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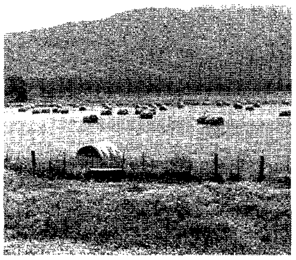
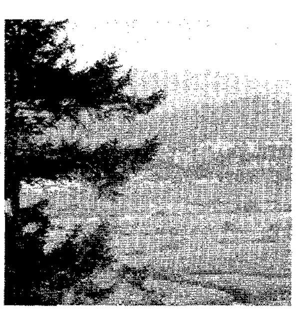


Selection of Herbaceous Energy Crops For The Western Corn Belt

Final Report Part I: Agronomic Aspects

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SELECTION OF HERBACEOUS ENERGY CROPS FOR THE WESTERN CORN BELT

Final Report Part I: Agronomic Aspects for the Period March 1, 1988 to November 30, 1993

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DISCLAIMER

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Finally, we thank Ms. Elinor Bryant for her excellent, patient, and cheerful efforts in the preparation of this report.

INTRODUCTION

For the past 16 years, the Federal Government, through the Department of Energy has considered commercialization of biomass as an important solution to U.S. energy needs and has funded research and demonstration projects to encourage its use (Cantor and Rizy, 1991). Two potential uses of biomass for energy now show much potential. The first is for electrical generation either by being burned alone or co-fired with coal and the second is to be fermented to a liquid fuel such as ethanol (Lynd et al., 1991). Since the ideal composition of biomass will vary depending upon the conversion technology used, it is necessary to determine chemical composition of all potential biomass crops.

The relative high cost of energy derived from biomass is a major deterrent to greater use of biomass for energy production. One of the most important methods of lowering the cost of dedicated biomass production is to increase the yield per unit of land area so that fixed costs can be applied to more tons of forage. Annual yield of many warm-season, annual crops, such as forage-type sorghums and forage corn, are often greater than those of perennial forage crops (Helsel and Wedin, 1981), but these annual crops often predispose soils to more erosion than occurs when sod-forming, perennial crops are planted.

The North Central Region of the USA is one of the most productive regions in the world. Significant improvements in yields in this region will have a large impact on potential biomass production. Because of the range of land capabilities, the same species and cropping system will not be suited for all sites. Prime farmland, without erosion potential, can support both perennial, sod-forming crops as well as annual row crops. Marginal, sloping land, however, is much more suited for cropping systems that feature perennial crops or planting of annual crops into perennial crop sod.

For this study, we selected grass and legume crops with potential for high biomass yields and those that offer protection from soil erosion. Cool-season perennial grasses produce a majority of their biomass in the spring, with a significant amount of growth in the fall. Reed canarygrass is extremely well adapted to marginal sites. It has out-produced other perennial grasses on marginal lands up to two fold (Cherney et al., 1986). Warm-season, perennial grasses have excellent potential for producing biomass because they have the C4 photosynthetic pathway and are very productive during the warm, dry summer months. We selected switchgrass and big bluestem for this study because they are capable of high yields with a single harvest per year and because they are well adapted to the area.

Perennial legumes can fix their own nitrogen and are useful for control of erosion, although they are not as effective as perennial, sod-forming grasses. A disadvantage of legumes is that most need to be periodically reseeded. Alfalfa was selected because it is generally very productive on good agricultural sites.

Annual grasses such as sorghum can be very productive but require high management inputs and can have serious soil erosion potential. Sweet sorghum, because of its rapid growth rate, wide adaptability, and production of high levels of soluble sugars in its stems, has been identified as having high potential for ethanol production (Smith et al., 1987). Smith and Buxton (1993) found that total sugar yield of sweet sorghum averaged about 6 Mg per ha, of which 54% was sucrose, 20% was fructose, and 26% was glucose. Sweet sorghum stems, however, are subject to lodging, especially under conditions of high plant density and high fertility. Forage-type sorghums (typically sorghum x sudangrass hybrids) can also be very productive.

In most temperate environments, cool-season, perennial forages, especially grasses, produce most of their biomass during cool springs with a second, but smaller, flush of growth in the late summer and early fall as temperatures are lowered and soil moisture conditions improve relative to mid summer. During hot, dry summers, production rates of cool-season forages are much lower. Conversely, warm-season forages have their most rapid growth during warm summers, with slower growth during cool springs and during late summers and early falls. Additionally, most warm-season, C4 forages species have higher water-use efficiency than cool-season, C3 forage species grown in the same environment (Tanner and Sinclair, 1983; Geng et al., 1989).

The research reported here was conducted to identify those species and cultural practices that would result in high biomass yields for various land capabilities with acceptable soil erosion potential. We also conducted research to determine if intercropping sorghum into alfalfa or reed canarygrass could increase biomass yields over alfalfa or reed canarygrass grown alone and still have the advantage for limiting soil erosion.

MATERIALS and METHODS

Experimental Sites and Weather Characteristics

The herbaceous biomass project was conducted at two sites from 1988 to 1992. The central Iowa location was the Bruner Farm of the Agronomy and Agricultural Engineering Research Center near Ames, and the southern Iowa location was the McNay Memorial Research Center near Chariton. Each location has a different Land Use Capability, soil type, and slightly different weather pattern.

The Ames site was on low erosive, highly productive soil having a Land Use Capability classification of I. The soil is a Harps (fine loamy mesic typic Calciaquoll) silty clay loam with a slope of 0 - 1%, having no impervious layer, a rooting depth to 2 m with the capacity to store 305 mm of available water. Conventionally tilled soybean in a corn-soybean-oat rotation were grown in 1987 previous to initiation of this experiment. Soil samples taken to a 15-cm depth before the initiation of the experiment revealed an average pH of 8.0, soil organic matter concentration of 7%, and available P and K of 6.5 and 123 ppm, respectively. The frost free growing season averages 160 days with 813 mm of rainfall.

The Chariton site was on erosive, lower productive soils, which have susceptibility to drought and a Land Use Capability classification of III. The soils were a mixture of Clarinda (fine silty montmorillonitic mesic typic Argiaquoll), Clearfield (fine silty mixed mesic typic Argiaquoll), and Grundy (fine montmorillonitic mesic aquic Arguidoll) silty clay loams with a 2 - 7% slope. The soils have a high clay content layer in the B horizon which retards rooting at a depth of 45 cm and has the capacity to store 250 mm of available water to a 2-m depth. The site was in conventionally managed red clover for 2 years previous to initiation of the experiment. Soil tests revealed an average pH of 6.8, organic matter concentration of 4%, and available P and K of 28 and 166 ppm, respectively. Lime was applied in late 1987 at a rate of 11 Mg/ha and incorporated. The frost free growing season averages 165 days with 865 mm of rainfall.

Experimental Design and Species Establishment

The experimental design at both locations was a randomized complete block in a split plot arrangement with four replicates. The main plots were cropping systems planted in strips 6 m wide by 31 m long with four subplots of 6 by 7 m. This design allowed mechanized operations in the main plots and the 6 m width (8 rows 76 cm apart when planted to row crops) was wide enough to reduce border effects from crops of differing heights.

Thirteen cropping systems were evaluated for total biomass production, quality of biomass, soil loss potential, and economic feasibility. The thirteen cropping systems were:

(A) Alfalfa: two-cut vs. three-cut per season
(B) Reed canarygrass: two cuttings, N=0, 70, 140, or 280 kg/ha
(C) Switchgrass: one cut, N=0, 70, 140, or 280 kg/ha
(D) Big bluestem: one cut, N=0, 70, 140, or 280 kg/ha
(E) Sweet sorghum: N=0, 70, 140, or 280 kg/ha
(F) Sorghum x sudangrass: N=0, 70, 140, or 280 kg/ha
(G) Sweet sorghum double-cropped with winter rye:
N=0, 70, 140, or 280 kg/ha
(H) Sorghum x sudangrass double-cropped with winter rye:
N=0, 70, 140, or 280 kg/ha
(I) Corn in a three year rotation with soybean and sweet sorghum:
N=0, 70, 140, or 280 kg/ha
(J) Soybean in a three year rotation with corn and sweet sorghum:
(K) Sweet sorghum (sole) and sweet sorghum double cropped with winter rye in a three year rotation with corn and soybean:
N=70 or 140 kg/ha
(L) Alfalfa intercropped with sweet sorghum and sorghum x sudangrass:
N=70 or 140 kg/ha
(M) Reed canarygrass intercropped with sweet sorghum and sorghum x sudangrass:
N=70 or 140 kg/ha

Nine crop species were used in the 13 cropping systems for this study. They were:

Alfalfa (*Medicago sativa*, L., cv Arrow)
Reed canarygrass (*Phlaris arundinacea*, L., cv Venture)
Switchgrass (*Panicum virgatum*, L., cv Cave-in-Rock)
Big bluestem (*Andropogon gerardii*, L., cv Sunny View)
Sweet sorghum (*Sorghum vulgare*, L., Moench cv. M-81E)
Sorghum x sudangrass (*Sorghum vulgare*, L., Moench cv. FFR201)
Corn (*Zea mays*, L., cv. Pioneer 3377)
Soybean [*Glycine max*, L., cv. Hack (Ames) and Pella (Chariton)]
Winter rye (*Secale cereale*, cv. Aroostock)

Alfalfa (Systems A & L) and reed canarygrass (Systems B & M) were seeded with an Almaco forage seeder on 14 April 1988 at Ames and on 13 April at Chariton. Alfalfa was frost seeded in March of 1989 to increase the stand at Chariton due to the limited stand from the stress of the 1988 drought. The reed canarygrass did not establish at Chariton and reseeding was done in late

August. The reed canarygrass emerged but winter killed when unusually warm weather initiated growth and then an arctic cold front dropped temperatures below -30°, killing the grass. Reseeding was done in April 1989 without tillage of the plots and establishment was weak but successful and no harvest was taken until 1990. As a result, System M was not initiated at Chariton. Alfalfa was seeded at 13 kg/ha and reed canarygrass at 10 kg/ha at Ames, whereas rates of 15 kg/ha and 12 kg/ha, respectively, were used at Chariton.

Switchgrass (System C) and big bluestem (System D) were planted with a Marlyss drill at Ames on 3 May 1988, and at Chariton on 29 April. Stand failure occurred in two of the four big bluestem replicates at Chariton. Reseeding of these grass plots occurred in April 1989. New seedlings were established but stands were weak and weed populations were great in these two replicates. These plots were mowed to keep the weeds in check and forage harvest of these two replicates was not taken until 1990. Seeding rate for switchgrass was 8 kg/ha and that for big bluestem were 13 kg/ha.

Winter rye (Systems G, H, & K) was planted no-till as soon as possible after sorghum and soybean harvests (about mid October) at a rate of 112 kg/ha (Ames) and 134 kg/ha (Chariton). The Ames site was planted with a "Tye" drill in 25-cm rows and the Chariton site was planted with a Gandy drill in 18-cm rows.

All row crop plots of sweet sorghum, sorghum x sudangrass, corn, and soybean (Systems E, F, G, H, I, J, K) consisted of eight 76-cm rows. Planting was done with a John Deere Maxemerge 4-row planter at Ames whereas planting was done with a Buffalo Kinze 6-row planter at Chariton. Corn was planted in late April/early May at a rate that would allow a final population of 65,500 plants/ha. Soybean were planted in early to mid May at a rate of 26 seeds/m to allow for a final population of 345,000 plants/ha. Corn and soybean plots were disked in the spring before planting. Sorghum was planted in late May/early June after winter rye (Systems G, H, & K), alfalfa (System L), or reed canarygrass (System M) had been harvested. A slot tiller was used to till the soil to a depth of 8-cm and a width of 10-cm for the sorghum rows in the established alfalfa or reed canarygrass before intercrop planting of sorghum. After planting sorghum and before emergence, Paraquat was sprayed in a band application 16-cm wide at a rate of 2.3 L/ha to burn back the established foliage to reduce competition for the emerging sorghum.

Low volume sorghum cups were used in the soybean boxes of the planters listed above to reduce the amount of sorghum seed planted (about 2.0 to 3.5 kg/ha), thus reducing the amount of thinning required. Sorghum rows were thinned to 10 plants/m to allow for a final population of 133,000 plants/ha.

Fertility, Pest Control, and Cultural Practices

The grass systems (B, C, & D) and the row crop systems (E, F, G, H, & I) had four levels of fertilizer nitrogen (0, 70, 140, and or 280 kg/ha) as subplots. All N fertilization was done by hand with 34-0-0 ammonium nitrate. No N was applied during the establishment year of the perennial grass systems. Winter rye in the double crop systems received half of the N in late March, with the remainder applied at the time of sorghum planting. Reed canarygrass received half of the N in mid April with the remainder applied in mid August. Switchgrass and big bluestem were fertilized with all of the N in late April. Corn plots were fertilized with N before the spring disking to facilitate incorporation. Monocrop sorghum plots were fertilized at the time of planting. The alfalfa and reed canarygrass intercrop systems received split applications of N in early April and again at the time of sorghum planting. Maintenance rates of P and K were applied to the entire experimental area in the fall of each year. Ames received 67 kg/ha P and 200 kg/ha K, and Chariton received 56 kg/ha P and 168 kg/ha K.

Alfalfa and perennial grass systems received no tillage once established. Corn and soybean plots were disked in the spring and cultivated twice after sufficient growth. Monocrop sorghum plots were field cultivated followed by harrowing in the spring to clear some of the sorghum stubble. Double crop sorghum/winter rye plots were deep chisel plowed in the fall before planting the winter rye and the sorghum was planted no-till into the rye stubble immediately after rye harvest. Monocrop sorghum was cultivated in a timely manner. An attempt was made to cultivate the double crop sorghum but it was detrimental to the sorghum and the practice was abandoned.

Alfalfa was sprayed once (occasionally twice) with Cygon 400 at 1.2 L/ha at Ames and 1.8 L/ha at Chariton each year to control potato leafhopper. The perennial grass systems at Chariton in 1990 and 1991 were sprayed with 2,4-D for broadleaf weed control. Lasso/Bladex (Ames & Chariton) at 5.8 L/ha or Dual (Chariton) at 3.5 L/ha was applied to corn plots for weed control. Dual at 2.9 L/ha or Lasso at 5.8 L/ha were applied to soybean plots at both locations. Iron chlorosis in soybean at Ames required application of Sequestren 138 0.5% X77 at 2.0 kg/ha a.i. each season. Sorghum seed was treated with Concep II (a seed softener) before planting to facilitate application of Dual at 2.3 L/ha at both locations.

Harvesting and Field Data Collection

Alfalfa (System A) contained a split treatment comparing two or three cut-harvests. The two cut system was harvested in late June and mid September. The three cut system was harvested in late May, late July, and mid September. Only two harvests were taken in the establishment year at Ames and no harvest was taken at Chariton in 1988 due to stress from the drought. Reed canarygrass was harvested once during the establishment year. Thereafter, reed canarygrass was harvested in late June and again in mid October before a killing frost. Switchgrass and big bluestem were harvested once in early October. Winter rye was harvested mid to late May when the plants were at 50% anthesis. The intercrop systems were harvested three times each year. The first harvest was in late May and consisted of only alfalfa or reed canarygrass. The plots were then slot tilled and planted to sorghum and the second harvest was taken in late August. The third harvest was taken in mid October just before a killing frost. The alfalfa, perennial grasses, rye and sorghum intercropped into alfalfa or reed canarygrass were harvested from the center of the 6 x 7 m plot with a flail-type Carter small plot forage harvester. The harvested area was 0.91 m x 7 m, leaving a stubble of 7 to 10 cm.

The row crops, sorghums and corn, were harvested with a John Deere Model R-6 one-row forage chopper in 1988 to 1990. A John Deere 3800 two-row forage chopper was used in 1991 and 1992. The area harvested was 1.5 x 7 m from the center of each 6 x 7 m subplot, which was the width of two 76-cm rows, and the material was chopped at a 12 mm length. Corn grain was hand harvested.

Soybean was harvested with a Massey Ferguson combine, which collected material from a 1.5 x 7 m area. This area consisted of two 76-cm wide rows harvested from the center of the 6 x 7 m subplot. The stover was collected on a tarp behind the combine and grain was collected into buckets in the grain bin of the combine.

A 500-600 g subsample of the harvested material was collected at each harvest, heated in a 700 watt microwave for 6-7 minutes to raise the internal temperature to approximately 100°C to impede respiration. The dry matter samples were then dried at 60°C to approximately 3% plant water. The subsamples were then weighed hot out of the dryer for dry matter concentration determination. Next, the dry samples were ground twice; first in a Wiley mill to pass through an 8 mm screen and then a representative subsample was ground in a UDY cyclone mill to pass through a 1 mm screen. The ground samples were stored in 60 mL glass jars for subsequent lab analysis.

Soil Erosion Estimates

Soil loss estimates were made on the cropping systems using the Universal Soil Loss Equation. These estimates are made as Mg/ha per year as determined by:

rainfall and runoff factor,

K = soil erodibility factor,

L = slope length factor,

S = slope steepness factor,

C = cover and management factor, and

P = support practice factor

Values for each factor were obtained as outlined in the Soil Conservation Service - Iowa Technical Guideline, 1990. This publication updates information obtained from the Agriculture Handbook 537 (Wischmeier and Smith, 1978). Units in these publications are based on the English unit system. Soil loss was computed for tons/acre per year and converted to Mg/ha per year.

The rainfall erosion index, R factor, was based on the cumulative effect of rainfall over a year. The equation that determines the index factors includes rainfall intensity and rainfall energy. An average annual value based on a 22-year data collection period determined the R factor for the erosion index. In Iowa there is two index numbers, 150 and 175, used by the SCS Guidelines. Both Ames and Chariton are included in R = 175.

The soil erodibility factor, K, is a quantitative value based on the soil loss for a particular soil type. This value is a factor of soil loss rate per erosion index units as measured on a unit plot. This unit plot is defined as a length of 22.1 m uniform 9% slope continuously in clean-tilled fallow. The soil erodibility factors for this study were obtained from county Soil Survey maps published by the SCS. The K factor was 0.24 for Ames and 0.37 for Chariton.

Steepness and length of slope greatly affect the soil loss rate. The topographic factors, LS, are a ratio of soil loss per unit area from a 22.1-m length of uniform 9% slope. The LS factors were obtained from the SCS-Iowa Technical Guide (Table II). At Ames the factor was 0.13 for all plots. At Chariton LS varied from 0.29 to 0.83 because of the variation in slope.

The factor for cover and management (C) is the ratio of soil loss from an area of land with a specific cover and management to that of an identical land area in clean-tilled continuous fallow. An annual C factor was determined for each of the thirteen cropping systems for each of five years for both sites. Sorghum was given the C factor used for corn silage.

This factor takes into account land used for the previous year. The C factor for row crops following a row crop is considerably higher than for a perennial grass following a row crop.

Perennial grasses and legumes were given similar C factors at both locations. Alfalfa was an exception in its first year following soybean at Ames with a factor of 0.31. After the first year, alfalfa was given a factor of 0.02 compared to a factor of 0.04 for grasses. If yields fell below 6.72 Mg/ha, the factor was multiplied by 1.2. The C factor for double cropping systems ranged between the higher monocrop row crops and the monocrop grasses.

The intercropping systems were based on alfalfa and grass factors.

The support practice factor, P, is the effect of contour or cross-slope tillage practices on sheet and rill erosion. These practices were not implemented into this study, therefore, P factor did not affect the USLE.

Soil Sampling

Several bulk samples were collected to a 15-cm depth from each replicates at both Ames and Chariton each fall before and during the experiment. After five seasons of cropping, each subplot was sampled to a 15 cm depth. Replicates 1 and 2 and replicates 3 and 4 were combined and submitted to the Iowa State Soil Testing Laboratory for analysis. Soil pH was determined by standard methods; soil P by the Bray P_1 test which measures a portion of the readily available P; and soil K by the normal neutral ammonium acetate extractant, which measures the water-soluble and exchangeable K.

Laboratory Methods

Cell wall structure was determined by sequential fiber analysis. This procedure determined neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) in accordance to the methodology of Georing and Van Soest (1970), with the alpha-amylase procedural modification proposed by Van Soest and Robertson (1980). Two milliliters of alpha-amylase solution were added after boiling the neutral detergent solution for 30 minutes. NDF is primarily made up of cellulose, hemicellulose, and lignin. These components are the remaining fiber left after boiling in a neutral detergent, which removes cell soluble materials including proteins, nonstructural carbohydrates, lipids, pectin, plant silica, some tannins, some minerals, and pigments. An estimate of hemicellulose was determined by the difference between NDF and ADF (NDF-ADF) values. ADF removes most protein and acid soluble material that would interfere with lignin determination. Lignin was estimated by the difference in the residue remaining after treatment with 72% sulfuric acid and ash values. The residue was ashed at 500°C for three hours. Cellulose concentration was estimated by subtracting the lignin and ash from the ADF value (ADF-(lignin+ash)).

Nitrogen content of plant material was determined by the Kjeldahl digestion and distillation methodology according to Bremner (1965). Potassium content of plant material was determined by flame photometry of the Kjeldahl digest using a Perkin Elmer 403 AA spectrophotometer. Nonstructural carbohydrate analysis of plant material for glucose plus fructose and sucrose was done by absorbance spectrophotometry using an LKB Biochrom Ultraspec 4050 spectrophotometer in accordance to the methodology of Nelson (1944) and Somoygi (1945).

RESULTS

Temperature and Precipitation

Figures 1 and 2 present deviations from normal monthly rainfall and precipitation. Both 1988, the seeding year, and 1989 were droughty years. Figure 1 shows the lack of spring and early summer rainfall for these years and Figure 2 shows the unusually high temperatures during the summer of 1988. Periods of drought stress also occurred in 1991. Excessive rainfall and cool temperatures occurred during the late summer of 1992.

Estimated Soil Loss

Table 1 presents the estimated soil loss per year for the 13 cropping systems. During the initial year at Ames the systems were established following soybeans that had been chiseled in the fall of 1988 and at Chariton the systems followed red clover sod which was chemically killed in the spring of 1988. At Chariton the systems with sorghum, corn, or soybeans were disked in the spring, which accounted for the larger soil losses of these systems in 1988. At Ames, with essentially zero slope, soil losses for 1989-92 were under 0.25 Mg/ha per year for alfalfa, reed canarygrass, switchgrass, or big bluestem. This also was true for the two intercrop systems because of total year ground cover. For the row crop systems at Ames the losses were under 5 Mg/ha per year.

At Chariton, with previous red clover sod in 1987, estimated soil losses were reduced during 1988 compared to those at Ames for the perennial crop. For 1989 through 1992 losses in reed canarygrass, switchgrass, big bluestem were under 0.4 Mg/ha at Chariton. For sole alfalfa and alfalfa intercrop with sorghum the losses were 2 Mg/ha. The largest soil losses were with systems of corn, soybeans, and continuous sorghum cropping. Losses were approximately 40 Mg/ha. Fall planting of rye after sorghum reduced the losses to under 25 Mg/ha. In summary, the sloping soils at Chariton had large soil losses associated with continuous row cropping systems, that were reduced some by double cropping with fall seeded rye. For the other systems, including

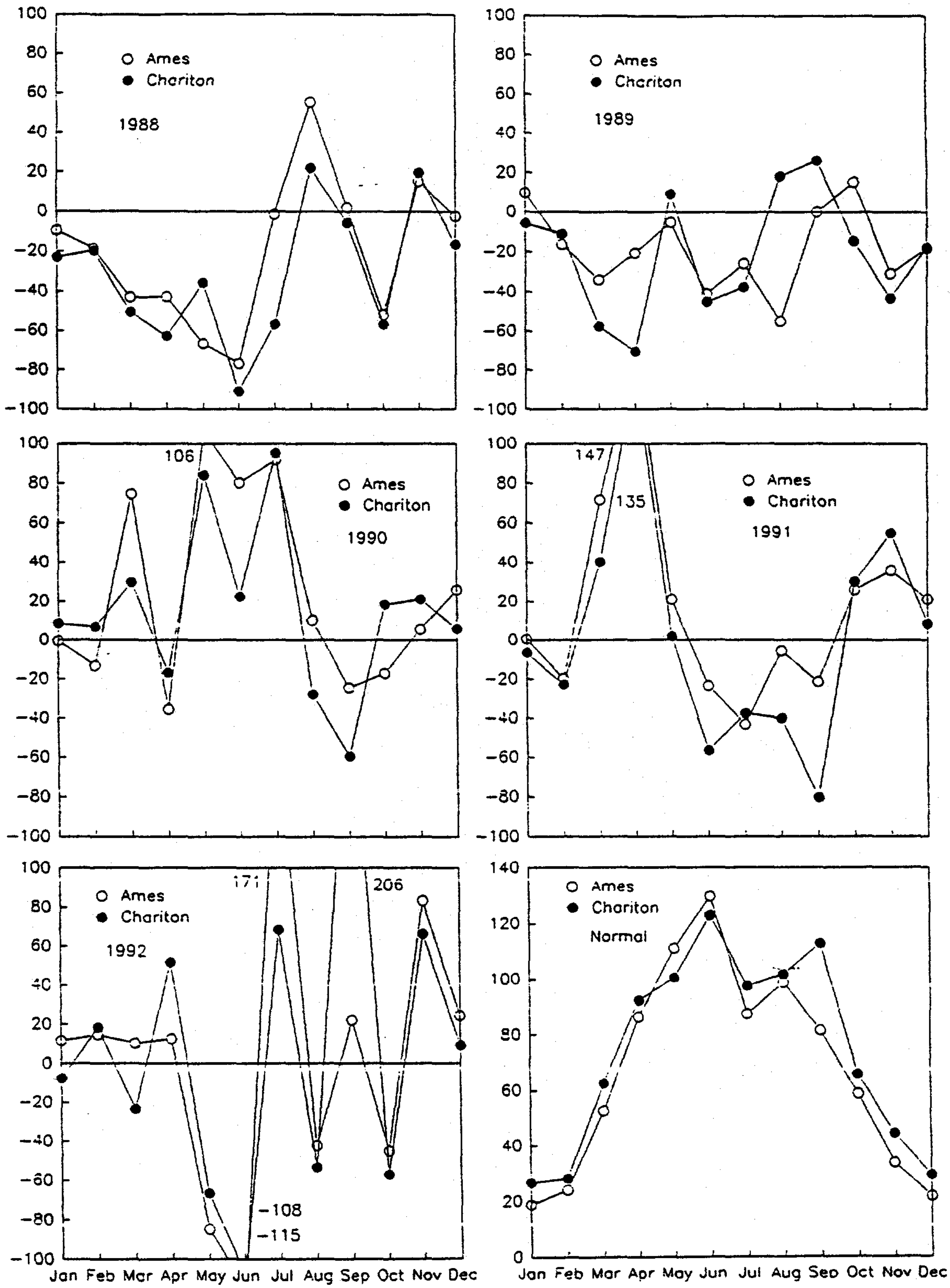

Figure 1. Deviations from normal precipitation (mm) during the growing seasons in 1988, 1989, 1990, 1991, and 1992.

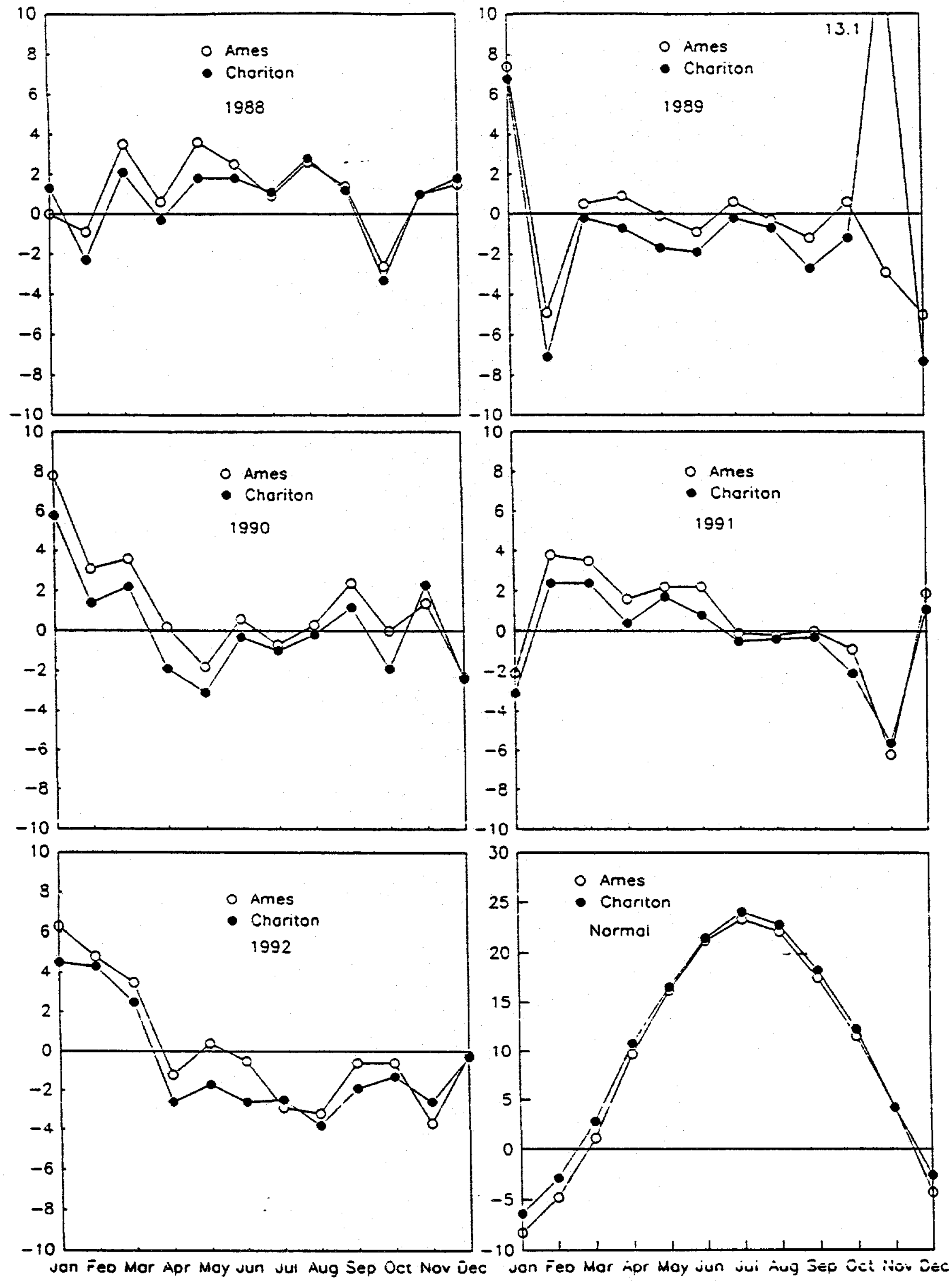

Figure 2. Deviations from normal temperatures (^0C) during the growing seasons in 1988, 1989, 1990, 1991, and 1992.

Table 1. Estimated soil loss (Mg/ha) for 13 cropping systems at two locations for five years using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

	CROPPING SYSTEM[†]													
	MONOCROP						DOUBLE CROP		ROTATION				INTERCROP	
Year	ALF	RCG	SWG	BBS	SS	SSH	SS/R	SSH/R	CORN	SB	SS/R	SS	ALF	RCG
							AMES							
1988	3.79	3.79	3.92	3.92	4.89	4.89	3.06	3.06	4.41	3.92	3.06	4.89	3.79	3.79
1989	0.25	0.04	0.04	0.04	4.89	4.89	3.06	3.06	4.41	4.88	3.06	4.89	0.25	0.04
1990	0.25	0.04	0.04	0.04	4.89	4.89	3.06	3.06	4.41	4.88	3.06	4.89	0.25	0.04
1991	0.25	0.04	0.04	0.04	4.89	4.89	3.06	3.06	4.41	4.88	3.06	4.89	0.25	0.04
1992	0.25	0.04	0.04	0.04	4.89	4.89	3.06	3.06	4.41	4.88	3.06	4.89	0.25	0.04
							CHARITON							
1088	1.90	1.94	1.85	1.99	13.89	13.13	22.27	22.27	13.89	14.53	22.02	11.46	2.02	1.96
1989	1.58	0.39	0.40	0.47	25.65	24.21	22.27	22.27	25.38	26.71	23.27	37.25	1.68	0.41
1990	1.58	0.31	0.33	0.36	35.62	33.62	22.27	22.27	33.52	35.26	22.27	35.62	1.68	0.41
1991	1.58	0.31	0.33	0.36	35.62	33.62	22.27	22.27	32.05	37.25	22.04	35.26	2.02	0.41
1992	1.58	0.31	0.33	0.36	35.62	33.62	22.27	22.27	31.73	35.62	23.27	37.25	2.02	0.41

[†]RCG=reed canarygrass, SWG=switchgrass, BBS=big bluestem, SWS=sweet sorghum, SSH=sorghum x sudangrass, SWS/R=sweet sorghum doublecropped with winter rye, SSH/R=sorghum x sudangrass doublecropped with winter rye, CORN=corn in a corn-soybean-sorghum three year rotation, and ROT=an average factor for plots in the corn-soybean-sorghum rotation.

intercropping of sorghum in alfalfa or reed canarygrass the losses were low and acceptable for sustainable agriculture.

Tables 2 and 3 present soil pH, soil K, and soil P for the cropping systems except for the sorghum interplanted in alfalfa or reed canarygrass (Table 2) and for rates of N (Table 3). The pH of soils at the two sites were widely different because of the high lime Harps soil at Ames. The effects of system, site x system, and N x system x site were not significant. The main effect of N rates decreased pH and the N x site was significant because the high lime soil at Ames buffered the pH at a value of about 8.0. The N x system interaction was significant at the 5% level but is difficult to interpret since there were no rates of N applied to the alfalfa.

The level of soil K was greater at Ames than at Chariton. Switchgrass, big bluestem and reed canarygrass used appreciably less K than did the other systems. Rates of N increased use of K as would be expected due to greater dry matter removal at high rates of N. The site x system interaction was significant and showed greater variations at Ames than at Chariton. The two other two-way and three-way interactions were not significant.

Soil test for available P on Harps soils are not useful because of the high lime effect; actually Harps soils seldom show any P deficiency. The effect of N and N x site showed greater use of P as N rate increased at the Chariton location. The other interactions were not significant.

System A, with Two or Three Cuttings Per Year

Table 4 presents yearly yield components for the two and three cut of alfalfa. Yield of dry matter and percentage dry matter at harvest were analyzed for 1989-92 at the two sites. The statistics below the means indicate that yield was greater at Ames, but year and number of cuts along with the site x year and year x cut interaction were significant. Three cuts yielded about 0.5 Mg/ha greater than the two cut. Except for 1988, the year of establishment, yield of alfalfa varied between 8-13 Mg/ha. Percentage dry matter is a weighted mean value for the cuts and reflects the maturity stage at harvest along with climate effects and some variation due to different dates of harvest at the two sites.

Table 2. Soil pH, soil potassium, and soil phosphorous in 1992 at two locations after five years of different cropping systems.

	CROPPING SYSTEM+									
Site	ALF	RCG	SWG	BBS	SWS	SSH	SWS/R	SSH/R	ROT	Mean
Soil pH (1992)										
Ames	8.03a*	8.06a	7.99a	7.99a	8.06a	7.97a	8.03a	8.01a	7.97a	8.01A
Chariton	6.88ab	6.71ab	6.89ab	6.59ab	6.91ab	7.00a	6.56b	6.76ab	6.86ab	6.80B
MEAN	7.46	7.38	7.44	7.29	7.48	7.49	7.30	7.39	7.42	7.41
Soil Potassium (mg/kg, 1992)										
Ames	147e	184c	222b	237a	144e	168d	148e	144e	173cd	174A
Chariton	125c	158a	148ab	162a	128c	127c	140bc	131c	136bc	139B
MEAN	136	171	185	200	136	147	144	137	154	157
Soil Phosphorous (mg/kg, 1992)										
Ames	4.5ab	4.0b	2.9b	8.9a	4.1ab	4.9ab	5.4ab	5.1ab	5.4ab	5.0B
Chariton	22.3c	26.1bc	30.1ab	31.6a	28.6abc	25.9bc	25.9bc	24.5c	26.6bc	26.8A
MEAN	13.4	15.1	17.6	20.3	16.4	15.4	15.6	14.8	16.0	16.1

+ALF=alfalfa (2 cut and 3 cut), RCG=reed canarygrass, SWG=switchgrass, BBS-big bluestem, SWS=sweet sorghum, SSH=sorghum x sudangrass, SWS/R=sorghum doublecropped with winter rye, SSH/R=sorghum x sudangrass doublecropped with winter rye, ROT=an average for the plots in the corn-soybean-sorghum three year rotation.

*Means for cropping systems at a site are not different at $P<0.01$ level if followed by the same letter. For the two site means, capital letters are used.

Table 3. Effect of N fertilization on soil pH, soil potassium, and soil phosphorous in 1992 at two locations after five years of different cropping systems listed in Table 2, except alfalfa was omitted

	N Rate (kg/ha)				
Site	0	70	140	280	Mean
			Soil pH (1992)		
Ames	8.02a*	8.03a	7.99a	7.99a	8.01A
Chariton	6.94a	6.92ab	6.86b	6.58c	6.82B
MEAN	7.48	7.48	7.43	7.29	7.42
			Soil Potassium (mg/kg, 1992)		
Ames	183a	165b	182a	176a	176A
Chariton	150a	139b	139ab	132b	140B
MEAN	167	152	160	154	158
			Soil Phosphorous (mg/kg, 1992)		
Ames	5.11a	3.60a	6.17a	6.22a	5.25
Chariton	30.83a	26.56b	26.06b	26.33b	27.44
MEAN	17.97	15.08	16.12	16.28	16.35

*Means for N level at a site are not different at P<0.01 if followed by the same letter. For the two site means capital letters are used.

Table 4. Means and statistics for System A, alfalfa with two or three cuttings per year

Year-N[a]	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	----------	----------	Mg/ha	----------	----------	----------		
				AMES				
1988-2	6.1	0.378	1.153	0.630	0.193		19.7	36.6
-3	6.2	0.371	1.218	0.634	0.198		29.2	37.5
1989-2	11.1	1.070	3.567	0.895	0.263	0.159	30.8	51.9
-3	12.9	1.022	3.459	1.259	0.360	0.219	24.7	46.2
1990-2	10.2	1.262	3.511	1.178	0.231	0.171	30.1	59.8
-3	12.1	1.251	3.548	1.473	0.310	0.200	27.0	53.6
1991-2	10.1						29.6	
-3	10.3						35.0	
1992-2	9.3						32.8	
-3	8.2						25.1	
				CHARITON				
1988-2								
-3								
1989-2	6.8	0.542	1.874	0.806	0.183	0.102	28.7	49.0
-3	7.6	0.539	1.788	0.773	0.216	0.138	26.8	42.3
1990-2	9.9	1.191	3.497	1.242	0.227	0.178	28.2	61.4
-3	11.0	1.018	3.147	1.408	0.312	0.244	23.5	51.4
1991-2	7.4						38.1	
-3	9.1						28.9	
1992-2	8.9						32.9	
-3	6.7						24.4	
				STATISTICS				
		$x10^{-2}$	$x10^{-2}$	$x10^{-2}$	$x10^{-3}$	$x10^{-3}$		
Site	118*						3	
Year	26**	35*	1	50**	1.5**	0	195**	469**
Cut	3	1	1	87*	6.1**	15.8**	600**	287**
SxY	18**						22**	
SxCut	1						80**	
YxCut	14**	1	4	1	0	2.0	53**	1
SxYxC	3						48**	

*Significant at $P < 0.05$ in this and all following tables.
**Significant at $P < 0.01$ in this and all following tables.
[a]Number of harvests per year.

The cell wall components and minerals were analyzed only for the Ames site for 1988-90. Except for cellulose, year and number of cuts frequently were significant. Compared to the perennial grasses in the other systems, percentage of neutral detergent fiber of alfalfa was less, indicating a greater amount of cell soluble components.

System B, Reed Canarygrass

Table 5 presents the data obtained for reed canarygrass. Dry matter yield and % DM were statistically analyzed for 1989-90 at Ames, but values are given for other years and for Chariton. Both year and rate of N were usually highly significant. Percentage dry matter values at harvest were about 10% greater than those for alfalfa. Reed canarygrass, in contrast to the other systems, had large responses to the highest rate of N supplied.

System C, Switchgrass

The results for switchgrass are presented in Table 6. Dry matter yield and percentage dry matter at harvest were analyzed at both sites for three years, 1990-92. The stand of switchgrass at Chariton was poor until 1990 but satisfactory at Ames. The main effect of site was not significant i.e., the mean yield for the three years at the two sites was similar. The site x year interaction was significant, but mainly due to the new stand of switchgrass at Chariton in 1990. Nitrogen fertilizer increased dry matter yield. Most of the N response was between the 0 and 70 kg/ha rate. The response between 70 and 140 rates usually was small. The site x N and year x N interactions were significant and again mainly due to newer stand of switchgrass at Chariton in 1990. At harvest switchgrass was relatively dry with dry matter percentages between 40-70 percent.

The cell wall and mineral components of switchgrass were analyzed only at Ames for 1989-90. Percentage NDF values were large indicating a large portion of the crop was cell wall fiber. The amount of N and K removed by the crop were small. Rates of N increased the amounts of N removed by the crop from 26 kg/ha in 1989 at the zero N rate to 104 kg for rate 4 (280 kg N/ha) in 1990. Years usually had a significant effect on the measured attributes with greater values in 1990 than in 1989.

System D, Big Bluestem

Big bluestem results are presented in Table 7. Dry matter yields and percentage dry matter were analyzed for the four years, 1989-92, at Ames and Chariton. The main effect of site was significant with greater dry matter yield at Ames than at Chariton. The main effect of years also varied from low values in 1989 and 1991 to greater yields in 1990 and 1992. Fertilizer N also increased yield. As for switchgrass, there was a large response between 0 and 70 kg/ha of N and except in 1992 little response above 140 kg/ha. Big bluestem had slightly greater percentage of dry matter at harvest than did

Table 5. Means and statistics for System B, reed canarygrass

Year-N[a]	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	----------	----------	----------	Mg/ha	----------	----------		
				AMES				
1988-1	5.97	0.298	1.542	1.564	0.076			
-2	5.2	0.208	1.447	1.368	0.069			
-3	5.5	0.234	1.580	1.485	0.858			
-4	5.2	0.300	1.447	1.338	0.071			
1989-1	3.0	0.113	0.838	0.680	0.033	0.047	38.7	59.3
-2	5.8	0.203	1.777	1.386	0.072	0.064	34.7	61.2
-3	7.9	0.316	2.464	1.951	0.111	0.120	33.0	63.2
-4	10.0	0.406	3.173	2.255	0.176	0.158	32.2	61.2
1990-1	5.8	0.220	1.652	1.517	0.071	0.071	42.6	63.9
-2	7.2	0.304	2.260	1.901	0.086	0.108	37.1	65.4
-3	10.3	0.432	3.356	2.660	0.133	0.166	34.7	65.9
-4	11.6	0.570	4.193	2.446	0.172	0.205	31.9	68.8
1991-1	4.6						34.3	
-2	6.8						34.3	
-3	7.9						32.1	
-4	11.4						31.4	
1992-1	2.9						45.3	
-2	4.5						38.8	
-3	6.8						35.4	
-4	12.3						34.8	
				CHARITON				
1990-1	7.1	0.291	1.226	1.840	0.086	0.100	35.8	66.9
-2	11.3	0.689	4.986	3.345	0.197	0.195	34.0	67.6
-3	11.8	0.411	3.891	3.025	0.143	0.120	36.2	68.3
-4	13.1	0.392	3.695	2.75	0.170	0.125	33.0	66.5
1991-1	4.8						38.8	
-2	7.9						40.2	
-3	9.9						38.7	
-4	10.5						39.1	
1992-1	6.3						34.0	
-2	7.9						32.7	
-3	10.9						35.7	
-4	12.8						34.0	
				STATISTICS				
		$\underline{X10^{-2}}$			$\underline{X10^{-3}}$	$\underline{X10^{-3}}$		
Site Year	16**	12**	5.1**	3.8**	2.4	13**	91**	183**
N	153**	16**	9.0**	3.6**	22.5**	24**	181**	19**
YxN	3	1	0	0	0.5	0	11	80**
SxYxN	0	0	0	0	0	0	0	0

[a]Rate 1,2,3,4 = 0, 70, 140, 280 kg/ha of N fertilizer in this and all following tables.

Table 6. Means and statistics for System C, switchgrass

Year-N	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	---------	---------	Mg/ha	---------	---------	---------		
				AMES				
1988-1	8.1	0.411	2.462	2.413	0.081		42.2	66.9
-2	7.7	0.349	2.351	2.333	0.081		42.0	66.7
-3	8.3	0.421	2.305	2.384	0.088		41.7	65.9
-4	7.9	0.397	2.401	2.497	0.083		40.9	66.6
1989-1	5.0	0.223	1.715	1.300	0.026	0.034	48.2	66.9
-2	8.0	0.445	2.772	2.431	0.048	0.051	47.9	73.0
-3	8.3	0.532	3.201	2.113	0.045	0.069	46.2	73.9
-4	8.1	0.474	3.108	2.181	0.057	0.071	45.5	73.0
1990-1	7.2	0.545	2.734	2.149	0.031	0.046	52.6	76.4
-2	11.6	0.974	4.851	3.198	0.061	0.091	50.6	79.7
-3	10.6	1.023	4.453	2.745	0.081	0.079	50.1	78.2
-4	13.3	1.286	5.442	3.605	0.104	0.088	51.3	78.7
1991-1	4.9						67.1	
-2	11.2						65.0	
-3	10.3						67.3	
-4	9.5						64.8	
1992-1	7.2						45.2	
-2	13.8						44.6	
-3	15.3						42.9	
-4	15.9						42.2	
				CHARITON				
1990-1	5.8	0.461	2.150	1.691	0.050	0.052	45.2	75.9
-2	6.6	0.517	2.649	1.745	0.049	0.059	45.3	75.5
-3	8.3	0.672	3.248	2.351	0.068	0.067	43.9	76.8
-4	8.3	0.593	3.193	2.378	0.087	0.078	45.0	74.5
1991-1	7.8						61.3	
-2	8.9						59.0	
-3	10.7						58.7	
-4	10.9						58.7	
1992-1	9.7						44.4	
-2	12.4						41.8	
-3	15.8						40.1	
- 4	17.4						39.5	
				STATISTICS				
					$x10^{-3}$	$x10^{-3}$	$x10^{-1}$	x10
Site	12						61**	
Year	200**	2.1**	22	6.7**	5**	3.0	347**	343*
N	140**	3.5**	6**	2.3**	4**	2.5*	3**	39
SxY	40						5	
SxN	18**						0.2	
YxN	11**	1.0**	1*	0.2	1*	0.3	0.6	0
SxYxN	2						0.3	

Table 7. Means and statistics for System D, big bluestem

Year-N	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	----------	----------	Mg/ha	----------	----------	----------		
				AMES				
1988-1	6.8	0.457	2.084	1.978	0.066		41.4	64.9
-2	5.7	0.273	1.674	1.826	0.057		41.0	67.6
-3	6.4	0.351	2.005	1.981	0.057		41.4	70.9
-4	5.5	0.272	1.687	1.493	0.061		37.7	68.1
1989-1	6.2	0.347	2.616	1.708	0.020	0.056	54.4	77.7
-2	6.9	0.493	2.960	1.793	0.022	0.071	53.1	75.7
-3	6.4	0.288	2.556	1.775	0.030	0.031	52.5	73.1
-4	8.2	0.543	3.462	2.224	0.049	0.047	52.2	77.8
1990-1	10.7	0.680	5.029	2.965	0.045	0.066	64.0	82.6
-2	10.7	0.906	4.844	2.970	0.054	0.068	63.6	83.1
-3	11.4	0.835	5.068	3.072	0.060	0.074	61.4	81.3
-4	11.9	1.031	5.410	3.224	0.064	0.072	62.5	82.4
1991-1	7.3						80.8	
-2	8.3						81.4	
-3	7.7						79.6	
-4	6.9						79.1	
1992-1	8.4						45.1	
-2	11.1						50.7	
-3	12.4						46.5	
-4	14.3						46.3	
				CHARITON				
1988-1								
-2								
-3								
-4								
1989-1	3.1	0.226	1.052	0.043	0.034	0.018	65.4	72.0
-2	3.1	0.131	1.112	0.824	0.029	0.019	59.2	67.8
-3	2.9	0.161	1.062	0.811	0.028	0.016	62.1	69.7
-4	3.0	0.201	1.069	0.864	0.028	0.026	64.4	69.9
1990-1	7.3	0.623	3.027	1.919	0.057	0.049	52.9	78.1
-2	9.7	0.774	4.252	2.739	0.081	0.068	55.3	81.6
-3	9.4	0.798	4.266	2.478	0.066	0.089	55.0	83.9
-4	9.4	0.881	3.859	2.417	0.108	0.084	54.5	79.0
1991-1	5.5						71.5	
-2	5.5						73.2	
-3	6.4						74.7	
-4	5.5						71.9	
1992-1	5.8						53.4	
-2	9.2						52.3	
-3	10.5						46.6	
- 4	12.8						48.6	
				STATISTICS				
		$X10^{-2}$	$X10^{-1}$	$X10^{-1}$	$X10^{-4}$	$X10^{-4}$	$X10^{-1}$	X10
Site	95**						40*	
Year	132**	158**	383**	111**	54**	27	636**	315*
N	27**	12*	7	2	8**	4	2	15
SxY	2						33**	
SxN	1						0	
YxN	16**	2	2	0	2	8	1	6
SxYxN	1						2	

switchgrass. Cell wall components and minerals were analyzed only at Ames for the year 1989-90 because of the below average stand at Chariton in 1989. Most of the attributes were significantly greater in 1990 than in 1989. Rates of N increased N removal from the soil, but as with switchgrass the amount of N removed was about 75 kg/ha for yields of 12 Mg/ha. The NDF values were in the 80 percent level which is indicative that big bluestem is a more stemmy feedstock than switchgrass.

System E, Sweet Sorghum Monoculture

Tables 8A and 8B present the results for sweet sorghum as a continuous monocrop for five years. Sites and replications in sites were the first partition. Year was the main plot with N rates as subplots. Dry matter yield and percentage dry matter were analyzed for the combination of two sites and 5 years.

The year and N effects significantly affected dry matter yield and their interaction showed little response from N rates during the first 2 years of the study. The greatest yields were in 1990. Percentage dry matter (Table 8B), as a measure of maturity, was affected by site, year and their interaction. Rate of N had no effect on percentage dry matter. The most mature crop was that of 1990.

Yields of cell wall components, N, percentage N, and NDF were analyzed for 1985-90 at both sites. Site and year had small effects on yield of cell wall components but N level had a larger effect, as would be expected since N also affected dry matter yield. Percentage of total cell wall components (Table 8B), NDF, was affected by most of the treatments with the largest effects of N, year x site, and year x N. Rates of N tended to increase NDF in 1988, had little effect in 1989, and tended to decrease NDF in 1990.

Yield of N was appreciably greater at Chariton than at Ames and the only other variable affecting yield of N was N rates. Tissue N was affected by N rates, with a greater percentage of N at Chariton than Ames and with greater percentages for 1989 than 1988 or 1990.

Components of sugar yield (Table 8A), and percentage total sugar (Table 8B) were analyzed for 1988-91 at both sites. In forage samples frozen upon

Table 8A. Means and statistics for system E, sweet sorghum monoculture.

Year-n	DM yld	Lignin	Cell	Hemi	Red. Sugar	Suc	Total sugar	N	K
				Mg/ha					
				Ames					
88-1	15.1	0.606	4.57	2.94				0.090	
2	15.3	0.707	4.45	2.95				0.115	
3	17.5	0.826	4.94	3.76				0.149	
4	16.7	0.728	4.88	3.81				0.152	
89-1	16.3	0.546	5.00	3.44	1.99	1.94	3.93	0.103	0.092
2	16.1	0.746	4.81	3.29	2.02	1.70	3.72	0.164	0.124
3	15.3	0.812	4.54	3.43	2.36	1.68	4.04	0.142	0.130
4	15.0	0.548	4.59	3.32	2.13	1.25	3.39	0.169	0.124
90-1	11.4	0.441	4.04	2.50	1.33	1.09	2.43	0.087	0.131
2	15.3	0.614	4.87	2.86	1.77	1.94	3.71	0.138	0.141
3	20.7	1.000	6.01	4.10	2.47	2.99	5.47	0.186	0.194
4	19.6	0.812	5.98	3.84	2.38	2.26	4.61	0.191	0.161
91-1	13.5				2.17	1.15	3.33		
2	16.7				2.95	1.35	4.30		
3	16.5				3.03	1.44	4.48		
4	16.3				3.04	1.07	4.11		
92-1	8.6								
2	17.7								
3	17.4								
4	16.4								
				CHARITON					
88-1	17.8	0.824	5.00	3.67				0.141	
2	16.8	0.753	4.76	3.87				0.169	
3	17.9	0.709	4.87	4.42				0.177	
4	19.3	0.762	5.33	4.52				0.215	
89-1	16.1	0.624	4.86	3.55	2.12	1.48	3.60	0.167	0.106
2	15.8	0.677	4.54	3.68	2.17	1.17	3.34	0.179	0.098
3	15.6	0.561	4.58	3.49	2.09	1.28	3.37	0.189	0.161
4	16.4	0.562	5.10	3.65	2.25	1.49	3.75	0.194	0.153
90-1	16.4	0.769	4.83	3.20	1.98	1.97	3.95	0.127	0.112
2	20.7	0.731	5.38	3.70	2.73	2.49	5.23	0.193	0.183
3	22.9	0.959	6.22	3.90	2.94	2.87	5.82	0.195	0.195
4	19.1	1.130	5.27	3.39	2.45	2.01	4.46	0.185	0.154
91-1	13.5				1.77	1.84	3.58		
2	17.7				2.87	2.08	4.95		
3	16.8				2.84	1.80	4.65		
4	17.2				2.80	2.10	4.91		
92-1	8.7								
2	16.1								
3	16.7								
4	16.5								
				STATISTICS					
		$x10^{-1}$						$x10^{-2}$	$x10^{-3}$
Site	42.3	0.7	0.70	3.86*	0.34	1.17	2.78	3.0**	113**
Year	56.4**	2.4	2.98	0.87	2.64*	4.65**	5.93*	0.2	283
N	128.4**	1.3*	1.52**	2.14**	2.50**	0.80*	5.63**	1.9**	23**
SxY	15.4	1.1	0.12	0.76	1.24	1.94	2.35	0.1	149**
SxN	2.0	1.3*	0.11	0.40	0.15	0.21	0.47	0.1	0
YxN	30.3**	1.1**	1.58**	0.68	0.46**	1.03**	2.50**	0.1	8
SxYxN	4.8	0.1	0.53	0.24	0.10	0.38	0.75	0.1	3

Table 8B. Means and statistics for system E, sweet sorghum monoculture.

Year-n	DM	Total sugar	N	K	NDF
	----------	----------	% ----------	----------	----------
			AMES		
88-1	20.5		0.597		55.3
2	19.8		0.757		54.7
3	20.2		0.853		55.7
4	20.0		0.906		57.9
89-1	31.5	24.1	0.630	0.56	57.5
2	31.8	23.2	1.015	0.77	57.5
3	28.5	26.4	0.927	0.85	56.8
4	29.2	22.9	1.099	0.81	57.8
90-1	31.2	21.3	0.771	1.15	63.1
2	33.0	23.8	0.891	0.97	55.4
3	32.5	26.4	0.903	0.94	54.8
4	32.6	23.6	0.952	0.83	54.8
91-1	24.1	24.4			
2	23.0	25.8			
3	23.2	27.1			
4	21.9	25.4			
92-1	24.0				
2	23.6				
3	23.4				
4	23.5				
			CHARITON		
88-1	23.7		0.794	0.64	53.7
2	22.9		1.006	1.37	56.9
3	23.3		0.972	0.89	56.9
4	26.7		1.115	1.01	57.1
89-1	27.5	22.0	1.030	0.69	57.0
2	27.1	21.4	1.128	0.64	56.5
3	27.7	21.6	1.212	1.04	56.8
4	27.8	22.9	1.178	0.93	58.3
90-1	35.1	24.0	0.760	0.70	54.0
2	33.1	25.1	0.922	0.88	48.0
3	34.0	25.4	0.854	0.85	49.3
4	33.8	23.4	0.977	0.80	51.6
91-1	28.8	26.3			
2	25.5	27.9			
3	25.6	27.8			
4	25.3	28.6			
92-1	26.6				
2	28.3				
3	26.6				
4	26.6				
			STATISTICS		
			$x10^{-1}$	$x10^{-1}$	$x10^{-2}$
Site	144**	0.7	4.5**	64**	105*
Year	588**	107.6*	2.4**	83**	94**
N	4	18.0*	3.2**	5*	20*
SxY	59**	36.7	1.1	58**	105**
SxN	3	9.1	0.1	1	8
YxN	4	4.0	0.0	5*	37**
SxYxN	4	2.9	0.2	1	5

harvest the ratio of sucrose to reducing sugar of M81E in our other studies is about 2 whereas in this study the ratio was 0.5. We microwaved the fresh samples and tried to dry them in an oven as soon as possible, but because of the large number of samples, these procedures usually were not timely and were not effective in preventing tissue invertase from converting sucrose to glucose and fructose. Possibly some sugar also was repired so the values for sugar herein are minimal values. Site did not affect sugar yield or percentage. Level of N increased sugar yield and percentage sugar. Sugar yields were greatest in 1990 and least in 1989. The highest rate of N tended to decrease the percentage sugar indicating that greater than optimum rates prolonged vegetative development and thereby delayed differentiation.

Yield of K and percentage K were analyzed for 1989-90. Yield of K was greater at Chariton than Ames, increased by N, and had a significant site x year interaction. Percentage K of forage was greater at Chariton than Ames and varied for year, and site x year.

System F, Monoculture of Sorghum x Sudangrass Hybrid

The results for monoculture of the sorghum x sudangrass hybrid are presented in Tables 9A and 9B. The attributes were analyzed across the same site-year-N combinations as reported for System E. Dry matter yield was affected by year, and N rate but not by site, which was similar to the response shown by System E. The site x year interaction was significant indicating less agreement of the two sites during a year. The variables affected percentage dry matter much like they did for System E. Yield of the three cell wall components was affected by N rate as for System E, but with less year x N effect and a greater site x year effect on cellulose. Again NDF was affected very similarly to that in System E. As in System E, yield of N was greater at Chariton than Ames with no interaction due to site, year, and N rate effects. Percentage N of tissue was affected by site and rate of N but no other treatment combinations had significant effects.

Sugar yields of the forage type sorghum were about 0.5 of those of sweet sorghum in System E. There was little effect of site, year, or N rate, but

Table 9A. Means and statistics for System F, SSH sorghum monoculture.

Year-n	DM yld	Lignin	Cell	Hemi	Red. sugar	Suc	Total sugar	N	K
	----------	----------	----------	----------	Mg/ha	----------	----------	----------	----------
					AMES				
88-1	14.4	0.867	4.19	3.12				0.100	
2	13.6	0.666	3.92	3.08				0.083	
3	14.6	0.903	4.41	3.02				0.111	
4	14.7	0.824	4.13	3.10				0.146	
89-1	13.1	0.455	3.87	2.43	0.792	1.98	2.78	0.083	0.126
2	14.7	0.511	4.59	2.64	1.102	2.26	3.37	0.113	0.175
3	16.3	0.737	4.68	3.03	1.069	1.98	3.05	0.152	0.228
4	16.4	0.663	4.93	2.74	1.203	1.90	3.11	0.188	0.150
90-1	10.8	0.584	3.20	2.37	0.680	0.78	1.46	0.077	0.148
2	11.4	0.621	3.13	2.13	0.733	0.70	1.43	0.101	0.140
3	15.3	0.794	4.28	2.70	0.884	0.78	1.66	0.158	0.178
4	16.9	0.998	4.56	3.05	0.850	0.97	1.82	0.194	0.213
91-1	14.3				0.949	1.37	2.32		
2	16.3				1.262	1.27	2.53		
3	16.7				1.295	1.18	2.41		
4	14.1				0.878	0.97	1.85		
92-1	11.5								
2	15.1								
3	15.6								
4	16.7								
					CHARITON				
88-1	12.8	0.54	3.81	3.18				0.150	0.195
2	14.1	0.51	3.89	3.54				0.189	0.150
3	13.9	0.67	3.68	3.42				0.191	0.151
4	14.0	0.84	3.76	3.45				0.190	0.191
89-1	15.1	0.74	3.46	2.97	0.83	0.81	1.65	0.179	0.133
2	14.2	0.66	3.51	2.93	0.70	0.52	1.23	0.205	0.149
3	13.5	0.57	3.19	2.55	0.71	0.46	1.18	0.189	0.072
4	15.7	0.69	3.56	3.59	0.83	0.73	1.56	0.238	0.189
90-1	15.2	0.83	3.38	2.45	0.68	1.19	1.87	0.147	0.144
2	20.4	1.03	4.14	3.01	1.02	1.36	2.38	0.223	0.198
3	21.8	1.02	4.65	3.71	1.03	1.42	2.45	0.269	0.180
4	22.7	1.14	4.58	3.19	1.00	1.26	2.26	0.315	0.222
91-1	14.1				0.79	1.40	2.20		
2	16.5				0.92	1.32	2.25		
3	16.4				0.90	1.23	2.13		
4	16.9				1.03	1.42	2.46		
92-1	8.7								
2	12.9								
3	12.6								
4	17.0								
					STATISTICS				
								$x\ 10^{-2}$	$x\ 10^{-3}$
Site	27.8	0.07	3.1	3.42	0.25	1.45	2.89	15.9**	133*
Year	50.9*	0.49	0.003	1.67	0.17	0.66	1.21	1.3	132**
N	89.1**	0.21*	1.78*	0.88	0.19*	0.04	0.11	3.5**	5
SxY	86.0**	0.37	4.39*	0.13	0.39	8.25**	11.4**	0.4	107*
SxN	5.8	0.04	0.477	0.12	0.04	0.04	0.14	0.2	11
YxN	15.3	0.04	0.93	0.38	0.04	0.06	0.15	0.4	2
SxYxN	4.8	0.05	0.258	0.53	0.09	0.13	0.37	0.1	5

Table 9B. Means and statistics for system F, SSH sorghum monoculture.

Year-n	DM	Total sugar	N	K	NDF
	%				
			AMES		
88-1	27.7		0.71		59.3
2	27.4		0.61		57.7
3	25.1		0.78		57.8
4	26.6		1.00		57.3
89-1	35.2	21.8	0.58	1.01	54.6
2	33.9	23.7	0.78	1.16	56.0
3	33.2	19.4	0.92	1.44	53.7
4	31.2	19.9	1.10	0.92	52.7
90-1	35.6	13.5	0.70	1.43	57.3
2	37.1	13.3	0.84	1.29	53.5
3	36.9	12.6	0.95	1.20	55.4
4	36.3	10.6	1.16	1.26	51.9
91-1	29.9	16.2			
2	29.9	15.9			
3	28.5	14.1			
4	29.4	13.0			
92-1	25.2				
2	25.0				
3	23.9				
4	23.5				
			CHARITON		
88-1	33.1		1.16	1.50	61.9
2	36.4		1.34	1.07	59.2
3	35.8		1.39	1.06	58.6
4	35.4		1.37	1.32	58.7
89-1	37.7	11.2	1.18	0.87	49.3
2	36.6	08.6	1.47	1.05	51.1
3	31.3	08.5	1.40	0.54	47.6
4	37.5	10.1	1.52	1.17	49.7
90-1	45.1	12.1	1.02	0.87	44.1
2	44.9	11.9	1.06	0.97	40.9
3	43.5	11.7	1.22	0.89	45.1
4	45.7	10.1	1.38	0.97	40.3
91-1	34.2	15.7			
2	34.9	13.6			
3	35.1	13.0			
4	33.4	14.5			
92-1	30.7				
2	30.1				
3	29.4				
4	28.4				
			STATISTICS		
				$x10^{-1}$	$x10^{2}$
Site	1378**	468**	4.81**	104**	616**
Year	814**	100**	0.06	80**	879**
N	16	23	0.57**	1	27
SxY	52*	309**	0.22	31**	365**
SxN	3	12	0.04	3	1
YxN	6	3	0.02	0	18
SxYxN	9	3	0.02	2	3

the site x year interaction was significant for sucrose and total sugar because of the very low yields of sucrose in 1989 at the Chariton site, but normal yields at Ames. The percentage sugar in forage was affected by site, year, and their interaction but not by N rate. The unusually low sucrose yield in 1989 at Chariton appeared to be real, but is difficult to explain.

The K uptake was greater in 1991 in agreement with greater dry matter yields and there was a minor effect of site and the site x year interaction. Percentage K of tissue was greater at Ames. In 1989, K percentages were similar at the two sites, but in 1990 the K percentages were much greater at Ames than at Chariton.

System G, Sweet Sorghum Portion of the Double Crop with Rye

The combinations of sites, years and N rates analyzed for each of the measured attributes were the same as for the monocrop of sorghum (System E). Dry matter yields were similar for the two locations, but significantly affected by year and rate of N (Tables 10A and 10B). None of the interactions were significant. During the droughty years of 1988 and 1989, sorghum yields were much reduced due to fall seeded rye using appreciable amounts of soil moisture before sorghum was planted. During the remaining three years, sorghum yield approached that of the monocropped sorghum. With adequate moisture there was a large response due to rate of N. Monocropped sorghum reached maximum yields with 70 to 140 kg/ha of N (Table 8A) whereas the double cropped with rye responded to the 280 kg/ha rate.

Percentage dry matter of the forage in System G usually was less than that of the monocropped sorghum. Both systems were harvested the same day. During the unusually dry and hot season of 1988, the double cropped sorghum had dry matter percentage of about 16 and 14 at Ames and Chariton, respectively,

whereas the monocropped had values of 20 and 24. The difference could be explained by drought imposed by the rye in delaying plant development. Rates of N had no effect, but the site and year along with the year x site, and year x N interactions were significant due to varying effects of the rye crop between years on growth, development, and response to N of sorghum.

Table 10A. Means and statistics for system G, sweet sorghum portion of the double crop with rye.

Year-n	DM yld	Lignin	Cell	Hemi	Red. Sugar	Suc	Total sugar	N	K
	---------- Mg/ha ----------								
				AMES					
88-1	4.8	0.170	1.59	1.32				0.031	
2	6.7	0.220	2.11	1.89				0.058	
3	6.8	0.322	2.18	1.77				0.072	
4	6.7	0.282	1.91	1.83				0.093	
89-1	7.8	0.370	2.33	2.01	0.80	0.66	1.46	0.064	0.121
2	11.8	0.546	3.69	2.85	1.28	1.19	2.47	0.110	0.147
3	13.6	0.537	4.27	2.67	1.58	1.19	2.77	0.093	0.100
4	14.8	0.773	5.09	3.38	1.71	1.19	2.90	0.196	0.248
90-1	9.8	0.518	3.35	2.34	1.13	0.59	1.69	0.076	0.140
2	11.7	0.570	4.02	2.55	1.50	0.97	2.47	0.085	0.145
3	14.0	0.667	5.07	3.21	1.49	0.90	2.49	0.135	0.164
4	12.8	0.579	4.23	2.96	1.63	0.92	2.56	0.130	0.144
91-1	6.6				0.53	0.42	0.95		
2	9.4				1.01	0.65	1.66		
3	15.5				2.02	1.18	3.27		
4	15.1				1.84	1.29	3.13		
92-1	10.0								
2	12.7								
3	14.3								
4	16.3								
				CHARITON					
88-1	5.8	0.212	1.74	1.65				0.095	
2	5.1	0.143	1.59	1.53				0.094	
3	4.9	0.134	1.46	1.43				0.103	
4	5.9	0.174	1.77	1.61				0.106	
89-1	9.4	0.399	2.98	2.46	0.89	0.48	1.37	0.117	0.118
2	9.3	0.385	2.98	2.26	1.15	0.37	1.53	0.136	0.143
3	9.3	0.303	3.01	2.27	1.14	0.29	1.44	0.150	0.105
4	10.4	0.359	3.29	2.65	1.25	0.33	1.58	0.163	0.148
90-1	8.4	0.265	2.79	2.17	0.86	0.59	1.45	0.064	0.118
2	8.4	0.450	2.78	1.82	1.01	0.69	1.71	0.062	0.102
3	14.1	0.666	4.17	2.87	1.35	1.79	3.14	0.104	0.132
4	19.4	0.962	5.12	3.84	2.12	2.08	4.21	0.219	0.156
91-1	6.9				0.62	0.81	1.44		
2	13.4				1.50	1.78	3.29		
3	15.1				2.05	2.13	4.17		
4	17.2				2.63	1.84	4.47		
92-1	6.1								
2	9.8								
3	11.9								
4	14.8								
				STATISTICS					
		$x10^{-1}$						$x10^{-2}$	$x10^{-3}$
Site	23	2.0*	6.27*	0.82	0.12	1.18	0.54	1.2*	43*
Year	246**	11.8**	40.59**	11.18**	1.19	4.35*	10.09*	1.8**	1
N	256**	1.7**	6.00**	2.31**	10.85**	5.53**	31.57**	2.6**	7
SxY	26	0.8	0.45	0.11	3.24**	12.60**	28.23**	0.2*	7**
SxN	9	0.1	1.31*	0.69	0.80**	0.04	0.83	0.1*	1
YxN	20	0.5	1.42**	0.73	0.92**	0.45*	1.91**	0.3**	4
SxYxN	14	1.1**	1.46**	0.51	0.60**	1.40**	3.45**	0.5**	3

Table 10B. Means and statistics for system G, sweet sorghum portion of the double crop with rye.

Year-n	DM	Total sugar	N	K	NDF
	------------------	------------------	%	------------------	------------------
			AMES		
88-1	17.3		0.646		67.8
2	17.3		0.891		65.9
3	15.1		1.076		63.8
4	14.0		1.431		62.0
89-1	27.1	18.7	0.805	1.47	60.5
2	28.9	20.9	0.959	1.31	59.9
3	26.5	20.4	0.677	0.71	55.4
4	29.3	19.6	1.299	1.64	64.0
90-1	27.1	17.3	0.782	1.44	64.6
2	29.4	21.1	0.742	1.26	61.7
3	30.5	17.1	0.973	1.17	64.9
4	29.1	20.0	0.972	1.11	61.3
91-1	17.4	14.4			
2	24.8	17.7			
3	25.5	21.1			
4	25.6	20.7			
92-1	22.4				
2	22.9				
3	21.7				
4	21.9				
			CHARITON		
88-1	14.3		1.68		64.3
2	14.4		1.84		65.6
3	14.6		2.08		62.5
4	14.7		1.81		62.0
89-1	25.6	14.6	1.30	1.32	63.2
2	23.1	16.5	1.51	1.66	61.0
3	24.2	15.5	1.61	1.13	63.2
4	24.3	15.2	1.56	1.37	60.6
90-1	30.4	17.3	0.76	1.45	63.4
2	33.8	20.3	0.73	1.20	60.6
3	35.7	22.3	0.73	0.95	54.7
4	36.7	21.7	1.13	0.79	51.8
91-1	30.2	20.9			
2	29.7	24.6			
3	28.4	27.6			
4	26.8	26.0			
92-1	25.8				
2	27.0				
3	28.1				
4	26.7				
			STATISTICS		
				$x10^{-1}$	x10
Site	93**	2.0	5.02**	34*	58
Year	1166**	63.5	2.75**	104**	139*
N	1	109.3**	0.59**	4	68
SxY	122**	360.7**	1.59**	29**	114
SxN	5	5.0	0.10*	2	20
YxN	12**	23.7**	0.07	4	27
SxYxN	6**	32.7**	0.15**	1	38

The yield of cell wall components were affected by year and N rate with smaller variations due to site. Most of the N effect was due to dry matter yield and the year effect from variation in dry matter yield due to variation in moisture stress. For the cellulose component of cell walls, the interactions of N x site, and N x year were significant whereas they were not with monocropped sorghum. Again the interactions appeared to be due to variations in drought imposed by the rye crop.

Rates of N had a large effect on sugar yields through the effect of N on dry matter yield. All three of the sugar components were affected by rate of N, site x year, and N x year. Nitrogen yield of the forage was affected by site, year, N rate, and all their interactions. The K yield of the forage was greater at Ames and the site x year interaction was significant.

Percentage total sugar tended to be increased by increasing rates of N. The increased biomass resulting from higher N rates had proportionally greater percentages of sugar than that with lower rates of N. The effect of N rate on increasing percentage of sugar was significant along with the site x year and year x N interactions.

Percentage N of tissue increased as N rate increased. Site, year, and N rate along with most of their interactions were significant. Percentage K was affected by year, site, and their interaction. The large dry matter yield response to rates of N at Chariton in 1990 shows the dilution of K by the increased production. There was a small effect of year on NDF but no significant effect of N in decreasing NDF as with monoculture sweet sorghum.

Table 11 presents some of the yield components of combined sweet sorghum and rye biomasses of System G. During the droughty years of 1988 and 1989, monocropped sweet sorghum (Table 8A) had greater biomass yields than the combined dry matter yields of sorghum plus rye. This was

Table 11. Means and statistics for System G, total biomass of sweet sorghum plus rye

Year-N	DM yld	Lignin	Cell	Hemi	N	K
	----------------------		Mg/ha	----------------------		
1988-1	9.1	0.341	3.137	2.422	0.084	
-2	11.7	0.503	3.727	3.096	0.121	
-3	12.0	0.514	3.950	3.072	0.145	
-4	12.3	0.519	3.841	3.282	0.185	
1989-1	10.1	0.489	3.206	2.540	0.091	0.132
-2	15.8	0.753	5.208	3.865	0.157	0.216
-3	19.0	0.791	6.178	3.892	0.178	0.188
-4	21.7	1.100	7.529	4.871	0.357	0.352
1990-1	11.6	0.560	4.115	2.780	0.097	0.163
-2	15.7	0.809	5.640	3.508	0.126	0.201
-3	19.6	0.936	7.270	4.419	0.223	0.258
-4	18.2	0.881	6.143	4.209	0.252	0.241
1991-1	19.9					
-2	14.2					
-3	20.5					
-4	20.7					
			CHARITON			
1988-1	10.3	0.382	3.303	2.767	0.187	
-2	9.9	0.472	2.968	2.796	0.186	
-3	9.6	0.440	2.989	2.735	0.176	
-4	11.4	0.539	3.370	3.056	0.210	
1989-1	11.8	0.494	3.841	3.023	0.154	0.148
-2	11.8	0.477	3.844	2.882	0.186	0.137
-3	11.9	0.386	3.929	2.922	0.210	0.137
-4	12.8	0.450	4.051	3.214	0.221	0.180
1990-1	12.4	0.447	4.429	2.990	0.096	0.176
-2	14.9	0.787	5.311	3.206	0.136	0.190
-3	21.1	0.981	6.729	4.481	0.223	0.231
-4	26.6	1.352	7.727	5.513	0.368	0.262
1991-1	11.7					
-2	18.8					
-3	21.3					
-4	23.6					
			STATISTICS			
					$x10^{-2}$	$x10^{-2}$
Site	4	.17	9.2**	.93	1.9*	102.1
Year	332**	1.20**	50.4**	7.76**	1.0**	101.3
N	351**	.49**	15.1**	6.98**	9.6**	3.0**
SxY	91**	.38*	7.0	2.44	.7**	2.0*
SxN	14*	.01	2.8**	.90	.3*	.6
YxN	33**	.08*	2.9**	1.19*	1.1**	.7
SxYxN	24**	.14**	2.7**	.94*	1.1*	.8

particularly evident with low rates of N. In contrast, during 1990 and 1991 the greater biomass yields were with double crop of sorghum plus rye. Year and N rates and their interactions were significant.

Variation in yields of cell wall components were similar to that of dry matter yield with the monocrop doing better in the two dry years whereas the double crop did better in 1990. The combined cellulose and hemicellulose yields were 10-12 Mg/ha with adequate N. Both year and N rate had significant effects on yield of cell wall components. The effects of site and its interactions had little effect on yield of cell wall components. The double crop removed considerably more N and K than did monocropped sorghum. Increasing rates of N increased both N nd K removal by the forages.

Table 12 presents yields of dry matter, lignin, cellulose, hemicellulose, N, and K along with percentages of dry matter and NDF of the mean of the rye components of Systems G and H. Dry matter yields were similar at the two sites, but all the other variables had highly significant effects on dry matter yield. The yields of the three cell wall components reacted much like total dry matter yield with cellulose the most similar. Most of the variables except site also affect N and K uptake by rye. Percentage dry matter at harvest was greatest at both sites in 1991 and approached 50%. Increasing rates of N slightly decreased the percentage dry matter indicating that adequate N decreased differentiation and maturity. Percentage NDF was greater at Ames than Chariton. When increasing rates of N increased yield, the percentage NDF decreased slightly. The dry matter yields of Systems E and G are shown in Figure 3.

Table 12. Means and statistics for System G and H, rye part of the double cropping systems.

Year-N	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	----------	----------	Mg/ha	----------	----------	----------		
				AMES				
1988-1	4.6	0.203	1.584	1.168	0.055		36.1	69.4
-2	5.1	0.290	1.722	1.243	0.065		36.0	67.8
-3	5.2	0.287	1.754	1.312	0.079		36.0	69.0
-4	5.7	0.852	1.965	1.485	0.089		36.8	68.9
1989-1	2.1	0.112	0.757	0.474	0.025	0.035	32.4	68.4
-2	3.6	0.199	1.344	0.868	0.048	0.059	29.8	69.1
-3	4.9	0.211	1.684	1.057	0.082	0.075	26.4	64.0
-4	5.6	0.254	1.975	1.190	0.129	0.097	23.3	63.9
1990-1	1.7	0.075	0.734	0.430	0.021	0.023	33.2	73.7
-2	3.9	0.216	1.613	0.934	0.040	0.052	29.2	72.9
-3	5.0	0.249	1.992	1.143	0.075	0.083	26.5	69.4
-4	5.7	0.297	2.077	1.330	0.122	0.105	23.1	65.9
1991-1	2.8						51.1	
-2	4.1						47.2	
-3	4.7						45.2	
-4	5.8						41.9	
1992-1								
-2								
-3								
-4								
				CHARITON				
1988-1	4.0	0.122	1.279	1.031	0.080		27.2	63.2
-2	4.7	0.284	1.402	1.214	0.086		28.6	65.1
-3	4.8	0.277	1.534	1.288	0.085		27.3	67.2
-4	5.6	0.355	1.650	1.468	0.104		28.1	65.3
1989-1	2.1	0.081	0.769	0.502	0.033	0.028	30.0	66.8
-2	2.4	0.098	0.810	0.581	0.050	0.028	29.1	64.1
-3	2.4	0.087	0.793	0.544	0.056	0.030	26.7	62.3
-4	2.5	0.101	0.828	0.588	0.062	0.035	27.2	62.3
1990-1	3.5	0.163	1.424	0.751	0.027	0.051	35.9	68.0
-2	6.5	0.346	2.587	1.363	0.073	0.094	32.3	66.4
-3	6.9	0.310	2.535	1.554	0.105	0.104	28.1	65.0
-4	7.2	0.380	2.616	1.559	0.146	0.103	27.2	61.5
1991-1	4.6						46.7	
-2	5.4						43.4	
-3	5.4						42.7	
-4	6.5						39.8	
1992-1								
-2								
-3								
- 4								
				STATISTICS				
		$x10^{-3}$	$x10^{-1}$	$x10^{-2}$	$x10^{-3}$	$x10^{-3}$	$x10^{+1}$	x10
Site	5.4	2	3	1	2*	1.4	28**	57**
Year	52.2**	276**	110**	503**	7**	26.1**	371**	15**
N	67.4**	164**	52**	256**	41**	15.2**	39**	10**
SxY	41.5**	155**	76**	187**	8**	27.6**	38**	1.7
SxN	3.5**	1	5**	7	2**	11.9**	2**	2.0
YxN	4.3**	17**	9**	30**	5**	8.1**	6**	4.7
SxYxN	2.0**	2	3**	14**	2**	0.5	1	1.5

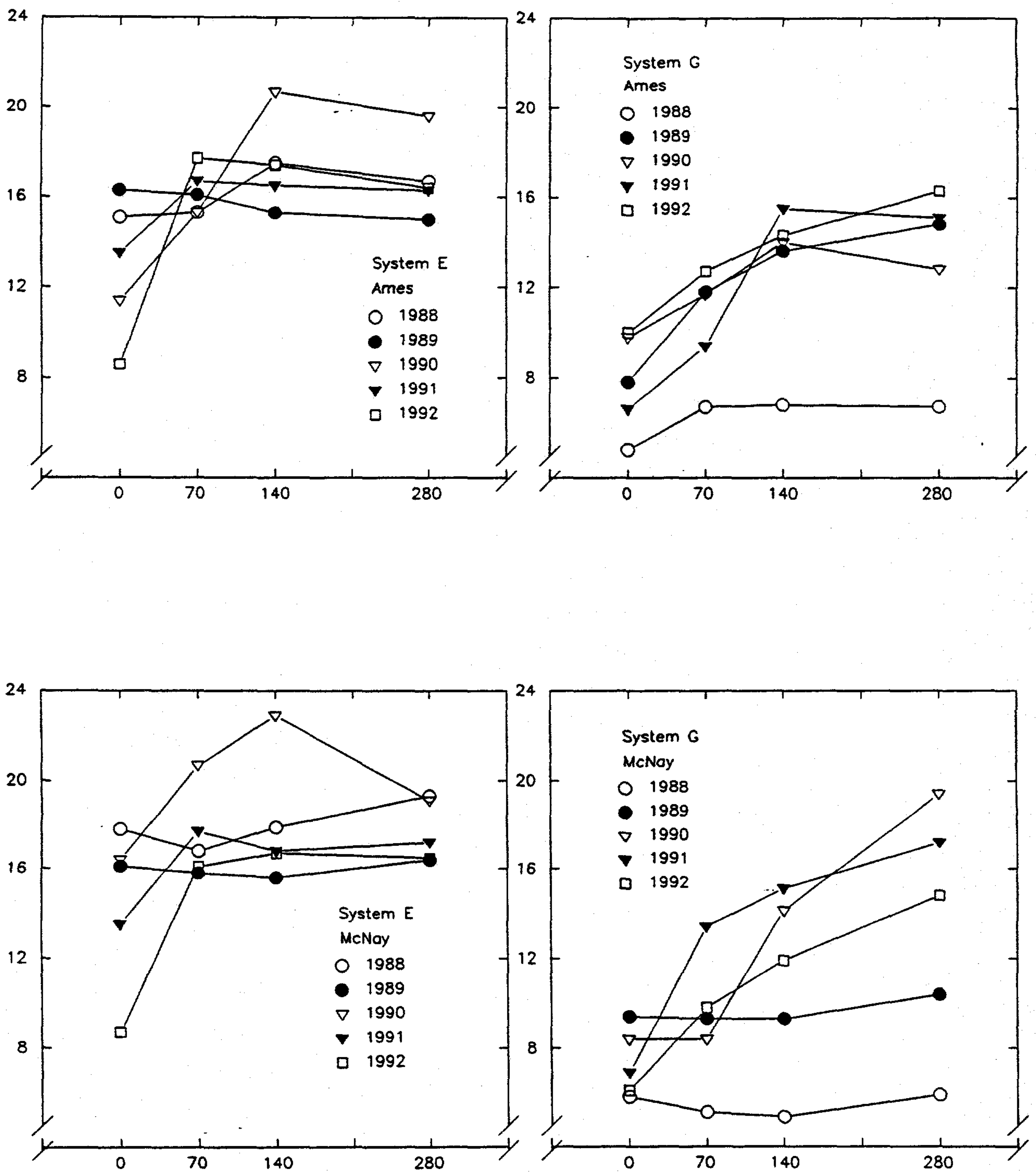

Figure 3. Dry matter yield Mg/ha for systems E and G at both locations as a function of rate of N fertilizer (0, 70, 140, and 280 kg N/ha).

System H, Double Crop of Sorghum x Sudangrass with Rye

Table 13A and 13B presents treatment means and statistics for the sorghum x sudangrass hybrid portion of the double crop with rye. Yields were similar at the two locations. The main effects of year and rate of N were significant and there was little interaction among the main effects. Dry matter yields increased with increasing rates of N, frequently responding from the highest rate of N applied. As for sweet sorghum, the double cropped forage sorghum responded more to N than did the sole crop. During the hot and dry season of 1988 the yields were low and showed little response to N. The yields of forage sorghum of the double crop at the highest rates of N were less than that of the monocrop. For example, at Chariton in 1990 the monocrop approached 23 Mg/ha whereas the forage sorghum of the double crop had a value of 17 Mg/ha at the greatest rate of N.

Lignin and hemicellulose were similar at the two sites but cellulose was considerably greater at Ames than at Chariton. Rates of N significantly increased yields of all three of the cell wall components. As with dry matter yield, N rate had a large effect on increasing sugar yields. Total sugar yields of the double cropped forage sorghum was slightly greater than that of monocropped sorghum in contrast to dry matter yields. Rate of N, year, and site all affected N yield of the crop. Rate of N also increased K yields, mainly due to the effect of N on increasing dry matter yield. Percentage dry matter (Table 13B), that reflects mainly stage of maturity, varied with site and year and their interaction. Percentage sugar varied with site, being greater at Ames in 1989-90 and about equal to Chariton in 1991. Rate of N increased the percentage N of the tissue. Site and year affected both percentage N and K. Percentage NDF was affected by most of the variables and showed much interaction.

Table 14 presents total biomass of sorghum plus rye for System H. Dry matter yield usually increased up to the highest rate of N. At 240 kg/ha of N yields were about 20 Mg/ha in 1990-91. Rates of N also increased yields of the cell wall components, N, and K.

Table 13A. Means and statistics for system H, SSH portion of the double crop with rye.

Year-n	DM yld	Lignin	Cell	Hemi	Red. Sugar	Suc	Total sugar	N	K
	----------	----------	----------	----------	Mg/ha	----------	----------	----------	----------
					AMES				
88-1	4.8	0.252	1.41	1.21				0.030	
2	6.8	0.309	2.10	1.69				0.044	
3	8.7	0.363	2.49	2.19				0.068	
4	10.6	0.591	3.22	2.54				0.108	
89-1	7.5	0.310	2.23	1.82	0.77	1.24	2.01	0.041	0.085
2	11.9	0.506	4.01	2.19	1.10	2.22	3.32	0.078	0.158
3	14.6	0.702	4.15	2.99	1.14	2.67	3.81	0.135	0.186
4	18.0	0.946	4.96	3.70	1.36	2.58	3.94	0.192	0.245
90-1	7.5	0.399	2.53	1.61	0.76	0.70	1.46	0.044	0.135
2	9.0	0.501	3.03	1.86	0.88	0.88	1.77	0.063	0.126
3	10.6	0.604	3.57	2.08	1.38	1.04	2.42	0.071	0.135
4	15.8	0.735	4.85	3.00	1.58	1.35	2.92	0.172	0.189
91-1	6.6				0.77	0.65	1.42		
2	8.5				1.30	0.84	2.13		
3	9.7				1.26	1.03	2.29		
4	13.5				1.75	1.49	3.24		
92-1	7.8								
2	13.6								
3	15.5								
4	16.9								
					CHARITON				
88-1	6.7	0.317	1.95	1.62				0.087	
2	6.6	0.308	1.86	1.61				0.094	
3	6.4	0.261	1.72	1.78				0.106	
4	6.9	0.283	2.02	1.73				0.106	
89-1	9.1	0.383	2.58	3.55	0.72	0.81	1.53	0.114	0.063
2	11.4	0.428	3.22	2.13	0.87	0.85	1.72	0.155	0.115
3	11.8	0.507	3.12	2.54	0.88	0.67	1.55	0.188	0.093
4	11.5	0.565	3.07	2.79	0.85	0.75	1.60	0.165	0.111
90-1	6.5	0.343	2.01	1.51	0.45	0.69	1.14	0.052	0.098
2	8.4	0.389	2.43	1.64	0.71	0.91	1.62	0.075	0.109
3	12.9	0.623	3.53	2.24	0.97	1.54	2.51	0.112	0.139
4	17.0	0.706	4.00	2.79	1.29	1.65	2.94	0.222	0.174
91-1	6.3				0.51	0.89	1.40		
2	10.4				1.26	1.63	2.89		
3	12.7				1.09	1.57	2.66		
4	14.9				1.34	1.84	3.18		
92-1	7.6								
2	8.4								
3	11.1								
4	13.8								
					STATISTICS				
		x10^{-2}						x10^{-2}	x10^{-3}
Site	29	20.4	8.7**	0.50	1.60*	1.38	5.96*	3.1**	100**
Year	122**	44.8**	16.2**	5.49**	0.35	1.16*	1.10	2.3**	1
N	337**	41.8**	10.1**	5.65**	2.02**	2.66**	9.29**	4.4**	18**
SxY	29	2.1	0.4	0.04	0.01	8.32**	8.50**	0.1	16
SxN	11	7.3	2.1**	0.79**	0.07	0.13	0.35	0.2	5
YxN	11*	3.5	1.0**	0.25	0.22*	0.11	0.56*	0.6**	5
SxYxN	11*	2.9	0.4	0.25	0.03	0.55**	0.75**	0.2	5

Table 13B. Means and statistics for system H, SSH portion of the double crop with rye.

Year-n	DM	Total sugar	N	K	NDF
	----------	----------	%	----------	----------
			AMES		
88-1	24.0		0.62		61.7
2	25.6		0.68		63.0
3	24.8		0.78		58.8
4	24.8		1.05		61.5
89-1	31.3	21.1	0.54	1.16	60.1
2	33.3	22.0	0.58	1.18	58.1
3	36.0	20.0	0.91	1.30	57.7
4	34.3	18.1	1.02	1.54	54.0
90-1	30.5	15.6	0.59	1.81	61.8
2	33.7	14.4	0.70	1.42	61.1
3	32.0	16.2	0.67	1.30	60.4
4	34.7	13.6	1.07	1.22	55.9
91-1	25.4	16.1			
2	24.1	18.3			
3	27.0	16.4			
4	26.3	17.0			
92-1	25.3				
2	25.5				
3	24.1				
4	24.1				
			CHARITON		
88-1	22.3		1.29		60.1
2	21.8		1.39		57.1
3	21.4		1.62		59.6
4	20.8		1.50		59.9
89-1	31.6	14.3	1.20	0.74	55.6
2	32.1	12.5	1.37	1.00	55.6
3	31.5	11.3	1.60	0.80	56.0
4	32.7	11.3	1.44	0.95	56.8
90-1	37.3	12.1	0.78	1.49	60.4
2	40.1	10.8	0.86	1.27	55.0
3	39.2	12.7	0.86	1.08	49.9
4	40.6	12.2	1.31	1.03	45.3
91-1	35.1	13.4			
2	34.6	19.1			
3	30.7	14.1			
4	31.6	14.8			
92-1	28.1				
2	28.7				
3	28.2				
4	27.7				
			STATISTICS		
				$x10^{-1}$	$x\ 10^{-2}$
Site	240**	422**	6.06**	95**	304*
Year	820**	82	0.65**	62**	153**
N	6	12	0.71**	4	84**
SxY	183**	90*	0.57*	24**	78**
SxN	10	2	0.05	2	6
YxN	8	18*	0.08	5*	45**
SxYxN	6	5	0.03	2	34*

Table 14. Means and statistics for System H, total biomass of SSH sorghum plus rye

Year-N	DM yld	Lignin	Cell	Hemi	N	K
	----------------------		Mg/ha		----------------------	
			AMES			
1988-1	9.6	0.486	3.030	2.451	0.087	
-2	11.9	0.605	3.932	2.973	0.111	
-3	14.0	0.626	4.232	3.507	0.155	
-4	16.4	0.858	5.225	3.940	0.194	
1989-1	9.3	0.416	2.874	2.242	0.064	0.113
-2	15.0	0.696	5.192	2.915	0.144	0.206
-3	19.1	0.870	5.627	3.882	0.213	0.248
-4	22.3	1.126	6.477	4.587	0.288	0.334
1990-1	9.1	0.467	3.237	2.031	0.063	0.158
-2	12.8	0.694	4.634	2.765	0.103	0.174
-3	15.1	0.833	5.357	3.158	0.135	0.205
-4	21.9	1.027	7.092	4.587	0.288	0.334
1990-1	8.9					
-2	12.0					
-3	14.2					
-5	19.4					
			CHARITON			
1988-1	10.2	0.511	2.953	2.568	0.156	
-2	11.1	0.547	3.290	2.769	0.174	
-3	11.4	0.509	3.259	3.047	0.203	
-4	12.5	0.629	3.722	3.229	0.210	
1989-1	10.9	0.450	3.258	2.566	0.143	0.089
-2	13.7	0.532	3.973	3.086	0.205	0.142
-3	14.0	0.596	3.845	3.248	0.240	0.120
-4	14.2	0.677	3.966	3.407	0.230	0.146
1990-1	.95	0.487	3.225	2.193	0.074	0.142
-2	15.0	0.744	5.068	2.982	0.146	0.208
-3	19.7	0.928	5.862	3.745	0.203	0.248
-4	24.1	1.075	6.620	4.243	0.366	0.274
1991-1	10.6					
-2	15.8					
-3	18.8					
-4	21.5					
			STATISTICS			
	$\times 10^{-1}$					$\times 10^{-3}$
Site	1	1.7	10.3**	0.5	0.047*	34*
Year	85	2.8	16.3**	0.3	0.005*	25
N	486*	7.7**	24.2**	11.6**	0.121**	53**
SxY	74	1.4	4.0**	0.7	0.001*	48
SxN	15	0.6	2.6**	0.9	0.003	7
YxN	22	0.5	1.9**	0.4*	0.014**	1
SxYxN	12	0.2	0.7	0.263	0.004*	6

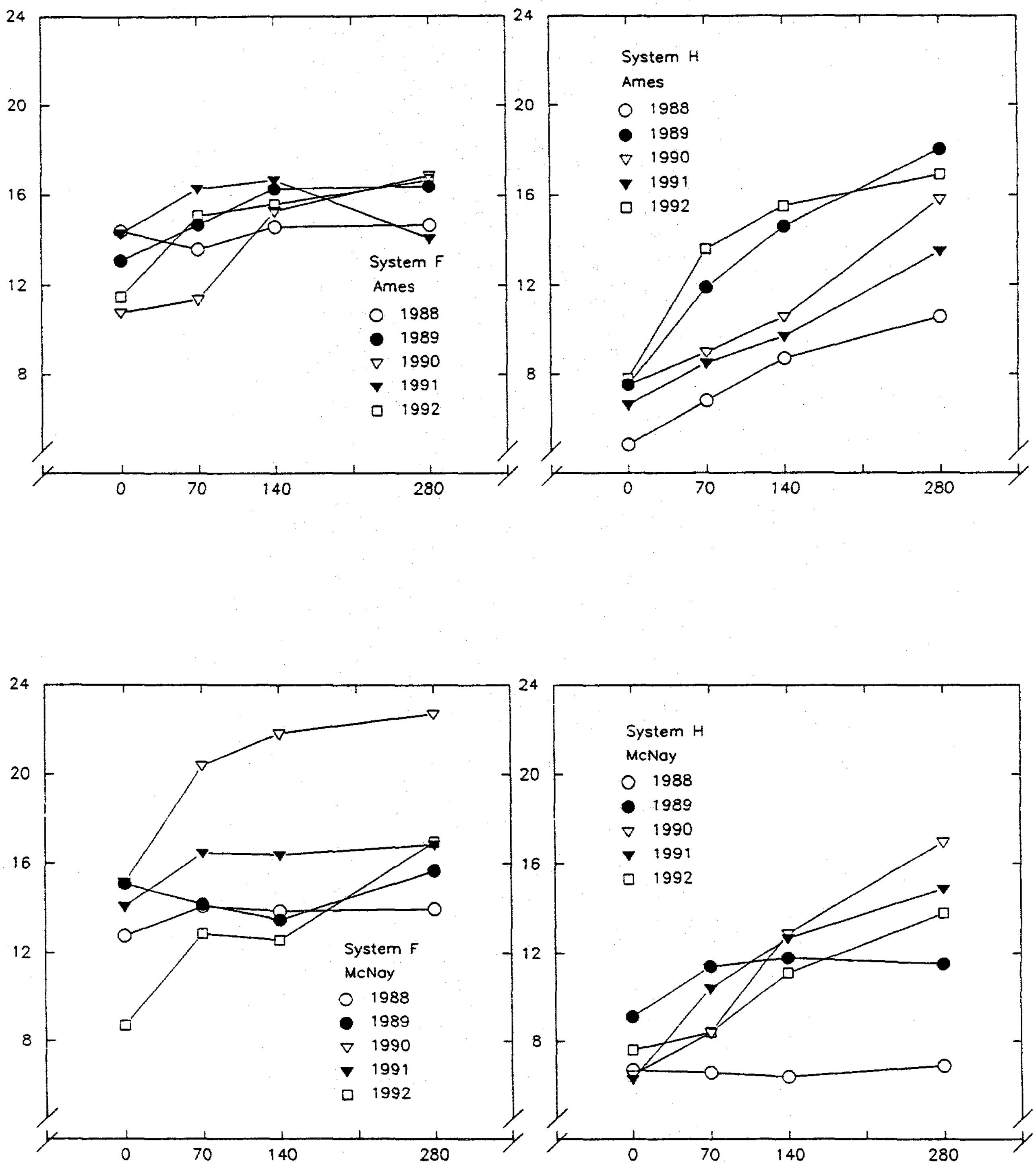

Figure 4. Dry matter yeild Mg/ha for systems F and H at both locations as a function of rate of N fertilizer (0, 70, 140, and 280 kg N/ha).

System K - Sweet Sorghum in Rotation with Corn and Soybeans

Table 15 presents the yield data for monocropped sweet sorghum (i.e., without fall seeded rye) when grown in a rotation with corn and soybean. The dry matter yields were similar to those of continuously monocropped sweet sorghum (Table 8A). Originally we thought that yield of continuously cropped sweet sorghum might decline with time of cultivation. The two rates of N, 70 and 140 kg/ha, did not significantly increase dry matter yield but in general the yield with 140 kg/ha was greater than that with 70 kg. Yield of cell wall components and of N and K of forage was little affected by site, year or N rate except yield of cellulose was greater in 1990. With only two years of data for these attributes, the lack of statistical significance could be expected. There was a significant interaction between site and year for percentage NDF similar to that for continuously cropped sorghum (Table 8B), but we cannot relate this to variation in time of harvest or weather pattern differences.

Table 16 presents the yield of the sweet sorghum portion of the double crop with fall seeded rye when grown as part of a three year rotation following a crop of soybean. Dry matter yield of sorghum was not different for the two rates of N, but the yields were considerably greater than those of continuous double cropped sorghum in System G (Table 10A). This was due to the residual N contribution from the previous crop of soybean to the fall rye and sorghum crops. The yield differences appear great enough to indicate a non-nitrogen contribution from the rotation.

The main factor affecting yield of the cell wall components, N, and K was difference between years.

Table 15. Means and statistics for System K, sweet sorghum monocropped in rotation.

Year-N	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	--------------------	--------------------	--------------------	Mg/ha	--------------------	--------------------		
				AMES				
1989-2	13.1	0.419	3.968	2.689	0.088	0.204	27.4	56.1
-3	16.1	0.576	4.986	3.014	0.120	0.144	27.2	55.1
1990-2	12.9	0.713	4.415	2.678	0.091	0.171	28.3	61.7
-3	16.8	0.822	5.797	3.616	0.135	0.176	30.4	62.0
1991-2	12.5						24.3	
-3	13.3						22.9	
1992-2	17.0						21.9	
-3	18.4						23.1	
				CHARITON				
1989-2	10.4	0.111	3.114	2.694	0.149	0.132	28.8	61.6
-3	12.1	0.488	3.529	3.195	0.187	0.146	27.9	60.9
1990-2	13.7	0.613	4.324	2.830	0.099	0.143	34.3	54.1
-3	19.5	0.731	5.440	3.545	0.169	0.194	36.0	51.0
1991-2	17.2						25.2	
-3	20.2						25.9	
1992-2	14.2						26.2	
-3	15.9						25.2	
				STATISTICS				
		10^{-2}	10^{-2}	10^{-2}	-10^{-3}	-10^{-3}		
Site	1.2	9.5	22.4	3.8	0.4	0.0	26.5	0.2
Year	10.1*	32.3	98.0*	5.5	0.1	0.4	64.2*	63.3
N	2.3	0.5	0.5	1.9	0.6	0.2	0.4	0.2
SxY	6.8	4.5	0.2	4.2	0.0	0.3	0.4	95.9
SxN	1.0	0.5	5.3	0.2	0.0	1.3	1.2	6.3
YxN	3.0	1.0	35.4	33.7	0.0	0.0	0.0	5.5

Table 16. Means and statistics for System K, of the sweet sorghum portion double cropped with rye in rotation.

Year-N	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	----------	----------	----------	Mg/ha	----------	----------		
				AMES				
1989-2	14.6	0.617	4.304	3.170	0.128	0.122	27.7	55.7
-3	18.9	0.938	5.719	4.015	0.200	0.238	28.6	56.0
1990-2	19.7	1.195	6.5443	3.863	0.163	0.186	31.3	59.4
-3	18.1	1.062	5.556	3.278	0.158	0.197	30.2	54.9
1991-2	13.3						22.4	
-3	14.1						22.6	
1992-2	18.31						23.8	
-3	19.91						22.4	
				CHARITON				
1989-2	14.7	0.654	4.743	3.787	0.202	0.193	28.1	62.7
-3	14.3	0.365	4.681	3.959	0.196	0.117	28.3	63.5
1990-2	21.6	1.012	5.980	3.584	0.175	0.192	35.0	49.5
-3	20.3	0.911	5.760	3.544	0.185	0.206	34.2	51.9
1991-2	15.1						24.8	
-3	19.0						24.0	
1992-2	18.7						27.4	
-3	17.5						27.8	
				STATISTICS				
		10^{-2}	10^{-3}	10^{-2}	10^{-3}	10^{-3}		
Site	1.0	4.3	95	0.9	4.6	1.1	36.0*	6.7
Year	9.2	20.6*	240*	14.5	0.4	0.1	59.4*	3.0
N	28.4	7.2	193	76.8*	4.3	0.0	0.3	2.5
SxY	18.2	0.5	43	0.1	1.1	0.1	4.3	98.6**
SxN	0.1	0.7	9	0.2	0.1	2.7	0.9	1.2
YxN	2.3	1.2	5	0.8	1.5	0.2	0.9	0.1

Table 17 is the rye part of the sorghum and rye double crop in rotation following soybean. The yield of rye showed no response to N in contrast to the highly significant effect of N on yield of rye in continuous double cropping of sorghum and rye (Table 12). In general the yields of rye following soybean were greater than yield of rye with the 240 kg/ha rate in the continuous sorghum-rye system. Cell wall components, N, and K were affected by year and site but not by N.

Total biomass of sorghum plus rye of the double crop in rotation is in Table 18. Dry matter yield was not affected by the two rates of N used. The dry matter yields in this table are similar or exceed the yields obtained with 240 kg/ha of N in the continuous double crop (Table 11). It appears that 70 kg/ha of N was adequate for the double crop when following soybeans in the three year rotation.

System I, Corn in the Three Year Rotation of Corn-Soybean-Sorghum

Table 19 presents the means and statistics for the stover part of the corn crop. Dry matter yield for stover varied with years with the least yield in the dry and hot season of 1988. There was a response to N with the highest rate of N usually producing the greatest yield. There was an interaction between site and year with the 1989 yields lesser at Chariton and the 1992 season lesser at Ames.

The three cell wall components usually had greater yields at Ames than at Chariton and with the least yields during 1988. Rate of N did not significantly affect yield of lignin, but increased yields of cellulose and hemicellulose. Rate of N increased N uptake yield. The percentage dry

Table 17. Means and statistics for System K, rye part of the double crop

Year-N	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	---Mg/ha---							
				AMES				
1989-2	6.28	0.278	2.700	1.172	0.086	0.078	31.5	68.2
-3	6.15	0.230	2.335	1.449	0.098	0.080	28.9	67.7
1990-2	5.32	0.261	2.053	1.300	0.083	0.094	26.5	68.3
-3	5.73	0.315	2.303	1.176	0.092	0.139	23.0	67.0
1991-2	6.19						42.0	
-3	6.13						40.7	
				CHARITON				
1989-2	3.41	0.143	1.272	0.835	0.048	0.067	37.0	68.0
-3	3.43	0.112	1.201	0.821	0.056	0.051	33.6	63.7
1990-2	7.25	0.343	2.719	1512	0.078	0.118	31.7	64.3
-3	7.22	0.344	2.668	1.461	0.094	0.133	27.6	63.5
1991-2	7.21						38.6	
-3	5.09						36.3	
				STATISTICS				
		$x10^{-3}$	$x10^{-1}$	$x10^{-2}$	$x10^{-3}$	$x10^{-3}$		$x10^{1}$
Site	2.0	10	12**	11	3**	0	49**	746*
Year	10.7**	125**	24**	69**	2*	22**	595**	83
N	0.0	0	1	1	1	1	99**	272
SxY	20.2**	16*	64**	107**	1	1	38**	1.7
SxN	3.5**	1	5**	7	2**	11.9**	2**	2.0
YxN	4.3**	17**	9**	30**	5**	8.1**	6**	4.7
SxYxN	2.0**	2	3**	14**	2**	0.5	1	1.5

Table 18. Means and statistics for System K, total biomass of sweet sorghum plus rye

Year-N	DM yld	Lignin	Cell	Hemi	N	K
			Mg/ha			
			AMES			
1989-2	19.38	0.697	6.668	3.861	0.174	0.282
-3	22.25	0.806	7.321	4.463	0.218	0.223
1990-2	18.22	0.975	6.468	3.977	0.173	0.265
-3	22.53	1.136	8.100	4.821	0.226	0.315
1991-2	18.69					
-3	19.43					
			CHARITON			
1989-2	13.81	0.587	4.386	3.534	0.197	0.199
-3	15.53	0.600	4.730	4.015	0.243	0.197
1990-2	20.95	0.956	7.042	4.342	0.178	0.261
-3	26.72	1.076	8.107	5.007	0.263	0.328
1991-2	24.41					
-3	25.29					
			STATISTICS			
		$x10^{-2}$	$x10^{-1}$	$x10^{-2}$	$x10^{-3}$	$x10^{-3}$
Site	0	8	92**	2	4	5
Year	84	106**	218**	259**	0	5
N	74	8	68*	336*	26**	2
SxY	163*	3	148**	88	0	7
SxN	1	1	4	4	1	3
YxN	19	1	14	9	1	3
SxYxN	2	0	3	0	1	16

Table 19. Means and statistics for System I, stover part of corn in rotation with soybean and sorghum

Year-N	DM yld	Lignin	Cell	Hemi	N	K	%DM	%NDF
	----------	----------	Mg/ha	----------	----------	----------		
				AMES				
1988-1	4.0	0.214	1.764	1.210	0.014		46.4	81.5
-2	3.8	0.172	1.676	1.326	0.013		52.9	85.8
-3	5.6	0.186	1.100	1.501	0.017		51.2	82.0
-4	5.0	0.194	2.054	1.579	0.027		55.8	79.1
1989-1	5.1	0.207	1.733	1.404	0.021	0.042	40.4	67.8
-2	7.2	0.276	2.655	1.891	0.040	0.093	44.8	69.0
-3	8.6	0.324	3.140	2.186	0.070	0.117	43.6	68.6
-4	8.4	0.354	3.168	2.315	0.055	0.060	45.0	70.0
1990-1	8.1	0.324	2.962	2.556	0.045	0.080	48.8	74.2
-2	8.7	0.473	3.503	2.549	0.040	0.094	52.1	76.6
-3	8.7	0.391	3.586	2.576	0.040	0.073	51.3	77.3
-4	10.2	0.435	3.968	3.158	0.059	0.096	50.7	75.8
1991-1	4.8						39.4	
-2	6.3						42.4	
-3	6.8						38.0	
-4	7.3						38.5	
1992-1	5.8						59.0	
-2	4.5						54.8	
-3	7.0						51.7	
-4	6.9						56.0	
				CHARITON				
1988-1	4.6	0.224	1.512	1.496	0.047		41.8	72.5
-2	4.2	0.234	1.455	1.294	0.055		40.4	73.0
-3	4.4	0.201	1.480	1.426	0.061		41.4	73.2
-4	4.9	0.258	1.485	1.611	0.067		42.7	71.7
1989-1	4.2	0.240	1.559	1.162	0.050	0.029	53.0	71.3
-2	4.0	0.197	1.396	1.032	0.052	0.090	48.6	68.6
-3	4.5	0.213	1.516	1.255	0.071	0.030	50.3	67.1
-4	4.2	0.150	1.439	1.124	0.061	0.032	44.0	66.2
1990-1	6.7	0.239	2.516	1.898	0.056	0.075	45.1	70.5
-2	5.4	0.251	2.034	1.530	0.045	0.048	44.6	73.3
-3	8.3	0.415	3.339	2.336	0.064	0.093	53.3	73.9
-4	9.8	0.444	3.723	2.956	0.087	0.128	51.3	72.9
1991-1	5.9						50.2	
-2	6.0						53.5	
-3	7.6						55.5	
-4	8.4						48.5	
1992-1	6.4						33.9	
-2	6.5						36.4	
-3	6.9						35.4	
- 4	6.6						32.4	
				STATISTICS				
		$x10^{-3}$	$x10^{-1}$	$x10^{-1}$	$x10^{-3}$	$x10^{-3}$	$x10^{+1}$	
Site	16	38**	128**	43*	12**	8.1	29	478*
Year	61**	230**	200**	98**	3*	14.7*	10	639*
N	25**	19	22**	14**	2**	2.0	1	15
SxY	20**	38	14	15**	1	8.1*	131**	168
SxN	2	5	5	2	0	2.1	5	6
YxN	2	11	5	3	1	3.2	3	13
SxYxN	2	21	6	2	0	2.2	3	11

matter of corn stover was nearly twice that of the sorghums at harvest with only the site x year interaction significant. Percentage NDF of corn stover was about 10 percentage points greater than that of the sorghums indicating the greater concentration of cellulose and hemicellulose inn corn stover.

Table 20 shows the dry matter yields of corn grain and of total biomass (grain + stover). Grain yield was greater at Ames than Chariton. The response to N was significant with a greater response at Ames than Chariton that resulted in a significant site x N interaction. The main effect of year was not significant, but the site x year interaction was large.

Total biomass yield responded similar to grain yield in being greater at Ames than Chariton whereas stover yields were not different at the two sites. In contract, stover yields varied enough with years to cause total biomass to vary with year whereas grain yield did not.

System L, Interplanting of Sorghums into a Permanent Stand of Alfalfa

Dry matter yield and percentage dry matter for the three harvests are presented in Table 21. The yield of harvest consisted of one alfalfa growth before interplanting sorghums. Statistical analyses are only for the 1989 and 1990 seasons. Yields were greater at Ames where a better stand was established and the interaction with year is the relative improvement of alfalfa yield during the second year at Chariton. Harvest 2 reflects the low yield of sorghums in 1989, particularly at Chariton, that resulted in a site x year interaction. Yields of sorghum approached 9 Mg/ha and were similar for the two types of sorghum. Harvest 3 mainly consisted of alfalfa growth, but also contained some regrowth of sorghum. In 1989 yields were about 5 Mg/ha, but in later years only slightly greater than 1 Mg/ha. Rates of N had no effect on dry matter yield of any of the

Table 20. Means and statistics for System I, grain and total plant biomass of corn in rotation with soybeans and sorghum (Mg ha^{-1})

	kg/ha of N fertilizer				kg/ha of N fertilizer			
Year	0	70	140	280	0	70	140	280
	Mg/ha							
	Ames - grain yield				Chariton - grain yield			
1988	3.7	4.8	6.7	6.9	2.9	3.1	2.9	2.9
1989	5.4	7.9	9.3	10.5	2.2	2.6	2.6	2.2
1990	3.0	6.4	7.9	8.5	4.8	3.6	5.8	4.6
1991	2.4	3.9	4.7	4.7	3.9	3.7	4.6	5.4
1992	2.7	3.8	4.7	5.4	4.1	5.2	5.4	5.2
Mean	3.4	5.4	6.7	7.2	3.8	3.6	4.3	4.1
	Ames - total plant biomass				Chariton - total plant biomass			
1988	7.7	8.6	11.3	11.9	7.5	7.3	7.3	7.8
1989	10.5	15.1	17.8	19.0	6.4	6.6	7.1	6.3
1990	11.1	15.1	16.6	18.7	9.1	8.1	12.6	13.2
1991	7.3	10.2	11.5	12.0	9.8	9.7	12.2	13.7
1992	8.5	7.2	11.7	12.2	10.5	11.7	12.3	11.8
Mean	9.0	11.2	13.8	14.8	8.7	8.7	10.3	10.6

STATISTICS

Source	d.f.	Mean Squares: Grain yield	Mean Squares: Total biomass
Site	1	130**	195**
Year	4	10	104**
N	3	38**	114**
SxY	4	58**	137**
SxN	3	16**	29**
YxN	12	1	4
SxYxN	12	2	7

Table 21. Mean and statistics for System L, sweet and SSH sorghums interplanted in alfalfa with two rates of N applied to sorghums. Harvest 1=late May harvest of alfalfa, Harvest 2=August harvest of mainly sorghum, and Harvest 3=after frost harvest of mainly alfalfa

		Harvest 1		Harvest 2		Harvest 3		Total	
Year N	Sorg. type	Yield	% DM	Yield	% DM	Yield	% DM	Yield	% DM
		Mg/ha		Mg/ha		Mg/ha		Mg/ha	
				AMES					
1989-2	SS	6.6	22.1	5.4	32.0	4.9	31.9	16.9	28.1
-2	SSH	6.5	22.0	5.9	33.2	5.7	31.4	18.1	28.6
-3	SS	6.2	21.1	4.9	30.7	4.8	31.9	15.9	27.3
-3	SSH	5.8	21.6	4.9	30.8	5.6	31.3	16.3	27.6
1990-2	SS	5.3	21.9	7.2	21.4	2.4	32.5	14.9	23.4
-2	SSH	4.8	21.8	6.5	23.4	2.3	32.4	13.6	24.5
-3	SS	5.4	23.2	7.8	20.3	2.3	32.3	15.5	23.2
-3	SSH	5.1	21.3	7.6	23.3	2.7	32.4	15.4	24.3
1991-2	SS	6.1	37.0	8.9	18.4	2.4	31.1	17.4	26.7
-2	SSH	5.5	36.6	9.2	20.8	2.4	31.4	17.1	27.4
-3	SS	6.3	37.0	9.1	18.4	2.5	29.5	18.0	26.6
-3	SSH	5.9	36.4	8.7	19.2	2.5	29.6	17.1	26.7
1992-2	SS	3.3	31.4	5.6	26.2	2.3	27.0	11.1	27.9
-2	SSH	2.9	31.2	5.3	26.4	2.1	27.8	10.3	28.0
-3	SS	3.3	30.8	6.5	29.0	2.1	27.9	11.9	29.5
-3	SSH	3.2	34.8	5.5	26.2	2.3	27.6	10.9	28.9
				CHARITON					
1989-2	SS	2.3	26.4	2.0	38.1	5.1	31.6	9.5	31.7
-2	SSH	2.8	26.0	2.3	37.4	5.0	30.0	10.1	30.5
-3	SS	2.5	27.3	2.3	39.5	5.4	35.1	10.2	34.3
-3	SSH	2.6	26.2	2.2	38.3	5.1	33.5	9.9	32.9
1990-2	SH	3.8	20.9	6.9	17.1	1.1	12.2	11.7	19.8
-2	SSH	3.6	20.3	8.2	20.1	2.1	15.4	14.1	22.8
-3	SS	3.9	20.8	8.1	17.2	1.2	12.2	13.4	19.6
-3	SSH	3.8	20.4	9.7	20.6	NA	15.4	15.4	23.0
				STATISTICS					
					$x10^{-1}$		$x10^{+1}$		
Site		103**	468	18	4	3	125**	260**	14
Year		0	122**	256**	339**	158**	129**	13	917**
SxY		21**	154**	65*	40**	2	152**	128*	194**
Type		0	4	2	3*	3*	1	6	11
SxY		1	0	3*	0	0	5	5	0
YxT		0	1	0	4**	0	28	0	27**
N		0	0	2	0	0	11	2	2
SxN		0	1	2	2*	0	13	4	12
YxN		1	0	8**	0	0	0	14**	3
TxN		0	1	0	0	0	12	0	0

*SS is sweet sorghum and SSH is the sorghum x sudangrass hybrid.

harvests meaning that alfalfa provided adequate N for the needs of the sorghums.

Total biomass yields of System L approached 18 Mg/ha which was greater than that of the alfalfa monocrop that approached 12 Mg/ha (Table 4). In fact, in 1989 the yields of Harvest 1 plus 3 were equal to that of a pure stand of alfalfa. Percentage dry matter was affected mainly by year and the site x year interaction due to stage of growth at harvest.

System M, Interplanting of Sorghum into Permanent Stands of Reed Canarygrass

Table 22 presents the results of system M consisting of interplanting sorghums in reed canarygrass for the Ames site. Harvest 1 consisted of reed canarygrass forage before sorghums were planted. Yields varied with year and were influenced by rate of N fertilizer. At Harvest 2 only rate of N affected sorghum yield. Harvest 3 was much less than Harvest 3 of System L because of less fall regrowth by reed canarygrass. Total biomass yields of system M was considerably less than that of System L. Part of the reason for the reduced yield may have been inadequate rates of N for both crops. Sole reed canarygrass responded to 240 kg/ha (Table 5) and we only used rates of 70 and 140 kg/ha that was split between the two crops.

Relationship between Dry Matter Yield and Percentage of Sugar NDF, Cellulose, and Hemicellulose

Data for Figures 3-6 were taken from Systems E and G with the variables being site, year and N rate. Figure 5 shows that large dry matter yields were associated with low percentages of NDF. Figure 6 plots the relationship of increased sugar percentages with increased dry matter yield. Figure 7 is the inverse relationship between percentage sugar and NDF. Figure 8 shows that hemicellulose decreases more than cellulose as dry matter yield increases. In sweet sorghum, those variables that produce large dry matter yields have lower percentages of NDF, cellulose and

Table 22. Mean and statistics for System M at Ames, sweet and SSH sorghums interplanted in reed canarygrass with two rates of N applied to sorghums. Harvest 1=June harvest of reed canarygrass, Harvest 2=Aug. harvest of mainly sorghums, Harvest 3 = after frost harvest of mainly reed canarygrass

		Harvest 1		Harvest 2		Harvest 3		Total	
Year N	Sorg. type*	Yield	% DM	Yield	% DM	Yield	% DM	Yield	% DM
		Mg/ha		Mg/ha		Mg/ha		Mg/ha	
				AMES					
1989-2	SS	2.5	23.8	3.9	35.4	1.1	43.4	7.5	32.4
-2	SSH	2.6	25.4	4.3	34.5	1.6	41.6	8.6	32.4
-3	SS	4.0	24.9	4.4	35.6	1.1	44.0	9.5	32.0
-3	SSH	3.9	23.8	5.1	34.4	1.1	36.6	10.1	30.3
1990-2	SS	2.3	24.1	5.2	33.5	0.7	35.0	8.2	30.9
-2	SSH	2.2	23.8	5.6	33.0	0.6	38.2	8.4	31.0
-3	SS	3.1	21.0	6.4	31.8	0.9	41.0	10.4	29.3
-3	SSH	3.1	20.8	6.2	31.8	0.8	36.4	10.1	28.7
1991-2	SS	4.4	33.0	5.6	28.2	0.8	40.4	10.9	31.5
-2	SSH	4.0	33.1	5.8	28.2	0.9	43.4	10.7	31.5
-3	SS	6.6	32.4	6.0	28.7	0.9	38.5	13.5	31.2
-3	SSH	5.9	31.4	6.5	27.7	1.0	40.8	13.5	30.3
1992-2	SS	1.8	29.8	4.7	34.0	0.9	42.1	7.3	34.5
-2	SSH	1.8	31.0	4.4	33.3	0.8	41.3	7.1	33.7
-3	SS	3.2	26.6	5.4	31.4	1.0	41.6	9.5	30.9
-3	SSH	3.3	27.0	5.6	28.7	1.0	39.0	9.9	29.1
				STATISTICS					
						$x10^{-2}$			
Year		25**	320**	8.9	125*	67	46	45	14
Type		0	0	0.9	12	8	19	1	8
YxT		0	1	0.3	2	10	37	1	1
N		32**	65**	9.2*	24*	3	14	78**	65**
YxN		1	10*	0.1	11	12	17	1	8**
TxN		1	5	0.0	2	5	64*	0	5
YxTxN		0	1	0.3	1	9	11	0	0

*SS = sweet sorghum, SSH = sorghum x sudangrass hybrid.

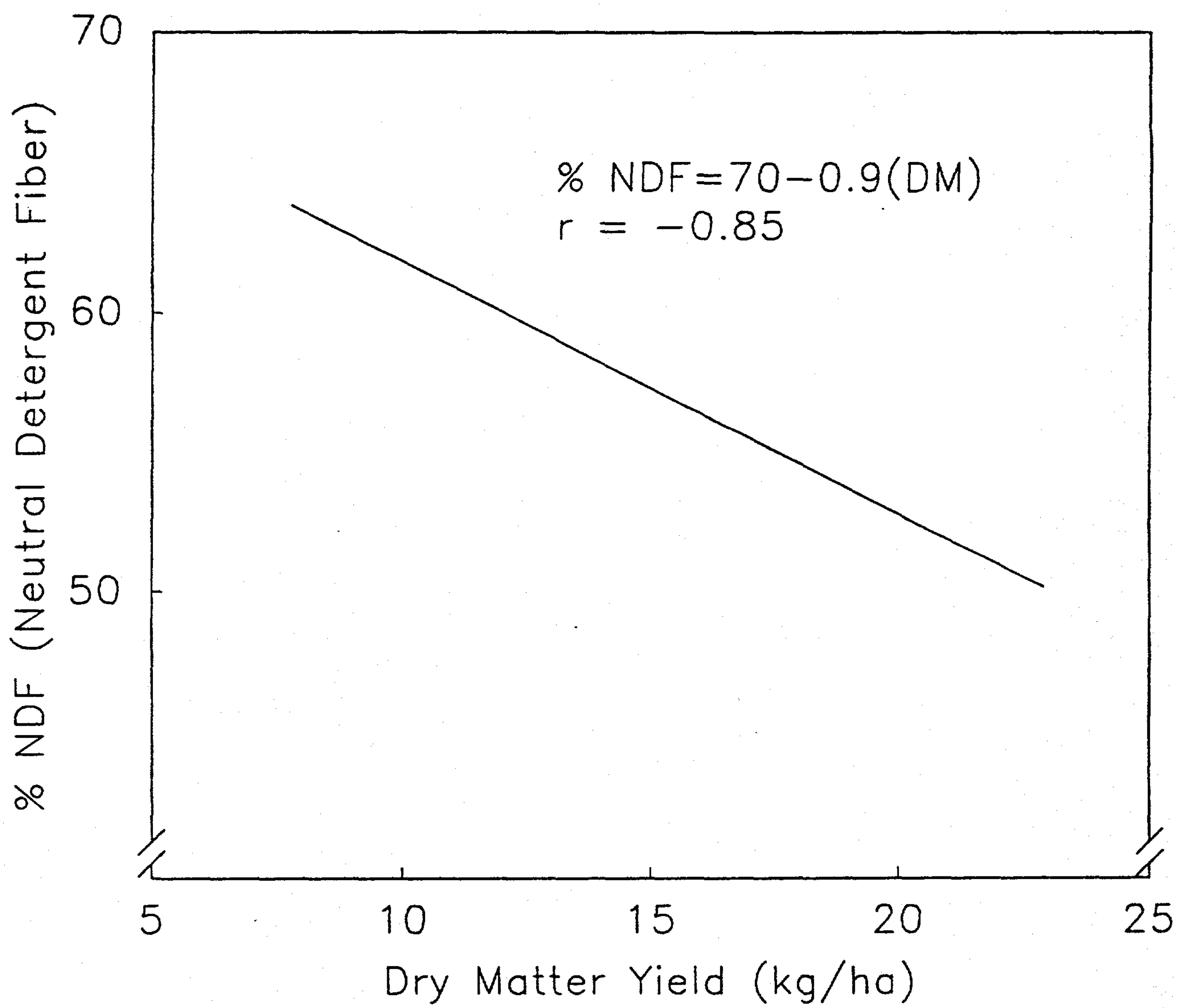

Figure 5. Inverse relationship of %NDF and dry matter yield at harvest of sweet sorghum

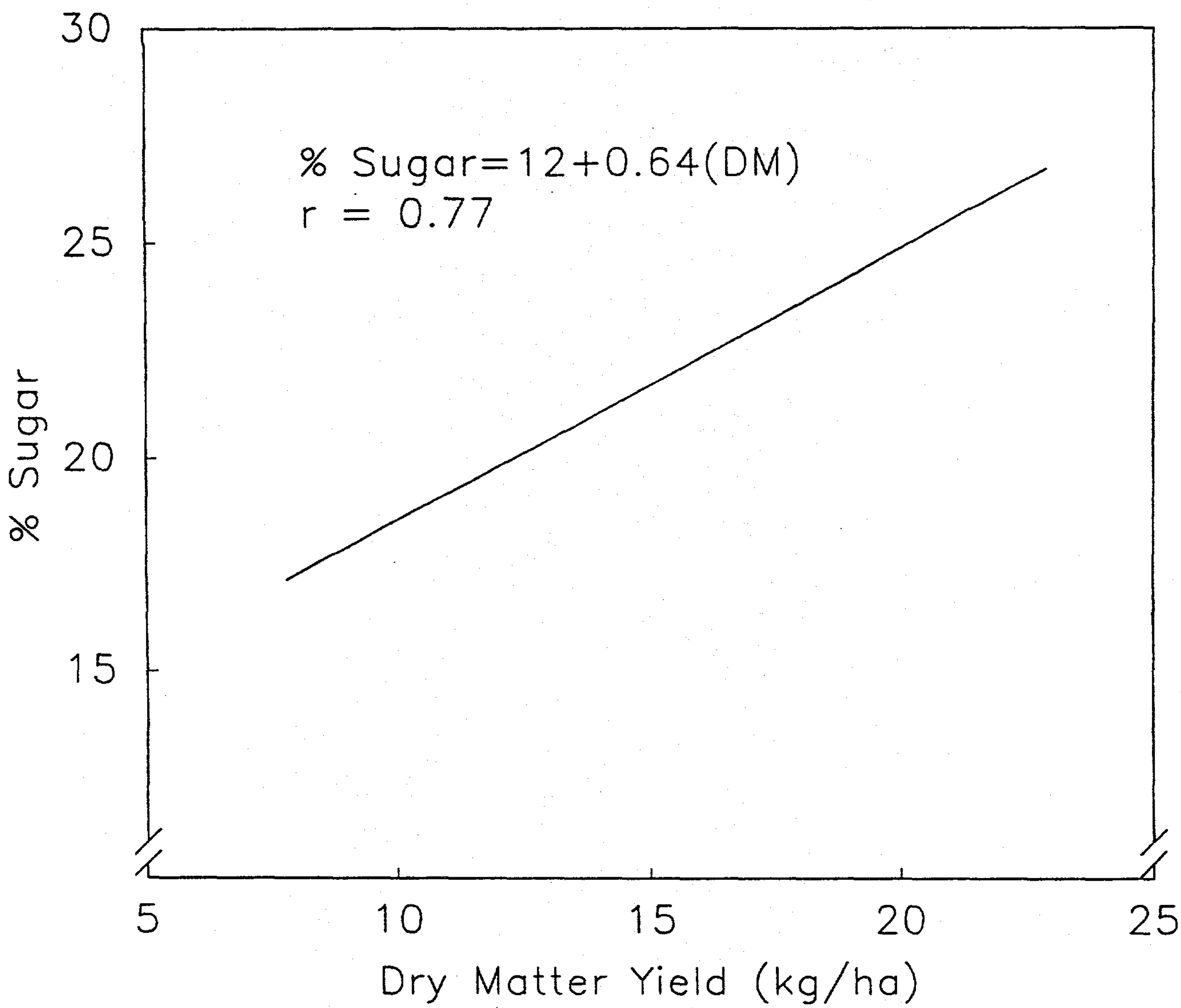

Figure 6. Positive relationship of % sugar and dry matter yield of sweet sorghum

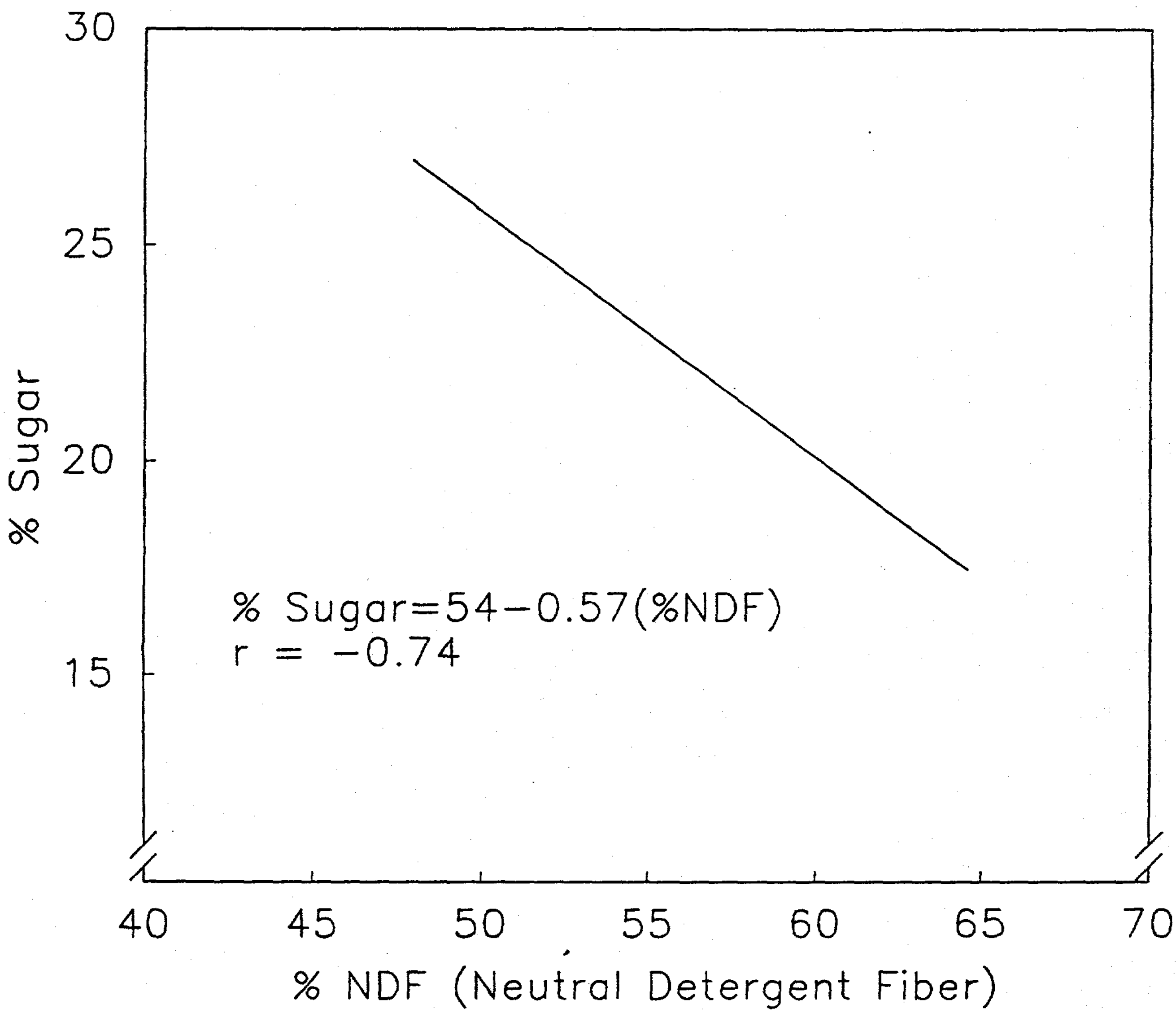

Figure 7. Opposite trands of %NDF and % sugar of sweet sorghum

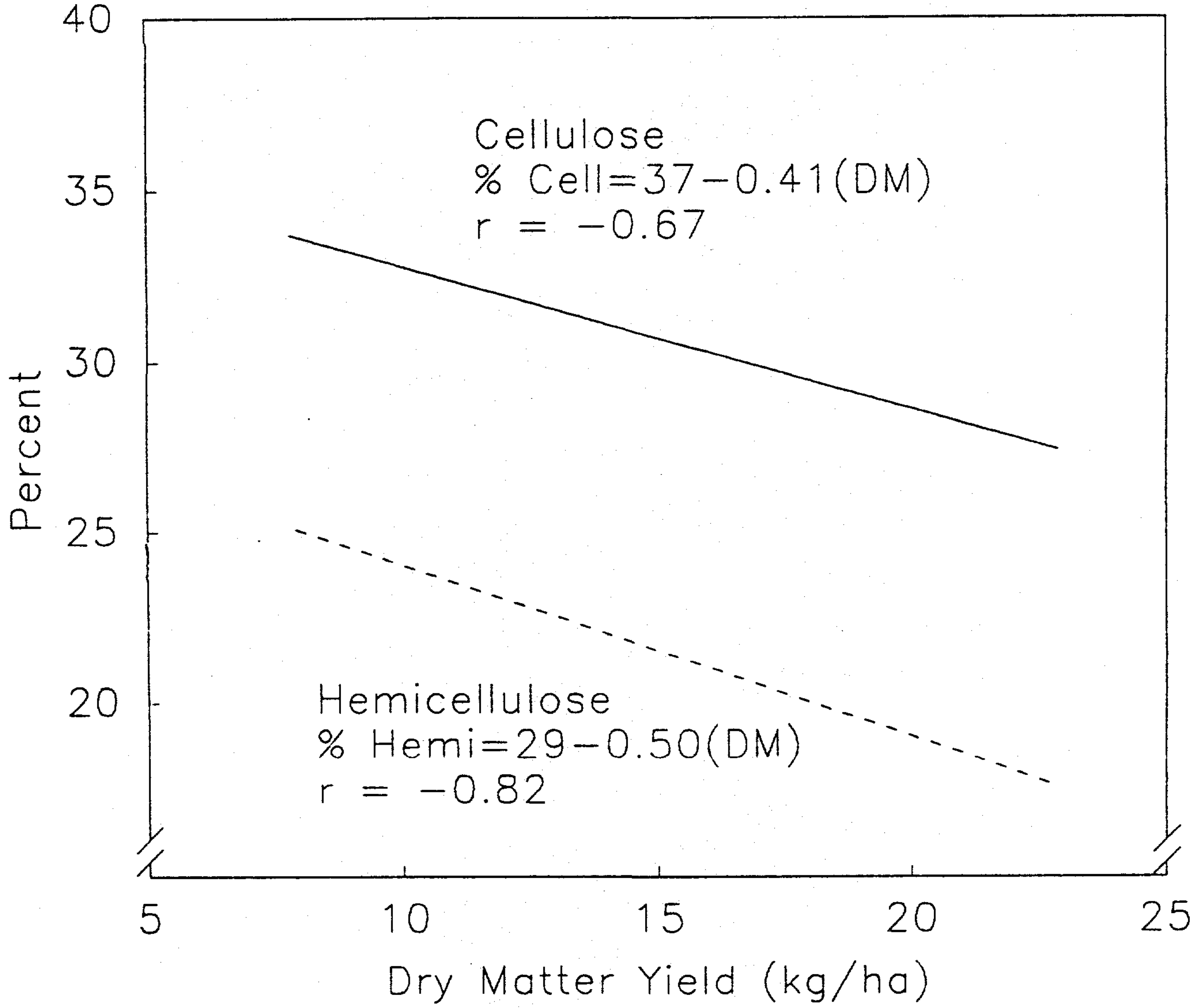

Figure 8. Inverse relationship of cellulose and hemicellulose with increasing dry matter yield. Within the range of dry matter shown, cellulose decreased 22% and hemicellulose 40%.

hemicellulose but larger percentages of sugar than lesser yielding crops of sweet sorghum.

Comparisons of Cropping Systems

Average yields of sole alfalfa at Ames were 70% greater than those of sole reed canarygrass fertilized with 70 kg of N/ha (Table 23). Raising the fertilizer rate from 70 to 140 kg N/ha increased reed canarygrass yields by 34%, but alfalfa yields were still 17% greater than those of reed canarygrass. During 1989 and 1990, alfalfa yields averaged approximately 3 Mg/ha higher at Ames than at Chariton (compare Tables 23 and 24). The 1991-1992 winter included several cycles of freezing and thawing, which caused severe crown heaving and death of approximately 25% of the alfalfa plants. This contributed to reduced alfalfa yields in 1992.

Sole sweet sorghum with 140 kg N/ha had yields that were 68% greater than those of alfalfa at Ames (Table 23) and were twice those of alfalfa at Chariton (Table 24). The M-81E sweet sorghum seeds were smaller than those of FFR 201 sorghum x sudangrass hybrid and consequently sweet sorghum had less seedling vigor than the hybrid with sweet sorghum plants being smaller than sorghum x sudangrass plants during the first two months of growth. Sorghum x sudangrass was earlier in maturity than sweet sorghum such that by late September, sorghum x sudangrass was at the mature seed stage, whereas sweet sorghum was approximately three weeks past anthesis. As a consequence, sorghum x sudangrass grew faster at the beginning of the season, but sweet sorghum had more vigorous growth late in the summer.

At Ames sole sweet sorghum yields averaged 15% more than those of sorghum x sudangrass when fertilized with 70 kg N/ha (Table 23). Increasing the fertilizer rate to 140 kg N/ha, raised sweet sorghum yields by only 6% and those of the sorghum x sudangrass hybrid by 12%, which reduced the yield difference between the two sorghums to 9%. Sorghum yields at Chariton were generally higher than those at Ames and sorghum at Chariton did not respond to the increase in N fertilization from 70 to

Table 23. Dry matter yields of cropping systems at Ames[a]

Cropping system	1989	1990	1991	1992	Mean
	Mg/ha				
Alfalfa[b]	12.9	12.1	8.4	8.2	10.4
			70 kg N/ha		
Reed canarygrass	5.8	7.2	6.8	4.5	6.1
Sweet sorghum (SWS)	16.1	15.3	16.7	17.7	16.5
Sorghum x sudangrass (SSH)	14.7	11.4	16.3	15.1	14.3
Alfalfa/SWS	16.9	14.9	17.4	11.1	15.1
Alfalfa/SSH	18.1	13.6	17.1	10.3	14.8
Reed canary-grass/SWS	7.5	8.2	10.9	6.6	8.3
Reed canary-grass/SSH	8.6	8.4	10.7	6.3	8.5
			140 kg N/ha		
Reed canarygrass	7.8	10.3	7.9	6.8	8.2
Sweet sorghum	15.3	20.7	16.6	17.4	17.5
Sorghum x sudangrass	16.3	15.3	16.7	15.6	16.0
Alfalfa/SWS	15.9	15.5	18.0	11.9	15.3
Alfalfa/SSH	16.3	15.4	17.1	10.9	14.9
Reed canary-grass/SWS	9.5	10.4	13.5	10.3	10.9
Reed canary-grass/SSH	10.1	10.1	13.5	10.7	11.1
Mean	12.8	12.6	13.5	10.7	

[a]$LSD_{(0.05)}$ for year X cropping system X N rate = 2.3, cropping system X N rate = 1.2, years = 1.7.
[b]No N fertilizer applied.

Table 24. Dry matter and chemical composition of biomass at Chariton. Data are averaged over years and N rates.

Cropping system	Yield	NDF[a]	ADF[a]	Lignin	Ash	N	K
	Mg/ha			%			
Alfalfa[b]	9.3	48.3	36.4	8.5	1.1	2.8	2.1
Sweet sorghum (SWS)	18.7	52.7	32.5	3.9	0.7	1.0	0.9
Sorghum x sudangrass (SSM)	17.4	46.2	28.2	3.8	0.9	1.3	0.9
Alfalfa/SWS	11.2	52.5	37.5	6.2	2.6	2.6	2.2
Alfalfa/SSH	12.7	53.1	37.8	5.8	2.3	2.5	2.1
$LSD_{(0.05)}$	1.6	2.3	1.7	0.8	0.7	0.1	0.2

[a]NDF = neutral detergent fiber, ADF = acid detergent fiber.
[b]No N fertilizer applied.

140 kg N/ha. Like Ames, sweet sorghum yields at Chariton were 7% greater than those of sorghum x sudangrass (Table 24).

The two sorghums were equally effective in increasing dry matter yields when intercropped into alfalfa or reed canarygrass at both locations (Tables 23 and 24) even though the hybrid initially displayed more vigor than sweet sorghum in these mixed stands. There was no difference in yield between the two N levels when the two sorghums were intercropped into alfalfa. Intercropping was more successful into alfalfa than into reed canarygrass (Table 23). Average biomass production of intercropped alfalfa was 45% greater than sole alfalfa at Ames and 28% at Chariton. Intercropping sorghum into reed canarygrass raised biomass production by 34% over sole reed canarygrass.

Sorghum intercropped into reed canarygrass appeared chlorotic and lacked vigor regardless of the N rate or the amount of rainfall received during the establishment period.

Because of the dry weather in late May of 1992, emergence of sorghum interseeded into alfalfa and reed canarygrass was delayed and stands were thin with a yield response that was less than in the previous years, especially for alfalfa.

Neutral detergent fiber concentration, an estimate of cell-wall concentration, was near 50% in alfalfa (Table 24 and 25), which was lowest of the species. Highest NDF concentrations were in reed canarygrass, with intermediate values in the sorghums. The NDF concentration of sweet sorghum was slightly higher than that of sorghum x sudangrass. The NDF concentration of the intercropped systems were intermediate to those of the two species when grown alone. The NDF concentrations were somewhat higher at Ames than at Chariton.

The NDF concentration minus lignin and ash (Table 6) is the estimate of cellulose + hemicellulose concentration in the dry matter. These values averaged approximately 56% reed canarygrass, 44% for sorghum x sudangrass, 50% for sweet sorghum, and 39% for alfalfa. Again, the values were somewhat higher for Ames than for Chariton. The ADF concentration minus

Table 25. Chemical composition of biomass grown at Ames. Data are averaged over years and N rates

Cropping system	NDF[a]	ADF[a]	Ash	K
	----------------	%	----------------	
Alfalfa[b]	49.9	39.0	1.7	1.7
Reed canarygrass	63.9	38.7	3.2	1.5
Sweet sorghum (SWS)	56.1	35.6	0.9	0.9
Sorghum x sudangrass (SSH)	54.7	36.1	1.6	1.3
Alfalfa/SWS	52.4	38.5	2.5	1.9
Alfalfa/SSH	54.5	39.0	2.4	2.2
Reed canarygrass/SWS	62.2	37.1	4.0	1.9
Reed canarygrass/SSH	62.5	37.9	3.7	2.0
$LSD_{(0.05)}$	2.4	1.8	0.9	0.2

[a]NDF = neutral detergent fiber, ADF = acid detergent fiber.
[b]No N fertilizer applied.

Table 26. Lignin and N concentration of biomass at Ames as influenced by N fertilizer application. Data are averaged over years.[a]

Cropping system	70 kg N/ha		140 kg N/ha	
	Lignin	N	Lignin	N
	-----------	----------- % -----------	-----------	-----------
Alfalfa[b]	9.1	3.0	9.1	3.0
Reed canarygrass	3.8	1.2	4.2	1.4
Sweet sorghum (SWS)	4.4	1.0	5.1	0.9
Sorghum x sudan-grass (SSH)	4.5	0.8	5.0	0.9
Alfalfa/SWS	7.8	2.5	7.3	2.6
Alfalfa/SSH	7.3	2.5	8.5	2.5
Reed canarygrass/SWS	3.0	1.7	3.6	1.8
Reed canarygrass/SSH	3.6	1.7	4.2	1.8

[a]$LSD_{(0.05)}$ for cropping system x N rate if 1.1 for lignin and 1 for N concentration in plant.
[b]No N fertilizer applied.

lignin and ash is an estimate of the cellulose concentration in the dry matter. These values averaged 32%, 29% for sweet sorghum, 27% for alfalfa, and 26% for sorghum x sudangrass. Once more the values were somewhat higher for Ames than for Chariton.

The ADF concentrations of alfalfa were approximately 11 percentage units less than those of NDF (Table 24 and 25), an estimate of hemicellulose concentration. The NDF - ADF difference was approximately 25 percentage units for reed canarygrass, 20 percentage units for sweet sorghum, and 18.5 percentage units for sorghum x sudangrass.

Nitrogen fertilizer had no significant effect on NDF, ADF, ash, or K concentrations. Highest K concentrations in the sole plantings was in alfalfa. Lignin concentrations were highest in alfalfa and lowest in reed canarygrass. The N main effect on lignin concentration was significant, but as seen in Table 26 the effect was not consistent for the cropping systems. The highest N concentration was also in alfalfa (Table 26). Addition of N fertilizer had only small effects upon the end concentration of herbage from the cropping systems.

At Chariton, sweet sorghum had higher NDF and ADF concentrations than the sorghum x sudangrass hybrid. The lignin concentration, however, was highest in the sorghum x sudangrass hybrid. Additionally, the sorghum x sudangrass hybrid had a higher nitrogen concentration than the sweet sorghum.

Thus our experiment has shown that yields of forage can be significantly improved by interseeding sorghum into both alfalfa and reed canarygrass. The success was greater within alfalfa. Sorghum interplanted into reed canarygrass often appeared yellow as though there was either a nitrogen deficiency or that there was some alleleopathy of the reed canarygrass upon the sorghum. Studies were conducted where additional nitrogen was applied to the sorghum, but the response did not illustrate higher yields. Sorghum did not respond to higher rates of nitrogen when interseeded into alfalfa. It is likely that maximum yields of sorghum interseeded into alfalfa can be obtained without application of nitrogen.

This would seem to be a very sustainable practice and minimize the requirement for nitrogen fertilization. In our experience, the tilt slots remained open from year to year and it was relatively easy to reestablish these each year. The alfalfa stands within the sorghum remained as high as those outside the sorghum indicating that this practice seemed to have no detrimental effect upon alfalfa.

Discussion

In addition to their value as livestock feed, forage crops may become important as energy crops for production of electricity and as feedstock for fermentation to ethanol in the future. Two potential uses are emerging. First, to meet requirements of the U.S. 1990 Clean Air Act and carbon monoxide standards set by the Environmental Protection Agency, cleaner burning petroleum fuels are now required in many urban areas. These improved fuels can be obtained by oxygenating gasoline with additives such as ethanol. Ethanol-blended gasolines have been sold in several states for the past decade.

Secondly, electrical generating plants are giving consideration to co-firing biomass with coal to reduce the SO_X emissions coming from existing coal plants. Forages and other herbaceous crops contain negligible sulfur or fuel-bound nitrogen, in contrast to both coal and oil. The Electric Power Research Institute (EPRI) has concluded that biomass from crops and trees could be used to supply 50,000 MW of electric capacity by the year 2010 (J. Turnbull. 1993). Strategies for achieving a sustainable, clean and cost-effective biomass resource. EPRI, Palo Alto, CA.)

Currently, almost all ethanol is produced by fermenting corn grain. This is now made profitable by tax incentives. Lowering of the cost of biomass used for energy conversion would improve the competitiveness of biomass as a fuel source. This might be done by using other crops or cropping systems that result in higher biomass yields. Sweet sorghum produces as much or more fermentable sugar in their stalks per unit of land as can be obtained from corn grain in the North Central Region of the USA

(Smith et al., 1987; Lueschen et al., 1991; Smith and Buxton, 1993). Smith and Buxton (1993) found sugar yields of about 6 Mg/ha at Ames, IA and Fort Collins, CO, of which about 54% was sucrose, 26% was glucose, and 20% was fructose. Nitrogen fertilizer had little effect on yield at either location.

McBee and Miller (1993) noted that concentration of nonstructural carbohydrates are near minimum in sorghum stems at early growth stages, but increase rapidly at panicle exertion (McBee and Miller, 1982).

Cherney et al. (1991) found that alfalfa yields were high on good cropland but were much lower on marginal cropland sites. Because alfalfa is drought resistant, yields were not as negatively affected in 1988 as in the perennial grass. They also noted that composition was not greatly influenced by location or nitrogen fertilization. Legumes typically contain twice as much cellulose as hemicellulose and are higher in lignin and crude protein concentration than grasses. Glucose and xylose are the primary neutral sugars in these species, with some arabinose.

Cherney et al. (1991) found that sweet sorghum yielded approximately 30% more dry matter than sorghum x sudangrass in all years except the drought year of 1988. Part of the increased yield was due to the ability of sweet sorghum to utilize more of the growing season. When sorghum was interseeded into tall fescue or reed canarygrass sod, paraquat treatment was effective in reducing competition of tall fescue but did not satisfactorily inhibit reed canarygrass growth. Although it was possible to establish sorghum in a reed canarygrass stubble, competition from the reed canarygrass (Venture) prevented the sorghum from contributing significantly to the yield component. Reed canarygrass showed good potential as a biomass species for use on poorly drained soils. Yields as high as 10,000 kg/ha were obtained and over 7,000 kg/ha were common. Two harvests per year have outyielded one cut per season.

Helsel and Wedin (1981) found that yields of forage sorghum and sorghum x sudangrass hybrid were among the highest of all the species that they tested in Iowa.

Helsel and Wedin (1983) determined the combustible energy values of several crops by bomb calorimetry. Corncobs (17.20 MJ/kg), grain sorghum panicles (17.33), and soybean stover (16.94) were significantly higher in energy than other crops or their residues (sorghum x sudangrass hybrid - 16.35; mean of 16.21 - 16.94 for all crops). They concluded that the lack of major differences in combustible energy among systems suggest little effect of environment within location.

Biomass is a cleaner source of energy than fossil fuel. Crop biomass, as compared with coal, is lower in sulfur (Steffgen, 1974). Biomass burns cleaner, being lower in CO_2 and SO_2 (Burwell, 1978), thus decreasing the polluting potential of the electrical generation plant.

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