J. Agronomy & Crop Science **191**, 35—40 (2005)

ISSN 0931-2250

Department of Crop and Soil Sciences, Cornell University, Ithaca, NY, USA

Optimum Stand Height for Forage Brown Midrib Sorghum × Sudangrass in North-eastern USA

T. F. Kilcer, Q. M. Ketterings, J. H. Cherney, P. Cerosaletti, and P. Barney

Authors' addresses: T. F. Kilcer, Field Crops Extension Educator, Cornell Cooperative Extension of Rensselaer County, 61 State St., Troy, NY 12180; Asst. Prof. Q. M. Ketterings (corresponding author; e-mail: qmk2@cornell.edu), Department of Crop and Soil Sciences, Cornell University, 817 Bradfield Hall, Ithaca, NY 14853; Prof. J. H. Cherney, Department of Crop and Soil Sciences, Cornell University, 513 Bradfield Hall, Ithaca, NY 14853; P. Cerosaletti, Dairy and Field Crops Extension Educator, Cornell Cooperative Extension of Delaware County, 34570 State Hwy 10, PO Box 184, Hamden, NY 13782; P. Barney, Field Crops Extension Educator, Cornell Cooperative Extension of St Lawrence County, 1894 State Highway 68, Canton, NY 13617, USA

With 2 figures and 1 table

Received November 11, 2003; accepted January 9, 2004

Abstract

Brown midrib sorghum × sudangrass is attracting attention in the north-eastern USA because of its ability to produce acceptable forage yields on marginal corn ground. Other potential advantages include conservation of soil on highly erosive ground, the possibility to spread manure mid-summer (after first cutting) when runoff risk is minimal, greatly reduced needs for herbicides and the potential to reduce the importation of phosphorus onto the farm. Best management practices need to be developed to take full advantage of the crop in the north-east. Seven field studies were conducted from 2000 to 2002 in four different agricultural regions in New York to determine the time of harvest optimum for yield and quality in one- to three-cut management systems. Yield, rather than a change in forage quality indicators, was the key determining factor for estimated milk production. However, to prevent the shift from vegetative to reproductive growth (and associated decline in quality) and to better manage the amount of water at harvest, we recommend that in the north-eastern USA brown midrib sorghum sudangrass be managed using a two-cut system with harvest taking place when stand heights are about 125 cm or less.

Key words: brown midrib — forage — forage quality — harvest management — north-eastern USA — sorghum sudangrass

Introduction

Conventional sorghum [*Sorghum bicolor* (L.) Moench.] and sorghum × sudangrass (*Sorghum sudanense* Piper) hybrids are not widely grown as a feed for lactating dairy cattle because of lower feeding value and lower yields than corn (*Zea mays* L.) silage (Aydin et al. 1999). Furthermore, old sorghum varieties had high levels of prussic acid (HCN, hydrocyanic acid) and thus a high potential for HCN poisoning (Fribourg 1995). However, recent research has found that sorghum enhanced with the brown midrib (BMR) gene has a feeding value that is much greater than that of conventional sorghum or sorghum × sudangrass hybrids and new varieties are low in prussic acid. The BMR mutant contains substantially less indigestible lignin and greater fibre digestibility (Cherney 1990, Fritz et al. 1990, Cherney et al. 1991, Aydin et al. 1999) and feeding studies showed that BMR sorghum may result in long-term milk production equal to that of corn silage (Grant et al. 1995, Aydin et al. 1999).

If a soil resource and climate are well suited to growing corn it is difficult to find an alternative forage crop that is economically superior to corn silage. However, in the north-east there is a significant agricultural land area that cannot produce economically viable yields of corn silage. Sorghum × sudangrass hybrids (S × S) are better adapted to drought, high temperature, excess water and low soil pH than corn. Thus, new BMR S × S hybrids may have the potential to economically compete with corn silage.

Growing BMR S × S may have potential environmental advantages over corn silage as well. The United States Department of Agriculture Natural Resources Conservations Service (USDA-NRCS 1995) estimated soil loss potential of S × S is less than half that of conventionally tilled corn; the

C factor for third year conventionally tilled corn is 0.40 vs. 0.19 for S × S (USDA-NRCS, 1995), because of greater crop vegetative soil cover with S × S. Nitrogen leaching under S × S may be substantially reduced (Long 1981) and split N applications throughout the summer may further aid in minimizing N leaching. A two- or three-cut management system for BMR S × S allows for manure applications after the spring runoff events and during the summer when the risk of runoff is considerably reduced. BMR S × S can be used as a double crop after first cut hay crop harvest and with an early September harvest it provides ground cover in the fall without the need of a rye seeding.

Although the potential environmental benefits are numerous, it is not well known how best to manage BMR S × S in the north-east as it has not been grown to a great extent in the region in the past. Although most forages decline in nutritive quality with age (see e.g. Nelson and Volenec 1995), it is unknown what the relationship between yield and quality is for BMR S × S. From 2000 to 2002, field trials were conducted to establish optimum stand cutting height (time of harvest) for both yield and quality. In this manuscript we report on the results of these studies.

Materials and Methods

Field trials

Seven field trials were conducted at four different locations in New York from 2000 to 2002. The first trial was conducted in 2000 on a Hoosic gravelly sandy soil (Dystrochrept) in Columbia County (NY). The site tested high in available phosphorus, medium in available potassium, and had a pH of 6.3–6.6. BMR S × S was planted with a seed density of 74 kg seed ha^{-1} using a conventional grain drill. Plots were 8.1 m^2 (1.8 m × 4.5 m). All plots received 17 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, and 84 kg K_2O ha^{-1} at planting and an additional 140 kg N ha^{-1} about a month after planting. A complete randomized block design in six replicates (blocks) was used. Treatments included eight different times of harvest with the first harvest taking place at an average stand height of 61 cm, and consecutive harvests at 1–2 week intervals until the crop was fully headed. Height was measured from the surface of the soil to the horizontal curve of the tallest leaf (canopy height). Average harvest stand heights at the time of harvest were 61, 99, 135, 170, 192, 231, 254 and 264 cm.

In 2001, trials focused on optimum timing of first cut harvest for stand height of 175 cm and less because the 2000 trial in Columbia County had shown that quality deteriorated to unacceptable levels with the formation of reproductive organs. In 2001, a trial was conducted on the same farm and soil type in Columbia County using a split-plot design in four replicates with N rate (84 or 168 kg of N ha^{-1}) as the main plots and stand height at harvest as the subplots. The site had a pH of 6.0 and was high in available phosphorus and potassium. The trial was established as in the previous year. Harvest took place in 1–2 week intervals during active growth periods in July and August/September. Average stand heights per treatment at the time of harvest were 77, 90, 100 and 117 cm when 84 kg N ha^{-1} was applied, and 85, 94, 106 and 120 cm when 168 kg N ha^{-1} was applied.

That same year, an identical trial was conducted on glacial outwash at high elevation in Delaware County (NY). This soil was classified as a Chenango gravelly silt loam (Dystrochrept). The pH was 5.8 and the site tested high in available phosphorus and potassium. This was the second year of BMR S × S after grass sod at the site. Additionally, the field had a recent history of dairy manure applications. The BMR S × S was seeded at a rate of 67 kg ha^{-1} using a conventional grain drill, cover chains and packer (following the drill). Starter nitrogen fertilizer was applied through the drill at a rate of 34 kg N ha^{-1}. Previous manure applications were estimated to supply approximately 56 kg N ha^{-1} (Klausner 1997). First cut harvests took place when the average S × S stand heights were 86, 117, 150 and 175 cm.

In 2002, identical trials were conducted on the farm in Columbia County (one trial), in northern NY on a lake deposited silt in St Lawrence County (one trial), and the glacial outwash in Delaware County, south-eastern NY (two trials) to study total yield under a two- or three-cut system. The St Lawrence County trial was conducted on a Muskellunge silty clay loam (Ochraqualf) with a pH of 6.6 and a medium phosphorus and potassium fertility status. The Columbia and Delaware plots were established on the same soil types as in previous years. Second cuts were obtained at three of the four locations. The year did not allow for a second cut at the northern New York site because of both late planting, record drought in the summer and an early winter. A third cut could be obtained in one of the trials in Delaware County only when first and second harvests were taken at stand heights of < 75 cm. In all other trials and management systems, a third cut was not feasible. Each plot received the equivalent of 168 kg N ha^{-1}, 29 kg of P_2O_5 ha^{-1} and 101 kg of K_2O ha^{-1} at planting while an additional 168 kg N ha^{-1} N was applied after the first cut. Targeted harvest heights for all 2002 trials were 75, 100, 120 and 140 cm. Actual harvest heights varied from 74 to 160 cm.

Forage quality analyses

For all trials, dry matter yields were measured and subsamples were analysed at the DairyOne Forage Testing Laboratory (Ithaca, NY, USA) for dry matter (DM), P, K, crude protein (CP), neutral detergent fibre (NDF), lignin, ash and 30 h *in vitro* true digestibility (IVTD). A dry matter correction factor for 60 °C dried forage was determined by NIR according to AOAC-991.01 (1995). This method is based on a calibration of the NIR scan with dry matter contents obtained after drying at 135 °C for 2 h (AOAC-930.15 1990). Forage samples were prepared for P and K analysis according to Greweling (1976). Samples were dry ashed for 4 h at 500 °C, cooled, and then dried again on a 100–120 °C hot plate after addition of 3 ml of 6 N HCl. Ashed samples were extracted in dilute acid (1.5 N HNO_3 and 0.5 N HCl), and plant P and K concentrations were determined by analysing dissolved minerals using a Thermo Jarrel Ash IRIS Advantage Inductively Coupled Plasma Radial Spectrometer (Jarrell Ash, Franklin, MA) (Greweling 1976). Nitrogen was determined by combustion (Leco Instruments, Inc., St Joseph, MI) (AOAC 990.03 1995) and multiplied by 6.25 to obtain CP, based on the assumption that BMR feed protein contains 16 % N. Neutral detergent fibre and sulfuric acid lignin were analysed according to Van Soest et al. (1991) using the ANKOM system (ANKOM Technology, Fairport, NY). Ash was determined by dry combustion (AOAC-942.05 1990). *In vitro* true digestibility was determined according to ANKOM Application Note 11/00 using the Daisy $II^{200/220}$ *in vitro* incubator and the $ANKOM^{200/220}$ fibre analyser (Ankom Technology, Macedon, NY). The 30-h NDF digestibility (dNDF) was calculated as (NDF − IVTD residue at 30 h)/NDF × 100. The alfalfa-grass spreadsheet of Milk2000 version 7.4 (developed by Schwab and Shaver at the University of Wisconsin-Madison) was used to estimate milk yields using standard values for neutral detergent insoluble crude protein (NDICP; 2.4 % on a dry matter basis) and ether extract (3.6 % on a dry matter basis) as reported for S × S silage in the 2001 Nutrient Requirements for Dairy Cattle (National Research Council). The 30-h dNDF was multiplied by 1.16 to obtain an estimate of the dNDF at 48 h (J.H. Cherney, unpublished data).

Data processing

Although stand height and yield were positively correlated in each trial and across sites, it was difficult to standardize stand height measurements across years and people. Therefore, we compared yield rather than stand height with quality parameters. Where site and year effects were not significant, data were pooled across all sites and years. Regression analyses were performed using PROC REG in SAS with total yield as independent variable and quality parameters and milk production predictions as dependent variables. Where site and year effects were not significant, the data were pooled across all sites. PROC MIXED was used to determine significance of differences in season yields for the three trials with two- to three-cut management in 2002.

Results

Growth rates

Growth rates during harvest windows ranged from an average of < 1 cm per day (all sites during mid-August and September of 2002) to 5 cm day^{-1} under moist and warm conditions in Columbia County in July of 2000 and Delaware County in July of 2002. In the 2000 trial at Columbia County, where harvest was carried out at 1–2 week intervals until the crop was fully headed, plants reached boot stage 35 days after planting, when an average stand height of 205 cm was reached. One week later, the plants were in the early heading stage and full head stage was reached 49 days after planting (stand height 254 cm). Growth rates were close to zero during the extended drought periods in early August in 2002 in all three counties. Averaged across all sites and years, dry matter yield (Mg ha^{-1}) could be predicted using stand height (stand height in cm) with the following equation:

$$\text{Dry matter yield}(\text{Mg ha}^{-1}) = 0.088 \times \text{Stand height}(\text{cm}) - 3.5 \quad r^2 = 0.74{*}{*}{*}$$

where *** is $P < 0.001$.

Yields increased by 49 kg dry matter ha^{-1} cm^{-1} during active growth of the first cut (July) period to 62 kg dry matter ha^{-1} cm^{-1} for the second cut growth period (mid-August to September).

Quality parameters

The average fibre content (%NDF) was greatest at a yield of 13.9 Mg dry matter ha^{-1} (Fig. 1a). This equals a harvest stand height of almost 200 cm. Average fibre digestibility (dNDF) fell below 85 % at yields > 4.1 Mg ha^{-1}. The 48-h digestibility of NDF (Fig. 1b), crude protein (Fig. 1c), and *in vitro* true digestibility (Fig. 1e) decreased with yield while lignin (Fig. 1d) showed a positive relationship with total biomass, especially after boot stage had been reached. The results of the 2001 trial in Columbia County suggest that the decline in protein content can be minimized with proper N fertilizer (or manure) management; in this trial, the average protein concentration of the forage was 12.0 % when 84 kg N ha^{-1} was applied and 13.8 % upon application of 168 kg N ha^{-1}.

Season biomass and predicted milk yields

Total season yields (two- to three-cut systems) ranged from 7.8 Mg ha^{-1} with harvest at stand heights of 81 cm to 11.8 Mg ha^{-1} where the average stand height at harvest was 124 cm (Table 1). The three-cut system where harvest took place at average stand heights of 81 cm yielded significantly less than a two-cut system with harvest at stand heights of 124 cm (Table 1).

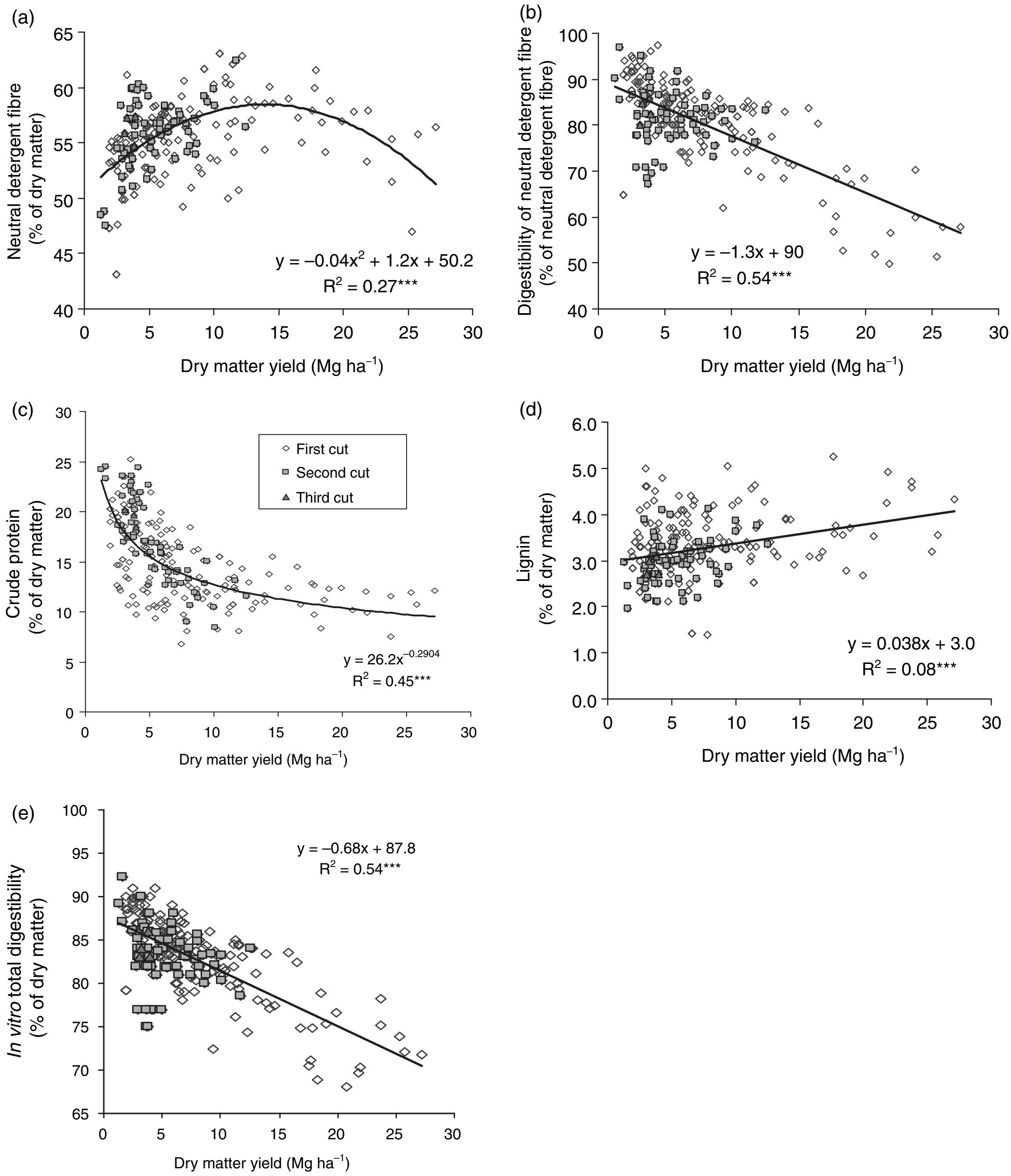

Fig. 1: Brown midrib sorghum × sudangrass dry matter yield (per cut) vs. percentage neutral digestible fibre (a), digestibility of neutral digestible fibre (b), crude protein (c), lignin (d) and *in vitro* total digestibility (e). Data originate from seven trials conducted in 2000–2002 in four different climatic regions of New York State

Despite a decrease in quality with increase in yield (Fig. 2a), dry matter yield and predicted milk yield per ha were highly correlated (Fig. 2b) independent of location, year or cutting.

Discussion

BMR S × S is not insensitive to extreme drought as demonstrated by the zero growth rates in early August in 2002 in all three counties. However, unlike corn, BMR S × S yield potential is not permanently damaged by severe drought and growth will continue relatively normally after drought.

In 2002, average corn silage yields in Columbia and Delaware Counties were 10.3 and 11.8 Mg ha^{-1} respectively (New York Agricultural Statistical Services 2003). These yields compare well with those obtained for BMR S × S in Columbia County (10.5 Mg ha^{-1}) and Delaware

Table 1: Brown midrib sorghum × sudangrass yields in two to three cut systems in Columbia and Delaware Counties, New York, in 2002

		Average stand height ± S.D. (cm)		
County	Soil	81 ± 6	97 ± 8	124 ± 15
Delaware	Dystrochrept	6.3 c	9.8 b	11.6 a
Delaware	Dystrochrept	9.1 b[1]	7.6 b	12.7 a
Columbia	Dystrochrept	7.6 b	8.2 b	10.5 a
All sites	–	7.8 b	8.5 b	11.8 a

Stand height applies to each of the two or three cuts in the system. Average values (Mg ha^{-1}) within columns with different letters (a, b, c) are statistically different at $\alpha = 0.05$.

[1] Three-cut harvest system.

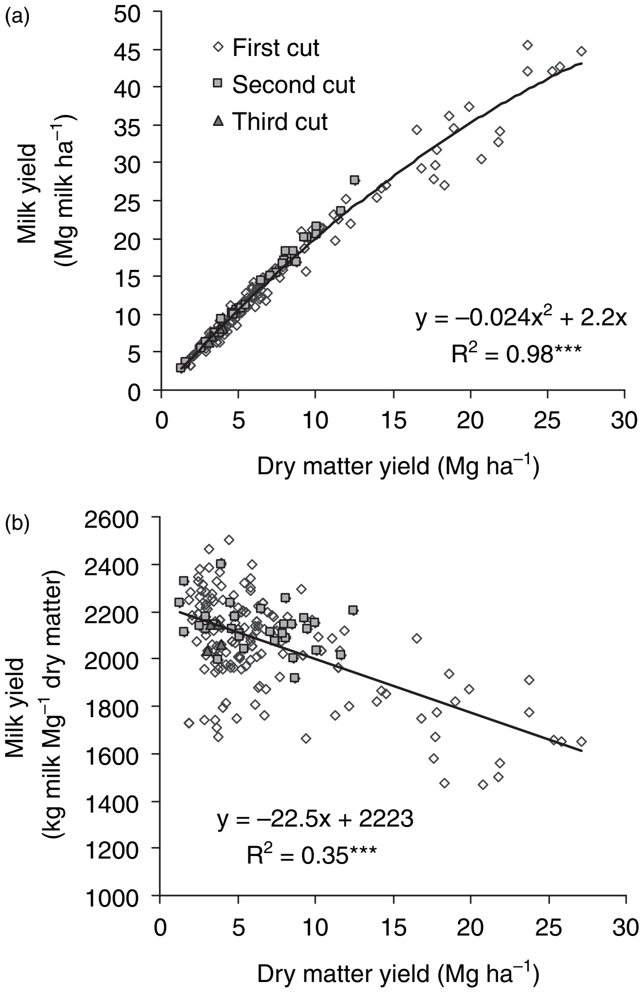

Fig. 2: Brown midrib sorghum × sudangrass dry matter yield (per cut) vs. predicted milk yield in Mg milk ha^{-1} (a) and in kg milk (b) Mg^{-1} forage dry matter and as estimated using Milk2000. Data originate from seven trials conducted in 2000–2002 in four different climatic regions of New York State

County (11.6–12.7 Mg ha^{-1}) under a two-cut management system with harvest at stand heights of 110–160 cm. However, site by site comparisons are needed integrating both yield and quality to investigate the competitive advantage of either corn or BMR S × S.

BMR S × S behaved more like corn than other grasses and legumes, with a relatively narrow range in optimum yield, but a relatively wide range for optimum quality. Most grasses and legumes have a distinct forage quality decline coinciding with increased yield. As dry matter yield was highly correlated with milk yield per hectare, we conclude that BMR S × S has a relatively large harvest window in which to achieve quality forage able to compete with corn silage. However, there are two reasons why a maximum stand height of about 125 cm may be preferred. First of all, the shift from vegetative to reproductive growth lowers quality. Secondly, the amount of water that needs to be evaporated increases with yield. The average moisture content at harvest across all studies was 84 % (ranges from 78 to 92 % moisture). Thus, per 10 Mg of BMR S × S at 84 % moisture, about 5.4 Mg of water will need to be evaporated to dry the forage down to 65 % moisture. Where planting is delayed until the end of June or early July, a two-cut system may not be feasible in northeastern USA climates and it may be advantageous to delay harvest beyond a 125-cm stand height if the extra dry matter is needed on the farm and the extra moisture can be dealt with. There was a trend towards decreasing crude protein concentrations with increasing height. Crude protein concentration at harvest can be optimized with appropriate N fertilization and manure management.

Acknowledgements

This research was funded with a grant from Garrison and Townsend Inc. and in-kind donations of Cornell Cooperative Extension of Rensselaer County, Cornell Cooperative Extension of Delaware County, and Cornell Cooperative Extension of St Lawrence County (NY).

References

AOAC-930.15, 1990: Moisture in animal feed. In: K. Helrich (ed.) Official Methods of Analysis of the Association of Official Analytical Chemists, 15th edn. AOAC, Arlington, VA, p. 69.

AOAC-942.05, 1990: Ash of animal feed. In: K. Helrich (ed.), Official Methods of Analysis of the Association of Official Analytical Chemists, 15th edn. AOAC, Arlington, VA, p. 70.

AOAC-990.03, 1995: Protein (crude) in animal feed, combustion method. In: W. R. Windham (ed.), Official methods of analysis of the association of official analytical chemists, Chapter 4, pp. 18—19 (16th edition). AOAC, Arlington, VA.

AOAC-991.01, 1995: Moisture in forage, near infrared reflectance spectroscopy. In: W. R. Windham (ed.), Official methods of analysis of the association of official analytical chemists, Chapter 4, pp. 2—4. (16th edition). AOAC, Arlington, VA.

Aydin, G., R. J. Grant, and J. O'Rear, 1999: Brown midrib sorghum in diets for lactating dairy cows. J. Dairy Sci. **82,** 2127—2135.

Cherney, J. H., 1990: Normal and brown midrib mutations in relation to improved lignocellulose utilization. In: D. E. Akin, and L. G. Lungdahl (eds), Microbial and Plant Opportunities to Improve Lignicellulosic Utilization by Ruminants, pp. 205—214. Elsevier, Amsterdam, The Netherlands.

Cherney, J. H., D. J. R. Cherney, D. E. Akin, and J. D. Axtell, 1991: Potential of brown-midrib, low-lignin mutants for improving forage quality. Adv. Agron. **47,** 157—198.

Fribourg, H. A., 1995: Summer annual grasses. In: R. F. Barnes, C. J. Nelson, M. Collins, and K. J. Moore (eds) Forages: An Introduction to Grassland Agriculture, 5th edn, pp. 463—472. Iowa State Press, Ames, IA.

Fritz, J. O., K. J. Moore, and E. H. Jaster, 1990: Digestion kinetics and cell wall composition of brown midrib sorghum × sudangrass morphological components. Crop Sci. **30,** 213—219.

Grant, R. J., S. G. Haddad, K. J. Moore, and J. F. Pederson, 1995: Brown midrib sorghum silage for mid-lactating dairy cows. J. Dairy Sci. **1978,** 1970—1980.

Greweling, T., 1976: Chemical analysis of plant tissue. Cornell Univ. Agric. Exp. Stn. Search Agriculture, Agronomy **6,** 1—35.

Klausner, S., 1997: Nutrient management: crop production and water quality. NRAES-101, Cornell Cooperative Extension, Ithaca, NY, 39 pp.

Long, F. L., 1981: The influence of sorghum sudangrass sorghum-bicolor-x-sorghum-sudanense roots on nutrient leaching. Agron. J. **73,** 537—546.

Nelson, C. J., and J. J. Volenec, 1995: Environmental aspects of forage management. In: R. F. Barnes, C. J. Nelson, M. Collins, and K. J. Moore (eds), Forages: An Introduction to Grassland Agriculture, 5th edn., pp. 55—69. Iowa State Press, Ames, IA.

New York Agricultural Statistical Services, 2003: 2002 New York Agricultural Statistics (Available online: http://www.nass.usda.gov/ny/Bulletin/2003/03-county.pdf [last accessed: August 27, 2004]).

USDA-NRCS, 1995: Electronic field office technical guide. Available online at http://www.nrcs.usda.gov/technical/efotg/ (last accessed: August 27, 2004).

Van Soest, P. J., J. B. Robertson, and B. A. Lewis, 1991: Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. **74,** 3583—3597.