Agronomic Evaluations of Maize Genotypes Selected for Extreme Fiber Concentrations

D. P. Wolf,* J. G. Coors, K. A. Albrecht, D. J. Undersander, and P. R. Carter

ABSTRACT

Maize (*Zea mays* L.) hybrids with good yields of grain and whole-plant dry matter are recommended for silage production. The stover can comprise more than 50% of the whole-plant dry matter and, therefore, can influence dry matter yield and nutritive value of the whole plant. The objective of this study was to determine relationships between agronomic characteristics (stover and whole-plant forage yield and moisture, grain yield and moisture, lodging, maturity, and ear percentage) and nutritional quality of maize forage in three populations. Twenty-four $S_{0.1}$ families (S_0-derived families in S_1) exhibiting a range in neutral detergent fiber (NDF) and lignin at mid-flower, were testcrossed to two commercial inbred lines (FR23 and LH74) to form two groups of F_1 hybrids. A third experimental group was created by self-pollinating the $S_{0.1}$ families to form $S_{0.2}$ families. This germplasm was evaluated at three environments in Wisconsin. For FR23 testcrosses, grain yield had a correlation coefficient of 0.53 with stover dry matter yield, 0.65 with whole-plant dry matter yield, and −0.03 with whole-plant in vitro true digestibility. For LH74 testcrosses, the similar correlation coefficients were 0.46, 0.54, and −0.02, respectively. Also for FR23 testcrosses correlation coefficients of stover yield with whole-plant yield, NDF, and in vitro true digestibility were 0.89, 0.53, and −0.28, respectively. For LH74 testcrosses the coefficients were, 0.85, 0.40, and −0.48, respectively. The results of this study demonstrate that stover yield and nutritional quality are important factors influencing whole-plant yield and nutritional quality of maize forage.

MAIZE IS GENERALLY VALUED as a grain crop; however it has substantial importance as a forage crop in many maize-growing regions. Approximately 2.4 million hectares of maize silage are harvested annually in the USA, with Wisconsin the top silage-producing state, harvesting about 300 000 ha.

It has generally been believed that a high-yielding grain hybrid will perform well as a silage hybrid. Vattikonda and Hunter (1983) observed a positive relationship between grain yield and dry matter yield of hybrids developed for grain yield. This relationship, however, has not been shown to be strong enough to justify selecting hybrids for silage production based solely on grain yield performance (Vattikonda & Hunter, 1983; Allen et al., 1991; Fairey, 1980).

Grain is highly digestible and can comprise a large fraction of the whole-plant forage. Therefore it seems likely that grain yield would have a strong association with whole-plant digestibility. Reported correlations are lower than those observed between grain and whole-plant dry-matter yields, however (Vattikonda and Hunter, 1983 and Allen et al., 1991). The relationship between ear percentage or grain content of the whole plant and whole-plant digestibility has also been studied. Ear percentage is the fraction of whole-plant forage comprised of grain and cob. Deinum and Bakker (1981) observed only a weak relationship between digestibility and ear percentage. Selection based on ear-to-stover ratio may not lead to higher total digestible nutrient yields per plant (Roth et al., 1970). Allen et al. (1991) reported a strong relationship between grain content and whole-plant digestibility (r = 0.80), but included a broad range of hybrids, some with very low grain yields.

Stover digestibility is well correlated with whole-plant digestibility, but stover digestibility is not strongly related to ear percentage or grain yield (Deinum and Bakker, 1981; Vattikonda and Hunter, 1983). Similarly, there seems to be no relationship between cell wall digestibility of the stover and ear percentage or grain yield (Dolstra and Medema, 1990; Deinum and Bakker, 1981). Deinum and Bakker (1981) concluded that in their environment, grain fill and cell wall composition, including degree of lignification, are independent. Therefore, whole-plant digestibility is influenced by two independent factors: whole-plant grain content and stover digestibility (Deinum and Bakker, 1981; Vattikonda and Hunter, 1983; Hunt et al., 1992).

The future genetic improvement of silage quality will likely focus on stover composition and digestibility (Deinum and Struik, 1989; Dolstra and Medema, 1990, and Johnson et al., 1985). A decrease in stalk lignin may increase stover digestibility (Colenbrander et al., 1975, and Miller et al., 1983) but may also lead to increased stalk lodging (Undersander et al., 1977; Twumasi-Afriyie and Hunter, 1982). However, Albrecht et al. (1986) observed that recurrent selection for improved stalk strength or stalk rot resistance was accompanied by decreases in cell wall and lignin concentrations and an increase in digestibility of the stalk. Selection increased total nonstructural carbohydrates, which diluted stalk fiber concentration and resulted in an increase in digestibility.

Two maize populations, WFISIHI and WFISILO, were developed at the Univ. of Wisconsin to study the effects

---

D.P. Wolf, Dep. of Agronomy, Iowa State Univ., Ames, IA 50011; J.G. Coors, K.A. Albrecht, D.J. Undersander and P.R. Carter, Dep. of Agronomy, Univ. of Wisconsin-Madison, Madison, WI 53706. Contribution of the Wisconsin Agric. Exp. Stn. Part of a thesis submitted by D.P. Wolf in partial fulfillment of requirements for the M.S. degree at the Univ. of Wisconsin-Madison. Received 23 Dec. 1992. *Corresponding author.

Published in Crop Sci. 33:1359–1365 (1993).

Abbreviations: ADF, acid detergent fiber; CP, crude protein; CWD, cell wall digestibility; IVTD, in vitro true digestibility; MS, mid-silk date; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy.

of cell wall composition on insect resistance (Beeghly, 1990; Buendgen et al., 1990). The populations express extreme fiber and lignin concentrations and are useful in examining relationships between nutritional and agronomic characteristics in maize (Wolf et al., 1993). Selection for fiber content and composition of maize stover may influence carbohydrate partitioning between endosperm and stover. If so, changes in stover fiber might be associated with changes in grain yield and stalk strength. Plant maturity may also change with selection for quality-related traits, because fiber and lignin increase dramatically as forages mature (Van Soest, 1982). If there is a large range in maturity in the germplasm under selection, then selection for stover composition may reflect, in part, changes in development.

The focus of the current research is to evaluate selected genotypes from three populations [WFISIHI, WFISILO, and BS9(CB)] for nutritional quality, dry matter yield, and moisture content of stover and whole-plant forage. Genotypes were also evaluated for grain yield and moisture content, maturity, stalk and root lodging, plant height, and ear percentage of whole-plant forage. Our objective was to determine relationships between the agronomic characteristics and nutritional quality of maize forage.

MATERIALS AND METHODS

Germplasm

The germplasm used in this study has been described previously by Wolf et al. (1993). Briefly, eight $S_{0.1}$ families (S_0-derived families in S_1) from each of WFISIHI, WFISILO, and BS9(CB)C2 were selected for this study. Within each population, four families were selected on the basis of high NDF and lignin content, and four families had low NDF and lignin content. Therefore, within each population there are two subpopulations, "hi" and "lo," each composed of four families.

In 1989, the 24 $S_{0.1}$ families were testcrossed to two commercial inbred lines, FR23 and LH74, to form two experimental groups of F_1 hybrids. At least 10 plants from each $S_{0.1}$ family were used to make the testcrosses. A third experimental group was created by selfing at least 10 plants from each $S_{0.1}$ family to form bulk $S_{0.2}$ families.

Field Experiments

The FR23 and LH74 hybrid trials and $S_{0.2}$ family trials were treated as three independent field experiments, as described previously by Wolf et al. (1993). Separate forage and grain trials were grown for each group at Madison and Arlington, WI, in 1990 and at Madison in 1991. Soil type at both locations is a Plano silt loam (fine-silty, mixed mesic Typic Arguidoll). The experimental design for all trials was a randomized complete block with three replications. Planting and agronomic procedures were identical for grain and forage trials and have been described previously (Wolf et al., 1993).

Mid-silk date and plant height were measured in the grain trials at Madison in 1990 and 1991. Mid-silk dates were measured as the days from 30 June until silks had appeared on 50% of the plants in each plot. Shortly after pollen shed, plant height was measured as the distance from the ground to the tip of the tassel.

Shortly before grain harvest, root and stalk lodging data were recorded at all environments. Plants leaning more than 30 ° from vertical were considered root lodged; stalks broken beneath the primary ear, stalk lodged. Lodging data were reported as a percentage of the total plot stand. Testcross trials were harvested with a self-propelled plot combine that recorded grain weight and moisture. The $S_{0.2}$ trials were hand harvested. Ears were harvested from 15 plants plot^{-1} in 1990, and from 20 plants plot^{-1} in 1991. Ears were harvested only from plants bordered by other plants. The ears were machine-shelled and the grain weight and moisture recorded. For all trials, grain weights were adjusted to 155 g kg^{-1} grain moisture.

Harvesting of forage trials has been previously described (Wolf et al., 1994). Trials were harvested when approximately 75% of the plots had a milk-line rating of 1/2 or lower (Crookston and Kurle, 1988). Before harvest, ears were removed from one row of each plot; this row was harvested as stover. The second row was harvested as whole-plant. Five ears from each plot were broken in the middle and kernel milk-line was determined. Milk-line was recorded on 4 to 0 scale, with 4 indicating early dent and 0 indicating black layer formation. Ratings of 3, 2, and 1 indicate the position of the milk-line as 3/4, 1/2, or 1/4 of the way from base to tip. Therefore, a rating of 3 indicates 3/4 of the kernel was milk.

The moisture content of each tissue was determined from the approximate 1 kg subsample of stover and whole-plant tissue that was collected from each plot and dried at 60 °C for 1 wk. Stover and whole-plant dry matter weights were calculated at 0 g kg^{-1} moisture. The difference between stover and whole-plant weights was divided by the whole-plant weight to determine percent ear. Laboratory assays of forage composition and digestibility, as well as methods of statistical analysis were as described in Wolf et al. (1993). All discussions of significance refer to $P < 0.05$.

RESULTS AND DISCUSSION

Growing conditions were favorable for maize in all environments. Cool and wet conditions in May 1990 delayed planting at Madison. In contrast, May 1991 was dry and warm, which allowed earlier planting at Madison. Above average temperatures in May and June of 1991 stimulated early growth and resulted in early harvest dates for all trials. As a result of these different environmental conditions, genotype-by-environment interactions were observed for numerous traits in all trials. The effect of the interaction was a change in magnitude for all environments. In general, a significant change in ranking of genotypes did not occur; therefore, means combined across environments are presented.

Grain Trials

Population BS9 had the highest grain yield in all three trials (Tables 1 and 2). In testcross trials WFISILO and WFISIHI had similar yields, while in the $S_{0.2}$ trial, WFISILO had a higher yield. Among subpopulations in the $S_{0.2}$ trial, BS9-lo, BS9-hi, and WFISILO-lo had similar high yields (Table 1). In testcross trials BS9-lo and BS9-hi had high yields, while WFISILO-lo had low yields relative to other subpopulations (Table 2).

For grain moisture, mid-silk date, and plant height, the general differences among populations and subpopulations were similar in all three trials. In general, population BS9 and subpopulations BS9-lo and BS9-hi had high grain moistures, late silking dates and were tall (Tables 1 and 2). Population WFISILO and subpopulation WFISILO-lo had low grain moistures, early silking dates and were short.

In the $S_{0.2}$ trial, population BS9 had the lowest root

Table 1. Mean values of agronomic traits from maize grain trials, for populations and subpopulations of $S_{0.2}$ families averaged across three environments. The range among 24 $S_{0.2}$ families is also shown.

	Yield	Moisture	RL†	SL‡	PHT§	MS¶
	Mg ha^{-1}	g kg^{-1}	— %	—	cm	d
Population x̄						
BS9	3.80	329	3.7	2.3	207	28.8
WFISIHI	2.89	289	8.5	5.6	187	26.9
WFISILO	3.33	287	8.6	6.6	183	24.1
Subpopulation x̄						
BS9-hi	3.63	335	0.9	1.5	195	30.0
BS9-lo	3.96	322	6.4	3.0	218	27.5
WFISIHI-hi	2.84	267	3.1	4.7	180	26.1
WFISIHI-lo	2.93	310	13.9	6.6	194	27.6
WFISILO-hi	2.94	303	4.3	2.7	186	26.4
WFISILO-lo	3.71	271	12.8	10.4	180	21.8
Range among families						
high	5.04	385	21.5	25.6	239	32.5
low	1.99	226	0.0	0.4	161	19.3
LSD (0.05)						
populations	0.35	16	ns	3.1	7	0.5
subpopulations	0.50	22	7.2	4.3	10	0.7
families	1.00	44	14.4	8.7	20	1.3
CV%	18.1	8.5	79.6	77.6	5.8	4.6

† RL = root lodging

‡ SL = stalk lodging

§ PHT = plant height

¶ MS = days after 30 June to mid-silk

and stalk lodging percentages. Differences were found within WFISIHI and WFISILO for root lodging and within WFISILO for stalk lodging. The "lo" subpopulations had more root or stalk lodging than the "hi" subpopulation. In testcross trials, no differences existed among populations for root lodging and stalk lodging (Table 2). Differences within and among subpopulations were due to the high lodging percent of a few individual testcrosses.

Grain yield was not related to any other trait evaluated in grain trials for $S_{0.2}$ families (Table 3). As expected, later-flowering families tended to be taller, and grain moisture was correlated with mid-silk date. Mid-silk date was also negatively correlated with root lodging.

For both testcross trials, grain yield was highly correlated with plant height and mid-silk date (Table 4). Grain moisture was highly correlated with mid-silk date in both trials. In general, elevated grain yields and high grain moisture were associated with taller, later-flowering testcrosses.

Forage Trials

In the $S_{0.2}$ trial the range in whole-plant moisture content among families was very broad (562 to 746 g kg^{-1}) (Table 5). Several families were, therefore, not harvested within the recommended range (630 to 700 g kg^{-1}) to obtain maximum dry matter yields and digestibility (Daynard and Hunter, 1975; Hunt et al., 1989). In the testcross trials, few testcrosses had whole-plant moisture contents outside of this range.

For both FR23 and LH74 testcrosses, there were relatively large ranges in whole-plant dry matter yields of 6.37 and 5.67 Mg ha^{-1}, respectively (Table 6). Previous studies of commercial hybrids have reported ranges of about 3 to 5 Mg ha^{-1} (Vattikonda and Hunter, 1983; Allen et al., 1990).

Overall, BS9 had higher yields and moisture contents

Table 2. Mean values of agronomic traits from grain trials, for populations and subpopulations of FR23 and LH74 maize testcrosses averaged across three environments. Ranges among 24 FR23 and 24 LH74 testcrosses are also shown.

	FR23 testcrosses						LH74 testcrosses					
	Yield	Moisture	RL†	SL‡	PHT§	MS¶	Yield	Moisture	RL	SL	PHT	MS
	Mg ha^{-1}	g kg^{-1}	— %	—	cm	d	Mg ha^{-1}	g kg^{-1}	— %	—	cm	d
Population x̄												
BS9	10.59	268	2.6	2.8	267	18.8	10.70	315	2.0	3.7	275	21.0
WFISIHI	9.42	266	1.4	2.8	260	18.0	9.53	293	2.0	3.4	263	19.5
WFISILO	9.43	261	2.2	2.3	255	16.6	9.37	286	1.2	3.5	256	18.8
Subpopulation x̄												
BS9-hi	10.77	269	2.4	3.0	264	19.2	10.77	318	1.1	3.3	271	21.8
BS9-lo	10.41	268	2.8	2.6	269	18.3	10.63	311	2.9	4.1	279	20.2
WFISIHI-hi	9.43	272	1.1	2.5	255	17.4	9.43	292	1.4	3.3	259	18.9
WFISIHI-lo	9.41	259	1.8	3.0	264	18.5	9.62	294	2.5	3.6	268	20.0
WFISILO-hi	9.71	275	1.2	1.1	260	17.6	9.39	302	1.3	2.6	261	20.0
WFISILO-lo	9.14	247	3.1	3.5	250	15.6	9.34	270	1.1	4.4	251	17.6
Range among testcrosses												
high	11.36	297	6.3	4.8	283	21.7	11.32	342	5.9	6.8	286	24.0
low	8.12	234	0.2	0.4	230	14.2	8.65	242	0.0	1.2	228	16.5
LSD (0.05)												
populations	0.33	5	ns	ns	4	0.4	0.43	5	ns	ns	4	0.5
subpopulations	0.45	7	1.6	1.6	6	0.6	0.61	7	ns	1.4	5	0.7
testcrosses	0.93	14	3.2	ns	11	1.3	1.20	13	ns	2.8	11	1.3
CV%	8.3	4.2	165.1	89.5	3.8	4.0	8.0	4.0	144.7	84.9	3.5	3.3

† RL = root lodging.

‡ SL = stalk lodging.

§ PHT = plant height.

¶ MS = days after 30 June to mid-silk.

Table 3. Phenotypic correlation coefficients (*n* = 24) among grain and forage agronomic traits for $S_{0.2}$ maize families.

		Grain moisture	RL†	SL‡	PHT§	MS¶	Stover		Whole-plant			ML#
							Yield	Moisture	Yield	Moisture	%Ear	
Grain												
	Yield	−0.22	0.09	0.17	0.20	−0.28	−0.02	0.04	0.15	−0.13	0.33	−0.22
	Moisture		−0.44*	−0.21	0.39	0.77**	0.73**	0.80**	0.65**	0.83**	−0.39	0.73**
	RL			0.50*	−0.12	−0.51*	−0.39	−0.47*	−0.37	−0.52**	0.18	−0.47*
	SL				−0.10	−0.29	−0.26	−0.23	−0.26	−0.32	0.01	−0.35
	PHT					0.46*	0.73**	0.37	0.68**	0.42*	−0.31	0.43*
	MS						0.78**	0.81**	0.65**	0.93**	−0.56**	0.88**
Stover												
	Yield							0.78**	0.90**	0.77**	−0.56**	0.73**
	Moisture								0.75**	0.94**	−0.36	0.79**
Whole-plant												
	Yield									0.68**	−0.16	0.56**
	Moisture										−0.45*	0.89**
	%Ear											−0.62**

*, ** significant at 0.05 and 0.01 probability levels, respectively.
† RL = percent root lodging.
‡ SL = percent stalk lodging.
§ PHT = plant height.
¶ MS = days after 30 June to mid-silk.
# ML = kernel milk-line.

for both stover and whole-plant forage in all trials (Tables 5 and 6). Stover moisture content, however, was not consistently higher than WFISIHI. Populations WFISIHI and WFISILO had similar whole-plant yields, while WFISILO had the lowest stover yields and forage moisture contents. However, WFISILO was not consistently lower than WFISIHI for stover yield.

In all trials, either subpopulation BS9-hi or BS9-lo had the highest yields and moisture contents for both whole-plant and stover forages. They were not consistently higher than each other or other subpopulations. Across all trials, WFISILO-lo and WFISIHI-hi generally had lower yields and moisture contents than other subpopulations.

Population WFISILO had the highest percent ear in both trials, and subpopulation WFISILO-lo had highest among subpopulations. Neither WFISILO or WIFISILO-lo were consistently higher than BS9 or BS9-hi and WFISILO-hi, however. Results for milk-line ratings generally reflect differences observed for other maturity-related traits such as grain and forage moisture contents and mid-silk date.

Nearly all correlations among forage traits were highly significant (Tables 3 and 4). As expected, stover yield and moisture were correlated with whole-plant yield and moisture. High stover and whole-plant yields were associated with late-maturing genotypes as measured by milk line. Percent ear was negatively correlated with stover yield and milk-line rating, indicating that the later maturing families produced more stover than ear.

Relationships between Grain and Forage Traits

In both the FR23 and LH74 trials, grain yield was correlated with stover and whole-plant yields (Table 4).

Table 4. Phenotypic correlation coefficients (*n* = 24) among grain and forage agronomic traits for FR23 maize testcrosses (above diagonal) and LH74 testcrosses (below diagonal).

	Grain		RL†	SL‡	PHT§	MS¶	Stover		Whole-plant			ML#
	Yield	Moisture					Yield	Moisture	Yield	Moisture	%Ear	
Grain												
Yield		0.23	−0.08	0.06	0.52**	0.64**	0.53**	0.56**	0.65**	0.51*	−0.11	0.49**
Moisture	0.48*		−0.14	−0.35	0.36	0.60**	0.55**	0.58**	0.51*	0.68**	−0.38	0.73**
RL	0.10	−0.02		−0.10	−0.03	−0.12	−0.06	−0.12	0.14	−0.11	0.35	−0.09
SL	0.21	−0.03	0.31		−0.13	−0.16	−0.24	−0.09	−0.20	−0.20	0.21	−0.23
PHT	0.63**	0.48*	0.27	0.12		0.73**	0.87**	0.58**	0.81**	0.69**	−0.59**	0.61**
MS	0.53**	0.81**	0.01	−0.11	0.62**		0.87**	0.72**	0.83**	0.83**	−0.57**	0.78**
Stover												
Yield	0.46*	0.63**	0.07	−0.20	0.62**	0.75**		0.73**	0.89**	0.83**	−0.73**	0.74**
Moisture	0.68**	0.74**	0.23	0.05	0.73**	0.70**	0.68**		0.73**	0.94**	−0.46*	0.75**
Whole-plant												
Yield	0.54**	0.65**	−0.04	−0.18	0.65**	0.77**	0.85**	0.63**		0.80**	−0.35	0.69**
Moisture	0.61**	0.79**	0.23	0.02	0.77**	0.83**	0.83**	0.93**	0.78**		−0.56**	0.85**
%Ear	−0.23	−0.36	−0.16	0.11	−0.34	−0.42*	−0.78**	−0.49*	−0.33	−0.56**		−0.49*
ML	0.52**	0.82**	−0.04	−0.08	0.52**	0.79**	0.58**	0.68**	0.66**	0.74**	−0.27	

*, ** significant at 0.05 and 0.01 probability levels respectively.
† RL = percent root lodging.
‡ SL = percent stalk lodging.
§ PHT = plant height.
¶ MS = days after 30 June to mid-silk.
# ML = kernel milk-line.

Table 5. Mean values of agronomic traits from maize forage trials for populations and subpopulations of $S_{0.2}$ families averaged across three environments. The range among 24 $S_{0.2}$ families is also shown.

	Stover		Whole-plant			Milk-line‡
	Yield†	Moisture	Yield	Moisture	Ear	
	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}	%	
Population x̄						
BS9	7.25	727	12.88	698	43.8	3.0
WFISIHI	5.72	696	10.08	662	42.3	2.7
WFISILO	5.34	682	10.56	627	48.4	2.2
Subpopulation x̄						
BS9-hi	6.98	740	12.68	712	44.4	2.9
BS9-lo	7.37	714	13.07	683	43.2	3.0
WFISIHI-hi	5.21	680	8.88	640	40.4	2.6
WFISIHI-lo	6.24	712	11.29	685	44.2	2.7
WFISILO-hi	5.64	689	10.97	655	47.2	2.7
WFISILO-lo	5.04	675	10.15	599	49.6	1.6
Range among families						
high	8.80	761	14.80	746	58.6	3.4
low	3.92	632	8.18	562	34.5	1.1
LSD (0.05)						
populations	0.28	12	0.75	11	3.1	0.3
subpopulations	0.40	17	1.05	16	4.4	0.4
families	0.82	35	2.17	33	9.0	0.9
CV%	13.5	3.1	13.1	3.1	19.6	18.5

† Yield = stover and whole-plant yields recorded as Mg ha^{-1} on a dry matter basis.

‡ Kernel milk-line recorded on a 4 to 0 scale, with 4 indicating early dent stage and 0 indicating black layer formation. Ratings of 3, 2, and 1 indicate the position of the milk-line as 3/4, 1/2, and 1/4 of the way from base to tip.

Allen et al. (1991) and Vattikonda and Hunter (1983) reported similar correlations of approximately $r = 0.5$ for grain yield with whole-plant yield. Grain yield, however, was not correlated with any forage trait in the $S_{0.2}$ family trial (Table 3).

In all trials, the correlation of stover yield with whole-plant yield was greater than grain yield with whole-plant yield. Ear percentage was not associated with grain yield, but was negatively associated with stover yield. In this germplasm, therefore, variation in whole-plant yield and ear percentage may be more strongly associated with stover yield than grain yield.

Mid-silk dates were correlated with all forage traits in both testcross and $S_{0.2}$ trials and reflected the influence of maturity on dry matter accumulation and seed development. This supports previously mentioned correlations with milk line; i.e., later-flowering genotypes generally had greater dry matter yields and moisture for both stover and whole-plant. Similar associations were observed between plant height and forage traits.

Relationships between Agronomic Traits and Forage Composition

In testcross trials, grain yield was not correlated with any forage component except whole-plant crude protein in the FR23 trial (Table 7). These results are similar to those of Allen et al., (1991), who did not observe relationships between grain yield and whole-plant composition. Vattikonda and Hunter (1983) found only a weak relationship between grain yield and whole-plant digestibility (approximately $r = 0.4$). They also observed that grain yield and stover digestibility were unrelated.

Percent ear was, however, correlated with whole-plant

Table 6. Mean values of agronomic traits from maize forage trials, for populations and subpopulations of FR23 and LH74 testcrosses averaged across three environments. Ranges among 24 FR23 and 24 LH74 testcrosses are also shown.

	FR23 testcrosses						LH74 testcrosses					
	Stover		Whole-plant				Stover		Whole-plant			
	Yield†	Moisture	Yield	Moisture	Ear	Milk-line‡	Yield	Moisture	Yield	Moisture	Ear	Milk-line
	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}	%		Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}	%	
Population x̄												
BS9	8.08	758	18.82	660	57.0	2.2	9.72	749	20.78	661	52.8	2.3
WFISIHI	7.71	753	17.20	653	55.0	1.8	8.69	734	18.63	638	53.2	1.9
WFISILO	7.32	740	17.24	632	57.4	1.5	8.50	724	19.24	624	55.6	1.6
Subpopulation x̄												
BS9-hi	7.97	756	18.91	659	57.9	2.2	9.25	749	20.61	660	54.9	2.4
BS9-lo	8.20	760	18.74	661	56.1	2.2	10.18	748	20.95	663	50.6	2.2
WFISIHI-hi	7.39	752	16.55	651	55.2	2.0	8.23	731	18.31	630	54.9	2.1
WFISIHI-lo	8.02	753	17.85	656	54.8	1.7	9.15	738	18.94	646	51.5	1.7
WFISILO-hi	7.81	747	17.87	648	55.9	1.8	9.18	730	20.26	637	54.4	1.9
WFISILO-lo	6.83	733	16.61	617	58.9	1.2	7.83	717	18.23	611	56.8	1.2
Range among testcrosses												
high	9.21	773	20.56	679	61.2	3.0	11.46	757	22.74	674	59.1	2.9
low	5.48	713	14.19	586	52.4	0.6	7.28	705	17.17	587	47.8	1.0
LSD (0.05)												
populations	0.30	6	0.50	6	1.9	0.2	0.34	6	0.71	6	1.9	0.2
subpopulations	0.43	8	0.70	9	2.7	0.2	0.48	8	1.00	8	2.7	0.3
testcrosses	0.85	16	1.40	17	ns	0.4	0.97	16	2.00	17	5.5	0.5
CV%	8.5	2.0	7.3	2.8	8.1	24.9	9.70	1.9	9.20	2.5	10.7	21.1

† Yield = stover and whole-plant yields recorded as Mg ha^{-1} on a dry matter basis.

‡ Kernel milk-line recorded on a 4 to 0 scale, with 4 indicating early dent stage and 0 indicating black layer formation. Ratings of 3, 2, and 1 indicate the position of the milk-line as 3/4, 1/2, and 1/4 of the way from base to tip.

Table 7. Phenotypic correlation coefficients (n = 24) among tissue composition traits and agronomic traits from maize grain and forage trials for $S_{0.2}$ families, and FR23 and LH74 testcrosses.

	Grain						Stover		Whole-plant			
	Yield	Moisture	RL†	SL‡	PHT§	MS¶	Yield	Moisture	Yield	Moisture	%Ear	Milk-line
$S_{0.2}$												
Stover												
NDF#	0.15	−0.60**	0.12	0.22	−0.49*	−0.34	−0.60**	−0.43*	−0.51*	−0.41*	0.31	−0.35
ADF††	0.00	−0.57**	0.23	0.21	−0.57**	−0.32	−0.65**	−0.41*	−0.63**	−0.39	0.21	−0.33
Lignin	−0.26	−0.18	−0.11	−0.07	−0.49*	0.00	−0.34	−0.11	−0.55**	−0.05	−0.31	0.08
IVTD‡‡	0.23	0.23	0.17	0.04	0.60**	−0.02	0.43*	0.12	0.50*	0.04	0.06	−0.07
CP§§	−0.57**	0.38	−0.23	−0.02	−0.41*	0.38	0.05	0.28	−0.19	0.37	−0.47*	0.36
CWD¶¶	0.42*	−0.06	0.29	0.20	0.52**	−0.23	0.22	−0.11	0.38	−0.20	0.28	−0.32
Whole-plant												
NDF	−0.78**	0.28	−0.22	−0.19	−0.05	0.54**	0.24	0.21	0.02	0.41*	−0.57**	0.56**
ADF	−0.79**	0.20	−0.13	−0.12	−0.13	0.49*	0.14	0.15	−0.13	0.34	−0.61**	0.50*
Lignin	−0.55*	0.21	−0.29	−0.18	−0.19	0.49*	0.09	0.24	−0.20	0.40	−0.61**	0.56**
IVTD	0.68**	−0.42*	0.37	0.37	−0.03	−0.64**	−0.36	−0.41*	−0.08	−0.58**	0.69**	−0.71**
CP	−0.28	0.45*	−0.16	0.01	−0.06	0.45*	0.18	0.38	−0.05	0.49*	−0.45**	0.45*
CWD	0.46*	−0.48*	0.43*	0.46*	−0.09	−0.61**	−0.40	−0.51*	−0.12	−0.63**	0.65**	−0.71**
FR23												
Stover												
NDF	−0.12	0.06	−0.20	−0.05	−0.32	−0.15	−0.36	−0.09	−0.38	−0.10	0.13	−0.07
ADF	−0.19	0.08	−0.36	−0.02	−0.27	−0.16	−0.34	−0.10	−0.44*	−0.11	0.02	−0.14
Lignin	0.04	0.24	−0.49*	−0.18	0.34	0.24	0.23	0.10	0.01	0.23	−0.47*	0.28
IVTD	−0.03	−0.20	0.30	0.05	0.17	−0.02	0.20	−0.11	0.27	−0.11	0.04	−0.09
CP	0.32	0.38	0.20	−0.22	−0.10	0.24	0.13	0.53**	0.25	0.41*	0.07	0.40
CWD	−0.17	−0.24	0.29	0.04	−0.02	−0.14	0.01	−0.25	0.10	−0.24	0.17	−0.18
Whole-plant												
NDF	−0.18	0.57**	−0.11	−0.40	0.35	0.42*	0.53**	0.35	0.30	0.53**	−0.67**	0.48*
ADF	−0.23	0.49*	−0.10	−0.33	0.38	0.35	0.48*	0.29	0.26	0.47*	−0.63**	0.44*
Lignin	−0.08	0.34	−0.35	−0.40	0.47*	0.36	0.47*	0.40	0.23	0.48*	−0.68**	0.41*
IVTD	−0.03	−0.44*	0.32	0.34	−0.14	−0.33	−0.28	−0.44*	−0.08	−0.51*	0.50*	−0.38
CP	−0.44*	0.16	0.08	−0.10	0.04	0.02	0.09	0.19	−0.01	0.21	−0.24	0.12
CWD	−0.22	−0.03	0.32	0.07	0.15	−0.03	0.15	−0.24	0.19	−0.15	0.01	−0.05
LH74												
Stover												
NDF	−0.01	−0.16	0.11	0.29	−0.06	−0.18	−0.61**	−0.11	−0.52**	−0.26	0.46*	0.04
ADF	−0.01	−0.16	0.16	0.28	0.04	−0.17	−0.56**	−0.08	−0.46*	−0.23	0.44*	0.03
Lignin	−0.08	−0.05	0.12	0.03	0.14	−0.06	−0.31	0.17	−0.32	0.01	0.18	0.14
IVTD	0.02	0.05	−0.09	−0.19	−0.09	0.08	0.43*	−0.05	0.33	0.11	−0.35	−0.17
CP	−0.03	0.45*	−0.30	−0.38	−0.27	0.31	0.34	0.24	0.28	0.25	−0.28	0.35
CWD	0.02	−0.08	−0.03	−0.01	−0.25	−0.05	0.06	−0.22	0.00	−0.10	−0.09	−0.27
Whole-plant												
NDF	−0.28	0.36	0.01	−0.16	0.17	0.43*	0.40	0.19	0.27	0.37	−0.39	0.34
ADF	−0.24	0.33	0.04	−0.09	0.22	0.44*	0.40	0.20	0.30	0.37	−0.37	0.32
Lignin	−0.31	−0.07	0.13	−0.12	0.14	0.05	0.21	0.04	0.08	0.12	−0.31	0.04
IVTD	−0.02	−0.46*	−0.07	0.20	−0.27	−0.50*	−0.48*	−0.54**	−0.36	−0.56**	0.43*	−0.59**
CP	−0.11	0.16	−0.08	−0.13	−0.09	0.10	0.33	0.12	0.22	0.18	−0.32	0.19
CWD	−0.35	−0.24	−0.08	0.11	−0.19	−0.21	−0.23	−0.52**	−0.21	−0.36	0.15	−0.43**

*, ** significant at the 0.05 and 0.01 probability levels respectively.
† RL = percent root lodging.
‡ SL = percent stalk lodging.
§ PHT = plant height.
¶ MS = days after 30 June to mid-silk.
# NDF = neutral detergent fiber.
†† ADF = acid detergent fiber.
‡‡ IVTD = *in vitro* true digestibility.
§§ CP = crude protein.
¶¶ CWD = cell wall digestibility.

IVTD in both testcrosses, but was not correlated with stover and whole-plant CWD. Deinum and Bakker (1981), found a weak relationship between percent ear and whole-plant digestibility (approximately r = 0.5). Allen et al. (1991) observed a strong relationship between grain content and whole-plant digestibility (r = 0.8), but no relationship between grain content and whole-plant CWD.

Unlike testcross trials, $S_{0.2}$ grain yield was correlated with all cell wall components of the whole plant. Grain yield of $S_{0.2}$ families was also positively correlated with whole-plant IVTD and CWD. As in the testcrosses, percent ear was correlated with whole-plant IVTD, but also correlated with all other whole-plant traits. Differences between $S_{0.2}$ and testcross trials for these correlations is likely the result of greater variation for grain yield and percent ear in the partially inbred $S_{0.2}$ families. In particular, populations WFISIHI and WFISILO have fairly severe inbreeding depression for grain yield. Percent ear for $S_{0.2}$ families ranged from 34 to 59%, while the testcrosses ranged from 52 to 68% for the FR23 trials and 48 to 59% for the LH74 trials (Tables 5 and 6). Those $S_{0.2}$ families with 34% ear were primarily stover and cob with very little grain.

In all trials, whole-plant yield was negatively correlated with one or more cell wall components of the stover, but it was not associated with cell wall components of the whole plant (Table 7). Whole-plant yield was not correlated with either IVTD or CWD on a stover or whole-plant basis. Stover yield was negatively associated with whole-plant IVTD, in LH74 testcrosses. In the FR23 trial, stover yield was positively associated with cell wall components of the whole plant. These observations support the theory that both stover quantity and quality are important factors influencing whole-plant nutritional quality.

In the LH74 and $S_{0.2}$ trial, stover yield was negatively associated with stover NDF and ADF, and positively associated with stover IVTD. This indicates that genotypes with higher stover yields had greater stover IVTD and lower NDF and ADF. This was not true, however, on a whole-plant basis. Those genotypes with higher stover yields tended to have lower whole-plant IVTD, particularly in the LH74 trial. A possible explanation for these observations is that differences in maturity influenced yield and quality relationships.

Maturity-related traits (milk-line rating, moisture contents of grain, whole plant or stover, and mid-silk date) tended to be negatively correlated with whole-plant IVTD and CWD. Therefore, later-maturing genotypes had lower whole-plant digestibilities. These relationships were most apparent in LH74 testcrosses and $S_{0.2}$ families. These sort of associations have not been observed in previous studies (Daynard and Hunter, 1975; Vattikonda and Hunter, 1983). The range in maturity, particularly in the $S_{0.2}$ trial, coupled with the fact that all plots within a trial were sampled on a single harvest date, may have confounded stage of physiological development with measures of digestibility. For example, a late-maturing $S_{0.2}$ family may have an exaggerated proportion of stover relative to grain, and hence, reduced whole-plant digestibility. Based on other correlations, however, the effect of relative maturity does not appear to have been large in these trials. Stover digestibility typically decreases as a maize plant matures (Wiersma et al., 1992; Daynard and Hunter, 1975; Hunt et al., 1989), but there were no significant correlations between any maturity-related trait and either stover IVTD or CWD in any trial.

Root lodging and stalk lodging were not consistently correlated with any trait. In particular, the lack of correlation between either root lodging or stalk lodging with stover components such as NDF, ADF, and lignin indicates that quality improvements can likely be realized without sacrificing resistance to lodging. Similar results were reported by Albrecht et al., (1986) and Lourenco et al., (1986).

Within the germplasm studied, whole-plant digestibility and cell wall composition had stronger associations with ear percentage and stover yield, than with grain yield. Ear percentage was associated with stover yield, but not grain yield. We reported in our companion paper (Wolf et al., 1993, this issue) that within this germplasm, stover nutritional quality had strong associations with whole-plant nutritional quality. Therefore, both stover quality and quantity are important factors influencing whole-plant nutritional quality. Increasing grain yield may not lead to increased whole-plant nutritional quality. While grain normally contributes 50% or more to whole-plant yield and thus markedly influences digestibility, the amount of relatively-less-digestible stover may negate quality improvements attributable to high grain yields. Based on the wide range in quality attributes measured among genotypes in this study, it seems likely that improvements in whole-plant nutritional quality may be achieved by improving stover digestibility without sacrificing grain yield.

REFERENCES

Albrecht, K.A., M.J. Martin, W.A. Russell, W.F. Wedin, and D.R. Buxton. 1986. Chemical and *in vitro* digestible dry matter composition of maize stalks after selection for stalk strength and stalk rot resistance. Crop Sci. 26:1051–1055.

Allen, M.S., K.A. O'Neil, D.G. Main, and J. Beck. 1990. Variation in fiber fractions and *in vitro* true and cell wall digestibility of corn silage hybrids. J. Dairy Sci. 73:(Suppl. 1.):129.

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.

Beeghly, H.H. 1990. The effect of cell wall constituents in determining resistance of maize to the European corn borer. Ph.D. diss. University of Wisconsin-Madison (Diss. Abstr. 90-33759).

Buendgen, M.R., J.G. Coors, A.W. Grombacher, and W.A. Russell. 1990. European corn borer and cell wall composition in three maize populations. Crop Sci. 30:505–510.

Colenbrander, V.F., V.L. Lechtenberg, and L.F. Bauman. 1975. Feeding value of low lignin corn silage. J. Anim. Sci. 41:332–333.

Crookston, R.K. and J.E. Kurle. 1988. Using the kernel milk line to determine when to harvest corn for silage. J. Prod. Agric. 1:293–295.

Daynard, T.B. and R.B. Hunter. 1975. Relationship among whole-plant moisture, dry matter yield, and quality of whole-plant corn silage. Can. J. Plant Sci. 55:77–84.

Deinum, B. and J.J. Bakker. 1981. Genetic differences in digestibility of forage maize hybrids. Neth. J. Agric. Sci. 29:92–98.

Deinum, B. and P.C. Struik. 1989. Genetic variation in digestibility of forage maize (*Zea mays* L.) and its estimation by near infrared reflectance spectroscopy (NIRS). An analysis. Euphytica 42:89–98.

Dolstra, O., and J.H. Medema. 1990. An effective screening method of genetic improvement of cell-wall digestibility in forage maize. p. 258–270. In J. Hinterholzer (ed.) Proc. 15th Congress of the Maize and Sorghum Section, EUCARPIA. 4–8 June, 1990. Baden near Vienna, Austria.

Fairey, N.A. 1980. Hybrid maturity and the relative importance of grain and stover for the assessment of the forage potential of maize genotypes grown in marginal and non-marginal environments. Can. J. Plant Sci. 60:539–545.

Hunt, C.W., W. Kezar, and R. Vinande. 1989. Yield, chemical composition, and ruminal fermentability of corn whole plant, ear, and stover as affected by maturity. J. Prod. Agric. 2:357–361.

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. Agric. 5:286–290.

Johnson, J.C., Jr., W.G. Monson, and W.T. Pettigrew. 1985. Variation in nutritive value of corn hybrids for silage. Nutr. Rep. Int. 32:953–958.

Lourenco, M.E., I.C. Anderson, and W.F. Wedin. 1986. Stover forage quality as affected by stalk strength in maize (*Zea mays* L.). p. 101–106. In O. Dolstra and P. Miedema (ed.). Breeding of silage maize. Proc. 13th Congress of the Maize and Sorghum Section, EUCARPIA, Wageningen, Netherlands. 9–12 Sept. 1985. PUDOC, Wageningen, Netherlands.

Miller, J.E., J.L. Geadelmann, and G.C. Marten. 1983. Effect of the brown midrib-allele on maize silage quality and yield. Crop Sci. 23:493–496.

Roth, L.S., G.C. Marten, W.A. Compton, and D.D. Stuthman. 1970. Genetic variation for quality traits in maize (*Zea mays* L.) forage. Crop Sci. 10:365–367.

Twumasi-Afriyie, S. and R.B. Hunter. 1982. Evaluation of quantitative methods for determining stalk quality in short season corn genotypes. Can. J. Plant Sci. 62:55–60.

Undersander, D.J., L.F. Bauman, V.L. Lechtenberg, and M.S. Zuber. 1977. Effect of cyclic selection for high and low crushing strength on rind pith and whole stalk composition in corn. Crop Sci. 17:732–734.

Van Soest, P.J. 1982. Nutritional Ecology of the Ruminant. O & B Books Inc., Corvallis OR.

Vattikonda, M.R. and R.B. Hunter. 1983. Comparison of grain yield and whole-plant silage production of recommended corn hybrids. Can. J. Plant Sci. 63:601–609.

Wiersma, D.W., P.R. Carter, K.A. Albrecht, and J.G. Coors. 1993. Kernel milkline stage and corn forage yield, quality, and water content. J. Prod. Agric. 6:94–99.

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 (this issue).