Impact of Defoliation on Corn Forage Quality

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ABSTRACT

Hail damage can be a serious problem on corn (*Zea mays* L.) grown for silage. The value of corn grown for silage is a function of both the yield and quality of the forage produced. An improved understanding of the effects of defoliation on forage quality would improve the ability of agronomists, farmers, and crop insurance adjusters to assess the economic impact of hail damage to corn harvested for forage. The objective of this study was to evaluate the effects of defoliation on the forage quality corn grown for silage production. Experiments were conducted during 2000, 2001, and 2002 at Arlington and Marshfield, WI, and State College, PA. Corn quality measures responded similarly to defoliation treatments across most environments. Increasing defoliation either did not affect quality, especially at V7 and V10 stages, or lowered quality, especially at the R1 and R4 stages of development. The largest differences in neutral detergent fiber (NDF), acid detergent fiber (ADF), and in vitro true digestibility occurred at R1 and R4. Starch content was most affected when defoliation occurred at R1. The response of NDF digestibility was inconsistent across environments. These changes in forage quality resulted in decreases in Milk Mg^{-1} and Milk ha^{-1} with increasing defoliation in most environments. Predictive models for estimating forage quality and yield losses can be used to improve estimates of the impact of defoliation caused by hail on corn grown for silage.

Hail damage can be a serious problem on corn grown for silage. Effective techniques to characterize the potential loss from defoliation caused by hail are essential for corn silage producers and the crop insurance industry. The value of corn grown for silage is a function of both the yield and quality of the forage produced. Defoliation can have a significant impact on the yield of corn harvested for forage. Lauer et al. (2004) estimated that the impact is a function of both the timing and extent of defoliation with 100% defoliation resulting in decreased forage yield by 43, 70, and 40% at V10, R1, and R4 growth stages (Ritchie et al., 1996), respectively. These impacts of defoliation on forage yield differ from those on grain, since the standard industry hail damage chart (National Crop Insurance Services, 1998) predicts a 97% grain yield reduction with 100% defoliation at R1.

Since the timing of defoliation likely impacts the amount of grain in the forage, there is the potential for defoliation to impact the forage quality of the corn harvested for silage following a hail event. These effects have not been well documented. Baldridge (1976) evaluated various levels of defoliation at different growth stages and reported that forage resulting from the 100% defoliation treatment at VT had lower carbohydrate and fat levels and higher fiber levels. Economic impacts of the hail damage in the Baldridge (1976) were determined by estimating the grain content of the defoliation treatments. Losses ranged from 2.1% with 25% defoliation at V7 to 84.7% with 100% defoliation at VT. Estimated economic losses were highest at VT compared to other stages of defoliation including 15 leaf stage and the milk stage. Dwyer et al. (1994) assessed hybrids that were damaged by a severe hailstorm in late August with crop maturities ranging from milk to full dent. They found no significant relationship between crop maturity (as estimated by corn heat units to maturity) at defoliation and harvest index. Mangen et al. (2005) reported that in some environments defoliation can affect grain protein or starch concentration, suggesting that silage quality could be impacted as well.

Since the Baldridge (1976) study, more comprehensive tools have been developed to characterize and evaluate forage quality. Schwab et al. (2003), for example, used in vitro true digestibility, crude protein, starch, and neutral detergent fiber concentration and digestibility to predict dairy cattle (*Bos taurus*) performance. An improved understanding of the effects of defoliation on forage quality would improve the ability of agronomists, farmers, and crop insurance adjusters to assess the economic impact of hail damage to corn harvested for forage. The objective of this study was to evaluate the effects of defoliation on the forage quality of corn grown for forage production under a range of conditions in Wisconsin and Pennsylvania. This study evaluated the effects of defoliation at different growth stages and intensities on forage quality indicators and predicted milk production expressed as Milk Mg^{-1} or Milk ha^{-1}.

MATERIALS AND METHODS

This study was an extension of Lauer et al. (2004) which focused on yield responses due to defoliation. A complete description of plot management details is described in that

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Abbreviations: ADF, acid detergent fiber; NDF, neutral detergent fiber.

Table 1. 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), starch content and crude protein of corn forage NIRS statistics.

Trait	N†	MEAN	SEC‡	R^2	SEV (C) §
NDF	78	46.4	1.48	0.97	1.68
ADF	78	26.0	0.80	0.98	1.04
IVTD	79	81.0	1.87	0.84	2.00
Protein	78	7.4	0.27	0.86	0.33
Starch	79	28.2	1.94	0.96	2.18

† N corresponds to the final number of data points used to develop NIRS calibration equations.

‡ SEC = standard error of calibration.

§ SEV(C) = standard error of cross-validation.

paper. Experiments were conducted during 2000, 2001, and 2002 at the University of Wisconsin Agricultural Research Stations near Arlington and Marshfield, WI, and the Russell Larson Agricultural Research Farm near State College, PA. The soil at Arlington was a Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudoll), at Marshfield a Withee silt loam (fine-loamy, mixed, superactive, frigid Aquic Glossuboralf), and at State College a Hagerstown silt loam (fine, mixed, superactive, mesic Typic Hapludalf). Management practices were typical of those used commercially in many dryland corn fields in the United States.

The design of each experiment was a randomized complete block with four replications. Defoliation treatments were applied at V7, V10, R1, and R4. At V7, 100% of the emerged leaf area was removed using shears. At V10, 50, and 100% of the emerged leaf area was removed. Partial leaf removal treatments were applied by measuring from the leaf tip and cutting the leaf end. At R1 and R4, 25, 50, and 100% of the emerged leaf area was removed. The control was a nondefoliated check treatment.

All plots were harvested in all environments shortly after the 50% kernel milk stage of the untreated control (Afuakwa and Crookston, 1984; Ritchie et al., 1996). Kernel milk is defined as the amount of milky starch remaining in the kernel (i.e., 25% kernel milk = 75% kernel milkline/starch line + 25% kernel milk). Each row was mechanically harvested using a one-row, tractor mounted forage chopper (New Holland 707, New Holland, PA) in Wisconsin and a one-row self propelled research chopper in Pennsylvania to collect yield and forage quality samples. A 1-kg subsample was collected for moisture and quality measurements. Samples were oven dried at 60°C for approximately 7 d, and then ground with a hammer mill to pass a 1-mm screen. Forage quality indicators were assessed using near infrared spectroscopy (NIRS, Marten et al., 1985). Each year, all samples were scanned using a NIRSystems 6500 near-infrared reflectance spectrophotometer.

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 NDF, ADF, in vitro true digestibility, and crude protein. The neutral detergent fiber procedure was modified by treating of samples with 0.1 mL of alpha-amylase during refluxing and again during sample filtration (Mertens, 1991). Total N was determined using a Leco Model 428 N analyzer (Dumas method). Crude protein was calculated by multiplying total N (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-h 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. Total starch was determined by methods of Ehrman (1996), where gelatinization is aided by sodium hydroxide and final glucose concentration is determined with an automated biochemistry analyzer, YSI-2700 (YSI Incorporated, Yellow Springs, OH), fit with a dextrose detection probe.

The calibration sets from 2000, 2001, and 2002 were combined to provide a single broad-based calibration set for forage composition. 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 1. Neutral detergent fiber concentration and in vitro true digestibility (IVTD) were used to calculate NDF digestibility (Van Soest, 1982) by the following equation:

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

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) have been used in other studies to evaluate the economic trade-off between cultivars (Schwab et al., 2003). In this approach, Milk Mg^{-1} is predicted using in vitro true digestibility, crude protein, starch, and NDF values from equations that estimate 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.

The agronomic quality measures were analyzed using SAS PROC GLM and PROC REG (SAS Institute, 2000) procedures. Data from all sites were analyzed using a combined analysis of variance (McIntosh, 1983), using environments (site-years) and replications as random effects and defoliation treatments as a fixed effect. Analyses of variance were performed for each environment, with defoliation treatments as a fixed effect and replication as a random effect. Mean separations were conducted using Fisher's Protected LSD ($P \leq 0.05$).

To describe the impact of defoliation for each growth stage, regression equations describing the relationship between forage quality and defoliation for each growth stage in each environment were developed with stepwise regression procedures using environment treatment means (not shown). For each growth

Table 2. Analysis of variance of environment (Env), replication (Rep), and defoliation treatment effects on crude protein (CP), acid-detergent fiber (ADF), neutral detergent fiber (NDF), in vitro true digestibility (IVTD), neutral detergent fiber digestibility (NDFD), starch, milk Mg^{-1}, and milk ha^{-1} of corn forage.

Variable	df	CP	ADF	NDF	IVTD	Starch	NDFD	Milk Mg^{-1}	Milk ha^{-1}
		mean square							
Env	8	807*	35,309*	111,572*	121,701*	139,155*	151,860*	1,313,947*	1,954,781,381*
Rep (Env)	27	15 NS†	896 NS	1,597 NS	363 NS	2,442 NS	283 NS	7,527 NS	14,515,098 NS
Defoliation	9	102*	56,171 *	120,600*	24,478*	116,507*	116,537*	407,052	1,669,516,258*
Env × Defoliation.	72	34*	2,579*	4,835*	1,054*	5,586*	5,586*	19,687	40,838,726*
Error	243	16	751	1,370	414	1,809	116	6,109	10,412,460

* Significant at the 0.05 level.

† NS, not significant at $P \leq 0.05$.

stage, the untreated control was used as the starting point to determine the relationship between forage quality and level of defoliation. In addition, regression equations for each growth stage over all environments were developed using individual environment treatment means.

RESULTS AND DISCUSSION

The growing seasons at Arlington during 2000, 2001, and 2002 were near the 30-yr average for monthly temperature. Precipitation during 2000 was greater than the 30-yr average (1970–1999) with significantly more precipitation in May and June, while precipitation during 2001 was average, and 2002 below average from July to September. The growing seasons at Marshfield during 2000, 2001, and 2002 were near the 30-yr average for monthly temperature. Precipitation during 2000 was near the 30-yr average, during 2001 was greater than average with significantly more precipitation in May and June, and during 2002 was above average for most of the growing season. The wet conditions in 2001 at Marshfield resulted in poor grain fill and lower energy and starch in the corn forage. The growing seasons at State College for 2000 and 2001 were quite favorable with near normal rainfall and below average temperatures; however, the 2002 growing season was hot and dry with below normal rainfall and above average temperatures in July and August.

Vegetative stages were defined using the collar method, which results in about two fewer leaves being classified than the typical staging system used by hail adjusters (Stevens et al., 1986). Thus, V7 corn would really be nine-leaf corn according to the hail adjuster's growth staging system. The combined analysis of variance indicated a significant defoliation treatment by environment interaction (Table 2) therefore defoliation effects were examined for each environment separately. Corn forage quality varied slightly in response to defoliation treatments across most environments (Table 3). Although there were minor differences in the response to defoliation at individual sites, generally increasing defoliation either did not affect quality, especially at V7 and V10 stages, or lowered quality, especially at the R1 and R4 stages of development. In the individual site analyses, fewer significant defoliation treatment differences were found in the more northern Marshfield location during 2000 and 2001 than at Arlington and State College. The largest differences in NDF, ADF, and in vitro true digestibility occurred at R1 and R4. These changes resulted in decreases in Milk Mg^{-1} and Milk ha^{-1} in most environments (Table 4).

In four of nine environments, crude protein was not affected by defoliation. In four of nine environments, crude protein tended to increase as defoliation increased at V7, V10, and R1, but at R4 defoliation decreased crude protein. An exception was at State College in 2002 where crude protein increased with increasing defoliation for the R4 stage. In two of nine environments, ADF and NDF were not affected by defoliation treatments. In the remaining environments, both ADF and NDF were usually not affected when defoliation occurred at V7 and V10, but increased for the R1 and R4 stages as defoliation increased. In vitro true digestibility was affected by defoliation treatment in seven of nine environments. Increasing defoliation decreased in vitro true digestibility at R1, usually at R4 but the response was not as great. Defoliation treatment affected starch content in eight of nine environments with R1 having the greatest decrease as defoliation increased.

Reductions in starch content were less than expected based on the reduction in grain content in Baldridge (1976) study. Defoliation treatment affected NDF digestibility differently depending on growth stage. Averaged across all environments, compared to the control, lower NDF digestibility was associated with the 25 and 100% defoliation at R1 and higher NDF digestibility was observed with the 100% defoliation at R4.

No significant regression relationships between any laboratory quality measure and defoliation were found in any environment at V7 (data not shown). For growth stages V10, R1 and R4, significant regression coefficients of determination were found at 4 of 27 stage-site-years for crude protein, 10 of 27 stage-site-years for ADF, 13 of 27 stage-site-years for NDF, 12 of 27 stage site-years for in vitro true digestibility, 8 of 27 stage-site-years for NDF digestibility, and 10 of 27 stage-site-years for starch content. The relationships most frequently fitted a quadratic vs. a linear response. At V10, 6 of 54 site-year data sets across the above six quality measures had significant coefficients describing the relationship between forage quality and defoliation. At R1, 30 of 54 site-year data sets resulted in significant coefficients describing the relationship between forage quality and defoliation, while significant coefficients were seen in 20 of 54 site-year data sets for R4.

Increasing leaf defoliation decreases grain yield (National Crop Insurance Services, 1998). Thus, both leaf loss and decreases in grain yield would combine to reduce forage quality (Table 3, Fig. 1). When adjusting for forage quality response to defoliation the response was best described using a quadratic relationship (Fig. 1). Forage quality response to defoliation varied according to the growth stage at which it occurred. The

Table 3. Corn forage quality response to defoliation at V7, V10, R1, or R4 growth stages (Ritchie et al., 1996).

Growth stage†	Leaf defoliation	Arlington, WI			Marshfield, WI			State College, PA			Mean
		2000	2001	2002	2000	2001	2002	2000	2001	2002	
	%	g kg^{-1}									
Crude protein											
Control	0	69.4	74.2	70.3	74.3	68.0	70.2	64.6	67.9	75.6	70.5
V7	100	70.0	76.7	69.8	77.7	72.7	75.5	66.5	72.2	78.3	73.2
V10	50	68.0	74.0	66.9	73.3	76.0	76.7	66.0	70.6	78.5	72.2
	100	68.8	78.3	71.4	71.9	71.0	79.1	66.2	75.0	84.9	74.0
R1	25	68.2	74.9	70.2	74.9	66.3	74.6	63.1	69.0	79.4	71.2
	50	68.8	78.1	71.7	81.8	75.5	72.5	65.8	67.5	77.6	73.2
	100	68.8	77.5	73.5	77.0	81.3	71.8	64.2	72.7	76.2	73.7
R4	25	66.4	73.2	69.0	79.4	76.3	75.6	64.6	65.3	77.4	71.9
	50	65.4	74.3	67.5	79.6	70.2	75.0	64.5	63.1	74.8	70.5
	100	63.7	72.2	64.1	71.5	61.0	76.9	63.1	66.0	80.9	68.8
LSD (0.05)		NS	3.1	4.2	NS	10.7	NS	NS	5.9	4.4	1.9
Acid Detergent Fiber											
Control	0	242	205	245	244	308	220	200	258	208	237
V7	100	249	200	244	289	290	224	194	189	194	230
V10	50	241	216	264	263	285	223	201	210	193	233
	100	234	220	241	261	307	245	197	226	214	238
R1	25	249	211	248	294	322	219	218	239	204	245
	50	274	223	251	295	283	227	208	255	200	246
	100	399	382	400	275	357	345	386	374	300	358
R4	25	243	220	243	266	292	224	207	294	198	243
	50	259	193	258	237	294	227	195	287	195	238
	100	358	265	306	252	356	288	276	307	201	290
LSD (0.05)		39	27	28	NS	NS	25	20	49	15	13
Neutral Detergent Fiber											
Control	0	421	375	442	450	575	401	396	469	392	436
V7	100	432	361	435	512	550	396	384	367	373	423
V10	50	418	383	466	476	540	402	394	396	370	427
	100	407	387	425	476	575	436	386	421	404	435
R1	25	428	380	435	515	585	399	421	436	386	443
	50	463	396	439	520	539	409	408	464	387	447
	100	642	614	652	493	668	585	661	629	553	611
R4	25	422	395	435	478	565	405	404	516	386	445
	50	447	360	456	438	570	409	386	504	382	439
	100	589	465	535	466	640	500	502	516	395	512
LSD (0.05)		52	36	44	NS	NS	35	29	68	27	17
In vitro true digestibility											
Control	0	830	851	822	821	657	835	843	796	858	813
V7	100	822	856	829	789	673	836	848	846	861	818
V10	50	831	849	810	809	683	831	840	832	862	816
	100	838	845	831	804	667	817	849	816	836	811
R1	25	827	849	825	786	644	831	832	816	852	807
	50	815	841	823	783	689	832	835	802	848	807
	100	730	758	736	797	615	747	711	719	768	731
R4	25	831	845	827	805	677	828	838	777	858	810
	50	822	859	815	812	678	831	847	787	854	812
	100	767	839	802	807	618	796	810	788	850	786
LSD (0.05)		25	17	20	NS	NS	16	12	31	16	9
Starch content											
Control	0	316	390	341	322	162	371	377	281	310	319
V7	100	274	394	358	260	190	366	392	406	321	329
V10	50	311	368	322	293	194	369	371	383	321	326
	100	326	371	366	295	155	328	374	330	235	309
R1	25	319	378	340	245	159	373	337	346	297	310
	50	281	356	348	238	193	369	374	312	297	308
	100	117	202	160	288	28	125	94	136	91	138
R4	25	318	359	354	291	174	360	365	254	297	308
	50	310	418	340	306	181	368	399	276	332	326
	100	204	345	288	281	138	315	310	323	371	286
LSD (0.05)		56	48	46	NS	82	41	34	80	44	20

(Continued on next page.)

Table 3 (continued).

Growth stage†	Leaf defoliation	Arlington, WI			Marshfield, WI			State College, PA			Mean
		2000	2001	2002	2000	2001	2002	2000	2001	2002	
	%	g kg^{-1}									
NDF Digestibility											
Control	0	597	601	597	601	408	588	605	566	637	578
V7	100	589	603	608	589	407	586	603	580	627	577
V10	50	598	607	592	598	413	580	594	576	628	576
	100	602	601	602	587	421	579	608	563	594	573
R1	25	596	602	598	585	391	576	601	577	618	572
	50	601	598	597	584	422	588	595	573	607	574
	100	580	606	595	588	424	567	563	553	580	562
R4	25	599	606	603	592	429	576	600	568	634	579
	50	601	610	595	572	435	587	603	578	620	578
	100	605	653	630	588	403	592	622	589	622	589
LSD (0.05)		12	14	14	12	NS	13	12	13	17	5

† V7, 7 leaf stage; V10, 10 leaf stage; R1, silking; R4, dough stage.

Table 4. Estimated milk production from corn forage in response to defoliation at V7, V10, R1, or R4 growth stages (Ritchie et al., 1996).

Growth stage†	Leaf defoliation	Arlington, WI			Marshfield, WI			State College, PA			Mean
		2000	2001	2002	2000	2001	2002	2000	2001	2002	
Milk per Megagram	%	kg Mg^{-1}									
Control	0	1700	1780	1670	1650	1110	1710	1750	1590	1740	1630
V7	100	1630	1800	1690	1540	1170	1720	1760	1760	1740	1640
V10	50	1700	1770	1630	1610	1200	1700	1740	1710	1730	1640
	100	1720	1760	1700	1590	1130	1650	1770	1660	1470	1600
R1	25	1690	1770	1680	1530	1070	1700	1710	1650	1670	1600
	50	1640	1740	1670	1520	1220	1700	1720	1600	1650	1600
	100	1330	1420	1340	1520	900	1340	1270	1300	1200	1300
R4	25	1700	1750	1690	1600	1170	1690	1730	1510	1680	1610
	50	1670	1810	1640	1630	1170	1700	1760	1540	1760	1630
	100	1450	1710	1570	1610	980	1560	1610	1540	1760	1530
LSD (0.05)		100	60	70	NS	NS	70	50	110	130	40
Milk per hectare		kg ha^{-1}									
Control	0	31,300	44,800	35,100	27,600	14,800	33,200	33,100	27,200	19,800	29,500
V7	100	30,300	35,300	30,200	20,500	14,200	24,200	26,500	26,400	17,000	24,900
V10	50	32,300	39,400	29,700	19,000	10,800	25,900	27,800	27,700	15,500	25,300
	100	27,200	25,100	21,900	9,500	7,500	16,200	23,100	15,800	7,200	17,000
R1	25	27,500	42,700	30,400	26,100	12,800	32,000	25,700	25,400	15,000	26,300
	50	27,500	36,200	28,400	23,500	12,300	27,400	25,100	22,000	14,300	24,000
	100	8,400	9,400	9,200	10,200	3,700	8,600	5,000	6,300	3,900	7,100
R4	25	31,500	41,800	33,200	25,600	14,400	32,400	30,700	21,800	15,800	27,300
	50	30,300	43,000	29,300	23,400	14,300	28,700	31,400	20,600	15,000	26,100
	100	16,700	23,900	20,800	18,400	7,200	17,300	16,900	15,400	13,000	16,500
LSD (0.05)		7,200	4,800	4,100	2,400	4,300	2,600	5,500	5,400	3,900	1,500

† V7, 7 leaf stage; V10, 10 leaf stage; R1, silking; R4, dough stage.

most sensitive growth stage of forage quality for defoliation treatment was near tasseling and silking (R1).

No significant relationship between defoliation and Milk Mg^{-1} or Milk ha^{-1} was found at the V7 development stage (Fig. 1). On average, however, Milk ha^{-1} was reduced in five of the nine environments with 100% defoliation at V7. Significant regression coefficients of determination were found at 11 of 27 stage-site-years for Milk Mg^{-1} and 20 of 27 stage-site-years for Milk ha^{-1}. Both Milk Mg^{-1} and Milk ha^{-1} were most affected by 100% defoliation at R1 (Fig. 1). Milk Mg^{-1} was not as strongly affected by leaf defoliation as Milk ha^{-1} indicating that defoliation effects on both forage yield and quality are important for economic decisions. In this study, averaged across all environments, Milk ha^{-1} decreased 16% when 100% defoliation occurred at V7 (Fig. 1 and Table 4. Likewise, 100% defoliation decreased Milk ha^{-1} 42, 76, and 56% at V10, R1, and R4 growth stages, respectively compared to forage yield decreases of 43, 70, and 40%, respectively (Lauer et al., 2004).

These experiments indicate that forage quality is maintained in most cases except at the high levels of defoliation at R1. Like the Montana experiments (Baldridge, 1976), the greatest forage quality changes occurred with the greatest defoliation levels at R1 and R4. Perhaps these are the key growth stages to consider adjustments for forage quality. Simulated hail treatments do not account for bruising, crippling, and other secondary effects; thus, the responses to defoliation treatments in this study may underestimate forage quality impacts. Mycotoxins were not measured in this study and could be a significant quality issue in some hail damaged corn silage. Using the equations listed in Fig. 1, agronomists can estimate the impact of defoliation on corn forage quality measures. In this study, responses

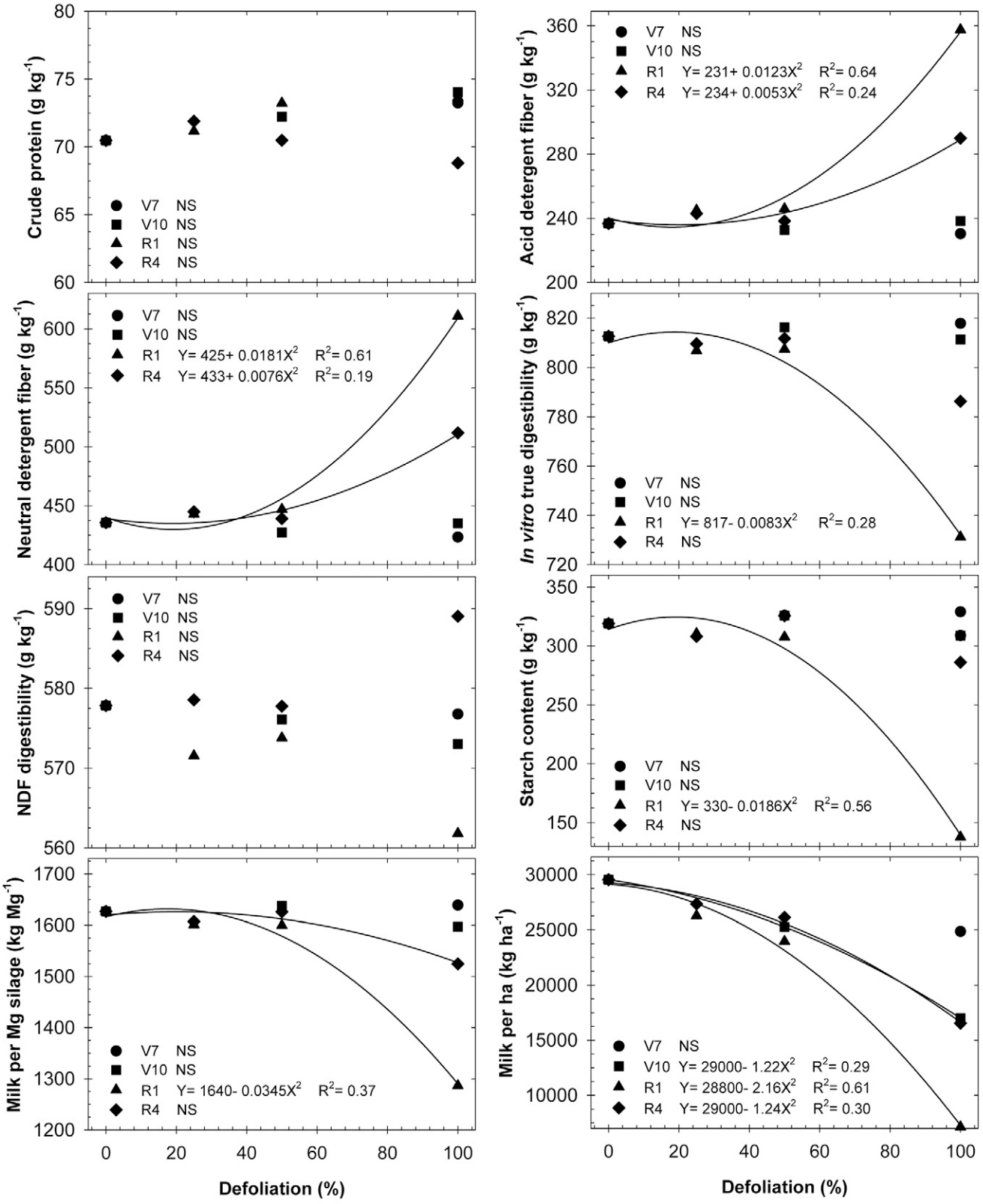

Fig. 1. Changes in corn forage quality changes with defoliation at V7, V10, R1, and R4 (Ritchie et al., 1996). Model equations used treatment means for each environment. Graph values are treatment means averaged across environments.

were generally consistent among the three environments, but it is difficult to predict how widely these results can be applied to other environments. These forage quality impacts, combined with yield impacts (Lauer et al., 2004) should improve the estimation of crop value of corn grown for silage following defoliation from hail and provide a basis for future studies in this area.

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