Fall Harvest Management of Alfalfa

by

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(ABSTRACT)

Alfalfa (*Medicago sativa* L.) harvest schedules are often interrupted by rainfall, unfavorable environmental conditions for growth, and unfavorable weather for hay curing. Interruptions in alfalfa harvest schedules can delay the final harvest until dates considered critical to winter survival. Harvests made between 20 September and 30 October are considered detrimental to the persistence of alfalfa stands in geographical areas such as western Virginia. The objectives of this study were to determine if a critical period for fall harvest management actually exists in Virginia, if length of the growth period prior to fall harvest (GPPFH) influences plant persistence and succeeding spring yields, and if photosynthesis offsets respiration and allows more flexible fall harvest management than is currently recommended.

Final alfalfa harvests were made 10, 20, or 30 September or 10, 20, or 30 October for 2 years in two identical experiments. Alfalfa was managed to achieve 30, 40, 50, or 60 days of growth prior to each fall harvest date. Total nonstructural carbohydrates (TNC) in tap roots and population of surviving plants were determined in December and March. Succeeding spring yields were measured in May. Zero, 45, and 60 percent shade were imposed following four fall harvest dates in a supplemental study to investigate the influence of photosynthesis on TNC levels and plant persistence. In the supplemental study, CO_2 exchange and TNC were measured at 2 week intervals in the fall following four fall harvest dates.

Harvests made during the fall period previously considered as critical did not cause over-wintering plant losses. Length of growth period prior to fall harvests was more important than date of fall harvest in making management decisions for fall harvest. Although spring yield generally increased with length of GPPFH, the spring growth appeared healthy; so one might expect a few days of delay prior to the first spring harvest to eliminate any detrimental influence of short length of GPPFH. Succeeding spring yields and TNC levels were generally high for the 50-day GPPFH, and fall harvest yield offset any reductions in spring yield observed in this study. In addition, fall harvests made with a 50-day GPPFH maintained quality and leafiness as opposed to a 60-day GPPFH.

Fall regrowth and plant maintenance were not dependent on root TNC accumulation. Photosynthesis offset TNC losses for regrowth and maintenance during the fall. High photosynthetic rates as compared to respiration occurred because temperatures were within the optimum range for photosynthesis of alfalfa during 68 % of the daylight hours from September through November.

There was no critical period for fall harvest management with the the environmental conditions experienced during this study. A 50 or 60-day GPPFH prior to fall harvest was adequate for plant persistence and high succeeding spring yields.

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Fall Harvest Management of Alfalfa: I Date of Fall Harvest and Length of Growth Period Prior to Fall Harvest

Abstract

Alfalfa (*Medicago sativa* L.) harvest schedules are often interrupted by various factors. Interruptions in alfalfa harvest schedules can delay the final harvest to dates considered critical to winter survival. The objectives of this study were to determine if a critical period for fall harvest management actually exists in Virginia and if length of the growth period prior to fall harvest (GPPFH) influences plant persistence and succeeding spring yields.

Final alfalfa harvest was made 10, 20, or 30 September or 10, 20, or 30 October for 2 years in two identical experiments. Alfalfa was managed to achieve a 30, 40, 50, or 60-day GPPFH. Total nonstructural carbohydrates (TNC) in tap roots and population of surviving plants were determined in December and March. Succeeding spring yields were measured in May as a measure accumulated influence of management treatments.

Harvests made at any time during the fall period did not cause over-wintering plant losses. Length of GPPFH was more important than date of fall harvest in making management decisions for fall harvest. Although spring yield generally increased with length of GPPFH, the spring growth appeared healthy; so one would expect a few days of delay prior to the spring harvest would eliminate any detrimantal influence of short length of GPPFH. Succeeding spring yields and TNC levels were generally high for the 50-day growth period and fall harvest yield would offset any reductions in spring yield observed in this study. In addition, fall harvests made with a 50-day GPPFH maintained quality and leafiness as opposed to the 60-day GPPFH.

There was no critical period for fall harvest management with the the environmental conditions experienced during this study. A 50 or 60-day growth period prior to fall harvest was adequate for plant persistence and high succeeding spring yields.

Introduction

Alfalfa (*Medicago sativa* L.) harvest schedules are often interrupted by rainfall, spring and summer grazing, pest invasions, less mature harvests to provide high nutrition, and unfavorable environmental conditions for growth and hay curing. Interruptions in alfalfa harvest schedules can delay the final harvest to dates considered critical to winter survival. Harvests made between 20 September and 20 October are considered detrimental to persistence of alfalfa stands in a climate such as Virginia.

A majority of the research that has provided the basis for current recommendations for fall alfalfa management has been conducted in the Northern United States and Canada (Collins and Taylor, 1980). Research in northern Alabama (Mays and Evans, 1973) and northern Virginia (Bryant and Blaser, 1964) suggest that a harvest made during late September and early October may not be detrimental to persistence of alfalfa in the Southeastern United States. In addition, Scholar, et al. (1983) found no influence of fall harvest date on alfalfa persistence in Oklahoma. Tesar and Yager (1985) suggested that fall harvest management practices should also be reevaluated in the North Central and Northeast United States.

Mays and Evans (1973) suggested photosynthesis occurring on sunny fall days might offset total nonstructural carbohydrate (TNC) losses in tap roots due to respiration and regrowth during the fall. Because of declining quality when harvests are delayed and the decline of favorable hay making conditions, recommendations for harvests made during the critical fall period could be advantageous to farmers.

Accumulation of TNC in tap roots during early fall is considered essential to the persistence of alfalfa (Willard, 1934; and Smith, 1968). However, no data point to a threshold TNC concentration above which no additional benefit to winter survival would result. Parsons and Davis (1960), Kust and Smith (1961), and Fulkerson (1970) demonstrated that fall harvests made prior to first killing frost reduced succeeding stands and yields in Ohio, Wisconsin, and Ontario, Canada, respectively. Nelson (1925) reported that fall temperature and rainfall in addition to date of last harvest influence fall growth for winter protection and the amount of winter-killing. In contrast, Mays and Evans (1973) reported that 'Williamsburg' alfalfa was tolerant to fall harvests during September and early October in northern Alabama. In addition, Bryant and Blaser (1964) reported that yields were improved by delaying the final harvest to late September with a four harvest system in northern Virginia.

A close relationship of persistence and spring yields exists with the level of TNC accumulation as observed by Grandfield (1935), Graumann et al. (1954), and Smith (1962). Bula and Smith (1954) found that as much as 50 % of TNC was utilized during the winter for respiration in Wisconsin. Kust and Smith (1961) reported that final harvest taken on 1 October as opposed to 30 August reduced TNC levels and succeeding spring yields in both three and four cut harvest schedules. Alternatively, Reynolds (1970) reported that TNC concentrations at the end of the second year were not positively correlated with yield in the spring of the third year under various harvest schedules in Tennessee.

Fall harvests are more likely to cause stand losses when TNC levels are low due to a short growth period prior to final harvest (Jung, 1975). Sprague et al., (1964) reported that fall alfalfa harvests at immature stages of growth decreased survival much more than harvests at immature stages during the spring and early summer in New Jersey.

Crown bud development has also been shown to be influenced by fall harvest management (Leach, 1969). Variations in regrowth were attributed to changes in shoot size and numbers (Leach, 1968). Grandfield (1943) reported that plants harvested on 8

October produced fewer crown buds than plants that were not cut in the fall in Kansas. Silkett et al. (1937) demonstrated that fall harvests made during September reduced both crown bud development and the number of stems produced in the succeeding spring in Michigan. Harvests made during October slightly reduced crown bud development and numbers of stems produced in the succeeding spring. October harvests may not have reduced bud and stem development as much as harvests made during September because of the occurrence of killing frost in early October.

Flowering is often used as an indication of physiological maturity and as a basis for harvest management. The short day length during the early fall in Virginia is not conducive to flowering. Therefore, fall harvest recommendations based on calendar date and length of the rest period may be of more use than maturity in Virginia.

This research was designed to determine if harvests made during late September and early October are detrimental to the persistence of alfalfa stands. Additionally, this research was designed to determine how many days of growth are required prior to harvests made during late September and early October to ensure that alfalfa stands are not damaged.

Materials and Methods

Field Study

'Arc' alfalfa was established at the Virginia Polytechnic Institute and State University Agronomy farm near Blacksburg, VA at 80°25' W longitude, 37°11' N latitude, and 610 m elevation. The soil was a mixture of Landisburg silt loam (fine-loamy, mixed, mesic Typic Fragidult) and Greendale silt loam (fine-loamy, siliceous, mesic Fluventic Dystrochrept). Soil test indicated 119 kg extractable P ha^{-1}, 352 kg exchangeable K ha^{-1} and a pH of 6.9 in the winter of 1983. Phosphorus and potassium were applied each fall according to soil test recommendations.

The experimental area was divided into two sites. Site one was planted in April 1983 and site two was planted in April 1984. 'Arc' alfalfa was broadcast seeded on both sites at a rate of 20.4 kg ha^{-1}. Harvest treatments were imposed on site one in 1984 and 1985 and on site two during 1985 and 1986.

The experimental design was a split plot with four replicates. Dates of fall harvest served as the main plots and lengths of growth period prior to fall harvest as subplots. Dates of fall harvests were 10, 20, or 30 September or 10, 20, or 30 October (Fig. 1). Lengths of growth period prior to each date of fall harvest (GPPFH) were 30, 40, 50, or 60 days.

The first harvest of each growing season was made about 20 May and subsequent summer harvests were staggered in order to impose various harvest dates and rest peri-

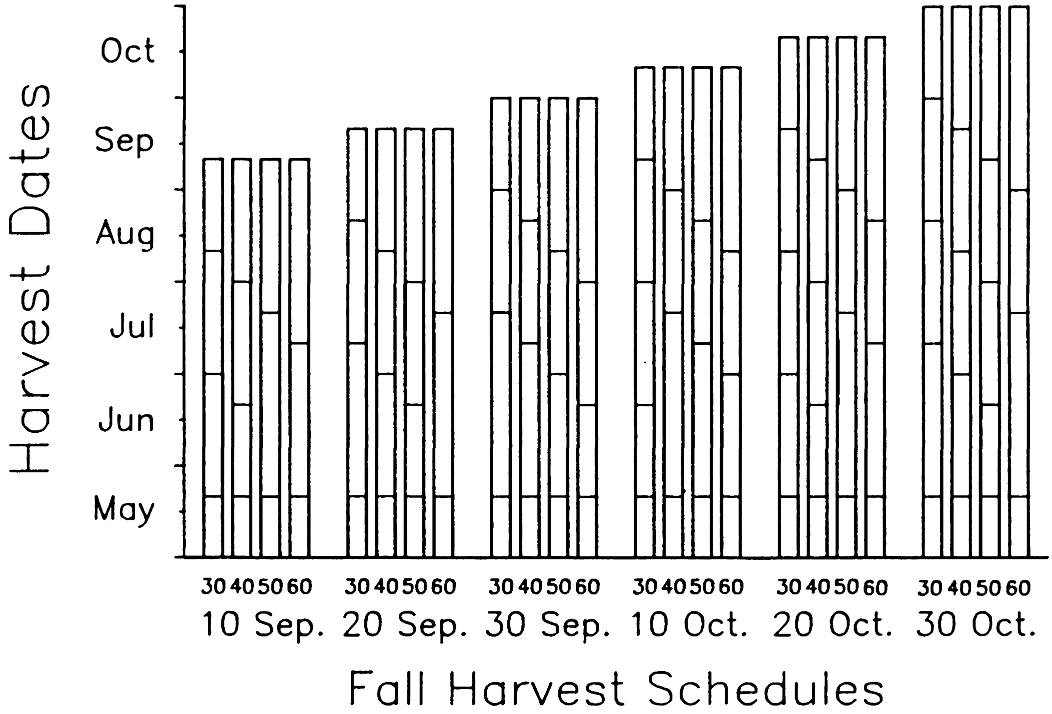

Fig. 1. Harvest schedules to achieve 30, 40, 50, and 60 days of growth prior to six dates of fall alfalfa harvest. Harvest dates are indicated by horizontal lines.

ods. Each treatment was allowed at least 40 days of growth prior to the next to last harvest to minimize the influence of staggered previous harvests on fall treatments.

A 1 by 8 m strip of each plot was harvested with a sickle-bar mower at a cutting height of 6.5 cm for the fall harvests in 1984. A 1 by 6.5 m strip of each plot was harvested to determine yield of fall (1984 to 86) and spring (1985 to 87) harvests. The harvested alfalfa was then subsampled for determination of dry matter concentration. The succeeding spring growth in 1987 contained weeds in many plots and each plot was subsampled for botanical composition. These yields were reported as weed-free alfalfa. In addition, the 1986 fall harvests were subsampled for determination of herbage N concentration by the Kjeldahl method (A.O.A.C., 1975).

Tap roots for TNC analysis were dug from each treatment at site one in mid-December 1984 and mid-March 1985. Tap roots were collected from each treatment at site two in mid-December 1985 and 1986 and mid-March 1986. In addition, TNC samples were collected at the penultimate harvest at site two in 1985 to ensure that the staggered harvest schedules during the summer were not influencing TNC levels prior to the imposition of fall harvest treatments. The roots were trimmed, washed, dried at 65°C, and ground through a Wiley mill to pass through a 1 mm screen. Total nonstructural carbohydrates were solubilized and hydrolyzed (Smith, 1969) and assayed as glucose equivalents (Davis, 1976).

The number of live plants in a 0.37 m^2 quadrate was recorded in early December 1984 for each plot at site one. Flags were placed in alternate corners of the quadrates to ensure that the same area could be sampled again. The number of live plants per quadrate was recorded again in late March 1984. Two 0.35 by 0.35 m areas were dug in each plot at site two in mid-December 1985 and mid-March 1986 to determine the number of live plants per unit of land area. The number of stems produced per square meter in the field was recorded prior to the spring harvest for 1985 at site one.

Plant Vigor Study

Three uniform plants were selected from each plot at site one on 14 Dec. 1984 and at site two on 15 Dec. 1985. Roots were trimmed 10 cm below the crown and branch roots were removed. All top growth was removed at 5 cm above the crown and plants were placed in 0.9 L pots with a vermiculite substrate. Pots were watered with a complete nutrient solution and rinsed with excess water twice a week to remove possible salt accumulation. Plants were placed in growth chambers with a 21/16°C day-night temperature cycle and a day length of 16 hours in 1985. The plants were grown in a greenhouse in 1986. Number of stems, plant weight, and root weight were recorded at early flowering.

Data from all studies were tested by analysis of variance. Regression analyses were used to determine the significance of linear and quadratic coefficients. Regression analyses were made for each fall harvest date and for each length of growth period when significant fall harvest date by length of growth period interactions were present.

Results and Discussion

Fall yields ranged from 0.03 to 2.71 Mg ha^{-1} for the various treatments over 3 years (Table 1). Fall yields generally decreased with fall harvest date. Fall yields on 10 and 20 Sep. 1986 were lower than other dates due to low rainfall prior to these harvest dates. All data for site one were similar to data at site two in 1985 and are not reported here.

Fall yields generally increased with the length of GPPFH with the exception of the 30 Sep. 1985 and 1986 fall harvest dates and the 20 Sep. 1986 fall harvest date (Table 1). In several cases there were quadratic relationships between fall yield and length of GPPFH. These relationships suggest that fall yield often declined or remained unchanged with increased GPPFH. This may have been due to leaf loss of old plants.

Crude protein (CP) concentrations of herbage at various fall harvest dates ranged from 158 to 296 g kg^{-1} (Table 2). Crude protein concentrations were influenced more by length of GPPFH than by fall harvest date. Crude protein declined with increased length of GPPFH with the exception of the 10 October fall harvest date. There was a quadratic relationship between CP concentrations and the length of GPPFH for the 10 October fall harvest date with CP concentration declining from 30 to 40 days of growth and then remaining constant from 40 to 60 days of growth. Crude protein levels were influenced most by fall harvest date at the 50 and 60-day GPPFH. Crude protein generally increased with fall harvest date for these growth periods. This most likely occurred because the alfalfa did not mature as quickly with the cooler temperatures associated with later fall harvest dates.

Table 1. Fall harvest yields in 1984, 1985, and 1986 as influenced by date of fall harvest and days of growth prior to fall harvest.

Fall harvest	Days of growth				Trend	
date	30	40	50	60	Linear	Quad.
	-------------------Mg ha^{-1}-------------------					
		1984† (site 1, year 1)				
10 Sep. 1984	1.48	1.68	2.51	2.71	**	NS
20	1.14	1.93	1.64	2.55	**	NS
30	0.59	0.88	1.48	1.45	**	NS
10 Oct.	0.18	0.79	0.93	1.12	**	NS
20	0.10	0.12	0.69	0.83	**	NS
30	-	0.37	0.39	0.63	NS	NS
Linear	**	**	**	**		
Quadratic	NS	NS	NS	NS		
		1985‡ (site 2, year 1)				
10 Sep. 1985	1.52	1.48	1.54	1.82	**	**
20	1.28	1.54	1.59	1.93	**	NS
30	1.17	1.31	1.01	1.14	NS	NS
10 Oct.	0.48	1.26	1.30	1.17	**	**
30	0.24	0.43	0.49	0.77	**	NS
Linear	**	**	**	**		
Quadratic	NS	**	*	NS		
		1986§ (site 2, year 2)				
10 Sep. 1986	0.89	0.54	1.00	0.94	*	*
20	1.14	1.17	0.76	1.12	NS	**
30	1.26	1.36	1.05	0.67	**	**
10 Oct.	0.86	1.37	1.34	1.11	**	**
20 Oct.	0.52	0.64	1.22	0.99	**	**
30	0.03	0.44	0.61	0.87	**	NS
Linear	**	**	**	**		
Quadratic	NS	**	*	NS		

*,** F value significant at the 5 and 1 % level, respectively. NS = not significant at the 0.05 level.

† The standard error of a days of growth period mean within a fall harvest is 0.107. The standard error of a fall harvest date mean within a days of growth period is 0.125.

‡ The standard error of a days of growth period mean within a fall harvest is 0.065. The standard error of a fall harvest date mean within a days of growth period is 0.071.

§ The standard error of a days of growth period mean within a fall harvest is 0.055. The standard error of a fall harvest date mean within a days of growth period is 0.067.

Table 2. Crude protein concentrations of herbage in 1986 as influenced by date of fall harvest and days of growth prior to fall harvest.

Fall harvest date	Days of growth 30	40	50	60	Trend Linear	Quad.
	--------------------g kg^{-1}	----------------				
		1986† (site 2, year 2)				
10 Sep. 1986	241	253	176	158	**	NS
20	271	244	192	163	**	NS
30	273	228	226	199	**	NS
10 Oct.	270	218	224	220	**	**
20	261	250	209	195	**	NS
30	296	261	238	195	**	NS
Linear	NS	NS	*	*		
Quadratic	NS	*	NS	NS		

*,** F value significant at the 5 and 1 % level, respectively. NS = not significant at the 0.05 level.

† The standard error of a days of growth period mean within a fall harvest is 0.87. The standard error of a fall harvest date mean within a days of growth period is 1.04.

Total nonstructural carbohydrates in tap roots on 15 December ranged from 214 to 351 g kg^{-1} and were generally not influenced by date of fall harvest (Table 3). Total nonstructural carbohydrate levels on 15 December declined slightly with delay of fall harvest for the 40 and 50-day GPPFH in 1984 and 1985. Total nonstructural carbohydrate levels on 15 December either increased with length of GPPFH or were not influenced by length of GPPFH. These data indicate that a 50-day GPPFH would allow high TNC levels before the onset of winter.

Total nonstructural carbohydrates on 15 March ranged from 141 to 261 g kg^{-1} (Table 4). There was no influence of fall harvest date or length of GPPFH on TNC levels on 15 Mar. 1985. With the exception of the 20 and 30 September fall harvest dates there was a quadratic relationship between TNC levels on 15 March and length of growth period prior to fall harvests in 1986. These quadratic relationships suggest maximum TNC levels on 15 March resulting from a 40 to 50-day GPPFH prior to the fall harvests and that a 50-day GPPFH would allow safe TNC levels for spring regrowth.

The number of live plants m^{-2} on 15 Dec. was not influenced by date of fall harvest in 1984 or by length of GPPFH in 1984 and 1985 (Table 5). The number of live plants m^{-2} increased with fall harvest date in 1985. Most of this increase occurred with the September fall harvest dates.

The number of live plants m^{-2} on 15 Mar. 1985 increased with both fall harvest date and length of GPPFH (Table 5). Again, most of the increase with fall harvest date occurred with the early harvest dates. There was no influence of fall harvest date or length of GPPFH on plant m^{-2} on 15 Mar. 1986.

The number of stems present 10 May ranged from 92 to 100 m^{-2} (Table 5). There was no influence of fall harvest date or length of GPPFH on spring stem density.

Table 3. Total nonstructural carbohydrates of tap roots on 15 Dec. 1984, 1985, and 1986 as influenced by date of fall harvest and days of growth prior to fall harvest.

Fall harvest	Days of growth					Trend	
date	30	40	50	60	Avg	Linear	Quad.
	----------g kg^{-1}----------						
	1984† (site 1, year 1)						
10 Sep. 1984	334	351	348	332		NS	NS
20	283	333	341	315		*	**
30	300	299	341	337		**	NS
10 Oct.	322	307	315	309		NS	NS
20	288	317	305	306		NS	NS
30	-	268	310	317		**	NS
Linear	NS	**	*	NS			
Quadratic	NS	NS	NS	NS			
	1985‡ (site 2, year 1)						
10 Sep. 1985	245	314	298	322		**	NS
20	272	292	323	289		NS	NS
30	288	285	298	289		NS	NS
10 Oct.	260	285	270	268		NS	NS
20	234	292	244	246		NS	NS
30	253	244	273	285		*	NS
Linear	NS	*	**	*			
Quadratic	NS	NS	NS	*			
	1986§ (site 2, year 2)						
10 Sep. 1986	274	249	254	253	263		
20	255	270	285	258	267		
30	256	246	276	243	255		
10 Oct.	231	214	251	261	239		
20	240	256	238	264	250		
30	234	227	258	256	244		
Avg	249	245	261	260		NS	NS
Linear					NS		
Quadratic					NS		

*,** F value significant at the 5 and 1 % level, respectively. NS = not significant at the 0.05 level.

† The standard error of a days of growth period mean within a fall harvest is 11.7. The standard error of a fall harvest date mean within a days of growth period is 12.6.

‡ The standard error of a days of growth period mean within a fall harvest is 13.5. The standard error of a fall harvest date mean within a days of growth period is 13.6.

§ The standard error of a days of growth period mean is 11.7. The standard error of a fall harvest date mean is 6.9.

Table 4. Total nonstructural carbohydrates of tap roots on 15 Mar. 1985, and 1986 as influenced by date of fall harvest and days of growth prior to fall harvest.

Fall harvest	Days of growth					Trend	
date	30	40	50	60	Avg	Linear	Quad.
	---------------------g kg^{-1}--------------------						
	1985† (site 1, year 1)						
10 Sep. 1984	173	177	185	157	173		
20	157	167	182	164	168		
30	174	175	175	195	180		
10 Oct.	177	142	163	189	168		
20	173	172	174	185	176		
30	-	149	185	154	163		
Avg	171	164	177	174		NS	NS
Linear					NS		
Quadratic					NS		
	1986‡ (site 2, year 1)						
10 Sep. 1985	189	261	196	205		NS	*
20	163	164	185	161		NS	NS
30	206	182	221	186		NS	NS
10 Oct.	145	198	217	163		NS	*
20	143	165	190	151		NS	*
30	141	194	173	162		NS	*
Linear	*	*	NS	NS			
Quadratic	NS	*	NS	NS			

*,** F value significant at the 5 and 1 % level, respectively. NS = not significant at the 0.05 level.

† The standard error of a days of growth period mean is 5.4. The standard error of a fall harvest date mean is 5.0.

‡ The standard error of a days of growth period mean within a fall harvest is 13.2. The standard error of a fall harvest date mean within a days of growth period is 14.2.

Table 5. Plant populations on 15 Dec. 1984 and 1985 and 15 Mar. 1985 and 1986 as influenced by date of fall harvest and days of growth prior to fall harvest. Stem counts were made on 10 May 1985.

Fall harvest	1984-85 (site 1)			1985-86 (site 2)	
date	15 Dec.	15 Mar.	10 May	15 Dec.	15 Mar.
	-----Plants m^{-2}-----		Stems m^{-2}	-----Plants m^{-2}-----	
10 Sep.	44	41	94.2	175	203
20	55	45	96.4	181	201
30	48	48	95.7	199	192
10 Oct.	65	55	96.3	205	225
20	53	50	97.2	183	191
30	54	53	93.5	200	194
Linear	NS	*	NS	*	NS
Quadratic	NS	NS	NS	NS	NS
Std. error	4.9	5.0	8.8	6.0	14
Growth period					
30	51	43	92.0	187	190
40	54	50	93.7	197	202
50	54	51	100.0	194	201
60	54	50	95.9	185	213
Linear	NS	*	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS
Std. error	2.7	2.0	11.0	6.3	12

*,** F value significant at the 5 and 1 % level, respectively. NS = not significant at the 0.05 level.

Spring yields ranged from 0.9511 to 3.10 Mg ha $^{-1}$ and were generally influenced more by length of GPPFH than by date of fall harvest (Table 6). Fall harvest date did not influence succeeding spring yields in 1985. In 1986, there was a quadratic relationship between spring yield and fall harvest date for the 40 and 50-day GPPFH. Spring yields increased with early fall harvest dates and then declined with later fall harvest dates. Fall harvest date did not influence spring yields with the 30 and 60-day GPPFH in 1986. Spring yields decreased with delay in fall harvest for the 50 and 60-day GPPFH in 1987. Most of this decrease occurred from the 20 October fall harvest date to the 30 October fall harvest date. This suggests that if a critical period for fall harvest exists in Virginia the period would occur after 20 October. Spring yield did not decrease with fall harvest date for the 30 and 40-day GPPFH because yields were generally low for all fall harvest dates for these GPPFH in 1987.

Spring yields generally increased with length of GPPFH (Table 6). Spring yield was not influenced by the length of GPPFH on the 30 Sep. 1985 fall harvest date. A quadratic relationship between spring yield and GPPFH for the 10 Oct. 1986 fall harvest date suggests a maximum spring yield between the 40 and 50-day GPPFH. The increase in spring yield from th 50 to 60-day GPPFH was generally small with the exception of the 30 October fall harvest date each year. This indicates that fall harvests made with a 50-day GPPFH would allow maximum yields for harvests made through 20 October. With the exception of 1987, spring yields were high for the 40-day GPPFH from 10 September through 10 October. These data suggest that a 40-day GPPFH would be adequate for early fall harvests in most years. Spring yields generally increased dramatically from the 50 to 60-day GPPFH for the 30 October fall harvest date. This suggests that fall harvests made after 20 October should be allowed a 60-day GPPFH.

Table 6. Spring harvest yields in 1985, 1986, and 1987 as influenced by date of fall harvest in 1984, 1985, and 1986 and days of growth prior to fall harvest.

Fall harvest	Days of growth					Trend	
date	30	40	50	60	Avg	Linear	Quad.
	------------------Mg ha^{-1}------------------						
	1985† (site 1, year 1)						
10 Sep.	2.36	2.53	2.86	2.83	2.65		
20	2.45	2.89	2.72	3.10	2.76		
30	2.43	2.47	2.80	2.75	2.61		
10 Oct.	2.28	2.61	2.88	2.89	2.69		
20	2.26	2.23	2.82	2.73	2.51		
30	-	2.11	2.30	2.80	2.41		
Avg	2.36	2.46	2.73	2.84		**	NS
Linear					NS		
Quadratic					NS		
	1986‡ (site 2, year 1)						
10 Sep.	2.42	2.37	2.71	2.82		**	NS
20	2.56	2.63	2.74	2.97		**	NS
30	2.71	2.81	2.83	2.77		NS	NS
10 Oct.	2.42	2.97	2.82	2.80		**	**
20	2.25	2.37	2.94	2.82		**	NS
30	2.54	2.46	2.38	2.85		*	**
Linear	NS	NS	NS	NS			
Quadratic	NS	**	*	NS			
	1987¶ (site 2, year 2)						
10 Sep.	1.39	1.34	1.96	2.20		**	NS
20	1.56	1.46	1.81	2.00		**	NS
30	1.11	1.69	1.66	1.77		**	*
10 Oct.	1.00	1.14	1.71	1.80		**	NS
20	1.01	0.95	1.74	1.84		**	NS
30	1.40	1.30	1.26	1.53		NS	NS
Linear	NS	NS	*	**			
Quadratic	NS	NS	NS	NS			

*,** F value significant at the 5 and 1 % level, respectively. NS = not significant at the 0.05 level.

† The standard error of a days of growth period mean is 0.14. The standard error of a fall harvest date mean is 0.06.

‡ The standard error of a days of growth period mean within a fall harvest is 0.11. The standard error of a fall harvest date mean within a days of growth period is 0.13.

¶ Yields were adjusted for percentage alfalfa by manual weed separations. The standard error of a days of growth period mean within a fall harvest is 0.12. The standard error of a fall harvest date mean within a days of growth period is 0.17.

Greenhouse regrowth and stem production from plants collected from the field on 15 Dec. 1985 and 1986 were not influenced by fall harvest date or length of GPPFH. This indicates that fall harvest management did not influence plant vigor going into the winter.

These data suggest that harvests made during the fall did not cause over-wintering plant losses and that length of GPPFH is more important than date of fall harvest in fall harvest management. Although spring yield generally increased with length of GPPFH, the spring growth appeared healthy and one might expect a few days of delay of spring harvest to eliminate any influence of length of GPPFH. Fall yields, spring yields, and TNC levels were generally high for the 50- day GPPFH and fall harvest yield would offset any reductions in spring yield observed in this study. In addition, fall harvests made with a 50-day GPPFH reduced loss of herbage quality due to leaf loss as opposed to the 60-day GPPFH.

'Arc' alfalfa is a moderately dormant variety. Varieties with Flemish background, that have limited sensitivity to daylength, might have responded differently to the treatments imposed in this study. One might expect these varieties to exhibit considerable regrowth following fall harvest at the expense of TNC and possibly increased sensitivity to fall harvest.

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Chapter II

Fall Harvest Management of Alfalfa: II The Influence of Photosynthesis, Carbohydrate Accumulation, and Respiration on Fall Harvest Management

Abstract

Alfalfa (*Medicago sativa* L.) harvest schedules are often interrupted by rainfall, unfavorable environmental conditions for growth, and unfavorable weather for hay curing. Interruptions in alfalfa harvest schedules can delay the final harvest to dates considered critical to winter survival. Harvests made between 20 September and 20 October are considered detrimental to the persistence of alfalfa stands in geographical

areas such as western Virginia. The objectives of this study were to determine if photosynthesis during the fall offsets loss of total nonstructural carbohydrates (TNC) for regrowth and respiration during the fall and allows more flexible fall harvest management than is currently recommended.

Final alfalfa harvests were made 16 September or 2, 16, or 30 October for 2 years. Alfalfa was managed to achieve 50 days of growth prior to each final fall harvest date. Gross photosynthesis, plant respiration, and TNC were measured at 2-week intervals in the fall following four fall harvest dates. Various levels of shade were imposed following four fall harvest dates of a supplemental study to evaluate the influence of photosynthesis on TNC levels and plant persistence.

Fall regrowth and plant maintenance were not dependent on root TNC accumulation. Photosynthesis offset respiration losses for regrowth and maintenance during the fall. High photosynthetic rates as compared to respiration were possible due to temperatures occurring within the optimum range for photosynthesis of alfalfa during 68% of the daylight hours from September through November. Slow regrowth, low respiration rates with cool temperatures, and relatively high photosynthetic rates with cool temperatures limited TNC losses following fall harvests.

Introduction

Regrowth of alfalfa following harvest is in part dependent on total nonstructural carbohydrates (TNC) accumulated in the root and crown tissue (Smith and Marten, 1970). In addition, leaf area remaining after harvesting is important in post-harvest recovery. Pearce et al. (1969) reported that as much as 70% of assimilated ^{14}C in the root can be lost from the root during the first 28 days of regrowth during the summer. These losses were primarily attributed to respiration and top growth.

Nonstructural carbohydrate accumulation in tap roots can provide energy for plants during periods of inadequate photosynthesis (Matches et al., 1963). Nonstructural carbohydrates are used to develop cold resistance, for energy to live through the winter, and to begin growth in spring (Smith, 1968). Harvest management influences TNC levels and must be considered prior to the winter season which is a period of inadequate photosynthesis. Many researchers in the Northern United States have reported that harvests made during a critical period of late September or October decreased the likelihood of winter survival (Grandfield, 1943; Graumann, et al.,1954; Kust and Smith, 1961; and Fulkerson, 1970). This presumably occurs because fall regrowth depletes TNC during a period of inadequate duration of photosynthesis with respect to respiration levels and limits TNC accumulation in tap roots in the Northern United States.

A longer period of favorable environmental conditions in the Southeastern United States may allow higher levels of photosynthesis and TNC accumulation following the last cutting made in the fall than occurs in northern states. Murata et al. (1965) reported the optimum temperature range for photosynthesis of alfalfa to be from 10 to 25°C. Daytime temperatures are within this range much of the time during the fall in Blacksburg, VA. Most locations in the Southeastern United States would have daytime temperatures within this range more frequently than Blacksburg. In addition, Murata et al. (1965) found that respiration decreased with decreasing temperature. Photorespiration also decreases with decreasing temperature while photosynthesis shows a minimal response to temperature (Gardner, 1985). Temperatures during the fall in the southeast may therefore be optimum or close to optimum for photosynthesis while decreasing respiration. This condition of high photosynthesis and low respiration in the fall when top growth is slow should favor TNC accumulation in alfalfa tap roots.

The alfalfa plant may be morphologically suited to rapid post-harvest recovery during the fall. Unlike summer harvests which remove most or all of the leaf area, alfalfa has considerable leaf area remaining close to the ground after fall harvests. This remaining leaf area is capable of continuous photosynthesis under favorable conditions which could provide photosynthate for plant recovery thus a critical period for fall harvest may not occur in the Southeastern United States.

The research was planned to determine if photosynthesis during the fall offsets loss of TNC for regrowth and respiration during the fall, reduces over-wintering losses, and therby allows more flexible fall harvest management than is currently practiced. In an attempt to better understand this relationship, gross photosynthesis and TNC in tap roots were measured at 2 week intervals following four dates of fall harvest. In another experiment, three levels of shade were imposed following harvest after four fall harvest dates in an attempt to limit photosynthesis and TNC accumulation. Prewinter TNC and succeeding spring yields were also measured.

Materials and Methods

'Arc' alfalfa was established in the spring of 1984 at the Virginia Polytechnic Institute and State University agronomy farm. The soils were a mixture of Landisburg silt loam (fine-loamy, mixed, mesic Typic Fragiudult) and Greendale silt loam (fine-loamy, siliceous, mesic Fluventic Dystrochrept). The soil had at least 119 kg extractable P ha^{-1}, 352 kg exchangeable K ha^{-1}, and a pH of 6.9 in the winter of 1983. Phosphorus and K were applied each fall according to soil test recommendations. Three hay harvests were made in the year of seeding and four hay harvests were made in 1985 on areas set aside for the 1986 studies.

Four harvest schedules were imposed during the season to typify possible harvest delays during the season (Fig. 1). The last harvest of the season occurred on 16 September, 2 October, 16 October, or 30 October. Each treatment had 50 days of regrowth prior to the fall harvest based on results of the experiment presented in the first chapter. The constant growth interval prior to each last cutting minimized differences that might occur due to staggered dates for the first three harvests.

Photosynthesis and Leaf Area Study

A randomized complete block design included four replications and 3.0 by 9.1 m experimental units. The study was conducted in 1985 and 1986 using a new area each year. Gross photosynthesis, leaf area index (LAI), and TNC in tap roots were measured at 14-day intervals after each fall harvest until mid-December each year. Tap

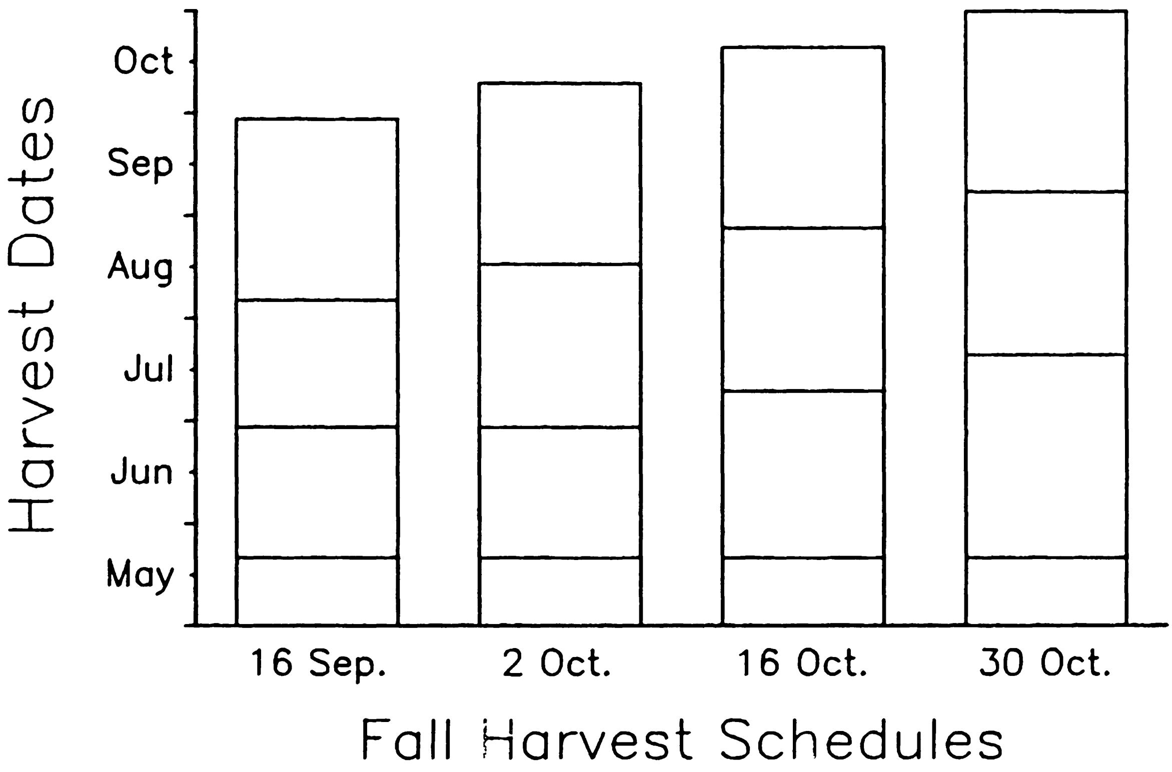

Fig. 2. Harvest dates for four harvest schedules. Harvest dates are indicated by horizontal lines.

roots were trimmed, washed, dried at 65°C, and ground with a Wiley mill to pass through a 1 mm screen. Total nonstructural carbohydrates were removed from tissue and hydrolized according to the method of Smith (1969). Data are reported as glucose equivalents using an automated procedure (Davis, 1976).

Gross photosynthesis was measured in the field using an open system. An acrylic plastic cylinder covering 0.246 m^2 was placed over the plants and sealed through the soil surface with a metal collar. The chamber was equipped with a fan, refrigeration unit, heater, and thermocouple as described by Pearce et al. (1965). Temperature was maintained between 15.5 to 18°C. Four 1000-watt metal halide lamps housed in a large reflector were placed over the chamber and provided a photon flux density of 600 µmole photon m^{-2} s^{-1}. An infared gas analyzer measured the difference between CO_2 concentration of the air entering and leaving the chamber. The air flow rate was 74 L min^{-1}. Measurements of top growth were taken with the lights on and in the dark. Measurements in the dark following top growth removal were used to determine soil emitted CO_2. Gross photosynthesis was calculated on a land (GP_{land}) and leaf area (GP_{leaf}) basis by subtracting dark CO_2 exchange (including ground and plant respiration) from CO_2 exchange in the light. Plant respiration (PR_{land}) was determined by subtracting CO_2 flux from the soil with the top growth removed in the dark (ground respiration) from $C0_2$ exchange in the dark (ground plus plant respiration).

Seven to ten stems were used to determine LAI. Leaf area index is the product of yield (g m^{-2}) • % leaves • specific leaf area (m^2 g^{-1}). The leaf percentage (by weight) was determined following manual separations of leaflet and non-leaflet tissue. Specific leaf area was determined with an electronic planimeter using seven representative leaves from each sample.

Data were tested by analysis of variance and mean separation was employed for each fall harvest date due to the different number of measurements made for each fall harvest date. Regression analyses were not used because there were not enough measurements made for some fall harvest dates. Mean separation was achieved using the Waller-Duncan, K-ratio t test, with a K-ratio = 100.

Shade Study

A split plot design included four replicates and 3.0 by 5.0 m experimental units. The four fall harvest dates served as main plots. Three levels of shade imposed after each of the four fall harvests served as subplots randomized within main plots. The study was conducted in 1985 and 1986 using a new area each year.

Shade cloth designed to reduce sunlight by 50% and 75% was supported by an iron frame over 1.5 by 1.5 m subplots. These were placed within each main plot immediately after each of the four fall harvests. Radiometer measurements indicated that the shade cloths actually reduced the light by 45 and 60 percent. Tap roots were collected from all treatments on 15 Dec. 1985 and 1986 for TNC analysis. Herbage from one 0.65 by 0.65 m quadrate per subplot was collected, dried, and weighed to determine residual spring yield on 15 May the year following treatment.

A vigor test was conducted in a greenhouse to determine the influence of photosynthesis on regrowth potential prior to winter. Three uniform plants were selected from each plot on 15 Dec. 1985 and 1986. Roots of these plants were trimmed 10 cm below the crown, and the branch roots were removed. All top growth was removed 5 cm above the crown and the plants were placed in 0.9 L pots with a vermiculite substrate. The pots were watered with a complete nutrient solution and rinsed with excess water twice each week to remove possible salt accumulation. Pots were placed in the greenhouse. The number of stems produced per plant and the weight of top growth produced per plant was recorded 4 weeks later.

Data were tested with analysis of variance, and mean separation was achieved using the Waller-Duncan, K-ratio t test, with a K-ratio = 100. Mean separation was employed across fall harvest date means when no significant date of fall harvest by shade level interaction was present.

Results and Discussion

Rainfall was above or near long-term means during each fall except during September and December 1985 and from 11 September through 10 October 1986 (Table 7). Temperatures were above or near long-term means during each fall except from 10 September to 10 October and December 1985 and mid-September and mid-October 1986. Daylight temperatures were within the optimum temperature range for photosynthesis of alfalfa as described by Murata et al. (1965) 68 % of the time from September through November. In general, lower temperatures occurred prior to photosynthesis measurements in 1986 than 1985 (Table 8).

Photosynthesis and Leaf Area Study

Regrowth following harvests made 16 September, or 2, 16, or 30 October was normal. Alfalfa photosynthesized through the fall until 15 Dec. 1986 for all fall harvest dates (Table 9). Photosynthesis was not detectable on 15 Dec. 1985. Low temperatures during December 1985 explain why photosynthesis was not detectable on 15 Dec 1985 but was in 1986 (Table 7). The lowest temperature to occur prior to a photosynthesis measurement was -13.4°C before the 15 Nov. 1986 measurement (Table 8). This low temperature did not keep photosynthesis from occurring at following measurements. This suggests that photosynthesis can occur following very low temperatures when the temperature returns to long term means. No photosynthesis was measurable on 15 Dec. 1985, although the lowest temperature to occur prior to this

Table 7. Average minimum temperature and rainfall of ten day periods observed during fall of 1985 and 1986. Departure (Dept.) is the difference from long term means. Duration of occurrence of temperatures between 10 and 25°C is expressed as a % of daylight hours.

		Min. temp.		Rainfall		Duration
Month	Dates	Obs.	Dept.	Obs.	Dept.	of 10-25°C
		---------°C--------		--------mm-------		%
			1985			
Sep.	1-10	15.4	0.9	2	-28	100
	11-20	5.0	-7.4	7	-23	86
	21-30	7.0	-3.7	4	-26	95
Oct.	1-10	5.3	-3.7	42	15	88
	11-20	8.5	1.2	3	-23	77
	21-31	4.8	-0.2	29	-1	73
Nov.	1-10	2.6	-0.5	97	74	63
	11-20	6.9	5.7	4	-19	87
	21-30	3.5	4.3	71	48	59
Dec.	1-10	-6.3	-3.7	4	-20	18
	11-20	-9.1	-5.2	14	-10	0
	21-31	-13.1	-7.9	1	-25	0
			1986			
Sep.	1-10	12.3	-2.3	79	49	99
	11-20	9.9	-3.0	12	-18	85
	21-30	15.1	4.4	6	-24	100
Oct.	1-10	10.0	1.0	4	-23	91
	11-20	2.6	-4.7	19	-7	66
	21-31	4.0	-1.0	38	8	73
Nov.	1-10	6.8	3.7	68	45	57
	11-20	-0.9	-2.1	12	-11	4
	21-30	-0.9	-0.1	39	16	28
Dec.	1-10	-2.1	0.5	30	6	6
	11-20	-4.2	-0.3	29	5	0
	21-31	-4.1	1.1	46	20	0

Table 8. Lowest temperature prior to dates of photosynthesis measurements.

Date of measurement	1985	1986
	------Temperature (°C)------	
2 Oct.	0.5	2.8
16 Oct.	0.5	0.0
30 Oct.	0.5	-3.0
15 Nov.	-1.8	-13.4
30 Nov.	-1.8	-13.4
15 Dec.	-9.5	-13.4

measurement was higher than in 1986. This indicates that the lowest temperature occurrence did not influence photosynthesis as much as the duration of cold temperatures.

Gross photosynthesis $_{land}$ ranged from 1.5 to 19.9 µmol CO_2 m^{-2} s^{-1} (Table 9). Gross photosynthesis $_{land}$ increased from 2 to 4 weeks following fall harvests for the 16 September and 2 October fall harvest dates both years. This increase in GP_{land} corresponded to increased LAI (Table 10). There was no difference in GP_{land} between 2 and 4 weeks following fall harvests for the 16 October and 30 October fall harvest dates. However, the increase from 6.3 to 14.1 µmol CO_2 m^{-2} s^{-1} from 2 weeks to 4 weeks following 16 October fall harvest in 1985 was significant at the 0.10 probability level. This increase also corresponded to an increase in LAI during this period. Gross photosynthesis $_{land}$ ranged from 1.5 to 14.1 µmol CO_2 m^{-2} s^{-1} during the fall following the 16 October and 30 October fall harvest dates. There were no differences in GP_{land} rates following the 16 October and 30 October fall harvest dates from 2 weeks following fall harvests until mid-December.

Gross photosynthesis $_{land}$ did not change from 4 to 6 weeks following fall harvests for the 16 September harvest date both years and the 2 October harvest date in 1985 (Table 9). In 1986, GP_{land} decreased from 19.9 to 6.9 µmol CO_2 m^{-2} s^{-1} between 4 and 6 weeks following the 2 October fall harvest date. Gross photosynthesis $_{land}$ declined or remained unchanged after 6 weeks following fall harvests. The decrease in GP_{land} from 30 Oct. to 15 Nov. 1986 for the 16 September and 2 October fall harvest dates was probably due to freeze damage to upper leaves due to the occurrence of a -13.4°C temperature prior to the 15 November measurement (Table 8). This low temperature failed to reduce GP_{land} for the 16 October fall harvest date most likely

Table 9. Gross photosynthesis on a land area basis of alfalfa regrowth at several dates following four fall harvest dates.

Date of harvest	2 Oct.	16 Oct.	30 Oct.	15 Nov.†	30 Nov.	15 Dec.
	------	------	------ $\mu mol\ m^{-2}_{land}\ s^{-1}$	------	------	------
				1985		
16 Sep.	8.3 b‡	14.4 a	16.2 a	9.8 b	-	0§
2 Oct.		10.3 b	13.9 a	13.2 a	-	0
16 Oct.			6.3 a	14.1 a	-	0
30 Oct.				9.8	-	0
				1986		
16 Sep.	12.7 b	18.5 a	18.1 a	5.3 c	4.5 c	1.0 d
2 Oct.		15.0 b	19.9 a	6.9 c	6.3 c	1.9 d
16 Oct.			4.4 a	3.0 ab	4.5 a	2.2 b
30 Oct.				1.5 a	2.6 a	1.6 a

† The 15 Nov. measurement was taken on 20 Nov. in 1985.

‡ Means within a row followed by the same letter are not significantly different at 0.05 level by Waller-Duncan K-ratio t test, with a K-ratio = 100.

§ Gross photosynthesis was not detectable on 15 Dec. 1985 and these values were not included in statistical analysis.

Table 10. Leaf area index of alfalfa regrowth at several dates following four fall harvest dates.

Date of harvest	Date of measurement: 2 Oct.	16 Oct.	30 Oct.	15 Nov.†	30 Nov.	15 Dec.
	---LAI---					
			1985			
16 Sep.	0.7 b‡	1.2 a	1.5 a	0.7 b	-	0§
2 Oct.		0.7 b	1.5 a	0.9 ab	-	0
16 Oct.			0.2 b	0.8 a	-	0
30 Oct.				0.5	-	0
			1986			
16 Sep.	0.9 bc	1.7 a	1.6 ab	1.5 ab	0.6 c	0
2 Oct.		1.1 b	1.8 a	1.4 ab	1.4 ab	0
16 Oct.			0.3 a	0.4 a	0.3 a	0
30 Oct.				0.1 a	0.1 a	0

† The 15 Nov. measurement was taken on 20 Nov. in 1985.
‡ Means within a row followed by the same letter are not significantly different at 0.05 level by Waller-Duncan K-ratio t test, with a K-ratio = 100.
§ Leaf area index was to low to be measured on 15 Dec. and these values were not included in statistical analysis.

because the plants were shorter and not as susceptible to freeze damage as the taller plants of the 16 September and 2 October fall harvest dates.

Leaf area index increased from 2 to 4 weeks following fall harvests with the exceptions of the 16 October and 30 October fall harvest dates in 1986 (Table 10). Leaf area index did not increase for these fall harvest dates because of low temperatures. In general, LAI values corresponded with GP_{land} values as indicated by significant correlations of 0.81 in 1985 and 0.72 in 1986. This relationship suggests that LAI was at least partially responsible for increases in GP_{land} in the early fall and decreases in GP_{land} in the late fall.

Gross photosynthesis $_{leaf}$ ranged from 0.9 to 7.8 μmol CO_2 m^{-2} s^{-1} following fall harvests (Table 11). There was no change in GP_{leaf} following any fall harvest in 1985 and few changes in GP_{leaf} following fall harvest in 1986. These data indicate that the leaves were not loosing their physiological photosynthetic capability. These data also suggest that any changes in the nonstructural carbohydrate status of the plant during the fall was influenced more by leaf area available for photosynthesis and possibly plant respiration rates than GP_{leaf}.

Plant respiration $_{land}$ rates ranged from 0.1 to 2.1 μmol CO_2 m^{-2} s^{-1} following fall harvests (Table 12). Gross photosynthesis $_{land}$ rates were 3 to 26 times higher than corresponding PR_{land} rates. This relationship suggests that the plants had a net intake of CO_2 during daylight hours through the fall for maintenance and growth. Plant respiration $_{land}$ rates remained unchanged from 2 weeks following fall harvests until 30 November for all fall harvest dates in 1985 and the 16 October and 30 October harvest dates in 1986 (Table 12). Plant respiration $_{land}$ was not detectable on 15 Dec. 1985 and 1986. Plant respiration $_{land}$ increased from 2 to 4 weeks following the 16 September fall harvest date in 1986. This increase may have been due to corresponding increase

Table 11. Gross photosynthesis on a leaf area basis of alfalfa regrowth at several dates following four fall harvest dates.

Date of	Date of measurement					
harvest	2 Oct.	16 Oct.	30 Oct.	15 Nov.	30 Nov.†	15 Dec.
	$\mu mol\ m^{-2}_{leaf}\ s^{-1}$					
				1985		
16 Sep.	3.0 a‡	2.8 a	2.7 a	3.5 a	-	0§
2 Oct.		4.6 a	2.3 a	3.8 a	-	0
16 Oct.			7.8 a	4.3 a	-	0
30 Oct.				5.8	-	0
				1986		
16 Sep.	3.5 a	2.6 a	2.9 a	0.9 a	6.4 a	-
2 Oct.		3.4 a	2.8 a	1.2 b	1.2 b	-
16 Oct.			3.6 a	2.7 a	3.5 a	-
30 Oct.				2.9 b	6.7 a	-

† The 15 Nov. measurement was taken on 20 Nov. in 1985.

‡ Means within a row followed by the same letter are not significantly different at 0.05 level by Waller-Duncan K-ratio t test, with a K-ratio = 100.

§ Gross photosynthesis was not detectable on 15 Dec. 1985 and these values were not included in statistical analysis. Leaf area index was not determined on 15 Dec. 1986 due to extreme small amount of leaf area.

in LAI (Table 10). Plant respiration $_{\text{land}}$ decreased between 4 and 6 weeks following fall harvests for the 16 September and 2 October fall harvest dates in 1986.

Tap root TNC levels generally remained unchanged from 2 weeks following fall harvests through mid-December (Table 13). This suggests that the plants were not depleting TNC for regrowth and maintenance during the fall. These data along with photosynthesis and respiration data suggest that photosynthesis was adequate for fall regrowth and maintenance.

Shade Study

Shade imposed in the field following each fall harvest reduced growth from plants collected in mid-December and grown in the greenhouse from 970 mg plant $^{-1}$ with no shade to 790 mg plant^{-1} with 60 percent shade in 1985 (Table 14). Shade did not reduce regrowth of plants grown in the greenhouse in 1986 (Table 15). The number of stems produced per plant was not influenced by shade level either year (Tables 14 and 15). These data suggest that photosynthesis during the fall may be important for plant vigor but not for the number of buds produced per plant.

Shade imposed during the fall following each fall harvest through mid-December decreased spring yields from no shade to 45 percent shade for all harvest dates except the 16 October fall harvest date (Table 14). Spring yields remained unchanged as shade increased from 45 to 60 percent shade for all fall harvest dates except the 30 October fall harvest date. Yield increased from 285 g m^{-2} at 45 percent shade to 351 g m^{-2} at 60 percent shade for the 30 October fall harvest date. There is no apparent

Table 12. Plant respiration on a land area basis of alfalfa regrowth at several dates following four fall harvest dates.

Date of harvest	2 Oct.	16 Oct.	30 Oct.	15 Nov.†	30 Nov.	15 Dec.
			$\mu mol\ m^{-2}_{land}\ s^{-1}$			
			1985			
16 Sep.	0.7 a‡	1.5 a	1.8 a	1.1 a	-	0§
2 Oct.		2.1 a	2.0 a	1.5 a	-	0
16 Oct.			1.1 a	1.9 a	-	0
30 Oct.				0.6 a	-	0
			1986			
16 Sep.	1.2bc	4.2a	2.5b	1.6bc	1.0c	0
2 Oct.		2.9a	3.0a	1.2b	1.0b	0
16 Oct.			0.8a	0.4a	0.5a	0
30 Oct.				0.5a	0.1a	0

† The 15 Nov. measurement was taken on 20 Nov. in 1985.

‡ Means within a row followed by the same letter are not significantly different at 0.05 level by Waller-Duncan K-ratio t test, with a K-ratio = 100.

§ Plant respiration was not detectable on 15 Dec. and these values were not included in statistical analysis.

Table 13. Total nonstructural carbohydrates of alfalfa tap roots through the fall following fall harvest dates.

Date of harvest	Date of measurement 2 Oct.	16 Oct.	30 Oct.	15 Nov.†	30 Nov.	15 Dec.
	g kg^{-1}					
			1985			
16 Sep.	261 b‡	289 b	316 a	277 b	-	281 b
2 Oct.		280 a	273 a	251 a	-	295 a
16 Oct.			272 a	277 a	-	271 a
30 Oct.				276 a	-	274 a
			1986			
16 Sep.	200 b	239 ab	286 a	287 a	310 a	293 a
2 Oct.		243 a	269 a	301 a	266 a	263 a
16 Oct.			285 a	279 a	250 a	234 a
30 Oct.				285 a	235 a	249 a

† The 15 Nov. measurement was taken on 20 Nov. in 1985.

‡ Means within a row followed by the same letter are not significantly different at 0.05 level by Waller-Duncan K-ratio t test, with a K-ratio = 100.

Table 14. Regrowth and stems produced from plants collected 14 Dec. and grown in the greenhouse as influenced by shade levels following four fall harvest dates in 1985. The influence of shade on tap root total nonstructural carbohydrate (TNC) levels on 14 Dec. and spring yields in 1985.

Date of harvest	% Shade 0	45	60
	Regrowth vigor (g $plant^{-1}$)		
16 Sep.	1000	1000	730
2 Oct.	810	940	810
16 Oct.	910	870	690
30 Oct.	1090	830	910
Avg	970 a†	930 ab	790 b
	Stems (no. $plant^{-1}$)		
16 Sep.	5.3	5.3	5.0
2 Oct.	5.3	4.6	5.0
16 Oct.	4.4	5.0	4.6
30 Oct.	5.1	4.3	6.0
Avg	5.0 a	4.8 a	5.1 a
	TNC (g kg^{-1})		
16 Sep.	281	242	206
2 Oct.	295	273	240
16 Oct.	271	240	238
30 Oct.	274	281	245
Avg	281 a	257 b	232 c
	Spring yield (g m^{-2})		
16 Sep.	289 a	243 b	232 b
2 Oct.	333 a	282 b	275 b
16 Oct.	323 a	308 a	323 a
30 Oct.	358 a	285 b	351 a

† Means within a row followed by the same letter are not significantly different at 0.05 level by Waller-Duncan K-ratio t test, with a K-ratio = 100.

Table 15. Regrowth and stems produced from plants collected 14 Dec. and grown in the greenhouse as influenced by shade levels following four fall harvest dates in 1986. The influence of shade on tap root total nonstructural carbohydrate (TNC) levels on 14 Dec. 1986.

Date of harvest	% Shade 0	45	60
	Regrowth vigor (g $plant^{-1}$)		
16 Sep.	798	1042	737
2 Oct.	628	829	815
16 Oct.	1027	985	1044
30 Oct.	871	1144	1122
Avg	844 a†	1001 a	908 a
	Stems (no. $plant^{-1}$)		
16 Sep.	5.7	5.5	3.7
2 Oct.	2.9	4.2	3.9
16 Oct.	3.9	4.5	5.1
30 Oct.	3.7	3.3	5.1
Avg	4.0 a	4.5 a	4.4 a
	TNC (g kg^{-1})		
16 Sep.	291	252	233
2 Oct.	265	242	250
16 Oct.	233	234	220
30 Oct.	247	264	251
Avg	259 a	247 ab	239 b

† Means within a row followed by the same letter are not significantly different at 0.05 level by Waller-Duncan K-ratio t test, with a K-ratio = 100.

reason for this increase. The general lack of influence of shade on the two latest fall harvest dates suggests that photosynthesis is not as important for the late fall harvest dates as the early fall harvest dates. Simple correlations of regrowth, stem production, and mid-December TNC levels with spring yield revealed that no one parameter explained more than 10 % of the variation in spring yields.

Total nonstructural carbohydrate levels of tap roots in mid-December declined with increased shade from 281 g kg^{-1} to 232 g kg^{-1} in 1985 and from 259 g kg^{-1} to 239 g kg^{-1} in 1986 (Tables 14 and 15). This suggests that photosynthesis during the fall was necessary for maximum TNC levels entering the winter period with all fall harvest dates. The failure of increased shade to consistently decrease regrowth while shade consistently decreased TNC levels in mid-December indicates that maximum TNC levels are not needed for maximum plant vigor before the onset of cold weather for spring regrowth.

Data collected from the shade study may have been confounded by different temperatures under shade cloth as opposed to no shade. Soil moisture and canopy temperature at 5 cm were not influenced by shade. Leaf temperatures could have been reduced by shading, resulting in lower respiration rates with increased shade.

These data support the recommendation for allowing 50 days of growth prior to last fall harvest in the previous chapter. High GP_{land} and low respiration during the fall with slow herbage dry matter accumulation in the fall allows recovery of fall harvested alfalfa without depletion of tap root TNC levels. High GP was possible due to temperatures occurring in the optimum range for photosynthesis during a majority of September through November. Plants with 50 days of growth prior to fall harvest were healthy and had sufficient environmental conditions to recover before the onset of winter weather.

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Appendix A

Additional Data

Table 16. Regrowth and stems produced from plants collected 15 Dec. and grown in the greenhouse as influenced by fall harvest dates and growth period prior to fall harvests in 1984 and 1985†.

Date of harvest	1984 Top growth	1984 Stems	1985 Top growth	1985 Stems
	mg	no.	mg	no.
10 Sep.	309	1.05	318	1.86
20	295	1.29	257	1.72
30	245	1.23	329	1.94
10 Oct.	242	1.29	272	1.73
20	249	0.88	273	1.92
30	279	1.14	253	1.78
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS
Std. error	22.6	0.077	25.5	0.121
Growth period				
30	260	0.86	311	1.83
40	250	1.10	272	1.85
50	293	1.11	257	1.73
60	277	1.21	301	1.88
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS
Std. error	22.6	0.077	25.5	0.121

*,** F value significant at the 5 and 1 % level, respectively. NS = not significant at the 0.05 level.

† Data expressed per g of root.

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