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Full Length Research Paper

Effects of cutting frequency on alfalfa yield and yield components in Songnen Plain, Northeast China

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The productivity and quality of alfalfa (*Medicago sativa* L.) is strongly influenced by cutting frequency (F). To clarify that the yield and quality of alfalfa if affected by F, an experiment was conducted on Songnen Plain in Northeast China to investigate the responses of yield components and quality to 3 cutting frequencies (F30, F40 and F60) among 3 cultivars (C) (Longmu, Aohan, Zhaodong). Result from two consecutive years showed that cutting frequency had a greater effect on reducing forage yield and yield components at F40. Cultivars had no effect on 2-year total forage yield and alfalfa quality. Alfalfa at the F40 always had higher crude protein (CP), and neutral detergent fibre (NDF) than F30 and F60 treatments. The interaction (C×F) on forage yield and components (CP and NDF) was not significant. This study provides evidence that: i) 40-day intervals can be advocated for cultivars growing in North-east China; and ii) at F40 utilization, Longmu is a well-adapted alfalfa variety in the Songnen Plain because of higher yield and quality under three cuttings.

Key words: Alfalfa, cutting frequency, yield, quality, Songnen Plain.

INTRODUCTION

Alfalfa (*Medicago sativa* L.) is an important crop planted for over 2,000 years in China and its demand is expected to reach one million tonnes each year for dairy industry (Li et al., 2010), with a great contribution to the development of agriculture and animal husbandry (Han et al., 2005). In China, the North-east prevalence that was observed as a result of the extreme climatic trend (Tang et al., 1996) is an ecotone system between agriculture and animal husbandry. The diet of animals in this area nearly exclusively relies on forage production characterized by a low-quality and a short period of production (Chen et al., 2010). So, insufficient feed supplies in the winter season seriously restrict the productivity of livestock (Long, 1995; Dong et al., 2003).

However, alfalfa had played an important role in eliminating the seasonal imbalance between livestock and forage production in northeast areas of China (Chen et al., 2010). Alfafa is one of the most valuable crops due to its great yield potential, high nutritional value (Jia et al. 2009), and a wide adaptation (Pietsch et al., 2007). In many countries, alfalfa is grown primarily for forage production to enhance livestock production (Iannucci et al., 2002). At one time, alfalfa had also increased the vegetation cover, preventing the degradation of grassland and assisted the sustainable development between agriculture and animal husbandry of the northeast area in China.

To explore the best management of alfalfa in the Songnen Plain, more attention must be paid to cutting frequency. In fact, cutting frequency, a critical factor influencing both productivity and persistence (Keoghan, 1982), is generally associated with the flowering time. This represents an extremely important variable being a trade-off among quantity, quality, and duration of the meadow (Teixeira et al., 2008). Moreover, these parameters are strongly linked to climatic conditions, management techniques (Sanchez et al., 2010), regrowth capability of the varieties (Dhont et al., 2003) and nutritional requirements for the livestock. Researchers had found that harvest time can affect forage yield and quality (Ghanbari and Lee, 2003). The aim to improve forage quality without reducing yields can be achieved by

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increasing the cutting frequency (Lemaire et al., 1993; Marten et al., 1988). However, this study did not clearly show a higher forage yield and the better digestibility of forage (Grignani, 1990).

Cutting frequency (F) is known to affect three yield components - plants area^{-1}, shoots plant^{-1}, and mass shoot^{-1} (Volenec et al., 1987), but it remains unclear which of the components are most affected and if its effect is similar among cultivars. Teixeira et al. (2007b) observed that mass shoot^{-1} was reduced with frequent cutting. Davis and Peoples (2003) reported that plants area^{-1} was reduced when alfalfa plants were cut frequently. In contrast, Belanger et al. (1992) observed similar rates of plant mortality among alfalfa varieties subjected to different defoliation frequencies. Nelson et al. (1986) reported that the number of shoots per square meter (shoots m^{-2}) was reduced when alfalfa plants were cut frequently.

The purpose of the present study was to test the influence of cutting frequency on the productive and qualitative characteristics of three alfalfa cultivars widely grown in the Songnen Plain in China. Our objectives in this study were to comprehend if cutting frequency affects alfalfa productivity (forage yield and yield components) and quality (CP and NDF) and to determine if these varieties had higher yield and quality with increased cutting frequency.

MATERIALS AND METHODS

Region and site description

The field experiment was carried out at the Frigid Forage Research Station located in the Shuihua region. The Research Station has an altitude of 160 m, longitude of 125°58', and latitude of 46°32' N in the north-westen of Songnen Plain, North-east China (Chen et al., 2010). The climate is classified as a typical chillness semi-wetness monsoon environment. Based on data from 1988 through 2008, the total yearly sunshine duration is 2713 h and the frost-free period is 130 days. The annual mean air temperature is 5.3°C with a maximum temperature of 31.2°C in July and a minimum temperature of -25.2°C in January. Average annual accumulated heat units (above 10°C) are 2,760°C. The average annual precipitation is 469.7 mm, of which about 75% falls between June and August and the evaporation is about 950 mm. The soil is dark loam (mostly Chernozem, FAO Taxonomy) with high melanic humus. The experimental area had an average soil pH of 8.12, an average soil organic matter content of 6.04%, total N content of 0.34%; the contents of NO^{-3}-N was 4.35%, the contents of NH^{+4}-N was 6.81% and available P was 22.35 ppm (Olsen method). Maize (*Zea mays* L.) was the previous crop on this field. The experiment was seeded on 1 May, 2008 and crops were grown for two years until 2011. The climate variables (rainfall, maximum and minimum temperatures) were recorded daily and are reported as average monthly data in Figure 1.

Experimental design

The treatments were a factorial combination of three alfalfa cultivars varieties (same fall dormancy): Longmu (C1), Aohan (C2), and Zhaodong (C3), and three cutting frequency: 30 (F30), 40 (F40) and 60 day (F60) intervals. The varieties are widely planted in this region with high yield and favorable adaptability to the northeast areas of China. Cultivars (C) were sown on 1 May 2008 in a randomized block design with three replicates. There are 27 plots in this study. Each plot is 3 m long and 2 m wide with inter-row spacing of 15 cm. Seeding rate is 15 kg ha^{-1} and seed were drilled uniformly. After seeding, the plots were compacted using a corrugated roller. Open perimeter area outside of the experiment was reserved to protect the experimental rows from interferential damage. No fertilizer or irrigation was applied during the experimental periods. Plots were hand-weeded during the growing period whenever necessary for proper weed control. The experiment was carried out for two consecutive years where cutting frequencies occurred during a 120-day period of each year from June 15 to October 12, except in the establishment year, in which the crop was harvested two times because of the temperature and photoperiod. During experimental period, there were 4, 3 or 2 shoot re-growth cycles for the 30, 40 and 60-day treatments, respectively. Plots were not harvested during the winter between 2009 and 2010.

Sampling and analytical methods

The shoot samples were cut to ground level with manual shears using 0.5 × 0.5 m quadrats for determination of the variables: shoots m^{-2} (number of shoots divided by 0.25 m^2), mass shoot^{-1} (total g of dry matter divided by the number of shoots) and shoot height. Forage yield (g DM m^{-2}) was determined by harvesting 2 × 2 m^{-2} of each plot (leaving margins and a 5 cm stubble). With forage yield data of each re-growth, the annual forage yield (total yield of all cuttings) and two-year total forage yield (adding the yield of each re-growth from both years) was calculated. Initial and final plant density was measured by counting plants per plot annually, before the end of April when the beginning of the spring re-growth started. Samples were dried in the oven for 72 h at 65°C (Vasilakogloua et al., 2008), then ground with a Wiley mill to pass a 1 mm screen and analyzed for quality components. Crude protein content (CP) was calculated by the methods of Association of Official Analytical Chemists-AOAC (1980). Neutral detergent fibre content (NDF) was determined using the procedure by Goering and Van Soest (1970).

The effects of C, F and the interactions (C×F) on six trait parameters including shoots m^{-2}, mass shoot^{-1}, height shoot^{-1}, forage yield (g DM m^{-2}), crude protein (CP), and neutral detergent fibre content (NDF) of alfalfa crop were analyzed with one-way ANOVA of general linear model (GLM) and a posteriori Tukey-Kramer LSD test ($P < 0.05$). Due to a lack of normality, some data were square root transformed as appropriate prior to analysis. Where F-tests were significant ($p < 0.05$), LSD was calculated to compare the means. Data were analyzed using the general linear models (GLM) procedure. All statistical analyses were performed using statistical computer software SAS (SAS Institute, Inc.1999).

RESULTS

Weather data

Weather conditions at Shuihua region of Songnen Plain during four consecutive growing seasons was recorded and 2010 growing season at Shuihua region was generally warmer and wetter than the 2009 growing season. The temperature profile during the 4-year trial was similar to the 30-year average with the highest temperature (25 to 28°C) recorded in July and August and the lowest just below 0°C recorded in December and

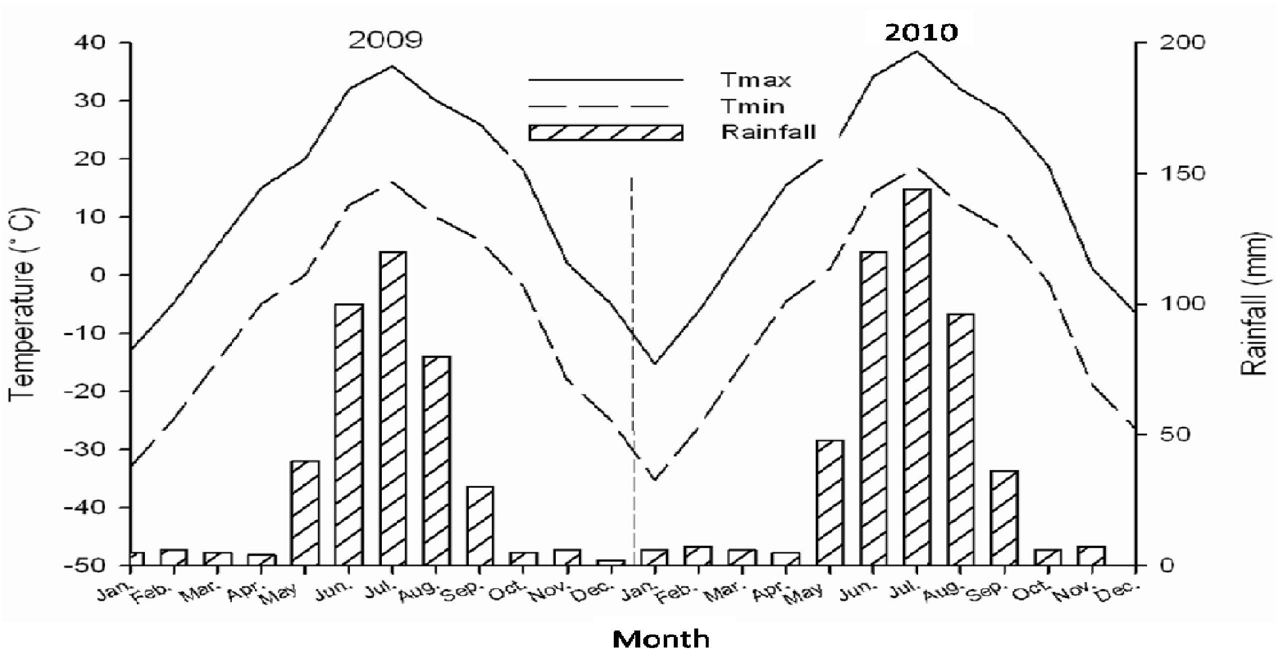

Figure 1. Monthly average of maximum and minimum temperatures and total rainfall for 2009 and 2010 at Lanxi County, China.

January (except for the 2008 when the minimum temperature occurred between January and February). The average of total annual rainfalls was about 500 mm, not much different from the prior 30-year average. Generally, the rainfalls were mainly recorded between June and August. No catastrophic weather occurred during the growing seasons between 2008 and 2011 at Shuihua region on Songnen Plain in North-east China (Figure 1).

Forage yield

Although weather conditions at Lanxi County differed considerably in 2009 and 2010, differences in the alfalfa yield production among years were relatively consistent over the 2 years. Positive effect of cutting frequency was recorded in 2009 and 2010 (Table 1). The interaction (C×F) was also significant during 30-, 40-, and 60-day re-growth periods in both years ($p < 0.05$). In the first year, F40 had significantly higher yield (614 g DM m^2) than F60 and F30 (520 and 318 g DM m^2, respectively). In 2009, 2010 and the 2-year total, F40 had also significantly higher yields than F60 and F30. Cultivars varieties for DM production observed in the experiment did not show any significance, except in 2009 year.

Shoots m^{-2}

The effect of cutting frequency on shoots m^{-2} was significantly observed in both years (Table 2). Cultivars varieties for shoots m^{-2} observed in the experiment did not show significant difference in both years. The (C×F) interaction for shoots m^{-2} in 2009 and 2010 year was not significant. In year 2009, the effect of F on shoots m^{-2} was significantly observed because the F40 and F60 treatments had greater shoot numbers (743 and 668 shoots m^{-2}, respectively) when compared to F30 (645 shoots m^{-2}), while the effect of C did not show significant difference, where C1 had more shoots (628 shoots m^{-2}) than C3 (586 shoots m^{-2}), with C2 being intermediate (628 shoots m^{-2}). In 2010, F40 and F60 had more shoots (972 and 876 shoots m^{-2}, respectively) than F30 (771 shoots m^{-2}). Total 2-year shoots m^{-2} for three cultivars in both years was obtained such that no difference was statistically significant at the 5% level, while C1 (Longmu) produced more shoots m^{-2} than C1 and C2 (Figure 2).

Mass shoot^{-1}

The effect of cutting frequency on mass shoot^{-1} was significantly observed in both years (Table 2). The mass shoot^{-1} for cutting frequency significantly ranged from 0.27 to 0.45 g DM in year 2009 and expanded from 0.28 to 0.46 g DM in year 2010. In 2009, the effect of F on mass shoot^{-1} was significantly observed because the F40 and F60 treatments had greater mass shoot^{-1} (0.45 and 0.33 7 g DM shoot^{-1}, respectively) when compared to F30(0.27 g DM shoot^{-1}). In 2010, the effect of F on mass shoot^{-1} was significantly observed because the F40 and

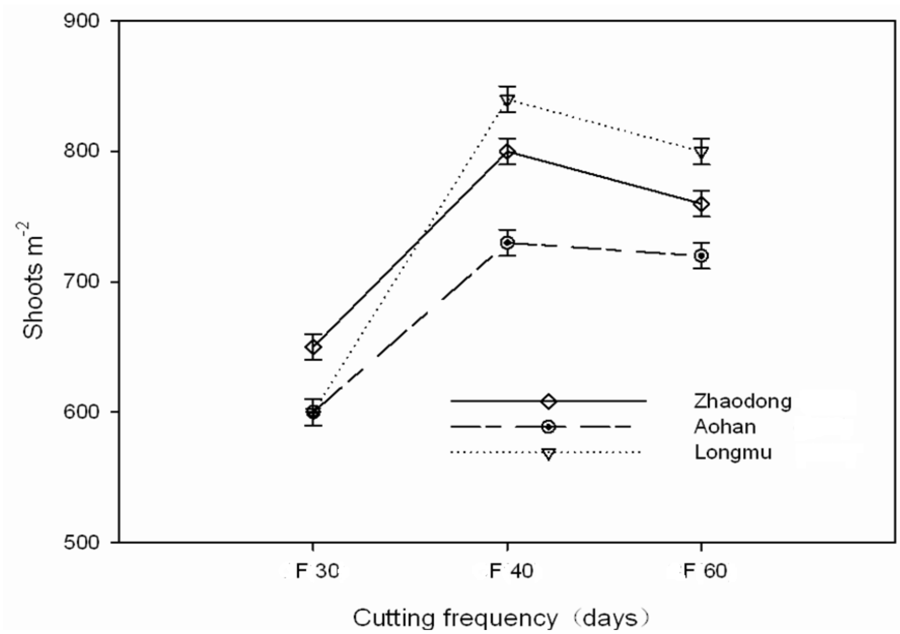

Figure 2. Average of two years (mean ± SE) of shoots m^{-2} of three alfalfa varieties under three cutting frequencies: F30, F40 and F60

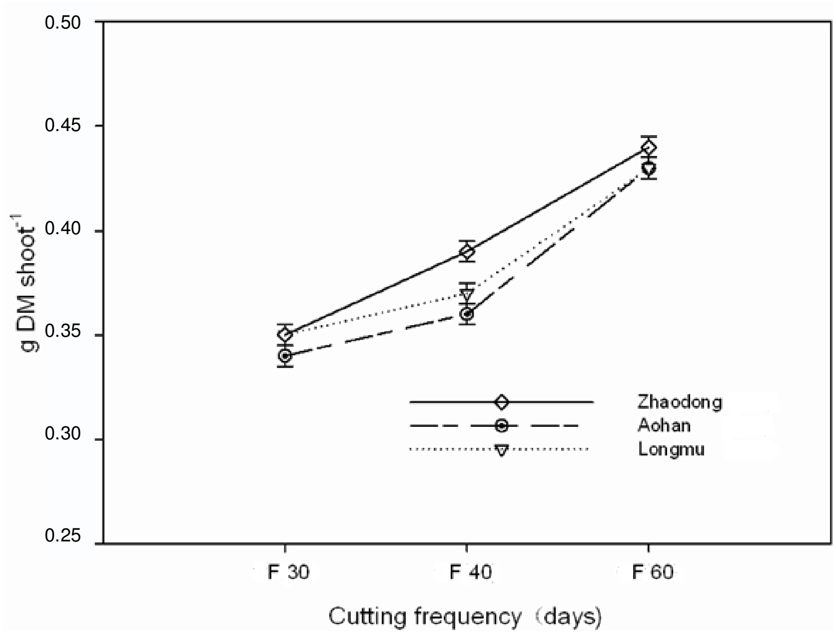

Figure 3. Average of two years (mean ± SE) of Mass $shoot^{-1}$ of three alfalfa varieties under three cutting frequencies: F30, F40 and F60.

F60 treatments had greater mass $shoot^{-1}$ (0.46 and 0.35 g DM $shoot^{-1}$, respectively) when compared to F30 (0.28 g DM $shoot^{-1}$). Although, mass $shoot^{-1}$ differed significantly at cutting frequency ($p < 0.05$), no difference in mass $shoot^{-1}$ occurred among C groups, where C1 had more mass $shoot^{-1}$ (0.35 g DM $shoot^{-1}$) than C2 (0.32 g DM $shoot^{-1}$), with the C1 alfalfa being intermediate (0.33 g DM $shoot^{-1}$). The interaction (C×F) for mass $shoot^{-1}$ was significant in the first and second years, similar results were obtained in both years (Table 2). Total 2-year mass $shoot^{-1}$ of cutting frequency in the experiment was significant, where the F60 had significantly higher yields than F30 and F40 (Figure 3). Cultivars varieties for mass $shoot^{-1}$ did not show significant difference in either years

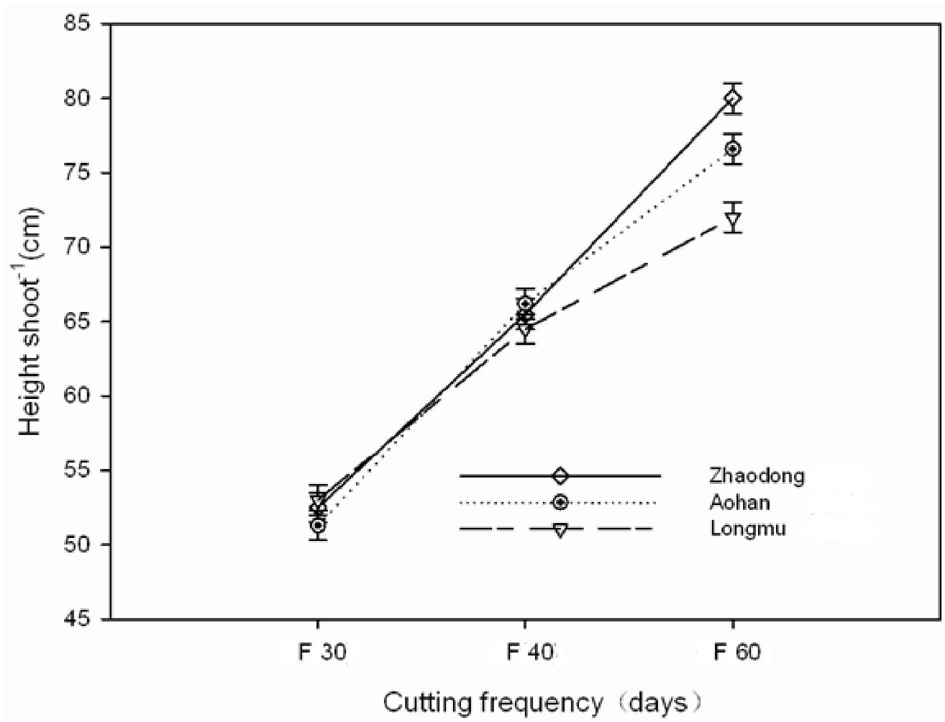

Figure 4. Average of two years (mean ± SE) of height shoot^{-1} of three alfalfa varieties under three cutting frequencies: F30, F40 and F60.

(Table 2) while it was easier for C3 (Zhaodong) to accumulate more mass DM of shoot than C1 and C2 (Figure 3).

Height shoot^{-1}

Total 2-year varieties for plant height observed in the experiment did not show significant difference in either years while in C3 (Zhaodong), it was easy to increase plant height than C1 and C2 (Figure 4). The F and interaction (C×F) for height shoot^{-1} was significant in both 2009 and 2010 (Table 2); while shoot height of all cultivars decreased with cutting frequency treatment in both years where the shoot height had shorter shoots at F30 and F40 compared to F60 ($p < 0.05$). Shoots from the F60 treatment were the tallest (75.60 and 76.60 cm) whereas F30 had the shortest (52.50 and 51.30 cm), and those in the F40 treatment were intermediate (65.50 and 66.20 cm). The effect of C did not show significant difference although C3 (Zhaodong) were tallest (63.20 cm in 2009 and 63.00 cm in 2010) whereas C1 (61.50 and 61.80 cm) was the shortest with the C2 alfalfa being intermediate (62.00 and 62.50 cm).

Forage quality

In 2009, F30 presented a higher crude protein percentage (CP, %) than F60 (25.50 and 18.42%, respectively), and those in the F40 were intermediate (22.56%) for the three varieties. In 2010, similar result was observed among F60, F40 and F30 (18.62, 22.70 and 25.33%, respectively). Meanwhile, there was significant interaction between varieties on CP in both years. For total 2-year, C1 (Longmu) had the highest CP than C2, whereas C3 were intermediate (Figure 5). Neutral detergent fibre content percent (NDF, %) of the diet is an indicator of potential DM intake and milk yield in dairy cows. In 2009, F30 or F40 presented a lower NDF than F60 for the three varieties. In 2010, similar result was observed among F60, F40 and F30 (33.62, 29.70 and 28.33%, respectively). For total 2-year, NDF of C1 (Longmu) had the lowest NDF content than C2, whereas C3 were intermediate (Figure 6).

DISCUSSION

In forage production, a major goal is to increase herbage yield (Wang et al., 2009). During the two production years, annual mean temperatures in each year were about the long-term average, but there were more rainfall events and total precipitations in 2010. Although there were no large deviations in monthly mean temperatures and accumulated rainfalls during the growing season from year to year, these weather variations were part of the reasons of annual total DM yield differences of the

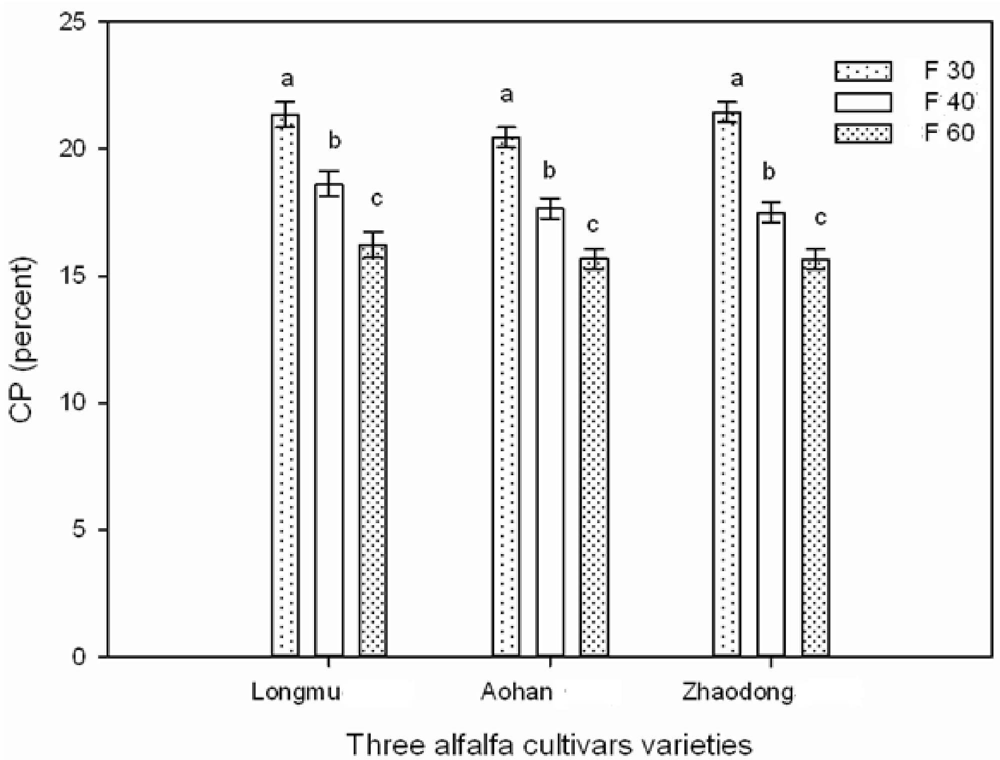

Figure 5. Average of two years (mean ± SE) of total crude protein (CP, %) of three alfalfa varieties under three cutting frequencies: F30, F40 and F60.

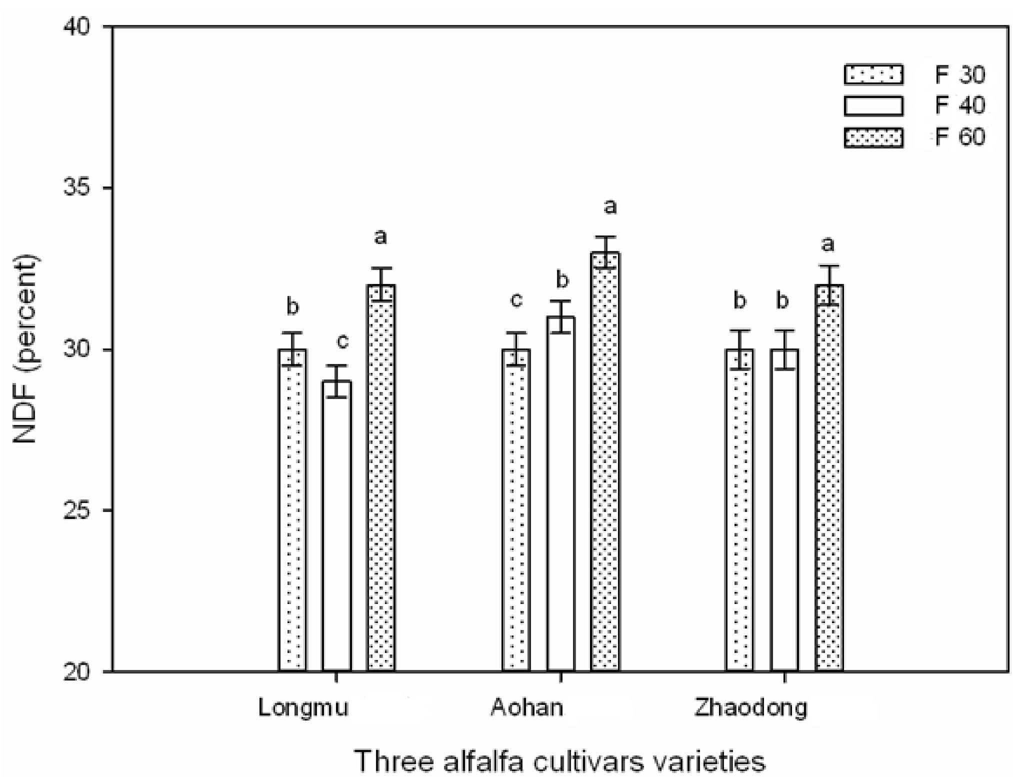

Figure 6. Average of two years (mean ± SE) of total neutral detergent fibre content (NDF, %) of three alfalfa varieties under three cutting frequencies: F30, F40 and F60.

Table 1. ANOVA results on effects of cutting frequency (F) on forage yield of cultivars varieties (C) over a two-year period at Lanxi county, in China.

Variation ¶	Forage yield (g DM m^{-2}) †		
	2009	2010	2-Year total
F60	520^b	680^b	1200^b
F40	614^a	852^a	1466^a
F30	348^c	416^c	764^c
Average	494	649	1143
LSD (0.05)	90	120	246
C1	452^a	714	1166
C2	436^{ab}	690	1126
C3	422^b	696	1138
Average	437	700	1143
LSD (0.05)	42	NS‡	NS

¶The cutting frequencies were 30-, 40- and 60-day for F30, F40 and CF60, respectively. The cultivars varieties were 'Longmu', 'Aohan' and 'Zhaodong' for C1, C2 and C3, respectively. †Forage yield of each F is average across all C, and forage yield of each C is average across all F. ‡NS indicates no statistically significant difference between group at $p \geq 0.05$. Different letters between rows are statistically different at $p < 0.05$.

Table 2. ANOVA results on effects of cutting frequency (F) on shoots m^{-2}, mass $shoot^{-1}$ and height $shoot^{-1}$ of cultivars varieties (C) over a two-year period at Lanxi County, China.

Variation ¶	Shoots m^{-2} (plant) †		Mass $shoot^{-1}$ (g DM) †		Height $shoot^{-1}$ (cm) †	
	2009	2010	2009	2010	2009	2010
F60	668^b	876^b	0.33^b	0.35^b	75.60^a	76.60^a
F40	743a	972^a	0.45^a	0.46^a	65.50^b	66.20^b
F30	645^c	771^c	0.27^c	0.28^c	52.50^c	51.30^c
Average	685	873	0.35	0.36	64.53	64.70
LSD (0.05)	16	3	0.10	0.10	9.66	10.00
C1	628	992	0.35	0.35	61.50	61.80
C2	606	959	0.32	0.34	62.00	62.50
C3	586	967	0.33	0.33	63.20	63.00
Average	607	973	0.33	0.34	62.23	62.10
LSD (0.05)	NS‡	NS	NS	NS	NS	NS

same varieties on DM yields. In alfalfa, forage yield was thought to be associated with variety. There were several studies illustrating the relationship in temperate regions with mild climate (Barnes et al., 1979; Stout and Hall, 1989). However, few studies investigated the relationship between cultivars with different fall dormancy ranking on forage yields (Li and Zhu, 2005; Wang et al., 2005).

In this study, the highest crops yield, shoots m^{-2}, and mass $shoot^{-1}$ occurred at F40 and the lowest crops yield, shoots m^{-2}, and mass $shoot^{-1}$ was at F30, indicating that F40 are most suitable for alfalfa growth in the temperate northern regions. Among the three varieties, the greatest DM yield was obtained from the C1 (Longmu), followed by the C2, and C3 had the lowest yield. This is in accordance with the findings of other studies in regions with similar climate (Han et al., 2004; Wang et al., 2004).

The interaction (C×F) on annual and 2-year total forage yield was not significant (Table 1), which is consistent with those of similar studies on alfalfa yield in Australia (Lodge, 1986) and in USA (Kallenbach et al., 2002). The results showed that the anterior had a greater effect on forage yield, which agrees with the results of others (Putnam and Orloff, 2003; Putnam et al., 2005). The decreased forage yield with frequent cutting was due to the decrease in shoots m^{-2} (Undersander et al., 1998), mass $shoot^{-1}$ (Berg et al., 2005, 2007) and height $shoot^{-1}$

(Griggs and Stringer, 1988). The decrease in these yield components could be due to a reduction in the amount of energy captured through photosynthesis, especially for a shorter re-growth length (F30), and a decrease in taproot organic reserves (Teixeira et al., 2007a; Ventroni, 2009), mainly nitrogen reserves (Avice et al., 1996). This reduction in reserves would have a negative effect on radiation use efficiency at the whole plant level because of a decline in photosynthetic capacity of the earliest initiated leaves post-defoliation (Teixeira et al., 2008), which together with subsequent reductions in canopy expansion rates (Teixeira et al., 2007c), diminished forage yield.

The largest annual forage yield difference of C1 vs. C3 was mainly explained by the greater mass shoot^{-1} and height shoot^{-1} of the nature of the cultivar. In 2010, there was no statistical difference in annual forage yield among cultivars, which showed no difference in mass shoot^{-1} and height shoot^{-1}. Therefore, the results of both years indicated that differences in forage yield ranking among cultivars can change with time, which agrees with the results of Ventroni et al. (2010). The range of shoot density obtained in the current experiment (336 to 700 shoots m^{-2}) was similar, compared to those of Cangiano and Pece (2005) (310 to 910 shoots m^{-2}), but lower than the density in the experiments undertaken by Teixeira et al. (2007b) (780 to 900 shoots m^{-2}) using broadcast-seeded plots. Our results confirm that increased cutting frequency caused a reduction in mass shoot^{-1} as reported by Teixeira et al. (2007b). Shoots m^{-2} was reduced with increased cutting frequency, which is in agreement with Nelson et al. (1986).

In the current experiment, shoots m^{-2} and mass shoot^{-1} both declined for all three cutting frequencies and resulted in the lowest forage yield at F30. There was no compensation between yield components. Conjectural reasons reported by Teixeira et al. (2007c) were that grazing alfalfa affected only canopy expansion rates compared with canopy architecture traits and development processes of canopy formation (leaf appearance, branching and shoot initiation). Therefore, it follows that alfalfa might have little plasticity among yield components where frequent defoliation increased tiller, diminished tiller mass, and resulted in no net change in forage yield (Chapman and Lemaire, 1993).

To find appropriate cutting frequency to achieve trade-off of higher quality and yields, researches had demonstrated that fertilization had significant effect on compensatory growth after cutting and increased forage fresh yield (Lei et al., 2005; Lithourgidis et al., 2006) and reduced yield loss from cutting (Ross et al., 2005). The present study results showed that forage yield decreased and forage quality improved at F40, which were in accordance with some other researches that cutting had significant effects on forage quality and yields (Chen et al., 2003; Yang et al., 2004). In this study, Longmu presented best response on CP and NDF at F40 utilization, Zhaodong was next best. Therefore, Longmu appeared to give a higher dry hay yields than the other two varieties under F40 conditions due to maximum compensatory growth.

Conclusion

Our study provides evidence that i) 40-day intervals can be advocated for cultivars growing in northeast area of China; and ii) Longmu is a well-adapted alfalfa variety in the Songnen Plain at F40 utilization because of higher hay yield and quality under three cutting frequencies. Therefore, further study should be conducted to seek optimal management practices to increase yield component and achieve the trade-off of higher quality and greater yields under proper management methods.

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