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Alfalfa (*Medicago sativa* L.) quality is improved from tractor traffic implemented during harvest

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Abstract

Studies documenting the consequences of harvest traffic in alfalfa production have addressed soil and plant growth parameters. One response was larger leaf/stem ratios in plants that were trafficked, which suggests higher quality. To fully understand how harvest traffic affects alfalfa quality a need for further analysis is warranted. Our objectives were to quantify differences in plant quality between trafficked and non-trafficked plants through 4 years of alfalfa production and to determine when these differences occur. The experimental units were furrow-irrigated raised beds with four harvests per year in Youngston clay loam soil in Fruita, Colorado. A John Deere 2280 swather and a John Deere 2955 tractor, driven over the alfalfa 7 days after swathing, were used to create four traffic treatments; plants that were never trafficked, plants trafficked only by the swather, plants trafficked only by the tractor, and plants trafficked by both the swather and the tractor. Quality was determined by measuring relative feed value, acid detergent fiber, neutral detergent fiber, and crude protein using near infrared reflectance spectroscopy. Alfalfa trafficked by the tractor had increased quality throughout the 4 years of production.

Key words: *Medicago sativa*, alfalfa quality, harvest traffic, crude protein, relative feed value

Introduction

Tractor traffic from harvest equipment used in alfalfa production can have significant impacts on soil and plant qualities. Alfalfa harvesting requires the use of various types of machinery at different times during each production cycle. It is estimated that 60%–70% of the field may be subjected to this traffic (Grimes et al. 1978; Rechel et al. 1987), e.g., swather, rake, bailer, and bail wagon. As a result of this traffic, there can be significant changes in soil and plant parameters. For example, in a study conducted in California from 1982 to 1988, two soil parameters, soil bulk density and water infiltration rates, were measured in two alfalfa experiments where traffic was the variable being studied. When comparing non-trafficked to trafficked areas, soil bulk density of trafficked areas increased by 17% at 0.05 m, 12% increase at 0.15 m, and 7% at 0.25 m depths with little change occurring down to 0.65 m (Meek et al. 1988). In the third year, soil hydraulic conductivity was higher at the surface in the non-trafficked treatment and the infiltration rates were also higher when no traffic was applied to the field (Meek et al. 1989).

Several studies were published from these same experiments demonstrating how stress from traffic affected plant functions e.g., yield and seasonal fine root distribution (Rechel et al. 1990, 1991). Rechel and Novotny (1996) presented data on changes in relative growth rates, unit leaf rates, and leaf area ratios in alfalfa as a result of stress from traffic. In addition, data were presented on leaf/stem (L/S) ratios from four different harvest cycles, two in 1984 and two in 1985, which showed significantly higher values in trafficked alfalfa than non-trafficked alfalfa. Because L/S is known to be correlated to increased quality (Hall 1993; Julier et al. 2000), Rechel and Novotny (1996) suggested harvest traffic may also improve alfalfa quality.

The ubiquitous characteristic of harvest traffic required for alfalfa production from the swather, rake, bailer, and bail wagon, warrants measuring the effects of this traffic on alfalfa quality. Alfalfa quality can be quantified by determining several plant characteristics with the most common being acid detergent fiber (ADF), neutral detergent fiber (NDF) (lower values for these indicate higher quality), and crude protein (CP) (higher values indicate higher quality). The above three plant quality parameters are commonly used to evaluate the response of alfalfa to different environmental and managerial practices. Relative feed value (RFV), which is calculated from a function of ADF and NDF, is used to guide producers in assessing monetary value.

In this study, we examine how harvest traffic effects RFV, ADF, NDF, and CP. Our objectives were to document (*i*) possible significant differences in quality between trafficked and

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non-trafficked alfalfa, and (*ii*) when, within a 4-year production cycle, significant differences in quality occur.

Materials and methods

The study was conducted at the Colorado State University Western Colorado Research Center at Fruita, CO. The soil is a Youngston clay loam (fine loam, mixed (calcareous), mesic, typic, torrifluvents). The elevation is 1371 m, with an average rainfall of 0.21 m per year. Alfalfa variety WL 323, a dormant variety FD 4 (fall dormancy scale: 1–11; 1, least fall growth), was sown in August 1996 at 20.2 kg ha^{-1} and harvested four times per year from 1997 to 2000, at 10% bloom. The alfalfa was surge irrigated (Hoffman and Martin 1993) for a total of 24 h once before the first harvest, twice between each of the following harvests, and then once after the final harvest for each year. The soil was allowed to dry prior to each harvest.

The treatment design and yield were published by Rechel et al. (2012). The experiment was conducted in an alfalfa field having a north–south orientation of rows and furrows. There was a minimum alfalfa border of 3.6 m surrounding the entire experimental area. Each experimental unit was 6.1 m long and 3.65 m wide, the width of the cutting bar of the John Deere 2280 swather, which weighed 2970 kg with 0.43 m wide power wheels. The experimental units were specifically designed to contain four 0.60 m wide beds with five 0.12 m wide furrows, plus an additional 0.20 m of alfalfa to the outside of each power wheel to accommodate the width of the swather bar. At each harvest, the right-hand set of wheels of the John Deere 2280 swather always traveled on the center of the westernmost bed of each experimental unit and moved in a north to south direction. After swathing all alfalfa was removed manually from the experimental area with a pitchfork within 5 days. There was no other equipment used, such as bailer, rake, or bail wagon.

Seven days after swathing, a John Deere 2955 tractor weighing 4004 kg with 0.38 m wide rear tires was driven over each experimental unit in the same north to south direction to simulate four different levels of harvest traffic. This implementation of harvest traffic by the tractor created plants having four different traffic treatments: lanes of plants subjected to only swather traffic (S), no traffic (NT), swather and tractor traffic (STR), and only tractor traffic (TR), which were analyzed for quality (Fig. 1).

The quality of alfalfa from each of these traffic treatments was determined from a randomly selected quadrat, 0.33 m^2 in area, from the lanes that received one of these four quality traffic treatments. These samples were hand-clipped to a height of approximately 0.03 m, were taken within 24 h before the experimental units were harvested by the swather, oven-dried (50 °C) for 24 h, and weighed. These plant samples were analyzed for RFV, ADF, NDF, and CP by the commercial Fas-Test Forage lab (Windsor, CO) using near-infrared reflection spectroscopy. The plant samples for quality analysis from the fourth harvest of the fourth year were lost leaving only the first three harvests for that year available for analysis.

The experiment was a completely randomized design with four treatments and four replications across 4 years. Multifactor linear models using R (www.r-project.org/) were used to quantify significant differences in quality. Linear models were used to estimate the effects of the swather traffic and tractor traffic on the quality parameters while accounting for the production year and seasonal harvest effects. Because there was no traffic applied before the first harvest in 1997, no significant differences among treatments were found at this time, as expected.

Results and discussion

Putnam and Orloff (2016) presented data on seasonal changes in alfalfa ADF and CP from data collected throughout 3 years using 10 different varieties. The results indicated that spring harvests produce higher quality than the following midsummer harvests, while fall had the highest quality of the production season. The data presented in Fig. 2 show a similar trend over 4 years for all four quality values examined, i.e., spring harvests had higher quality over the two midsummer harvests, and fall harvests had the highest quality for each year.

Swather traffic

Statistical analysis of the changes in quality from swather traffic was examined using a multifactor linear model. Traffic from the swather only caused a significant increase in ADF and CP in the fourth harvest of the first year and an increase in ADF in the fourth harvest of the third year. In this experiment where four quality parameters were examined throughout 15 harvests in 4 years, only three of the 60 total occurrences showed statistically significant increases in quality. This is consistent with a type I error of 0.05. This analysis suggests that swather traffic has minimal impact on quality.

The effect of swather traffic on yield has also been documented to be minimal. Rechel et al. (2012) observed this in their experiment, while Grimes et al. (1978) also documented that swather traffic had little impact on yield. Thus, the impact of swather traffic on alfalfa physiology may not be an important variable to consider when evaluating the consequences of traffic on alfalfa.

Tractor traffic

Statistical analysis of tractor traffic treatments, 7 days after swathing, using a multivariate linear model, for each harvest are presented in Table 1. This data address objectives (*i*) and (*ii*) as stated in the introduction. Significant differences between trafficked and non-trafficked were first observed in the fourth harvest of the first year. In the second year, 1998, plants from the first harvest had significantly higher RVF and ADF, while the second harvest had only an increase in ADF. The third and fourth harvests had significant increases in quality in all but one observation (NDF in the fourth harvest). In the third year, 1999, the first, third, and fourth harvests had significant improvement in all four quality parameters. The fourth year, 2000, the second harvest had significant increases in the four quality parameters, while the first and third harvests had none.

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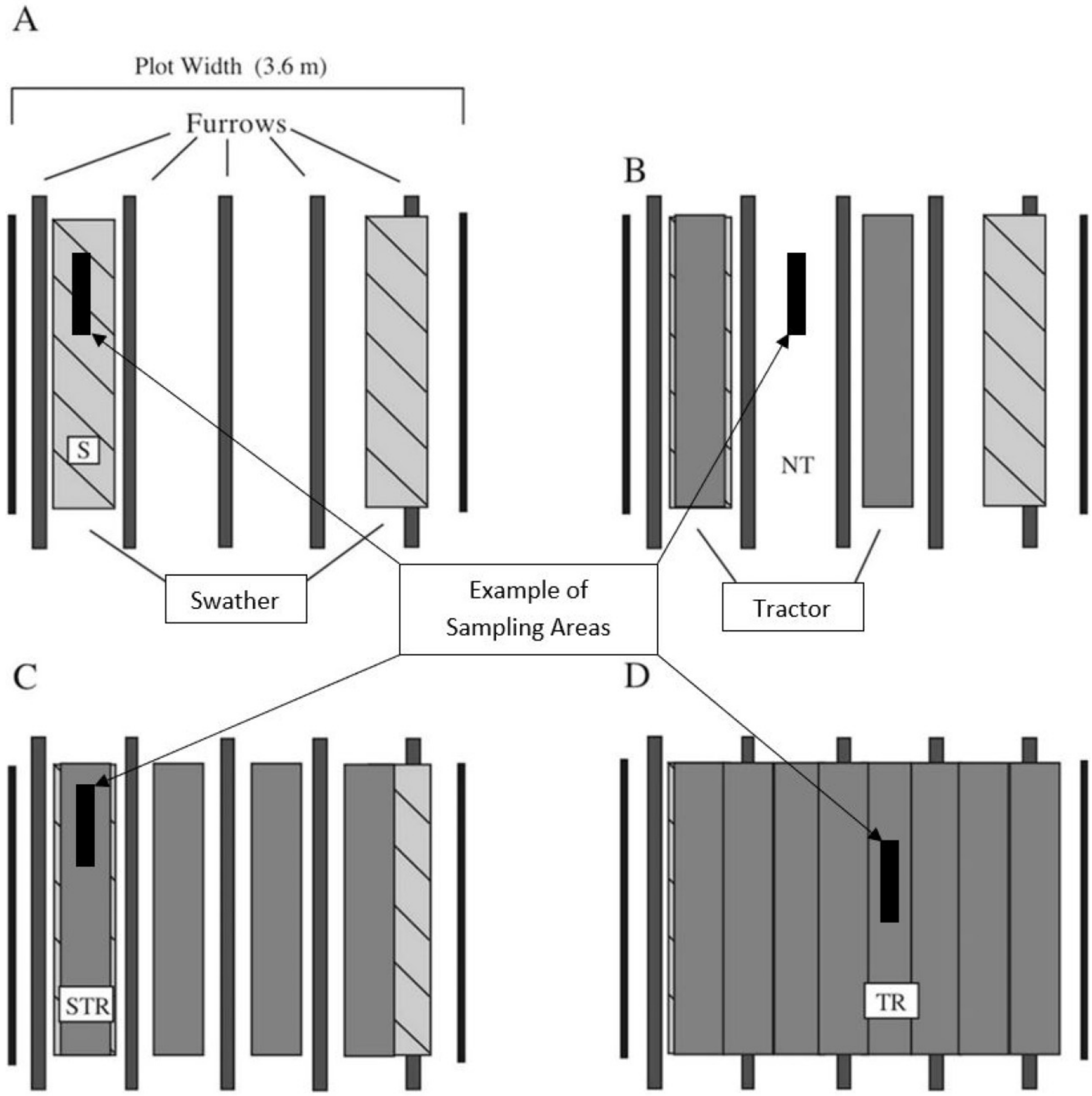
Fig. 1. Diagram showing the four levels of simulated harvest traffic on the alfalfa plots implemented 7 days after swathing by a John Deere 2955. Designated traffic treatments used to quantify quality: no traffic (NT), tractor traffic (TR), swather plus tractor traffic (STR), and swather traffic (S). Alfalfa samples were selected according to the four traffic patterns designed for a yield experiment (Rechel et al. 2012).



As the crop matured throughout the first 3 years of production, there was an increase in the number of harvests that showed significant improvement in quality due to traffic. In the fourth year, significant differences may have been expected in the third and fourth harvests based on the results observed in 1998 and 1999. However, plant health usually declines in this year, with an observed decline in yield caused by an increase in various pathogens, parasitic nematodes, and plant competition (Sheaffer et al. 1988). This physiological state, in fourth year plants, may confound the interaction between traffic and quality resulting in no quality differences in the first and third harvests.

The results from applying a multifactor linear model to the entire experiment are presented in Table 2. All four quality parameters for each year of the experiment show a significant increase in quality, which resulted in significant increases in the combined 4-year quality totals, addressing object (*i*). The analysis shows that tractor traffic has a significant effect on quality starting the first year of production, which addresses objective (*ii*) as to when differences were observed.

In this study, the effect of tractor traffic on quality was not always confined to the specific year of production that the traffic was applied. For example, tractor traffic applied in October 1998 resulted in a significant increase in all four quality parameters in the spring harvest of May 1999 (Table 1). The above observations suggest that the response of the alfalfa crown to traffic is not only at the time of tractor impact but may alter the plants' hormonal, anatomical, and physiological status through winter dormancy, resulting in significant increases in quality the following spring.

Seasonal changes in quality represent a profound physiological shift in the performance of alfalfa plants. As shown

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Fig. 2. Alfalfa quality as quantified by relative feed value, acid detergent fiber, neutral detergent fiber, and crude protein for each harvest through 4 years from plants subjected to a single pass of the John Deere 2280 swather and a single pass of a John Deere 2955 tractor implemented 7 days after swathing, traffic from both, and non-trafficked alfalfa.

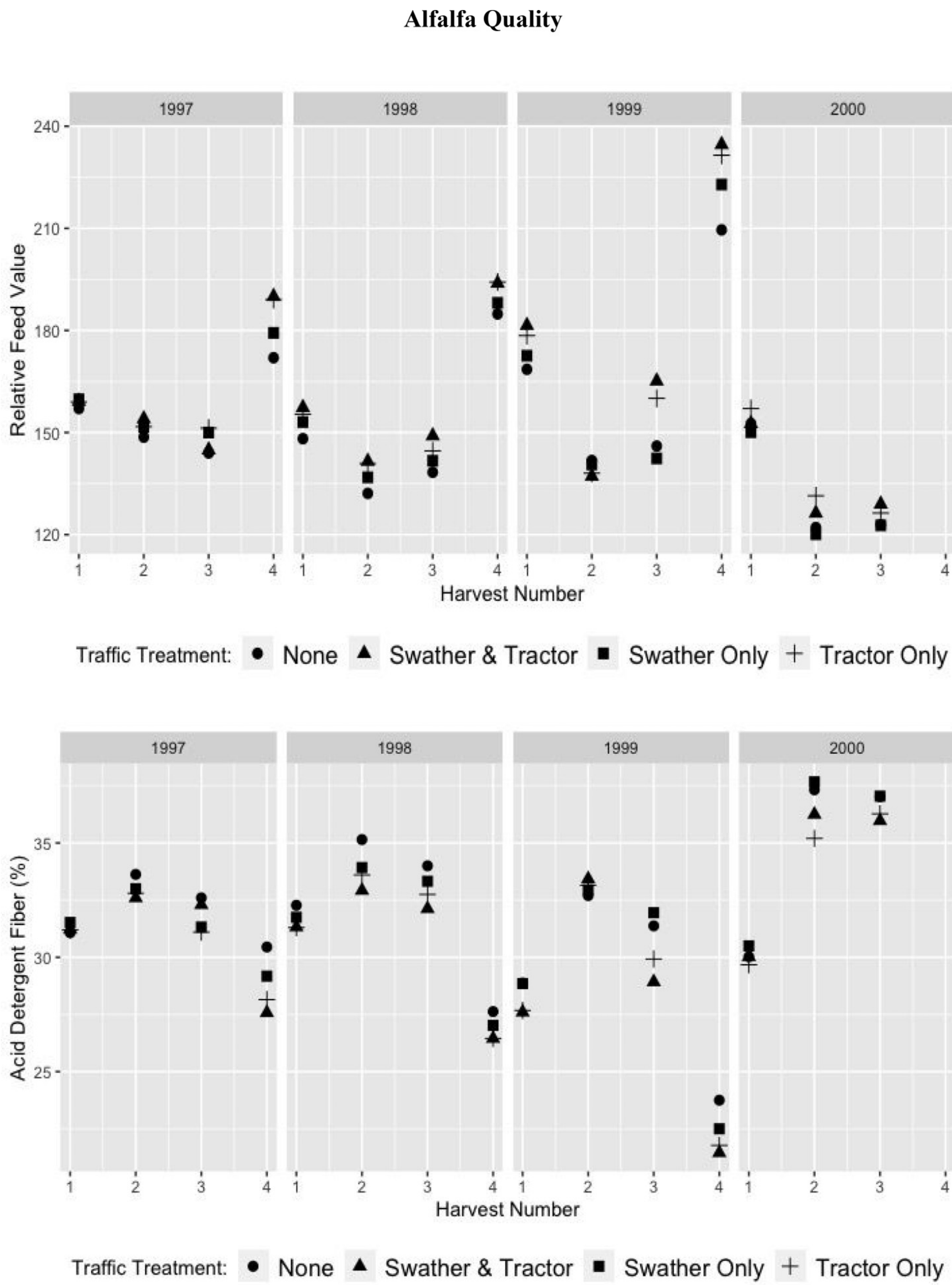

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Fig. 2. (*continued*).

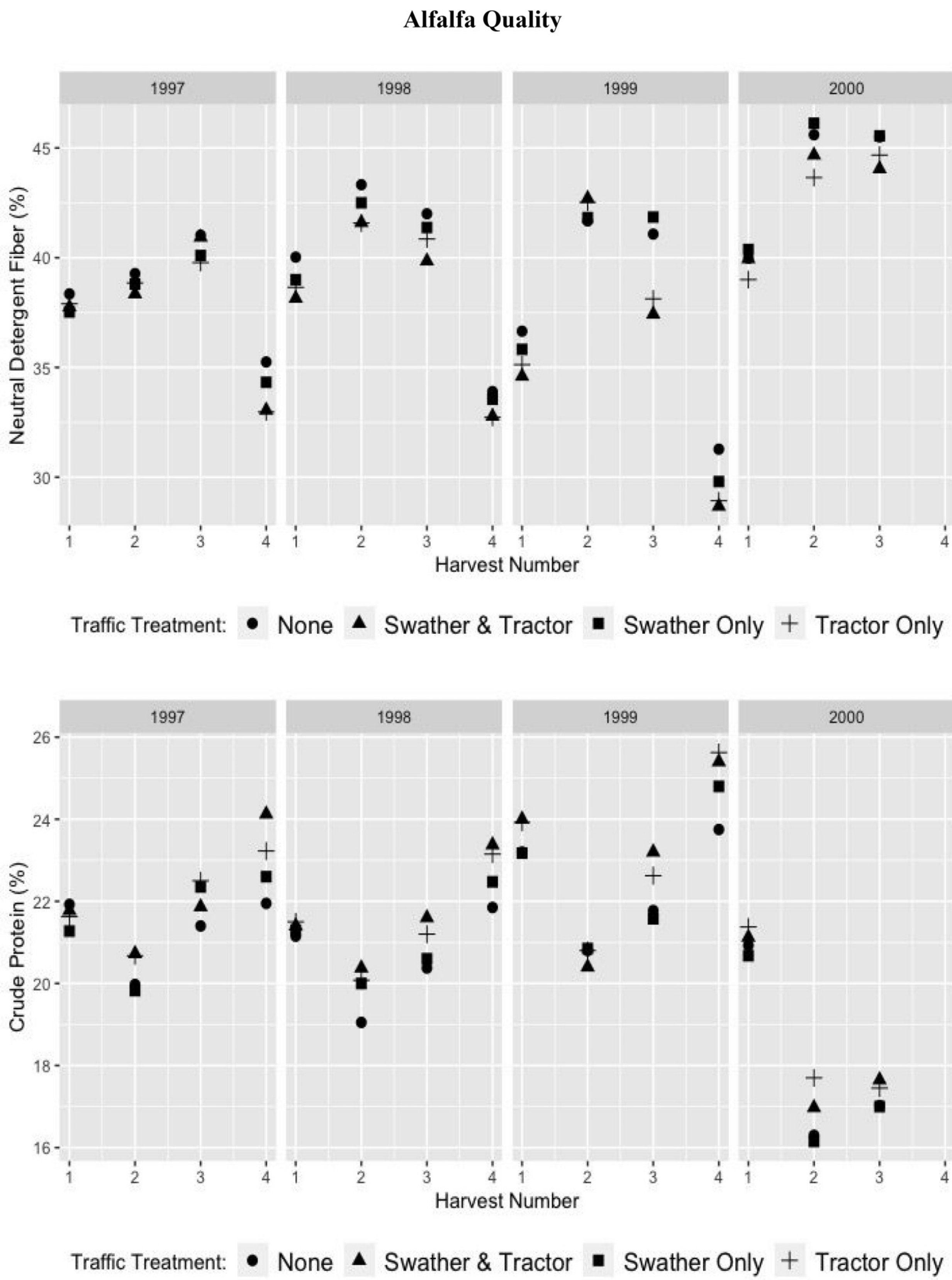

Table 1. Quality changes in alfalfa between trafficked and non-trafficked plants per harvest for relative feed value, acid detergent fiber, neutral detergent fiber, and crude protein caused by traffic from a John Deere 2955 tractor, implemented 7 days after swathing, as determined by a multifactor linear model.

Time	Quality parameters			
Year/harvest	Relative feed value (change)	Acid detergent fiber (% change)	Neutral detergent fiber (% change)	Crude protein (% change)
1997/1	0.66	−0.09	−0.11	0.10
1997/2	2.76	−0.61	−0.44	0.80
1997/3	1.58	−0.36	−0.29	0.37
1997/4	13.91***	−1.95***	−1.78***	1.40**
1998/1	5.74*	−0.70	−1.11*	0.23
1998/2	6.75	−1.28*	−1.33	0.70
1998/3	6.80*	−1.23*	−1.34*	0.91***
1998/4	7.58**	−0.88	−0.98**	1.10***
1999/1	9.40**	−1.23***	−1.38*	0.78**
1999/2	−3.59	0.46	0.86	−0.23
1999/3	18.39***	−2.24***	−3.69***	1.24***
1999/4	16.84**	−1.51***	−1.74**	1.24***
2000/1	3.48	−0.41	−0.70	0.45
2000/2	7.76*	−1.78**	−1.70*	1.11**
2000/3	4.84	−0.91	−1.16	0.54

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.

Table 2. Yearly combined quality changes between trafficked and non-trafficked alfalfa for relative feed value, acid detergent fiber, neutral detergent fiber, and crude protein caused by traffic from a 2955 John Deere tractor, implemented 7 days after swathing, as determined by a multifactor linear model.

Time	Quality parameters			
Year	Relative feed Value (change)	Acid detergent fiber (% change)	Neutral detergent fiber (% change)	Crude protein (% change)
1997	4.82**	−0.76**	−0.67*	0.67**
1998	6.72***	−1.02***	−1.19***	0.73***
1999	10.26***	−1.13***	−1.48***	0.76***
2000	5.36**	−1.03**	−1.19**	0.70***
4 years	6.85***	−0.97***	−1.13***	0.71***

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.

in Fig. 1, the second harvest in 1998 and 1999 shows a similar decrease in the four quality parameters as compared to spring/fall harvests and yet, in general, these two harvests show no significant response to traffic (Putnam and Orloff 2016). The lack of response in quality may be another manifestation of the seasonal changes in plant physiology.

The growth dynamics of alfalfa crowns as a result of damage from tractor traffic could explain the observed increase in quality. When traffic is applied, newly growing shoots are at least 7 days old. Some shoots are subjected to the cleats of the tractor that make them non-functional (Grimes et al. 1978). Within a few days of the traffic event, these crowns will again produce shoots as the growth cycle continues and the new, younger shoots will have higher quality (Nelson and Moser 1994). Thus, the alfalfa canopy will consist of younger shoots with higher quality and older shoots that were not damaged by traffic and have lower quality. A consequence will be higher quality from the trafficked treatments caused by this combination of young and old shoots. However, there were no significant differences observed in the first three harvests of 1997, the second harvests of 1998 and 1999, and the first and third harvests of 2000. Therefore, the above explanation, referring to the combination of young and old shoots, can only partially resolve the data presented here.

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Alfalfa responds to the stress from traffic with lower yields, lower leaf area index, and slower growth rates (Rechel et al. 1987, 1991). Water and salinity stress on alfalfa can also cause similar changes in quality. Vough and Martin (1971) observed that ADF was lower when grown under conditions of water stress and low temperatures. Helene et al. (1992) had similar observations, while Hall (1993) found water stressed alfalfa responded with an increase in leaf area and L/S. Research has shown one consequence of subjecting alfalfa to saline environments is an increase in RFV (Ferreira et al. 2015; Yanzhe et al. 2021). Reviews on this topic have been written by Buxton and Fales (1994) and Moore et al. (2020). The result of this study complements the general conclusion that stressing alfalfa plants results in higher quality.

Conclusions

One tractor–traffic event, 7 days after swathing, increased alfalfa quality. Typically, there are several traffic events during harvesting operations involving four different pieces of equipment, implemented at different stages of plant growth, with different weights and wheel configurations: swather, rake, bailer, and bale wagon. The evidence here justifies examining how these multiple passes from harvest equipment effect quality. Even though significant increases in quality were first observed from the fourth harvest of the first year, the greatest effect was in the following 3 years, suggesting long-term studies are required to ascertain the potential cumulative effect of tractor traffic applied during 4 years of production on quality.

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Data availability

Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

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Project administration: ER
Supervision: ER
Validation: DM
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