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QUALITY IN ALFALFA-GRASS MIXTURES

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By

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ABSTRACT

THE RELATIONSHIP BETWEEN PLANT MATURITY AND FORAGE QUALITY IN ALFALFA-GRASS MIXTURES

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Research was conducted to determine effects of including grass with alfalfa (*Medicago sativa* L.) on forage yield, quality, alfalfa chemical composition and stem characteristics, and to define an index for predicting forage quality of mixtures which could be used in determining quality-maturity relationships. Alfalfa was seeded alone and in mixture with bromegrass (*Bromus inermus* Leyss.) and timothy (*Phleum pratense* L.). Addition of grass to alfalfa reduced forage quality in spring, with little or no reduction of forage quality in summer regrowth. With few exceptions, dry matter yields, alfalfa chemical composition and stem characteristics were not altered by addition of grass. A relative maturity index (RMI) was developed to predict forage quality of mixtures. Using the RMI, it was determined that forage quality-maturity relationships of mixtures follow similar trends to those of pure alfalfa. A producers maturity index (PMI), requiring minimal time to calculate, was developed to predict forage quality of mixtures.

ACKNOWLEDGEMENTS

To all those who have helped....

PREFACE

Chapters one and two of this thesis are written in the style required for publication in the *Agronomy Journal*.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

COMPARING ALFALFA AND ALFALFA-GRASS MIXTURES FOR FORAGE QUALITY AND YIELD

ABSTRACT

There has been little research on the impact of growing grass in association with alfalfa (*Medicago sativa* L.) when benefits such as reduced pest damage were considered. Research was conducted to determine if including a small amount of perennial grass in mixture with alfalfa would have an effect on forage quality, yield, alfalfa chemical composition, or alfalfa stem characteristics. Alfalfa was seeded alone and in mixture with bromegrass (*Bromus inermus* Leyss.) and timothy (*Phleum pratense* L.) in the summer of 1990. Samples were taken on a regular basis and forage quality parameters of crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and relative feed value (RFV) were determined. Including grass in mixture with alfalfa resulted in lower forage quality in spring growth. There were few differences in forage quality parameters among treatments in summer growth. Few differences were observed among treatments in dry matter or crude protein yield. Alfalfa quality, maturity, and stem characteristics were not affected by growing in mixture with bromegrass or timothy. Although forage quality in spring growth was reduced, other benefits of alfalfa-grass mixtures such as increased pest control may outweigh the potential decrease in quality.

INTRODUCTION

Including a small amount of grass in mixture with alfalfa (*Medicago sativa* L.) has not been a commonly used procedure in recent years. Planting alfalfa in pure stands to produce high forage yield and quality has been the accepted practice. Seeding with a companion crop is a declining practice (Peters and Linscott, 1988) and less than 20 percent of new seedings include a mixture of alfalfa with other perennial species (Tesar and Marble, 1988). Use of alfalfa-grass mixtures has declined over the years due to higher alfalfa yield and quality goals, pesticide availability, crop value and use, and the greater difficulty in managing alfalfa-grass mixtures. Alfalfa-grass mixtures have potential advantages compared to pure stands of alfalfa including: 1) reduced insect damage, 2) increased yield, 3) extended stand life, 4) enhanced weed control, 5) increased ground cover and erosion control, and 6) more efficient use of nutrients.

Including grass in mixture with alfalfa may alter the behavior of the key pests in alfalfa, alfalfa weevil (*Hypera postica* Gyllenhall) and potato leafhopper (*Empoasca fabae* Harris), resulting in lower insect populations and reduced crop damage. Alfalfa weevil is primarily a pest of first cutting alfalfa in the North Central region (Day, 1981) while potato leafhopper occurs mostly in second and third cuttings (Landis, 1993). Infestations by these two pests have been associated with reduced crude protein concentration (CP) in alfalfa (Walstrom et al., 1970; Hower and Byers, 1977; Wilson et al., 1979; Cuperus et al., 1983). Leafhopper damage may result in severe CP loss as alfalfa reaches maturity (Shaw and Wilson, 1986). Coggins (1991) and Coggins and Landis (in prep) found that grass in mixture with alfalfa reduced pest populations and damage. However, the proportion of grass necessary to influence the insects may have a negative impact on forage yield or quality.

Mixtures of alfalfa and grass may provide similar or greater yields than alfalfa seeded alone (Ahlgren and Burcalow, 1950; Chamblee, 1958; Smith, 1960; Chamblee and Collins, 1988; Sheaffer et al., 1990). McCloud and Mott (1953) reported that yields from alfalfa-grass mixtures were from 5 to 66 percent greater than yields of pure alfalfa stands. Although yields of mixtures may be much greater than yields of pure alfalfa stands, the reported increases commonly have been in the range of 10 to 15 percent (Chamblee, 1972). However, some researchers have found no difference in yields among pure alfalfa and alfalfa-grass mixtures (Wilsie, 1974; Tesar and Marble, 1988; Mooso and Wedin, 1990). In a review of literature, Chamblee (1972) stated that many research reports expressed no yield advantage for mixtures.

Alfalfa-grass mixtures have the potential to increase stand life. As alfalfa stands age, plant density decreases (Meyer and Bolger, 1983). Triplett et al. (1977) found that alfalfa had a limited capacity to expand into areas vacated by other plants. In the alfalfa-grass mixtures, as alfalfa plant density decreases, grass plant density tends to increase, thus extending the life of the stand.

Alfalfa-grass mixtures may also provide enhanced weed control. It is well documented that weeds in alfalfa stands are detrimental to alfalfa yields (Wakefield and Skaland, 1965; Robinson et al., 1978; Wilson, 1981; Schmidt, 1991). However, total forage yield (alfalfa and weeds) may be unchanged as a result of weed presence (Kapusta, 1973). Although certain weeds, such as dandelion (*Taraxacum officinale* Weber) may have comparable quality to alfalfa (Sheaffer and Wyse, 1982), weed content in forages is usually negatively correlated with quality (Cords, 1973). Grasses in mixture with alfalfa may help prevent weed invasion (Chamblee, 1972; Drolsom and Smith, 1976; Sollenberger et al., 1984; Casler and Walgenbach, 1990). Subsequent benefits of reduced weed population may be seen in a reduced weed seed bank, increased palatability, and decreased drying time of forages (Kapusta and Streiker, 1975; Dutt et al., 1982; Doll, 1984).

Greater ground cover and increased control of soil erosion may also be benefits of including grass with alfalfa. Heath et al. (1985) found that timothy (*Phleum pratense* L.), which is a non-competitive grass, in mixture with alfalfa, will increase total ground cover without decreasing alfalfa yield or persistence. Including grass in mixture with alfalfa may reduce erosion since grasses have a fibrous root system in the upper soil horizon. Tesar and Jackobs (1972) stated that grass roots resist erosion better than do alfalfa roots and that grass should be included with alfalfa when erosion is likely to occur.

Alfalfa and grasses grown in mixtures may also be advantageous in other aspects. The mixtures have potential to make more efficient use of nutrients. Increased grass growth resulting from nitrogen (N) fixation by alfalfa is an example of efficient nutrient use. Root excretion of N and decomposition of dead nodules and roots could be the method of N transfer from alfalfa to grass (Tesar, 1974). Craig et al. (1981) found that grasses increased the specific nodule activity of alfalfa grown in mixture with grasses. This agrees with Ta and Faris (1987a,b) who determined that the N transfer increased up to 13 kg ha^{-1} and that N content of timothy increased up to 50 percent when timothy was grown with alfalfa compared to timothy grown alone. Increasing the number of harvests and a greater proportion of alfalfa in the mixture increased the N transfer activity between alfalfa and timothy up to 30 percent. The increase in available N stimulates grass growth and may add to the N content of the grass which is a direct indicator of CP. Parsons (1958) found that N applied as fertilizer increased the CP of bromegrass (*Bromus inermus* Leyss.), orchardgrass (*Dactylis glomerata* L.), and timothy while CP in alfalfa was unchanged.

Other advantages of alfalfa-grass mixtures may include decreased field drying time and reduced rain penetration of bales when stored outside (Miller, 1984; Heath et al., 1985). Grass inclusion also may help reduce frost heaving and winter injury of the legume (Smith, 1960).

There are also certain disadvantages to growing alfalfa and grasses in combination. Potential disadvantages include: 1) a reduction in forage quality, 2) an increase in management needs, and 3) competition between the grass and legume components.

Including grass in mixture with alfalfa may result in lower forage quality than that of pure alfalfa due to a faster rate of maturation of the grass component. Since grasses mature faster than alfalfa, earlier harvest may be required to maintain high quality. Optimal yield and quality in alfalfa may be attained by harvesting at bud to one-tenth bloom. However, by this time grass may already be in the flowering stage and quality will be reduced (Tesar and Jackobs, 1972). The extent to which forage quality is reduced may be determined by the proportion of grass in total forage yield. Sheaffer et al. (1990) found that in Minnesota, alfalfa-orchardgrass mixtures in 2- and 3-cut schedules had higher CP and in vitro dry matter digestibility (IVDMD) than alfalfa-bromegrass mixtures. However, in 4-cut schedules, the alfalfa-bromegrass combination was higher in CP and IVDMD. Neutral detergent fiber (NDF) was greater and thus quality was lower for alfalfa-bromegrass in all cutting schedules. In the 3-cut system, CP was highest and NDF was lowest for pure alfalfa. Reich and Casler (1985) also found that NDF and acid detergent fiber (ADF) were 10 to 15 g kg^{-1} higher in an alfalfa-bromegrass mixture when compared to pure alfalfa.

Alfalfa-grass mixtures may require a higher level of management than do pure-seeded alfalfa stands. Most often, mixtures are managed using methods developed for alfalfa monocultures (Smith et al., 1986). Yield, quality, and persistence are functions of the variety selected, seeding rate, physical and chemical soil features, environment, and harvest procedures. The harvest procedures, which are the most critical factors in management after the seeding has been established, include: 1) time of initial (1st) and subsequent harvests, and 2) cutting height and frequency. Harvesting before adequate carbohydrates have been stored is especially limiting for regrowth of alfalfa, bromegrass, and timothy. For bromegrass and timothy, early cutting during stem elongation precedes development of new tillers or basal buds (Kunelius et al., 1974; Heath et al., 1985) and regrowth must come from buds which are much lower or underground. Harvest of regrowth, based on an alfalfa schedule of approximately 35 days between consecutive cuttings, may (depending on the environment) occur before grass tillers are fully developed and will reduce aftermath yield and persistence of the grass component (Rhykerd et al., 1967; Chamblee, 1972).

Height of cutting has also been found to affect stand persistence. Increasing cutting height of bromegrass from 4 to 10 cm increased stand persistence (Marten and Hovin, 1980). Smith et al. (1973) determined that the annual number of cuttings and stubble height had a greater effect on mixtures of alfalfa with bromegrass or timothy than on mixtures of alfalfa with orchardgrass or reed canarygrass (*Phalaris arundinacea* L.). Mixtures with bromegrass or timothy were most severely affected in stands with 4 cm cutting height and 3 cuttings per year.

Another disadvantage of including grass with alfalfa may be competition for resources of nutrients, water, and light. Competition for limited resources may reduce yield, quality, and persistence of the mixtures. Therefore, it is important to consider the legume's or grasses' competitive ability and specific environmental or nutrient requirements when seeding grass with alfalfa.

The extent to which competition occurs between the components of the alfalfa-grass mixture for soil nutrients depends on the individual species. When vying for nutrients, grass components may be quite competitive and become the dominant species. This often occurs when N is added to a mixture containing orchardgrass (Hamilton et al., 1969; Sheaffer et al., 1990). Competition for potassium (K) is important since it may be a limiting factor in legume vigor and survival. Lack of K in the soil favors growth of grass due to its fibrous root system and profile (Jung and Baker, 1984). Grasses have a tendency to take up a greater share of the available K when grown in mixtures with legumes which may account for suppressive effects on legumes (Rhykerd et al., 1967; Chamblee, 1972). When phosphorus is limiting, alfalfa is favored due to the deeper root development.

Competition between alfalfa and grass for soil water may or may not be important. Since the rooting profile of alfalfa and grasses are different, use of soil water in the upper horizon should favor the grass. However, Chamblee (1958) found that in a mixed stand, under favorable conditions, alfalfa and orchardgrass used approximately the same amount of water from the upper horizon (30 cm). Soil water in the lower horizons was depleted to a greater degree by alfalfa. Limiting soil water in the upper horizon favors deep-rooted alfalfa.

Alfalfa and grass will also compete for light, which may be a critically limiting growth factor for either species. Alfalfa in mixtures with grass is more likely to be adversely affected by light competition than are the grasses which require less light for full growth. The light saturation point for orchardgrass is reached at approximately 40 percent of the maximum light intensity of alfalfa (Blackman and Black, 1959). Experiments by Jung and Baker (1984) showed orchardgrass to be shade-tolerant, exhibiting normal photosynthetic rates at only 30 percent of full sunlight.

Seeding a small amount of perennial grass in mixture with alfalfa may provide benefits to the producer without sacrificing quality or yield. Little research has been done to associate the impact of grass on forage quality and yield when other benefits, such as reduced pest damage, are considered.

Objectives of this research were to determine if including grass in mixture with alfalfa had a significant effect on: 1) forage quality, 2) forage yield, and 3) alfalfa quality, maturity, and stem characteristics.

MATERIALS and METHODS

Field experiments were established in the summer of 1990 at the Michigan State University Botany farm (MSU) in East Lansing, Michigan on a Capac loam soil (fine-loamy, mixed, mesic Aeric Ochraqualfs) and at the Kellogg Biological Station (KBS) in Hickory Corners, Michigan on an Oshtemo sandy loam soil (coarse-loamy, mixed, mesic Typic Hapludalf). No fertilizer was applied to either site prior to seeding because soil tests did not call for fertilizer additions.

The MSU location was prepared by applying bentazon [3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide] at 1.12 kg a.i. ha^{-1} with crop oil at 0.383 l ha^{-1} in June to control yellow nutsedge (*Cyperus esculentus* L.)(Table A1). Glyphosate [N-(phosphonomethyl) glycine] was applied at 1.68 kg a.i. ha^{-1} in early August prior to tillage to control quackgrass (*Elytrigia repens* Nevski). Seedbed preparation included moldboard plowing, disking twice, and field cultivating. Treatments were established with a drill using 18 cm rows in mid-August.

The KBS location was prepared by plowing and disking in late April of 1990 (Table A1). Lime was applied at 2240 kg ha^{-1} and incorporated by disking and field cultivating followed by cultipacking in mid-May. Treatments were established with a drill using 18 cm rows in early June.

Experimental treatments at both locations included:

1) alfalfa seeded alone (A),

2) alfalfa seeded with bromegrass (AB),

and 3) alfalfa seeded with timothy (AT).

All plots were seeded with 'Big Ten' alfalfa at 14.6 kg ha^{-1}. The grasses in mixture with alfalfa were seeded at the rate of 5.6 and 4.5 kg ha^{-1} for bromegrass and timothy, respectively. Plot size was 11.9 x 21.3 m at KBS and 9.9 x 13.7 m at MSU. Experimental design at both locations was a randomized complete block with four replications. To avoid a confounding effect from differential insect damage, insecticides were applied to portions of all plots as needed to control potato leafhopper (*Empoasca fabae* Harris).

On a weekly basis from early vegetative to one-tenth bloom stage of alfalfa, samples were collected from each plot (Table 1.1). At each sampling, a quadrat was randomly placed within the plot and all above-ground plant material collected. Quadrat size for the first harvest cycle (spring growth) was 0.5 m^2 and quadrat size for second and third harvest cycles (summer regrowth) was 0.914 m^2. Sample size was increased for regrowth so that sufficient plant material was collected for forage quality analyses. Samples were collected from different areas of each plot during the harvest cycles so that no area was sampled more than once per year. Plot

Table 1.1. Sampling dates of alfalfa-grass mixtures in 1991 and 1992 at Kellogg Biological Station (KBS) and Michigan State University (MSU).

Harvest cycle	1991		1992	
	KBS	MSU	KBS	MSU
One				
	8 May	7 May	5 May	7 May
	12 May	15 May	12 May	14 May
	20 May	21 May	19 May	21 May
	28 May	29 May	26 May	28 May
	5 June	4 June	2 June	4 June
Two				
	3 July	2 July	30 June	2 July
	12 July	9 July	7 July	9 July
	18 July	16 July	14 July	16 July
Three				
	12 August	14 August	11 August	13 August
	20 August	21 August	18 August	20 August
	26 August	28 August	25 August	27 August

samples were hand separated into three components: alfalfa, perennial grass, and weeds. Individual components were dried at 60°C for 72 hours and weighed. Alfalfa and grass samples were ground with a Wiley mill through a 2 mm screen and a subsample ground through a 2 mm screen in a UDY cyclone mill (Fort Collins, Colorado) for forage quality analyses.

All samples of alfalfa and grass were analyzed for CP, ADF, and NDF. Relative feed value (RFV) was calculated according to the following equation from Hesterman et al. (1991):

$$RFV = ((88.9-(0.779 \times \%ADF))x(120/\%NDF))/1.29.$$

Acid detergent fiber and NDF were determined by the methods of Van Soest and Goering (1970) and are expressed on a dry matter basis. Dry matter content was determined by drying subsamples at 100°C. Ash content was determined by burning the samples at 500°C for 6 hours. Crude protein concentration was determined by Hach modified Kjeldahl procedures (Watkins et al., 1987).

The entire plot areas were harvested on 8 June, 19 July, and 27 August at KBS and on 15 June, 24 July, and 3 September at MSU in 1991. In 1992, the harvest dates were 4 June, 21 July, and 1 September for KBS and 11 June, 20 July, and 1 September for MSU. Dates referred to as the recommended harvest dates are sampling date five in harvest cycle one and sampling dates three in harvest cycles two and three. These sampling dates are referred to as recommended harvest dates for each cycle because the dates of harvest coincide with recommended times for harvesting forage on a three-cut per year schedule (early-June, mid-July, and late-August).

Data were analyzed by Analysis of Variance (Statistix 3.5 Analytical Software. St. Paul, MN) and the means separated by Fishers Protected Least Significant Difference (Ott, 1988). Figures used to illustrate differences in forage quality among treatments in each harvest cycle were developed by regressing the forage quality parameters on Julian date. Regressions, using all replications, were analyzed to determine if the slopes were linear or quadratic. Figures with non-linear regressions include standard error bars. Figures with linear regressions include the regression equation and r^2 for each treatment. Linear regressions were compared using the method of Zar (1984). In cases where a valid comparison of slopes was possible, the results were included into the following section. In harvest cycles two and three of 1991, no data on forage quality are presented for sampling dates one and two. No quality analyses could be done due to insufficient sample volume.

RESULTS and DISCUSSION

Forage quality

Results of forage quality analyses are presented for both locations and the average of locations for 1991 and 1992 in Appendix tables A2 to A6. Adding bromegrass or timothy to alfalfa resulted in similar or lower CP and RFV than that of pure alfalfa in harvest cycle one of 1991 and 1992 (Tables A2 and A3). Acid detergent fiber was not consistently altered by including grass with alfalfa while NDF of mixtures was similar or greater than that of pure alfalfa (Tables A2 and A3). Although differences among treatments in forage quality were not consistent at all sampling dates in harvest cycle one, including grass with alfalfa tended to reduce CP, RFV, and increased NDF of the forage (Figures 1.1 to 1.3). Including grass with alfalfa had a minimal effect on ADF (Figure 1.4). This point is reinforced by a comparison of slopes which showed no significant differences among treatments.

In comparisons that were significant, average crude protein concentration of alfalfa-brome and alfalfa-timothy mixtures were 3.3 and 3.0 percentage points lower than that of pure alfalfa. Acid detergent fiber increased by an average of 1.7 percentage points when bromegrass was included with alfalfa. Neutral detergent fiber averaged 6.3 percentage points higher in the alfalfa-brome and 4.7 percentage points higher in the alfalfa-timothy compared to pure alfalfa. Relative feed value for the alfalfa-brome and alfalfa-timothy mixtures averaged 32 and 19 units lower, respectively, than that of pure alfalfa. Including grass with alfalfa decreased the CP up to 13 percent while RFV was decreased up to 17 percent. The addition of grass increased ADF up to 7 percent and NDF up to 16 percent. Generally, addition of bromegrass to alfalfa stands reduced forage quality to a greater extent than did the addition of timothy.

At the recommended harvest dates for harvest cycle one, including grass with alfalfa generally resulted in lower CP and RFV with higher NDF while ADF was unaffected (Tables A2 and A3). The differences among treatments seemed to be most pronounced for the quality parameters of CP and NDF. Sheaffer et al. (1990) showed similar results in comparison of alfalfa and alfalfa-grass mixtures. They found that averages for CP were similar or higher and averages for NDF similar or lower for alfalfa than alfalfa-bromegrass when comparing yearly results for a 3-cut

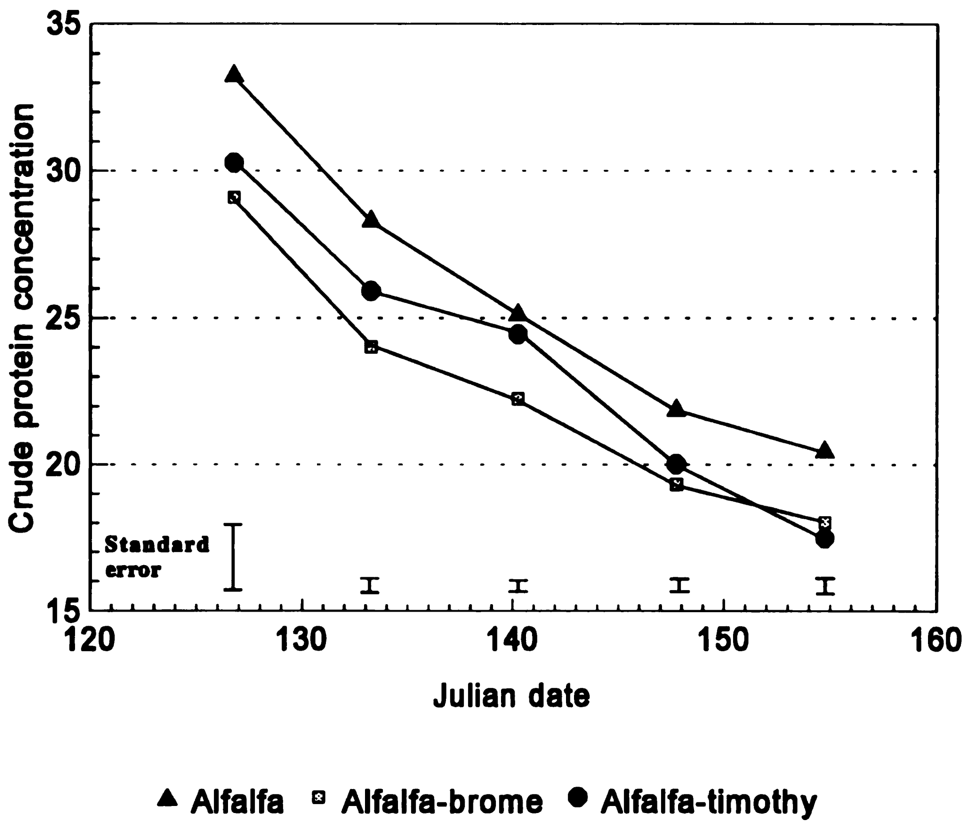

Figure 1.1. Average crude protein concentration in alfalfa and alfalfa-grass mixtures for 1991 and 1992 in harvest cycle one.

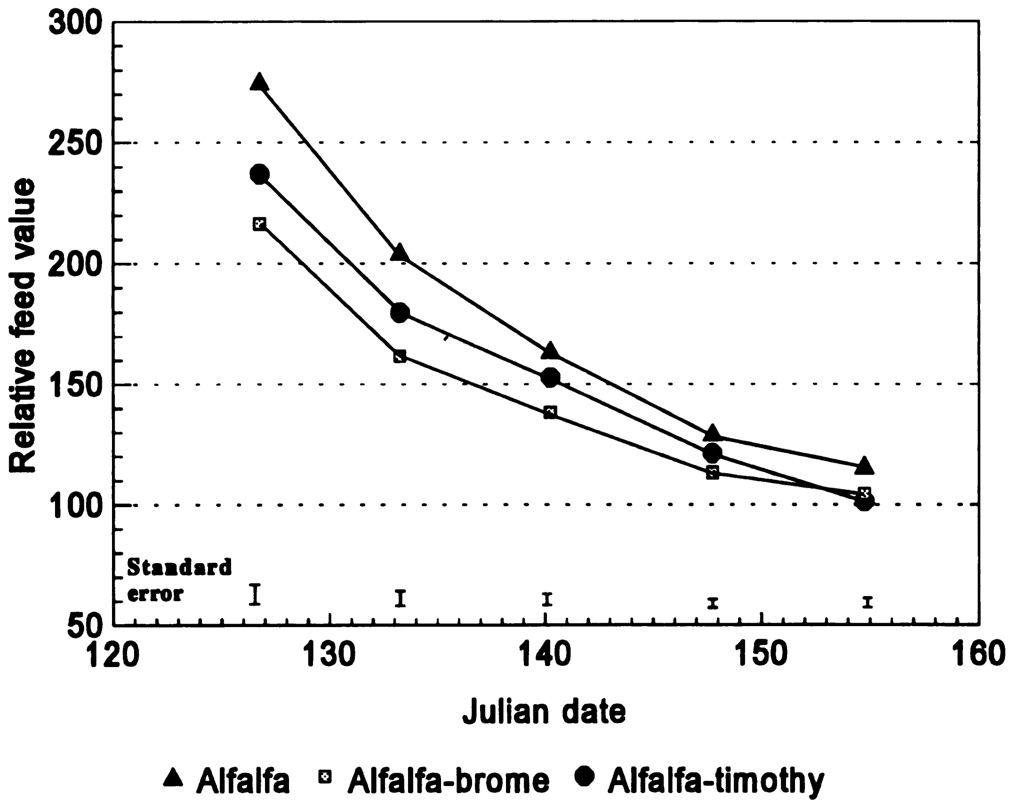

Figure 1.2. Average relative feed value in alfalfa and alfalfa-grass mixtures for 1991 and 1992 in harvest cycle one.

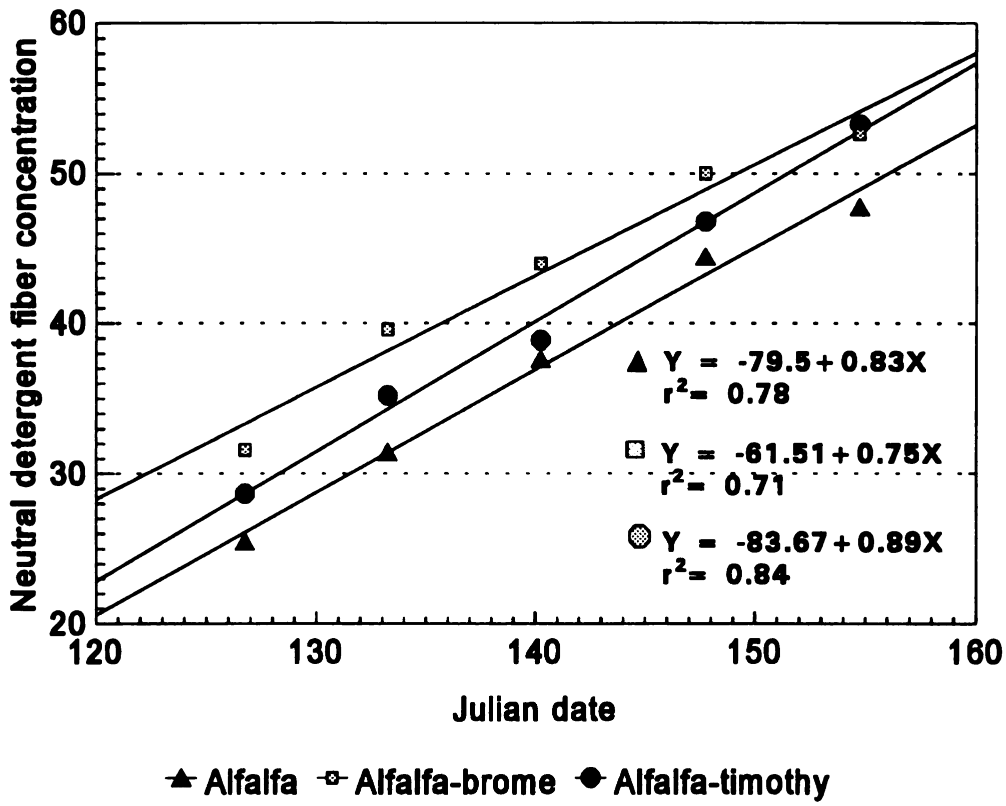

Figure 1.3. Average neutral detergent fiber concentration in alfalfa and alfalfa-grass mixtures for 1991 and 1992 in harvest cycle one.

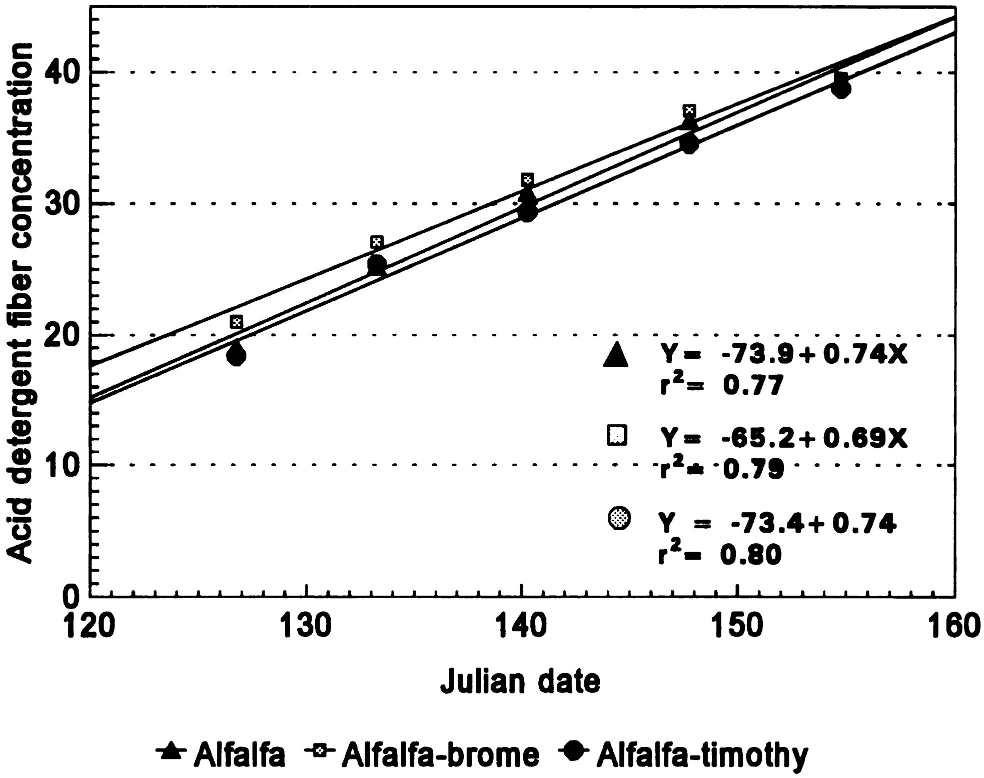

Figure 1.4. Average acid detergent fiber concentration in alfalfa and alfalfa-grass mixtures for 1991 and 1992 in harvest cycle one.

schedule in Minnesota. In harvest cycles two and three of 1991 and 1992, forage quality was not consistently reduced by including grass with alfalfa (Tables A4, A5,and A6). At the recommended harvest dates in both harvest cycles, there were no consistent differences among treatments. If harvested at the recommended harvest date or one week earlier in harvest cycle two of 1992, alfalfa-timothy had lower ADF than that of pure alfalfa (Figure A1). Alfalfa-bromegrass had lower NDF and RFV than that of pure alfalfa if harvested one week prior to the recommended harvest date in harvest cycle two or three of 1992 (Figures A2 to A5). In harvest cycle two of 1992, a comparison of slopes showed no significant differences among treatments for CP, ADF, or NDF. However, slopes representing RFV were significantly different among all treatments.

To more fully understand the differences in forage quality among treatments, especially in harvest cycle one, the alfalfa component of the mixtures was compared to alfalfa grown alone (Tables A9 to A20). With few exceptions, we found no significant differences in forage quality. Therefore, differences in the forage quality between alfalfa grown alone and alfalfa-grass mixtures can be attributed to the grass component. In situations where forage quality is lower in the mixture, it is due to lower forage quality of the grass. Forage quality of grasses has been shown to be lower than that of alfalfa at the same cutting date (Reich and Casler, 1985; Ta and Faris, 1987b; Sheaffer et al., 1990). It follows that the proportion of grass in a mixture will determine the extent of decrease in forage quality between pure alfalfa and an alfalfa-grass mixture. The first harvest (spring growth) produced the majority of seasonal grass growth (Table 1.2). This is expected since grasses produce

Table 1.2. Grass proportion in alfalfa-brome and alfalfa-timothy mixtures at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) at the recommended harvest dates in 1991 and 1992.

			Harvest		
Year	Location	Treatment	1	2	3
1991					
	KBS				
		Alfalfa-brome	.29	.19	.09
		Alfalfa-timothy	.32	.05	.01
	MSU				
		Alfalfa-brome	.17	.21	.06
		Alfalfa-timothy	.17	.17	.01
	AVG				
		Alfalfa-brome	.23	.17	.08
		Alfalfa-timothy	.24	.11	.01
1992					
	KBS				
		Alfalfa-brome	.25	.13	.12
		Alfalfa-timothy	.27	.09	.09
	MSU				
		Alfalfa-brome	.23	.04	.05
		Alfalfa-timothy	.41	.08	.05
	AVG				
		Alfalfa-brome	.24	.09	.08
		Alfalfa-timothy	.34	.09	.07

maximum growth in spring whereas alfalfa is more dominant in summer growth (Chamblee and Collins, 1988). In regrowth (harvests two and three), grass proportion was much less than in harvest one and therefore had much less effect on the forage quality (Table 1.2). Another reason for reduced impact of grass on forage quality is that the grass is usually in a vegetative stage during summer growth and thus similar in quality to early spring growth. Wright et al. (1967) stated that aftermath growth of bromegrass was primarily in the vegetative stage and had similar digestibility to first growth bromegrass in boot stage. Since the grass contributes more to total yield and is lower in quality when harvested in spring, forage quality will be reduced.

Simple linear regressions of forage quality on grass proportion, across all sampling dates and harvest cycles, resulted in coefficients of determination of 0.25, 0.02, 0.23, and 0.12 for CP, ADF, NDF, and RFV respectively ($p<0.05$; DF = 246). Although all regressions were significant, the percentage of variation that could be accounted for by grass proportion was low. In this experiment, grass proportion alone was not adequate to estimate effect of grass on forage quality. When harvesting at different times in multiple harvest cycles, both quality and proportion of grass must be considered when determining effects of grass on total forage quality.

Forage yield

Dry matter yields were similar among treatments at every recommended harvest date in both years with the exception of harvest three in 1992 in which alfalfa-timothy was greater than alfalfa (Figures 1.5 and 1.6). Numerical dry matter

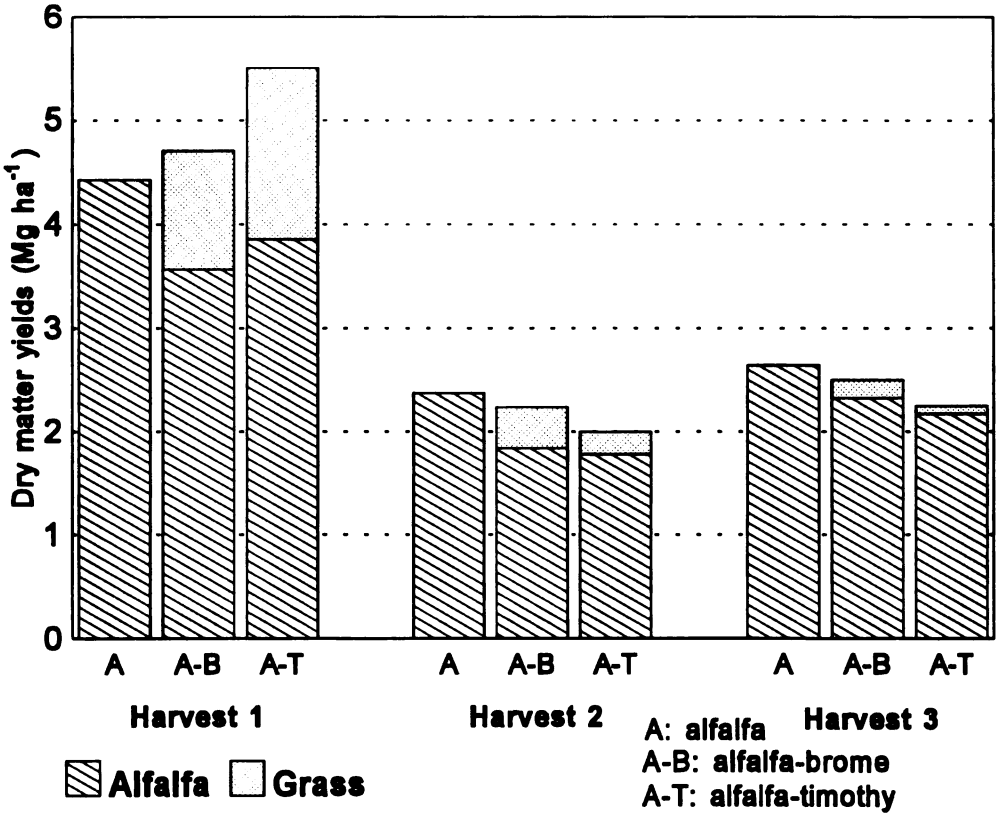

Figure 1.5. Dry matter yields of alfalfa and alfalfa-grass mixtures at the recommended harvest dates in 1991 (average of locations).

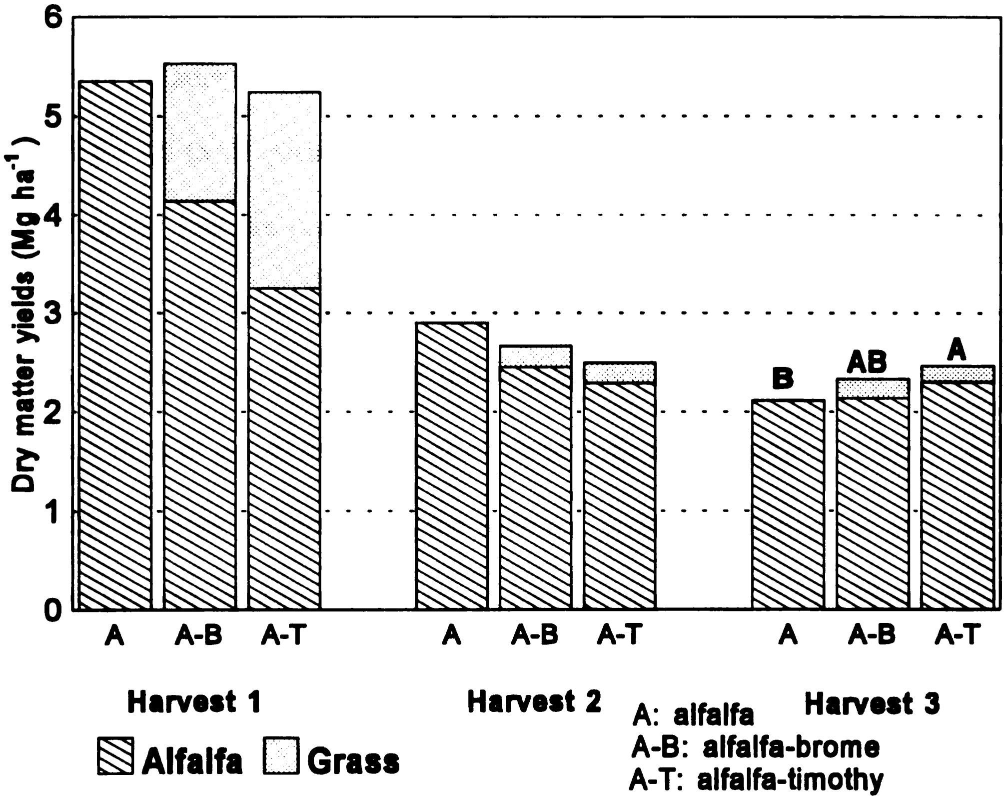

Figure 1.6. Dry matter yields of alfalfa and alfalfa-grass mixtures at the recommended harvest dates in 1992 (average of locations). (Different letters on bars indicate significant difference among forage yields at $p<=0.05$)

yields are presented in Appendix Table A7. These results are similar to those of Tesar (1974), who found that dry matter yield of alfalfa and alfalfa-grass mixtures [average for mixtures of alfalfa with bromegrass, orchardgrass, tall fescue (*Festuca arundinacea* Schreb.), or reed canarygrass] were 9139 and 9340 kg ha^{-1} respectively. Dry matter yields from harvest one accounted for approximately one-half of the total seasonal yields in both years (49.4, 51.5, and 55.2 percent for A, AB, and AT respectively). Vaughn et al. (1950) stated that alfalfa yields in first harvest accounted for 40 to 45 percent of the seasonal yield. While 40 to 45 percent was somewhat lower that the results presented, inclusion of grass which provides most of the seasonal growth in spring, increased the percentage.

At the recommended harvest dates, grass proportion was much greater in harvest one than in either harvest two or three with the exception of MSU in 1991 (Table 1.2). A large percentage of the seasonal yields of bromegrass and timothy (71 and 84 percent, respectively) were in harvest one (Table 1.3). These results agree with Kunelius (1974) who found that for bromegrass and timothy, up to 79 percent of seasonal yields occurred at the first harvest. Paulsen and Smith (1968) found that up to 85 percent of seasonal bromegrass production occurred in first harvest when grown in mixtures with alfalfa. The average contribution to total seasonal yields by bromegrass and timothy were 17.4 and 19.2 percent. Casler et al. (1987) stated that, based on visual evaluations, bromegrass accounted for 20 percent of the total dry matter yield of an alfalfa-bromegrass mixture. Generally, in harvest one, timothy accounted for a larger percentage of total yield than did bromegrass, while in regrowth, bromegrass accounted for a greater percentage of total yield.

Table 1.3. Dry matter yields of bromegrass and timothy at recommended harvest dates when averaged over location and year.

	Grass	
Harvest	Bromegrass	Timothy
	---------------- kg ha^{-1} ----------------	
One	1219	1646
Two	314	220
Three	196	94
Total	1729	1960

Crude protein yields

There were no statistical differences in CP yields among treatments at any recommended harvest date in either location or year with the exception of harvest three of 1992 where alfalfa-timothy was greater than alfalfa alone (Figures 1.7 and 1.8). Numerical yields are presented in Appendix Table A8. First harvest yields accounted for approximately 45 percent of seasonal CP yields. In harvests two and three, CP yields were approximately two-thirds that of harvest one. It is not surprising that yields are higher for harvest one than regrowth. Although CP of the forages averaged up to 6 percentage points greater in regrowth, the greater CP concentration was more than offset by the lower dry matter yields.

Alfalfa quality, maturity, stem characteristics

Characteristics of alfalfa grown in mixtures and alone were compared at all sampling dates within each harvest cycle (Appendix tables A9 to A20). The characteristics compared were CP, ADF, NDF, mean stage weight (MSW), mean stage count (MSC), alfalfa stem length (ASL), and alfalfa stem weight (ASW). Few significant differences were detected among treatments. Most differences occurred in harvest cycle two or three for the characteristic of ASW. The results of these comparisons show that the alfalfa plant was not greatly affected by growing in mixture with bromegrass or timothy. However, bromegrass and timothy are not among the most competitive grasses grown in mixture with alfalfa. Jones et al. (1988) found that alfalfa was taller and more mature when grown in mixture with reed canarygrass. Experiments with a more competitive grass may show more

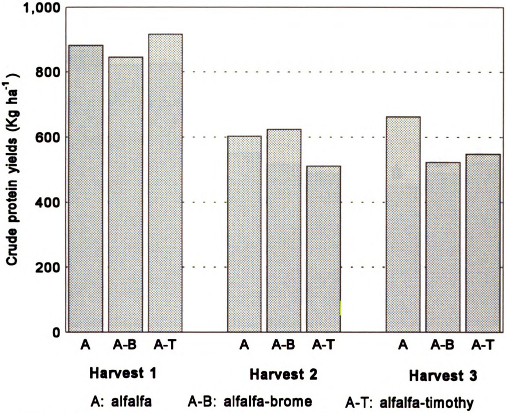

Figure 1.7. Crude protein yields of alfalfa and alfalfa-grass mixtures at the recommended harvest dates in 1991 (average of locations).

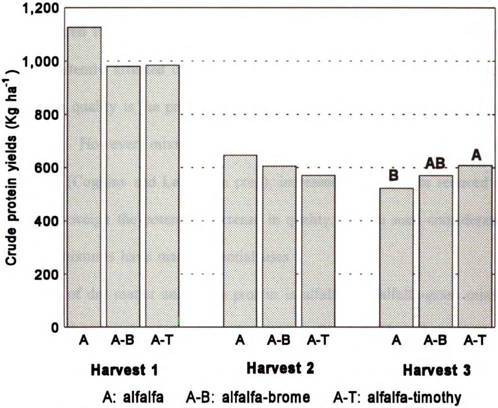

Figure 1.8. Crude protein yields of alfalfa and alfalfa-grass mixtures at the recommended harvest dates in 1992 (average of locations). (Different letters on bars indicate significant difference among forage yields at p<=0.05).

pronounced differences. These comparisons do not address whether the alfalfa is being affected in other ways such as altered plant density, stand life, or root characteristics.

CONCLUSIONS

Including grass in mixture with alfalfa resulted in moderately reduced forage quality compared to pure alfalfa in spring growth but quality of summer regrowth was not consistently affected by including grass in mixture with alfalfa. If achieving highest forage quality is the primary goal, then pure stands of alfalfa would be recommended. However, mixtures may provide other benefits such as increased insect control (Coggins and Landis, in prep), increased stand life, or reduced erosion which may outweigh the potential decrease in quality. Given such considerations, alfalfa-grass mixtures have many potential uses.

Yields of dry matter and crude protein in alfalfa and alfalfa-grass mixtures were similar when harvested three times annually. Total yields and seasonal distribution are consistent with many other research findings.

Alfalfa quality, maturity, and stem characteristics were not affected by growing in mixtures with grass. Further research needs to be done to determine what effects these grasses have on alfalfa stand life, plant density, and root characteristics.

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CHAPTER TWO

PREDICTING FORAGE QUALITY OF ALFALFA AND ALFALFA-GRASS MIXTURES

ABSTRACT

Growing grass in mixture with alfalfa (*Medicago sativa* L.) requires management practices that may be different than those used for pure stands of alfalfa. Determining time for harvest of optimum quality and the relationship between forage quality and plant maturity in alfalfa-grass mixtures is not well researched. This research was conducted to develop a maturity index for alfalfa-grass mixtures that could be used to predict forage quality and, using that index, to examine the relationship between forage quality and plant maturity. Alfalfa was seeded alone and in mixture with bromegrass (*Bromus inermus* Leyss.) and timothy (*Phleum pratense* L.) in the summer of 1990. Samples were taken on a regular basis throughout three harvest cycles in 1991 and 1992 and samples were analyzed for forage quality [crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and relative feed value (RFV)]. Forage quality measurements were regressed on plant maturity indicators to determine which indicators would best estimate forage quality. Simple regressions using alfalfa stem length (ASL) and growing degree days (GDD) predicted forage quality of mixtures and pure alfalfa in spring growth. Multiple regressions using days from initiation of regrowth (DAYS) and alfalfa stem weight (ASW) predicted forage quality of alfalfa in summer regrowth while equations with ASW and grass stem weight (GSW) predicted forage quality of mixtures in regrowth. A relative maturity index (RMI) was developed

that predicted all four forage quality parameters of alfalfa-grass mixtures. The relationship between forage quality and plant maturity in mixtures is similar to that of pure alfalfa. Fiber content increases, while crude protein concentration and relative feed value decreases, with increasing maturity. The RMI developed in this research can be used to predict forage quality of mixtures. In contrast to other predictors of forage quality, RMI provided good estimates of all measured quality parameters in all growth cycles evaluated. A producers maturity index (PMI) was also developed which can be used to predict all four forage quality parameters. The maturity indicator used in PMI equations was alfalfa stem length (ASL). The PMI provided prediction equations that were comparable in accuracy to the RMI. The PMI may not provide the level of precision in defining maturity that is necessary for research purposes. However, the minimal time required to collect measurements makes it well suited to on-farm use.

INTRODUCTION

Including grass in mixture with alfalfa (*Medicago sativa* L.) has the potential to provide many benefits such as reduced insect damage, increased yields, and extended stand life. However, growing mixtures presents management challenges that may be different than those of pure alfalfa stands. Determining the optimum time for harvest of maximum quality forage and how the plant maturity of the mixtures relates to forage quality are not well researched. To date, no forage quality prediction method has been developed to accommodate grass-legume mixtures. This would be a valuable management tool because it would allow an optimum point to be specified for harvest of maximum quality.

Alfalfa and grass indexes have been separately developed that provide accurate identification of plant maturity or growth stages. These indexes have been used as the basis for predicting forage quality, primarily in alfalfa, and for evaluating forage quality and plant maturity relationships. However, an index that takes into account the maturity of both the alfalfa and grass, when grown in mixture, has not been developed.

Optimum harvest time for alfalfa in pure stands has been thoroughly researched and may be determined by using a system such as Kalu and Fick's (1981) mean stage by weight (MSW). Presently, the method employed by producers for staging alfalfa uses general morphological stages (vegetative, bud, flower, and seed development) as predictors of optimum harvest time. However, these morphological stages lack the quantitative precision needed for research purposes (Kalu and Fick, 1981). Grass phenology may be determined by using modified scales from other species or a method developed for perennial grasses such as the "Nebraska system for staging perennial grasses" (Moore et al., 1990). Limited information exists on using staging methods to predict quality of grasses.

Generally, forage quality and plant maturity are inversely related. Liu (1977) found a negative relationship between alfalfa maturity and quality as indicated by crude protein concentration (CP) and in vitro true digestibility (IVTD). As acid detergent fiber (ADF) in alfalfa increases with maturity, quality decreases, although at full bloom a point is reached at which no further decrease in quality is noted (Fick and Onstad, 1988). For grasses, CP also decreases with age (Heath et al., 1985). In vitro dry matter digestibility (IVDMD) was found to decrease with maturity at a rate of 5 g kg^{-1} day^{-1} for bromegrass (*Bromus inermus* Leyss), orchardgrass (*Dactylis glomerata* L.), and timothy (*Phleum pratense* L.) (Pritchard et al., 1963).

Alfalfa growth can be divided into discreet stages according to defined methods (Kalu and Fick, 1981; Sanderson and Wedin, 1989) and these stages can then be used to predict forage quality. The different methods developed to quantify growth stage of alfalfa include: 1) MSW, 2) mean stage by count (MSC), 3) growing degree days (GDD), 4) calendar days (DAYS), and 5) phenological scales.

Mean stage by weight is a maturity index that takes into account environmental and physiological history of the crop and allows the user to specify the morphological stage of development in alfalfa (Kalu and Fick, 1983). Mean stage by weight is defined as the average stage of individual stems present, weighted for dry weight of herbage in each stage. The specific 10 stages are: 0) early vegetative: stem length ≤15 cm, 1) mid-vegetative: stem length 16-30 cm, 2) late vegetative: stem length >31 cm, 3) early bud: 1 to 2 nodes with visible buds, 4) late bud: ≥3 nodes with visible buds, 5) early flower: 1 node with 1 open flower, 6) late flower: ≥2 nodes with open flowers, 7) early seed pod: 1 to 3 nodes with green seed pods, 8) late seed pod: ≥4 nodes with green seed pods, and 9) ripe seed pod: nodes with mostly brown mature seed pods (Kalu and Fick, 1981). To determine MSW, a minimum of 40 stems must be individually viewed and placed into one of the stages according to stem length and phenological characteristics. The individual stage samples are dried and weighed. Numbers are entered into the formula: $MSW = \Sigma (S \times D)/W$, where S is stage number (0 to 9), D is dry weight of stems in stage S, and W is total dry weight for stems in all stages.

Mean stage by weight is a good predictor of alfalfa quality because it takes into account the environment, plant morphology, and plant physiology (Jung and Baker, 1984; Miller, 1984), all of which affect quality. Fick and Janson (1990) agreed that MSW is a robust method for predicting forage quality [CP, IVTD, neutral detergent fiber (NDF), ADF, and acid detergent lignin (ADL)] and stated that it may be applied across a large range of environments. Mean stage by weight has been shown to be highly correlated with CP, NDF, IVDMD, and ADF ($r^2 = 0.88$, 0.95, 0.97, and 0.90 respectively) in alfalfa herbage (Kalu and Fick, 1983; Sanderson and Wedin, 1989).

Mean stage by count is similar to MSW since it uses the same stage descriptions. However, MSC is the average of individual stages present, weighted for number of stems present in each stage. Instead of recording individual and cumulative stage dry weights, the number of stems in each stage and total number of stems for all stages are recorded. The numbers are entered into the formula: MSC = Σ (S x N)/ C, where S is stage number (0 to 9), N is number of stems in stage S, and C is total number of stems in all stages.

Hintz and Albrecht (1990) found MSC and MSW provided the lowest root mean square error (RMSE) values among plant maturity descriptors evaluated to predict alfalfa chemical composition (CP, NDF, ADF, and ADL). Predicting plant development using MSC closely parallels prediction based on MSW, where MSC increases 0.45 to 0.83 stages week^{-1} and MSW increases 0.60 to 0.97 stages week^{-1} (Kalu and Fick, 1983). Although MSC is quicker to use and provides good estimates of phenological stage, MSW is more robust (Mueller and Fick, 1989). This is because in older, lodged canopies where regrowth has started, MSC gives equal value to individual stems whereas MSW is affected proportionally by stem weights. Use of MSC in canopies from 6-10 weeks old may be of no value since one cannot distinguish between stages due to the effect of new growth on calculations (Kalu and Fick, 1981). Therefore, MSW is a better indicator because it shows faster apparent stage development, which should make it easier to determine the specific stage.

Growing degree days may also be used to quantify phenological development. This method uses local weather data and a base temperature for the specific crop to predict phenological stage (Fick and Onstad, 1988). For alfalfa, a base temperature of 5°C is used. The formula is: ((H + L)/ 2) - B, where H is daily high temperature, L is daily low temperature, and B is base or threshold temperature (Metcalfe and Elkins, 1980). Growing degree days are recorded only for positive numbers. If L is less than B, B is used in place of L to prevent GDD from becoming a negative number. The precise time at which GDD accumulation should be initiated is not agreed upon by all references. In spring growth, GDD may start from the last occurrence of air temperatures below 2°C (Onstad and Fick, 1983), when air temperature reaches and remains above 5°C (Kalu and Fick, 1983), or when "growth starts" (Fick and Onstad, 1988). Accumulation of GDD during regrowth may be charted from the start of growth or immediately after harvest of the previous crop.

Growing degree days may be highly correlated to phenological development of alfalfa. Onstad and Fick (1983) found that heat sums (or GDD) provided high coefficient of determination values (0.75 to 0.97) when used to predict leaf proportion, CP, and IVTD of alfalfa. Crude protein and IVDMD in alfalfa were found to be closely associated to GDD (Buxton and Marten, 1989). Alfalfa lignin content is also predicted more accurately by GDD than by MSW (Fick and Onstad, 1988). Although quality of spring growth is less sensitive to temperature variations, GDD should provide an advantage over DAYS, especially when making predictions over years and locations (Buxton and Marten, 1989). Using GDD may be more desirable than MSW or MSC since minimal labor is required to chart progress.

Calendar days are based solely on the chronological age of the crop in days. Precise time at which DAYS begins is also a matter of debate. Generally, DAYS begins with the initiation of new shoot (plant) growth. Reid et al. (1959) used April 30 as the starting date for first growth of forage while Buxten and Marten (1989) used May 1 for grasses. Starting date is likely a function of regional climate and latitude.

Staging by DAYS provides variable results. Onstad and Fick's (1983) results showed that DAYS could adequately predict alfalfa CP and IVTD. In 1988, Fick and Onstad found that alfalfa leaf in vitro true digestibility (LIVTD) was more closely related to DAYS than MSW or GDD. Cutting forages based only on DAYS may not account for variations in forage quality and maturity. Van Soest et al. (1978) agreed that alfalfa harvested using DAYS instead of stage of development may have variable quality at the same "DAY" value as a result of different maturation rates.

Staging plants by height or length is also possible. However, physical size of the plant is environment-dependent and may be highly variable. After testing 15 different morphological characters as predictors of alfalfa quality, Hintz and Albrecht (1990) showed that height of the tallest stem may be a good measure of alfalfa chemical composition.

Staging of perennial grasses may be accomplished by using the system described by Moore et al. (1990). The "Nebraska system for identifying growth stages of perennial grasses" has five primary growth stages. These primary stages are: 1) seedling, 2) vegetative, 3) transition, 4) reproductive, and 5) seed ripening. Stages 1, 4, and 5 have six substages to describe the ontogeny of primary shoots or tillers. Stages 2 and 3 are not limited in number of substages since plants may continue to develop leaves or nodes prior to reaching the reproductive stage.

Zadok's scale uses a decimal code to define growth stage of cereals. There are 10 primary stages including: 1) germination, 2) seedling growth, 3) tillering, 4) stem elongation, 5) booting, 6) inflorescence emergence, 7) anthesis, 8) milk development, 9) dough development, and 10) ripening. Within each primary stage, there are 10 substages which define events in cereal plant development. Because of the number of stages and highly specific definitions, the Zadok scale would be too cumbersome to use with large sample numbers or in the field.

The Feeke scale, commonly used on cereal grains, may be adapted to grasses. This scale divides growth into four basic stages which are: 1) tillering, 2) stem elongation, 3) heading, and 4) ripening (Copeland et al., 1989). The stages used by Feeke are defined with less difficulty than Zadok's scale.

Other methods of staging phenology numerically include that of Simon and Park (1983) or Hedlund and Hoglund (1983). These two methods parallel each other closely in their description of phenological stages. Each stage describes a specific phenological occurrence similar to Zadok's scale. However, due to the large number of stages (93 and 95, respectively), these methods are also extremely time consuming.

Limited information exists on using grass staging methods to predict forage quality or on the relationship between phenological stage and quality of grasses. In

1989, Buxton and Marten found herbage IVDMD and CP in spring growth of bromegrass, orchardgrass, and reed canarygrass (*Phalaris arundinacea* L.) was closely related (r^2 = 0.88 to 0.99) to DAYS, GDD, and morphological stage (Simon and Park's method). Ohlsson (1987) also used Simon and Parks method to stage timothy and found a linear relationship (r^2 = 0.78) to NDF concentration. Results of Sanderson and Wedin (1989) do not agree. They found NDF concentrations in stems and leaf blades of bromegrass and stems of timothy were not closely associated with Simon and Park's staging method.

Maturity indexes for alfalfa and grasses have been developed that provide accurate identification of growth stages. These indexes have been used to predict alfalfa quality and to a limited extent to predict grass quality. However, no means has been developed to predict the forage quality of alfalfa-grass mixtures.

Objectives of this research were to: 1) develop a maturity index for alfalfa-grass mixtures that included either bromegrass or timothy and 2) using that index, determine the relationship between forage quality and plant maturity in the mixtures.

MATERIALS and METHODS

Field and laboratory methods

Field plot management and sampling techniques were the same as in Chapter One. Plot samples were hand-separated into three components: alfalfa, perennial grass, and weeds. Both the alfalfa and grass were measured for stem length and stage of maturity. Stem length was determined on 6 randomly selected stems of alfalfa or grass by measuring from the base to the most distant leaf tip or terminal end. Stem lengths were adjusted for height of cutting so that the resulting values indicated length from the ground to tallest plant feature. Approximately 75 stems of alfalfa were randomly selected from the sample and maturity stage for each stem determined according to Kalu and Fick's (1983) method for MSW and MSC. The maturity of the grass was determined by using the method of Moore et al. (1990) for MSW and MSC. In most cases, all of the grass component was staged, unless the sample was unusually large. The number of grass stems staged often exceeded 100. All individual stages and remaining samples were dried at 60°C for 72 hours. Alfalfa and grass samples were ground with a Wiley mill through a 2 mm screen and a subsample ground through a 2 mm screen in a UDY cyclone mill (Fort Collins, Colorado) for forage quality analyses. Sample analyses and relative feed value (RFV) equations were the same as in Chapter One.

For all regression procedures, the maximum size of any data set was 256 samples. Regression equations for mixtures in regrowth were developed from 1992 data only since 1991 data was unavailable.

Simple, multiple, and stepwise regression

Prediction equations for the forage quality parameters, using all measured independent variables, were developed by using multiple regression (Statistix 3.5 Analytical Software. St. Paul, MN) to determine the best 1, 2, and 3 factor equations. Simple regression was used to determine equations for each forage quality parameter and predictor combination. Stepwise regression was used to de

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determine overall best prediction equations. The predictors used as independent variables were: alfalfa MSW (AMSW), grass MSW (GMSW), alfalfa MSC (AMSC), grass MSC (GMSC), alfalfa stem length (ASL), grass stem length (GSL), DAYS, GDD, alfalfa stem weight (ASW), and grass stem weight (GSW). Mean stage by weight, MSC, and stem length procedures have been discussed previously. The starting point for DAYS in harvest cycle one was 1 April while the starting point in harvest cycles two and three was at the initiation of regrowth. Accumulation of GDD was initiated when more than 5 consecutive days showed positive accumulations along with initial plant growth in the plots. Preliminary comparisons were made between GDD's with base temperatures of 40 and 50 degrees Fahrenheit. Subsequently, the equation [1] for GDD (in Fahrenheit) based on Metcalfe and Elkins (1980) was used:

GDD =[(Daily high temp - Daily low temp)/2]- 40 [1].

Stem weight of alfalfa and grass was determined by dividing the total dry weight of staged samples by total number of stems in the staged sample.

For regression equations, approximately one-half of the total data set was selected at random and used to develop prediction equations. Stepwise regressions were developed using forward selection. The best prediction equations for 1, 2, and 3 factor multiple regressions, simple regressions, and stepwise regressions were based on Adjusted r^2 and lowest RMSE. Adjusted values were used for comparisons since they do not increase with the addition of another independent variable (predictor) unless the new variable increases the predictive power of the equation.

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Index development

A random subset of approximately half of all replicate samples was selected for use in developing a relative maturity index (RMI) which could predict forage quality parameters in alfalfa-grass mixtures. In its development, we were interested in identifying an index with applicability over time, location, harvest cycles, and plant maturity that used maturity indicators from both alfalfa and grass. Model selection and development was initiated by selecting a group of independent variables which could be used to predict the forage quality parameters of CP, ADF, NDF, and RFV. Predictors used to develop prediction equations were: AMSW, GMSW, AMSC, GMSC, ASL, GSL, ASW, and GSW.

Within a computer spreadsheet, values for one predictor of alfalfa and one predictor of grass were combined to get a single number. The values (individually and when added) used in determining the number were also subjected to mathematical transformations (square roots and variable weighting). The variables used in equations were weighted by multiplying both the alfalfa and grass by a percentage, so that when added together the percentages equalled one-hundred. The weighting percentages were applied to the variables in a range from 10 to 90 percent with increments of 10 percent. Weighting variables of 80 percent for alfalfa and 20 percent for grass approximated the ratio of alfalfa to grass dry matter yields. The simple and transformed equations resulted in RMI values which were used as independent variables, while the forage quality parameters were used as dependent variables, in regression. Individual indicators of alfalfa or grass maturity were included into comparisons to determine if variation that could be accounted for was altered by pairing of alfalfa and grass maturity indicators. The equations that provided the highest r^2 and lowest RMSE values were selected. Implementation and use over a wide range of environments was used as a selection criteria in situations where equation models provided similar r^2 and RMSE. Transformations with square roots provided consistent increases in r^2. Weighting variables provided little difference or greatly reduced r^2.

Complicated models using up to six of the variables were also tested. Some increase in r^2 was achieved although the inordinate time required to determine measurements associated with these characteristics was used as a basis for disqualification. Stem weights and lengths were also eliminated on the basis of lower r^2.

The RMI model developed is given in equation [2]:

RMI = 2.67*[square root(AMSW) + square root(GMSW)] [2].

When the conversion factor of 2.67 is used, RMI values will range from 0 to 13.9 which would be the values obtained by simple addition of AMSW (stages from 0 to 9) and GMSW (stages from 0 to 4.9). Values of RMI from the data used in model development or validation ranged from 4.0 to 11.3.

The model that resulted from the above procedures was used to predict values for remaining replicate samples that were not used in model formation. These predicted values were correlated to measured values of the same samples for model validation. The correlation coefficients for CP, ADF, NDF, and RFV were 0.78, 0.92, 0.86, and 0.89, respectively [Degrees of freedom (DF)= 124]. The prediction equations for each forage quality parameter were then recalibrated by regressing the forage quality parameters on the RMI using the entire data set.

After the initial model was developed, it was apparent that it could not be easily used in the field. Therefore, a second method of predicting forage quality of the mixtures which could be quickly and easily used in the field was developed. This producers maturity index (PMI) was developed by using a random subset of one-half of all replicate samples. The same four forage quality parameters were used as dependent variables and regressed on the independent variables which included ASL, GSL, GDD, DAYS, Σ(ASL,GSL), and the square roots of each one. Selection of the independent variable used in the PMI was based primarily on the highest r^2 and lowest RMSE, although time required for making such measurements was also considered. The equations developed from the above procedures were used to predict values for remaining replicate samples that were not used in model formation. These predicted values were correlated to measured values of the same samples for validation. The correlation coefficients for CP, ADF, NDF, and RFV were 0.26, 0.40, 0.35, and 0.32, respectively (DF=121). These equations were recalibrated as describe previously.

Forage quality and plant maturity

The graphs used to illustrate the relationship between forage quality of the mixtures and plant maturity were developed by regressing forage quality parameters on plant maturity. The data points for forage quality and maturity indicate treatment values for both mixtures at each of the 11 yearly sampling dates (same as in Chapter One) when averaged over location and year. All regressions were significant in linear form ($p<0.01$, DF=10).

RESULTS and DISCUSSION

Simple regression

In most cases, predicting forage quality of alfalfa based on alfalfa characteristics accounted for a greater percent of variation than when predicting forage quality of the mixtures using grass characteristics (Tables B1 to B4). There was a greater ability to predict ADF and NDF than CP or RFV using forage quality predictors. Hintz and Albrecht (1990) also showed that, in simple and multiple factor regression equations, r^2 was often higher for ADF and NDF than for CP. The percentage variation in the forage quality parameters that could be accounted for by the maturity predictors was greater in harvest cycle one than in regrowth (Tables B1 to B4). Quality parameters of alfalfa in harvest cycle one were predicted more accurately than those of mixtures (Tables B1 and B3). In regrowth, with the exception of CP, the quality parameters of the mixtures were predicted with greater accuracy than those of pure alfalfa (Tables B2 and B4).

In alfalfa, the best predictors in harvest cycle one were ASL, AMSW, and AMSC. For regrowth the best predictors were ASW and DAYS. In the mixtures, the best predictors in harvest cycle one were ASL and GDD, while in regrowth AMSC and ASW were best. Alfalfa stem length provided consistently good prediction of forage quality characteristics ($r^2>0.64$) for alfalfa and mixtures in harvest cycle one. Hintz and Albrecht (1990) stated that simple regression equations ba

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based on height were better than those based on MSC or MSW of alfalfa.

Alfalfa mean stage by weight and AMSC were among the better predictors of ADF, NDF, and RFV in harvest cycle one for alfalfa and mixtures, and for mixtures in regrowth. Both predictors adequately accounted for variability in CP in harvest cycle one for alfalfa ($r^2>0.73$), but not for mixtures. Both were poor predictors ($r^2<0.51$) of forage CP in regrowth of alfalfa, mixtures, and of the other quality parameters in alfalfa regrowth. In all cases AMSC accounted for more of the variations in predicting forage quality than did AMSW.

For alfalfa in harvest cycle one, simple equations using ASL appeared to be the best choice for predicting all four forage quality characteristics. However, equations with AMSW or AMSC were nearly as good.

Multiple regression

The same forage quality parameters and maturity descriptors were used to develop equations with 1, 2, and 3 factors (Tables B5 and B6). Using three-factor instead of two-factor equations increased the percentage variation in forage quality that could be accounted for by the maturity descriptors by a maximum of 4 percent. The predictors most often added when going from two to three-factor equations were ones involving staging methods which would greatly increase the time required for obtaining measurements. In harvest cycle one, using more than one factor in equations minimally increased the percent variation that could be accounted for in alfalfa (< 1 percent) while the increase for mixtures was somewhat greater (< 7 percent). In regrowth, adding a second factor increased the percent variation accounted for by up to 15 percent for equations of alfalfa and up to 9 percent for equations of mixtures. Alfalfa regrowth benefitted the most from inclusion of another factor.

Approximately an equal number of maturity characteristics to describe alfalfa or grass were used in the 1, 2, and 3-factor equations. In harvest cycle one, predictors used in equations for alfalfa most often were ASL or AMSC, whereas in mixtures GDD and GSW occurred most often. In regrowth, common predictors in alfalfa equations were DAYS and ASW, while ASW and GSW were commonly occurring predictors in equations for mixtures. Growing degree days or DAYS occurred infrequently in prediction equations for alfalfa in harvest cycle one, although these predictors accounted for almost half of all predictors used in equations for alfalfa regrowth. The consistency in appearance of predictors in many equations, even though they may not have the highest r^2 or lowest RMSE, may lead to a model for predicting forage quality characteristics that uses fewer maturity predictors in the equation thereby making the model easier to use.

For alfalfa in regrowth, two-factor equations provided some benefits in terms of increased r^2 and lower RMSE over simple equations. Two-factor equations containing DAYS and ASW were good predictors of all quality parameters. An equation using DAYS and ASW was selected for ADF over an equation using ASL and ASW, even though the r^2 was lower and RMSE higher, so that the model could be used for all four quality parameters.

Stepwise regression

The predictors of forage quality parameters for alfalfa and grass were entered into stepwise regression to determine the best single equation for each forage quality parameter (Table B7). For alfalfa in all harvests periods, ASL and ASW were the most commonly occurring predictors of forage quality. In mixtures, GMSW, ASW, and GSW were the most common predictors. Equations for predicting forage quality of the mixtures included maturity predictors from both alfalfa and grass. Generally, when grass was present (mixtures), predictors that described grass were included in equations.

A comparison of stepwise equations to simple and multiple equations shows trends similar to those indicated in the comparison between multiple and simple regressions. For alfalfa in harvest cycle one and regrowth, equations selected by the stepwise procedure are identical to those of 2-factor multiple regression equations. For mixtures, in harvest cycle one or regrowth, stepwise equations were able to account for a somewhat greater percentage variation in forage quality than did simple regression equations. However, for mixtures there was little difference in r^2 values between stepwise equations and 2-factor multiple regression equations. Even when the percentage variation in forage quality that was accounted for did not increase much by stepwise regression, RMSE values were usually reduced. If the goal was to select best equations based only on RMSE values, then stepwise equations would be considered. For research purposes, where small differences in accuracy of prediction can be critical, stepwise equations may be the best choice.

The best prediction equations for alfalfa and the mixtures in harvest cycle one may use only one factor (Table 2.1). An additional factor will account for a greater percent variation of the predictors used in equations although the extra time required may not be a worthwhile trade-off. The best simple equations are given by the predictors ASL and GDD. Both predictors provide good estimates of all forage quality parameters although GDD has a slight advantage due to higher r^2 and lower RMSE. Neither ASL or GDD was the best predictor of CP but were included because of the reduced time required to collect measurements.

The choice for best predictors in regrowth of mixtures is not as clear. In simple equations, AMSC and ASW were the better predictors of all quality parameters except CP. Two-factor equations increased r^2 and decreased RMSE. The greatest benefit of using to two-factor equations may be that the same predictors can be used for all quality parameters. The best equations used the predictors of ASW and GSW.

Developing maturity indexes for alfalfa-grass mixtures

The RMI values calculated from the equation described in the materials and methods could be used to predict forage quality parameters (Table 2.2). Using RMI to predict CP accounted for less percentage variation than when predicting the other quality parameters. The model index that we developed can be considered a relative maturity index for alfalfa-grass mixtures. The indexes of Kalu and Fick (1983) or Moore et al. (1990) have specific definitions for each index value. Extensive test models and comparisons were made in attempts to determine specific ranges in

Table 2.1. Recommended equations for predicting forage quality parameters in alfalfa and alfalfa-grass mixtures.

Harvest cycle	Treatment	r^2	RMSE†	DF	MODEL
One	Alfalfa	.82	2.51	38	CP‡=36.3 - 0.22(ASL§)
		.90	2.87	38	ADF=13.7 + 0.35(ASL)
		.90	3.02	38	NDF=19.8 + 0.37(ASL)
		.84	28.96	38	RFV=306 - 2.71(ASL)
	Mixtures	.59	3.29	72	CP=32.4 - 0.01(GDD)
		.88	2.86	73	ADF=12 + 0.03(GDD)
		.84	3.91	73	NDF=21.5 + 0.03(GDD)
		.77	23.33	73	RFV=259 - 0.16(GDD)
Regrowth	Alfalfa	.74	1.81	45	CP=38.4 - 0.25(DAYS) - 1.82(ASW)
		.68	2.95	46	ADF=15.3 + 0.22(DAYS) + 3.53(ASW)
		.69	3.56	46	NDF=13.5 + 0.54(DAYS) + 2.12(ASW)
		.72	26.81	46	RFV=353 - 4.22(DAYS) - 18.34(ASW)
	Mixtures	.55	2.27	47	CP=33.4 - 2.47(ASW) - 14.69(GSW)
		.84	1.81	47	ADF=17.24 + 5.46(ASW) + 6(GSW)
		.83	2.06	47	NDF=23.4 + 4.92(ASW) + 21.91(GSW)
		.84	13.34	47	RFV=262 - 34.55(ASW) - 130.6(GSW)

† RMSE, root mean square error; DF, degrees of freedom
‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value
§ ASL, alfalfa stem length; DAYS, days from initiation of regrowth; GDD, growing degree days; GSW, grass stem weight; ASW, alfalfa stem weight
All regressions were significant ($p<0.01$)

Table 2.2. Prediction equations used to estimate forage quality parameters for the Relative Maturity Index (RMI) and Producers Maturity Index (PMI).

Forage quality	r^2	DF†	RMSE	Model
RMI				
Crude protein	.59	243	2.96	43.11 - 2.42(RMI‡)
Acid detergent fiber	.84	243	2.76	11.37 + 0.38(RMI) + 0.25(RMI^2)
Neutral detergent fiber	.77	243	4.01	32.69 - 3.36(RMI) + 0.54(RMI^2)
Relative feed value	.78	243	21.1	370 - 26.85(RMI)
PMI§ (centimeters)				
crude protein	.59	243	2.95	37.92 - 2.2(PMI¶)
acid detergent fiber	.87	243	2.49	5.41 + 3.96(PMI)
neutral detergent fiber	.79	243	3.92	21.79 + 1.17(PMI) + 0.27(PMI^2)
relative feed value	.82	243	19.04	380 - 46.47(PMI) + 1.69(PMI^2)
PMI (inches)				
crude protein	.59	243	2.95	37.92 - 3.51(PMI)
acid detergent fiber	.87	243	2.49	5.41 + 6.3(PMI)
neutral detergent fiber	.79	243	3.92	21.79 + 1.86(PMI) + 0.69(PMI^2)
relative feed value	.82	243	19.04	380 - 74.06(PMI) + 4.3(PMI^2)

† DF, degrees of freedom; RMSE, root mean square error
‡ RMI = 2.67*[square root (alfalfa mean stage weight) + square root (grass mean stage weight)]
§ PMI equations are given for centimeters and inches
¶ PMI = square root of alfalfa stem length

alfalfa and grass maturity at a given range of the index. This was done to determine if the RMI could have specific descriptions of plant stages for each index value such as those described by Kalu and Fick (1983) and Moore et al. (1990). No specific stages of growth for alfalfa or grass could be associated with any given RMI value (Appendix Figures B1 to B3).

There was no basis for developing a different model for alfalfa-brome and alfalfa-timothy or for harvest cycle one and regrowth. The current model predicted values in harvest cycle one and for alfalfa-timothy mixtures with greater accuracy (higher r^2) than for regrowth or alfalfa-brome. Models that included ASL with other maturity predictors somewhat increased r^2. If models for predictions were to be used for early growth of alfalfa-grass stands, including stem length could be beneficial.

Models with either MSW or MSC provided similar estimates of forage quality. While MSC is an easier method to use, its utility is limited in more mature stands because new growth originating from the crown buds is included in the sample. Within the data, MSC showed a trend towards a decreasing rate of maturity between sampling dates four and five. This is consistent with Kalu and Fick (1983) who found that MSC is not as good a predictor once alfalfa crown buds begin to elongate.

Although RMI provides goods estimates of forage quality, the time required to gather measurements reduces its utility for on-farm use. Predicting forage quality using easily obtainable measurements would be much more useful.

The PMI equations developed can be used to predict all four forage quality parameters (Table 2.2). The square root of ASL is the predictor that was selected for inclusion in the equations since it accounted for the greatest percent variation and had the lowest RMSE. This predictor was just marginally better than either combination of ASL and GSL or of ASL alone. The square root of ASL is by itself a better predictor and would require less time to calculate than would a predictor that also included GSL. The square root of ASL is better than ASL itself, accounting for more variation in prediction with a lower RMSE. The minimal increase in calculations required (square root function) should not be of concern since it is expected that a calculator would be necessary to tabulate the forage quality prediction equations.

Although the recalibrated equations for the PMI account for a greater percent variation with this set of data than does the RMI, it is not unreasonable to expect that given the great variability that exists in stem lengths due to environment, PMI in many cases may not be as good a prediction method as RMI. The validation statistics derived from this data bear out this point. For the PMI, correlations were considerably lower and P values higher than those of RMI. Validation of the recalibrated equations using an independent data set could be expected to show similar results.

The needs of the producer and the researcher in predicting forage quality may be different. Research needs dictate a method where precise measurements can be made throughout growth cycles. Specifically, researchers may need to identify discreet morphological and phenological characteristics. These characteristics, such as MSW stages, occur in a defined order according to life cycle regardless of environmental influence. However, simple indicators of maturity such as plant height may not follow such a defined system.

The advantages of using ASL to predict forage quality are realized primarily though a reduction in time required to collect measurements and that no specialized knowledge (determining MSW) is required. However, there are potential disadvantages that must be considered. Plant stem length is a more arbitrary means of estimating forage quality since it does not proceed from one defined stage to another as does MSW. While it is generally true that plant height increases with age, the rate of increase (or relative growth rate), and times for initiation and ceasing of growth may be influenced more so by environmental factors such as temperature, soil nutrients, and soil moisture than by life cycle. So depending on specific environment, plants at various locations could be much different in stem length while maturity is similar or alternatively plants could have similar stem length and varied maturity.

Stem length as a predictor may also be limited in regrowth or late in spring growth periods. Relative growth rate of alfalfa in regrowth may be much different than that of spring growth. Also, in late spring growth the relative growth rate diminishes and little further increase may be seen. However, plant physiological processes that alter fiber content and nutrient value continue. Essentially this limitation is similar to the one found with using MSC for predicting forage quality. Alfalfa stem length may have its limitations but in most cases producers are likely to cut at earlier maturities before the relative growth rate diminishes greatly.

The needs of the producer focus on determining the quality of the forage at any given time regardless of a scientifically defined maturity. While plant maturity will affect decisions of when to harvest relating to carbohydrate accumulation and subsequent stand duration or to yield, harvesting high quality forage is a primary goal of the producer. To determine the optimal time to harvest high quality forage, the producer needs a method that requires minimal time and financial investment. The FMI should meet such needs.

Determining the relationship between forage quality and plant maturity in alfalfa-grass mixtures

To determine the relationship between forage quality and plant maturity of mixtures, it was necessary to have a single means of quantifying maturity that accounted for the maturity of both alfalfa and grass. The equation described in materials and methods was used as the basis for quantifying maturity of mixtures. While the index provides no specific descriptions of the alfalfa or grass stages, a larger index number indicates a more mature forage. Harvest cycles were combined since they showed similar trends.

Crude protein concentration and RFV both decreased with increasing forage maturity for the alfalfa-brome (r^2 = 0.77 and 0.88) and alfalfa-timothy mixtures (r^2 = 0.92 and 0.92)(Figures 2.1 and 2.2). Acid detergent fiber and NDF showed the opposite trend by increasing with increasing maturity (Figures 2.3 and 2.4). Coefficients of determination for alfalfa-brome were 0.95 and 0.78 while those of alfalfa-timothy were 0.94 and 0.91 for ADF and NDF, respectively. The coefficients

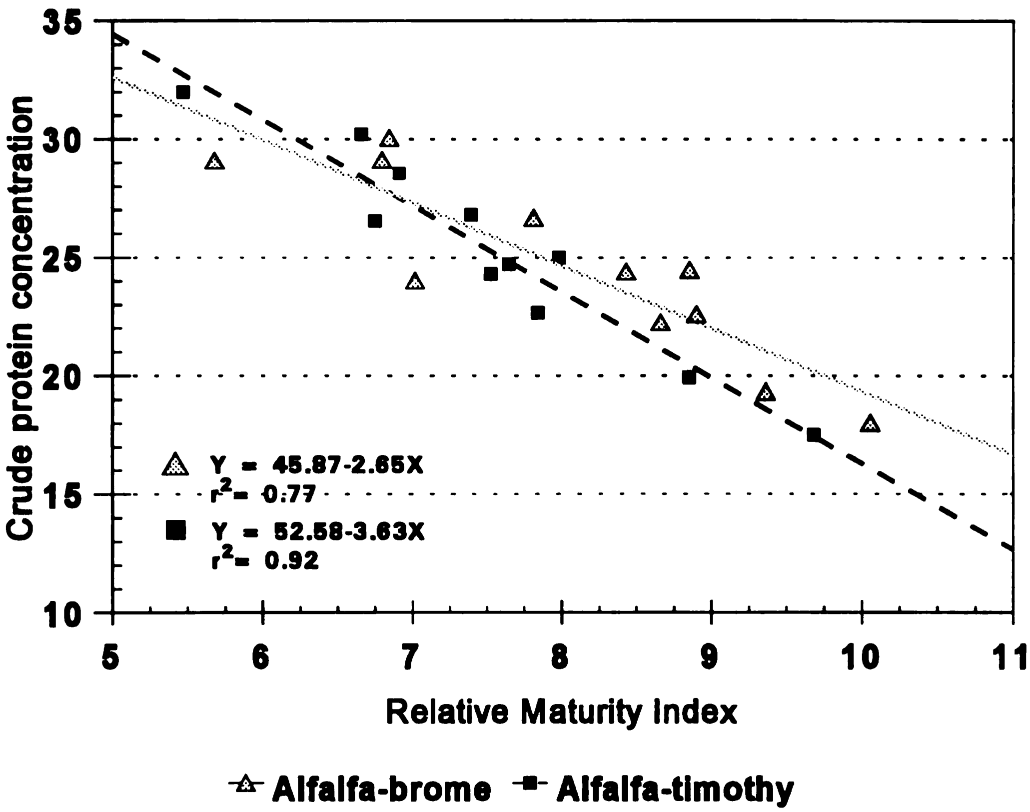

Figure 2.1. The relationship between crude protein concentration and forage maturity in alfalfa-grass mixtures.

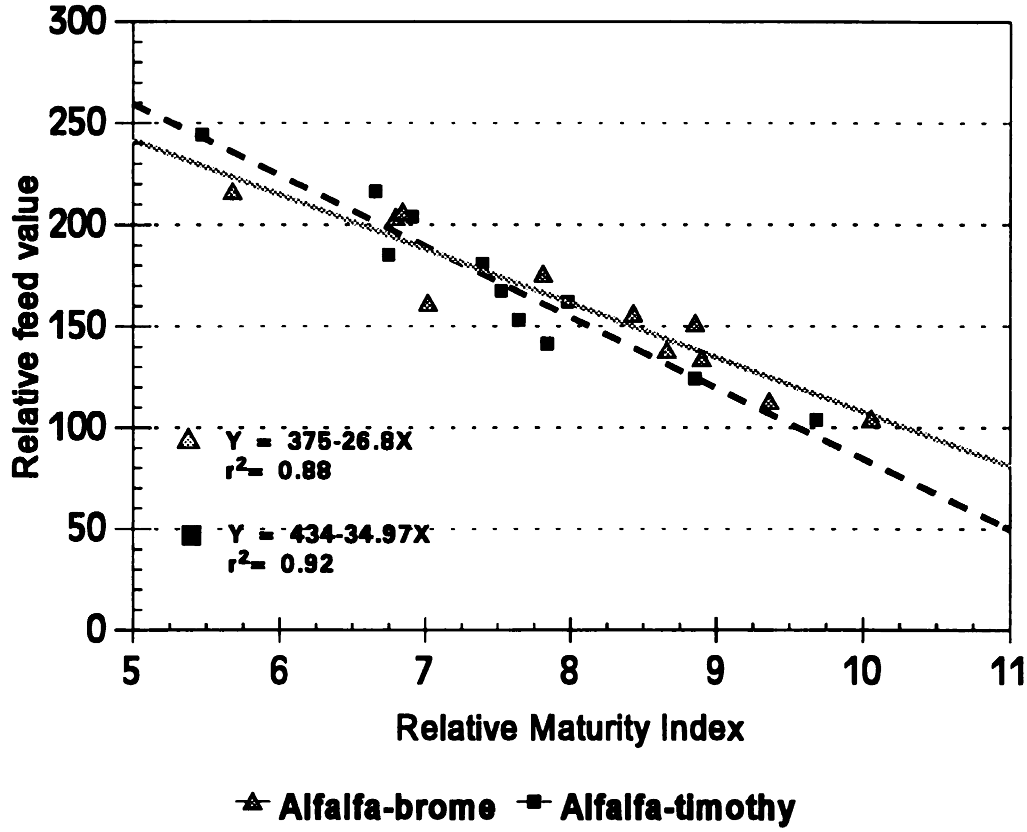

Figure 2.2. The relationship between relative feed value and forage maturity in alfalfa-grass mixtures.

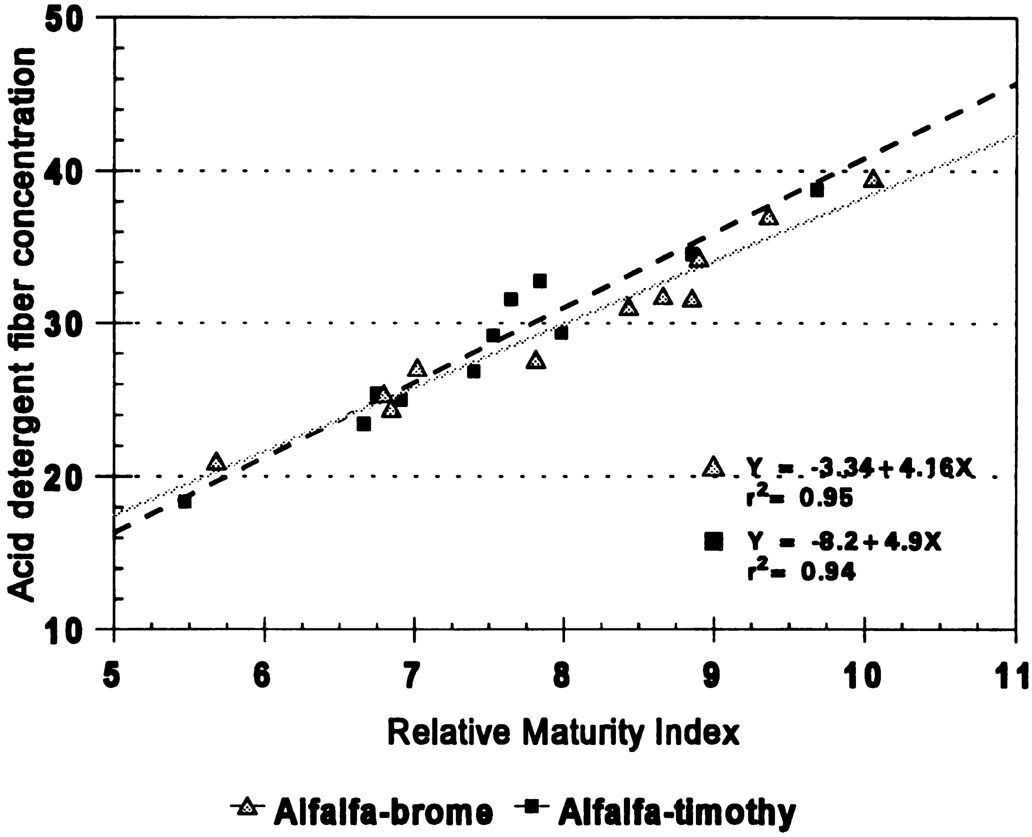

Figure 2.3. The relationship between acid detergent fiber and forage maturity in alfalfa-grass mixtures.

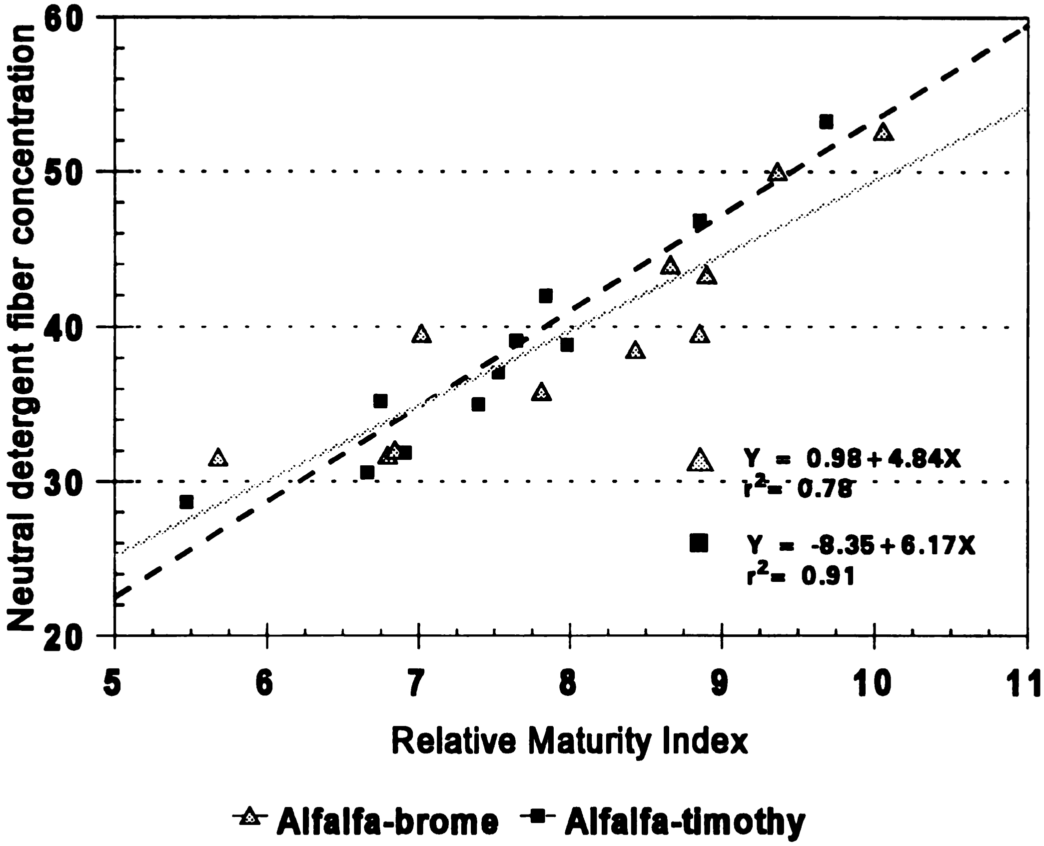

Figure 2.4. The relationship between neutral detergent fiber and forage maturity in alfalfa-grass mixtures.

of determination indicated, that with one exception, the percentage variation in forage quality that could be accounted for by maturity descriptors in the alfalfa-timothy was greater than that of alfalfa-brome. The trends seen in the quality-maturity relationship of the mixtures were similar to the trends seen in pure alfalfa, where fiber content increases and CP and RFV decrease with increasing maturity, as shown by many other research findings (Mellin et al. 1962; Van Soest, 1978; Kalu and Fick, 1983; Cleale and Bull, 1986; Buxton and Marten, 1989; Ohlsson, 1987).

For all forage quality characteristics, the relationship between forage quality and plant maturity was similar for alfalfa-brome and alfalfa-timothy. The alfalfa-timothy mixture has a greater change in forage quality with maturity than did the alfalfa-brome mixture (Table 2.3). This is primarily a result of the alfalfa-timothy mixture being higher in quality in the beginning of the harvest cycle and having a slower rate of maturation throughout the harvest cycle.

CONCLUSIONS

The equations developed in this experiment showed that ASL is a good predictor of forage quality in spring growth of established alfalfa and mixtures, although GDD may be a slightly better choice for mixtures. For regrowth, most one factor equations did not seem to adequately account for variability in forage quality. Two-factor equations improved accuracy somewhat and allowed for the same equation to be used for all quality parameters. For alfalfa in regrowth, two-factor equations with DAYS and ASW were selected while for mixtures equations with ASW and GSW were selected as the best equations based on r^2, RMSE, and

Table 2.3. Rate of change per unit increase of RMI in forage quality parameters of the alfalfa-grass mixtures.

Parameter	Alfalfa-brome	Alfalfa-timothy
Crude protein	-2.65	-3.63
Acid detergent fiber	4.15	4.90
Neutral detergent fiber	4.84	6.17
Relative feed value	-26.8	-35.0

applicability over a wide range of environments.

Stepwise regression equations often provided higher r^2 and lower RMSE than simple or multiple regression equations. However, the gains were marginal and the extra time required to obtain measurements may not be justified.

Two indexes were developed for alfalfa-grass mixtures to predict forage quality characteristics. The first one, a relative maturity index (RMI), takes into account the maturity of both species and should be useful throughout the growth cycle. This index may be useful primarily for scientific research. The second index, a producers maturity index (PMI), which uses ASL as a predictor may not provide the level of precision needed throughout growth cycles for research purposes. However, for field purposes ASL should be a good intermediate between accuracy and ease of use (Hintz and Albrecht, 1990).

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APPENDIX A

Table A.1. Dates of field operations for alfalfa-grass establishment in 1990 at Kellogg Biological Station (KBS) and Michigan State University (MSU).

	Location	
Operation	KBS	MSU
Bentazon and crop oil application	---	7 June,1990
Glyphosate application	---	3 August, 1990
Primary tillage	23 April, 1990	9 August, 1990
Lime application	9 May, 1990	-----
Seedbed preparation	19 May, 1990	9 August, 1990
Seeding date	5 June, 1990	10 August, 1990

Table A.2. Forage quality in harvest cycle one at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) for 1991.

Sampling date †	Treatment	CP‡ KBS	CP‡ MSU	CP‡ AVG	ADF KBS	ADF MSU	ADF AVG
1	Alfalfa	29.8a§	33.1	31.5a	20.7	21.4	21.1
	Alfalfa-brome	26.0b	29.0	27.5b	22.2	24.3	23.3
	Alfalfa-timothy	25.9b			21.3	26.4	23.5
	LSD¶	2.2	NS	3.3	NS	NS	NS
	CV#	8.7	13.4	12.6	5.7	15.5	12
2	Alfalfa	27.4a	25.4	26.4a	27.8	31.0	29.7
	Alfalfa-brome	22.0c	23.0	22.5b	28.2	31.3	29.7
	Alfalfa-timothy	24.0b	23.5	23.7b	28.4	30.0	28.9
	LSD	1.2	NS	1.8	NS	NS	NS
	CV	10.1	7.8	8.7	7.9	6.5	8.3
3	Alfalfa	25.7a	22.4a	24.1a	32.8	35.7	34.2
	Alfalfa-brome	21.4b	21.1b	21.3c	33.5	36.9	35.2
	Alfalfa-timothy	23.0b	23.4a	23.2b	32.8	35.2	35.0
	LSD	1.7	1.1	0.8	NS	NS	NS
	CV	10.8	5.9	8.6	3.8	6.3	6.7
4	Alfalfa	22.2a	20.4	21.3a	40.5	41.7	41.1
	Alfalfa-brome	19.0b	19.4	19.2b	40.2	41.6	40.9
	Alfalfa-timothy	21.0ab	19.8	20.4ab	39.7	40.2	39.8
	LSD	2.1	NS	1.6	NS	NS	NS
	CV	9.3	6.7	8.1	2.3	4.9	4.0
5	Alfalfa	20.7a	19.2	19.9a	42.6	43.9	43.3
	Alfalfa-brome	17.5b	18.7	18.1b	44.4	43.2	43.8
	Alfalfa-timothy	16.6b	19.3	18.2b	44.0	44.6	44.3
	LSD	2.8	NS	1.5	NS	NS	NS
	CV	14.1	5.7	10.8	5.9	6.5	6.0

† Sampling date corresponds to Julian date: 1, 128 and 127; 2, 132 and 135; 3, 140 and 141; 4, 148 and 149; 5, 156 and 155 for KBS and MSU, respectively.
‡ CP, crude protein concentration; ADF, acid detergent fiber concentration
§ Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$); NS, not significant
# Coefficient of variability (as %)

Table A.2. (cont'd).

Sampling date †	Treatment	NDF‡ KBS	NDF‡ MSU	NDF‡ AVG	RFV KBS	RFV MSU	RFV AVG
1	Alfalfa	26.9b§	27.7	27.3b	252a	253	253a
	Alfalfa-brome	33.0a	34.1	33.5a	203b	192	197b
	Alfalfa-timothy	32.6a	32.3	32.5a	206b	197	207b
	LSD¶	2.9	NS	3.8	22	NS	43
	CV#	10.9	15.7	12.9	12	26	19
2	Alfalfa	33.1	38.2	35.3b	191	158	175a
	Alfalfa-brome	41.6	43.0	42.3a	150	140	145b
	Alfalfa-timothy	38.2	40.5	39.7a	164	151	157ab
	LSD	NS	NS	4.0	NS	NS	22
	CV	12.6	8.1	10.5	15	10	13
3	Alfalfa	38.2c	44.3b	41.3c	155a	129	142a
	Alfalfa-brome	47.6a	48.6a	48.1a	123b	115	119c
	Alfalfa-timothy	43.3b	45.3b	44.3b	138ab	126	132b
	LSD	4.1	2.4	1.8	18	NS	9
	CV	11.5	5.8	9.1	13	8	12
4	Alfalfa	47.2b	51.4	49.3	113	103	108
	Alfalfa-brome	53.6a	53.2	53.4	100	99	100
	Alfalfa-timothy	49.8ab	51.5	50.9	107	104	106
	LSD	4.8	NS	NS	NS	NS	NS
	CV	7.5	5.2	6.4	7	8	8
5	Alfalfa	52.4	53.4	52.9b	99	96	97
	Alfalfa-brome	58.6	54.8	56.7a	87	94	91
	Alfalfa-timothy	59.7	56.9	57.8a	85	89	87
	LSD	NS	NS	3.7	NS	NS	NS
	CV	8.5	5	7.2	11	9	10

† Sampling date corresponds to Julian date: 1, 128 and 127; 2, 132 and 135; 3, 140 and 141; 4, 148 and 149; 5, 156 and 155 for KBS and MSU, respectively.
‡ NDF, neutral detergent fiber; RFV, relative feed value
§ Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$); NS, not significant
# Coefficient of variability (as %)

Table A.3. Forage quality in harvest cycle one at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) for 1992.

Sampling date †	Treatment	CP‡ KBS	CP‡ MSU	CP‡ AVG	ADF KBS	ADF MSU	ADF AVG
1	Alfalfa	37.4a§	32.9a	35.1a	16.3b	17.7b	17.0b
	Alfalfa-brome	31.0c	30.4b	30.7b	18.4a	19.1a	18.7a
	Alfalfa-timothy	34.4b	29.7b	32.0b	16.3b	18.8a	17.6b
	LSD¶	2.9	2.4	1.7	1.7	0.8	0.8
	CV#	10.6	7.7	10.5	8.8	4.7	8
2	Alfalfa	31.9a	28.9	30.4a	20.4b	24.7	22.6b
	Alfalfa-brome	24.3c	26.8	25.6c	23.5a	25.3	24.4a
	Alfalfa-timothy	28.5b	26.8	27.7b	21.1b	25.3	23.2b
	LSD	2.7	NS	1.5	1.4	NS	7.5
	CV	12.5	7.5	10.2	7.9	4.5	9.7
3	Alfalfa	28.1a	24.6	26.3a	25.8	29.0	27.4
	Alfalfa-brome	24.8b	21.7	23.3b	26.8	30.0	28.4
	Alfalfa-timothy	28.4a	22.8	25.6a	25.0	30.4	27.7
	LSD	2.1	NS	1.4	NS	NS	NS
	CV	11.3	7.4	12.7	6.5	4.3	8.9
4	Alfalfa	24.0a	21.9a	22.6a	30.3b	32.5	31.4b
	Alfalfa-brome	19.0b	20.0b	19.5b	32.7a	33.7	33.2a
	Alfalfa-timothy	21.3ab	18.6c	20.0b	30.9b	31.9	31.4b
	LSD	3.3	1.2	1.5	1.8	NS	1.1
	CV	10.9	7.9	9.8	4.2	3.8	4.5
5	Alfalfa	21.0	21.2a	21.1a	33.2	36.8	35.0
	Alfalfa-brome	17.6	18.2ab	17.9b	33.7	36.9	35.3
	Alfalfa-timothy	18.2	16.3b	17.2b	33.3	37.5	35.4
	LSD	NS	3.5	2.0	NS	NS	NS
	CV	11.7	14.4	12.8	2.9	2.2	5.8

† Sampling date corresponds to Julian date: 1, 125 and 127; 2, 132 and 134; 3, 139 and 141; 4, 146 and 148; 5, 153 and 155 for KBS and MSU, respectively.
‡ CP, crude protein concentration; ADF, acid detergent fiber concentration
§ Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$); NS, not significant
# Coefficient of variability (as %)

Table A.3. (cont'd).

Sampling date †	Treatment	NDF‡			RFV		
		KBS	MSU	AVG	KBS	MSU	AVG
1	Alfalfa	22.6c§	24.8b	23.7b	314a	283a	298a
	Alfalfa-brome	30.8a	28.4a	29.6a	228c	243b	236c
	Alfalfa-timothy	26.9b	28.8a	27.9a	265b	242b	254b
	LSD¶	2.9	3.2	1.9	24	26	16
	CV#	15.6	9.9	12.7	16	10	13
2	Alfalfa	26.2c	31.4b	28.8c	260a	207a	234a
	Alfalfa-brome	39.2a	34.6a	36.9a	169c	187b	178c
	Alfalfa-timothy	31.7b	34.6a	33.2b	213b	187b	200b
	LSD	4.6	2.6	2.4	27	16	14
	CV	18.9	6.9	13.9	19	8	16
3	Alfalfa	32.3b	35.6	33.9b	199a	174	186a
	Alfalfa-brome	39.9a	39.8	39.8a	160b	155	158b
	Alfalfa-timothy	34.6b	39.7	37.2a	189a	153	171b
	LSD	4	NS	3.1	21	NS	15
	CV	13.2	9	11.5	14	10	14
4	Alfalfa	39.0b	40.2b	39.6b	156a	147a	152a
	Alfalfa-brome	49.3a	43.9a	46.6a	120c	133b	127c
	Alfalfa-timothy	42.9b	46.0a	44.5a	141b	130b	135b
	LSD	5	2.4	2.4	15	8	8
	CV	11.7	7.1	9.5	12	8	10
5	Alfalfa	40.9	44.3b	42.6b	143	127a	135a
	Alfalfa-brome	47.9	49.3ab	48.6a	123	114b	119b
	Alfalfa-timothy	46.8	54.2a	50.5a	125	103b	114b
	LSD	NS	5.2	3.7	NS	12	10
	CV	9.6	9.7	10.4	15.7	10	12

† Sampling date corresponds to Julian date: 1, 125 and 127; 2, 132 and 134; 3, 139 and 141; 4, 146 and 148; 5, 153 and 155 for KBS and MSU, respectively.
‡ NDF, neutral detergent fiber; RFV, relative feed value
§ Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$); NS, not significant
# Coefficient of variability (as %)

Table A.4. Forage quality in harvest cycle two and three for sampling date three at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) for 1991.

Harvest cycle	Treatment	CP†			ADF			NDF			RFV		
		KBS	MSU	AVG	KBS	MSU	AVG	KBS	MSU	AVG	KBS	MSU	AVG
Two													
	A‡	26.7a§	24.5	25.6	32.9	33.4	33.1	39.8	32.3	36.1	150	184	167
	AB	25.4b	26.3	26.3	31.7	31.9	31.8	40.5	36.3	38.4	149	167	158
	AT	27.0a	24.8	26.1	29.3	31.4	30.9	37.2	33.1	35.0	166	183	173
	LSD¶	0.5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV#	4.7	4.6	5.7	11.7	5.5	8.6	10.7	13.1	14.1	14	13	15
Three													
	A	26.8	24.7b	25.9a	31.5	34.7	33.1	40.1	41.2	40.8	150	140b	146b
	AB	26.4	25.1a	25.8a	30.8	33.6	32.7	39.3	41.5	40.6	155	148a	152ab
	AT	25.4	24.2c	25.0b	33.9	34.4	34.2	39.9	44.2	42.0	149	149a	160a
	LSD	NS	0.3	0.4	NS	NS	NS	NS	NS	NS	NS	2	10
	CV	6.1	4.2	6.4	8.7	4.1	7.8	6.1	5.6	6.3	9	5	9

† CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value
‡ A, alfalfa; AB, alfalfa-brome; AT, alfalfa-timothy
§ Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$); NS, not significant
# Coefficient of variability (as %)

Table A.5. Forage quality in harvest cycle two at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) for 1992.

Sampling date †	Treatment	CP‡ KBS	CP‡ MSU	CP‡ AVG	ADF KBS	ADF MSU	ADF AVG	NDF KBS	NDF MSU	NDF AVG	RFV KBS	RFV MSU	RFV AVG
1	A§	25.9	31.6	28.8	26.3	25.0	25.7	32.7	29.5	31.1	195	219	207
	AB	26.5	31.7	29.1	25.1	25.6	25.4	33.2	30.2	31.7	195	213	204
	AT	25.5	31.6	28.6	25.0	24.9	25.0	33.9	29.8	31.9	191	217	204
	LSD¶	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV#	4.1	2.7	10.6	4.9	2.6	3.9	5.3	3.0	7.1	6	4	7
2	A	23.0	26.0	24.5	26.9b††	34.7a	30.8a	34.9b	39.3	37.1	183a	146	165ab
	AB	22.1	26.7	24.4	29.0a	33.3ab	31.1a	38.0a	39.1	38.5	163b	150	156b
	AT	22.5	26.1	24.3	25.8b	32.6b	29.2b	34.3b	39.8	37.1	187a	148	168a
	LSD	NS	NS	NS	1.7	1.5	1.0	2.8	NS	NS	19	NS	9
	CV	2.9	2.5	8.2	8.2	3.7	12.1	6.9	1.5	6.8	10	2	12
3	A	21.4	23.0	22.2	31.4	39.6a	35.5a	39.6	44.7	42.1	152	121	137
	AB	21.4	23.8	22.6	30.4	38.2ab	34.3a	41.2	45.4	43.3	147	121	134
	AT	21.3	24.0	22.6	29.4	36.2b	32.8b	39.5	44.4	42.0	156	127	141
	LSD	NS	NS	NS	NS	2.1	1.3	NS	NS	NS	NS	NS	NS
	CV	1.9	4.3	6.1	5.0	4.8	12.3	4.5	4.0	7.1	6	6	12

† Sampling date corresponds to Julian date: 1, 181 and 183; 2, 188 and 190; 3, 195 and 197 for KBS and MSU, respectively.
‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value
§ A, alfalfa; AB, alfalfa-brome; AT, alfalfa-timothy
¶ Least significant difference ($P \leq 0.05$); NS, not significant
# Coefficient of variability (as %)
†† Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)

Table A.6

Table A.6. Forage quality in harvest cycle three at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) for 1992.

Sampling		CP‡			ADF			NDF			RFV		
date †	Treatment	KBS	MSU	AVG	KBS	MSU	AVG	KBS	MSU	AVG	KBS	MSU	AVG
1	A§	29.8a¶	31.2	30.5	24.5ab	22.5	23.5	30.7b	26.7b	28.7a	211a	249a	230a
	AB	27.5b	32.5	30.0	25.5a	23.3	24.4	35.7a	28.4a	32.0b	180b	232b	206b
	AT	28.9a	31.5	30.2	23.8b	23.1	23.4	32.7ab	28.5a	30.6b	201a	232b	216b
	LSD#	1.6	NS	NS	1.3	NS	NS	3.1	1.4	1.5	18	15	11
	CV††	5	3.4	6.6	4.1	3.9	5.3	7.8	4.7	10.9	8	6	12
2	A	26.9	28.9	27.9	27.0	26.4	26.7	33.5b	32.0	32.8a	189a	199a	194a
	AB	25.3	28.1	26.7	27.8	27.5	27.6	37.7a	34.0	35.8b	167b	185b	176b
	AT	25.9	27.7	26.8	27.3	26.4	26.9	35.6ab	34.3	35.0b	177ab	185b	181b
	LSD	NS	NS	NS	NS	NS	NS	2.6	NS	1.5	15	13	9
	CV	4.9	4	5.9	4.3	4.0	4.3	6.5	4.7	6.4	7	6	7
3	A	23.8	25.8	24.8	31.2	32.0	31.6	38.9	37.8	38.3	155	158	157
	AB	23.3	25.6	24.5	31.2	32.1	31.7	40.9	38.3	39.6	147	156	151
	AT	23.3	26.2	24.7	31.2	32.0	31.6	40.2	38.0	39.1	150	157	153
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV	2.5	4	6	3.1	5.5	4.6	4.3	5.0	3.6	5	7	6

† Sampling date corresponds to Julian date: 1, 223 and 225; 2, 230 and 232; 3, 237 and 239 for KBS and MSU, respectively.
‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value
§ A, alfalfa; AB, alfalfa-brome; AT, alfalfa-timothy
¶ Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)
# Least significant difference ($P \leq 0.05$); NS, not significant
†† Coefficient of variability (as %)

Table A.7. Dry matter yields at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) for locations in 1991 and 1992.

			Recommended harvest date			
Year	Location	Treatment	1	2	3	Total†
			kg ha^{-1}			
1991	KBS	Alfalfa	4810	2151	2307	9268
		Alfalfa-brome	5245	2095	1841	9003
		Alfalfa-timothy	6257	1679	1729	9638
	LSD‡		NS	NS	NS	NS
	CV§		18	22	26	12
	MSU	Alfalfa	4043	2585	2975	9604
		Alfalfa-brome	4162	2371	3149	9682
		Alfalfa-timothy	4755	2313	2667	9735
	LSD		NS	NS	NS	NS
	CV		22	14	13	10
	AVG	Alfalfa	4427	2368	2641	9436
		Alfalfa-brome	4704	2233	2495	9342
		Alfalfa-timothy	5506	1996	2198	9687
	LSD		NS	NS	NS	NS
	CV		23	20	27	11.2
1992	KBS	Alfalfa	5341	2400	2138	9878
		Alfalfa-brome	5506	2304	2327	10137
		Alfalfa-timothy	5099	2043	2500	9642
	LSD		NS	NS	NS	NS
	CV		12	12	11	8
	MSU	Alfalfa	5367	3393	2088	10847
		Alfalfa-brome	5552	3023	2336	10911
		Alfalfa-timothy	6381	2947	2432	11765
	LSD		NS	NS	NS	NS
	CV		14	14	14	9
	AVG	Alfalfa	5354	2896	2113b¶	10363
		Alfalfa-brome	5529	2664	2332b	10524
		Alfalfa-timothy	5740	2495	2466a	10703
	LSD		NS	NS	250	NS
	CV		14	21	12	10.3

† Sum of harvests ‡ Least significant difference ($P \leq 0.05$); NS, not significant
§ Coefficient of variability (as %)
¶ Treatments with the same letter are not significantly different ($P \leq 0.05$)

Table A.8. Crude protein yields at Kellogg Biological Station (KBS), Michigan State University (MSU), and average (AVG) for locations in 1991 and 1992.

Year	Location	Treatment	Recommended harvest date 1	2	3	Total†
			---------- kg ha^{-1} ----------			
1991	KBS	Alfalfa	992	572	595	2153
		Alfalfa-brome	914	614	482	2130
		Alfalfa-timothy	1021	466	344	1856
	LSD§		NS	NS	NS	NS
	CV¶		12	32	28	8
	MSU	Alfalfa	772	634	735	2141
		Alfalfa-brome	776	624	751	2104
		Alfalfa-timothy	831	576	680	2208
	LSD		NS	NS	NS	NS
	CV		19	16	9	9
	AVG	Alfalfa	882	603	662	2155
		Alfalfa-brome	845	624	523	2046
		Alfalfa-timothy	917	511	548	1914
	LSD		NS	NS	NS	NS
	CV		18	17	25	8
1992	KBS	Alfalfa	1118	514	508	2140
		Alfalfa-brome	955	493	543	1991
		Alfalfa-timothy	930	434	581	1944
	LSD		NS	NS	NS	NS
	CV		13	12	14	8
	MSU	Alfalfa	1134	778	535	2447
		Alfalfa-brome	1005	717	598	2320
		Alfalfa-timothy	1039	706	635	2381
	LSD		NS	NS	NS	NS
	CV		14	12	12	8
	AVG	Alfalfa	1126	646	522b¶	2294
		Alfalfa-brome	980	605	570ab	2155
		Alfalfa-timothy	984	570	608a	2162
	LSD		NS	NS	57	NS
	CV		14	24	12	11.4

† Sum of harvests ‡ Least significant difference ($P \leq 0.05$); NS, not significant
§ Coefficient of variability (as %)
¶ Treatments with the same letter are not significantly different ($P \leq 0.05$)

Table A.9. Effects on alfalfa quality as a result of including grass at Kellogg Biological Station in 1991.

Sampling date †	Trt	Harvest cycle 1			Harvest cycle 2			Harvest cycle 3		
		CP‡	ADF	NDF	CP	ADF	NDF	CP	ADF	NDF
1										
	A§	29.8	20.7	26.9	28.8	21.3	30.2	31.3	25.0	31.4
	AB	29.4	20.8	27.3	29.5	20.1	30.7	30.4	25.6	31.3
	AT	28.2	20.7	27.5	29.1	20.4	27.3	30.5	24.2	30.9
	LSD¶	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV#	4	6.3	3.5	4	7.7	10.6	3.7	6.5	4.2
2										
	A	26.8	27.8	33.1	30.6	26.1	32.4	27.9	28.4	35.9
	AB	26.3	25.1	30.6	31.6	25.4	32.5	27.5	31.1	36.6
	AT	26.1	27.9	33.0	31.6	24.3	32.2	27.0	30.3	38.2
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV	3.6	10.3	8.4	5.7	10.4	8.2	4.8	9.2	6.6
3										
	A	25.7	32.8	38.2	26.7	32.9	39.8	26.8	31.5	40.1
	AB	25.0	31.6	38.1	27.0	30.6	36.8	26.8	30.2	37.5
	AT	24.1	32.9	39.5	28.0	27.6	36.6	25.4	32.3	40.3
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV	6	4.7	6	4.2	13.4	11.2	6.5	8.4	7.6
4										
	A	22.2	40.5	47.2						
	AB	22.4	39.2	45.4						
	AT	22.0	39.5	46.3						
	LSD	NS	NS	NS						
	CV	3.6	3.1	3.3						
5										
	A	20.7	42.6	52.4						
	AB	20.0	44.3	52.4						
	AT	19.3	43.7	53.0						
	LSD	NS	NS	NS						
	CV	6	6.4	4.8						

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 128; 2, 132; 3, 140; 4, 148; 5, 156. Harvest cycle 2: 1, 184; 2, 193; 3, 199. Harvest cycle 3: 1, 224; 2, 232; 3, 238.
‡ CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber
§ A, alfalfa; AB, alfalfa-bromegrass; AT, alfalfa-timothy
¶ Least significant difference ($P \leq 0.05$); NS, not significant
# Coefficient of variability (as %)

Table A.10. Effects on alfalfa quality as a result of including grass at Kellogg Biological Station in 1992.

Sampling date †	Trt	Harvest cycle 1			Harvest cycle 2			Harvest cycle 3		
		CP‡	ADF	NDF	CP	ADF	NDF	CP	ADF	NDF
1										
	A§	37.4	16.3	22.6	25.9	26.3	32.7	29.8	24.5	30.7
	AB	36.2	16.3	22.2	27.1	24.8	31.2	28.9	24.6	30.7
	AT	36.3	15.1	22.5	26.0	24.7	31.7	29.7	23.2	29.6
	LSD¶	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV#	5.5	7.2	4.5	3.8	5.4	4.2	4.2	4.1	3.5
2	A	31.9a††	20.4	26.2	23.0	26.9b	34.9ab	26.9	27.0	33.5
	AB	29.7b	20.8	27.2	22.3	28.9a	36.5a	25.9	27.3	34.4
	AT	31.5a	19.5	25.7	23.0	25.5b	32.5b	26.3	27.1	33.9
	LSD	0.9	NS	NS	NS	1.8	2.5	NS	NS	NS
	CV	4.4	5.7	4.2	3	8.7	7.6	4.4	4.2	3.9
3										
	A	28.1b	25.8	32.3	21.4	31.4	39.6	23.8	31.2	38.9
	AB	28.6ab	24.9	31.3	21.9	30.2	38.0	23.8	31.2	38.4
	AT	29.6a	24.6	31.9	21.8	29.2	37.3	23.7	31.1	38.5
	LSD	1.1	NS	NS	NS	NS	NS	NS	NS	NS
	CV	6.8	5.3	4.4	2.7	5.4	4.8	2.5	3.3	3.8
4										
	A	23.3	30.3	39.0						
	AB	22.7	31.1	38.9						
	AT	23.3	30.2	38.4						
	LSD	NS	NS	NS						
	CV	2.9	2.4	2.3						
5										
	A	21.0	33.2	40.9						
	AB	20.2	31.9	41.1						
	AT	20.3	32.9	40.8						
	LSD	NS	NS	NS						
	CV	5.6	3.7	3.1						

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 125; 2, 132; 3, 139; 4, 146; 5, 153. Harvest cycle 2: 1, 181; 2, 188; 3, 195. Harvest cycle 3: 1, 223; 2, 230; 3, 237.

‡ CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber

§ A, alfalfa; AB, alfalfa-bromegrass; AT, alfalfa-timothy

¶ Least significant difference ($P \leq 0.05$); NS, not significant

Coefficient of variability (as %)

†† Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)

Table A.11. Effects on alfalfa quality as a result of including grass at Michigan State University in 1991.

Sampling date †	Trt	Harvest cycle 1			Harvest cycle 2			Harvest cycle 3		
		CP‡	ADF	NDF	CP	ADF	NDF	CP	ADF	NDF
1										
	A§	33.1	21.4	27.7	33.2	21.8	21.4	31.4	25.4	31.8a¶
	AB	31.3	23.3	29.5	33.5	21.6	19.4	32.8	23.3	28.5b
	AT	32.3	23.3	29.5	34.8	21.2	20.4	32.4	23.5	29.8b
	LSD#	NS	NS	NS	NS	NS	NS	NS	NS	1.9
	CV††	10.4	15.3	11.2	5.1	10.4	8.7	2.9	6.7	5.8
2										
	A	25.4	31.0	38.2	30.4	30.3	25.9	28.7	28.9	35.9
	AB	25.4	29.2	36.1	30.8	27.2	25.1	28.4	28.5	36.0
	AT	24.3	29.2	36.6	30.4	29.9	23.9	29.6	28.3	34.9
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV	5.5	7.5	5.7	3.2	6.5	10.6	6.6	6.1	6.4
3										
	A	22.4	35.7	44.3	24.5b	33.4	32.3	24.7	34.7	41.2
	AB	23.6	36.3	43.0	26.4a	30.7	30.7	24.6	33.9	40.6
	AT	24.5	35.4	42.6	26.0a	30.2	27.5	24.5	35.6	42.9
	LSD	NS	NS	NS	1.1	NS	NS	NS	NS	NS
	CV	6.3	6.3	5.3	4.0	8	13.9	4	5	5.6
4										
	A	20.4	41.7	51.4						
	AB	21.0	41.2	49.6						
	AT	21.1	40.4	48.1						
	LSD	NS	NS	NS						
	CV	4.6	5.1	5.9						
5										
	A	19.2	43.9	53.4						
	AB	19.9	43.4	51.3						
	AT	20.1	45.9	54.0						
	LSD	NS	NS	NS						
	CV	5.4	7	5.2						

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 127; 2, 135; 3, 141; 4, 149; 5, 155. Harvest cycle 2: 1, 183; 2, 190; 3, 197. Harvest cycle 3: 1, 226; 2, 233; 3, 240.

‡ CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber

§ A, alfalfa; AB, alfalfa-bromegrass; AT, alfalfa-timothy

¶ Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)

Least significant difference ($P \leq 0.05$); NS, not significant

†† Coefficient of variability (as %)

Table A.12. Effects on alfalfa quality as a result of including grass at Michigan State University in 1992.

Sampling date †	Trt	Harvest cycle 1 CP‡	Harvest cycle 1 ADF	Harvest cycle 1 NDF	Harvest cycle 2 CP	Harvest cycle 2 ADF	Harvest cycle 2 NDF	Harvest cycle 3 CP	Harvest cycle 3 ADF	Harvest cycle 3 NDF
1										
	A§	32.9	17.7	24.8	31.6	25.0	29.5	31.2	22.5	26.7
	AB	32.5	18.4	25.3	31.7	25.6	29.6	32.6	23.3	27.4
	AT	31.9	18.1	24.9	32.0	24.8	28.8	32.0	22.8	26.2
	LSD¶	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV#	3.4	3.8	2.5	2.7	2.7	3.1	3.7	4.1	4.1
2										
	A	28.9	24.7	31.4	26.0	34.6	39.3a††	28.9	26.4	32.0
	AB	28.6	24.5	30.5	26.6	33.4	38.3ab	27.9	27.5	33.0
	AT	28.4	24.8	30.9	26.7	32.9	37.8b	28.2	26.3	31.6
	LSD	NS	NS	NS	NS	NS	1.1	NS	NS	NS
	CV	6.1	4.9	5.2	2.5	3.5	2.2	4	4.2	3.9
3										
	A	24.6	29.0	35.6	23.0	39.6a	44.7	25.8	32.0	37.8
	AB	23.8	28.8	34.5	23.6	38.5ab	44.9	25.5	32.2	37.4
	AT	24.1	30.0	36.1	24.3	36.6b	43.1	26.4	32.1	37.0
	LSD	NS	NS	NS	NS	2.2	NS	NS	NS	NS
	CV	4.8	4.3	5.0	4.7	4.5	4.6	4.2	5.7	5.1
4										
	A	21.9	32.5	40.2						
	AB	21.8	33.0	39.9						
	AT	22.2	30.8	37.5						
	LSD	NS	NS	NS						
	CV	3.0	5.1	5.1						
5										
	A	21.2	36.8	44.3						
	AB	21.1	35.3	42.7						
	AT	20.2	35.8	44.2						
	LSD	NS	NS	NS						
	CV	5.4	3.6	3						

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 127; 2, 134; 3, 141; 4, 148; 5, 155. Harvest cycle 2: 1, 183; 2, 190; 3, 197. Harvest cycle 3: 1, 225; 2, 232; 3, 239.

‡ CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber

§ A, alfalfa; AB, alfalfa-bromegrass; AT, alfalfa-timothy

¶ Least significant difference ($P \leq 0.05$); NS, not significant

Coefficient of variability (as %)

†† Forage quality parameters with the same letter are not significantly different ($P \leq 0.05$)

Table A.13. Effects on alfalfa maturity as a result of including grass at Kellogg Biological Station in 1991.

Sampling date †	Treatment	Harvest cycle 1		Harvest cycle 2		Harvest cycle 3	
		MSW‡	MSC	MSW	MSC	MSW	MSC
1	Alfalfa	0.9	0.7	3.3	2.6	2.2	1.6
	Alfalfa-Brome	0.9	0.7	3.2	2.6	2.8	2.3
	Alfalfa-Timothy	0.9	0.7	3.0	2.2	2.5	1.8
	LSD§	NS	NS	NS	NS	NS	NS
	CV¶	11.9	14	8.5	13.6	13.6	19.6
2							
	Alfalfa	1.7	1.2	3.6	2.7	3.6	3.1
	Alfalfa-Brome	1.5	1.1	3.8	3.0	3.0	2.4
	Alfalfa-Timothy	1.5	1.1	3.5	2.9	3.7	3.0
	LSD	NS	NS	NS	NS	NS	NS
	CV	14	14.5	9.5	15.5	15.3	19.2
3							
	Alfalfa	2.9	2.5	5.5a#	4.7	3.9	3.2
	Alfalfa-Brome	2.9	2.3	5.5a	4.7	3.8	3.1
	Alfalfa-Timothy	3.0	2.4	4.6b	3.8	3.8	3.1
	LSD	NS	NS	0.7	NS	NS	NS
	CV	5.2	6.6	11.4	14.3	11.7	12.6
4							
	Alfalfa	3.7	3.5				
	Alfalfa-Brome	3.7	3.4				
	Alfalfa-Timothy	3.8	3.5				
	LSD	NS	NS				
	CV	2.5	3.9				
5							
	Alfalfa	5.4	4.9				
	Alfalfa-Brome	5.3	4.7				
	Alfalfa-Timothy	5.7	5.1				
	LSD	NS	NS				
	CV	7.6	7.4				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 128; 2, 132; 3, 140; 4, 148; 5, 156. Harvest cycle 2: 1, 184; 2, 193; 3, 199. Harvest cycle 3: 1, 224; 2, 232; 3, 238.

‡ MSW, mean stage by weight; MSC, mean stage by count

§ Least significant difference ($P \leq 0.05$)

¶ Coefficient of variability (as %)

Characteristics with the same letter are not significantly different ($P \leq 0.05$)

Table A.14. Effects on alfalfa maturity as a result of including grass at Kellogg Biological Station in 1992.

Sampling date †	Treatment	Harvest cycle 1 MSW‡	Harvest cycle 1 MSC	Harvest cycle 2 MSW	Harvest cycle 2 MSC	Harvest cycle 3 MSW	Harvest cycle 3 MSC
1	Alfalfa	0.6	0.4	1.8	1.4	2.2	1.7
	Alfalfa-Brome	0.5	0.4	1.7	1.3	2.4	2.0
	Alfalfa-Timothy	0.5	0.3	1.7	1.3	2.2	1.8
	LSD§	NS	NS	NS	NS	NS	NS
	CV¶	18.2	21.9	11.3	11.9	11.4	14
2							
	Alfalfa	1.3	1.0	2.3	1.8b#	2.7	2.2
	Alfalfa-Brome	1.1	1.1	2.7	2.2a	2.9	2.4
	Alfalfa-Timothy	1.3	1.1	2.4	1.9b	2.8	2.3
	LSD	NS	NS	NS	0.3	NS	NS
	CV	3.4	15.4	11.3	15.4	6	7
3							
	Alfalfa	2.2	1.8	3.6	2.9	2.9	2.5
	Alfalfa-Brome	2.2	1.9	3.8	3.2	3.0	2.5
	Alfalfa-Timothy	2.2	1.9	3.6	2.9	2.8	2.5
	LSD	NS	NS	NS	NS	NS	NS
	CV	4.3	5	7.1	8.8	6.9	7.2
4							
	Alfalfa	2.6	2.3				
	Alfalfa-Brome	2.6	2.3				
	Alfalfa-Timothy	2.6	2.2				
	LSD	NS	NS				
	CV	3.8	3.8				
5							
	Alfalfa	3.0	2.6				
	Alfalfa-Brome	2.9	2.6				
	Alfalfa-Timothy	2.7	2.4				
	LSD	NS	NS				
	CV	4.8	5.2				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 125; 2, 132; 3, 139; 4, 146; 5, 153. Harvest cycle 2: 1, 181; 2, 188; 3, 195. Harvest cycle 3: 1, 223; 2, 230; 3, 237.
‡ MSW, mean stage by weight; MSC, mean stage by count
§ Least significant difference ($P \leq 0.05$)
¶ Coefficient of variability (as %)
# Characteristics with the same letter are not significantly different ($P \leq 0.05$)

Table A.15. Effects on alfalfa maturity as a result of including grass at Michigan State University in 1991.

Sampling date †	Treatment	Harvest cycle 1		Harvest cycle 2		Harvest cycle 3	
		MSW‡	MSC	MSW	MSC	MSW	MSC
1	Alfalfa	1.3	0.9	2.8	1.9	2.1	1.4
	Alfalfa-Brome	1.3	1.0	3.1	2.4	2.2	1.7
	Alfalfa-Timothy	1.4	1.0	2.8	2.0	2.4	1.8
	LSD§	NS	NS	NS	NS	NS	NS
	CV¶	31.2	31.2	10.7	16.4	8.4	23.7
2							
	Alfalfa	2.1	1.9	3.6	2.9	2.7	2.2
	Alfalfa-Brome	2.2	1.9	3.7	3.0	2.7	2.2
	Alfalfa-Timothy	2.2	1.9	3.6	2.9	2.8	2.3
	LSD	NS	NS	NS	NS	NS	NS
	CV	8.2	8.7	4.7	4.4	8.6	9.7
3							
	Alfalfa	2.9	2.6	4.7	3.5	3.2	2.7
	Alfalfa-Brome	3.1	2.8	4.3	3.5	3.3	2.6
	Alfalfa-Timothy	3.0	2.7	4.5	3.6	3.3	2.6
	LSD	NS	NS	NS	NS	NS	NS
	CV	7.7	8.6	9.4	9.7	5.5	5.2
4							
	Alfalfa	3.7	3.5				
	Alfalfa-Brome	3.8	3.6				
	Alfalfa-Timothy	3.7	3.4				
	LSD	NS	NS				
	CV	3.5	5.6				
5							
	Alfalfa	5.2	4.5				
	Alfalfa-Brome	5.1	4.3				
	Alfalfa-Timothy	5.2	5.6				
	LSD	NS	NS				
	CV	5.1	8.5				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 127; 2, 135; 3, 141; 4, 149; 5, 155. Harvest cycle 2: 1, 183; 2, 190; 3, 197. Harvest cycle 3: 1, 226; 2, 233; 3, 240.
‡ MSW, mean stage by weight; MSC, mean stage by count
§ Least significant difference ($P \leq 0.05$)
¶ Coefficient of variability (as %)

Table A.16. Effects on alfalfa maturity as a result of including grass at Michigan State University in 1992.

Sampling date †	Treatment	Harvest cycle 1		Harvest cycle 2		Harvest cycle 3	
		MSW‡	MSC	MSW	MSC	MSW	MSC
1	Alfalfa	0.7	0.5	1.7	1.4	1.7	1.3
	Alfalfa-Brome	0.7	0.6	1.9	1.5	1.8	1.4
	Alfalfa-Timothy	0.6	0.5	1.7	1.3	1.6	1.2
	LSD§	NS	NS	NS	NS	NS	NS
	CV¶	19.6	24.4	11.5	11.2	22.5	23.1
2							
	Alfalfa	1.8	1.6	4.0ab#	2.5	2.6	2.1
	Alfalfa-Brome	1.8	1.5	4.5a	2.6	2.7	2.1
	Alfalfa-Timothy	1.8	1.5	2.9b	2.6	2.5	2.0
	LSD	NS	NS	1.1	NS	NS	NS
	CV	6	6.2	29.3	4.5	6.6	8.3
3							
	Alfalfa	2.4	2.1	3.7	3.1	2.9	2.5
	Alfalfa-Brome	2.3	2.1	3.8	3.2	2.8	2.5
	Alfalfa-Timothy	2.4	2.1	3.7	3.1	2.9	2.5
	LSD	NS	NS	NS	NS	NS	NS
	CV	5.2	5.5	6.3	7.1	4.8	5.6
4							
	Alfalfa	2.7	2.4				
	Alfalfa-Brome	2.7	2.4				
	Alfalfa-Timothy	2.7	2.4				
	LSD	NS	NS				
	CV	3.8	2.2				
5							
	Alfalfa	3.0	2.6				
	Alfalfa-Brome	2.8	2.5				
	Alfalfa-Timothy	2.9	2.5				
	LSD	NS	NS				
	CV	4.8	5.3				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 127; 2, 134; 3, 141; 4, 148; 5, 155. Harvest cycle 2: 1, 183; 2, 190; 3, 197. Harvest cycle 3: 1, 225; 2, 232; 3, 239.
‡ MSW, mean stage by weight; MSC, mean stage by count
§ Least significant difference ($P \leq 0.05$)
¶ Coefficient of variability (as %)
# Characteristics with the same letter are not significantly different ($P \leq 0.05$)

Table A.17. Effects on alfalfa stem characteristics as a result of including grass at Kellogg Biological Station in 1991.

Sampling date †	Treatment	Harvest cycle 1		Harvest cycle 2		Harvest cycle 3	
		ASL‡	ASW	ASL	ASW	ASL	ASW
1	Alfalfa	17	0.8	27	0.8a§	27	0.9
	Alfalfa-Brome	17	0.7	23	0.6ab	27	1.1
	Alfalfa-Timothy	16	0.6	20	0.5b	26	0.9
	LSD¶	NS	NS	NS	0.2	NS	NS
	CV#	15.7	37.3	18.3	27.9	12.8	38.2
2							
	Alfalfa	25	1.3	27	1.3	37	1.8
	Alfalfa-Brome	25	0.8	31	1.3	37	1.7
	Alfalfa-Timothy	28	1.0	27	0.9	41	1.8
	LSD	NS	NS	NS	NS	NS	NS
	CV	34.2	33.7	13.6	37.8	22	35.1
3							
	Alfalfa	44	2.1	43	2.3	43	1.9
	Alfalfa-Brome	40	1.1	42	1.9	44	1.9
	Alfalfa-Timothy	40	1.1	35	1.5	47	1.8
	LSD	NS	NS	NS	NS	NS	NS
	CV	10.8	48.3	19.3	28.1	17.1	46.7
4							
	Alfalfa	71	2.9a				
	Alfalfa-Brome	64	1.8b				
	Alfalfa-Timothy	66	2.3b				
	LSD	NS	0.5				
	CV	9.71	25.9				
5							
	Alfalfa	84	3.0				
	Alfalfa-Brome	81	2.3				
	Alfalfa-Timothy	86	2.5				
	LSD	NS	NS				
	CV	7.9	19.9				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 128; 2, 132; 3, 140; 4, 148; 5, 156. Harvest cycle 2: 1, 184; 2, 193; 3, 199. Harvest cycle 3: 1, 224; 2, 232; 3, 238.
‡ ASL, alfalfa stem length; ASW, alfalfa stem weight
§ Characteristics with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$)
# Coefficient of variability (as %)

Table A.18. Effects on alfalfa stem characteristics as a result of including grass at Michigan State University in 1991.

Sampling date †	Treatment	Harvest cycle 1		Harvest cycle 2		Harvest cycle 3	
		ASL‡	ASW	ASL	ASW	ASL	ASW
1	Alfalfa	19	0.9	23	0.7	25	1.4
	Alfalfa-Brome	24	1.2	26	0.8	24	1.5
	Alfalfa-Timothy	24	0.9	24	0.6	25	1.1
	LSD§	NS	NS	NS	NS	NS	NS
	CV¶	25.2	78.8	17.4	26.2	12	29
2							
	Alfalfa	42	1.6	43	1.5	41	2.1
	Alfalfa-Brome	46	1.7	41	1.6	39	2.1
	Alfalfa-Timothy	42	1.6	41	1.6	40	2.4
	LSD	NS	NS	NS	NS	NS	NS
	CV	14.6	53.1	8.1	26.6	11.8	26.2
3							
	Alfalfa	56	1.9	44	2.3	60	3.5
	Alfalfa-Brome	59	1.5	45	1.8	56	3.2
	Alfalfa-Timothy	56	1.5	41	1.9	55	2.8
	LSD	NS	NS	NS	NS	NS	NS
	CV	15.2	40.2	10.4	31	6.9	19.6
4							
	Alfalfa	71	2.3				
	Alfalfa-Brome	83	2.2				
	Alfalfa-Timothy	74	1.7				
	LSD	NS	NS				
	CV	14.3	29.4				
5							
	Alfalfa	78	2.9				
	Alfalfa-Brome	77	2.1				
	Alfalfa-Timothy	79	2.2				
	LSD	NS	NS				
	CV	16.2	35				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 127; 2, 135; 3, 141; 4, 149; 5, 155. Harvest cycle 2: 1, 183; 2, 190; 3, 197. Harvest cycle 3: 1, 226; 2, 233; 3, 240.

‡ ASL, alfalfa stem length; ASW, alfalfa stem weight

§ Least significant difference ($P \leq 0.05$)

¶ Coefficient of variability (as %)

Table A.19. Effects on alfalfa stem characteristics as a result of including grass at Kellogg Biological Station in 1992.

Sampling date †	Treatment	Harvest cycle 1		Harvest cycle 2		Harvest cycle 3	
		ASL‡	ASW	ASL	ASW	ASL	ASW
1	Alfalfa	12	1.3a§	24	1.9a	22	1.5
	Alfalfa-Brome	12	0.8b	24	1.5b	25	1.1
	Alfalfa-Timothy	12	0.8b	23	1.7ab	23	1.2
	LSD¶	NS	0.2	NS	0.2	NS	NS
	CV#	10.6	28.0	11.8	10.6	18	20.5
2							
	Alfalfa	23	1.9	21b	2.2	32	2.5a
	Alfalfa-Brome	24	1.4	29a	2.2	32	1.8b
	Alfalfa-Timothy	22	1.5	23ab	1.9	36	2.2ab
	LSD	NS	NS	6	NS	NS	0.4
	CV	9.2	23.5	21.2	14.7	18	18.4
3							
	Alfalfa	37	2.0	30	2.6	36b	2.3
	Alfalfa-Brome	38	1.7	34	2.2	36b	2.2
	Alfalfa-Timothy	38	1.8	28	2.0	42a	2.5
	LSD	NS	NS	NS	NS	3.6	NS
	CV	8.4	17.6	14.8	16.1	12	11.8
4							
	Alfalfa	52	2.5				
	Alfalfa-Brome	51	1.9				
	Alfalfa-Timothy	48	2.1				
	LSD	NS	NS				
	CV	7.2	19.1				
5							
	Alfalfa	62	3.6a				
	Alfalfa-Brome	63	2.7b				
	Alfalfa-Timothy	57	2.5b				
	LSD	NS	0.8				
	CV	8	23.0				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 125; 2, 132; 3, 139; 4, 146; 5, 153. Harvest cycle 2: 1, 181; 2, 188; 3, 195. Harvest cycle 3: 1, 223; 2, 230; 3, 237.
‡ ASL, alfalfa stem length; ASW, alfalfa stem weight
§ Characteristics with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$)
# Coefficient of variability (as %)

Table A.20. Effects on alfalfa stem characteristics as a result of including grass at Michigan State University in 1992.

Sampling date †	Treatment	Harvest cycle 1 ASL‡	Harvest cycle 1 ASW	Harvest cycle 2 ASL	Harvest cycle 2 ASW	Harvest cycle 3 ASL	Harvest cycle 3 ASW
1	Alfalfa	13	1.7	24b§	1.2	18	1.0
	Alfalfa-Brome	15	1.8	27a	1.7	19	1.0
	Alfalfa-Timothy	13	1.3	21c	1.3	19	0.8
	LSD¶	NS	NS	1.2	NS	NS	NS
	CV#	13.1	24.1	10.8	27.8	19.7	18.9
2							
	Alfalfa	35	2.6	42	3.2	29	1.5
	Alfalfa-Brome	31	2.5	43	2.7	33	1.7
	Alfalfa-Timothy	32	2.3	38	2.2	32	1.4
	LSD	NS	NS	NS	NS	NS	NS
	CV	11.7	14.3	15	20.3	11.3	14.4
3							
	Alfalfa	46	2.4	59	3.7	45	2.3
	Alfalfa-Brome	50	2.0	67	3.1	42	2.4
	Alfalfa-Timothy	47	2.2	57	2.9	46	2.5
	LSD	NS	NS	NS	NS	NS	NS
	CV	12.9	19	12.1	16.2	8.3	12.5
4							
	Alfalfa	63	3.1				
	Alfalfa-Brome	62	2.8				
	Alfalfa-Timothy	61	2.2				
	LSD	NS	NS				
	CV	6.2	22				
5							
	Alfalfa	70	3.6				
	Alfalfa-Brome	67	2.8				
	Alfalfa-Timothy	73	2.5				
	LSD	NS	NS				
	CV	13.2	23.6				

† Sampling date corresponds to Julian date. Harvest cycle 1: 1, 127; 2, 134; 3, 141; 4, 148; 5, 155. Harvest cycle 2: 1, 183; 2, 190; 3, 197. Harvest cycle 3: 1, 225; 2, 232; 3, 239.
‡ ASL, alfalfa stem length; ASW, alfalfa stem weight
§ Characteristics with the same letter are not significantly different ($P \leq 0.05$)
¶ Least significant difference ($P \leq 0.05$)
# Coefficient of variability (as %)

Table A.21. Weather data in 1990 and 1991 at Kellogg Biological Station (KBS) and Michigan State University (MSU).

Location	Month	Monthly mean air temperature (°C)		
		1991	1992	30 year mean†
KBS	April	10.9	7.9	8.1
	May	18.8	15.2	14.2
	June	22.4	18.2	19.4
	July	22.9	20.2	21.5
	August	21.9	18.9	20.6
	September	16.4	16.3	16.7
	October	12.4	9.9	10.6
	November	2.8	3.6	3.7
MSU	April	10.1	6.2	8.6
	May	18.0	13.7	14.8
	June	21.1	17.3	19.9
	July	22.1	19.2	22.3
	August	20.9	17.8	21.4
	September	14.9	15.2	17.6
	October	11.1	8.6	11.4
	November	1.7	3.3	4.3
		Monthly precipitation (cm)		
KBS	April	13.64	7.26	8.97
	May	8.61	2.49	8.03
	June	7.16	3.07	10.67
	July	14.91	15.32	8.64
	August	15.77	8.56	9.02
	September	5.66	13.92	7.57
	October	18.72	7.29	7.34
	November	6.86	11.23	6.88
	Total	91.33	69.14	67.12
MSU	April	10.8	9.75	7.14
	May	3.53	1.85	6.93
	June	7.49	4.5	8.99
	July	9.17	18.52	7.67
	August	6.91	3.81	7.92
	September	2.11	5.84	6.35
	October	8.86	4.93	5.59
	November	5.99	11.35	5.64
	Total	54.86	60.55	56.23

† Long term mean (1951-1980) from the National Weather Service

Table A.22. Soil tests used to determine fertilizer requirements in spring 1991 for Kellogg Biological Station (KBS) and Michigan State University (MSU).

	Location	
	KBS	MSU
	----- kg ha^{-1} -----	
Phosphorus	207	174
Potassium	296	452
Calcium	2061	3763
Magnesium	385	497
pH	6.7	6.8

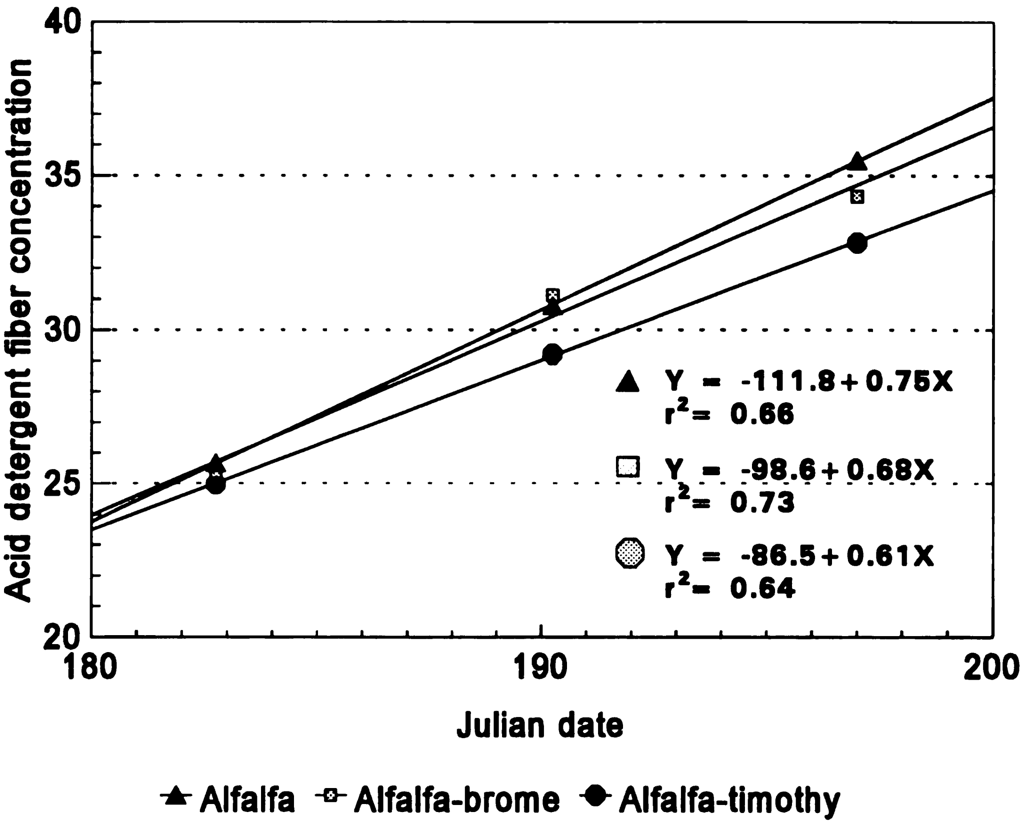

Figure A.1. Acid detergent fiber concentration of alfalfa and alfalfa-grass mixtures in harvest cycle two of 1992.

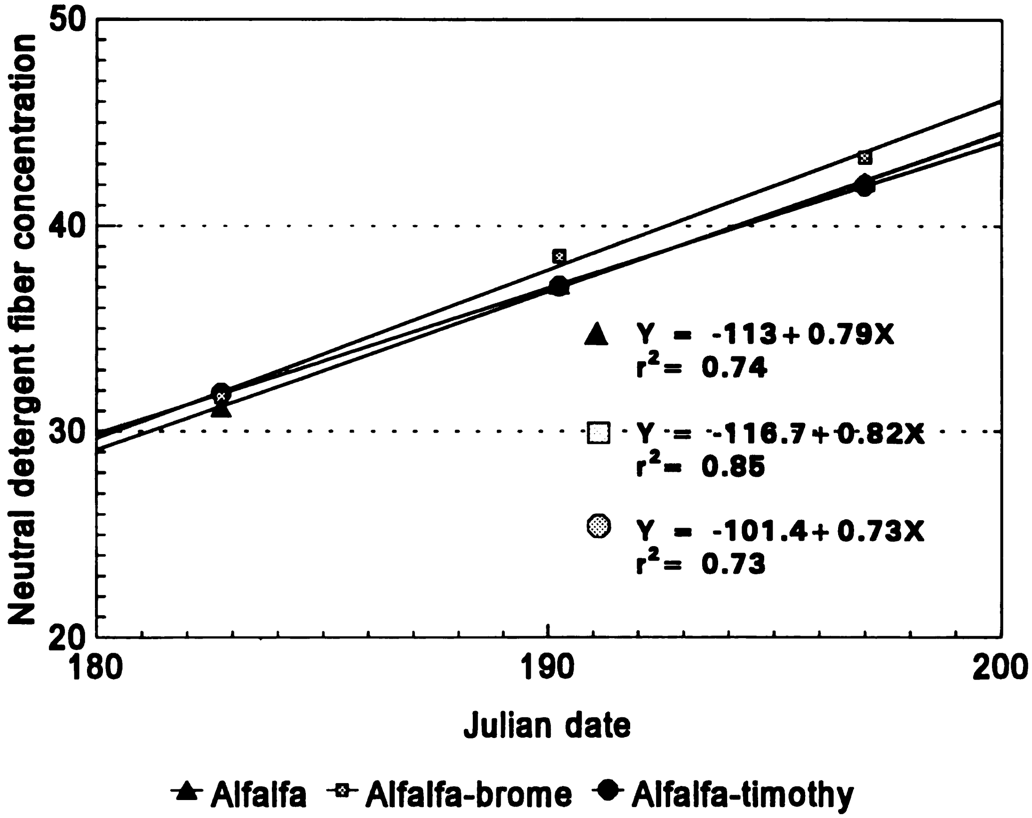

Figure A.2. Neutral detergent fiber concentration of alfalfa and alfalfa-grass mixtures in harvest cycle two in 1992.

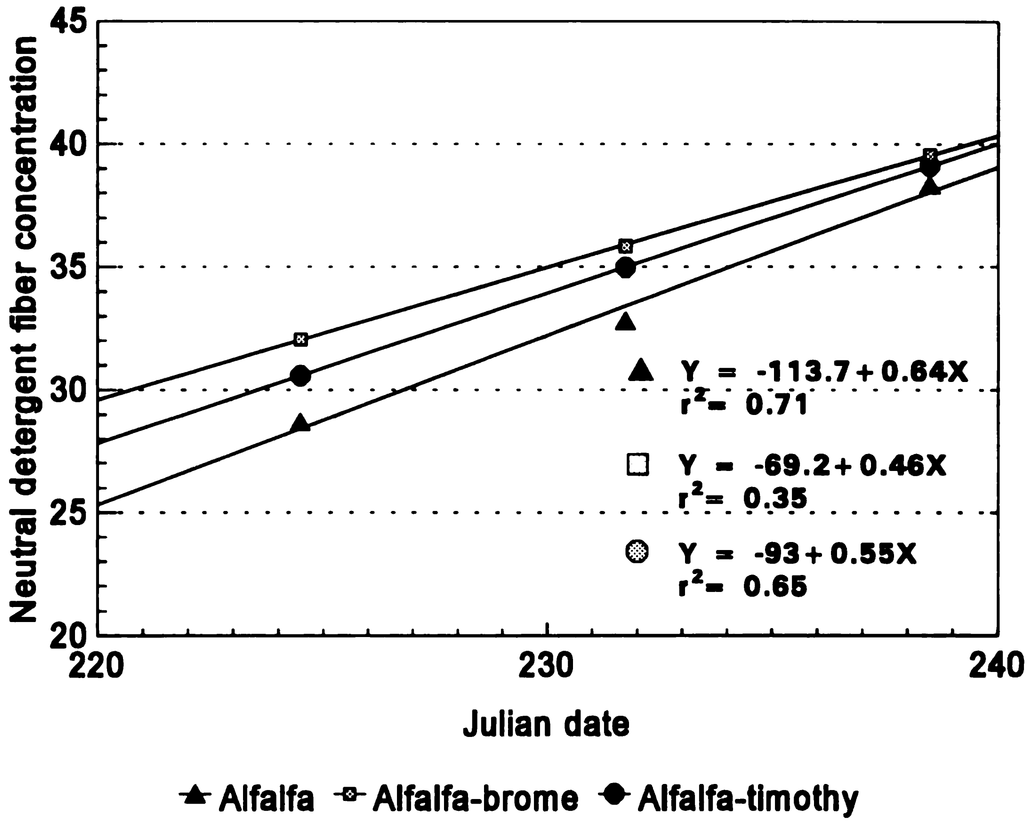

Figure A.3. Neutral detergent fiber of alfalfa and alfalfa-grass mixtures in harvest cycle three of 1992.

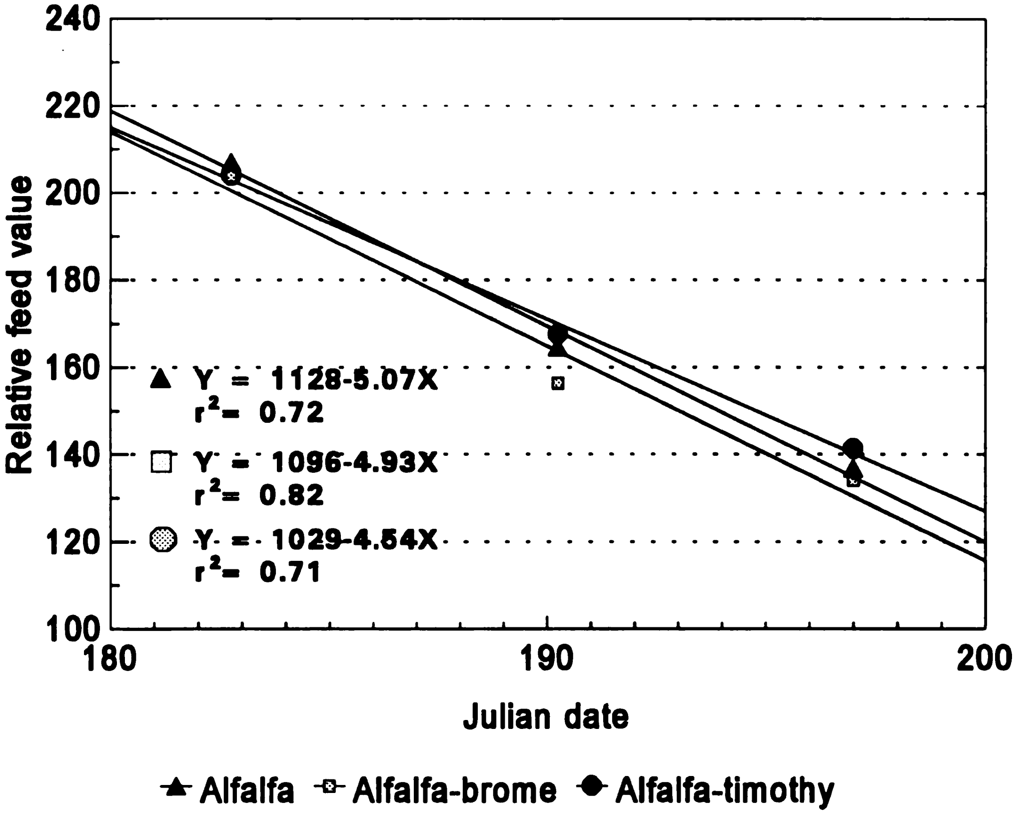

Figure A.4. Relative feed value of alfalfa and alfalfa-grass mixtures in harvest cycle two of 1992.

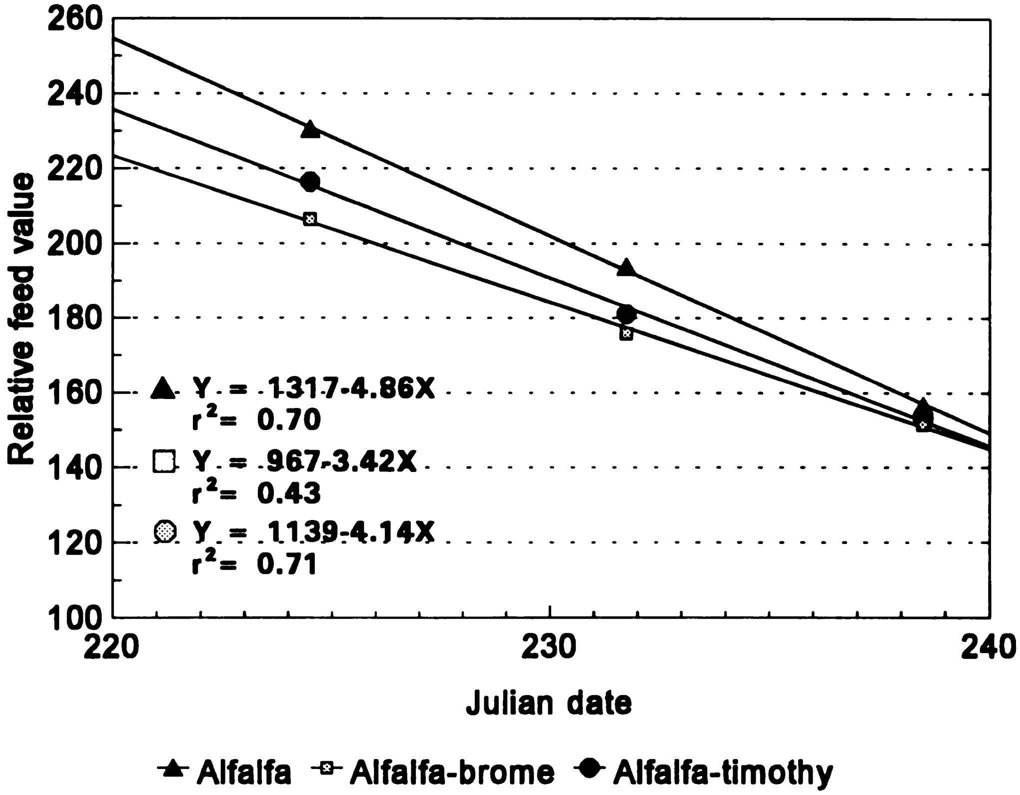

Figure A.5. Relative feed value of alfalfa and alfalfa-grass mixtures in harvest cycle three of 1992.

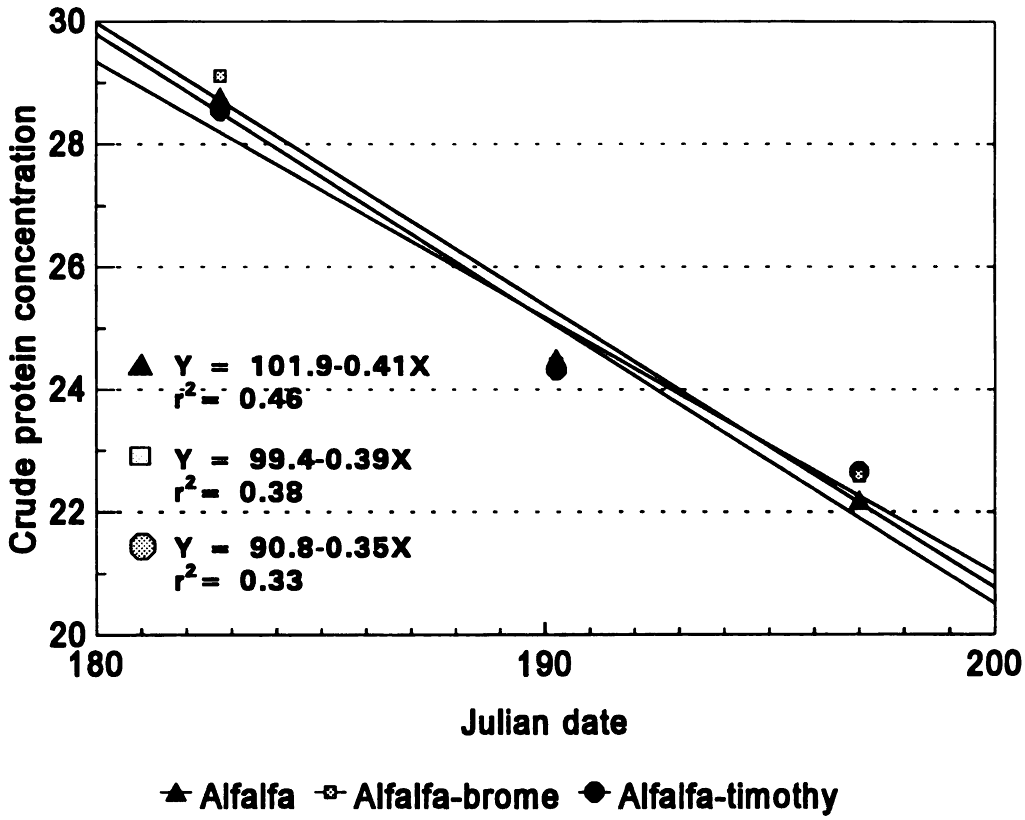

Figure A.6. Crude protein concentration of alfalfa and alfalfa-grass mixtures in harvest cycle two of 1992.

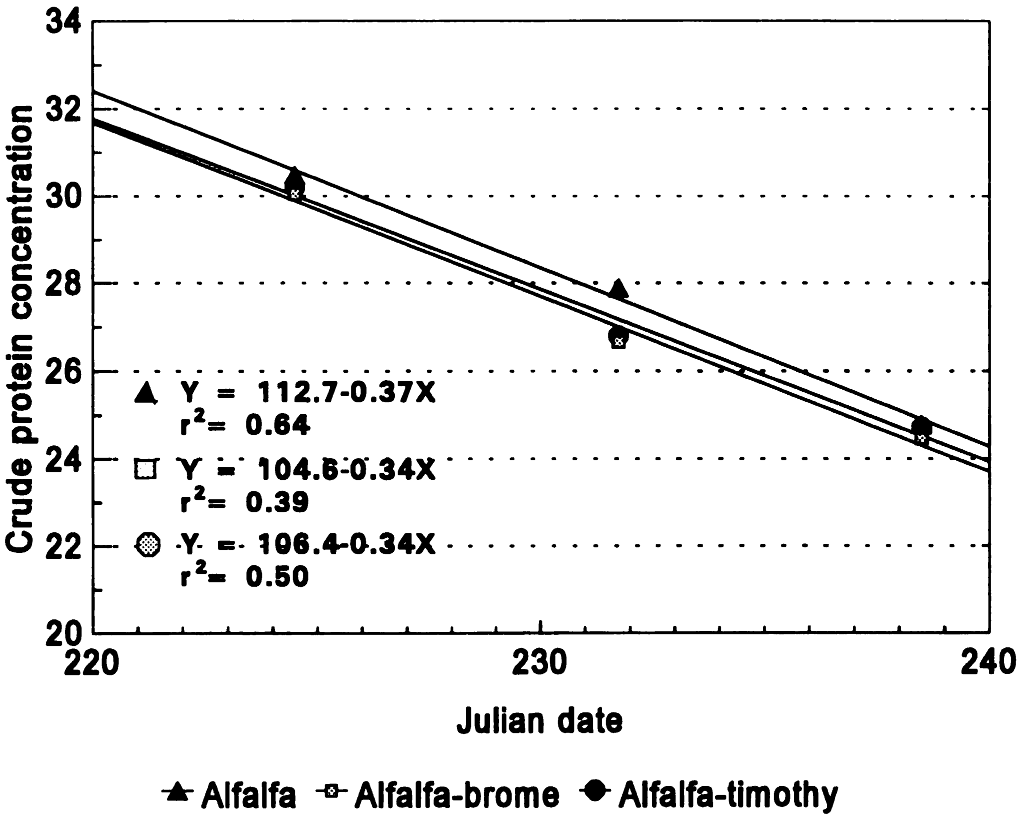

Figure A.7. Crude protein concentration of alfalfa and alfalfa-grass mixtures in harvest cycle three of 1992.

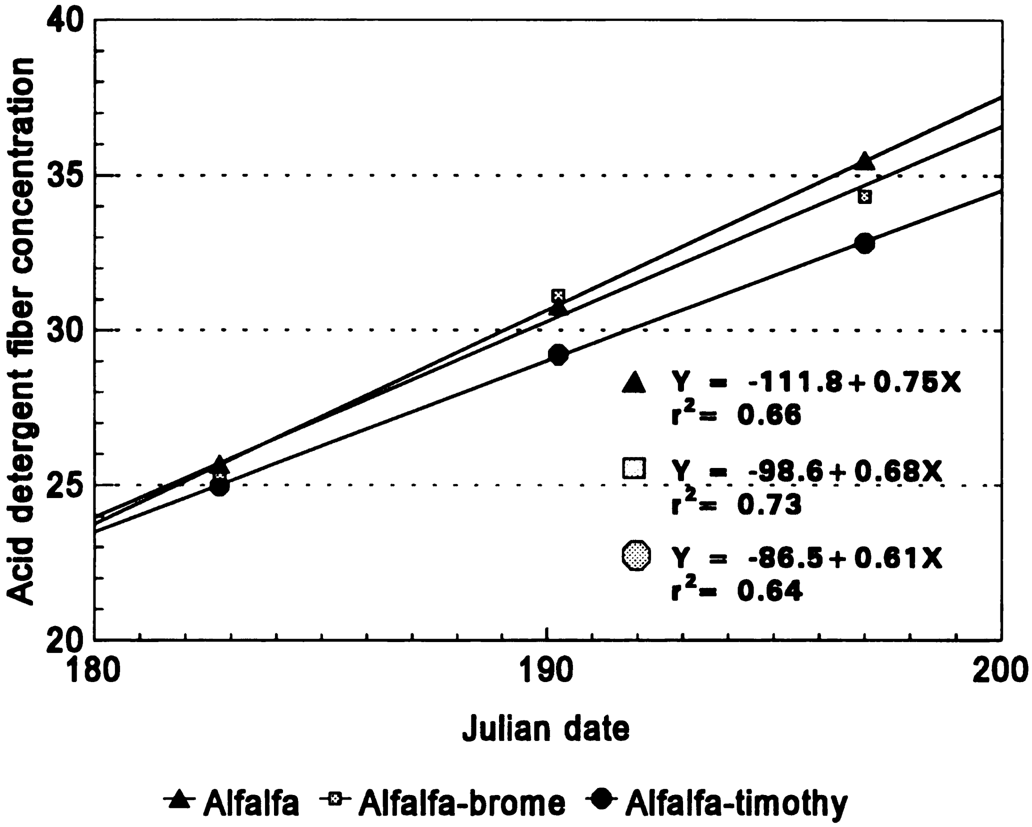

Figure A.1. Acid detergent fiber concentration of alfalfa and alfalfa-grass mixtures in harvest cycle two of 1992.

APPENDIX B

Table B.1. Predicting forage quality of alfalfa in harvest cycle one using simple regression.

FQP†	Predictor	r^2	RMSE	INT	Linear
CP‡					
	ASL§	0.82	2.51	36.3	- 0.22
	DAYS	0.78	2.72	50.9	- 0.49
	AMSW	0.75	2.92	35.8	- 3.84
	AMSC	0.73	3.01	35.1	- 4.13
	GDD	0.67	3.35	37.6	- 0.02
	ASW	0.42	4.46	34.6	- 3.69
ADF					
	AMSC	0.94	2.18	14.7	+ 7.16
	AMSW	0.93	2.44	13.7	+ 6.55
	ASL	0.9	2.87	13.7	+ 0.35
	GDD	0.87	3.26	10.2	+ 0.03
	DAYS	0.77	4.35	-7.6	+ 0.75
	ASW	0.45	6.68	16.6	+ 5.87
NDF					
	AMSC	0.94	2.27	20.8	+ 7.62
	AMSW	0.93	2.5	19.7	+ 6.98
	ASL	0.9	3.02	19.8	+ 0.37
	GDD	0.86	3.54	16.1	+ 0.03
	DAYS	0.78	4.49	-3.2	+ 0.8
	ASW	0.44	7.16	23	+ 6.16
RFV					
	ASL	0.84	28.96	306	- 2.71
	AMSC	0.81	30.81	295	- 53.13
	AMSW	0.81	30.99	303	- 48.94
	DAYS	0.73	37.19	474	- 5.83
	GDD	0.73	37.35	326	- 0.22
	ASW	0.4	55.21	283	- 44.49

† FQP, forage quality parameters; RMSE, root mean square error; INT, intercept

‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

§ ASL, alfalfa stem length; DAYS, days from 1 April; AMSW, alfalfa mean stage weight; AMSC, alfalfa mean stage count; GDD, growing degree days; ASW, alfalfa stem weight

Table B.2. Predicting forage quality of alfalfa in regrowth using simple regression.

FQP†	Predictor	r^2	RMSE	INT	Linear
CP‡					
	DAYS§	0.62	2.2	39.2	- 0.38
	ASW	0.57	2.32	33.2	- 3.11
	GDD	0.3	2.97	35.2	- 0.01
	ASL	0.22	3.13	33.2	- 0.17
	AMSC	0.17	3.23	32.3	- 1.81
	AMSW	0.13	3.3	32.4	- 1.47
ADF					
	ASW	0.63	3.2	19.9	+ 4.75
	ASL	0.63	3.2	15.5	+ 0.39
	DAYS	0.48	3.79	13.8	+ 0.49
	AMSC	0.38	4.1	18.5	+ 3.87
	AMSW	0.34	4.24	17.7	+ 3.32
	GDD	0.31	4.36	17.4	+ 0.01
NDF					
	DAYS	0.65	3.82	12.6	+ 0.7
	ASW	0.45	4.75	24.5	+ 5.01
	GDD	0.4	4.98	18.1	+ 0.02
	ASL	0.29	5.42	22.3	+ 0.3
	AMSC	0.21	5.71	24.2	+ 3.61
	AMSW	0.16	5.91	24.2	+ 2.86
RFV					
	DAYS	0.66	29.39	361	- 5.57
	ASW	0.49	36.3	268	- 40.79
	GDD	0.41	39.06	317	- 0.14
	ASL	0.3	42.3	284	- 2.71
	AMSC	0.21	44.93	269	- 28.64
	AMSW	0.15	46.63	267	- 22.28

† FQP, forage quality parameters; RMSE, root mean square error; INT, intercept

‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

§ DAYS, days from initiation of regrowth; ASW, alfalfa stem weight; GDD, growing degree days; ASL, alfalfa stem length; AMSC, alfalfa mean stage count; AMSW, alfalfa mean stage weight

Table B.3. Predicting forage quality of mixtures in harvest cycle one using simple regression.

FQP†	Predictor	r^2	RMSE	INT	Linear
CP‡	DAYS§	0.69	2.83	43.5	- 0.4
	GSL	0.65	3.05	32.1	- 0.17
	ASL	0.64	3.06	30.5	- 0.17
	GMSW	0.63	3.11	35.7	- 5.78
	GDD	0.59	3.29	32.4	- 0.01
	GMSC	0.57	3.35	38.5	- 8.43
	AMSC	0.54	3.48	29.2	- 3.01
	AMSW	0.54	3.49	29.6	- 2.76
	GSW	0.5	3.63	27.6	- 7.11
	ASW	0.25	4.45	29	- 3.5
ADF	GDD	0.88	2.86	12	+ 0.03
	AMSC	0.88	2.87	17.7	+ 6.27
	AMSW	0.88	2.92	16.9	+ 5.75
	ASL	0.88	2.93	16.4	+ 0.32
	GSL	0.79	3.85	14.3	+ 0.31
	DAYS	0.77	4.02	-4.4	+ 0.69
	GSMW	0.75	4.18	8.1	+ 10.24
	GMSC	0.61	5.23	4.9	+ 14.01
	ASW	0.33	6.82	19.4	+ 6.6
	GSW	0.24	7.27	25.6	+ 8.15
NDF	GDD	0.84	3.91	21.5	+ 0.03
	ASL	0.83	4.03	26.5	+ 0.36
	AMSC	0.8	4.32	28.2	+ 6.97
	AMSW	0.79	4.4	27.4	+ 6.38
	DAYS	0.77	4.66	1.8	+ 0.81
	GSL	0.76	4.79	24	+ 0.35
	GMSW	0.76	4.8	16.2	+ 12
	GMSC	0.64	5.81	11.7	+ 16.8
	GSW	0.4	7.5	34.9	+ 12.22
	ASW	0.27	8.28	30.7	+ 7.01
RFV	ASL	0.79	23.33	236	- 1.84
	GDD	0.77	24.43	259	- 0.16
	AMSC	0.75	25.2	226	- 35.45
	AMSW	0.75	25.3	231	- 32.56
	DAYS	0.75	25.55	364	- 4.18
	GSL	0.73	26.5	249	- 1.8
	GMSW	0.72	26.69	289	- 61.56
	GMSC	0.62	31.27	312	- 86.67
	GSW	0.35	40.89	191	- 60.12
	ASW	0.29	42.91	217	- 37.71

† FQP, forage quality parameters; RMSE, root mean square error; INT, intercept

‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

§ DAYS, days from 1 April; GSL, grass stem length; ASL, alfalfa stem length; GMSW, grass mean stage weight; GDD, growing degree days; GMSC, grass mean stage count; AMSC, alfalfa mean stage count; AMSW, alfalfa mean stage weight; GSW, grass stem weight; ASW, alfalfa stem weight

Table B.4 Predicting forage quality of mixtures in regrowth using simple regression.

FQP†	Predictors	r^2	RMSE	INT	Linear
CP‡	GDD§	0.65	2.01	38.9	- 0.02
	DAYS	0.6	2.15	39.2	- 0.43
	AMSC	0.51	2.39	33.9	- 3.5
	GMSW	0.41	2.61	36.9	- 6.8
	ASW	0.38	2.69	31.9	- 2.9
	AMSW	0.36	2.73	32.7	- 2.34
	GMSC	0.34	2.77	38.8	- 9.04
	GSW	0.29	2.87	29.1	- 18.42
	GSL	0.18	3.08	32.4	- 0.2
	ASL	0.14	3.15	29.6	- 0.1
ADF	ASW	0.83	1.89	17.8	+ 5.64
	ASL	0.78	2.11	19.0	+ 0.29
	AMSC	0.7	2.46	16.9	+ 5.46
	AMSW	0.6	2.85	17.8	+ 4.01
	GSL	0.51	3.17	15.6	+ 0.44
	DAYS	0.39	3.54	14.9	+ 0.47
	GDD	0.3	3.79	17.3	+ 0.02
	GMSW	0.12	4.25	20.8	+ 5.14
	GMSC	0.1	4.3	19.4	+ 6.86
	GSW	0.08	4.33	26.6	+ 14.25
NDF	AMSC	0.77	2.41	22.5	+ 6.36
	ASW	0.64	3.01	25.6	+ 5.57
	AMSW	0.62	3.1	24	+ 4.53
	ASL	0.61	3.16	26.8	+ 0.29
	DAYS	0.44	3.76	19.9	+ 0.55
	GSL	0.43	3.8	22.9	+ 0.45
	GDD	0.41	3.87	21.5	+ 0.02
	GSW	0.34	4.1	31.9	+ 29.34
	GMSW	0.23	4.43	24.6	+ 7.61
	GMSC	0.15	4.65	23.7	+ 9.24
RFV	AMSC	0.77	15.95	267	- 42.43
	ASW	0.69	18.64	249	- 38.4
	AMSW	0.64	20.1	258	- 30.68
	ASL	0.6	21.35	238	- 1.89
	GSL	0.47	24.46	268	- 3.14
	DAYS	0.45	24.95	285	- 3.7
	GDD	0.41	25.87	273	- 0.13
	GSW	0.29	28.21	203	- 182.8
	GMSW	0.21	29.87	250	- 48.85
	GMSC	0.14	31.04	258	- 60.69

† FQP, forage quality parameters; RMSE, root mean square error; INT, intercept

‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

§ GDD, growing degree days; DAYS, days from initiation of regrowth; GSL, grass stem length; ASL, alfalfa stem length; GMSW, grass mean stage weight; GMSC, grass mean stage count; AMSC, alfalfa mean stage count; AMSW, alfalfa mean stage weight; GSW, grass stem weight; ASW, alfalfa stem weight

Table B.5. Best 1, 2, and 3 factor regression models for forage quality of alfalfa and mixtures in harvest cycle one.

Forage	Factors	r^2	RMSE†	MODEL
Alfalfa				
	1	0.82	2.51	CP‡=36.3 - 0.22(ASL§)
	2	0.82	2.46	CP=41.9 - 0.15(ASL) - 0.18(DAYS)
	3	0.83	2.38	CP=37.5 - 5.69(AMSW) + 6.3(AMSC) - 0.23(ASL)
	1	0.94	2.18	ADF=14.7 + 7.16(AMSC)
	2	0.95	2.04	ADF=14.1 + 5.15(AMSC) + 0.11(ASL)
	3	0.95	2.01	ADF=18 + 5.23(AMSC) + 0.15(ASL) - 0.13(DAYS)
	1	0.94	2.27	NDF=20.8 + 7.62(AMSC)
	2	0.95	2.12	NDF=20.2 + 5.51(AMSC) + 0.11(ASL)
	3	0.95	2.1	NDF=20.6 + 5.29(AMSC) + 0.14(ASL) - 0.63(ASW)
	1	0.84	28.96	RFV=306 - 2.71(ASL)
	2	0.85	27.64	RFV=309 - 20.33(AMSW) - 1.67(ASL)
	3	0.85	27.67	RFV=300 - 31.71(AMSW) - 1.69(ASL) + 0.06(GDD)
Mixtures				
	1	0.69	2.83	CP=43.5 - 0.4(DAYS)
	2	0.76	2.54	CP=32.9 - 0.01(GDD) - 4.57(GSW)
	3	0.77	2.46	CP=35.2 - 2.36(GMSC) - 0.01(GDD) - 3.95(GSW)
	1	0.88	2.86	ADF=12 + 0.03(GDD)
	2	0.92	2.33	ADF=13.3 + 0.16(ASL) + 0.01(GDD)
	3	0.93	2.24	ADF=14.7 + 0.21(ASL) + 0.01(GDD) - 1.37(ASW)
	1	0.84	3.91	NDF=21.5 + 0.03(GDD)
	2	0.90	3.01	NDF=20.8 + 0.03(GDD) + 5.50(GSW)
	3	0.91	2.85	NDF=18.7 + 2.75(GMSW) + 0.02(GDD) + 4.54(GSW)
	1	0.79	23.33	RFV=236 - 1.84(ASL)
	2	0.82	21.46	RFV=262 - 0.14(GDD) - 26.05(GSW)
	3	0.84	20.37	RFV=278 - 19.71(GMSW) - 0.10(GDD) - 19.23(GSW)

† RMSE, root mean square error

‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

§ ASL, alfalfa stem length; DAYS, days from 1 April; GMSW, grass mean stage weight; GDD, growing degree days; GMSC, grass mean stage count; AMSC, alfalfa mean stage count; AMSW, alfalfa mean stage weight; GSW, grass stem weight; ASW, alfalfa stem weight

Table B.6. Best 1, 2, and 3 factor regression models for forage quality of alfalfa and mixtures in regrowth.

Forage	Factors	r^2	RMSE†	MODEL
Alfalfa				
	1	0.62	2.2	CP‡=39.2 - 0.38(DAYS§)
	2	0.74	1.81	CP=38.4 - 0.25(DAYS) - 1.82(ASW)
	3	0.75	1.77	CP=38.4 - 0.4(DAYS) + 0.005(GDD) - 1.53(ASW)
	1	0.63	3.2	ADF=19.9 + 4.75(ASW)
	2	0.78	2.43	ADF=15 + 0.24(ASL) + 2.97(ASW)
	3	0.8	2.36	ADF=13 + 0.22(ASL) + 0.12(DAYS) + 2.49(ASW)
	1	0.65	3.82	NDF=12.6 + 0.7(DAYS)
	2	0.69	3.56	NDF=13.5 + 0.54(DAYS) + 2.12(ASW)
	3	0.69	3.57	NDF=14.3 - 0.66(AMSW) + 0.58(DAYS) + 2.21(ASW)
	1	0.66	29.39	RFV=361 - 5.57(DAYS)
	2	0.72	26.82	RFV=353 - 4.22(DAYS) - 18.34(ASW)
	3	0.72	26.68	RFV=346 + 6.20(AMSW) - 4.6(DAYS) - 19.21(ASW)
Mixtures				
	1	0.65	2.01	CP=38.9 - 0.02(GDD)
	2	0.74	1.75	CP=38.9 - 0.01(GDD) - 10.47(GSW)
	3	0.78	1.6	CP=41 - 2.73(GMSW) - 0.01(GDD) - 9.66(GSW)
	1	0.83	1.89	ADF=17.8 + 5.64(ASW)
	2	0.87	1.62	ADF=17.5 + 0.14(ASL) + 3.47(ASW)
	3	0.89	1.5	ADF=16.5 + 1.55(AMSC) + 0.11(ASL) + 2.69(ASW)
	1	0.77	2.41	NDF=22.5 + 6.36(AMSC)
	2	0.83	2.06	NDF=23.4 + 4.92(ASW) + 21.91(GSW)
	3	0.87	1.85	NDF=22.1 + 2.67(AMSC) + 3.08(ASW) + 15.68(GSW)
	1	0.77	15.95	RFV=267 - 42.43(AMSC)
	2	0.84	13.34	RFV=262 - 34.55(ASW) - 130.63(GSW)
	3	0.87	12.05	RFV=270 - 16.63(AMSC) - 23.05(ASW) - 91.83(GSW)

† RMSE, root mean square error

‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

§ DAYS, days from initiation of regrowth; ASL, alfalfa stem length; GMSW, grass mean stage weight; GDD, growing degree days; AMSC, alfalfa mean stage count; AMSW, alfalfa mean stage weight; GSW, grass stem weight; ASW, alfalfa stem weight

Table B.7. Prediction models based on stepwise regression of all factors for alfalfa and alfalfa-grass mixtures in harvest cycle one and regrowth.

Harvest cycle	Forage	r^2	RMSE†	MODEL
One	Alfalfa	0.82	2.51	CP‡=36.3 - 0.22(ASL§)
		0.95	2.04	ADF=14.1 + 5.15(AMSC) + 0.11(ASL)
		0.95	2.12	NDF=20.2 + 5.51(AMSC) + 0.11(ASL)
		0.85	27.64	RFV=309 - 20.33(AMSW) - 1.67(ASL)
	Mixtures	0.78	2.41	CP=41.3 - 2.01(GMSW) - 0.31(DAYS) + 1.95(ASW) - 2.51(GSW)
		0.94	2.11	ADF=15.1 + 5.65(GMSW) - 5.02(GMSC) + 0.18(ASL) + 0.01(GDD) - 1.48(ASW)
		0.93	2.53	NDF=21.6 + 3(GMSW) + 0.13(ASL) + 0.02(GDD) - 2.75(ASW) + 4(GSW)
		0.84	20.37	RFV=278 - 19.71(GMSW) - 0.1(GDD) - 19.23(GSW)
Regrowth	Alfalfa	0.74	1.81	CP=38.4 - 0.25(DAYS) - 1.82(ASW)
		0.78	2.43	ADF=15 + 0.24(ASL) + 2.97(ASW)
		0.69	3.56	NDF=13.5 + 0.54(DAYS) + 2.12(ASW)
		0.72	26.82	RFV=353 - 4.22(DAYS) - 18.34(ASW)
	Mixtures	0.8	1.52	CP=40.7 - 2.41(GMSW) - 0.01(GDD) - 0.88(ASW) - 9.63(GSW)
		0.89	1.5	ADF=16.5 + 1.55(AMSC) + 0.11(ASL) + 2.69(ASW)
		0.88	1.76	NDF=19.3 + 2.84(GMSW) + 2.23(AMSC) + 0.16(ASL) + 14.55(GSW)
		0.87	12.05	RFV=270 - 16.63(AMSC) - 23.05(ASW) - 91.83(GSW)

† RMSE, root mean square error

‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

§ ASL, alfalfa stem length; DAYS, days from 1 April in Harvest cycle one and days from initiation of regrowth in regrowth; GMSW, grass mean stage weight; GDD, growing degree days; AMSC, alfalfa mean stage count; AMSW, alfalfa mean stage weight; GSW, grass stem weight; ASW, alfalfa stem weight

Table B.8. Comparison of r^2 and RMSE† among the best simple, 2 and 3 factor multiple, and stepwise equations.

			r^2				RMSE			
Harvest cycle	Treatment		1	2	3	Stepwise	1	2	3	Stepwise
One	Alfalfa									
		CP‡	0.82	0.82	0.83	0.82	2.51	2.46	2.38	2.51
		ADF	0.94	0.95	0.95	0.95	2.18	2.04	2.01	2.04
		NDF	0.94	0.95	0.95	0.95	2.27	2.12	2.1	2.12
		RFV	0.84	0.85	0.85	0.85	28.96	27.64	27.67	27.67
	Mixtures									
		CP	0.69	0.76	0.77	0.78	2.83	2.54	2.46	2.41
		ADF	0.88	0.92	0.93	0.94	2.85	2.33	2.24	2.11
		NDF	0.84	0.90	0.91	0.93	3.91	3.01	2.85	2.53
		RFV	0.79	0.82	0.84	0.84	23.33	21.46	20.37	20.37
Regrowth	Alfalfa									
		CP	0.62	0.74	0.75	0.74	2.2	1.81	1.77	1.81
		ADF	0.63	0.78	0.8	0.78	3.2	2.43	2.36	2.43
		NDF	0.65	0.69	0.69	0.69	3.82	3.56	3.57	3.56
		RFV	0.66	0.72	0.72	0.72	29.39	26.82	26.68	26.82
	Mixtures									
		CP	0.65	0.74	0.78	0.8	2.01	1.75	1.6	1.5
		ADF	0.83	0.87	0.89	0.89	1.89	1.62	1.5	1.5
		NDF	0.77	0.83	0.87	0.88	2.41	2.06	1.85	1.76
		RFV	0.77	0.84	0.87	0.87	15.95	13.34	12.05	12.05

† RMSE, root mean square error
‡ CP, crude protein concentration; ADF, acid detergent fiber concentration; NDF, neutral detergent fiber concentration; RFV, relative feed value

Table B.9. High, low, and mean values for forage quality characteristics used to develop equations in alfalfa.

Harvest cycle	Characteristic†	HIGH	LOW	MEAN
One				
	CP	39.9	18.4	26.5
	ADF	48.8	14	29.5
	NDF	56.6	19.9	36.6
	RFV	364	84	185
	AMSW	5.57	0.56	2.39
	AMSC	5.07	0.38	2.04
	ASL	88.5	10	44.2
	GDD	1306	258	649
	DAYS	66	35	49
	ASW	4.42	0.10	2.17
Regrowth				
	CP	35.1	21.4	27.8
	ADF	39.3	16.9	28.2
	NDF	47.6	20.3	33.2
	RFV	332	114	197
	AMSW	5.82	1.36	3.17
	AMSC	5.10	1.11	2.52
	ASL	61.3	18	32.5
	GDD	1348	493	856
	DAYS	40	17	30
	ASW	3.57	0.09	1.76

† CP, crude protein concentration (%); ADF, acid detergent fiber concentration (%); NDF, neutral detergent fiber concentration (%); RFV, relative feed value; AMSW, alfalfa mean stage weight; AMSC, alfalfa mean stage count; ASL, alfalfa stem length (cm); GDD, growing degree days; DAYS, days from 1 April in harvest cycle one and from initiation of regrowth in regrowth; ASW, alfalfa stem weight (g)

Table B.10. High, low, and mean values for forage quality characteristics used to develop equations for mixtures.

Harvest cycle	Characteristic†	HIGH	LOW	MEAN
One				
	CP	38.8	13.6	22.8
	ADF	48.2	16.4	31.1
	NDF	62.9	24.4	43.2
	RFV	290	77	150
	AMSW	5.92	0.34	2.45
	GMSW	3.61	1.15	2.21
	AMSC	5.10	0.20	2.12
	GMSC	2.83	1.15	1.84
	ASL	98.2	9.8	45.7
	GSL	100.8	16.2	53.4
	GDD	1306	258	698
	DAYS	66	35	51
	ASW	3.40	0.24	1.75
	GSW	2.83	0.05	0.64
Regrowth				
	CP	34.1	20.9	26.2
	ADF	38.4	21.9	28.9
	NDF	45.4	26.5	36.5
	RFV	252	121	173
	AMSW	5.52	0.86	2.76
	GMSW	2.55	1.15	1.58
	AMSC	3.59	0.68	2.20
	GMSC	2.17	1.08	1.39
	ASL	76.8	15.8	33.9
	GSL	46.7	17.8	30.2
	GDD	1065	493	757
	DAYS	40	21	30
	ASW	3.54	0.60	1.96
	GSW	0.53	0.03	0.16

† CP, crude protein concentration (%); ADF, acid detergent fiber concentration (%); NDF, neutral detergent fiber concentration (%); RFV, relative feed value; AMSW, alfalfa mean stage weight; ASL, alfalfa stem length (cm); GSL, grass stem length (cm); DAYS, days from 1 April in harvest cycle one and from initiation of regrowth in regrowth; GMSW, grass mean stage weight; GDD, growing degree days; GMSC, grass mean stage count; AMSC, alfalfa mean stage count; AMSW, alfalfa mean stage weight; GSW, grass stem weight (g); ASW, alfalfa stem weight (g)

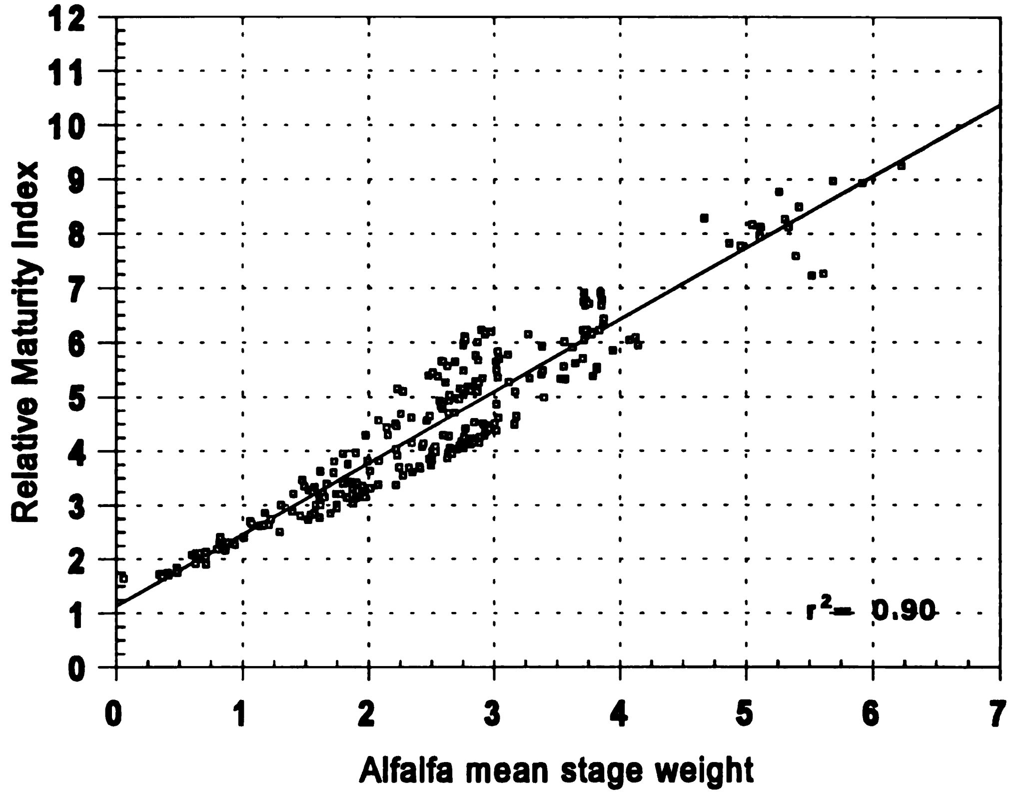

Figure B.1. Alfalfa mean stage weight plotted against the corresponding index values for both mixtures in all harvest cycles, locations, and replications.

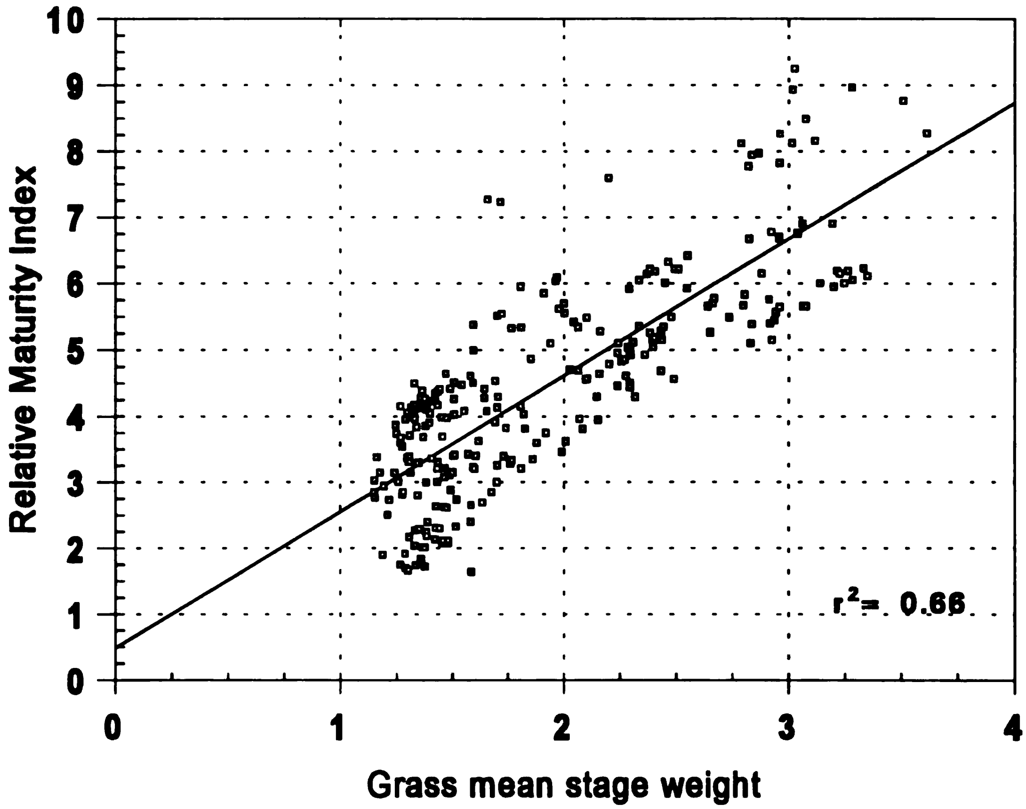

Figure B.2. Grass mean stage weight plotted against the corresponding index values for both mixtures in all harvest cycles, locations, and replications.

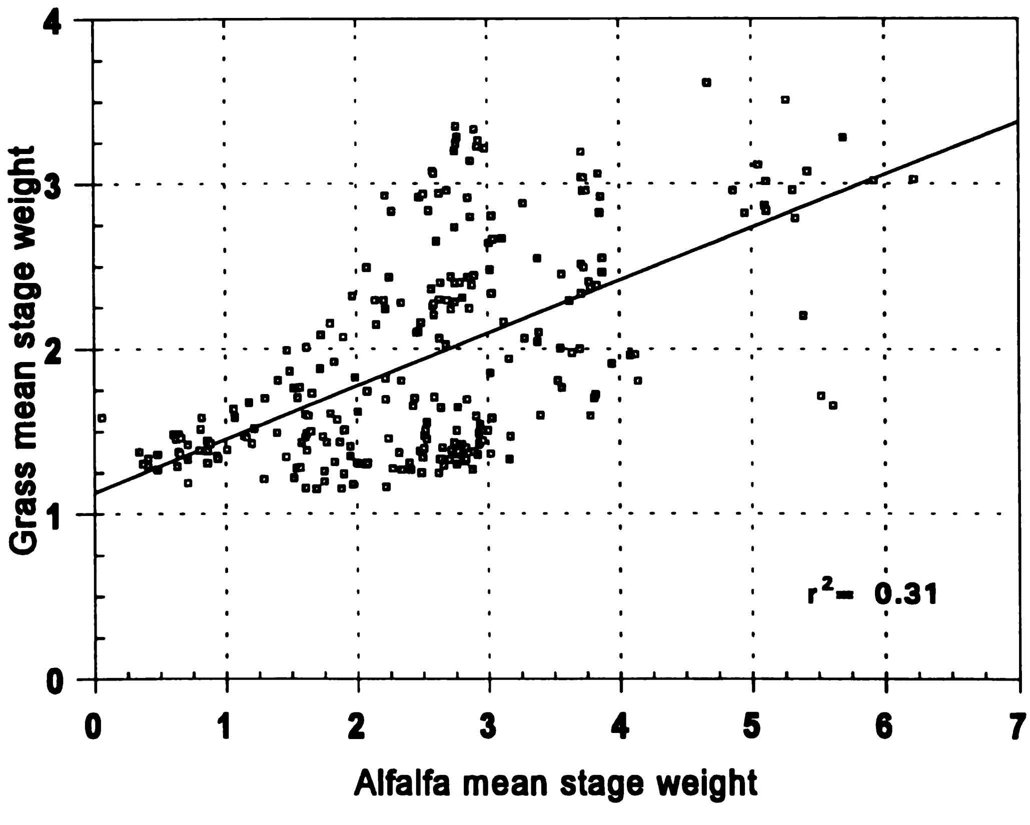

Figure B.3. Alfalfa mean stage weight plotted against grass mean stage weight for both mixtures in all harvest cycles, locations, and replications.