seasonal average nitrogen concentration (%)
NDFCT	= Weighted seasonal average NDF concentration (%)
ADFCT	= Weighted seasonal average ADF concentration (%)
CELCT	= Weighted seasonal average cellulose concentration (%)
ADLCT	= Weighted seasonal average ADL concentration (%)

INTRODUCTION AND OVERVIEW

An assessment of the probable role of biomass energy in the future global energy situation by the Intergovernmental Panel on Climate Change (IPCC) suggests that if steps are not taken to slow the release of greenhouse gasses into the atmosphere, we can expect global temperatures to increase at the rate of 0.3^{o}C per decade and that sea level would increase by 6 cm per decade (Clarke, 1991). Biomass energy would not contribute to net global CO_2 levels since the gasses released during its utilization were only recently removed from the atmosphere. In a national workshop to assess the role of biomass in alleviating potential global warming, the absence of information on the sustainability of biomass production on soils of limited agricultural potential was cited as a major constraint to the assessment of the role of biomass (Auld and Collins, 1991). Research on the sustainability of yields, recycling of nutrients, and emphasis on reduced inputs of agricultural chemicals in the production of biomass were listed among the critical research needs to clarify optimum cropping practice in biomass production. Soil productivity might also benefit from biomass production by perennial grasses since these species reduce rainfall runoff and soil erosion to a fraction of that lost under row crop systems (Browning, 1973). Considerable land area is available in the U.S. for possible conversion to the production of biomass, as much as 60 million hectares by some estimates (Robertson and Shapouri, 1993).

Switchgrass (Panicum virgatum L.)is among the warm season perennial grasses that are native to North America (Parrish and Wolf, 1993). This species, along with others such as big bluestem (Andropogon gerardii Vitman), were the dominant grass components of the tall grass prairies of the midwestern U.S. Unlike some other C_4 grasses introduced from tropical regions, switchgrass has sufficient cold hardiness to survive throughout the U.S. Thus, although there are other species capable of higher yields in the subtropical portion of the U.S., switchgrass is generally found to be among the highest yielding perennial grasses in more northern latitudes. Due to its wide adaptation, switchgrass has been identified as the perennial grass with greatest potential for application in a herbaceous biomass production system.

Among the adaptational advantages of switchgrass and some other perennial warm species, is rooting depths that are greater than for cool season grasses. Work cited by Jung (1986) showed that KY-729 switchgrass had 7-fold greater root mass in the surface 0-15 cm of a low P soil in Pennsylvania than did orchardgrass (Dactylis glomerata L.). Switchgrass had some roots as deep as 60 cm whereas orchardgrass had little rooting below about 30 cm depth.

Within large portions of the southern, northeastern and midwestern U.S., tall fescue (Festuca arundinacea Schreb.) is the predominant existing cool season perennial grass species. Estimates are that 25 million acres of tall fescue are already present in this region. This species is adapted to a wide range of soil types, drainage conditions and fertility levels. It produces a dense sod that provides excellent erosion control throughout the year, a characteristic that has led to the use of tall fescue in roadside plantings, strip mine reclamation, and recreational grasslands in addition to its use as a pasture and hay crop. Among cool season grass species used in the U.S., tall fescue is considered moderately responsive to nitrogen fertilization. Recommended nitrogen application rates for tall fescue in Kentucky are in the range of 150 kg ha^{-1} annually.

Environmental and cost concerns often favor the use of symbiotically fixed N in the production of perennial grasses. Among perennial grasses English and Bhat (1991) studied the economics of biomass production and concluded that fertilizer costs were among the major determinants of biomass production costs. Previous experience suggests that significant grass genotype effects exist for compatibility with legumes and, if this is true of switchgrass, that compatibility in mixtures might be a fruitful subject for future breeding efforts. One legume for which some experience exists for production in switchgrass mixtures is bigflower vetch (Vicia grandiflora L.). A winter annual species grown with switchgrass might also intercept and hold N and P which might otherwise move through the root zone prior to growth initiation by switchgrass. Much more information is available regarding legume compatibility with tall fescue. Tall fescue is ecologically suitable for mixtures with some legume species such as red clover (Trifolium pratense L.). Red clover is generally found to be less productive than alfalfa (Medicago sativa L.) when both are grown on soils suitable to alfalfa. However, red clover suffers little yield penalty when on soils with pH levels as low as 5.5, where alfalfa production is not possible.

Although considerable research has been done examining cutting regime and fertilization effects on yield and chemical composition of tall fescue, that work was done with the objective of producing forage for animal feeding. For livestock feeding, early maturity harvesting is well known to produce a higher quality product by increasing nitrogen concentrations and reducing fiber concentrations. Designing systems for biomass energy production from tall fescue requires research that takes into account the differences in composition needed for biomass versus forage.

Although specific biomass composition goals depend greatly on the conversion process selected, sufficient information exists to suggest that certain compositional characteristics are advantageous or detrimental. For example, the presence of significant silica concentrations is detrimental because this compound yields no energy and is abrasive to equipment used in the harvest and processing steps. High concentrations of protein are not advantageous for energy production whereas high N forages are considered high in quality. In the case of conversion of fiber to ethanol, the presence of maximum concentrations of fiber would appear to be important to allow maximum energy extraction by a minimum number of processing steps. Switchgrass cultivars may differ significantly in chemical composition (Vogel et al., 1984). Hay of switchgrass genotypes selected for higher digestibility tended to be lower in NDF than low digestibility genotypes.

Two studies were designed to measure biomass yield and composition of switchgrass and tall fescue. One field experiment assessed the influence of switchgrass cultivars and nitrogen fertilization management on the yield and composition of biomass. The same experiment was utilized to follow phenological effects on switchgrass biomass composition. A second field experiment was designed to evaluate harvest and nitrogen management effects on biomass yield and composition of tall fescue. Specific objectives of these of these studies were:

(1) To evaluate biomass production and composition of switchgrass grown alone and with bigflower vetch.

(2) **To evaluate biomass productivity and composition of tall fescue grown alone and with perennial legumes.**

Both objectives address the hypothesis that production systems can be designed to produce high yields of biomass with minimal inputs of fertilizer N. Achievement of this goal would reduce the potential for movement of NO_3 and other undesirable N forms outside the biomass production system into the environment. In addition, management systems involving legumes could reduce the cost of biomass production. The hypothesis was tested for switchgrass by comparing stands receiving fertilizer N as NH_4NO_3 to stands including bigflower vetch, a winter annual legume. Considerable information is available in the literature regarding productivity of tall fescue. This additional research was conducted to improve our understanding of the ecology of legume mixtures with this species under harvest management systems designed to maximize biomass production.

MATERIALS AND METHODS

Climatic and Soil Conditions

Both experiments were conducted at the University of Kentucky Spindletop Research Farm, Fayette County, KY. The site is located at latitude N 38° 02' longitude W 84° 36' and at an elevation of 294 m. Annual precipitation averages approximately 1168 mm at this site although seasonal totals have been below that level for most of the last 10 years. January is the coldest month at this location with an average temperature of -1° C. July is the hottest month with an average temperature of 24° C. Monthly mean temperatures during April and May were highest in 1991 and relatively similar in the other years. July mean maximum temperatures ranged from 28.9-30.0°C (Appendix 1). During the period covered by this experiment, precipitation levels were generally consistent and ranged from 1201 to 1392 mm, numerically above the long-term norm in every year (Appendix 2).

The soil type at this site is primarily Maury silt loam characterized by high native P levels, moderate pH and low K levels. This soil is relatively shallow and has poor water holding capacity leading to frequent moisture stress. Soil samples were collected prior to initiation of these experiments. The soil of the tall fescue site had 269 kg ha^{-1} of available P, 673 kg ha^{-1} of exchangeable K and a pH of 6.0. The switchgrass site had 269 kg ha^{-1} of available P, 451 kg ha^{-1} of exchangeable K and a pH of 6.2. No P was applied during either experiment. Potassium was applied annually or every other year as necessary to maintain soil K levels.

Switchgrass Study

Four switchgrass genotypes, Blackwell, Carthage, Kanlow and KY1625 were evaluated in an established field experiment. Treatments were assigned in a factorial arrangement with four N treatments, each replicated three times in plots measuring 3 x 8 m. Nitrogen fertilization treatments consist of 0, 75 and 150 kg/ha of fertilizer N as NH_4NO_3 in a split application. The fourth nitrogen treatment received no fertilizer N. This treatment was interseeded with bigflower vetch which was allowed to grow during late winter and early spring without harvest to provide N for switchgrass. Vetch was included during 1989, 1990 and 1992. During 1991, the vetch was removed as a result of herbicide application to remove an invading legume which was competing severely with switchgrass in the vetch plots.

Yield harvests were made in late July or early August when switchgrass reached anthesis maturity. Exceptions were made in cases of severe lodging. All plots were harvested on the same dates.

Yield was measured by clipping the central 0.6 m of each plot after removing 0.6 m from each end. This procedure was followed to avoid border effects that can introduce serious errors when studying species or treatments that differ in height or vigor. Harvesting the entire plot in such cases would allow competition between adjacent plots to influence yield and composition. Following clipping, the fresh weight of all biomass from the harvested area was determined for each plot. Two samples of 800-1200 g fresh weight will be randomly selected from each plot after mixing. One sample was weighed immediately, dried at 60°C for 48 h and reweighed for determination of moisture concentration. The second shoot sample was held at 4°C and hand separated into switchgrass, legume and weed components. These separated components were dried separately at 60°C for 48 h and weighed for determination of the botanical composition of the biomass harvested from each plot.

Developmental information regarding N responses of switchgrass was obtained by sequential sampling of switchgrass biomass leading up to the first harvest each year. At each of five dates spaced at 3 week intervals, random samples of switchgrass shoot tissue were clipped above a 8 cm stubble. Actual sampling and yield harvest dates are shown below. These samples were dried and ground for compositional analysis. Tissue samples from each sampling date were analyzed for N, NDF, ADF, cellulose and ADL to thoroughly characterize changes in switchgrass biomass composition due to maturation, variety and N fertilization. When bigflower vetch reached anthesis, generally during mid-May, one or two randomly selected one-square-foot areas was identified from which shoot tissue was clipped. Following clipping, roots were dug, separated into switchgrass, vetch and other species and dried at 60°C for 48 h for dry matter determination. Root samples were ground and analyzed for total nitrogen.

Sampling Dates For Switchgrass Biomass Study

Year							
1989		1990		1991		1992	
Month	Day	Month	Day	Month	Day	Month	Day
Developmental Stage Sampling Dates							
5	18	5	9	5	7	5	20
6	8	5	31	5	21	6	3
6	29	6	20	6	4	6	17
7	20	7	11	6	18	7	14
8	1	8	2	7	2	8	18
Yield Harvest Dates							
8	1	8	8	7	19	8	18
10	4	10	30	9	26		

Biomass samples from sequential sampling and from yield harvests were dried and analyzed to characterize biomass composition effects of each treatment. All samples were ground to pass a 1 mm screen and analyzed for total nitrogen (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, hemicellulose, and acid detergent lignin using a Pacific Scientific near infrared reflectance spectrophotometer calibrated by analyzing selected samples for N using a colorimetric technique after digestion in concentrated H_2SO_4, NDF, ADF, ADL, cellulose and hemicellulose using the methods of Goering and Van Soest (1970) as modified by Robertson and Van Soest (1980).

Tall Fescue Study

In the second experiment, two tall fescue cultivars; Johnstone and KY31; two cutting regimes; two or three harvests per season; and six N/legume treatments; 0, 75, 150 and 225 kg/ha of N annually and mixtures with alfalfa and birdsfoot trefoil were assigned in factorial combinations in each of four replicates. Harvest management was the main plot in a split plot design. Harvest management treatments consisted of cutting regimes emphasizing early or late maturity harvesting schedules. These treatments are referred to as Early and Late, respectively. Following the first harvest, a variable number of additional harvests was taken through the season depending upon growing conditions. The late harvest schedule generally resulted in one less harvest through the season than the early schedule.

Plots in this study were 1.7 x 7.3 m. At each harvest a 0.6 m strip was clipped through the center of each plot after removing 0.6 m from each end to eliminate border effects. Two subsamples of approximately 800 g were randomly collected from the harvested material after weighing the total biomass. One subsample was weighed immediately and dried at 60°C for 48 h for determination of moisture concentration. The other sample was held at 4°C and separated into botanical components including grass, legume and weeds. Each component was dried and weighed as described above. Samples of grass and legume biomass was analyzed for total N, neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, and acid detergent lignin (ADL).

Sampling Dates For Tall Fescue Biomass Study

Schedule	1990		1991		1992		1993	
	Month	Day	Month	Day	Month	Day	Month	Day
Early Harvest								
	5	2	5	1	5	26	5	17
	7	3	6	13	8	12	8	17
	9	11	8	8	9	30	10	
			10	8				
Late Harvest								
	5	2	5	15	6	10	6	8
	7	18	7	2	9	30	10	11
	9	11	10	8				

In order to allow comparison of harvest schedule treatments, total seasonal yield was calculated for each plot for both field experiments by summing over individual harvests. Separate values were also determined for legume, weed and grass components from each harvest and seasonal yields calculated for each botanical component. Yield values presented for grass include yields contributed by unseeded species present in the botanical sample. Weighted seasonal biomass composition values were determined using individual harvest yield, botanical composition, and biomass chemical composition data. Data were analyzed by analysis of variance procedures.

CHAPTER 1

YIELD AND BIOMASS COMPOSITION OF SWITCHGRASS WITH NITROGEN FERTILIZATION OR IN MIXTURES WITH BIGFLOWER VETCH

RESULTS AND DISCUSSION

DM and Constituent Yields

Switchgrass yields responded significantly to increasing N application rates up to the maximum rate used in this study of 150 kg ha^{-1} (Tables 1.2 and 1.4 and Fig. 1.1). Over the 4-yr study, switchgrass receiving 150 kg ha^{-1} of N produced an average of 12.9 Mg ha^{-1}, 2.5 Mg ha^{-1} more than plots receiving one-half that rate of N. Nitrogen fertilizer use efficiency for the first 75 kg ha^{-1} increment added was 27 kg DM kg^{-1} N added. The second 75 kg ha^{-1} increment of N fertilizer resulted in an additional 33 kg ha^{-1} DM kg^{-1} N. This is in contrast to the general consensus regarding N response of this species which indicates that N fertilization rates below 100 kg ha^{-1} generally maximize yields.

The treatment including vetch produced nearly identical yields as the unfertilized pure stands of switchgrass. In 1991, when vetch was removed in the spring just after growth initiation in order to allow the switchgrass stand in that treatment to improve, yields from the vetch treatment were similar to those from plots receiving 75 kg ha^{-1} of N (Table 1.12). This finding suggests that early season competition from vetch delayed switchgrass growth initiation and reduced switchgrass shoot numbers per unit area and offset any potential yield response to legume N.

Yield response to N fertilization varied across years ($P<0.01$) (Tables 1.2 and 1.12). In 1989, biomass yields from the vetch treatment totaled only 5.8 Mg ha^{-1} compared with yields of 9.1 Mg ha^{-1} for unfertilized pure switchgrass stands. In the other years, biomass yields from the vetch treatment were within 0.8 Mg ha^{-1} of those from the unfertilized control.

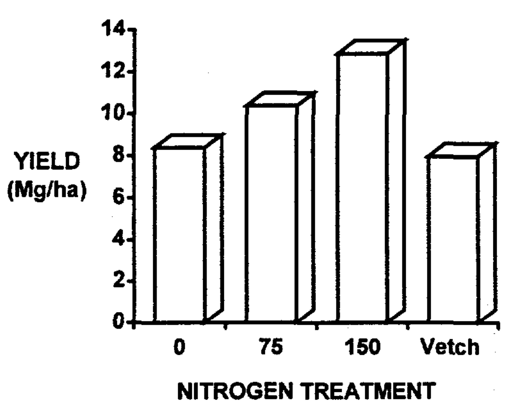

Fig. 1.1 Dry matter yields of switchgrass and switchgrass-vetch mixtures.

Of the four switchgrass cultivars evaluated in this work, Kanlow produced yields numerically higher than those from either of the other species included (Table 1.6). Cultivars differed most in yield at the 150 kg ha^{-1} N fertilization rate (Table 1.8). more responsive than the other cultivars (Table 1.8). Kanlow yielded 14.7 Mg ha^{-1} at the 150 kg ha^{-1} N level, compared with 13.2 Mg ha^{-1} for Carthage, the next highest yielding cultivar. Carthage yields were especially low in the absence of N fertilization. That cultivar produced at least 1 Mg ha^{-1} less than any other cultivar when no N was applied.

Year to year fluctuations in yield were large (Table 1.10), with mean annual yields ranging from as little as 7.3 Mg ha^{-1} in 1992 to as much as 12.2 Mg ha^{-1} in the previous year (Fig 1.2). Warm April and May temperatures during 1991 compared with other years caused faster early-season growth rates and allowed a larger second harvest yield. During 1992, late winter and early spring precipitation levels were low. Year to year fluctuations in yield were largest for the treatment receiving 150 kg ha^{-1} of N. A range of 6.5 Mg ha^{-1} existed between the highest and lowest annual yield for plots receiving 150 kg ha^{-1} of N annually compared with year-to-year fluctuations of 4.9-5.2 Mg ha^{-1} for the other treatments.

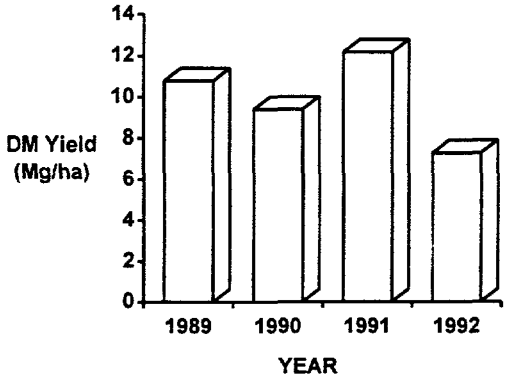

Fig. 1.2 Year effects on DM yields of switchgrass.

The harvested biomass contained from 59 to 100 kg ha^{-1} of N, depending upon the N fertilization rate used (Table 1.4). Whereas DM yields from the vetch treatment were nearly identical to those from the unfertilized control, N yields from the legume treatment were equal to those from switchgrass receiving 75 kg ha^{-1} of N. This finding indicates that significant amounts of N were being contributed to the switchgrass by the associated vetch crop. Total fiber yields, estimated by measuring NDF concentrations, ranged from 6.5 to 10.0 Mg ha^{-1} for unfertilized plots and those receiving 150 kg ha^{-1} of N, respectively (Table 1.4 and Fig. 1.3). Cultivar trends in total fiber yields and yields ADF, cellulose, hemicellulose, and ADL were similar to those discussed above for DM yield (Table 1.6). The total fiber yield was comprised of roughly equal yields of cellulose and hemicellulose.

Constituent Concentrations

Nitrogen concentration responded to increased N fertilization but the difference was very small compared with the yield effects discuss earlier (Tables 1. 3 and 1.15 and Fig. 1.4). The concentrations of N found in switchgrass biomass are very low compared with those found in cool season grasses (See Chapter 4) and indicate efficient utilization of soil and applied N by this species. Switchgrass from the vetch treatment had considerably higher concentrations of N than even the switchgrass fertilized with 150 kg ha^{-1} of N.

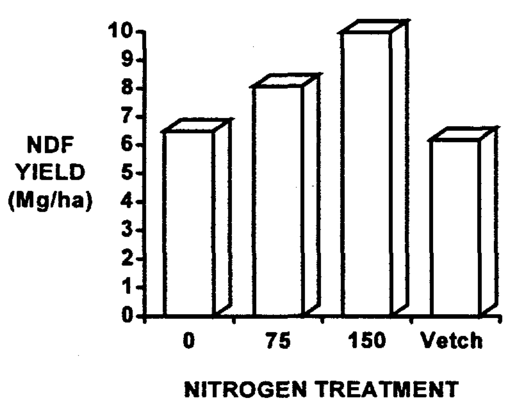

Fig. 1.3 Neutral detergent fiber yields of switchgrass and switchgrass-vetch mixtures

Fertilization effects on fiber concentrations in switchgrass biomass were very small (Table 1.5). Switchgrass growing in vetch mixtures was often at a slightly earlier maturity stage at the time of harvest than the same cultivars in other fertilization treatments. This would account for the generally lower fiber concentrations in switchgrass from vetch mixtures. Cultivar effects on biomass fiber concentrations were also small although some were statistically significant (Tables 1.3 and 1.7). KY1625 had lower concentrations of NDF, ADF, cellulose and ADL than either of the other cultivars but had higher concentrations of hemicellulose than Kanlow or Blackwell. Hemicellulose was measured indirectly as the difference between NDF and ADF in these studies. Further analysis would be needed to determine the exact nature of these cultivar differences in fiber composition, however these results do suggest that it might be possible to shift switchgrass fiber composition if that were desirable for conversion purposes.

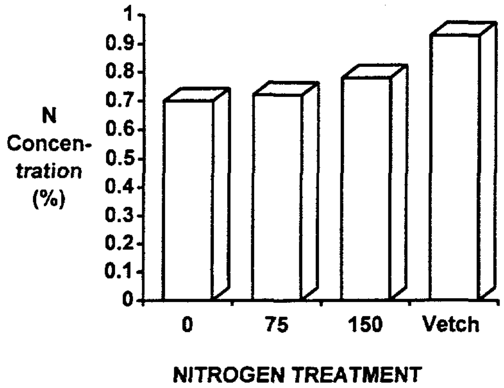

Fig. 1.4 Nitrogen concentration switchgrass biomass from four N fertilization treatments.

Table 1.1 Description of variables in a 4-year field experiment to evaluate switchgrass cultivar and N fertilization regime effects on biomass production and composition.

Variable	Levels	Values
Y (Years)	4	1989, 1990, 1991, 1992
R (Replicates)	3	1, 2, 3
N (Nitrogen treatments)	4	0, 75, 150, Vetch
CV (Cultivars)	4	Blackwell, Carthage, Kanlow, KY1625

Table 1.2 Analysis of variance of DM and constituent yields of four switchgrass cultivars managed with various N fertilization rates over a 4-year period.

Source	DF	TYLD	TNIT	TNDF	TADF	TCEL	THC	TADL
		---------------------------------- Pr > F ----------------------------------						
R	2	0.7973	0.3294	0.8430	0.8800	0.8903	0.7936	0.6605
N	3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CV	3	0.0059	0.0001	0.0016	0.0001	0.0001	0.0255	0.0002
N*CV	9	0.0462	0.0052	0.0464	0.0399	0.0483	0.0580	0.0496
YR	3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
N*YR	9	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CV*YR	9	0.4024	0.0258	0.3673	0.2507	0.1765	0.5608	0.0632
N*CV*YR	27	0.4788	0.1153	0.4949	0.3931	0.3540	0.6049	0.4171

Table 1.3 Analysis of variance of weighted seasonal switchgrass concentrations of total nitrogen and fiber constituents.

Source	NDAVG	ADAVG	NAVG	CAVG	HCAVG	ADLAVG
	------------	------------	------------	Pr > F	------------	------------
R	0.2490	0.3859	0.0265	0.1729	0.7623	0.3763
N	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
CV	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
N*CV	0.0675	0.0459	0.0087	0.0500	0.3013	0.1170
YR	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
N*YR	0.0075	0.0001	0.0120	0.0001	0.0001	0.0002
CV*YR	0.0004	0.0045	0.0001	0.0002	0.0003	0.0006
N*CV*YR	0.2552	0.8773	0.0143	0.7130	0.0681	0.2314

Table 1.4 Nitrogen fertilization effects on total DM yield and on yields of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose. hemicellulose, and acid detergent lignin in switchgrass biomass from four cultivars averaged over four years.

Nitrogen fertilization treatment	TYLD	TNIT	TNDF	TADF	TCEL	THC	TADL
	-----------------	-----------------	----------	Mg ha^{-1}	----------	-----------------	-----------------
0	8.4 c†	0.059 c	6.5 c	3.7 c	3.0 c	2.9 c	0.56 c
75	10.4 b	0.075 b	8.1 b	4.6 b	3.8 b	3.5 b	0.69 b
150	12.9 a	0.100 a	10.0 a	5.7 a	4.7 a	4.3 a	0.87 a
Vetch	8.0 c	0.074 b	6.2 c	3.4 c	2.8 c	2.8 c	0.50 c

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 1.5 Nitrogen fertilization effects on concentrations of nitrogen, neutral detergent fiber, acid detergent fiber, acid detergent lignin in switchgrass biomass from four cultivars averaged over four years.

Nitrogen fertilization treatment	NAVG	NDAVG	ADAVG	CAVG	HCAVG	ADLA
	-----------------	-----------------	---------- %	----------	-----------------	-----------------
0	0.70 c†	77.7 a	43.5 b	35.3 b	34.1 a	6.6 a
75	0.72 c	77.5 a	44.2 ab	36.0 a	33.3 b	6.7 a
150	0.78 b	77.9 a	44.5 a	36.4 a	33.4 b	6.8 a
Vetch	0.93 a	76.7 b	42.2 c	34.7 c	34.5 a	6.1 b

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 1.6 Cultivar effects on total DM yield and on yields of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over four N-fertilization treatments and four years.

Cultivar	TYLD	TNIT	TNDF	TADF	TCEL	THC	TADL
	--Mg ha^{-1}--						
Blackwell	10.2 ab†	0.083 a	7.92 a	4.57 ab	3.73 ab	3.35 ab	0.71 a
Carthage	9.7 ab	0.078 a	7.49 ab	4.21 bc	3.46 bc	3.28 ab	0.64 ab
Kanlow	10.7 a	0.067 b	8.40 a	4.78 a	3.99 a	3.62 a	0.71 a
KY1625	9.1 b	0.079 a	6.97 b	3.82 c	3.12 c	3.15 b	0.57 b

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 1.7 Cultivar effects on concentrations of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over four N-fertilization treatments and four years.

Cultivar	NAVG	NDAVG	ADAV	CAVG	HCAVG	ADLAVG
	--%--					
Blackwell	0.81 a†	77.4 b	44.6 a	36.2 b	32.8 c	6.9 a
Carthage	0.82 a	77.4 b	43.4 b	35.4 c	34.1 ab	6.5 b
Kanlow	0.65 b	78.6 a	44.7 a	36.9 a	33.9 b	6.6 b
KY1625	0.86 a	76.3 c	41.8 c	33.9 d	34.5 a	6.2 c

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 1.8 Nitrogen fertilization rate and cultivar effects on total DM yield and on yields of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over 4 years.

N	Cultivar	TYLD	TNIT	TNDF	TADF	TCEL	THC	TADL
		------------------------------Mg ha^{-1}------------------------------						
0	Blackwell	9.1	0.063	7.17	4.15	3.36	3.02	0.66
0	Carthage	7.2	0.052	5.57	3.10	2.53	2.47	0.48
0	Kanlow	9.0	0.059	7.10	4.00	3.33	3.10	0.58
0	KY1625	8.2	0.063	6.24	3.39	2.77	2.85	0.50
75	Blackwell	11.1	0.089	8.59	5.00	4.10	3.59	0.76
75	Carthage	10.8	0.081	8.36	4.76	3.92	3.60	0.71
75	Kanlow	10.1	0.052	7.96	4.61	3.82	3.35	0.69
75	KY1625	9.7	0.080	7.41	4.09	3.31	3.32	0.61
150	Blackwell	12.7	0.108	9.81	5.69	4.68	4.13	0.87
150	Carthage	13.2	0.108	10.37	5.93	4.83	4.45	0.93
150	Kanlow	14.7	0.094	11.67	6.66	5.55	5.00	1.00
150	KY1625	10.8	0.093	8.33	4.63	3.80	3.70	0.69
Vetch	Blackwell	8.0	0.075	6.12	3.44	2.80	2.68	0.54
Vetch	Carthage	7.4	0.072	5.68	3.07	2.55	2.60	0.44
Vetch	Kanlow	8.8	0.068	6.89	3.88	3.26	3.01	0.56
Vetch	KY1625	7.8	0.080	5.92	3.19	2.61	2.73	0.46

Table 1.9 Nitrogen fertilization rate and cultivar effects on concentrations of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over four years.

N	Cultivar	NDAVG	ADAVG	NAVG	CAVG	HCAVG	ADLA
		----------------------------	----------------------------	%----------	----------------------------	----------------------------	----------
0	Blackwell	78.3	45.5	0.67	36.5	32.9	7.3
0	Carthage	77.7	43.2	0.72	34.9	34.5	6.6
0	Kanlow	78.8	44.4	0.66	36.6	34.5	6.4
0	KY1625	75.7	41.1	0.76	33.3	34.6	6.1
75	Blackwell	77.9	45.4	0.80	36.9	32.5	7.0
75	Carthage	77.1	43.9	0.74	35.8	33.2	6.6
75	Kanlow	78.6	45.4	0.53	37.3	33.2	6.8
75	KY1625	76.6	42.3	0.81	34.0	34.2	6.4
150	Blackwell	77.4	45.0	0.85	36.8	32.4	7.0
150	Carthage	78.4	44.8	0.81	36.5	33.5	7.0
150	Kanlow	79.0	45.3	0.63	37.4	33.7	6.8
150	KY1625	76.9	42.8	0.86	35.0	34.1	6.3
Vetch	Blackwell	76.2	42.6	0.93	34.6	33.5	6.5
Vetch	Carthage	76.6	41.5	1.00	34.3	35.1	5.9
Vetch	Kanlow	78.0	43.8	0.78	36.4	34.2	6.2
Vetch	KY1625	76.0	41.0	1.02	33.4	35.0	5.9

Table 1.10 Year effects on total DM yield and on yields of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over nitrogen fertilization treatments and cultivars.

Year	TYLD	TNIT	TNDF	TADF	TCEL	THC	TADL
	----------	----------	----------	Mg ha^{-1}	----------	----------	----------
1989	10.8 b†	0.079 b	8.3 b	4.7 b	3.9 b	3.6 b	0.68 b
1990	9.4 c	0.077 b	7.1 c	3.9 c	3.2 c	3.1 c	0.52 c
1991	12.2 a	0.099 a	9.7 a	5.4 a	4.6 a	4.2 a	0.88 a
1992	7.3 d	0.053 c	5.8 d	3.3 d	2.5 d	2.4 d	0.54 c

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 1.11 Year effects on concentrations of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over nitrogen fertilization treatments and cultivars.

Year	NAVG	NDAVG	ADAVG	CAVG	HCAVG	ADLA
	----------	----------	----------	%	----------	----------
1989	0.76 b†	76.7 c	43.0 c	35.9 b	33.7 b	6.2 b
1990	0.83 a	75.4 b	41.7 d	34.8 c	33.7 b	5.6 c
1991	0.83 a	79.1 a	44.4 b	37.5 a	34.7 a	7.2 a
1992	0.73 b	78.6 c	45.3 a	34.2 d	33.2 b	7.4 a

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 1.12 Nitrogen fertilization rate and year effects on total DM yield and on yields of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over cultivars.

N	Year	TYLD	TNIT	TNDF	TADF	TCEL	THC	TADL
		------------------------------Mg ha^{-1}	------------------------------					
0	1989	9.1	0.063	6.88	3.84	3.20	3.04	0.54
0	1990	7.2	0.050	5.47	3.01	2.50	2.46	0.39
0	1991	11.1	0.083	8.828	4.94	4.18	3.87	0.80
0	1992	6.2	0.041	4.91	2.84	2.10	2.07	0.49
75	1989	12.8	0.087	9.86	5.76	4.81	4.10	0.83
75	1990	9.8	0.071	7.46	4.20	3.48	3.26	0.57
75	1991	11.5	0.93	9.08	5.05	4.28	4.03	0.81
75	1992	7.6	0.051	5.92	3.45	2.57	2.48	0.57
150	1989	15.5	0.115	12.06	6.78	5.67	5.28	1.01
150	1990	12.6	0.106	9.57	5.45	4.55	4.13	0.76
150	1991	14.3	0.114	11.41	6.50	5.48	4.91	1.07
150	1992	9.1	0.066	7.14	4.17	3.19	2.97	0.65
Vetch	1989	5.8	0.052	4.37	2.37	1.98	2.00	0.34
Vetch	1990	7.9	0.081	5.81	3.11	2.62	2.70	0.38
Vetch	1991	11.9	0.106	9.37	5.22	4.43	4.14	0.84
Vetch	1992	6.4	0.055	5.05	2.88	2.20	2.18	0.45

Table 1.13 Nitrogen fertilization treatment and year effects on concentrations of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over cultivars.

N	Year	NDAVG	ADAVG	NAVG	CAVG	HCAVG	ADLAV
		----------	----------	%	----------	----------	----------
0	1989	76.3	42.5	0.70	35.5	33.8	6.0
0	1990	75.9	41.7	0.70	34.6	34.3	5.4
0	1991	79.4	44.4	0.76	37.6	34.9	7.2
0	1992	79.0	45.5	0.66	33.7	33.5	7.8
75	1989	76.8	44.8	0.69	37.4	32.0	6.4
75	1990	75.9	42.6	0.72	35.4	33.3	5.7
75	1991	79.0	44.0	0.80	37.3	35.1	7.0
75	1992	78.4	45.6	0.66	34.0	32.9	7.6
150	1989	77.8	43.7	0.75	36.4	34.2	6.5
150	1990	76.0	43.2	0.85	36.1	32.8	6.0
150	1991	79.5	45.4	0.81	38.2	34.1	7.5
150	1992	78.4	45.7	0.73	35.0	32.7	7.1
Vetch	1989	75.9	41.1	0.91	34.3	34.7	5.8
Vetch	1990	73.8	39.5	1.03	33.2	34.3	4.8
Vetch	1991	78.6	43.7	0.90	37.0	34.8	6.7
Vetch	1992	78.5	44.5	0.88	34.2	34.0	6.9

Table 1.14 Cultivar and year effects on total DM yield and on yields of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over nitrogen fertilization treatments.

Cultivar	Year	TYLD	TNIT	TNDF	TADF	TCEL	THC	TADL
		-------	-------	-------	Mg ha^{-1}	-------	-------	-------
Blackwell	1989	11.1	0.087	8.48	4.88	4.08	3.61	0.69
Blackwell	1990	9.3	0.081	7.07	3.99	3.33	3.07	0.55
Blackwell	1991	12.4	0.110	9.81	5.61	4.67	4.21	0.95
Blackwell	1992	8.1	0.054	6.33	3.79	2.85	2.54	0.65
Carthage	1989	10.0	0.076	7.71	4.36	3.60	3.35	0.66
Carthage	1990	9.6	0.084	7.21	4.01	3.35	3.20	0.55
Carthage	1991	12.2	0.098	9.66	5.42	4.58	4.24	0.87
Carthage	1992	6.9	0.053	5.39	3.06	2.32	2.33	0.47
Kanlow	1989	12.2	0.071	9.57	5.48	4.60	4.09	0.81
Kanlow	1990	9.9	0.065	7.68	4.32	3.61	3.36	0.55
Kanlow	1991	12.9	0.081	10.34	5.83	5.08	4.51	0.91
Kanlow	1992	7.6	0.051	6.03	3.52	2.67	2.51	0.57
KY1625	1989	9.8	0.081	7.40	4.03	3.37	3.37	0.57
KY1625	1990	8.6	0.076	6.35	3.43	2.86	2.92	0.44
KY1625	1991	11.4	0.108	8.86	4.86	4.03	4.00	0.78
KY1625	1992	6.7	0.051	5.28	2.96	2.23	2.31	0.48

Table 1.15 Cultivar and year effects on concentrations of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass averaged over nitrogen fertilization treatments.

Cultivar	Year	NDAVG	ADAVG	NAVG	CAVG	HCAVG	ADLAV
		-------	-------	---%---	-------	-------	-------
Blackwell	1989	76.3	43.6	0.79	36.3	32.7	6.2
Blackwell	1990	75.8	42.6	0.89	35.6	33.2	5.8
Blackwell	1991	79.1	45.2	0.89	37.6	33.9	7.7
Blackwell	1992	78.6	47.1	0.68	35.4	31.6	8.1
Carthage	1989	77.0	43.3	0.80	35.8	33.8	6.5
Carthage	1990	74.8	41.4	0.87	34.6	33.5	5.6
Carthage	1991	79.4	44.5	0.80	37.6	34.9	7.1
Carthage	1992	78.5	44.3	0.79	33.5	34.2	6.9
Kanlow	1989	78.3	44.4	0.63	37.5	33.9	6.4
Kanlow	1990	77.3	43.3	0.66	36.1	34.0	5.5
Kanlow	1991	80.0	45.1	0.62	39.3	34.9	7.0
Kanlow	1992	78.8	46.0	0.68	34.8	32.8	7.4
KY1625	1989	75.2	40.8	0.83	34.1	34.4	5.7
KY1625	1990	73.7	39.7	0.88	33.1	34.0	5.1
KY1625	1991	77.9	42.7	0.96	35.4	35.2	6.9
KY1625	1992	78.4	43.9	0.77	33.1	34.4	7.1

Table 1.16 Nitrogen fertilization rate, cultivar, and year effects on total DM yield and on yields of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass.

N	CV	Year	TYLD	TNIT	TNDF	TADF
			----------Mg ha^{-1}----------			
0	Blackwell	1989	8.8	0.057	6.82	3.94
0	Blackwell	1990	7.6	0.057	5.87	3.29
0	Blackwell	1991	13.1	0.099	10.51	6.06
0	Blackwell	1992	6.9	0.037	5.47	3.30
0	Carthage	1989	8.2	0.065	6.22	3.45
0	Carthage	1990	6.5	0.047	4.94	2.70
0	Carthage	1991	8.9	0.064	7.11	3.97
0	Carthage	1992	5.1	0.033	4.00	2.26
0	Kanlow	1989	10.2	0.064	8.05	4.51
0	Kanlow	1990	7.7	0.045	5.93	3.30
0	Kanlow	1991	11.6	0.076	9.28	5.21
0	Kanlow	1992	6.4	0.050	5.14	2.97
0	KY1625	1989	8.8	0.066	6.42	3.45
0	KY1625	1990	7.0	0.052	5.14	2.74
0	KY1625	1991	10.8	0.095	8.36	4.54
0	KY1625	1992	6.4	0.041	5.03	2.81
75	Blackwell	1989	13.4	0.102	10.20	6.09
75	Blackwell	1990	10.6	0.083	8.22	4.73
75	Blackwell	1991	11.4	0.103	9.00	5.03
75	Blackwell	1992	8.9	0.066	6.98	4.16
75	Carthage	1989	12.5	0.090	9.68	5.63
75	Carthage	1990	10.8	0.076	7.97	4.51
75	Carthage	1991	12.4	0.103	9.88	5.52
75	Carthage	1992	7.6	0.053	5.90	3.37
75	Kanlow	1989	14.1	0.069	11.00	6.52
75	Kanlow	1990	9.0	0.051	6.98	3.95
75	Kanlow	1991	10.4	0.052	8.35	4.70
75	Kanlow	1992	7.1	0.035	5.51	3.26
75	KY1625	1989	11.3	0.087	8.57	4.80
75	KY1625	1990	9.0	0.073	6.66	3.59
75	KY1625	1991	11.8	0.113	9.13	4.95
75	KY1625	1992	6.7	0.045	5.29	3.00
150	Blackwell	1989	16.2	0.135	12.40	7.03
150	Blackwell	1990	12.1	0.110	9.15	5.24
150	Blackwell	1991	13.0	0.120	10.29	5.98
150	Blackwell	1992	9.5	0.068	7.41	4.49
150	Carthage	1989	14.0	0.102	11.05	6.22
150	Carthage	1990	13.2	0.124	10.04	5.72
150	Carthage	1991	16.4	0.137	13.03	7.50

150	Carthage	1992	9.3	0.068	7.37	4.27
150	Kanlow	1989	18.3	0.104	14.38	8.24
150	Kanlow	1990	14.7	0.096	11.41	6.54
150	Kanlow	1991	16.1	0.097	13.04	7.27
150	Kanlow	1992	9.9	0.068	7.82	4.59
150	KY1625	1989	13.5	0.119	10.41	5.66
150	KY1625	1990	10.3	0.093	7.69	4.28
150	KY1625	1991	11.8	0.103	9.26	5.24
150	KY1625	1992	7.7	0.059	5.96	3.34
Vetch	Blackwell	1989	6.0	0.056	4.51	2.46
Vetch	Blackwell	1990	6.9	0.077	5.03	2.71
Vetch	Blackwell	1991	12.1	0.118	9.47	5.35
Vetch	Blackwell	1992	7.0	0.047	5.46	3.22
Vetch	Carthage	1989	5.1	0.050	3.91	2.14
Vetch	Carthage	1990	8.0	0.091	5.89	3.12
Vetch	Carthage	1991	11.0	0.088	8.62	4.70
Vetch	Carthage	1992	5.5	0.059	4.29	2.34
Vetch	Kanlow	1989	6.2	0.050	4.85	2.66
Vetch	Kanlow	1990	8.4	0.069	6.41	3.49
Vetch	Kanlow	1991	13.5	0.098	10.68	6.13
Vetch	Kanlow	1992	7.1	0.055	5.63	3.25
Vetch	KY1625	1989	5.6	0.052	4.21	2.24
Vetch	KY1625	1990	8.1	0.086	5.92	3.12
Vetch	KY1625	1991	11.1	0.121	8.69	4.71
Vetch	KY1625	1992	6.2	0.060	4.83	2.70

Table 1.17 Nitrogen fertilization rate and cultivar effects on yields of cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass.

N	Cultivar	Year	TCEL	THC	TADL
			------------------Mg ha^{-1}	------------------	
0	Blackwell	1989	3.24	2.88	0.59
0	Blackwell	1990	2.73	2.58	0.44
0	Blackwell	1991	5.00	4.45	1.03
0	Blackwell	1992	2.45	2.17	0.60
0	Carthage	1989	2.83	2.77	0.53
0	Carthage	1990	2.23	2.24	0.36
0	Carthage	1991	3.38	3.14	0.64
0	Carthage	1992	1.67	1.74	0.37
0	Kanlow	1989	3.84	3.54	0.60
0	Kanlow	1990	2.75	2.63	0.40
0	Kanlow	1991	4.52	4.07	0.82
0	Kanlow	1992	2.22	2.17	0.50
0	KY1625	1989	2.91	2.97	0.45
0	KY1625	1990	2.29	2.39	0.36
0	KY1625	1991	3.80	3.82	0.71
0	KY1625	1992	2.06	2.22	0.49
75	Blackwell	1989	5.09	4.11	0.84
75	Blackwell	1990	3.95	3.48	0.67
75	Blackwell	1991	4.22	3.93	0.84
75	Blackwell	1992	3.13	2.82	0.70
75	Carthage	1989	4.72	4.04	0.80
75	Carthage	1990	3.75	3.47	0.63
75	Carthage	1991	4.69	4.36	0.89
75	Carthage	1992	2.52	2.54	0.53
75	Kanlow	1989	5.44	4.48	0.98
75	Kanlow	1990	3.27	3.03	0.52
75	Kanlow	1991	4.11	3.66	0.71
75	Kanlow	1992	2.45	2.25	0.55
75	KY1625	1989	4.00	3.76	0.71
75	KY1625	1990	2.95	3.06	0.44
75	KY1625	1991	4.10	4.18	0.79
75	KY1625	1992	2.20	2.29	0.51
150	Blackwell	1989	5.98	5.38	0.95
150	Blackwell	1990	4.35	3.91	0.74
150	Blackwell	1991	4.98	4.32	1.04
150	Blackwell	1992	3.41	2.92	0.75
150	Carthage	1989	5.09	4.83	1.00
150	Carthage	1990	4.80	4.32	0.82
150	Carthage	1991	6.29	5.53	1.23

150	Carthage	1992	3.26	3.11	0.66
150	Kanlow	1989	6.89	6.13	1.30
150	Kanlow	1990	5.47	4.87	0.88
150	Kanlow	1991	6.32	5.77	1.12
150	Kanlow	1992	3.50	3.23	0.72
150	KY1625	1989	4.72	4.76	0.81
150	KY1625	1990	3.58	3.41	0.58
150	KY1625	1991	4.32	4.02	0.88
150	KY1625	1992	2.59	2.61	0.49
Vetch	Blackwell	1989	2.04	2.05	0.37
Vetch	Blackwell	1990	2.28	2.32	0.33
Vetch	Blackwell	1991	4.46	4.12	0.89
Vetch	Blackwell	1992	2.42	2.24	0.56
Vetch	Carthage	1989	1.78	1.77	0.31
Vetch	Carthage	1990	2.64	2.77	0.40
Vetch	Carthage	1991	3.96	3.92	0.74
Vetch	Carthage	1992	1.83	1.95	0.33
Vetch	Kanlow	1989	2.25	2.19	0.35
Vetch	Kanlow	1990	2.93	2.91	0.41
Vetch	Kanlow	1991	5.37	4.55	0.97
Vetch	Kanlow	1992	2.49	2.38	0.51
Vetch	KY1625	1989	1.85	1.97	0.32
Vetch	KY1625	1990	2.62	2.81	0.38
Vetch	KY1625	1991	3.91	3.99	0.75
Vetch	KY1625	1992	2.07	2.13	0.41

Table 1.18 Nitrogen fertilization treatment and cultivar effects on concentrations of nitrogen, neutral detergent fiber, acid detergent fiber, cellulose, hemicellulose, and acid detergent lignin in switchgrass biomass.

N	Cultivar	Year	NDAVG	ADAVG	NAVG	CAVG	HCAVG	ADLAV
			--------	--------	%	--------	--------	--------
0	Blackwell	1989	77.1	44.6	0.64	36.6	32.5	6.7
0	Blackwell	1990	76.8	43.1	0.75	35.8	33.8	5.8
0	Blackwell	1991	80.4	46.3	0.76	38.3	34.0	7.9
0	Blackwell	1992	79.0	47.8	0.54	35.5	31.2	8.7
0	Carthage	1989	76.3	42.3	0.78	34.7	34.0	6.5
0	Carthage	1990	75.9	41.4	0.71	34.3	34.4	5.5
0	Carthage	1991	79.9	44.6	0.72	38.0	35.3	7.2
0	Carthage	1992	78.8	44.4	0.66	32.7	34.3	7.4
0	Kanlow	1989	78.6	43.9	0.63	37.4	34.7	5.8
0	Kanlow	1990	77.4	43.0	0.59	35.7	34.4	5.2
0	Kanlow	1991	79.5	44.6	0.66	38.7	34.9	7.1
0	Kanlow	1992	79.8	46.1	0.78	34.5	33.7	7.7
0	KY1625	1989	73.3	39.4	0.75	33.2	33.9	5.1
0	KY1625	1990	73.7	39.2	0.76	32.7	34.5	5.2
0	KY1625	1991	77.6	42.1	0.89	35.2	35.5	6.6
0	KY1625	1992	78.4	43.7	0.65	32.1	34.7	7.6
75	Blackwell	1989	76.3	45.5	0.76	38.0	30.8	6.3
75	Blackwell	1990	77.6	44.7	0.78	37.3	32.9	6.4
75	Blackwell	1991	79.2	46.1	0.90	37.0	34.4	7.4
75	Blackwell	1992	78.9	47.0	0.75	35.3	31.9	7.9
75	Carthage	1989	77.1	44.9	0.72	37.5	32.3	6.4
75	Carthage	1990	74.1	41.9	0.71	34.8	32.2	5.9
75	Carthage	1991	79.6	45.9	0.83	37.7	35.0	7.1
75	Carthage	1992	77.8	44.4	0.69	33.2	33.5	7.0
75	Kanlow	1989	78.1	46.2	0.51	38.7	31.8	6.9
75	Kanlow	1990	78.0	44.0	0.58	36.5	33.9	5.9
75	Kanlow	1991	81.2	45.5	0.51	39.6	35.3	6.9
75	Kanlow	1992	77.8	46.0	0.50	34.5	31.7	7.7
75	KY1625	1989	75.8	42.5	0.77	35.4	33.3	6.4
75	KY1625	1990	73.8	39.9	0.81	32.7	33.9	4.9
75	KY1625	1991	77.5	42.0	0.96	34.8	35.5	6.7
75	KY1625	1992	79.2	44.9	0.68	32.9	34.3	7.6
150	Blackwell	1989	76.9	43.5	0.83	36.9	33.4	5.9
150	Blackwell	1990	75.5	43.3	0.90	35.9	32.3	6.1
150	Blackwell	1991	79.2	46.1	0.93	38.4	33.1	8.0
150	Blackwell	1992	78.1	47.3	0.72	35.9	30.8	8.0
150	Carthage	1989	78.9	44.4	0.73	36.4	34.5	7.2
150	Carthage	1990	76.1	43.3	0.94	36.3	32.8	6.2

150	Carthage	1991	79.6	45.9	0.83	38.5	33.7	7.5
150	Carthage	1992	78.9	45.7	0.73	34.9	33.3	7.0
150	Kanlow	1989	78.5	44.9	0.57	37.5	33.5	7.1
150	Kanlow	1990	77.7	44.5	0.65	37.2	33.1	6.0
150	Kanlow	1991	81.2	45.5	0.60	39.5	35.7	7.0
150	Kanlow	1992	78.8	46.3	0.68	35.3	32.5	7.2
150	KY1625	1989	77.1	41.8	0.88	35.0	35.3	6.0
150	KY1625	1990	74.6	41.6	0.90	34.7	33.0	5.6
150	KY1625	1991	78.0	44.1	0.88	36.4	33.9	7.4
150	KY1625	1992	77.8	43.6	0.77	33.8	34.2	6.4
Vetch	Blackwell	1989	74.8	40.7	0.93	33.7	34.1	6.1
Vetch	Blackwell	1990	73.3	39.5	1.12	33.3	33.8	4.8
Vetch	Blackwell	1991	78.2	44.1	0.97	36.8	34.0	7.4
Vetch	Blackwell	1992	78.4	46.1	0.69	34.8	32.3	7.9
Vetch	Carthage	1989	75.8	41.4	0.98	34.5	34.4	6.0
Vetch	Carthage	1990	73.3	38.8	1.13	32.8	34.5	4.9
Vetch	Carthage	1991	78.8	43.2	0.80	36.4	35.6	6.8
Vetch	Carthage	1992	78.5	42.8	1.09	33.4	35.7	6.1
Vetch	Kanlow	1989	78.2	42.8	0.82	36.2	35.4	5.7
Vetch	Kanlow	1990	76.1	41.5	0.82	34.8	34.5	4.9
Vetch	Kanlow	1991	78.8	45.2	0.72	39.5	33.7	7.1
Vetch	Kanlow	1992	78.9	45.6	0.77	34.9	33.3	7.2
Vetch	KY1625	1989	74.7	39.6	0.92	32.9	35.0	5.6
Vetch	KY1625	1990	72.7	38.3	1.06	32.1	34.5	4.7
Vetch	KY1625	1991	78.5	42.5	1.10	35.1	36.0	6.8
Vetch	KY1625	1992	78.1	43.5	0.98	33.6	34.6	6.6

CHAPTER 2

PHENOLOGICAL PATTERNS OF BIOMASS COMPOSITION OF FOUR SWITCHGRASS CULTIVARS RECEIVING NITROGEN FERTILIZATION OR GROWN IN MIXTURES WITH BIGFLOWER VETCH

Nitrogen concentration decreased rapidly with advancing switchgrass maturity starting with the first sample collected shortly after shoot emergence in spring (Fig. 2.1). The rate of decline slowed after head emergence which would coincide approximately with the third sampling date.

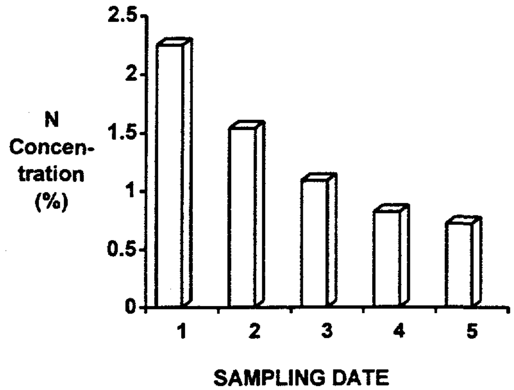

Fig. 2.1 Nitrogen concentration switchgrass biomass from five sampling dates during switchgrass shoot development.

The N fertilization treatment x sampling date interaction was significant ($P<0.01$) for N concentration (Tables 2.2 and 2.11). Nitrogen-fertilized switchgrass had much higher N concentrations on the first sampling dates than did the unfertilized control. This difference was absent by the last sampling date, possibly a result of dilution in the additional biomass produced in fertilized plots. Switchgrass from vetch mixture was similar to unfertilized switchgrass on the first sampling date but was a minimum of 0.2% higher in N than unfertilized pure switchgrass biomass on later dates. On the last two sampling dates, switchgrass receiving 75 or 150 kg ha^{-1} of N also tended to have lower N concentration than switchgrass from vetch plots. This pattern may be in response to delayed switchgrass shoot development due to vetch competition.

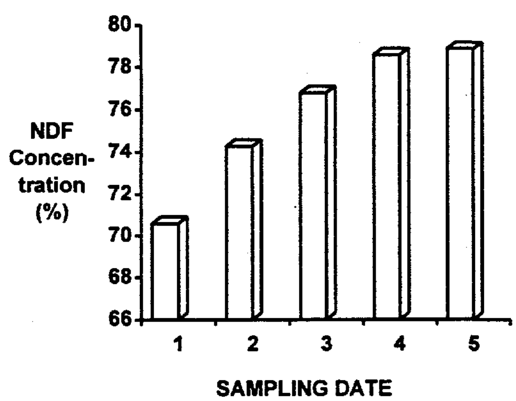

Fig. 2.2 NDF concentrations in switchgrass biomass from five sampling dates during switchgrass shoot development.

Neutral detergent fiber concentration increased from less than 71% just after growth initiation to nearly 79% on the last sampling date (Table 2.10 and Fig. 2.2). This increase was significant with each successive sampling except that no further increase occurred after the fourth date. Although the increase in NDF was statistically significant, it was small compared with the compositional changes with advancing maturity observed for cool season grasses (Collins and Casler 1990a; 1990b). The concentrations of NDF present in very young tissue was much higher than in cool season grass shoots of comparable age. Similar NDF concentrations might be expected in very mature tissue of cool season species. Research has shown that much greater proportions of the cross sectional area of C4 grasses is occupied by vascular tissue than is the case for cool season grasses (Akin and Burdick, 1975).

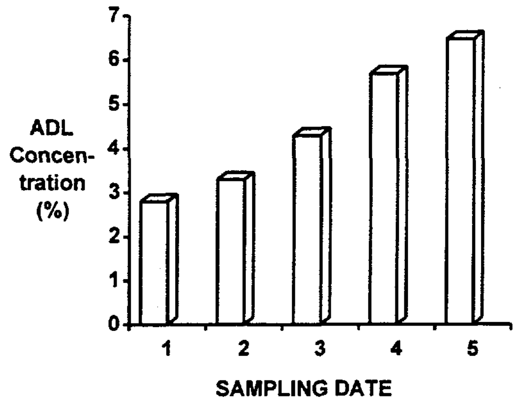

Fig. 2.3 Acid detergent lignin concentration switchgrass biomass from five sampling dates during switchgrass shoot development.

Phenological changes in ADF concentration were somewhat larger than for NDF (Table 2.10). However, ADL changed more across the sampling dates than any other fiber constituent, increasing more than two-fold (Table 2.10 and Fig. 2.3).

Significant sampling date by nitrogen fertilization treatment interaction effects were also observed for ADF, cellulose and ADL, but not for NDF concentrations (P=0.1814) (Table 2.2). Concentrations of ADF and cellulose in immature switchgrass from the vetch mixtures were higher than in fertilized switchgrass but the reverse was true for the most mature shoots.

Averaged over sampling dates and N fertilization treatments, KY1625 and Carthage had higher concentrations of N than Blackwell, and Kanlow was lowest in N (Table 2.4). This ranking is similar to that found in the harvested forage discussed earlier (Table 1.7). The absence of any cultivar by sampling date interaction for N concentration indicates that Kanlow's low N concentration was present across all maturity stages. This finding indicates that dilution may not adequately explain Kanlow's tendency toward lower N concentrations. At very early developmental stages, before any difference in yield, all cultivars should have the same N concentration.

Table 2.1 Treatments in a 4-year field experiment to evaluate switchgrass developmental changes in biomass composition.

Variables	Levels	Values
YR (Year)	4	1989, 1990, 1991, 1992
CV (Cultivar)	4	Blackwell, Carthage, Kanlow, KY1625
N (Nitrogen treatments)	4	0, 75, 150, Vetch
SD (Sampling dates)	5	1, 2, 3, 4, 5

Table 2.2 Analysis of variance for nitrogen fertilization, cultivar, year and sampling date effects on chemical composition of switchgrass biomass.

Source	DF	NIT	NDF	ADF	CEL	HCEL	ADL
			-----------------------------	Pr > F	-----------------------------		
N	3	0.0001	0.0226	0.0652	0.0038	0.5330	0.0813
CV	3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CV*N	9	0.0546	0.2591	0.1708	0.1309	0.6322	0.8269
YR	3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
YR*N	9	0.0001	0.0811	0.0050	0.5155	0.2370	0.0001
YR*CV	9	0.0004	0.0001	0.5460	0.0382	0.0018	0.0001
YR*CV*N	27	0.7669	0.3952	0.2191	0.8027	0.0760	0.1380
SD	4	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
N*SD	12	0.0001	0.1814	0.0001	0.0522	0.0003	0.0001
CV*SD	12	0.2476	0.7980	0.5430	0.6716	0.5039	0.0043
CV*N*SD	36	0.9268	0.9998	0.9103	0.8996	0.9292	0.9486

Table 2.3 Nitrogen fertilization regime main effects on switchgrass biomass composition averaged over cultivars, developmental stages and years.

Nitrogen fertilization treatment	NIT	NDF	ADF	CEL	HCEL	ADL
	%					
0	1.12 d†	75.8 ab	38.9 a	33.3 b	36.9 a	4.5 a
75	1.23 c	76.2 a	39.4 a	33.9 a	36.8 a	4.6 a
150	1.45 a	75.7 b	39.1 a	33.8 a	36.7 a	4.6 a
Vetch	1.34 b	75.7 b	38.9 a	33.4 ab	36.9 a	4.5 a

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 2.4 Cultivar main effects on switchgrass biomass composition averaged over nitrogen fertilization rates, developmental stages and years.

Cultivar	NIT	NDF	ADF	CEL	HCEL	ADL
	%					
Blackwell	1.28 b†	75.8 b	39.9 a	34.2 a	35.9 c	4.8 a
Carthage	1.35 a	75.6 bc	38.8 b	33.3 b	36.8 b	4.6 b
Kanlow	1.14 c	76.9 a	39.8 a	34.5 a	37.1 ab	4.4 bc
KY1625	1.36 a	75.1 c	37.7 c	32.4 c	37.4 a	4.3 c

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 2.5 Switchgrass cultivar and nitrogen fertilization rate effects on biomass chemical composition averaged over four years and five developmental stages each year.

Cultivar	Nitrogen fertilization treatment	NIT	NDF	ADF	CEL	HCEL	ADL
		-------------	-------------	--------------%	-------------	-------------	-------------
Blackwell	0	1.11	76.1	40.1	34.1	36.0	4.9
Blackwell	75	1.23	76.2	40.5	34.7	35.8	4.9
Blackwell	150	1.44	75.5	39.7	34.1	35.8	4.8
Blackwell	Vetch	1.33	75.3	39.4	33.7	35.9	4.7
Carthage	0	1.14	75.4	38.4	32.7	37.0	4.6
Carthage	75	1.30	76.1	39.5	34.0	36.6	4.6
Carthage	150	1.53	75.3	38.5	33.3	36.8	4.7
Carthage	Vetch	1.43	75.6	38.6	33.2	37.0	4.5
Kanlow	0	1.07	76.7	39.8	34.3	36.9	4.4
Kanlow	75	1.06	77.0	39.8	34.5	37.2	4.5
Kanlow	150	1.26	77.0	39.9	34.8	37.1	4.4
Kanlow	Vetch	1.17	76.9	39.8	34.5	37.1	4.4
KY1625	0	1.17	75.1	37.4	31.9	37.7	4.2
KY1625	75	1.31	75.3	37.7	32.4	37.6	4.5
KY1625	150	1.55	75.1	38.2	33.0	36.9	4.3
KY1625	Vetch	1.42	75.1	37.7	32.3	37.4	4.2

Table 2.6 Year main effects on switchgrass biomass chemical composition averaged over cultivars, nitrogen fertilization rate treatments, and five developmental stages per season.

Year	NIT	NDF	ADF	CEL	HCEL	ADL
	----------	----------	----------	%	----------	----------
1989	1.19 c†	73.5 c	38.6 c	33.5 b	34.9 d	4.3 c
1990	1.49 a	73.1 c	36.5 d	31.7 d	36.6 c	3.8 d
1991	1.34 b	79.7 a	41.3 a	36.9 a	38.3 a	4.6 b
1992	1.11 d	77.2 b	39.8 b	32.3 c	37.4 b	5.5 a

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 2.7 Year and nitrogen fertilization treatment interaction effects on switchgrass biomass chemical composition averaged over four cultivars and five developmental stages.

Year	Nitrogen fertilization treatment	NIT	NDF	ADF	CEL	ADL
		-------------	-------------	%	-------------	-------------
1989	0	1.00	72.9	37.8	32.9	4.0
1989	75	1.20	73.9	39.2	34.1	4.5
1989	150	1.43	73.4	38.6	33.7	4.4
1989	Vetch	1.13	73.6	38.7	33.3	4.4
1990	0	1.28	73.2	36.7	31.6	3.8
1990	75	1.36	73.3	36.9	31.9	3.9
1990	150	1.66	73.1	36.6	32.0	3.8
1990	Vetch	1.68	72.8	36.0	31.4	3.5
1991	0	1.24	79.6	41.1	36.4	4.5
1991	75	1.30	80.0	41.4	37.2	4.5
1991	150	1.44	79.6	41.3	37.0	4.7
1991	Vetch	1.38	79.4	41.5	36.9	4.7
1992	0	0.98	77.5	40.1	32.0	5.8
1992	75	1.05	77.4	40.1	32.4	5.6
1992	150	1.26	76.7	39.7	32.5	5.4
1992	Vetch	1.16	77.1	39.4	32.2	5.4

Table 2.8 Year and cultivar interaction effects on switchgrass biomass chemical composition averaged over nitrogen fertilization rate treatments and five developmental stages per season.

Year	Cultivar	NIT	NDF	ADF	CEL	ADL
		----------	----------	%	----------	----------
1989	Blackwell	1.17	73.4	39.6	34.2	4.5
1989	Carthage	1.28	73.4	38.3	33.19	4.4
1989	Kanlow	1.00	75.0	39.3	34.5	4.2
1989	KY1625	1.31	72.3	37.1	32.2	4.2
1990	Blackwell	1.55	73.0	37.4	32.7	4.0
1990	Carthage	1.55	72.7	36.3	31.4	4.0
1990	Kanlow	1.37	74.2	37.5	32.5	3.6
1990	KY1625	1.50	72.4	34.9	30.4	3.4
1991	Blackwell	1.33	79.7	42.1	37.0	4.9
1991	Carthage	1.42	79.1	40.8	36.6	4.8
1991	Kanlow	1.15	81.0	42.1	38.3	4.3
1991	KY1625	1.46	78.9	40.3	35.7	4.4
1992	Blackwell	1.06	77.1	40.6	32.8	6.0
1992	Carthage	1.14	77.3	39.6	32.1	5.3
1992	Kanlow	1.06	77.3	40.4	32.9	5.6
1992	KY1625	1.18	76.9	38.6	31.4	5.2

Table 2.9 Year, cultivar and nitrogen fertilization treatment interaction effects on switchgrass biomass chemical composition averaged over five developmental stages per season.

Year	Cultivar	Nitrogen fertilization treatment	NIT	NDF	ADF	CEL	ADL
			---------	---------	%	---------	---------
1989	Blackwell	0	1.02	73.2	39.3	33.8	4.4
1989	Blackwell	75	1.13	74.2	41.0	35.6	4.7
1989	Blackwell	150	1.37	72.8	39.0	34.1	4.3
1989	Blackwell	Vetch	1.17	72.9	38.9	33.4	4.4
1989	Carthage	0	1.02	72.2	37.4	32.4	4.1
1989	Carthage	75	1.31	73.7	38.8	33.7	4.4
1989	Carthage	150	1.59	73.1	38.3	33.3	4.4
1989	Carthage	Vetch	1.20	74.0	38.7	33.0	4.7
1989	Kanlow	0	0.89	74.2	38.2	33.7	3.8
1989	Kanlow	75	1.00	75.1	39.5	34.6	4.3
1989	Kanlow	150	1.18	75.5	39.7	34.8	4.5
1989	Kanlow	Vetch	0.93	75.1	39.9	34.7	4.4
1989	KY1625	0	1.07	71.9	36.4	31.8	3.7
1989	KY1625	75	1.35	72.5	37.3	32.4	4.4
1989	KY1625	150	1.57	72.4	37.6	32.5	4.2
1989	KY1625	Vetch	1.24	72.6	37.1	32.0	4.0
1990	Blackwell	0	1.34	73.3	37.7	32.8	4.2
1990	Blackwell	75	1.46	73.6	38.1	33.2	4.2
1990	Blackwell	150	1.73	72.8	37.0	32.4	4.0
1990	Blackwell	Vetch	1.69	72.5	36.8	32.3	3.8
1990	Carthage	0	1.31	72.5	36.4	31.0	4.0
1990	Carthage	75	1.44	73.6	36.8	31.9	4.1
1990	Carthage	150	1.72	72.8	36.4	31.8	4.0
1990	Carthage	Vetch	1.76	71.9	35.7	30.9	3.7
1990	Kanlow	0	1.18	74.5	38.0	32.5	3.6
1990	Kanlow	75	1.22	74.2	37.9	32.6	3.8
1990	Kanlow	150	1.50	74.3	37.7	33.0	3.7
1990	Kanlow	Vetch	1.56	74.0	36.6	32.1	3.2
1990	KY1625	0	1.28	72.6	34.9	30.1	3.5
1990	KY1625	75	1.32	72.0	34.7	30.2	3.5
1990	KY1625	150	1.68	72.5	35.4	30.8	3.5
1990	KY1625	Vetch	1.70	72.6	34.7	30.3	3.2
1991	Blackwell	0	1.20	80.6	42.5	37.1	4.9
1991	Blackwell	75	1.28	79.5	42.2	37.1	4.8
1991	Blackwell	150	1.43	79.5	42.2	37.1	5.1
1991	Blackwell	Vetch	1.42	79.2	41.3	36.7	4.8
1991	Carthage	0	1.30	78.6	40.2	35.8	4.7

1991	Carthage	75	1.34	80.1	41.8	37.4	4.8
1991	Carthage	150	1.58	78.5	40.1	36.3	4.9
1991	Carthage	Vetch	1.46	79.1	41.2	36.8	4.7
1991	Kanlow	0	1.13	80.9	41.7	37.7	4.3
1991	Kanlow	75	1.10	81.2	41.5	38.1	4.1
1991	Kanlow	150	1.18	81.2	42.4	38.7	4.4
1991	Kanlow	Vetch	1.17	80.7	42.7	38.5	4.6
1991	KY1625	0	1.33	78.5	39.8	35.1	4.2
1991	KY1625	75	1.49	79.4	40.1	36.1	4.4
1991	KY1625	150	1.57	79.1	40.5	36.0	4.6
1991	KY1625	Vetch	1.47	78.4	40.7	35.7	4.6
1992	Blackwell	0	0.89	77.3	40.9	32.8	6.1
1992	Blackwell	75	1.06	77.7	40.4	32.9	5.9
1992	Blackwell	150	1.24	76.7	40.4	32.8	5.8
1992	Blackwell	Vetch	1.06	76.7	40.5	32.7	6.0
1992	Carthage	0	0.92	78.1	39.6	31.4	5.6
1992	Carthage	75	1.12	77.1	40.7	33.0	5.0
1992	Carthage	150	1.24	77.1	39.4	32.0	5.4
1992	Carthage	Vetch	1.29	77.2	38.7	31.9	5.0
1992	Kanlow	0	1.09	77.1	41.3	33.3	5.9
1992	Kanlow	75	0.94	77.6	40.5	32.6	5.7
1992	Kanlow	150	1.19	76.9	39.7	32.8	5.2
1992	Kanlow	Vetch	1.04	77.7	40.1	32.9	5.4
1992	KY1625	0	1.02	77.4	38.4	30.6	5.4
1992	KY1625	75	1.08	77.2	38.7	31.0	5.5
1992	KY1625	150	1.36	76.3	39.2	32.5	5.1
1992	KY1625	Vetch	1.26	76.9	38.2	31.4	5.0

Table 2.10 Developmental stage main effects on switchgrass biomass chemical composition averaged over cultivars, nitrogen fertilization rate treatments and years.

Sampling date	NIT	NDF	ADF	CEL	HCEL	ADL
	------------------	------------------	------------------ %	------------------	------------------	------------------
1	2.25 a†	70.6 c	31.9 e	28.5 e	38.7 a	2.8 e
2	1.54 b	74.3 c	35.7 d	32.0 d	38.6 a	3.3 d
3	1.09 c	76.8 b	39.7 c	34.6 c	37.1 b	4.3 c
4	0.82 d	78.6 a	43.3 b	36.1 b	35.3 c	5.7 b
5	0.72 e	78.9 a	44.7 a	36.8 a	34.2 d	6.5 a

†Means in the same column followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 2.11 Developmental stage and nitrogen fertilization treatment interaction effects on switchgrass biomass chemical composition averaged over cultivars and years.

Nitrogen fertilization treatment	Sampling date	NIT	NDF	ADF	CEL	HCEL	ADL
		-----------------------------	-----------------------------	----------------------------- %-----------------------------	-----------------------------	-----------------------------	-----------------------------
0	1	1.98	70.2	32.0	28.3	38.2	2.9
0	2	1.29	74.3	35.7	31.7	38.6	3.3
0	3	0.97	77.3	39.3	34.2	38.0	4.2
0	4	0.72	78.3	43.0	35.8	35.3	5.6
0	5	0.66	78.9	44.5	36.4	34.4	6.6
75	1	2.32	70.4	31.9	28.7	38.4	2.7
75	2	1.47	74.7	35.5	31.9	39.2	3.3
75	3	0.99	77.3	40.0	34.9	37.3	4.5
75	4	0.70	79.4	44.2	36.7	35.2	5.9
75	5	0.64	79.0	45.3	37.4	33.7	6.7
150	1	2.60	70.6	31.0	28.2	39.6	2.7
150	2	1.87	73.5	35.2	31.9	38.4	3.2
150	3	1.20	76.6	40.0	35.1	36.5	4.4
150	4	0.83	78.6	43.7	36.4	34.9	5.9
150	5	0.73	79.3	45.3	37.4	34.0	6.7
Vetch	1	2.08	71.2	32.5	28.9	38.7	2.8
Vetch	2	1.54	74.6	36.4	32.4	38.1	3.5
Vetch	3	1.19	76.1	39.5	34.3	36.6	4.3
Vetch	4	1.01	78.3	42.4	35.5	35.9	5.5
Vetch	5	0.86	78.5	43.6	36.1	34.9	6.2

Table 2.12 Developmental stage and cultivar interaction effects on switchgrass biomass chemical composition averaged over nitrogen fertilization rate treatments and four years.

Cultivar	Sampling date	NIT	NDF	ADF	CEL	HCEL	ADL
		---	---	---	%	---	---
Blackwell	1	2.25	70.6	32.1	28.8	38.6	2.8
Blackwell	2	1.53	74.3	36.8	32.9	37.5	3.6
Blackwell	3	1.06	76.3	40.5	35.1	35.8	4.6
Blackwell	4	0.78	79.0	44.5	36.8	34.5	6.3
Blackwell	5	0.78	78.6	45.6	37.3	33.0	6.9
Carthage	1	2.36	70.5	32.0	28.4	38.6	2.8
Carthage	2	1.61	73.9	35.2	31.5	38.7	3.5
Carthage	3	1.14	76.6	39.3	34.3	37.2	4.4
Carthage	4	0.89	78.2	43.0	35.8	35.2	5.8
Carthage	5	0.74	78.8	44.3	36.4	34.5	6.6
Kanlow	1	2.08	71.3	32.6	29.4	38.7	2.7
Kanlow	2	1.38	75.1	36.3	32.5	38.8	3.2
Kanlow	3	0.97	77.8	40.4	35.5	37.5	4.2
Kanlow	4	0.70	79.8	44.0	37.0	35.8	5.5
Kanlow	5	0.58	80.4	45.9	38.2	34.5	6.5
KY1625	1	2.30	69.9	30.9	27.5	39.1	2.8
KY1625	2	1.66	73.7	34.4	30.9	39.3	3.1
KY1625	3	1.18	76.6	38.6	33.6	37.9	4.1
KY1625	4	0.88	77.6	41.8	34.8	35.8	5.4
KY1625	5	0.79	77.9	43.0	35.2	34.9	6.1

Table 2.13 Developmental stage, cultivar and nitrogen fertilization treatment interaction effects on switchgrass biomass chemical composition averaged over four years.

Cultivar	Nitrogen fertilization treatment	Sampling date	NIT	NDF	ADF	CEL	ADL
			----------	----------	%	----------	----------
Blackwell	0	1	1.99	70.2	31.7	28.0	3.0
Blackwell	0	2	1.24	74.6	36.9	32.5	3.5
Blackwell	0	3	0.99	77.2	40.8	35.5	4.6
Blackwell	0	4	0.68	79.0	44.8	37.1	6.2
Blackwell	0	5	0.65	79.5	46.3	37.6	7.2
Blackwell	75	1	2.29	70.8	32.5	29.3	2.8
Blackwell	75	2	1.46	75.4	37.5	33.7	3.6
Blackwell	75	3	0.97	76.5	40.5	35.0	4.9
Blackwell	75	4	0.68	80.0	45.6	37.6	6.5
Blackwell	75	5	0.75	78.4	46.3	37.9	6.9
Blackwell	150	1	2.57	70.5	31.0	28.2	2.7
Blackwell	150	2	1.90	73.2	35.8	32.3	3.4
Blackwell	150	3	1.16	76.1	40.5	35.2	4.6
Blackwell	150	4	0.77	78.7	44.8	36.9	6.4
Blackwell	150	5	0.81	78.8	46.2	37.9	7.0
Blackwell	Vetch	1	2.13	71.0	33.1	29.6	2.9
Blackwell	Vetch	2	1.51	74.1	37.2	33.1	3.7
Blackwell	Vetch	3	1.11	75.5	40.2	34.6	4.5
Blackwell	Vetch	4	0.99	78.3	42.9	35.6	5.9
Blackwell	Vetch	5	0.91	77.7	43.7	35.8	6.7
Carthage	0	1	1.93	70.5	32.0	28.2	2.9
Carthage	0	2	1.31	74.3	35.5	31.3	3.6
Carthage	0	3	0.94	76.8	38.9	33.6	4.3
Carthage	0	4	0.82	76.8	42.1	34.9	5.6
Carthage	0	5	0.67	78.4	43.6	35.3	6.6
Carthage	75	1	2.55	70.8	33.3	29.8	2.4
Carthage	75	2	1.54	74.0	34.8	31.3	3.4
Carthage	75	3	1.02	77.1	40.1	34.9	4.7
Carthage	75	4	0.73	79.5	44.1	36.8	5.8
Carthage	75	5	0.66	79.2	45.3	37.2	6.6
Carthage	150	1	2.78	69.8	30.3	27.4	2.8
Carthage	150	2	1.97	73.1	34.7	31.4	3.4
Carthage	150	3	1.28	76.5	39.5	34.8	4.4
Carthage	150	4	0.91	78.2	43.1	35.9	5.9
Carthage	150	5	0.72	79.2	45.2	37.1	7.0
Carthage	Vetch	1	2.18	70.9	32.2	28.3	2.9
Carthage	Vetch	2	1.61	74.3	36.0	32.1	3.6

Carthage	Vetch	3	1.34	75.9	38.9	33.8	4.3
Carthage	Vetch	4	1.10	78.2	42.7	35.6	5.8
Carthage	Vetch	5	0.91	78.5	43.1	36.0	6.1
Kanlow	0	1	1.97	70.2	33.7	30.1	2.9
Kanlow	0	2	1.20	74.6	35.9	32.0	3.1
Kanlow	0	3	0.91	77.9	39.5	34.6	4.0
Kanlow	0	4	0.65	79.7	43.7	36.6	5.4
Kanlow	0	5	0.64	80.9	46.2	38.2	6.6
Kanlow	75	1	2.07	70.9	32.4	29.1	2.7
Kanlow	75	2	1.30	75.4	35.9	32.0	3.1
Kanlow	75	3	0.88	78.7	40.5	35.5	4.2
Kanlow	75	4	0.59	80.5	44.5	37.3	5.6
Kanlow	75	5	0.46	79.7	45.8	38.5	6.8
Kanlow	150	1	2.40	71.9	31.2	28.7	2.4
Kanlow	150	2	1.63	74.8	36.2	33.0	3.1
Kanlow	150	3	1.03	77.7	40.9	36.3	4.3
Kanlow	150	4	0.70	79.9	44.7	37.6	5.8
Kanlow	150	5	0.56	80.6	46.2	38.5	6.6
Kanlow	Vetch	1	1.86	72.1	32.8	29.7	2.7
Kanlow	Vetch	2	1.40	75.6	37.2	33.2	3.6
Kanlow	Vetch	3	1.06	77.1	40.7	35.4	4.4
Kanlow	Vetch	4	0.87	79.2	43.0	36.6	5.2
Kanlow	Vetch	5	0.68	80.5	45.3	37.7	6.2
KY1625	0	1	2.02	70.0	30.5	26.7	2.7
KY1625	0	2	1.43	73.6	34.6	31.1	3.1
KY1625	0	3	1.03	77.3	38.1	33.0	3.9
KY1625	0	4	0.73	77.8	41.6	34.4	5.4
KY1625	0	5	0.66	76.8	42.1	34.4	6.0
KY1625	75	1	2.37	68.9	29.5	26.5	2.7
KY1625	75	2	1.59	74.0	33.8	30.6	3.1
KY1625	75	3	1.09	77.1	38.9	34.1	4.3
KY1625	75	4	0.80	77.7	42.6	35.4	5.8
KY1625	75	5	0.70	78.5	43.7	35.6	6.5
KY1625	150	1	2.65	70.3	31.7	28.6	2.9
KY1625	150	2	1.99	73.0	34.0	30.8	3.0
KY1625	150	3	1.34	76.0	39.3	34.3	4.1
KY1625	150	4	0.93	77.4	42.1	35.2	5.5
KY1625	150	5	0.82	78.6	43.7	36.0	6.1
KY1625	Vetch	1	2.16	70.6	31.7	28.0	2.9
KY1625	Vetch	2	1.64	74.2	35.3	31.4	3.2
KY1625	Vetch	3	1.26	75.8	38.2	33.2	4.0
KY1625	Vetch	4	1.08	77.4	40.8	34.1	5.0
KY1625	Vetch	5	0.96	77.6	42.5	34.9	5.9

CHAPTER 3

NITROGEN PRODUCTION BY BIGFLOWER VETCH IN SWITCHGRASS MIXTURES AND PARTITIONING OF NITROGEN IN ABOVE AND BELOW-GROUND TISSUES AT VETCH ANTHESIS

Sampling for assessment of N contribution by vetch was done each year when the winter annual legume reached anthesis. The dates for sampling were May 31, May 9 and May 20 in 1989, 1990 and 1992, respectively. Yields of vetch and switchgrass shoot and root were estimated from random quadrat samples taken outside the yield measurement area for biomass yield determination, which occurred much later. Switchgrass had just initiated its growth when these samples were taken and thus switchgrass shoot yields were very low compared with those of switchgrass roots or vetch shoots.

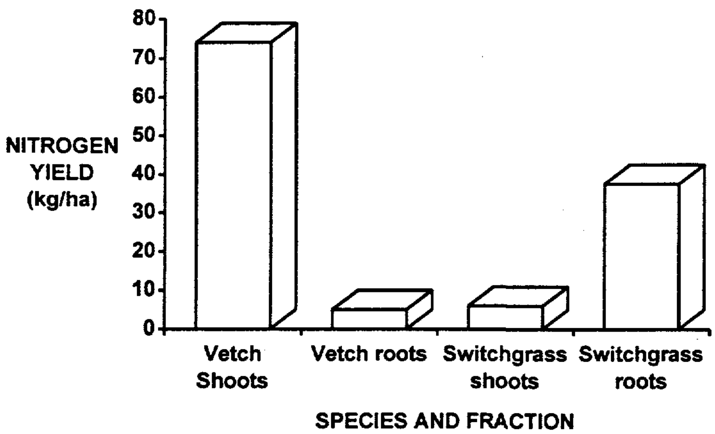

Fig. 3.1 Nitrogen yields of switchgrass and switchgrass-vetch mixtures.

Year effects on switchgrass and vetch root and shoot yields in samples collected when the vetch crop reached anthesis were highly significant but no cultivar main effects were detected (Table 3.1). Significant cultivar by year interaction effects were found for switchgrass shoot weights probably because Blackwell and KY1625 yields in 1989 were approximately twice that of Kanlow and Carthage. Much more switchgrass shoot growth was present when samples were taken in that year. Switchgrass shoot weights varied widely across years, from 755 kg ha^{-1} in 1989 to 141 kg ha^{-1} in 1990 (Table 3.5).

Switchgrass consistently had much more DM in its root and stubble fraction, from 4 to 8 Mg ha^{-1}, than in the shoot fraction when these samples were collected (Table 3.5). The opposite was true for vetch, most of the biomass present was in the shoot fraction. Vetch roots contributed very little DM to the total for that species (Table 3.4 and 3.5). Shoots comprised more than 90% of vetch biomass except in 1989 when 13% of vetch biomass was in the root and stubble fraction.

Shoots of both species had higher N concentration than their respective root tissues (Tables 3.4 and 3.5). Of the two root fractions, vetch had much higher N concentrations. Vetch root samples contained any attached nodules. Switchgrass root tissue had N concentrations similar to those found in the most mature switchgrass shoot biomass.

In spite of its very low N concentrations, the switchgrass root fraction contained similar quantities of N as the vetch shoot fraction (Tables 3.4 and 3.5 and Fig. 3.1). Vetch roots never contributed more than 8 kg ha^{-1} of N but shoots provided from 67 to 82 kg N ha^{-1}. Not all of the N contained in legume biomass is the result of symbiotic fixation. Based on earlier research one-half to two-thirds of the total N content of perennial forage legumes results from symbiotic fixation, the remainder being derived from soil-N pools (Heichel et al., 1984).

Under the extensive type of management system imposed in this experiment, which avoided inputs such as herbicides or mowing for control of vetch shoot growth, the use of vetch-switchgrass mixtures is clearly not viable as a biomass production system. Although vetch grew well and contained quantities of N equivalent to the fertilization rates generally found to maximize switchgrass yields, the switchgrass component of the mixture was negatively affected. Further research is needed to determine whether systems that incorporated a timely mowing or herbicide application to stop further vetch growth just before switchgrass initiates its own growth could avoid the detrimental effects seen in this study. In an earlier field study, Collins (1992) found that maize (Zea mays L.) planted using minimum tillage techniques following 'Dart' alfalfa produced grain yields of 9.2 Mg ha^{-1} compared with yields of 5.0, 6.8, 8.3 and 8.2 Mg ha^{-1} for maize receiving 0, 75, 150 or 225 kg ha^{-1} of N, respectively. Termination of legume growth by herbicide application about one week prior to maize planting was very effective in avoiding any shading of maize seedlings. In one year of that study, under drought conditions, maize emergence was delayed in legume stubble plantings. An ineffective nodulating alfalfa genotype included to quantify the contribution of fixation to the system resulted in maize grain yields of only 5.4 Mg ha^{-1}.

Table 3.1 Significance of year and cultivar effects on switchgrass and bigflower vetch shoot and root dry matter biomass yields at vetch anthesis.

Source of variation	df	Switchgrass shoot yield	Switchgrass root yield	Vetch shoot yield	Vetch root yield
		--- Pr > F ---			
YR	2	0.0001	0.0005	0.0315	0.0001
YR*CV	6	0.0549	0.6178	0.3072	0.0732
CV	3	0.3602	0.3965	0.4424	0.3259

Table 3.2 Significance of year and cultivar effects on switchgrass and bigflower vetch shoot and root nitrogen concentrations at vetch anthesis.

Source of variation	df	Switchgrass shoot N	Switchgrass root N	Vetch shoot N	Vetch root N
		--- Pr > F ---			
YR	2	0.0001	0.5600	0.0002	0.0003
YR*CV	6	0.4731	0.5956	0.2084	0.3436
CV	3	0.1505	0.3210	0.0406	0.3677

Table 3.3 Significance of year and cultivar effects on switchgrass and bigflower vetch shoot and root nitrogen yields at vetch anthesis.

Source of variation	Units	YR	YR*CV	CV
df	#	2	6	3
Switchgrass shoot N yield	Pr > F	0.0001	0.0249	0.3217
Switchgrass shoot N yield	Pr > F	0.0012	0.7003	0.4696
Vetch shoot N yield	Pr > F	0.6709	0.4336	0.9215
Vetch root N yield	Pr > F	0.0058	0.2087	0.3558
Vetch total N yield	Pr > F	0.5221	0.4390	0.9230
Switchgrass N yield	Pr > F	0.0052	0.5384	0.4177

Table 3.4 Cultivar effects on yield and nitrogen concentrations in switchgrass and bigflower vetch shoot and root tissue at vetch anthesis (mid to late May) in 3 years.

Variable	Units	Blackwell	Carthage	Kanlow	KY1625
Switchgrass shoot yield	kg ha^{-1}	493 †	301	283	429
Switchgrass root yield	kg ha^{-1}	6890	5709	4483	4997
Vetch shoot yield	kg ha^{-1}	3105	2440	2280	2652
Vetch root yield	kg ha^{-1}	279	240	341	270
Switchgrass shoot N	%	1.76	1.81	1.52	1.88
Switchgrass root N	%	0.70	0.68	0.59	0.69
Vetch shoot N	%	2.54	2.93	3.00	2.98
Vetch root N	%	2.07	1.81	1.85	1.93
Switchgrass shoot N yield	kg ha^{-1}	7.7	5.0	3.8	7.7
Switchgrass root N yield	kg ha^{-1}	47.6	38.7	28.0	35.7
Vetch shoot N yield	kg ha^{-1}	78.1	73.3	68.6	76.0
Vetch root N yield	kg ha^{-1}	5.5	4.3	5.7	4.8
Vetch total N yield	kg ha^{-1}	83.6	77.7	74.3	80.7
Switchgrass total N yield	kg ha^{-1}	55.3	43.7	31.8	43.2

† No significant ($P < 0.05$) cultivar effect was found for any variable.

Table 3.5 Year effects on yield and nitrogen concentrations in switchgrass and bigflower vetch shoot and root tissue at vetch anthesis in 3 years.

Variable	Units	1989	1990	1992
Switchgrass shoot yield	kg ha^{-1}	755a†	141 b	233 b
Switchgrass root yield	kg ha^{-1}	3789 b	8482 a	4286 b
Vetch shoot yield	kg ha^{-1}	3339 a	1872 b	2643 ab
Vetch root yield	%	501 a	123 b	223 b
Switchgrass shoot N	%	1.43 b	2.14 a	1.65 b
Switchgrass root N	%	0.67 a	0.63 a	0.70 a
Vetch shoot N	%	2.47 b	3.41 a	2.71 b
Vetch root N	%	1.48 b	2.20 a	2.06 a
Switchgrass shoot N yield	kg ha^{-1}	10.8 a	3.2 b	3.9 b
Switchgrass root N yield	kg ha^{-1}	25.2 b	58.1 a	29.3 b
Vetch shoot N yield	kg ha^{-1}	81.8 a	66.9 a	73.3a
Vetch root N yield	kg ha^{-1}	7.8 a	2.9 b	4.6 ab
Vetch total N yield	kg ha^{-1}	89.6 a	69.8 a	77.8 a
Switchgrass total N yield	kg ha^{-1}	36.0 b	61.2 a	33.2 b

†Means in the same row followed by the same letter are not significantly different at the 0.05 level by Tukey's test.

Table 3.6 Year by cultivar interaction effects on shoot and root yields of switchgrass and bigflower vetch at vetch anthesis in 3 years.

Year	Cultivar	Switchgrass shoot yield	Switchgrass root yield	Vetch shoot yield	Vetch root yield
		---------- kg ha^{-1} ----------			
1989	Blackwell	1066	5236	3962	452
1989	Carthage	472	2624	2192	316
1989	Kanlow	470	3121	3013	782
1989	KY1625	1012	4174	4190	456
1990	Blackwell	179	10258	1835	166
1990	Carthage	118	7964	2037	153
1990	Kanlow	122	7833	2239	80
1990	KY1625	145	7874	1375	93
1992	Blackwell	233	5174	3509	219
1992	Carthage	312	6537	3089	251
1992	Kanlow	258	2493	1585	161
1992	KY1625	129	2942	2389	262

Table 3.7 Year by cultivar interaction effects on shoot and root nitrogen concentrations of switchgrass and bigflower vetch at vetch anthesis in 3 years.

Year	Cultivar	Switchgrass shoot N	Switchgrass root N	Vetch shoot N	Vetch root N
		----------	---------- %	----------	----------
1989	Blackwell	1.41	0.67	2.32	1.43
1989	Carthage	1.61	0.67	2.38	1.49
1989	Kanlow	1.07	0.67	2.65	1.54
1989	KY1625	1.63	0.67	2.52	1.48
1990	Blackwell	2.19	0.61	3.39	2.24
1990	Carthage	2.03	0.65	3.45	2.23
1990	Kanlow	2.00	0.59	3.54	2.16
1990	KY1625	2.33	0.69	3.25	2.19
1992	Blackwell	1.69	0.82	1.90	2.56
1992	Carthage	1.78	0.72	2.95	1.73
1992	Kanlow	1.47	0.53	2.81	1.85
1992	KY1625	1.67	0.71	3.17	2.13

Table 3.8 Year by cultivar interaction effects on shoot and root nitrogen yields of switchgrass and bigflower vetch at vetch anthesis in 3 years.

Year	Cultivar	Switchgrass shoot N yield	Switchgrass root N yield	Vetch shoot N yield	Vetch root N yield
		----------	---------- $kg\ ha^{-1}$	----------	----------
1989	Blackwell	14.6	34.8	91.2	6.9
1989	Carthage	7.2	17.4	51.4	5.0
1989	Kanlow	5.1	20.8	78.8	12.3
1989	KY1625	16.5	27.8	105.7	6.9
1990	Blackwell	4.2	69.3	63.7	3.9
1990	Carthage	2.4	53.8	74.5	3.6
1990	Kanlow	2.6	50.0	82.1	1.8
1990	KY1625	4.2	59.1	47.2	2.2
1992	Blackwell	4.2	38.8	79.4	5.8
1992	Carthage	5.5	44.8	94.1	4.4
1992	Kanlow	3.7	13.3	44.7	3.0
1992	KY1625	2.4	20.0	75.0	5.1

Table 3.9 Year by cultivar interaction effects on total nitrogen yields of switchgrass and bigflower vetch at vetch anthesis in 3 years.

Year	Cultivar	Vetch total N yield	Switchgrass N yield
		---------- kg ha^{-1} ----------	
1989	Blackwell	98.0	49.4
1989	Carthage	56.4	24.7
1989	Kanlow	91.1	25.9
1989	KY1625	112.5	44.2
1990	Blackwell	68.6	73.5
1990	Carthage	78.1	56.2
1990	Kanlow	83.9	52.5
1990	KY1625	49.4	62.6
1992	Blackwell	85.1	42.9
1992	Carthage	98.4	50.3
1992	Kanlow	47.7	17.0
1992	KY1625	80.1	22.7

CHAPTER 4

BIOMASS YIELD AND COMPOSITION OF TALL FESCUE RECEIVING NITROGEN FERTILIZATION OR GROWN IN MIXTURES WITH ALFALFA OR BIRDSFOOT TREFOIL

Dry Matter Yields

Botanical composition information was used along with total DM yield (referred to as sward yield) to calculate separate yields for grass, legume, and weed components). In order to allow more ready assessment of the non-legume contribution to the yields, grass yields include yield contributions of any weed species present. Legume yields reported are those of the seeded legume species.

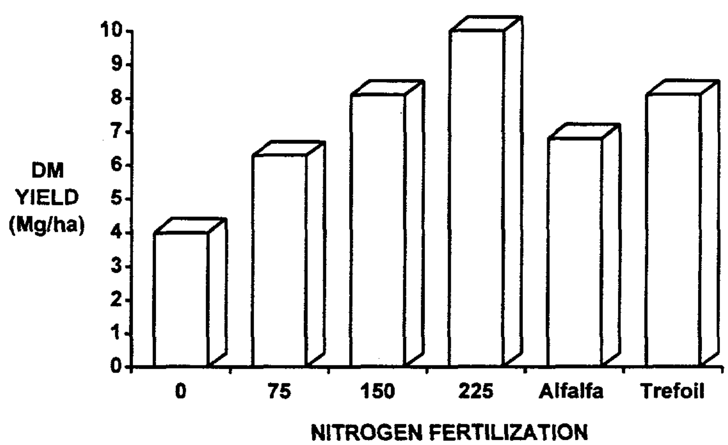

Fig. 4.1 Dry matter yields of tall fescue and tall fescue-legume mixtures.

Harvest management regime had significant effects on sward, grass, and weed yields but not on legume DM yields (Tables 4.2 and 4.3). Sward yields were 1.4 Mg ha^{-1} greater under the late harvest regime. Weed yields made up more than one-half of the additional yield from later harvesting, however, suggesting that greater management inputs such as herbicides might be necessary to avoid a shift in botanical composition. Biomass from nonseeded species made up about one-fifth of the total production in the late regime compared with 14% for the early regime.

Sward yields were nearly identical for the two tall fescue cultivars but more of the biomass produced by Johnstone consisted of weedy species (Tables 4.2 and 4.4). In addition to being a Lolium-Festuca amphiploid (Buckner et al., 1985), Johnstone does not contain the fungal endophyte (Acremonium coenophialum Morgan-Jones Gams) present in KY31 and most other tall fescue cultivars (Collins, 1991). Tall fescue containing the endophyte produces high concentrations of several alkaloids (Bush et al., 1976) that have significant physiological activity on ruminants consuming the grass. These alkaloids catalyze thiaminase activity leading to the breakdown of thiamine, an essential growth factor for many microorganisms and for most vertebrates. Ergot alkaloids present in very low concentrations also may exert their effects directly on satiety centers in the brain. Considering the range of documented effects of these alkaloids on biological systems, their presence and concentrations should be considered in assessing the value of tall fescue for biomass energy conversion.

Sward yields of tall fescue were very responsive to increasing N fertilization rate (Table 4.5 and Fig. 4.1). Although the tall fescue and switchgrass experiments are not comparable statistically, it is clear that tall fescue, a cool-season species, does not approach the yields possible with switchgrass in this environment. The difference appears to be that the yields possible with switchgrass without fertilization are about 4 Mg ha^{-1} higher than for tall fescue. In fact, the efficiency of utilization of added N by tall fescue was comparable to that of switchgrass. The first 75 kg ha^{-1} increment of N added produced 31 kg DM kg^{-1} N and the last 75 kg increment produced 25 kg DM kg^{-1} N (Table 4.5). The percentage of total biomass that was from nonseeded species decreased as N fertilization rate was increased due not to a reduction in weed yields but to an increase in grass yields (Table 4.5). The impact of N fertilization treatment on weed yields and weed percentage in the total biomass was most apparent for the late harvest regime (Table 4.7). Under the early harvest regime, weed percentage was nearly constant at 10-12% of the total biomass, regardless of N fertilization treatment whereas weed percentage varied from 14 to 29%, being highest in unfertilized plots, under the late harvest regime.

Year-to-year differences in sward, grass, legume and weed yields were highly significant but much smaller than those reported earlier for switchgrass (Table 4.8). Year variation in yield was not closely associated with annual precipitation (Appendix 2) since the highest mean yields came in 1992, the year with the lowest total precipitation. That year was characterized by higher precipitation amounts during July, 232 mm, than in any other year of the study. July 1993 was dry, receiving only 81 mm of precipitation, and sward yields were low in that year. Legume yields fluctuated widely over the four years of the study (Tables 4.2 and 4.11). Yields of birdsfoot trefoil were more consistent than those of alfalfa which produced less than 1 Mg ha^{-1} in 1990 and nearly 3 Mg ha^{-1} in 1992.

Year-to-year fluctuations in total biomass yield from tall fescue were much smaller, 9.6 to 10.5 Mg ha^{-1}, than for switchgrass. The distribution of total yield over a larger number of harvests for tall fescue than for switchgrass may be responsible. Tall fescue grows more slowly under the dry, hot mid-summer period but begins growth earlier in spring and continues to grow into November in fall. With such a long growing season, tall fescue would require somewhat less feedstock stockpiling than would be necessary for a species harvested only once each year.

The compatibility of legumes with tall fescue is reflected in the high yields produced by legume mixtures, especially those including birdsfoot trefoil. Sward yields of mixtures of tall fescue with that species were similar to those from pure grass stands receiving 150 kg ha^{-1} of N annually. At current prices for N fertilizer, 150 kg ha^{-1} of N would cost about \$76 ha^{-1} per year.

Constituent Yields

Harvest management regime effects on N yields were not significant but effects on NDF and other fiber constituents were similar to those for DM yield (Tables 4.13 and 4.15. Tall fescue cultivar effects on N and fiber yields were not significant. Fiber yields when 225 kg ha^{-1} of N were applied, 6.4 Mg ha^{-1} were about two-thirds as much as yields harvested from switchgrass with 150 kg ha^{-1} of N applied, 10.0 Mg ha^{-1}.

Total removal of N in the harvested biomass increased three fold when 225 kg ha^{-1} of N fertilizer was applied (Table 4.19). Application of 225 kg ha^{-1} of N resulted in biomass that contained 112 kg ha^{-1} more N than unfertilized plots, indicating that approximately one-half of the applied N was recovered in the harvested biomass.

Constituent Concentrations

Much lower concentrations of NDF in tall fescue biomass were partially responsible for the lower fiber yields of that species compared with switchgrass (Table 4.20). Concentrations of NDF and ADF were significant higher in biomass harvested under the late regime, however, the difference was small and late harvested tall fescue averaged only 64% NDF compared with values near 80% for switchgrass. Tall fescue had N concentrations averaging more than twice those of switchgrass. Increasing N fertilization rate increased biomass N concentration significantly but the fertilization effect was small compared with the effect of legume mixtures. Alfalfa mixtures with tall fescue averaged 1.84% N, equal to the concentration in pure grass receiving 150 kg ha^{-1} of N. Grass mixtures with birdsfoot trefoil had 2.16% N, and were also significant lower in NDF than the biomass harvested from any other fertilization treatment.

Table 4.1 Description of variables in a 4-year field experiment to evaluate tall fescue cultivar, N fertilization regime, harvest management, and legume mixture effects on biomass production and composition.

Class	Levels	Values
R	4	1, 2, 3, 4
YR	4	1990, 1991, 1992, 1993
MGT	2	Late, Early
GR	2	Johnstone, KY31
NT	6	0, 75, 150, 225, Alfalfa, Trefoil

Table 4.2 Analysis of variance of tall fescue cultivar, N fertilization regime, harvest management, and legume mixture effects on biomass yield over a 4-year period (Sward yields include grass, legume and weed yields).

Source	DF	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
		Pr > F				
MGT	1	0.0059	0.0029	0.6562	0.0160	0.0292
GR	1	0.2398	0.3900	0.3806	0.0003	0.0001
NT	5	0.0001	0.0001	0.0001	0.0009	0.0001
GR*NT	5	0.9806	0.6276	0.0342	0.0090	0.0530
MGT*GR	1	0.7327	0.9104	0.5169	0.7668	0.3951
MGT*NT	5	0.1511	0.1284	0.3848	0.0052	0.0035
MGT*GR*NT	5	0.6974	0.4024	0.3106	0.5492	0.7079
YR	2	0.0001	0.0051	0.0001	0.0001	0.0001
YR*MGT	2	0.0001	0.0001	0.2218	0.0001	0.0001
YR*GR	2	0.8055	0.9729	0.7245	0.0120	0.0044
YR*NT	10	0.0001	0.0273	0.0001	0.0001	0.0001
YR*GR*NT	10	0.4469	0.1917	0.5583	0.0397	0.0452
YR*MGT*GR	2	0.4149	0.3879	0.6128	0.3030	0.2467
YR*MGT*NT	10	0.0001	0.0659	0.0001	0.0045	0.0872

Table 4.3 Harvest management main effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Harvest management	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
	--------------------------Mg ha^{-1}			----------------------	----%---
Late	7.93	7.07	0.86	1.62	21.2
Early	6.51	5.68	0.82	0.81	14.0

Table 4.4 Grass cultivar main effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Grass	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
	--------------------------Mg ha^{-1}			----------------------	----%---
Johnstone	7.12	6.32	0.79	1.33	19.2
KY31	7.32	6.43	0.89	1.11	16.0

Table 4.5 Nitrogen treatment main effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Nitrogen treatment	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
	---------------------------Mg ha^{-1}			-------------------------	----%---
0	3.97 d	3.97 e	0.00	1.10 b	27.5 a
75	6.29 c	6.30 c	0.00	1.08 b	16.4 bc
150	8.14 b	8.13 b	0.00	1.07 b	12.6 c
225	9.98 a	9.98 a	0.00	1.35 a	13.3 c
Alfalfa	6.76 c	4.77 d	1.99 b	1.31 ab	18.6 b
Trefoil	8.12 b	5.11 d	3.05 a	1.40 ab	17.0 bc

Table 4.6 Grass cultivar and nitrogen fertilization treatment interaction effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Grass	Nitrogen treatment	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
		---------------------Mg ha^{-1}			------------------	----%---
Johnstone	0	3.84	3.85	0.00	1.12	28.2
Johnstone	75	6.23	6.23	0.00	1.19	18.2
Johnstone	150	8.03	8.02	0.00	1.09	13.1
Johnstone	225	9.92	9.92	0.00	1.63	16.1
Johnstone	Alfalfa	6.75	4.59	2.16	1.29	18.5
Johnstone	Trefoil	7.93	5.32	2.59	1.65	20.4
KY31	0	4.10	4.09	0.00	1.08	26.3
KY31	75	6.36	6.36	0.00	0.97	14.5
KY31	150	8.25	8.25	0.00	1.05	12.1
KY31	225	10.04	10.04	0.00	1.08	10.6
KY31	Alfalfa	6.77	4.94	1.81	1.33	18.8
KY31	Trefoil	8.42	4.91	3.51	1.15	13.5

Table 4.7 Harvest management and nitrogen fertilization treatment interaction effects on total biomass yields and yields of grass and legume, and weed yield and percentage in tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Harvest management	Nitrogen treatment	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
		---Mg ha^{-1}---				---%---
Late	0	4.79	4.79	0.00	1.40	29.3
Late	75	7.11	7.11	0.00	1.54	21.0
Late	150	8.40	8.40	0.00	1.25	14.0
Late	225	10.75	10.80	0.00	1.80	16.5
Late	Alfalfa	7.30	5.47	1.83	1.83	24.4
Late	Trefoil	9.23	5.91	3.32	1.91	21.8
Early	0	3.15	3.15	0.00	0.80	25.7
Early	75	5.49	5.48	0.00	0.62	11.7
Early	150	7.88	7.87	0.00	0.88	11.3
Early	225	9.21	9.22	0.00	0.90	10.1
Early	Alfalfa	6.22	4.06	2.15	0.79	12.9
Early	Trefoil	7.12	4.32	2.78	0.89	12.2

Table 4.8 Year main effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue stands (Sward yields include grass, legume and weed yields).

Year	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
	---------------------Mg ha^{-1}			---------------------	----%---
1990	7.01 b	6.50 a	0.51 c	1.15 b	16.7 b
1991	7.53 a	6.44 a	1.09 a	0.75 c	9.7 c
1992	7.53 a	6.46 a	1.06 a	1.09 b	15.6 b
1993	6.81 b	6.11 b	0.69 b	1.89 a	28.3 a

Table 4.9 Year and harvest management interaction effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Year	Harvest management	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
		--------------------Mg ha^{-1}			--------------------	----%---
1990	Late	7.15	6.71	0.44	1.34	19.0
1990	Early	6.88	6.29	0.58	0.95	14.5
1991	Late	8.46	7.26	1.20	0.99	11.3
1991	Early	6.60	5.62	0.98	0.51	8.0
1992	Late	8.13	7.05	1.07	1.56	20.3
1992	Early	6.92	5.87	1.05	0.62	10.8
1993	Late	7.98	7.27	0.71	2.60	34.1
1993	Early	5.64	4.96	0.67	1.17	22.6

Table 4.10 Year and grass cultivar interaction effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Year	Grass	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
		------Mg ha^{-1}------				----%---
1990	Johnstone	6.87	6.41	0.45	1.19	17.3
1990	KY31	7.16	6.58	0.58	1.10	16.2
1991	Johnstone	7.49	6.41	1.08	0.75	9.7
1991	KY31	7.56	6.46	1.10	0.75	9.6
1992	Johnstone	7.38	6.40	0.97	1.25	17.9
1992	KY31	7.67	6.51	1.16	0.93	13.2
1993	Johnstone	6.73	6.05	0.66	2.12	31.8
1993	KY31	6.89	6.17	0.72	1.66	24.9

Table 4.11 Year and nitrogen fertilization treatment interaction effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Year	Nitrogen treatment	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
		------------------------Mg ha^{-1}			------------------	----%---
1990	0	3.79	3.79	0.00	0.89	21.2
1990	75	6.31	6.31	0.00	1.08	15.7
1990	150	8.22	8.19	0.00	0.87	10.2
1990	225	10.46	10.46	0.00	0.77	7.5
1990	Alfalfa	5.40	4.81	0.57	1.00	17.5
1990	Trefoil	7.90	5.41	2.51	2.26	28.5
1991	0	4.49	4.49	0.00	0.68	13.8
1991	75	6.18	6.18	0.00	0.54	7.8
1991	150	7.77	7.77	0.00	0.36	4.5
1991	225	10.06	10.06	0.00	0.84	8.2
1991	Alfalfa	7.50	4.77	2.73	1.09	13.0
1991	Trefoil	9.16	5.36	3.80	0.97	10.6
1992	0	3.90	3.90	0.00	1.15	30.0
1992	75	6.55	6.55	0.00	0.73	10.7
1992	150	8.28	8.28	0.00	0.59	6.9
1992	225	9.78	9.78	0.00	1.06	9.9
1992	Alfalfa	8.04	5.11	2.93	1.72	21.3
1992	Trefoil	8.60	5.14	3.46	1.31	14.6
1993	0	3.70	3.70	0.00	1.67	45.0
1993	75	6.15	6.15	0.00	1.98	31.4
1993	150	8.29	8.29	0.00	2.45	28.9
1993	225	9.63	9.63	0.00	2.75	27.7
1993	Alfalfa	6.09	4.37	1.72	1.43	22.8
1993	Trefoil	7.03	4.55	2.42	1.04	14.2

Table 4.12 Year, harvest management and grass cultivar interaction effects on total biomass yields and yields of grass and legume, and weed yield and percentage of tall fescue over a 4-year period (Sward yields include grass, legume and weed yields).

Year	Harvest management	Grass cultivar	Sward yield	Grass yield	Legume yield	Weed yield	Weed %
			-------------------Mg ha^{-1}			----------------------	-%--
1990	Late	Johnstone	6.97	6.60	0.37	1.31	18.1
1990	Late	KY31	7.33	6.82	0.51	1.38	19.8
1990	Early	Johnstone	6.77	6.23	0.54	1.07	16.5
1990	Early	KY31	6.98	6.34	0.63	0.83	12.5
1991	Late	Johnstone	8.41	7.22	1.20	0.95	10.7
1991	Late	KY31	8.50	7.30	1.20	1.02	11.8
1991	Early	Johnstone	6.57	5.61	0.95	0.54	8.8
1991	Early	KY31	6.63	5.62	1.01	0.47	7.3
1992	Late	Johnstone	8.05	7.13	0.92	1.79	23.3
1992	Late	KY31	8.21	6.98	1.23	1.33	17.3
1992	Early	Johnstone	6.70	5.68	1.02	0.72	12.5
1992	Early	KY31	7.14	6.05	1.09	0.53	9.1
1993	Late	Johnstone	7.76	7.15	0.61	2.84	37.7
1993	Late	KY31	8.21	7.39	0.82	2.36	30.5
1993	Early	Johnstone	5.71	4.95	0.72	1.39	25.9
1993	Early	KY31	5.58	4.95	0.62	0.96	19.4

Table 4.13 Analysis of variance of tall fescue cultivar, N fertilization regime, harvest management, and legume mixture effects on biomass component yields over a 4-year period.

Source	DF	NITYT	NDFYT	ADFYT	NITGY	NDFYG	ADFYG
		----------------------------Pr > F----------------------------					
MGT	1	0.1674	0.0023	0.0024	0.0686	0.0010	0.0008
GR	1	0.4774	0.2986	0.2382	0.8465	0.5314	0.4930
NT	5	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
GR*NT	5	0.8666	0.9916	0.9974	0.6543	0.5309	0.6298
MGT*GR	1	0.5208	0.9580	0.8110	0.7340	0.6852	0.7648
MGT*NT	5	0.1731	0.2503	0.3058	0.0041	0.1809	0.2175
MGT*GR*NT	5	0.8152	0.5004	0.6466	0.5876	0.1311	0.1770
YR	2	0.0001	0.0014	0.0001	0.0001	0.3018	0.0140
YR*MGT	2	0.0285	0.0001	0.0001	0.0526	0.0001	0.0001
YR*GR	2	0.7478	0.6499	0.5680	0.3897	0.7083	0.7305
YR*NT	10	0.0001	0.0205	0.0151	0.0001	0.1294	0.0882
YR*GR*NT	10	0.4014	0.5393	0.7446	0.0590	0.2239	0.2940
YR*MGT*GR	2	0.7227	0.8598	0.9168	0.3315	0.5700	0.5632
YR*MGT*NT	10	0.0009	0.0546	0.0075	0.2209	0.3172	0.2484

Table 4.14 Analysis of variance of tall fescue cultivar, N fertilization regime, harvest management, and legume mixture effects on biomass constituent concentrations over a 4-year period.

Source	DF	NITCT	NDFCT	ADFCT
		----------Pr > F----------		
MGT	1	0.0071	0.0094	0.0057
GR	1	0.5560	0.8457	0.5178
NT	5	0.0001	0.0001	0.0001
GR*NT	5	0.4468	0.5378	0.9688
MGT*GR	1	0.0790	0.8174	0.4115
MGT*NT	5	0.9675	0.7607	0.9045
MGT*GR*NT	5	0.8840	0.0084	0.0351
YR	2	0.0001	0.0839	0.0001
YR*MGT	2	0.0001	0.0002	0.0001
YR*GR	2	0.8511	0.7924	0.8583
YR*NT	10	0.0001	0.0001	0.0005
YR*GR*NT	10	0.9015	0.9908	0.9953
YR*MGT*GR	2	0.7213	0.5366	0.5565
YR*MGT*NT	10	0.1765	0.8238	0.7885

Table 4.15 Harvest management main effects on biomass constituent yields of tall fescue over a 4-year period.

Harvest management	NITYT	NDFYT	ADFYT	NITGY	NDFYG	ADFYG
	------------------------------	------------------------------	------------------------------	Mg ha^{-1}	------------------------------	------------------------------
Late	0.134	5.00	2.79	0.112	4.63	2.52
Early	0.126	4.12	2.29	0.103	3.78	2.03

Table 4.16 Harvest management main effects on biomass constituent concentrations of tall fescue over a 4-year period.

Harvest management	NITCT	NDFCT	ADFCT
	------------------------	%	------------------------
Late	1.67	63.6	35.3
Early	1.82	61.2	33.8

Table 4.17 Grass cultivar main effects on biomass constituent yields of tall fescue over a 4-year period.

Grass cultivar	NITYT	NDFYT	ADFYT	NITGY	NDFYG	ADFYG
	-----------	-----------	-----Mg ha^{-1}-----	-----------	-----------	-----------
Johnstone	0.129	4.50	2.49	0.108	4.17	2.26
KY31	0.132	4.62	2.58	0.107	4.23	2.30

Table 4.18 Grass cultivar main effects on biomass constituent concentrations of tall fescue over a 4-year period.

Grass cultivar	NITCT	NDFCT	ADFCT
	-----------	-----%-----	-----------
Johnstone	1.75	62.4	34.4
KY31	1.74	62.4	34.6

Table 4.19 Nitrogen fertilization treatment main effects on biomass constituent yields of tall fescue over a 4-year period.

Nitrogen treatment	NITYT	NDFYT	ADFYT	NITGY	NDFYG	ADFYG
	----------------------------------	----------------------	$Mg\ ha^{-1}$	----------------------	----------------------	----------------------------------
0	0.064 d	2.68 e	1.44 d	0.064 e	2.68 e	1.44 e
75	0.096 c	4.20 cd	2.27 c	0.096 cd	4.20 c	2.27 c
150	0.131 b	5.30 b	2.87 b	0.131 b	5.30 b	2.87 b
225	0.176 a	6.44 a	3.49 a	0.176 a	6.44 a	3.49 a
Alfalfa	0.130 b	4.01 d	2.34 b	0.082 d	3.14 de	1.71 de
Trefoil	0.184 a	4.73 bc	2.83 c	0.095 c	3.47 d	1.88 d

Table 4.20 Nitrogen fertilization treatment main effects on biomass constituent concentrations of tall fescue stands over a 4-year period.

Nitrogen treatment	NITCT	NDFCT	ADFCT
	----------------------	%	----------------------
0	1.57 d	65.4 ab	35.1 a
75	1.52 d	66.1 a	35.6 a
150	1.63 cd	65.7 ab	35.6 a
225	1.75 bc	63.9 b	34.6 ab
Alfalfa	1.84 b	58.0 c	33.3 bc
Trefoil	2.16 a	55.4 d	33.0 c

Table 4.21 Harvest management and grass cultivar interaction effects on biomass nitrogen concentrations of tall fescue stands over a 4-year period.

Harvest management	Grass cultivar	NITCT
		------%-----
Late	Johnstone	1.65
Late	KY31	1.68
Early	Johnstone	1.85
Early	KY31	1.79

Table 4.22 Harvest management and nitrogen fertilization treatment interaction effects on nitrogen concentrations in total biomass and in grass biomass of tall fescue over a 4-year period.

Harvest management	Nitrogen treatment	NITYT	NITGY
		-------------Mg ha^{-1}	-----------
Late	0	0.074	0.074
Late	75	0.102	0.102
Late	150	0.122	0.122
Late	225	0.178	0.178
Late	Alfalfa	0.133	0.090
Late	Trefoil	0.194	0.103
Early	0	0.055	0.055
Early	75	0.090	0.090
Early	150	0.140	0.140
Early	225	0.174	0.174
Early	Alfalfa	0.127	0.075
Early	Trefoil	0.173	0.087

Table 4.23 Year main effects on biomass constituent yields of tall fescue stands over a 4-year period.

Year	NITYT	NDFYT	ADFYT	NITGY	NDFYG	ADFYG
	----------------------------------	-----------------	Mg ha^{-1}	-----------------	----------------------------------	
1990	0.144 a	4.33 b	2.34 b	0.129 a	4.14 a	2.18 b
1991	0.140 a	4.74 a	2.65 a	0.111 b	4.29 a	2.33 a
1992	0.107 b	4.61 a	2.64 a	0.083 c	4.18 a	2.33 a

Table 4.24 Year main effects on biomass constituent concentrations of tall fescue stands over a 4-year period.

Year	NITCT	NDFCT	ADFCT
	---------------	%	---------------
1990	2.02 a	62.1 a	33.4 b
1991	1.83 b	63.2 a	35.0 a
1992	1.39 c	61.9 a	35.2 a

Table 4.25 Year by harvest management interaction effects on biomass constituent yields of tall fescue stands over a 4-year period.

Year	Harvest	NITYT	NDFYT	ADFYT	NITGY	NDFYG	ADFYG
		----------Mg ha^{-1}----------					
1990	Late	0.148	4.41	2.36	0.134	4.25	2.23
1990	Early	0.140	4.24	2.30	0.123	4.02	2.12
1991	Late	0.148	5.53	3.14	0.118	5.00	2.76
1991	Early	0.131	3.96	2.16	0.104	3.58	1.89
1992	Late	0.106	5.05	2.86	0.084	4.64	2.56
1992	Early	0.108	4.18	2.42	0.083	3.73	2.09

Table 4.26 Year by harvest management interaction effects on biomass constituent concentrations of tall fescue over a 4-year period.

Year	Harvest management	NITCT	NDFCT	ADFCT
		----------%----------		
1990	Late	2.04	62.0	33.2
1990	Early	2.00	62.1	33.6
1991	Late	1.70	66.0	37.3
1991	Early	1.95	60.4	32.7
1992	Late	1.26	62.8	35.4
1992	Early	1.52	61.0	35.0

Table 4.27 Year by nitrogen fertilization treatment interaction effects on biomass constituent yields of tall fescue stands over a 4-year period.

Year	Nitrogen treatment	NITYT	NDFYT	ADFYT	NITGY	NDFYG	ADFYG
		------------------------------		Mg ha^{-1}		------------------------------	
1990	0	0.072	2.45	1.30	0.072	2.45	1.30
1990	75	0.119	4.01	2.11	0.119	4.01	2.11
1990	150	0.162	5.15	2.69	0.162	5.15	2.69
1990	225	0.219	6.59	3.44	0.219	6.59	3.44
1990	Alfalfa	0.104	3.37	1.84	0.092	3.16	1.68
1990	Trefoil	0.187	4.39	2.61	0.108	3.47	1.84
1991	0	0.074	2.97	1.59	0.074	2.97	1.59
1991	75	0.094	4.18	2.25	0.094	4.18	2.25
1991	150	0.127	5.23	2.84	0.127	5.23	2.84
1991	225	0.179	6.65	3.66	0.179	6.65	3.66
1991	Alfalfa	0.158	4.37	2.57	0.088	3.17	1.71
1991	Trefoil	0.207	5.05	2.99	0.103	3.53	1.91
1992	0	0.046	2.61	1.43	0.046	2.61	1.43
1992	75	0.075	4.41	2.44	0.075	4.41	2.44
1992	150	0.105	5.51	3.09	0.105	5.51	3.09
1992	225	0.130	6.07	3.37	0.130	6.07	3.37
1992	Alfalfa	0.127	4.30	2.61	0.067	3.10	1.74
1992	Trefoil	0.157	4.76	2.89	0.076	3.39	1.89

Table 4.28 Year by nitrogen fertilization treatment interaction effects on biomass constituent concentrations of tall fescue over a 4-year period.

Year	Harvest management	NITCT	NDFCT	ADFCT
		----------------------	%	----------------------
1990	0	1.86	63.6	33.7
1990	75	1.88	63.8	33.5
1990	150	1.99	63.3	33.0
1990	225	2.10	63.4	33.1
1990	Alfalfa	1.92	62.2	33.8
1990	Trefoil	2.37	56.0	33.2
1991	0	1.68	65.7	34.9
1991	75	1.54	67.4	36.2
1991	150	1.63	67.2	36.5
1991	225	1.79	65.8	36.2
1991	Alfalfa	2.06	58.4	33.9
1991	Trefoil	2.28	54.7	32.3
1992	0	1.19	66.8	36.6
1992	75	1.16	67.2	37.1
1992	150	1.28	66.5	37.2
1992	225	1.35	62.5	34.7
1992	Alfalfa	1.54	53.3	32.2
1992	Trefoil	1.83	55.3	33.5

Table 4.29 Year by nitrogen fertilization treatment by grass cultivar interaction effects on nitrogen yield in the grass component of biomass over a 4-year period.

Year	Nitrogen treatment	Grass cultivar Johnstone	KY31
		--------------Mg ha^{-1}-------------	
1990	0	0.060	0.085
1990	75	0.118	0.121
1990	150	0.160	0.163
1990	225	0.211	0.226
1990	Alfalfa	0.094	0.090
1990	Trefoil	0.118	0.098
1991	0	0.080	0.069
1991	75	0.094	0.093
1991	150	0.125	0.128
1991	225	0.188	0.170
1991	Alfalfa	0.080	0.097
1991	Trefoil	0.099	0.106
1992	0	0.045	0.047
1992	75	0.073	0.078
1992	150	0.104	0.106
1992	225	0.140	0.120
1992	Alfalfa	0.069	0.064
1992	Trefoil	0.082	0.070

Table 4.30 Year by harvest management by nitrogen fertilization treatment interaction effects on biomass constituent yields of tall fescue stands over a 4-year period.

Year	Harvest management	Nitrogen treatment	NITYT	NDFYT	ADFYT
			-----------------	Mg ha^{-1}	--------------
1990	Late	0	0.086	2.89	1.55
1990	Late	75	0.134	4.29	2.24
1990	Late	150	0.154	4.80	2.49
1990	Late	225	0.225	6.57	3.42
1990	Late	Alfalfa	0.112	3.57	1.97
1990	Late	Trefoil	0.175	4.35	2.50
1990	Early	0	0.059	2.00	1.06
1990	Early	75	0.105	3.72	1.97
1990	Early	150	0.169	5.51	2.89
1990	Early	225	0.212	6.60	3.45
1990	Early	Alfalfa	0.096	3.16	1.71
1990	Early	Trefoil	0.199	4.43	2.71
1991	Late	0	0.088	3.82	2.08
1991	Late	75	0.100	5.04	2.77
1991	Late	150	0.113	5.51	3.04
1991	Late	225	0.181	7.54	4.26
1991	Late	Alfalfa	0.175	5.19	3.07
1991	Late	Trefoil	0.232	6.08	3.65
1991	Early	0	0.061	2.12	1.10
1991	Early	75	0.088	3.33	1.74
1991	Early	150	0.140	4.95	2.63
1991	Early	225	0.177	5.76	3.07
1991	Early	Alfalfa	0.141	3.56	2.06
1991	Early	Trefoil	0.182	4.01	2.33
1992	Late	0	0.048	2.97	1.63
1992	Late	75	0.074	4.79	2.63
1992	Late	150	0.099	6.01	3.33
1992	Late	225	0.128	6.53	3.59
1992	Late	Alfalfa	0.111	4.33	2.52
1992	Late	Trefoil	0.176	5.64	3.44
1992	Early	0	0.044	2.24	1.23
1992	Early	75	0.077	4.02	2.25
1992	Early	150	0.111	5.02	2.84
1992	Early	225	0.133	5.61	3.15
1992	Early	Alfalfa	0.144	4.27	2.71
1992	Early	Trefoil	0.138	3.89	2.34

Table 4.31 Analysis of variance of tall fescue cultivar, N fertilization regime, and harvest management effects on cellulose and ADL concentrations and yields in biomass produced from tall fescue pure stands and mixtures over a 4-year period.

Source	DF	CELYT	ADLYT	CELYG	ADLYG	CELCT	ADLCT
		---------------------------Pr > F-------------------------------					
MGT	1	0.0008	0.0025	0.0004	0.0018	0.0033	0.0046
GR	1	0.6754	0.0483	0.9761	0.0231	0.6773	0.0044
NT	5	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
GR*NT	5	0.8170	0.7742	0.3404	0.7586	0.7590	0.9001
MGT*GR	1	0.8681	0.4307	0.4504	0.9183	0.5768	0.0954
MGT*NT	5	0.2060	0.0195	0.5683	0.5917	0.9302	0.0305
MGT*GR*NT	5	0.5179	0.6025	0.0894	0.1612	0.0292	0.2910
YR	2	0.4229	0.0020	0.5732	0.0001	0.6968	0.0001
YR*MGT	2	0.0001	0.0001	0.0002	0.0003	0.0001	0.0002
YR*GR	2	0.7667	0.8108	0.6991	0.1895	0.4534	0.9729
YR*NT	10	0.0481	0.0251	0.0356	0.0009	0.0285	0.0455
YR*GR*NT	10	0.9402	0.1972	0.6571	0.4458	0.9884	0.0702
YR*MGT*GR	2	0.9025	0.9803	0.4449	0.2706	0.3994	0.7184
YR*MGT*NT	10	0.0594	0.0242	0.1949	0.3066	0.5343	0.2792

Table 4.32 Harvest management main effects on cellulose and ADL concentrations and yields in biomass produced from tall fescue pure stands and mixtures over a 4-year period.

Harvest management	CELYT	ADLYT	CELYG	ADLYG	CELCT	ADLCT
	--------------------	---------- $Mg\ ha^{-1}$	----------	--------------------		------%-----
Late	2.55	0.35	2.30	0.26	30.9	4.09
Early	1.95	0.26	1.73	0.18	28.9	3.66

Table 4.33 Grass cultivar main effects on cellulose and ADL concentrations and yields in biomass produced from tall fescue pure stands and mixtures over a 4-year period.

Grass cultivar	CELYT	ADLYT	CELYG	ADLYG	CELCT	ADLCT
		----------	---------- $Mg\ ha^{-1}$	--------------------		-----%----
Johnstone	2.23	0.29	2.02	0.21	30.0	3.72
KY31	2.27	0.32	2.02	0.23	29.8	4.02

Table 4.34 Nitrogen fertilization treatment main effects on cellulose and ADL concentrations and yields in biomass produced from tall fescue pure stands and mixtures over a 4-year period.

Nitrogen treatment	CELYT	ADLYT	CELYG	ADLYG	CELCT	ADLCT
	-------------------------Mg ha^{-1}				---------------------------	---%---
0	1.29 e	0.14 d	1.29 e	0.137 d	30.7 a	3.18 b
75	2.02 d	0.23 c	2.02 c	0.230 c	31.6 a	3.55 b
150	2.55 b	0.29 bc	2.55 b	0.288 b	31.8 a	3.58 b
225	3.06 a	0.34 b	3.06 a	0.343 a	30.8 a	3.45 b
Alfalfa	2.17 cd	0.36 b	1.51 de	0.162 d	27.8 b	4.48 a
Trefoil	2.39 bc	0.45 a	1.66 d	0.170 d	26.8 b	4.98 a

Table 4.35 Year main effects on cellulose and ADL concentrations and yields in biomass produced from tall fescue pure stands and mixtures over a 4-year period.

Year	CELYT	ADLYT	CELYG	ADLYG	CELCT	ADLCT
		------------------Mg ha^{-1}	------------------	------------------		---%---
1991	2.27	0.29	2.03	0.21	30.0	3.69
1992	2.23	0.32	2.00	0.24	29.9	4.05

Table 4.36 Year by harvest management interaction effects on cellulose and ADL concentrations and yields in biomass produced from tall fescue pure stands and mixtures over a 4-year period.

Year	Harvest management	CELYT	ADLYT	CELYG	ADLYG	CELCT	ADLCT
		------------------	------------------Mg ha^{-1}	------------------	------------------		---%---
1991	Late	2.69	0.35	2.41	0.26	31.9	4.06
1991	Early	1.85	0.22	1.65	0.15	28.0	3.33
1992	Late	2.41	0.34	2.20	0.27	30.0	4.11
1992	Early	2.05	0.29	1.81	0.21	29.7	3.99

Table 4.37 Year by nitrogen fertilization treatment interaction effects on cellulose and ADL concentrations and yields in biomass produced from tall fescue pure stands and mixtures over a 4-year period.

Year	Nitrogen treatment	CELYT	ADLYT	CELYG	ADLYG	CELCT	ADLCT
		----------------------	----------------------	Mg ha^{-1}	----------------------	----------------------	---%---
1991	0	1.36	0.15	1.36	0.15	30.0	3.26
1991	75	1.95	0.21	1.95	0.21	31.3	3.36
1991	150	2.46	0.25	2.46	0.25	31.7	3.20
1991	225	3.21	0.33	3.21	0.33	31.7	3.19
1991	Alfalfa	2.18	0.33	1.51	0.14	28.8	4.33
1991	Trefoil	2.45	0.45	1.68	0.15	26.5	4.83
1992	0	1.23	0.12	1.23	0.12	31.4	3.10
1992	75	2.09	0.25	2.09	0.25	31.9	3.75
1992	150	2.65	0.33	2.65	0.33	31.9	3.95
1992	225	2.91	0.36	2.91	0.36	30.0	3.71
1992	Alfalfa	2.17	0.39	1.51	0.18	26.8	4.64
1992	Trefoil	2.34	0.45	1.64	0.18	27.1	5.14

Appendix 1. Monthly maximum and minimum mean temperatures for 1989, 1990, 1991, 1992 and 1993 measured within 300 m of both field studies.

Month	1989		1990		1991		1992		1993	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
	°C									
January	9.4	-1.1	10.6	0.0	6.7	-2.8	7.2	-1.1	7.8	-1.1
February	5.6	-4.4	12.8	-0.6	10.0	-0.6	11.1	0.0	6.1	-5.0
March	15.6	1.7	15.6	2.2	14.4	4.4	13.3	2.2	10.0	0.6
April	18.3	5.0	18.3	3.9	20.0	10.6	18.9	6.7	17.2	6.1
May	21.7	10.0	21.7	10.0	26.7	16.1	22.8	10.0	23.9	12.2
June	27.8	16.7	28.9	16.1	28.9	17.2	26.1	15.0	28.3	15.6
July	30.0	18.9	29.4	18.3	30.6	18.9	28.9	18.9	32.2	20.6
August	29.4	16.7	29.4	18.3	30.0	16.7	26.1	16.1	30.0	18.3
September	25.0	13.3	26.1	16.1	26.7	13.3	25.0	13.3	23.9	13.3
October	20.6	6.1	20.6	8.3	21.1	8.9	19.4	6.1	17.8	6.7
November	13.9	0.6	16.1	5.6	12.2	2.2	12.2	3.3	11.7	2.2
December	2.8	-10.0	10.6	-8.9	10.0	0.0	7.2	-1.7	5.0	-2.2

Appendix 2. Monthly precipitation totals for 1989, 1990, 1991, 1992 and 1993 measured within 300 m of both field studies.

Month	1989	1990	1991	1992	1993
	mm				
January	94	114	90	113	75
February	250	95	110	52	103
March	180	55	143	144	105
April	81	62	78	61	83
May	126	166	163	87	63
June	144	118	67	102	165
July	98	123	148	232	81
August	99	132	90	139	118
September	105	55	81	88	94
October	74	121	78	21	105
November	73	67	32	113	163
December	46	284	203	49	70
Total	1370	1392	1284	1201	1224

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