Stand Density Effects on Herbage Yield and Forage Quality of Alfalfa

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ABSTRACT : Optimum stand density of alfalfa (*Medicago sativa* L.) varies with locations and climates. Stand density is one of the factors that determines herbage yield, forage quality and persistence of alfalfa. As establishment costs increase, the question arises whether present population densities are optimum for obtaining maximum herbage yield and forage quality. The objectives of this study were: 1) to determine the optimum plant density for highest herbage yield and forage quality for the dehydrated alfalfa industry under Edmontons climatic conditions in Alberta, Canada; 2) to compare herbage yield and forage quality of the cultivars 'Algonquin' and 'Vernal' grown at a range of stand densities. Alfalfa seedlings of both cultivars were either transplanted at spacings of 6, 10, 15 and 25 cm or direct seeded at the 4.5 cm plant spacings, providing population densities of 494, 278, 100, 45 and 16 plants/m^2. The experimental design was a randomized complete block with a split-plot arrangement having three replicates; the main plots consisted of two alfalfa cultivars Algonquin and Vernal, and the sub-plots were the five population densities. The cultivar Vernal had significantly higher annual yield than did the cultivar Algonquin. There was no significant effect of plant density on herbage yield. There was no difference in crude protein (CP) between the two cultivars. At the first cut, there was a significant quadratic effect of plant density on CP content and the greatest CP occurred at the 100 plants/m^2 density. Crude protein was not affected by plant density at the second cut. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were not affected by plant density. The cultivar Algonquin usually had a lower ADF and NDF than cultivar Vernal. In conclusion, high population densities (278 plants/m^2 or more) of alfalfa did not improve herbage yield and forage quality compared with low plant population densities (100 plants/m^2 or less) of alfalfa. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 7 : 929-934)*

Key Words : Stand Density, Alfalfa, Herbage Yield, Forage Quality, Vernal, Algonquin

INTRODUCTION

The alfalfa used in the dehydration industry is cut in late bud to early flowering stage to provide high quality plant material (Anonymous, 1991). Stand persistence, high productivity, and excellent forage quality are primary goals for alfalfa producers. The alfalfa dehydration industry is one of the highest value added agricultural industries on the Canadian Prairies and providing significant seasonal employment in rural areas. Alberta has natural advantages for the dehydration industry because of its large forage production base, suitable climate, low cost of energy, and extensive irrigation headworks (Anonymous, 1990).

Volenec et al. (1987) reported that alfalfa could be described by three yield components: plants per area, shoots per plant, and yield per shoot. However, the yield component concept is not easy to apply to sown swards of alfalfa because plant number is difficult to define unless plants are destructively harvested.

The plant population density of alfalfa required for maximum herbage has been a matter of controversy, with estimates ranging from 22 to 215 plants/m^2 (Tesar and Jacobs, 1972; Bolger and Meyer, 1983; Nelson et al., 1986). The density required for maximum yield varies depending on the area and climate being 140 plants/m^2 in California (Marble and Peterson, 1981), 140 in Michigan (Tesar, 1977, 1978), 230 in Ohio (Van Keuren, 1973), and 260 in Illinois (Jacobs and Miller, 1970). Sund and Barrington (1976) excavated plants from a three year old stand to determine the effects of seeding rate on plant population density and herbage yield found that even when plant populations differed by approximately three-fold, there was no effect on herbage yield.

Major factors influencing the potential feeding value of alfalfa during growth and development include : growth stage at the time of cutting, leaf to stem ratio and climatic and edaphic factors. The latter includes: geographic location, seasonal and annual radiation, diurnal variation in light levels, ambient and soil temperature, soil type, soil moisture and fertility, disease and insect damage, and weed infestation. The influence of plant population on forage quality is not well researched. Bolger and Meyer (1983), evaluating one year old stands, reported no effect of plant

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population (11, 22, 33, 44, 55, or 100 plants/m^2) on alfalfa herbage concentrations of crude protein (CP) and acid detergent fiber (ADF). According to McGuire (1981) the CP content of alfalfa did not vary across seeding rates of 8.4, 11.2, 16.9, and 22.5 kg/ha or row widths of 6.7 and 13.4 cm in the cultivars Vernal and DuPuits in Ohio, USA.

The objective of this study was to determine the optimum stand density for high herbage yield and forage quality in Edmonton, Alberta, Canada.

MATERIALS AND METHODS

Root trainers (2.5×2.5×4 cm) were filled with a media composed of peat moss, black soil, and coarse sand (1:1:1). To determine if there are differences in yield and forage quality due to cultivars, two alfalfa cultivars Vernal and Algonquin that was released in 1953 and 1973, respectively, were used. Vernal alfalfa (*Medicago sativa* L.) was released for seed increase by the Wisconsin and Utah Agricultural Experiment Stations on Feb. 3, 1953. Vernal is a broad-crowned variety and excels in cold and bacterial wilt (*Corynebacterium insidiosum* (McCull) H. L. Jens) resistance. Vernal is especially adapted to the northern states and Canada, where both bacterial wilt and extreme winter conditions cause stand losses (Graber, 1956). Algonquin is a cultivar of alfalfa (*Medicago sativa* L.) developed at the Agriculture Canada Research Station, Ottata, Ontario. It is a winterhardy, 16-clone synthetic with resistance to bacterial wilt. Algonquin was developed by backcrossing plants resistant to bacterial wilt into the cultivar Rhizoma. Algonquin is adapted to all areas of Canada where Vernal or Iroquois alfalfa are used. The main area of use would be in eastern Canada (Baenziger, 1975). Approximately 8,800 seeds of cultivars Algonquin and Vernal were pre-inoculated with *Rhizobium meliloti* and planted into root trainers in 1992. The plants were grown for five weeks in the greenhouse at 20℃ and a 16 hr photoperiod. Plants were watered daily and fertilized biweekly with a liquid fertilizer ($N:P_2O_5:K_2O$= 20:20:20). The fungicide 'NO-Damp' was sprayed twice one day after planting and again after emergence for control of damping-off fungi.

Seedlings were then transplanted equidistantly into 2.25 m^2 (1.5×1.5 m) plots at distances of 6, 10, 15 and 25 cm from each other. These spacings represent population densities of 278, 100, 45 and 16 plants/m^2 and have 16, 10, 6, and 4 rows/m^2, respectively. Transplanting occurred on June 15, 1992. However, due to the difficulty of transplanting seedlings at 4.5 cm spacings, plots were seeded by hand into a grid using previously prepared templates. The experimental design was a split plot, randomized complete block design having three replications. The main plots were the cultivars Algonquin and Vernal and the sub-plots were plant densities (16, 45, 100, 278 and 494 plants/m^2). Sub-plots were separated by a 30 cm border.

In 1992, the seeding year, plots were harvested once at the late seed pod stage on September 15, 1992. In the first production year alfalfa was first harvested at one tenth bloom stage on June 18, 1993, and again at the one tenth bloom stage on August 18, 1993. To estimate herbage yield per ha 65, 40, 15, 7, and 3 plants per plot were clipped to a stubble height of 5 cm from the center of each plot and the same area was clipped in each plot. Harvested plant material was dried at 65℃ for 72 hr in a forced air dryer before weighing.

The shoot samples were ground with a cyclone mill through a 1 mm mesh screen. Samples from the first and second harvests in 1993 were analyzed for CP, ADF and NDF by Norwest Labs, Edmonton, Alberta. Crude protein was analyzed by a Leco Nitrogen Analyzer (LECO FP 428, St. Joseph, MI). Acid detergent fiber and NDF were analyzed by the method of Goering and Van Soest (1970).

Analysis of variance was performed on the data using PROC GLM procedures of SAS (SAS Institute Inc., 1989). The stand density effects were partitioned into linear and quadratic components using orthogonal polynomial coefficients. The average monthly temperatures and precipitation were recorded at the Edmonton International Airport by Environment Canada in Alberta from June 1992 to August 1993 (table 1).

RESULTS AND DISCUSSION

Herbage yield

Herbage yields of the cultivars at the first cut ranged from 5.3 to 9.1 t DM/ha over the population densities when alfalfa was cut at one tenth bloom stage (table 2). Herbage yield of Vernal was 16% higher than cultivar Algonquin on average over all plant densities at the first cut. This was surprising since Vernal is an older cultivar than is Algonquin. Min et al. (1999) reported that cultivar Vernal was a slightly winter hardy than cultivar Algonquin in the 278 and 494 plants/m^2. There was also a significant ($p<0.01$) quadratic relationship between plant density and herbage yield at the first harvest. The greatest herbage yield of alfalfa occurred at the stand density of 45 plants/m^2 and lowest at the 16 plants/m^2. At the second cut, there were no significant effects of cultivar, plant density, and cultivar×plant density interaction. Herbage yields of the cultivars at the second cut ranged from 4.2 to 5.6 t DM/ha over all stand densities and were lower than the first cut, mainly due to shorter intervals of favorable growth after the first cut. Two-cut management system in

Table 1. Average monthly temperature (T, ℃) and precipitation (P, mm) in 1992, 1993 and the 30-year averages at the Edmonton International Airport

Month	1992		1993		30-year	
	T	P	T	P	T	P
January	-	-	-14	5	-14	20
February	-	-	-10	7	-10	15
March	-	-	-3	28	-5	15
April	-	-	6	37	5	20
May	-	-	13	40	12	41
June	17	24	15	90	15	77
July	16	80	16	71	17	102
August	15	25	15	55	16	75
September	9	47	-	-	11	48
October	5	12	-	-	5	18
November	-3	19	-	-	-5	20
December	-15	24	-	-	-12	20

Table 2. Effect of stand density on herbage yield of alfalfa in 1993

Density	Cultivar		Cultivar		Cultivar	
(plants/m^2)	Algonquin	Vernal	Algonquin	Vernal	Algonquin	Vernal
	1st cut (18 June)		2nd cut (18 August)		Annual total	
	t DM/ha					
16	5.3±0.12	7.3±0.13	4.8±0.10	5.6±0.12	10.1±0.21	12.9±0.19
45	7.8±0.15	9.1±0.15	4.2±0.11	4.7±0.10	12.0±0.17	13.8±0.18
100	7.4±0.13	9.1±0.14	4.4±0.14	4.6±0.13	11.8±0.16	13.7±0.20
278	7.2±0.16	8.1±0.15	4.6±0.13	4.9±0.14	11.7±0.17	13.0±0.17
494	7.5±0.17	7.7±0.16	5.1±0.12	5.6±0.12	12.6±0.19	13.3±0.18
Cultivar (C)	**		NS		**	
Plant density (P)						
Linear	NS		NS		NS	
Quadratic	**		NS		NS	
C×P	NS		NS		NS	

Values are mean±SE; NS=Not significant; ** Significant at the p<0.01 level.

alfalfa is typical in Edmonton's climatic conditions.

Annual herbage yields of alfalfa ranged from 10.1 to 13.8 Mg/ha in 1993 and Vernal produced 12% higher herbage yield than did Algonquin. These significant yield differences were mainly attributed to the significantly higher yield in Vernal than in Algonquin at the first cut. Although there was a significant ($p<0.01$) quadratic relationship between plant density and yield at the first harvest, there was no significant effect of plant density on herbage yield in regards to the annual yield. The difference in annual yield between a 4.5 (494 plants/m^2) and a 25 cm plant spacing (16 plants/m^2) was 1.4 Mg/ha. Although there were fewer plants per unit area at a low density, these plants compensated by producing more shoots per plants, a higher yield per shoot, and having better winter survival (data not shown). This indicates that a high population density gives little yield advantage compared with a low population density for the cultivars tested. Carmer and Jacobs (1963) studied seeding rates of 4.5, 9.0, 13.4 and 17.9 kg/ha in 10.0 and 20.0 cm row spacings and when broadcast. They observed that annual total yields were higher at the seeding rate of 9.0 kg/ha than at the 4.5 kg/ha; however, no additional yield increase was obtained at seeding rates higher than 9.0 kg/ha. In this study, increasing stand density did not result in significant increases in the herbage yield of alfalfa. Further research is required to determine if herbage yields in different cultivars can be increased by managerial practices (i.e., planting dates, cutting height, cutting frequency, and soil fertility levels).

Forage quality

1) Crude protein

One of the main objectives of this study was to determine whether stand density affected forage

Table 3. Effect of plant density on crude protein content of alfalfa in 1993

Density (plants/m^2)	1st cut		2nd cut	
	Algonquin	Vernal	Algonquin	Vernal
	%			
16	15.6±1.4	15.1±1.5	22.3±1.3	19.9±1.7
45	16.5±1.6	15.4±1.4	22.5±1.6	20.6±1.7
100	17.4±1.4	16.2±1.6	23.1±1.5	22.4±1.6
278	16.9±1.7	15.3±1.5	23.1±1.6	20.4±1.8
494	15.7±1.7	15.6±1.8	22.7±1.5	21.8±1.6
Cultivar (C)	NS		*	
Plant density (P)				
Linear	NS		NS	
Quadratic	*		NS	
C×P	NS		*	

Values are mean±SE; NS=Not significant * Significant at p<0.05 level.

Table 4. Effect of plant density on acid detergent fiber content of alfalfa in 1993

Density (plants/m^2)	1st cut		2nd cut	
	Algonquin	Vernal	Algonquin	Vernal
	%			
16	38.5±3.2	40.5±3.0	35.1±3.3	39.0±3.4
45	39.3±2.8	40.5±3.2	35.1±2.9	37.5±3.1
100	37.6±2.9	38.6±2.9	35.5±3.4	38.3±3.3
278	37.5±3.1	40.7±3.3	34.4±3.2	40.2±2.9
494	38.3±3.1	37.9±3.1	36.8±3.3	36.5±3.2
Cultivar (C)	*		*	
Plant density (P)				
Linear	NS		NS	
Quadratic	NS		NS	
C×P	NS		NS	

Values are mean±SE; NS=Not significant; * Significant at p<0.05 level.

quality. In the first production year, there was a significant ($p<0.05$) quadratic effect of stand density on crude protein (CP) at the first harvest (table 3). The greatest CP occurred at the 100 plants/m^2 stand density and the lowest at the 16 plants/m^2. The CP content ranged from 15.1 to 17.4% at the first cut over the range of stand densities. Algonquin had similar CP contents to Vernal across all the stand density treatments. An interesting finding was that the CP content of herbage at the lowest density (16 plants/m^2) was not different from that at the highest stand density (494 plants/m^2) although there was a 31 times difference in stand density.

At the second harvest, there was a significant ($p<0.05$) cultivar effect and significant ($p<0.05$) cultivar×plant density interaction. However, there was no significant difference in CP between the lowest and the highest plant densities. This indicates that plants having finer stems at the high population densities do not necessarily have higher CP content than those at the low population densities with thicker stems. Similar to the first harvest, the CP of Algonquin was a little higher than that of Vernal at most densities (table 3). The CP content at the second harvest was higher than at the first harvest across all the plant densities in both cultivars. According to Kreuger and Hansen (1974) in South Dakota, USA, during the seeding and production years, the percent of CP in alfalfa was not affected by the seeding rates although alfalfa stems were finer at the higher seeding rates. McGuire (1981) in Ohio also reported that the CP content was not influenced by the seeding rates ranging from 8.4 to 22.5 kg/ha. Therefore, planting high seeding rates do not appear to increase CP content of alfalfa.

2) Acid detergent fiber

The ADF ranged from 38 to 41% and was not affected by plant densities at the first harvest or the second harvest (table 4). This is in agreement with Sund and Barrington's (1976) results. They reported that seeding rates of 6.7 to 40.4 kg/ha did not

Table 5. Effect of plant density on neutral detergent fiber content of alfalfa in 1993

Density (plants/m^2)	1st cut		2nd cut	
	Algonquin	Vernal	Algonquin	Vernal
	%			
16	47.7±3.8	50.2±3.6	42.8±3.3	46.9±3.5
45	49.3±3.5	49.6±3.7	43.7±3.3	44.8±3.4
100	46.5±3.6	48.1±3.5	42.8±3.5	44.9±3.4
278	46.2±3.5	50.3±3.7	41.3±3.7	47.9±3.3
494	47.7±3.5	47.3±3.8	43.3±3.4	44.0±3.6
Cultivar (C)	*		*	
Plant density (P)				
Linear	NS		NS	
Quadratic	NS		NS	
C×P	NS		NS	

Values are mean±SE; NS=Not significant; * Significant at p<0.05 level.

influence alfalfa cell wall constituents, ADF, or acid detergent lignin (ADL) in Wisconsin, USA. In this study, there was a significant ($p<0.05$) difference in ADF content due to cultivars at the first harvest in 1993. Algonquin had significantly lower ($p<0.05$) ADF than Vernal (i.e., 38 vs. 40% for Algonquin and Vernal, respectively).

At the second harvest (cut at one tenth bloom stage), the ADF ranged from 34 to 40%. As in the first cut, there was a significant ($p<0.01$) cultivar effect and Vernal had higher ADF than Algonquin (i.e., 35 vs. 38% for Algonquin and Vernal, respectively). The average ADF content at the second harvest was a slightly lower than at the first harvest at all plant densities as cuts proceed. This is in agreement with Meyer (1985) who reported that concentrations of ADF, acid detergent lignin (ADL), and NDF were unaffected by plant population even though shoot production ranged from 19 to 33 per plant.

3) Neutral detergent fiber

The NDF content ranged from 47 to 50% at the first harvest when alfalfa was cut at the one tenth bloom stage (table 5). There was a significant ($p<0.05$) difference in NDF due to cultivars. Algonquin had a lower NDF than Vernal (i.e., 47 vs. 49% for Algonquin and Vernal, respectively) at the first harvest. However, there was no significant effect of plant density or cultivar×plant density interaction on NDF content.

At the second harvest there was a significant NDF ($p<0.05$) difference in cultivars and Vernal had higher NDF than Algonquin (43 vs. 46% for Algonquin and Vernal, respectively). The NDF content did not vary with plant density and these findings are consistent with previous studies (Van Keuren, 1973; Meyer, 1985; Cherney et al., 1986). The NDF at the second harvest was lower than at the first harvest. These differences between the first and second harvest might be partly attributable to differences in origin of stems. Nelson and Smith (1968) reported that stems from crown buds in spring growth have a low leaf to stem ratio compared to stems from axillary basal buds in regrowth after cutting. In both the first and second cuts, Algonquin had significantly lower NDF content than Vernal. This was the opposite to the leaf to stem ratio results with Algonquin having a higher leaf to stem ratio than Vernal (data not shown) consistent with lower NDF contents than Vernal.

In this study, forage quality parameters, i.e., CP, ADF and NDF were generally not affected by plant population density in alfalfa. Forage quality was generally changed more by cultivars indicating that selecting alfalfa cultivar having high CP and lower fiber contents appear to be better practice to increase nutritive values rather than changing stand density.

In conclusion, the alfalfa cultivar Vernal had significantly higher annual yield than did the cultivar Algonquin. High stand densities (278 plants/m^2 or more) did not increase herbage yield and forage quality of alfalfa compared with low plant population densities (100 plants/m^2 or less). Using lower seeding rates may enable alfalfa producers to reduce the establishment costs and increase their marginal profit.

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