Annual Forages: New Approaches for C-4 Forages

Jeffrey F. Pedersen
University of Nebraska-Lincoln, jpedersen1@unl.edu

Index | Search | Home | Table of Contents

Pedersen, J.F. 1996. Annual forages: New approaches for C-4 forages. p. 246-251. In: J. Janick (ed.), Progress in new crops. ASHS Press, Alexandria, VA.

Annual Forages: New Approaches for C-4 Forages

Jeffrey F. Pedersen

The current agricultural paradigm in the U.S. is heavily biased towards the production and marketing of crops as commodities. This paradigm is kept in place by grain handling and marketing infrastructure, as well as government farm programs, designed for crops as commodities. Sorghum (*Sorghum bicolor* L. Moench) and maize (*Zea mays* L.) grown for grain certainly fit into this current paradigm.

A new approach to agricultural production and marketing, identity preserved products, is gaining in importance. This is made possible through new technologies and markets demanding products designed specifically for their needs. Examples of investment in identity preserved products include Pioneer Hi-Bred's new research facility for grain quality (Johnson 1995), DuPont's current emphasis on value-added maize (Freiberg 1994), and Iowa State University's value-added grain marketing program (Wrage 1995). However, marketing strategies for such new grain products must be outside the current norm of sale to a local elevator and resale of a bulk commodity to grain consumers.

Sorghum and maize grown for forage are already outside of the current marketing structure for grain crops. They are typically grown, stored, and fed on the same farm. Management decisions including choice of hybrids can be based on end use. As such, it could be argued that the current paradigm for production and utilization of forages in the United States, especially annual forages, is very favorable for the development and marketing of identity preserved hybrids and varieties designed for specific end users.

ATTRIBUTES OF SORGHUM AND MAIZE FORAGE

Both sorghum and maize produce extremely high yields of high quality forage. Typical forage sorghum yields in the central U.S. (Nebraska, 1991-1993) are 27 Mg/ha, and forage maize yields are 31 Mg/ha (USDA Agricultural Statistics 1994). When grown for silage, grain content often approaches 50% ensuring high energy content (Irlbeck et al. 1993). Both sorghum and maize offer year-to-year management flexibility since they are annuals. Both also require considerably more management inputs than other forages. However, forage sorghum being very heat and drought tolerant is usually grown without irrigation. Nearly all forage maize is harvested, stored, and utilized as silage. Forage sorghum is grazed, baled for hay, green chopped, or ensiled.

Quality of the non-grain components of the forage has been historically viewed as relatively poor. To date, breeding emphasis has been for high grain yields in both sorghum and maize. High grain content has been relied upon to provide high energy content in ensiled crops. For grazing and hay type forage sorghum, harvestable dry matter yield has been emphasized. However, if 50% or more of the dry matter of ensiled forages, and up to 100% of dry matter production of forage sorghum is non-grain, quality enhancement of the forage component should contribute significantly to improved animal performance.

Users of maize silage as a forage source have always been relatively quality conscious. Producers of sorghum for forage often utilize a very different decision tree. The decision to plant forage sorghum is often based on many factors which include government programs, anticipated rainfall, pasture conditions, availability of harvesting equipment, etc. However, the decision to select a particular hybrid or variety of forage sorghum is increasingly made on perceived quality. Often these perceptions are based on animal acceptance or palatability and can outweigh yield in the process of selecting a hybrid or variety.

NEW APPROACHES TO FORAGE SORGHUM IMPROVEMENT

New genetic discoveries can typically take 10-15 years to move through testing and integration into useful lines, to commercially available products. *Brown midrib* mutants were originally induced and described in sorghum 17 years ago (Porter et al. 1978). This trait is associated with reduced lignin content and up to a 55% concomitant increase in forage digestibility expressed in both sorghum and sudangrass (*Sorghum bicolor* L. Moench var. *sudanense*) (Fritz et al. 1981) and their hybrids (Cherney et al. 1986; Fritz et al. 1990).

Such increases in digestibility are associated with increased animal performance. Lusk et al. (1984) fed a *brown midrib* sorghum silage and a corn silage to dairy cows and showed milk and fat corrected milk production to be equal (normal sorghum is usually associated with lower animal performance). More recently in our lab, milk production from cows fed silage of a pre-commercial *brown midrib* sorghum, normal sorghum, maize, and alfalfa was measured (Grant et al. 1995). Milk production was similar for cows fed the *brown midrib* sorghum, alfalfa, and corn silage. Cows fed the normal sorghum silage produced approximately 23% less milk than those fed *brown midrib* silage (Table 1). Milk fat production was similar for cows fed the *brown midrib* sorghum, alfalfa, and corn silage. Cows fed the normal sorghum silage produced approximately 35% less milk fat than cows fed *brown midrib* sorghum, alfalfa, and corn silage. Incorporation of the *brown midrib* trait into sorghum clearly improves animal performance.

Although not widely documented in the literature, it is common knowledge among sorghum breeders that the *brown midrib* trait is also associated with decreased agronomic performance. This is being overcome with applied breeding effort. Although replicated comparisons were not made in our above study, the pre-commercial *brown midrib* sorghum hybrid and the normal sorghum hybrid both yielded nearly 9000 kg/ha dry matter with no apparent differences in lodging or disease noted at harvest. Regretfully, the fate of this *brown midrib* sorghum hybrid is currently unknown due to changes in ownership and management of the company that provided the hybrid. However, commercial availability of another *brown midrib* sorghum hybrid is anticipated for the crop year 1997 (Jerry O'Rear, Garrison & Townsend, Inc. pers. commun.). Considerable effort is currently being invested in development of *brown midrib* seed parent (female) inbred lines for use in hybrid production by this and other public sector research programs.

Another new approach to forage sorghum improvement involves the use of alternate sources of cytoplasmic male sterility. Stephens and Holland (1954) originally described a system, now known as the A1 system, for hybrid sorghum seed production based on the interaction of the nuclear and cytoplasmic genes of two races of sorghum, milo, and kafir. In this system, sorghum lines are classified based on their ability to restore fertility or maintain male sterility in A1 cytoplasm. This limits potential heterotic combinations, but because of A1 cytoplasm's stability and ease of use, it has been adopted as the commercial standard and is used for essentially all commercial hybrid sorghum seed production. Alternate sources of cytoplasmic sterility do, however, exist and offer unique opportunities (Schertz and Ritchey 1978).

As alluded above, many new heterotic combinations are possible using alternate sources of cytoplasmic male-sterility. One alternate male-sterile cytoplasm, A3, has very few known restorers of male fertility. This allows the production of male-sterile forage hybrids with a much reduced risk of volunteer outcrosses with weedy sorghums the subsequent year. Although male-sterile hybrids would obviously not be acceptable for grain production, such hybrids may offer improvements in quality for grazing applications by removing seed as a strong carbohydrate sink, and increasing the non-structural carbohydrates in the forage.

A common forage sorghum hybrid is A1 cytoplasmic male-sterile 'Redlan' (a grain sorghum seed parent line) pollinated with 'Greenleaf' sudangrass (Harvey 1977). We recently obtained A1 and A3 male sterile versions of 'Redlan' and three other seed parent lines, produced hybrid seed, and conducted an experiment to compare hybrid forages in these two cytoplasms. Preliminary results showed equivalent dry matter yields, days to 50% anthesis (a measure of maturity), and height between A1 and A3 versions of the same hybrids (Table 2).

NEW APPROACHES TO FORAGE MAIZE IMPROVEMENT

Recent changes in approach to forage maize improvement in the U.S. have focused on variation in the forage quality of the stover portion of the plant. Most previous breeding efforts have emphasized increasing grain yield as a means of increasing the energy content of the overall forage since it is very digestible and makes up a large proportion of the whole-plant dry matter. Surprisingly, correlations between maize grain yield and whole plant yield, stover yield, and whole-plant digestibility are low (Table 3). Increases in the forage quality of maize will, therefore, probably focus on improvement of stover quality.

Brown mid-rib mutants have been known in maize since at least 1926 (Eyster). However, widespread use of these mutants in commercial hybrids has not occurred because they are also associated with poor grain and stover yield, and susceptibility to lodging (Miller et al. 1983; Lee and Brewbaker 1984).

Several recent studies have investigated the relationships among various forage quality traits in maize (Allen et al. 1991; Wolf et al. 1993). Jung and Buxton (1994) utilized a multiple regression approach to identify the principle components of maize polysaccharide degradability (quality), and concluded that because of the complex interactions in cell-wall organization, no single cell-wall component, or simple combination, can accurately predict degradability of maize cell walls. Significant genetic variation for maize stover digestibility has been shown by several researchers (Hunt et al. 1992; Lundvall et al. 1994) (Table 4). Although as pointed out by Deinum and Bakker (1981), "breeding for stover quality will not be simple as a good correlation between stover quality and stover morphology has not yet been found," it appears that as concluded by Wolf et al. (1993) "future efforts to improve whole-plant digestibility should concentrate on stover digestibility."

New Markets for C-4 Forages

The above discussions centered on approaches to design sorghum and maize forages for the major existing market, i.e. livestock. If we move past this "old" marketing paradigm, some exciting new markets for these forage materials open up. The first and possibly the potentially largest is energy production. Lueschen et al. (1991) reported ethanol yields of 3048 liters/ha from fermentable carbohydrates in 'Keller' sweet sorghum sap with no nitrogen fertilization (residual soil N was approximately 90 kg/ha prior to the experiment). Although the authors indicate that the study was inconclusive, reduced N inputs compared to maize grain could make energy balances favorable. New technologies to convert the fiber to fermentable carbohydrates will make yields and energy balances even more favorable, and are discussed in another paper in this volume (Vogel and Shearman 1996).

Other potential new markets for sorghum and maize forages includes uses in the paper and construction industries. Sorghum stalk residue following grain harvest have been combined with high strength adhesives to produce a product very similar to wafer board (Barbara Kliment, Nebraska Sorghum, Board pers. commun.). This product demonstrates a viable alternate use of sorghum or maize stalks. However, it has not reached the commercial marketplace.

Another promising alternate use of sorghum stalk residues, the production of paper products, is receiving current market interest due to high pulp and paper prices (Tim Lust, National Sorghum Board, pers. commun.). The short cellulose fibers of sorghum stalks are similar to hardwood fibers. Production options include fine white paper, magazine print, copy paper, newsprint, and heavy unbleached paper for use in corrugated boxes.

We have also investigated the potential of using forage sorghum for remediation of chemically (N) contaminated soils, as well as genetic variation for this character (Pedersen et al. 1995). In general, sorghum has a very high N-uptake potential and an extensive root system which is very effective in scavenging N from the soil. Three hybrids each of six types of sorghum (tropical, forage, sudangrass, sorghum x sudangrass, grain, and sweet) were evaluated for N accumulation on a municipal biosolids disposal site. Tropical sorghum and sorghum x sudangrass had the highest dry matter production and accumulated the most nitrogen. Biomass produced was adequate for beef maintenance diets, and may be a useful biomass source for ethanol production from cellulose (Table 5).

CONCLUSIONS

New approaches for genetic improvement of forage sorghum and forage maize are being used to develop superior products for livestock feeding, the major existing market. These products are good current examples of a defined market need supporting the development of identity preserved, value added hybrids. These forage products are already marketed outside of the normal commodity grain/grain elevator paradigm common to much of U.S. agriculture. As the marketplace demands new raw materials from agriculture, crops such as sorghum and maize can be genetically modified to meet those specific needs. Successful integration of new approaches and new raw products into the marketplace will depend in part on new marketing structures which will include identity preserved value-added, agricultural products which must be developed specifically for targeted markets.

REFERENCES

- Allen, M.S, K.A. O'Neil, D.G. Main, and J. Beck. 1991. Relationship among yield and quality traits of corn hybrids for silage. J. Dairy Sci. 74:(suppl. 1):221.
- Cherney, J.H., K.J. Moore, J.J. Volenec, and J.D. Axtell. 1986. Rate and extent of digestion of cell wall components of brown-midrib sorghum species. Crop Sci. 26:1055-1059.
- Deinum, B. and J.J. Bakker. 1981. Genetic differences in digestibility of forage maize hybrids. Neth. J. Agr. Sci. 29:92-98.
- Eyster, W.H. 1926. Chromosomes VIII in maize. Science 64:22.
- Freiberg, B. 1994. Will DuPont's muscle speed up value-added ag production? Seed Crops Ind. December:4-36.
- Fritz, J.O., R.P. Cantrell, V.L. Lechtenberg, J.D. Axtell, and J.M. Hertel. 1981. Brown midrib mutants in sudangrass and grain sorghum. Crop Sci. 21:706-709.
- Fritz, J.O., K.J. Moore, and E.H. Jaster. 1990. Digestion kinetics and cell wall composition of brown midrib sorghum x sudangrass morphological components. Crop Sci. 30:213-219.
- Grant, R.J., K.J. Moore, and J.P. Pedersen. 1995. Brown midrib sorghum silage for midlactation dairy cows. J. Dairy Sci. 78:1970-1980.
- Harvey, P.H. 1977. Sorghum germplasm base in the U.S. Proc. 32nd Annual Corn and Sorghum Research Conference, Am. Seed Trade Assn., Chicago. p. 168-198.
- Hunt, C.W., W. Kezar, and R. Vinande. 1992. Yield, chemical composition, and ruminal fermentability of corn whole plant, ear, and stover as affected by hybrid. J. Prod. Agr. 5:286-290.
- Irlbeck, N.A., J.R. Russell, A.R. Hallauer, and D.R. Buxton. 1993. Nutritive value and ensiling characteristics of maize stover as influenced by harvest maturity and generation, plant density and harvest date. Anim. Feed Sci. Tech. 41:51-64.

- Johnson, K.L. 1995. From seed to feed testing. Farm Ind. News 28:30.
- Jung, H.-J.G. and D.R. Buxton. 1994. Forage quality variation among maize inbreds: relationships of cell-wall composition and in-vitro degradability for stem internodes. J. Sci. Food Agr. 66:313-322.
- Lee, W.C. and J.L. Brewbaker. 1984. Effects of brown midrib-3 on yields and yield components of maize. Crop Sci. 24:105-108.
- Lueschen, W.E., D.H. Putnam, B.K. Kanne, and T.R. Hoverstad. 1991. Agronomic practices for production of ethanol from sweet sorghum. J. Prod. Agr. 4:619-625.
- Lusk, J.W., P.K. Karau, D.O. Balogu, and L.M. Gourley. 1984. Brown midrib or corn silage for milk production. J. Dairy Sci. 67:1739-1744.
- Lundvall, J.P., D.R. Buxton, A.R. Hallauer, and J.R. George. 1994. Forage quality variation among maize inbreds: in vitro digestibility and cell-wall components. Crop Sci. 34:1672-1678.
- Miller, J.E., J.L. Geadelmann, and G.C. Martin. 1983. Effect of the brown midrib-allele on maize silage quality and yield. Crop Sci. 23:493-496.
- Pedersen, J.F., K.J. Moore, S. Schroth, and D.T. Walters. 1995. Nitrogen accumulation of six groups of sorhgum grown on a municipal biosolids use site. Water Environ. Res. 67:1076-1080.
- Porter, K.S., J.D. Axtell, V.L. Lechtenberg, and V.F. Colenbrander. 1978. Phenotype, fiber composition, and in vitro dry matter disappearance of chemically induced brown midrib (*bmr*) mutants of sorghum. Crop Sci. 18:205-208.
- Schertz, K.F. and J.J. Ritchey. 1978. Cytoplasmic-genic male-sterility systems in sorghum. Crop Sci. 18:890-893.
- Stephens J.C. and R.F. Holland. 1954. Cytoplasmic male-sterility for hybrid sorghum seed production. Agron. J. 46:320-323.
- Toy, J.J., J.F. Pedersen, K.J. Moore, and R.D. Lee. 1993. Fertility and forage yield of sorghum hybrids in A1 and A3 cytoplasm. Proc. 1993 American Forage and Grasslands Conference, Mar. 29-31, Des Moines, IA. p. 192-195.
- USDA National Agricultural Statistics Service. 1994. USDA Agricultural Statistics. U.S. Government Printing Office, Washington, DC.
- Vogel, K.P. and R. Shearman. 1996. Perennial grasses: New applications and uses. p. 263-270. In: J. Janick (ed)., Progress in new crops. Am. Soc. Hort. Sci., Alexandria, VA.
- Wolf, D.P., J.G. Coors, K.A. Albrecht, D.J. Undersander, and P.R. Carter. 1993. Forage quality of maize genotypes selected for extreme fiber concentrations. Crop Sci. 33:1353-1359.
- Wrage, K. 1995. NIR scanners may get value-added grain market rolling. Seed Crops Ind. February:6-26.

Table 1. Performance of midlactation cows as influenced by forage source (Grant et al. 1995).

	Yield (kg/d)	
Diet	Milk	Fat
Normal sorghum	20 b[z]	0.7 b
bmr sorghum	26 a	1.1 a
Alfalfa	30 a	1.1 a

Maize	26 a	1.1 a

[z]Mean separation in columns by Duncan's Multiple Range Test, 10% level.

Table 2. Mean values for total seasonal dry matter production, days to anthesis, and plant height of A1 vs. A3 sorghum x sudangrass hybrids (Toy et al. 1993).

Seed parent	Dry matter yield (kg/ha)	Days to anthesis (days)	Height (cm)
A1 Martin	10600[z]	77	162
A3 Martin	12300	77	169
A1 Redbine58	12500	76	168
A3 Redbine58	12200	76	172
A1 Wheatland	10400	82	152
A3 Wheatland	10700	82	151
A1 Ks24	11000	79	159
A3 Ks24	11100	79	165

[z]No significant differences were shown for the single degree of freedom contrasts shown in this table at 5% level.

Table 3. Correlation of maize grain yield with whole-plant dry matter yield, stover yield, and whole-plant digestibility in two testcrosses (Wolf et al. 1993)

	Maize grain yield correlation (r)	
Variable	Testcross A	Testcross B
Dry matter yield		
whole plant	0.65	0.54
stover	0.53	0.46
Whole plant digestibility	-0.03	-0.02

Table 4. Extreme variation for in vitro digestible dry matter among 45 maize inbred lines (Lundvall et al. 1994)

	In vitro dry matter digestibility (g/kg)		
Inbred	Early-harvest stems	Leaves	Late-harvest stems
B57	727	676	576
bm1bm1	654	665	497
LAN232	666	589	502
B52	513	632	461
L289	557	583	262
LSD (5%)	31	20	49

Table 5. Dry matter yield, nitrogen accumulation, and in vitro dry matter digestibility (IVDMD) of six types of sorghum grown on a site containing high soil nitrogen (Pedersen et al. 1995).

Type	Dry matter yield (Mg/ha)	Nitrogen accumulated (kg/ha)	IVDMD (%)
Grain sorghum	13.5	204	63
Sudangrass	15.6	208	50
Sorghum x sudangrass	19.5	251	52
Forage sorghum	17.1	240	61
Sweet sorghum	15.8	203	60
Tropical sorghum	19.4	266	54
SE	0.7	11	1

Last update June 6, 1997 aw