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Forage Quality of Potato Leafhopper Resistant and Susceptible Alfalfa Cultivars

R. Mark Sulc,* Keith D. Johnson, Craig C. Sheaffer, Daniel J. Undersander, and Edzard van Santen

ABSTRACT

Glandular-haired alfalfa (*Medicago sativa* L.) cultivars resistant to potato leafhopper [*Empoasca fabae* Harris] (PLH) have not been evaluated for forage quality across a wide region. Our objective was to compare forage quality of PLH resistant and susceptible alfalfa cultivars with and without insecticide control of PLH across the Midwest USA. Six commercially released PLH resistant and five susceptible cultivars were evaluated from 1996 to 1997 in field experiments in Ohio, Indiana, Wisconsin, and Minnesota. The resistant cultivar group was more mature at harvest but equal to or higher ($P \leq 0.05$) in crude protein (CP) concentration than the susceptible group regardless of insecticide treatment. Averaged over all harvests, the CP advantage for the resistant group was 11 to 13 g kg^{-1} for insecticide treated and untreated controls, respectively. Without insecticide, the resistant group was equal to or lower ($P \leq 0.05$) in neutral detergent fiber (NDF) and equal to or higher ($P \leq 0.05$) in in vitro digestible dry matter (IVDDM) than the susceptible group, except at harvests when PLH severely stunted the susceptible cultivars, which likely increased leaf/stem ratio. With insecticide, the resistant group was lower in NDF by 15 to 25 g kg^{-1} and higher in IVDDM by 19 g kg^{-1} than the susceptible group. Potato leafhopper feeding had less effect on forage quality and maturity of PLH resistant cultivars than susceptible cultivars. The PLH resistant cultivars we evaluated generally had higher forage quality than susceptible cultivars when grown with or without insecticide application despite being more mature at harvest.

Potato leafhopper is a serious insect pest of alfalfa in the eastern half of the USA and portions of Canada. Potato leafhopper feeding in alfalfa reduces stem length and mass, increases leaf/stem ratio, and decreases morphological stage of development (Hower and Flinn, 1986; Hutchins et al., 1989; Hutchins and Pedigo, 1990; Oloumi-Sadeghi et al., 1988, 1989). Reductions in plant height and yield are probably the most commonly documented responses to PLH feeding and are considered the primary cause of economic loss from this pest (Faris et al., 1981; Hower and Flinn, 1986; Hutchins et al., 1989; Oloumi-Sadeghi et al., 1988). Feeding by PLH also affects chemical composition of alfalfa, such as reduced carotene, ash, Ca, and phosphate concentration of alfalfa (Kindler et al., 1973; Smith and Medler, 1959).

Potato leafhopper feeding damage caused a 3 to 39% reduction in CP concentration of the total herbage relative to the CP concentration of undamaged alfalfa (Hower and Flinn, 1986; Hutchins et al., 1989; Oloumi-Sadeghi et al., 1989). The reduction in CP appears to be associated more closely with the leaf rather than the stem component in alfalfa plants. For example, CP concentration of alfalfa leaves was lower while in stems, it was maintained or actually enhanced by PLH feeding (Hutchins et al., 1989; Oloumi-Sadeghi et al., 1989). In another study, after only 1 wk of leafhopper feeding, leaf CP concentration was 22 to 35% lower relative to the CP concentration of uninjured alfalfa (Flinn et al., 1990).

Less information is available on the effect of PLH feeding on alfalfa fiber concentration and forage digestibility. Hutchins et al. (1989) reported that NDF concentration of total herbage was largely unaffected but the trend was for NDF to increase with PLH feeding damage. They also reported that IVDDM concentration of total herbage was not affected by PLH but severe PLH feeding damage actually enhanced stem and leaf digestibility.

In 1997, seed companies began marketing several PLH resistant alfalfa cultivars (Holin, 1997). Growth and yield performance of PLH resistant cultivars have been reported (Hansen et al., 2002; Lefko et al., 2000; Sulc et al., 2001), but limited information is available on their forage quality traits in response to PLH feeding. In New York, Hansen et al. (2002) reported that PLH resistant cultivars were consistently higher in CP concentration than susceptible cultivars. Fiber concentrations in PLH resistant cultivars were consistently lower than in susceptible cultivars during the seeding year, but differences were less consistent in established stands.

Forage quality of PLH resistant cultivars has not been evaluated across a wide geographic area. We recently reported the yield performance of PLH resistant cultivars grown in four Midwest states (Sulc et al., 2001). The PLH resistant cultivars had less yield losses caused by PLH feeding than standard susceptible cultivars. Here we report forage quality of those same PLH resistant and susceptible cultivars. Our objective was to evaluate forage quality of PLH resistant and susceptible alfalfa cultivars across a wide geographic area both with and without insecticide applications to control PLH. We

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Abbreviations: CP, crude protein; IVDDM, in vitro digestible dry matter; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy; PLH, potato leafhopper.

hypothesized that PLH feeding would have less effect on forage quality of PLH resistant cultivars compared with standard susceptible cultivars.

MATERIALS AND METHODS

Plot Establishment and Maintenance

Field experiments were established in April and May 1996 in Ohio, Indiana, Wisconsin, and Minnesota. Characteristics of the experimental sites and details of establishment are described by Sulc et al. (2001). The experimental design at all locations was a randomized complete block with four replicates and a split-plot restriction on treatment arrangement. Whole-plot treatments consisted of insecticide treated and untreated controls. Subplot treatments were alfalfa cultivars. Insecticide applications were made on a scheduled basis to the treated plots. The insecticide used was cyfluthrin [cyano (4-fluoro-3-phenoxyphenyl)-methyl-3-(2,2-dichloroethenyl) 2,2-dimethylcyclopropanecarboxylate] at 0.028 kg a.i. ha^{-1}. In the seeding year (1996), insecticide was applied to the first growth of alfalfa ≈68 d after seeding at Indiana and Wisconsin and 36 and 53 d after seeding at Ohio. No insecticide was applied nor was it necessary in the first growth at Minnesota. Cyfluthrin was again applied ≈15 d after the first harvest in the seeding year at all locations. In the subsequent year, cyfluthrin was applied ≈15 d after the first and second harvests at Minnesota and Wisconsin and ≈15 d after the first, second, and third harvests at Indiana and Ohio.

Fourteen cultivars (subplot treatments) were included in the experiment (Sulc et al., 2001). Nine were experimental cultivars having the glandular-haired trait selected for resistance to PLH. Six of those PLH resistant cultivars were released for commercial sale beginning in 1997 (Ameriguard 301, Interceptor, 5347LH, Trailblazer, DK 121HG, and Arrest). The other three PLH resistant cultivars (CW4242, CW5351, and CW5332) were not released for commercial sale. Five cultivars were selected to represent commercially available non-glandular-haired, PLH susceptible alfalfa (5454, AlfaLeafII, Innovator+Z, Rushmore, and Vernal).

All seed was inoculated with *Rhizobium meliloti* Dangeard and treated with metalaxyl [*N*-(2,6-dimethylphenyl)-N-(methoxy-acetyl)-alanine methyl ester] before planting. Conventional tillage was used to prepare the seedbed. Cultivars were seeded at 11 kg ha^{-1} in rows spaced 15 cm apart. Subplot size varied among locations, ranging from 1.5 to 2.3 m wide and 4.9 to 6.1 m long. Seed quantity of the PLH resistant cultivars was low, which limited the subplot size. Whole-plot (insecticide treated and untreated controls) size varied among locations, ranging from 21 to 32 m wide and 4.9 to 6.1 m long. Whole-plot treatments were separated by at least 3 m, and a minimum of 1.5 m of PLH susceptible alfalfa bordered all sides of each whole plot. Weeds were controlled with herbicides as needed (Sulc et al., 2001). Alfalfa weevil (*Hypera postica* Gyll.) was controlled in early May 1997 and 1998 at Indiana with carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranylmethyl carbamate) at 0.56 kg a.i. ha^{-1}. At the other locations, alfalfa weevil populations did not justify insecticide control.

Harvest and Sampling

Plots were harvested twice during the seeding year at all locations. The first harvest was taken 68 to 80 d after seeding, and the second harvest was ≈35 d after the first. In the year after seeding, three harvests were taken at Minnesota and Wisconsin and four at Indiana and Ohio. The first harvest at all locations was taken when alfalfa reached early flowering stage (late May to the first week of June). Summer harvests occurred at ≈35-d intervals in Indiana and Ohio and at 40- to 47-d intervals in Minnesota and Wisconsin. Samples were collected for forage quality analyses at all harvests in the seeding (1996) and first production (1997) year at Wisconsin (total of five harvests), Indiana (six harvests), and Ohio (six harvests). Samples were not collected at the first harvest in 1996 at MN because of variability in the rate of establishment and presence of annual weeds. Forage quality samples were collected for the remaining four harvests taken in 1996 and 1997 at Minnesota. Forage samples, 300 to 500 g fresh weight, were hand-clipped just before harvest from two to three locations within each subplot, leaving a 6-cm stubble, and then dried at 60°C for 48 h. Dried samples were ground to pass through a 2-mm screen in preparation for forage quality analysis.

Morphological stage of development was determined at each harvest on four PLH resistant (Ameriguard 301, 5347LH, Trailblazer, and CW5332) and all five standard susceptible cultivars at Wisconsin, Indiana, and Ohio. All 14 cultivars were sampled for stage of development at Minnesota. For each selected cultivar, 40 to 50 stems were collected at random from each of three replications to determine stage of development according to the mean stage by count method (Kalu and Fick, 1981).

Populations of PLH were monitored at all locations on a weekly basis beginning in June to provide a measure of the general PLH density within the experiment (Sulc et al., 2001). Ten pendulum sweeps were made through the alfalfa canopy using an insect net with a 38-cm diameter. The total number of PLH adults and nymphs was recorded along with the average canopy height in the border areas. The PLH density and canopy height data were related to economic thresholds. The economic threshold level was defined as the number of PLH adults plus nymphs collected per 10 sweeps of a sweep net equivalent to the stem height of alfalfa expressed in inches (Willson et al., 2000).

Forage Quality Analysis

Quality of whole-plant forage was analyzed on all samples collected. Crude protein (Kjeldahl N × 6.25), IVDDM (Marten and Barnes, 1979), and NDF (Goering and Van Soest, 1970) were predicted via near-infrared reflectance spectroscopy (NIRS) analysis (Model 6500, NIRSystems, Silver Springs, MD). Equations for NIRS were developed in Minnesota using the software program Calibrate (NIRS 3 version 4.0, Infrasoft Int., Port Matilda, PA) with the modified partial least squares regression option (Shenk and Westerhaus, 1991a, 1991b). In 1996, 20 monitoring samples selected at random from all locations were analyzed via conventional chemical analysis for CP, NDF, and IVDDM and then were added to a large research data set (N = ≈500) to predict concentration of those traits in samples from all locations. In 1997, 100 samples from the 1996 data set were selected from all locations using the Match program (Infrasoft Int., Port Matilda, PA) and combined with ≈30 monitoring samples selected from the 1997 samples. This data set of 130 samples was used in developing the prediction equation for the 1997 samples. All conventional chemical analyses for calibrating NIRS were conducted at the University of Minnesota. Each year, the equations were effective in predicting CP, NDF, and IVDDM of the sampled forage (Table 1).

Data Analysis

Mixed-model methodology as implemented in SAS PROC MIXED (Littell et al., 1996) was used to analyze the response data by location. Insecticide treatment, cultivar group (commercially released PLH resistant, PLH resistant and not commercially released, and standard commercially available PLH susceptible), harvest time, and their interactions were considered fixed effects whereas replicates, main-plot error, subplot error, and experimental error were considered random effects. We used a type I error rate of $P = 0.05$ for insecticide treatment, cultivar group, and harvest time main effects. For the interaction effects, we used a higher type I error rate ($P = 0.15$), extending the ideas of Carmer and coworkers (Carmer, 1976; Carmer and Walker, 1988) regarding risk assessment for comparing means in crop performance trials. Least square means and associated standard errors were calculated when appropriate.

Table 1. Calibration statistics for near-infrared reflectance spectroscopy analysis to predict crude protein (CP), neutral detergent fiber (NDF), and in vitro digestible dry matter (IVDDM) concentrations in alfalfa.

Forage quality variable	Mean	SEC†	R^2	SECV‡	1 − VR§
	g kg^{-1}				
1996					
CP	223	0.599	0.96	0.655	0.95
NDF	368	0.951	0.98	1.050	0.97
IVDDM	729	1.299	0.94	1.443	0.93
1997					
CP	225	0.663	0.95	0.836	0.92
NDF	389	1.165	0.95	1.349	0.94
IVDDM	697	1.485	0.94	1.640	0.92

† SEC, standard error of calibration.
‡ SECV, standard error of cross validation.
§ 1 − VR, one minus the variance ratio (similar interpretation as R^2 value).

RESULTS AND DISCUSSION

We were most interested in the insecticide treatment × cultivar group interaction in the interpretation of forage quality results. When analyzing data over all harvests, significant interactions were found for harvest × insecticide treatment, harvest × cultivar group, and harvest × insecticide treatment × cultivar group for the traits evaluated; however, those interactions were due primarily to changes in magnitude of differences among cultivar groups and treatments across harvests rather than to changes in rank. Ranking of cultivar groups was consistent for the forage quality traits evaluated. The PLH resistant, not commercially released cultivar group nearly always ranked intermediate between the commercially released PLH resistant and the standard PLH susceptible cultivar groups, both across and within treatments (data not shown). This reflects its intermediate ranking in yield and response to insecticide treatment relative to the other two groups (Sulc et al., 2001). Thus, we have focused our presentation of forage quality results on comparing the performance between the commercially released PLH resistant group (six cultivars) and the PLH susceptible cultivar group (five cultivars). To provide the reader with a frame of reference for the forage quality results presented herein, we begin with a brief summary of the PLH density and forage yield results as reported by Sulc et al. (2001).

Potato Leafhopper Density and Alfalfa Yield

Potato leafhopper density in untreated alfalfa varied considerably among locations. In general, the further south the location, the higher was the PLH density and plant injury (Sulc et al., 2001). In the seeding year (1996), the greatest injury (plant stunting, injury scores, and yield loss) from PLH feeding occurred at Ohio. In 1997, economic thresholds were reached in the second, third, and fourth growth intervals at Ohio and in the second and third growth intervals at Indiana. In contrast, economic thresholds were reached only in the second growth interval at Wisconsin and Minnesota. Insecticide applications reduced PLH populations to less than 15% of those in untreated plots, such that PLH densities in treated plots remained far below the economic threshold (data not shown). Insecticide applications increased total yield of all cultivars, the response declining with increasing latitude (Sulc et al., 2001). Depending on location, total yield loss due to PLH ranged from 5 to 23% for the susceptible cultivar group and only 1 to 10% for the resistant group (Sulc et al., 2001). Yield loss for the resistant group was less than half that observed for the susceptible group in Ohio and Indiana where PLH densities were high. In control plots at those two locations, PLH nymph densities in the resistant cultivars were usually less than 50% of the densities in the susceptible cultivars (Sulc et al., 2001).

Maturity Stage

The group of PLH resistant cultivars was more mature at harvest than the susceptible group at three of the four locations (Table 2). Hansen et al. (2002) reported a similar trend. At Indiana and Ohio, group differences were larger in control than in treated plots, leading to an insecticide treatment × cultivar group interaction ($P \leq 0.01$). The severe PLH-induced stunting of plants in the susceptible group in control plots at Indiana and Ohio likely caused them to be less mature at harvest during the summer months compared with plants in the resistant group that suffered less PLH damage (Tables 2 and 3). Other investigators have reported morphological development delays in PLH-infested plots of standard susceptible cultivars (Hutchins and Pedigo, 1990; Oloumi-Sadeghi et al., 1988).

Delayed morphological development is an important form of injury associated with leaf-mass–consuming and assimilate-removing insects (Hutchins et al., 1990). If the delay is great enough, the number of harvests possible during the growing season may be reduced. Under the high PLH densities at Indiana and Ohio, maturity stage of the resistant group was less affected than that of the susceptible group, as evidenced by smaller differences between treated and untreated controls (Table 3). The implication is that with uncontrolled PLH infestations, resistant cultivars were in better physiological condition at harvest than susceptible cultivars; therefore, it is likely that the desired harvest intervals can be maintained more easily when growing resistant compared with susceptible cultivars in the absence of insecticide treatment.

Table 2. Maturity stage and forage quality of potato leafhopper resistant (R) and susceptible (S) alfalfa cultivar groups grown without (control) and with (treated) insecticide for control of potato leafhopper at four locations. Values are means across all harvests at each location.

Trait† and location	Control			Treated			
	R	S	Difference	R	S	Difference	SED‡
Maturity stage				stage§			
Minnesota	3.5	3.4	0.1NS¶	3.8	3.6	0.2NS	0.10
Wisconsin	4.2	4.0	0.2*	4.4	4.2	0.2**	0.07
Indiana	2.6	1.6	1.0**	2.8	2.6	0.2**	0.07
Ohio	1.8	1.2	0.6**	2.2	2.2	0.0NS	0.07
CP				$g\ kg^{-1}$			
Minnesota	202	191	11**	211	202	9**	1.6
Wisconsin	234	220	14**	241	227	14**	2.0
Indiana	213	195	18**	229	218	11**	1.3
Ohio	236	226	10**	246	235	11**	1.8
NDF							
Minnesota	436	446	−10**	441	459	−18**	3.6
Wisconsin	356	379	−23**	364	389	−25**	4.2
Indiana	370	357	13**	389	404	−15**	2.9
Ohio	338	338	0NS	349	371	−22**	2.6
IVDDM							
Minnesota	624	609	15**	625	605	20**	3.9
Wisconsin	724	705	19**	719	700	19**	3.0
Indiana	703	708	−5*	684	666	18**	2.6
Ohio	743	737	6**	734	714	20**	2.2

* Significant difference at the 0.05 probability level.
** Significant difference at the 0.01 probability level.
† CP, crude protein; NDF, neutral detergent fiber; IVDDM, in vitro digestible dry matter.
‡ SED, standard error of the difference.
§ Maturity stage (Kalu and Fick, 1981), where 1 = midvegatative, 2 = late vegetative, 3 = early bud, 4 = late bud, and 5 = early flower stages.
¶ NS, not significant ($P > 0.05$).

Crude Protein

Cultivar Group Differences

The PLH resistant cultivar group was higher in CP concentration than the susceptible cultivar group when averaged over all harvests at each location, regardless of insecticide treatment (Table 2). Averaged across locations, the CP advantage of the resistant group was 13 g kg^{-1} in control plots and 11 g kg^{-1} in treated plots. In the seeding year, Hansen et al. (2002) reported a CP advantage for PLH resistant over susceptible cultivars averaging 21 and 9 g kg^{-1} in control and insecticide treated plots, respectively. In established stands, they found an average CP advantage for resistant cultivars of 8 and 5 g kg^{-1} in control and insecticide treated plots, respectively.

Table 3. Maturity stage and forage quality differences between insecticide-treated and untreated controls for potato leafhopper resistant (R) and susceptible (S) alfalfa cultivar groups at four locations. Differences were calculated as treated − control and are means across all harvests at each location.

Trait† and location	R	SED‡	S	SED
Maturity stage		stage§		
Minnesota	0.3NS¶	0.15	0.3NS	0.15
Wisconsin	0.3**	0.07	0.2**	0.06
Indiana	0.3**	0.10	1.0**	0.09
Ohio	0.4**	0.07	1.0**	0.06
CP		$g\ kg^{-1}$		
Minnesota	9**	2.2	11**	2.3
Wisconsin	7**	1.9	7**	2.1
Indiana	16**	1.4	23**	1.5
Ohio	10**	1.5	9**	1.6
NDF				
Minnesota	6NS	4.6	13**	4.8
Wisconsin	7NS	3.9	11**	4.3
Indiana	19**	2.5	47**	2.8
Ohio	11**	2.4	33**	2.6
IVDDM				
Minnesota	1NS	5.5	−4NS	5.8
Wisconsin	−5NS	2.8	−5NS	3.1
Indiana	−19**	2.5	−42**	2.7
Ohio	−9**	2.8	−23**	2.9

** Significant difference at the 0.01 probability level.
† CP, crude protein; NDF, neutral detergent fiber; IVDDM, in vitro digestible dry matter.
‡ SED, standard error of the difference.
§ Maturity stage differences (see Table 2 for stage descriptions).
¶ NS, not significant ($P > 0.05$).

The harvest × cultivar group interaction was significant ($P \leq 0.15$) at all locations, and the harvest × insecticide treatment × cultivar group interaction was significant ($P \leq 0.01$) at all locations except Minnesota. The interactions were primarily due to changes in magnitude of cultivar group differences with treatment level and harvest rather than to changes in ranking. Among harvests, the CP advantage of the resistant over the susceptible group ranged from 1 to 31 g kg^{-1} in control plots and from −1 to 25 g kg^{-1} in treated plots (Fig. 1). The CP advantage for the resistant group was significant ($P \leq 0.05$) in 19 of 21 harvest–location comparisons in the control plots and in 14 of 21 comparisons in the treated plots. The resistant group was never significantly lower ($P \leq 0.05$) in CP concentration than the susceptible group.

Insecticide Treatment Effects

Insecticide treatment effectively controlled PLH feeding and increased average CP concentration for both groups of cultivars at every location, as shown by positive treated vs. control differences (Table 3). The CP advantage for insecticide treatment ranged from 7 to 23 g kg^{-1}, which is within the range of response for

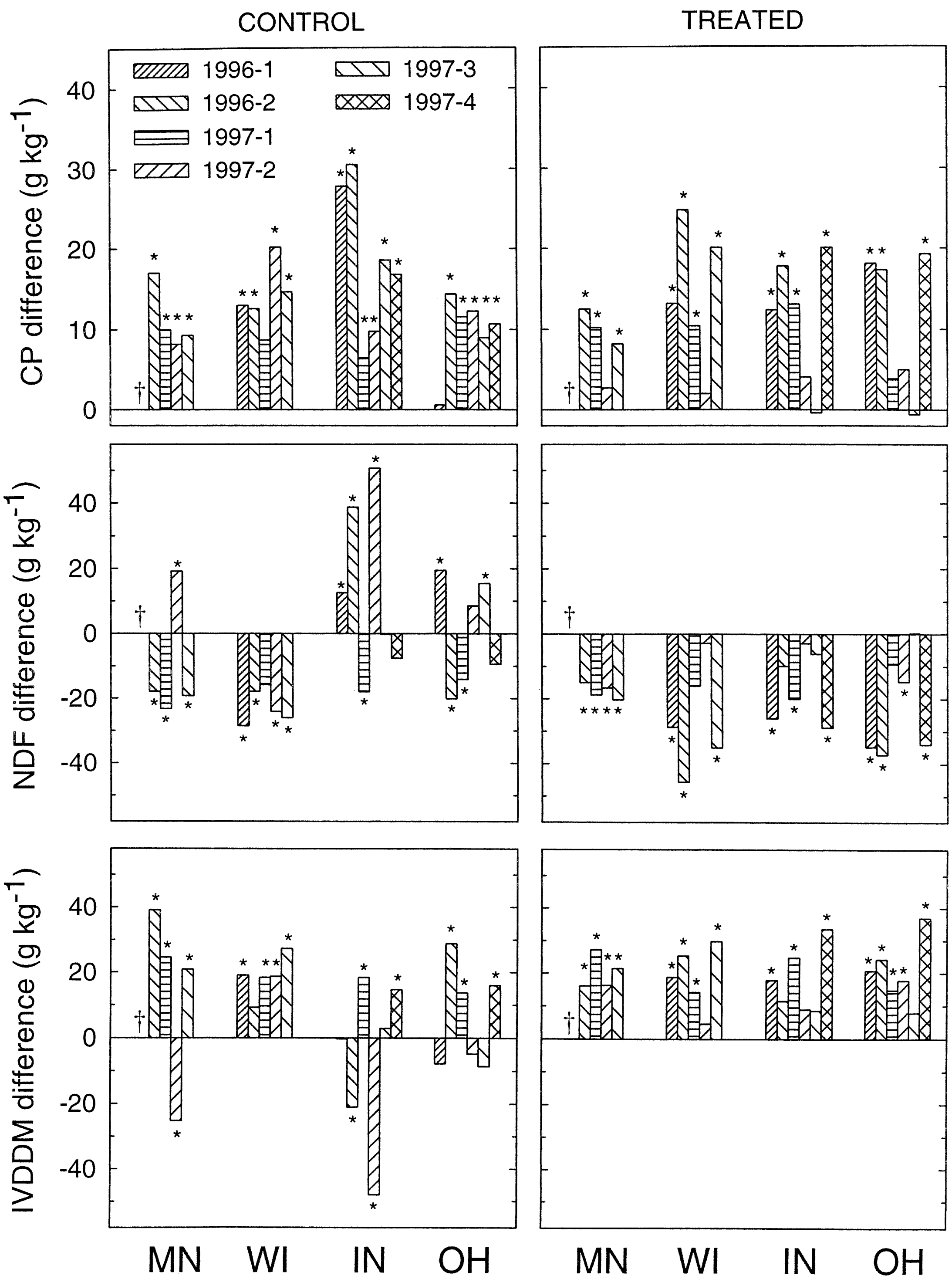

Fig. 1. Differences in forage quality of potato leafhopper resistant vs. susceptible alfalfa cultivar groups for individual harvests of control (no insecticide applied) and treated (insecticide applied) plots at four locations in 1996 and 1997. Each bar represents the magnitude of the resistant − susceptible group difference for an individual harvest. CP, crude protein; NDF, neutral detergent fiber; IVDDM, in vitro digestible dry matter; *, the difference between the resistant and susceptible group mean was significant at $P \leq 0.05$. †, first harvest in 1996 at Minnesota was not sampled for forage quality.

insecticide treatment reported by other investigators (Hower and Flinn, 1986; Hutchins et al., 1989; Oloumi-Sadeghi et al., 1989). Insecticide treatment increased ($P \leq 0.05$) CP concentration in 28 of the 42 location–harvest–cultivar group comparisons (data not shown). More importantly, insecticide treatment increased ($P \leq 0.05$) CP concentration in 81% of all harvests when PLH density exceeded the economic action threshold (data not shown). Insecticide treatment decreased ($P \leq 0.05$) CP concentration in only 6 of the 42 location–harvest–

cultivar group comparisons (data not shown). Only at Indiana was CP concentration of the resistant group affected less by PLH feeding than the susceptible group (Table 3; treatment × cultivar group, $P \leq 0.01$ for Indiana).

Fiber Concentration and Dry Matter Digestibility

Cultivar Group Differences

The PLH resistant cultivar group was lower in average NDF (−15 to −25 g kg^{-1}) and higher in average IVDDM (18 to 20 g kg^{-1}) than the susceptible group in treated plots at all locations (Table 2). Similar differences were found in control plots at Minnesota and Wisconsin; however, a different pattern was observed in control plots at Indiana and Ohio, resulting in an insecticide treatment × cultivar group interaction ($P \leq 0.01$) for NDF and IVDDM at those two locations. In control plots at Indiana, the resistant cultivar group was higher in NDF and slightly lower in IVDDM than the susceptible group (Table 2). At Ohio, the resistant group was equal in NDF and slightly higher in IVDMD than the susceptible group in control plots. The changes in rank and magnitude of differences between cultivar groups for average NDF and IVDMD are better understood by evaluating the responses at individual harvests.

The harvest × insecticide treatment × cultivar group interaction was significant ($P \leq 0.06$) for NDF and IVDDM at all locations. To illustrate this interaction, the resistant vs. susceptible group differences were plotted for each harvest (Fig. 1). Bars pointing downward (negative difference) indicate the resistant group mean was numerically smaller than the mean for the susceptible group. Bars pointing upward (positive difference) indicate the resistant group mean was numerically greater than the mean for the susceptible group. In treated plots, the resistant group was equal to or lower ($P \leq 0.05$) in NDF (bars point downward) and equal to or higher ($P \leq 0.05$) in IVDDM (bars point upward) than the susceptible group for individual harvests at all locations (Fig. 1). The same trend was observed in control plots at Wisconsin; however, in control plots at the other three locations (Minnesota, Indiana, and Ohio), ranking of cultivar group means varied across individual harvests. For example, the resistant group was higher ($P \leq 0.05$) in NDF at six harvests and lower ($P \leq 0.05$) in IVDDM at three harvests when compared with the susceptible group in control plots at Minnesota, Indiana, and Ohio. Those rank reversals of cultivar groups in control plots occurred at summer harvests when PLH densities were high, resulting in severe stunting of the susceptible cultivars (Sulc et al., 2001). Apparently, the less-stunted plants in the resistant cultivar group at those harvests contributed to higher NDF and lower IVDDM levels than in the severely stunted susceptible group. There likely was an increase in leaf/stem ratio in the susceptible cultivars, as was observed by Hutchins et al. (1989), who also reported that severe PLH feeding injury sometimes slightly enhanced stem and leaf digestibility of alfalfa.

Our data demonstrate a trend for the commercially released resistant cultivar group to be equal to or slightly superior in forage quality traits compared with the group of susceptible cultivars we tested, with only a few exceptions (Fig. 1). The commercially released resistant cultivar group was equal to or lower in NDF and equal to or higher in IVDDM than susceptible cultivars, except at harvests when high PLH density resulted in severe stunting of the susceptible cultivars. In treated plots or when PLH density was low in control plots, the resistant group was never higher in NDF or lower in IVDDM than the susceptible group. At individual harvests in treated plots, the resistant group was 0 to 46 g kg^{-1} lower in NDF and 5 to 37 g kg^{-1} higher in IVDDM than the susceptible group (Fig. 1). In control plots, differences in NDF and IVDDM between resistant and susceptible groups varied widely across individual harvests, especially at Indiana and Ohio where PLH densities were higher during the summer months. Hansen et al. (2002) reported that PLH resistant cultivars were equal to or lower in fiber concentration than susceptible cultivars in New York regardless of insecticide treatment. The same was true in our study at the two northern locations (Minnesota and Wisconsin), with the exception of the second harvest at Minnesota in 1997 (Fig. 1).

Insecticide Treatment Effects

Insecticide treatment increased average NDF concentrations for both cultivar groups, with six of eight comparisons being significant (Table 3). Insecticide treatment decreased average IVDDM concentrations of both cultivar groups at Indiana and Ohio where PLH densities and injury were greater than at Minnesota and Wisconsin. There was an insecticide treatment × cultivar group interaction ($P \leq 0.01$) for NDF and IVDDM at Indiana and Ohio. Insecticide treatment had a smaller effect on NDF and IVDDM concentration for the PLH resistant compared with the susceptible group at Indiana and Ohio (Table 3). This is consistent with the higher PLH densities and greater PLH feeding injury on susceptible cultivars at those two locations during the summer months, as discussed previously. Across summer harvests at Indiana and Ohio when PLH density exceeded the economic action threshold, insecticide treatment increased NDF by an average of 48 g kg^{-1} for the susceptible group and by only 17 g kg^{-1} for the resistant group when compared with corresponding control plots. Across those same harvests, insecticide treatment decreased IVDDM by 38 g kg^{-1} for the susceptible group and by only 16 g kg^{-1} for the resistant group.

SUMMARY AND CONCLUSIONS

Differences in forage quality traits between the PLH resistant and susceptible cultivar groups were found, and those differences varied with level of PLH infestation. We conclude that the PLH resistant cultivars evaluated in this study generally were higher in forage quality than the susceptible cultivars even though they were more mature at harvest, a condition usually associated with lower forage quality. The PLH resistant cultivar group was equal to or higher in CP than the susceptible cultivar group across all locations and harvests, regardless of being treated or not with insecticide. The CP advantage for the resistant group averaged over harvests ranged from 9 to 18 g kg^{-1}. The resistant group was lower in NDF and higher in IVDDM than the susceptible group, except at harvests when high PLH density resulted in severe stunting of susceptible cultivars. With severe stunting, the susceptible group was lower in NDF and higher in IVDMD, most likely due to an increase in leaf/stem ratio and delayed maturity. Nevertheless, the yield reduction caused by PLH injury to susceptible cultivars (Sulc et al., 2001) would likely more than offset this relatively small advantage in forage quality.

We hypothesized that PLH feeding would have less effect on forage quality of PLH resistant cultivars compared with standard susceptible cultivars. The results support that hypothesis since NDF and IVDDM of the resistant group were altered less by PLH feeding than for the susceptible cultivar group. This likely was the result of lower PLH populations and less plant damage in resistant cultivars compared with susceptible cultivars (Sulc et al., 2001). In evaluating the influence of PLH damage on least-cost feed rations, Hutchins and Pedigo (1998) concluded that the economic injury levels for alfalfa differed with the class of animals being fed (e.g., equine, dairy, and beef). This demonstrated the need to refine forage economic injury levels based on the contribution of the crop to the final feed value of the consuming animal. Based on the forage quality differences reported here and the yield differences reported previously for PLH resistant vs. susceptible cultivar groups (Sulc et al., 2001), we conclude there is a need to evaluate anew the economic injury thresholds for PLH resistant alfalfa cultivars, taking into consideration both forage yield and quality characteristics in relation to the consuming animal. Furthermore, because genetic improvements in host resistance to PLH have been achieved since this research was initiated, forage quality evaluation of new PLH resistant cultivars is warranted to ascertain whether the patterns reported here still hold or if they are even more accentuated, especially under high PLH densities.

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