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Forage Yield and Quality of Corn Cultivars Developed in Different Eras

J. G. Lauer,* J. G. Coors, and P. J. Flannery

ABSTRACT

Gains in corn (*Zea mays* L.) grain yield over time are well documented, but corresponding changes in forage and stover yield and quality have received less attention. Our objective was to describe yield and quality changes of representative cultivars used by farmers in the northern Corn Belt. Six open-pollinated cultivars used prior to 1930, 24 cultivars representing four 15-yr eras between 1931 and 1990, and six modern cultivars, for a total of 36 cultivars, were divided into early- and late-maturity trials. Each trial was grown at three locations in Wisconsin during 1997 and 1998. Since 1930, corn forage dry matter yield has increased at the rate of 0.128 to 0.164 Mg ha^{-1} yr^{-1} with stover dry matter yields increasing at the rate of 0.043 to 0.054 Mg ha^{-1} yr^{-1}. Forage crude protein has not changed significantly with time. Forage neutral detergent fiber concentration has decreased 0.825 to 0.948 g kg^{-1} yr^{-1}, while forage in vitro digestibility increased 0.538 to 0.612 g kg^{-1} yr^{-1}. Stover neutral detergent fiber concentration and in vitro digestibility have not changed over time. Since 1930 forage, stover, and ear yield have increased 1.4, 0.7, and 2.4% yr^{-1}, respectively. This trend will no doubt continue, but greater progress might be made if corn forage breeding improvement concentrates on yield and quality changes in stover.

THE NUTRITIVE VALUE OF corn forage has been of concern for the last 30 yr (Roth et al., 1970). Corn forage is economically important. The USA has the largest corn forage area of all countries with up to four million ha harvested annually. Wisconsin is the principle corn forage producing state in the U.S. with about 400 000 ha annually harvested as forage (Anonymous, 1998).

No significant breeding effort to improve corn forage yield or quality attributes has been undertaken by corn breeders. However, corn grain yields in the U.S. have increased from approximately 1.3 Mg ha^{-1} in 1930 to 8.7 Mg ha^{-1} in 1994 (Troyer, 1999). Before 1930, average grain yields were static because no yield gains were realized from breeding advances or changes in management practices. Since 1930, steady grain yield increases have occurred due to the use of improved hybrid cultivars, increased use of fertilizers, better weed control, higher plant densities and improved management (Cardwell, 1982). Gain in grain yield over time is well documented and ranges from 0.078 to 0.110 Mg ha^{-1} yr^{-1} (Hallauer et al., 1988).

Newer improved cultivars have increased grain yield because of continued improvement in genetic potential and adaptation to improved cultural practices (Olson and Sander, 1988). For example, newer cultivars compared with cultivars of the 1930s have greater yields at all plant densities, but especially at high densities due

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Published in Crop Sci. 41:1449–1455 (2001).

Abbreviations: NIRS, near infra-red reflectance spectroscopy.

to decreased bareness of newer cultivars. Improvement for resistance to root and stalk lodging has occurred to permit machine harvesting. Newer cultivars are superior to older cultivars regardless of soil fertility level (Castleberry et al., 1984; Duvick, 1984).

Concepts of nutritive value of corn forage reflect ruminant requirements. Desirable forage characteristics include high dry matter yield, high protein concentration, high energy concentration (high digestibility), high intake potential (low fiber concentration), and optimum dry matter concentration at harvest for acceptable forage fermentation and storage (Carter et al., 1991). The most limiting constraint on nutritional value of corn forage is low protein concentration, and feed rations usually require a nitrogen supplement to satisfy rumen microbial requirements. Forage yields have increased at the rate of 0.13 Mg ha^{-1} yr^{-1} from 1.9 Mg ha^{-1} in 1950 to 6.5 Mg ha^{-1} in 1990 (Coors and Lauer, 2000). Corresponding changes in forage quality are not known. Retrospective analyses of genetic yield and quality improvement may provide an understanding of potential and indicate pathways for future yield and quality improvement. The objective of this study was to describe forage yield and quality changes of representative cultivars used by northern Corn Belt farmers since 1930.

MATERIALS AND METHODS

The corn cultivars used for this research were chosen on the basis of the era in which they were developed, the amount of use in the northern Corn Belt, and current availability (Table 1). The cultivars were divided into early- and late-maturity classes based on whether they had relative maturities greater than or less than 100 d relative maturity. Open-pollinated cultivars were obtained originally either from the Plant Introduction Center at Ames, IA or from the University of Wisconsin. Seed supplies for open-pollinated cultivars were increased by sib pollinating at least 100 plants and compositing equal quantities of seed from each plant within each population. Public double-cross, three-way, and single cross cultivars were developed from inbreds that have been maintained at the University of Wisconsin. Potential public cultivars were first chosen based on a review of production records of the UW Foundation Seeds Program and the Wisconsin Crop Improvement Association, and the most popular cultivars in a given era were identified. The University of Wisconsin had an active inbred development and cultivar corn-breeding program that started in the late 1920s, and several of the inbreds developed by this program were widely used in cultivars grown throughout the northern Corn Belt. If parental inbreds used for production of popular cultivars were still available, then the cultivars were remade in the UW field corn breeding nursery in 1995 and 1996. For the most modern era, 1991 to 1998, commonly used commercial cultivars were chosen, and commercial seed lots available in 1997 and 1998 were used for evaluation.

The experimental design of each trial at each location was a randomized complete block with three replicates. Plots consisted of two rows 7.6 m long and 0.76 m apart. To reduce microclimatic and competitive influences from adjacent plots, cultivars were divided into early- and late-maturity trials. Early-trials were located near Arlington, Fond du Lac, and Marshfield, and late-trials were located near Arlington, Fond du Lac, and Lancaster, WI. Plots were established by seeding at 65 000 seeds ha^{-1} and thinning to a constant plant density. Mean plant density of trials varied from 51 900 to 59 800 plants ha^{-1}. Other management practices were similar to corn production practices of the surrounding area.

At harvest, one row was stripped of ears. Forage moisture and kernel milkline was assessed to provide an estimate of plant development (Wiersma et al., 1993). Each row was mechanically harvested using a one row, tractor mounted forage chopper (New Holland 707, New Holland, PA) and measured for yield. A 1-kg subsample was collected for moisture and quality measurements. Samples were ground to pass through a 1 mm screen.

The near infra-red reflectance spectroscopy (NIRS) broad based prediction equations for determining forage composition were developed through evaluations of a large number of corn cultivars by the corn breeding project and the corn agronomy program in the UW Department of Agronomy during 1992, 1993, 1995, and 1996. Replicated forage trials were conducted at numerous locations throughout Wisconsin. Forage samples from each plot were collected at approximately 65% forage moisture. Forage samples and stover samples were collected from approximately 25 plants for each sample in each plot. Samples were oven dried at 60°C for approximately 7 d, and then ground with a hammer mill to pass a 1-mm screen. Each year, all samples were scanned using a NIRSystems 6500 near-infrared reflectance spectrophotometer (Marten et al., 1985).

Standard NIRS procedures were used to select calibration sets for broad based prediction equations for wet laboratory analyses (Martens and Naes, 1989; Shenk and Westerhaus, 1991; 1994). Samples (0.75 g) from each calibration set were analyzed for neutral detergent fiber, acid detergent fiber, in vitro true digestibility, and crude protein. A modification to the neutral detergent fiber procedure was the treatment of samples with 0.1 ml of alpha-amylase during refluxing and again during sample filtration (Mertens, 1991). Total nitrogen was determined using a Leco Model 428 nitrogen analyzer (Dumas method). Crude protein was calculated by multiplying total nitrogen (Bremner and Breintenbeck, 1983) by 6.25. All compositional data were calculated on a dry matter basis. Duplicate 0.25-g samples were used to determine in vitro true digestibility by a modification of the method of Goering and Van Soest (1971). The 48-hour fermentation was performed in centrifuge tubes (Tilley and Terry, 1963; Marten and Barnes, 1980; with inoculum enrichment of Craig et al., 1984), except that buffer and mineral solutions were as described by Goering and Van Soest (1971). After removal from the incubator, tubes were placed in a freezer. Undigested residue was subjected to the NDF procedure as described previously.

The calibration sets from 1992, 1993, 1995, and 1996 were combined in order to provide a single broad based calibration set for forage composition. Stover prediction equations were based on calibrations performed in 1992 and 1993 because broad based stover evaluations were discontinued in subsequent years. From the data obtained in the laboratory, prediction equations were developed relating NIR wavelengths to each of the quality variables (Shenk and Westerhaus, 1991, 1994). Criteria used to select equations were high coefficients of multiple determination and low standard errors of calibration and cross validation. Modified partial least square (PLS) analyses were used to determine the wavelengths to include in calibrations (Martens and Naes, 1989). Statistics relating to NIRS prediction are provided in Table 2.

Neutral detergent fiber concentration and in vitro true digestibility were used to calculate cell wall digestibility (Van Soest, 1982) by the following equation:

Table 1. Forage yield and quality performance of corn cultivars representative of different eras grown during 1997 and 1998.

Cultivar	Era of use	Pedigree	Relative maturity	Kernel development	Forage: Dry matter yield	Forage: Moisture	Forage: Crude protein	Forage: Acid detergent fiber	Forage: Neutral detergent fiber	Forage: In vitro true digestibility	Forage: Cell wall digestibility	Forage: Milk Mg^{-1}	Forage: Milk ha^{-1}
			days	percent milk	Mg ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg Mg^{-1}	kg ha^{-1}
Early trials†													
Golden Glow	1900–1930	Open-pollinated cultivar	95	40	11.9	633	81	267	499	744	488	676	8 137
Minnesota 13	1900–1930	Open-pollinated cultivar	95	20	5.4	575	92	284	528	721	474	569	3 465
Northwestern Dent	1900–1930	Open-pollinated cultivar	85	0	4.4	579	98	298	545	707	464	506	2 342
W335	1931–1945	(W83XW703)(W9XWM13R)	90	30	13.3	615	79	252	481	758	497	741	10 395
W255	1931–1945	(WDXW9)(WHXWJ)	80	20	11.7	575	83	237	462	764	488	790	9 658
W416	1931–1945	(W9XWM13R)(W153RXW374)	95	40	13.9	629	79	250	481	757	497	740	10 401
W270	1946–1960	(W79AXW75)(W41AXW59E)	85	20	8.5	575	86	265	492	743	479	687	6 336
W335A	1946–1960	(W703XW83)(W153RXW182B)	90	30	15.0	591	81	236	456	768	491	810	12 230
W273	1946–1960	(W59MXW117)(W182BXW182E)	85	20	12.9	626	80	241	457	766	488	803	10 672
W346	1961–1975	(W59MXW117)(W153RXW37A)	90	30	11.6	597	81	235	457	770	497	813	10 131
W415	1961–1975	(W64AXW182E)(W153RXW37A)	95	40	14.8	629	80	231	449	769	485	827	12 174
W434	1961–1975	(W182EXW117)(OH43XW37A)	95	40	16.2	618	76	231	452	775	502	833	13 526
A554xCM105	1976–1990	A554XCM105	85	20	15.2	555	83	227	453	772	496	824	12 418
W2343	1976–1990	(W59EXW629A)XA641	80	30	11.9	581	84	242	468	761	490	771	9 740
W4363	1976–1990	(W153RXW438)XA632	95	30	18.6	623	78	229	451	779	510	846	15 580
Mycogen 4120	1991–1998	Commercial cultivar	90	40	20.2	600	77	226	454	779	513	839	17 094
Dekalb DK401	1991–1998	Commercial cultivar	90	60	18.7	625	78	221	443	779	501	860	16 211
Pioneer 3905	1991–1998	Commercial cultivar	85	30	16.4	594	75	221	424	777	475	889	14 882
LSD(0.05)				10	2.3	28	4	23	34	22	19	112	2 645
Late trials‡													
Funks Yellow Dent	1900–1930	Open-pollinated cultivar	115	40	13.2	695	82	266	494	752	499	704	9 526
Pride of the North	1900–1930	Open-pollinated cultivar	100	20	11.0	597	83	252	476	755	484	744	8 220
Silver King	1900–1930	Open-pollinated cultivar	100	30	7.9	638	88	285	526	719	467	568	4 615
W456	1931–1945	(W9XWM13R)(WR3XW26)	100	20	13.5	565	77	254	482	753	486	726	9 992
W531	1931–1945	(WM13RXWR3)(W23XW26)	105	20	13.3	608	77	250	474	755	482	747	10 005
W645	1931–1945	(W23XW26)(WR3XWF9)	115	20	16.5	570	75	233	461	770	500	805	13 543
W513	1946–1960	(M14XW32)(W182BXW182D)	105	20	16.7	630	85	236	455	760	473	794	13 545
W613	1946–1960	(WF9XM14)(W182DXW22R)	112	30	15.9	619	81	246	472	755	479	750	11 783
W463	1946–1960	(M14XW64A)(W182BXW182E)	100	20	16.2	609	81	240	457	756	467	780	13 110
W545	1961–1975	(W64AXW182E)(OH43XM14)	105	30	16.8	643	81	236	454	770	493	818	14 118
W601	1961–1975	(WF9XW64A)XC123	110	20	15.0	602	79	242	464	765	492	789	12 071
W554	1961–1975	(WF9XA635)(M14XC123)	100	30	15.7	618	83	254	486	749	486	711	11 700
A641xMO17	1976–1990	A641XMO17	110	20	21.1	558	76	232	452	771	491	824	18 054
W540xB73	1976–1990	W540XB73	110	40	23.8	665	75	241	458	774	506	821	19 605
W5472	1976–1990	A632XW438	105	20	20.6	585	80	228	444	771	483	839	17 762
Cargill 4327	1991–1998	Commercial cultivar	105	40	19.4	650	73	213	416	791	497	935	18 350
Pioneer 3394	1991–1998	Commercial cultivar	110	40	24.8	657	73	226	438	787	513	887	22 638
Dairyland 1407	1991–1998	Commercial cultivar	110	40	24.1	625	70	221	428	782	492	894	22 086
LSD(0.05)				7	3.2	35	3	17	25	18	18	85	3 537

† Arlington, Fond du Lac, and Marshfield.
‡ Arlington, Fond du Lac, and Lancaster.

Table 2. Statistics for near infra-red reflectance spectroscopy (NIRS) calibration and prediction of neutral detergent fiber (NDF), acid-detergent fiber (ADF), in vitro true digestibility (IVTD), and protein of corn forage and stover.

	NIRS statistics				
Trait	Mean	N†	R^2	SEC‡	SEV(C)§
		Forage			
NDF, %	44.71	391	0.92	1.33	1.41
ADF, %	22.33	394	0.93	0.83	0.89
IVTD, %	80.33	397	0.89	0.96	1.1
Protein, %	8.02	392	0.94	0.25	0.27
		Stover			
NDF, %	68.94	206	0.96	0.64	0.72
ADF, %	38.76	207	0.91	0.63	0.68
IVTD, %	68.03	207	0.81	1.08	1.18
Protein, %	7.24	207	0.92	0.34	0.4

† N corresponds to the final number of data point used to develop NIRS calibration equations.
‡ SEC = standard error of calibration.
§ SEV(C) = standard error of cross-validation.

Cell wall digestibility

$$= \{[\text{NDF} - (100 - \text{IVTD})]/\text{NDF}\} \times 100 \quad [1]$$

The calculated performance indices of bovine Milk Mg^{-1} (kg milk Mg^{-1} of corn forage) and Milk ha^{-1} (kg milk ha^{-1} of corn forage) were used to evaluate the economic trade off between cultivars (Undersander et al., 1993). Milk Mg^{-1} was predicted using in vitro true digestibility, crude protein, and neutral detergent fiber values from equations used to calculate feed intake and animal requirements for a standard dairy cow with 613 kg of body weight producing 36 kg of milk per day at 3.8% fat. Milk ha^{-1} is the product of Milk Mg^{-1} and dry matter yield of corn forage.

Data were analyzed with Proc GLM (SAS Institute, 1995). Linear regression analysis (Proc REG) was used to examine the relationship between various forage and stover yield, quality and performance index measurements, and the era of release. Cultivars from each era were averaged for yield, quality, and performance indices and regressed as dependent variables on the midpoint of the appropriate eras as independent variables (year 0 = 1930). Open-pollinated cultivars were grouped and set to 1930. Regression coefficients were described when significant ($P \leq 0.05$).

RESULTS AND DISCUSSION

A significant change in cultivar development occurred in the 1960s when farmers grew cultivars at higher plant densities to take advantage of higher rates of fertilizer

Table 3. Stover yield and quality performance of corn cultivars representative of different eras grown during 1997 and 1998.

Cultivar	Dry matter yield	Moisture	Crude protein	Acid detergent fiber	Neutral detergent fiber	In vitro true digestibility	Cell wall digestibility
	$Mg\ ha^{-1}$	$g\ kg^{-1}$					
Early trials†							
Golden Glow	7.6	697	64	349	619	678	478
Minnesota 13	4.3	633	69	347	624	689	502
Northwestern Dent	4.1	600	74	340	613	696	504
W335	7.7	688	63	356	640	689	513
W255	5.5	669	65	348	632	695	518
W416	7.8	696	67	344	625	700	521
W270	5.3	633	73	335	610	709	523
W335A	7.3	676	64	359	646	684	511
W273	6.9	699	66	347	625	694	510
W346	6.3	670	66	343	623	704	525
W415	7.4	719	67	347	629	695	515
W434	8.2	715	66	352	639	695	523
A554xCM105	7.2	659	61	374	676	674	518
W2343	7.4	655	68	340	622	705	527
W4363	10.1	706	67	333	609	712	528
Mycogen 4120	9.3	695	61	367	660	682	518
Dekalb DK401	8.6	718	62	361	648	687	516
Pioneer 3905	8.2	704	63	354	629	682	495
LSD(0.05)	1.3	23	5	16	23	17	20
Late trials‡							
Funks Yellow Dent	9.7	725	70	334	591	691	478
Pride of the North	6.8	633	64	355	629	682	494
Silver King	6.5	667	69	339	608	699	506
W456	7.7	650	58	368	656	681	513
W531	8.2	668	61	350	628	692	509
W645	7.8	642	57	358	645	690	519
W513	8.5	728	67	349	623	687	497
W613	8.6	702	64	359	639	682	502
W463	7.9	714	64	351	624	684	494
W545	9.8	712	69	347	625	697	515
W601	7.6	682	60	368	651	678	505
W554	8.4	703	67	353	631	686	503
A641xMO17	9.8	647	57	381	674	666	505
W540xB73	12.5	746	65	345	608	686	484
W5472	9.3	699	62	362	644	679	501
Cargill 4327	9.4	732	63	351	616	688	493
Pioneer 3394	12.9	745	63	370	643	669	485
Dairyland 1407	11.6	706	67	357	633	685	502
LSD(0.05)	1.7	36	5	17	26	NS	20

† Arlington, Fond du Lac, and Marshfield.
‡ Arlington, Fond du Lac, and Lancaster.

(Duvick and Cassman, 1999). In general, as plant density increases, forage yield and NDF concentration increase, and digestibility decreases (Graybill et al., 1991; Pinter et al., 1994; Cox, 1997; Cuomo et al., 1998). For the production practices used in this study, all cultivars were grown at the same plant density of approximately 55 000 plants ha^{-1}, which was intermediate to modern recommendations and the practices used when farmers grew open pollinated cultivars between 1900–1930. Our intent was to grow cultivars at a similar population in order to assess genetic changes occurring for yield and quality.

Mean forage yield and quality performance of all cultivars for 1997 and 1998 is shown in Table 1. Cultivar effects were significant for all forage yield and quality measures. Lowest forage yield, in vitro true digestibility, and greatest acid detergent and neutral detergent fiber concentration were found in open-pollinated cultivars, while converse levels for these variables were found in modern cultivars. For example, the older open-pollinated cultivar, "Silver King," produced a forage yield of 7.9 Mg ha^{-1} and the more recent cultivar, "Pioneer 3394," yielded 24.8 Mg ha^{-1}. The range in forage dry matter yield among cultivars in the early- and late-maturity trials was 15.8 and 16.9 Mg ha^{-1}. Cultivar development differences can be estimated using kernel milkline and forage moisture. The range in kernel development was 60 and 20% kernel milk for the early- and late-trials. The range in forage harvest moisture was 78 and 137 g kg^{-1} for the early- and late-trials. In Wisconsin environments, forage moisture decreases about 5 g kg^{-1} d^{-1} during September, while kernel milk decreases about 25% every 6 to 7 d (Wiersma et al., 1993).

Cultivar effects were significant for all stover yield and quality measurements, except stover in vitro true digestibility (Table 3). The range in stover moisture was 119 and 112 g kg^{-1} for the early- and late-maturity trials.

The maturity range in these cultivars was small enough to allow meaningful comparisons of yield without undue concerns about maturity effects. This was further confirmed by the narrow range in kernel development and harvest moistures of era groups where forage moisture ranged from 29 to 63 g kg^{-1} and kernel milkline ranged from 10 to 20% kernel milk (data not shown).

More recent era groups produced higher forage yields than older era groups, with the exception of the late-maturity 1961–1975 group. More recent corn cultivars showed a consistent improvement in yield over older corn cultivars in this study. The apparent yearly rate of forage yield increase due to genetic improvement was positive and characterized by high coefficients of determination (Fig. 1 and Table 4). Forage yield has increased 0.128 to 0.164 Mg ha^{-1} yr^{-1} since 1930 depending upon trial maturity. Stover dry matter yield has increased at a slower rate of 0.043 to 0.054 Mg ha^{-1} yr^{-1}. Forage, stover and ear yield have increased from 1930 levels at the rate of 1.4, 0.7 and 2.4% yr^{-1}, respectively. Other workers have reported forage yield increases of 0.5% yr^{-1} (Meghji et al., 1984) and −0.1 to 0.6% yr^{-1} or −0.02 to 0.08 Mg ha^{-1} yr^{-1} (Barriere et al., 1987).

Most quality changes have occurred in forage rather than stover. Forage crude protein concentration has not changed significantly since 1930. Corn forage acid detergent and neutral detergent fiber concentrations have been shown to be inversely related to corn forage digestibility (Roth et al., 1970; Crasta et al., 1997). Likewise, in this study, forage acid detergent fiber concentration has decreased 0.544 to 0.698 g kg^{-1} yr^{-1} and neutral detergent fiber concentration has decreased 0.825 to 0.948 g kg^{-1} yr^{-1} (Fig. 1 and Table 4). Forage in vitro true digestibility has increased 0.538 to 0.612 g kg^{-1} yr^{-1} since 1930. No change was observed for forage cell wall digestibility indicating that little digestibility improvement has taken place over time in the stover portion of the plant in U.S. cultivars grown in the northern Corn Belt. This was confirmed by the stover quality data.

Stover quality effects, where significant, went in opposite directions compared to forage quality effects (Fig.

Table 4. The relationship between yield and quality measurements and mean era of use of corn cultivars grown during 1997 and 1998. Data were pooled across year, location, hybrid, and replication (n = 108) and regressed against era midpoint (0 = 1930).

	Forage		Stover	
Trait†	**Regression equation**	**R^2**	**Regression equation**	**R^2**
Early trials				
DM yield, Mg ha^{-1}	y = 9.35 + 0.128 x‡	0.82	y = 5.83 + 0.043 x	0.85
CP, g kg^{-1}	NS	–	NS	–
ADF, g kg^{-1}	y = 266 − 0.698 x	0.74	NS	–
NDF, g kg^{-1}	y = 499 − 0.948 x	0.71	y = 622 + 0.296 x	0.73
IVTD, g kg^{-1}	y = 741 + 0.612 x	0.69	NS	–
CW digestibility, g kg^{-1}	NS	–	NS	–
Milk, kg Mg^{-1}	y = 669 + 3.15 x	0.70	–	–
Milk, kg ha^{-1}	y = 6702 + 132 x	0.84	–	–
Late trials				
DM yield, Mg ha^{-1}	y = 11.9 + 0.164 x	0.90	y = 7.40 + 0.054 x	0.91
CP, g kg^{-1}	NS	–	NS	–
ADF, g kg^{-1}	y = 259 + 0.544 x	0.81	NS	–
NDF, g kg^{-1}	y = 488 − 0.825 x	0.84	NS	–
IVTD, g kg^{-1}	y = 746 + 0.538 x	0.87	y = 689 − 0.166 x	0.73
CW digestibility, g kg^{-1}	NS	–	NS	–
Milk, kg Mg^{-1}	y = 699 + 2.76 x	0.87	–	–
Milk, kg ha^{-1}	y = 8340 + 179 x	0.92	–	–

† DM, dry matter; CP, Crude protein; ADF, acid-detergent fiber; NDF, neutral-detergent fiber; IVTD, in vitro true digestibility; CW digestibility, cell wall digestibility.
‡ x = year (1930 = 0).

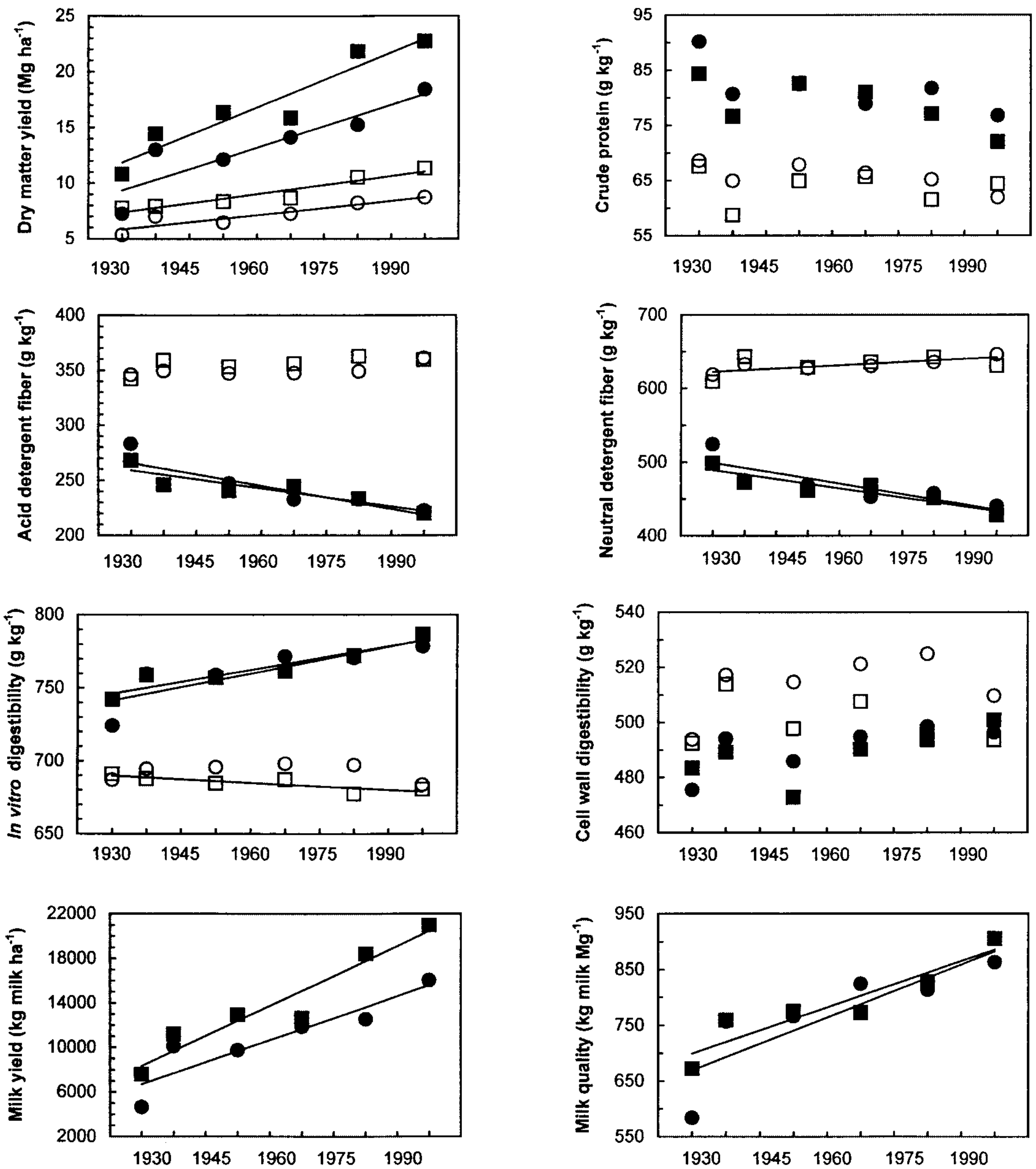

Fig. 1. Relationship between forage yield and quality measures and corn cultivars used by northern Corn Belt farmers during different eras. Data are averaged across year, location, cultivar and replicate (n = 108). Circles = early trials, squares = late trials. Closed circles and squares = forage, open circles and squares = stover. For regression equations, see Table 4.

1 and Table 4). In the early-trials, neutral detergent fiber concentration of stover increased over time at the rate of 0.296 g kg^{-1} yr^{-1}. In the late-trials, stover in vitro true digestibility decreased 0.166 g kg^{-1} yr^{-1}. The most likely reason why little change has occurred to stover quality over time is lack of attention by breeders for stover improvement. It is easier for breeders to select for yield or quality improvement, but difficult to breed for both.

Forage quality predicted using the animal response model of Milk Mg^{-1} forage has improved at the rate of 2.76 to 3.15 kg milk Mg^{-1} yr^{-1} (Fig. 1 and Table 4). When combined with forage yield increases over time, corn forage Milk ha^{-1} has increased 132 to 179 kg milk ha^{-1} yr^{-1}.

Averaging data across all trials (data not shown), corn forage yield has increased over time at the rate of 0.15 Mg ha^{-1} yr^{-1} (R^2 = 0.90) with stover yields increasing at the rate of 0.048 Mg ha^{-1} yr^{-1} (R^2 = 0.93). Forage crude protein concentration has not changed significantly since 1930. Over time, forage neutral detergent fiber concentration has decreased 0.89 g kg^{-1} yr^{-1} (R^2 = 0.81), while forage in vitro digestibility increased 0.58 g kg^{-1} yr^{-1} (R^2 = 0.82). Stover neutral detergent fiber concentration and in vitro digestibility have not changed over time. Overall forage quality, as measured using Milk Mg^{-1} forage, has improved at the rate of 3.0 kg milk Mg^{-1} forage yr^{-1} (R^2 = 0.82), and when combined with yield increases over time has resulted in a gain of 156 kg milk ha^{-1} yr^{-1} (R^2 = 0.92).

The economic benefits from improving corn forage quality can be substantial. Over the last 70 years, increases in corn forage yield and quality can be attributed to increased grain yield. Grain is nearly completely digestible, thus lowering fiber concentration and increasing digestibility. Little change has occurred in the quality of the stover portion of corn forage cultivars available in the northern Corn Belt. Breeders of other forage crops have been quite successful in improving both yield and nutritive value, and the molecular basis of nutritional attributes is becoming clearer in corn as well. Recent renewed interest in corn forage cultivars has resulted in the commercial production of brown midrib (Miller et al., 1983) and leafy (Dwyer et al., 1998) cultivars. These cultivars represent divergent directions for the corn forage ideotype. It is unclear whether corn breeders should focus on improving cultivar quality using these alternative ideotypes or if continued progress can be made with conventional cultivar development.

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