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Research Article

Effect of Cutting Height on Productivity and Forage Quality of Alfalfa in Alpine Area of Korea

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ABSTRACT

Cutting management has been identified as a critical factor in the alfalfa production systems because it has a significant impact on maximizing yield and maintaining the forage quality. The objective of this experiment was to determine the proper cutting height according to harvesting time for optimizing nutrient yield and forage nutritive quality of alfalfa grown in alpine regions of Korea. Alfalfa was sown at a seeding rate of 30 kg/ha in August 2018 and harvested at four cuttings in 2019 (3 May, 2 July, 11 September, and 13 October). Cutting heights were adjusted at 5, 15, and 25 cm above the soil surface. Alfalfa plant was tallest at the third cutting (109 cm), which was on average 35 cm taller than the first or second cutting. Relative feed value (RFV) remained unaffected by cutting height at the first harvest, but increased consistently in subsequent harvests as cutting height increased. Alfalfa collected at the first and fourth cuttings had the highest RFV (mean 152), which was on average 8 and 67 units higher than the second and third harvests, respectively. At each harvest, *in vitro* dry matter digestibility was highest in alfalfa cut at a 25-cm height. Dry matter (DM) production at each cutting height was highest in the first cutting, accounting for on average 36-37% of total annual DM production, and lowest in the fourth harvest, accounting for about 11-13% of the total DM yield. The total dry matter production (in four harvests) was 4,218 kg/ha higher when alfalfa was subjected to a cutting height of 5 cm rather than 25 cm. Cutting height had no effect on total crude protein yield, but from the first to fourth cutting, the protein yield followed a decreasing trend. Finally, there were visible declines in forage nutritive quality when alfalfa was cut at a shorter height. However, the magnitude of difference in total forage yield may outweigh the slight decline in forage quality when alfalfa is cut at a lower height. The findings of this study could help the alfalfa growers make better harvest management decisions.

(**Key words**: Alfalfa, Yield, Component quality, Cutting management)

Ⅰ. INTRODUCTION

Alfalfa is an important source of fiber and protein in dairy and beef rations (Palmonari et al., 2014; Robertson et al., 2015). Therefore, precise information about productivity and the nutritive quality of alfalfa forage is critical for increasing the profitability of forage-based livestock production systems (Rimi et al., 2012; Santillano-Cázares et al., 2014; Arnold et al., 2019). Accurate information about alfalfa harvesting management is required to maximize alfalfa cultivation productivity, forage nutritive quality, and thus profitability (Bouton, 2007). Poor alfalfa management practices, such as improper cutting management and harvesting frequency, have harmed alfalfa productivity in many locations. As a result, extensive research into optimizing cultivation and harvesting techniques is required to increase the economic efficiency of alfalfa production (Noland et al., 2018).

Cutting height is an important factor in the management of alfalfa production system because it has a significant impact on regrowth rate, yield, and forage nutritive quality (Tudsri et al. 2002; Wadi et al. 2004; Yolcu et al. 2006). Fiber and protein fractions as well as digestibility are all important factors in determining forage nutritive quality (Jeranyama and Garcia, 2004; Wood et al., 2019). For example, the recommended NDF (neutral detergent fiber) concentration ranges between 400 and 550 g/kg DM (dry matter) at the time of alfalfa harvest, and deviations from these values may have a negative impact on animal productivity (Cherney et al., 2006; Parsons et al., 2009; Undersander et al., 2004; Wood et al., 2019).

Parsons et al. (2012) found that alfalfa cut at a greater height had less NDF and greater digestibility. Seid et al. (2005) studied the effect of alfalfa stubble heights (5, 10, 15 and 20 cm) and identified that alfalfa cut at a 10-cm height was optimum considering

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the yield and forage nutritive quality. Yolcu et al. (2006) also suggested that biomass productivity (DM and nitrogen) was greater in alfalfa subjected to a lower cutting height. Shen et al. (2013) identified that alfalfa cut closer to the soil surface increased total forage yield over the two harvests. Although several studies have reported the relationship between cutting height and alfalfa yield and nutritive quality, there are still uncertainties about the optimal cutting height in modern varieties and its interaction with harvesting time in different geographical locations and climatic conditions (Jungers et al., 2020). In particular, new varieties with different reconvey rates may respond differently to the cutting height and harvest timing. This necessitates additional research to accurately quantify their yield and quality response to cutting height regimes and its interaction with harvesting time. Forage producers need precise information on how cutting height affects yield and forage quality in order to make more informed decisions about the cutting height when harvesting alfalfa. Therefore, the objective of this study was to determine the optimum cutting height according to the harvesting time that maximized yield and nutritive quality of alfalfa grown in the Northern regions of Korea.

Ⅱ. MATERIALS AND METHODS

1. Study location and alfalfa management

Alfalfa (*Medicago sativa* L. var. P5444) was sown at a seeding rate of 30 kg/ha in the experimental field of Seoul National University, Pyeongchang campus (located at 37°32′46.1″N, 128°26′17.9″E; 600 m above sea level) on August 28, 2018. Nitrogen (18 kg/ha) and phosphate (180 kg/ha) fertilizers were applied on the day of sowing, while potassium fertilizer was applied (120 kg/ha) at day of sowing and each harvest. Alfalfa was harvested four times at the beginning of flowering in 2019 (May 3, July 2, September 11 and October 13). Cutting height at each harvest was set at 5-, 15-, or 25-cm above the soil surface. The detailed meteorological data (temperature and precipitation) collected during the experimental period is illustrated in Fig. 1. During the study period, the mean temperature averaged from −5 to 24°C. The mean precipitation averaged from 5 to 300 mm.

2. Measurements

The harvested alfalfa samples were dried at 65°C in a forced-air drying oven for 72 h for determination of DM content. The dried samples were subsequently milled using a Willey mill with a 1-mm screen and preserved at 4°C in a dark, dry storage room until analysis. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were measured according to the method of Van Soest et al. (1991) using an Ankom^{2000} Fiber Analyzer (Ankom Technologies, Inc., Macedon, NY, USA). Nitrogen (N) was determined via the Dumas combustion method, using an Elemental Analyzer (Euro Vector EA3000; EVISA Co., Ltd, Milan, Italy), and

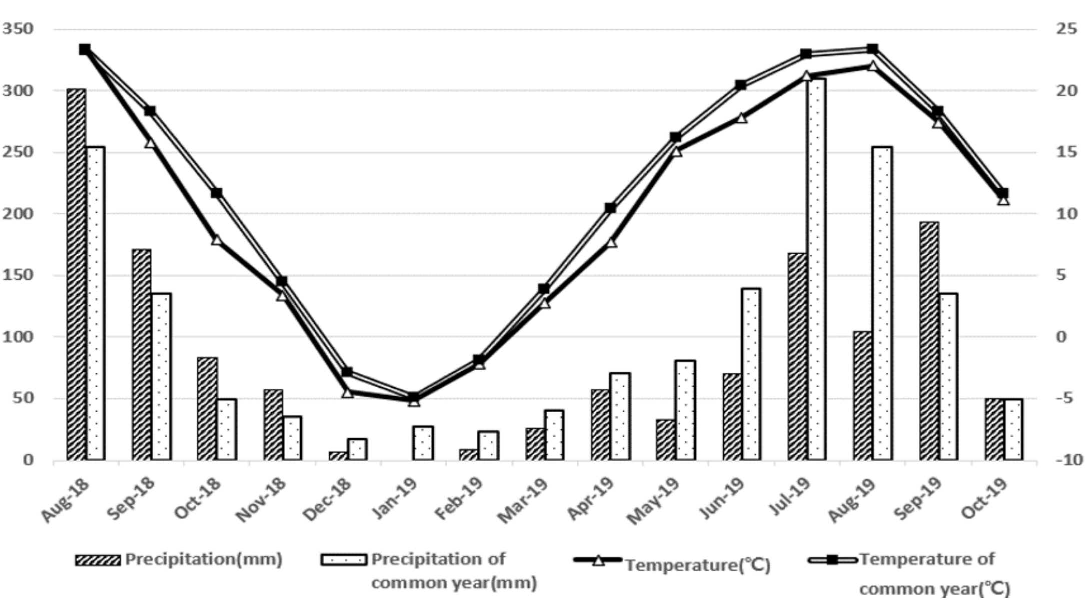

Fig. 1. Temperature and precipitation comparison during the experimental period and common years.

crude protein (CP) was calculated as N × 6.25. Relative feed value (RFV) was calculated according to the equation of Rohweder et al. (1978) as (dry matter intake × digestible dry matter)/1.29, where dry matter intake = 120/(NDF%) and digestible dry matter = 88.9 – (0.779 × ADF) (Holland et al., 1990). *In vitro* dry matter digestibility was determined using the two-stage technique of Tilley and Terry (1963) using an Ankom[II] Daisy Incubator (Ankom Technologies, Inc., Macedon, NY, USA).

3. Statistical analysis

Data were analyzed through the general linear model producer of SAS (version 9.0, SAS Institute Inc., Cary, NC). The effect of cutting height on the nutritive quality and yield of alfalfa is completely randomized block design, and split plot design was applied to the impact of harvest time (main plot) and cutting height (sub plot). Significance level was set at $P < 0.05$.

Ⅲ. RESULTS

1. Forage quality

Effects of cutting height in alfalfa harvested at four different dates on plant height and forage quality components are presented in Table 1. Plant height was longest in the third harvest (109 cm), intermediate in the first and second cuttings (mean 73.9 cm), and shortest in the fourth harvest (41.3 cm). Cutting height had no effect on plant height at each harvest. At first harvest, cutting height had no effect on NDF or RFV, but CP content increased as cutting height increased. In subsequent harvests, as cutting height increased, ADF and NDF contents decreased while CP, TDN, and RFV increased consistently.

The highest and lowest levels of CP and TDN existed in alfalfa samples collected at the fourth and third harvests, respectively. At each harvest, IVDMD was highest in alfalfa clipped at the greatest height (25 cm). Alfalfa samples collected at the fourth harvest had the greatest IVDMD (85.9%), which

Table 1. Effects of harvesting time and cutting height on plant height and forage quality of alfalfa grown in northern area of Korea

Treatments		Plant height, cm	Alfalfa quality components, %					
Harvest time	Cutting height, cm		CP	ADF	NDF	IVDMD	TDN	RFV
1st	5	76.4	17.5^{c}	27.8^{a}	43.1	79.1^{b}	66.9^{b}	145
	15	74.7	18.2^{b}	28.3^{a}	42.1	77.7^{c}	66.6^{b}	148
	25	75.7	19.5^{a}	26.7^{b}	39.7	80.7^{a}	67.8^{a}	160
	Mean	75.6^{B}	18.4^{C}	27.6^{C}	41.6^{C}	79.2^{B}	67.1^{B}	151^{A}
2nd	5	73.3	16.5^{c}	33.4^{a}	46.3^{a}	76.4^{b}	62.5^{c}	127^{c}
	15	68.9	19.6^{b}	30.7^{b}	43.3^{b}	76.8^{b}	64.7^{b}	140^{b}
	25	74.2	21.1^{a}	23.5^{c}	39.8^{c}	83.4^{a}	70.4^{a}	165^{a}
	Mean	72.1^{B}	19.1^{B}	29.2^{B}	43.1^{B}	78.9^{B}	65.9^{C}	144^{B}
3rd	5	107.5	12.7^{c}	48.3^{a}	62.4^{a}	63.4^{b}	50.8^{c}	76^{c}
	15	108.3	14.4^{b}	45.0^{b}	60.4^{a}	64.9^{b}	53.4^{b}	83^{b}
	25	110.2	17.8^{a}	38.8^{c}	56.4^{b}	69.7^{a}	58.3^{a}	97^{a}
	Mean	108.7^{A}	15.0^{D}	44.0^{A}	59.7^{A}	65.1^{C}	54.1^{D}	85^{C}
4th	5	42.0	24.0^{c}	30.8^{a}	45.9^{a}	80.7^{c}	64.6^{c}	132^{c}
	15	41.5	27.7^{b}	24.6^{b}	42.2^{b}	87.5^{b}	69.4^{b}	154^{b}
	25	40.3	31.0^{a}	23.0^{c}	39.1^{c}	89.6^{a}	70.8^{a}	169^{a}
	Mean	41.3^{C}	27.6^{A}	26.1^{D}	42.4^{BC}	85.9^{A}	68.3^{A}	152^{A}

A–D Within a column, different superscripts in capital letters indicate that main plots differ; a–c lowercase letters indicate that sub-plots differ ($P < 0.05$).

CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; IVDMD = *in vitro* dry matter digestibility; TDN = total digestible nutrients; RFV = relative feed value.

Table 2. Effects of harvesting time and cutting height on dry matter content and yield of alfalfa grown in northern area of Korea

Treatments		Dry matter (% in DM)	Yield (kg/ha)		
Harvest time	Cutting height, cm		Fresh matter	Dry matter	TDN
1st	5	30.39[a]	24,611[a]	7,478 [a]	5,004[a]
	15	28.63[b]	23,667[b]	6,774[b]	4,510[b]
	25	27.33[c]	22,334[c]	6,102[c]	4,136[c]
Mean		28.78[A]	23,537[A]	6,785[A]	4,550[A]
2nd	5	22.94[a]	24,278[a]	5,569[a]	3,481[a]
	15	21.33[b]	22,000[a]	4,694[b]	3,036[b]
	25	20.65[b]	18,555[b]	3,831[c]	2,696[b]
Mean		21.64[B]	21,611[B]	4,698[B]	3,071[B]
3rd	5	21.79	22,556	4,940	2,503
	15	21.08	23,889	5,026	2,681
	25	21.24	21,278	4,520	2,633
Mean		21.37[B]	22,574[AB]	4,829[B]	2,606[C]
4th	5	17.83	14,889	2,669	1,724
	15	16.22	12,945	2,093	1,453
	25	16.82	11,834	1,985	1,405
Mean		16.96[C]	13,222[C]	2,249[C]	1,527[D]

[A–D] Within a column, different superscripts in capital letters indicate that main plots differ; [a–c] lowercase letters indicate that sub-plots differ ($P < 0.05$).
TDN = total digestible nutrients.

was 21 percentage units higher than those collected in the third harvest. There was no difference in IVDMD between alfalfa harvested at the first and second harvests (mean 79.0%). Alfalfa obtained from the first and fourth cuttings had the highest RFV (mean 152), which was 8 and 67 units higher than the second and third harvests, respectively.

2. Alfalfa forage yield

Alfalfa DM content and yield at each harvest (DM or TDN basis) as affected by cutting height and harvesting time, are presented in Table 2. Dry matter content of first- and second-harvested alfalfa decreased as cutting height increased. Cutting height had no effect on alfalfa DM content in the third or fourth cuttings. Dry matter content was highest in the first cutting (28.8%), intermediate in the second and third harvests (21.5%), and lowest in the fourth cutting (17.0%). Alfalfa DM production decreased as cutting height increased in the first and second cuttings. However, cutting height had no effect on the DM yield in the third and fourth harvests, which averaged 4,829 and 2,249 kg/ha, respectively. A similar pattern was observed in total TDN yield.

The cumulative DM yield (in four harvests) of alfalfa based on cutting height is presented in Fig. 2. In general, the total DM yield was greater when alfalfa was cut at a lower height. For example, alfalfa cut at a 5-cm height yielded 4.218 kg/ha more DM than alfalfa cut at a 25-cm height. At each cutting height, DM production was generally highest at the first cutting, accounting for 36-37% of the total annul DM yield, intermediate in the second and third cuttings (23-27%), and then decreased to the lowest level in the fourth harvest, which accounted only 11-13% of the total DM production. Cutting height had no effect on total CP production. However, total CP production followed a decreasing pattern from the first to fourth cutting (Fig. 3).

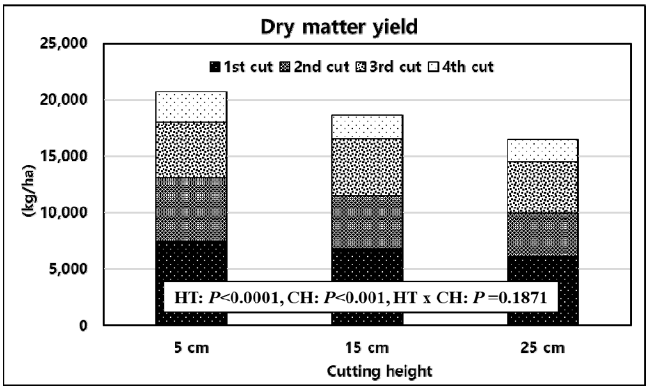

Fig. 2. Total DM yield of alfalfa according to cutting height. HT: harvest time, CH: cutting height.

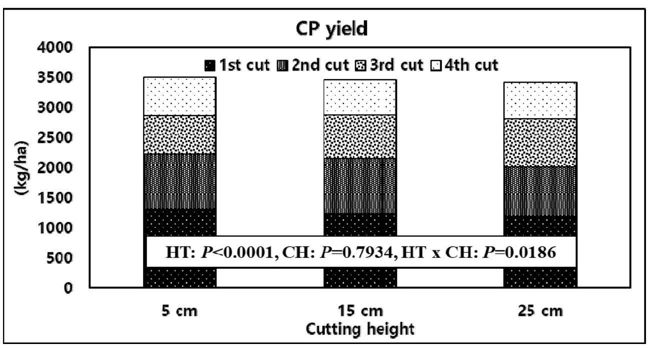

Fig. 3. Total CP yield of alfalfa according to cutting height and harvesting time. *HT: harvest time, CH: cutting height.

Ⅳ. DISCUSSION

Previous research has found that excessively low cutting heights could have a negative impact on postharvest growth rate in perennial forage species. This is primarily due to the removal of a greater proportion of photosynthetic leaf area and non-structural carbohydrates, which is associated with the stress and potential declines in DM production in subsequent harvests (Ward and Blaser, 1961; Volesky and Anderson, 2007). However, in the current experiment, regrowth rate (as indicated by plant height) was not affected by cutting height and the minimum cutting length (5 cm) evaluated in this study had seemingly no damage on alfalfa growth in the subsequent harvests, as evidenced by the minimal difference in crop height before each harvest.

In the present experiment, alfalfa harvested at a greater stubble height had a lower fiber concentration (NDF and ADF), which could be explained by the differential distribution of fiber fractions in leaf and stem. Cell-wall fractions are more concentrated in alfalfa stem than in leaf (Buxton and Hornstein 1986; Parsons et al., 2009), while leaf fraction has 2 to 3 times greater protein than stem (Albrecht et al., 1987; Andrzejewska et al., 2020). This suggests that the leaf: stem ratio clearly represents the nutritive quality of alfalfa (Ta et al., 2020). Therefore, cutting alfalfa at greater stubble heights result in an increased proportion of leaf to stem, and thus enhancement of forage nutritive quality (Yolcu et al., 2006). A Wisconsin-based study identified that each 2.54-cm reduction in cutting height translated to a 4-unit reduction in RFV (Wiersma and Weiderholt, 2007). Daniel et al. (2007) reported that each inch increase in cutting height resulted in a 0.9–7 unit decrease in RFV. Wiersma and Weiderholt (2007) also determined a 4-unit reduction in RFV for every 2.54-cm decrease in cutting height, with the reduction being most noticeable in the first and second cuttings.

Alfalfa nutritive quality progressively declines with plant development because the leaf-to-stem-proportion decreases (Veronesi et al., 2010; Sulc et al., 2021). Moreover, with increased maturity in alfalfa, cell-wall fractions and lignin begins to accumulate in the stem, causing digestibility to decrease as cutting height decreases. Leaf digestibility changes only slightly as alfalfa matures, which explains why longer cutting height had a relatively smaller effect on digestibility with plant development.

Sheaffer (1983) reported that the third-cut alfalfa had higher forage quality than first-cut alfalfa (more CP and less NDF and ADF), which contradicts our findings. Stallcup et al. (1987) also identified that alfalfa cut for the second time had a lower fiber fraction but a higher CP than the first-cut alfalfa. The findings of Sulc et al. (2021) confirmed that as the duration of alfalfa regrowth increased (advancing maturity), lignin and NDF content increased while CP and digestible NDF diminished. The substantial decline in IVDMD in the third-cut alfalfa was an expected finding because of a much higher NDF and ADF accumulated in these alfalfa samples. According to Mahyuddin (2008), fiber fractions (NDF and ADF) correlate negatively with IVDMD of various forages, whereas CP correlates positively.

In agreement with our finding that a shorter cutting height resulted in a greater DM yield, previous studies in United states also suggested that Vernal alfalfa subjected to a cutting height of 2.54 versus 7.62 cm or more produced more total forage production per growing season (Smith and Nelson, 1967; Wiersma and Wiederholt, 2007). Shen et al. (2013) also reported that alfalfa yield was maintained at a high level when cut at a lower stubble height (5 vs. 10 cm), which was explained by the rapid remobilization of carbon and nitrogen reserves in the stubble to the regrowing shoots (Volenec et al., 1996; Meuriot et al. 2004). Wiersma and Wiederholt (2007) suggested that for each 2.4-cm reduction in cutting height, alfalfa forage yield increased by approximately 0.5-ton DM/acre per season. Belesky and Fedders (1997) also reported that alfalfa yield was 61% greater when cut at 2 to 5 cm stubble heights than a 10-cm height. Daniel et al. (2007) reported that during the first harvest, each inch increase in cutting height reduced average yield by 0.13 tons/ha.

In this experiment, alfalfa DM production was highest at the first cutting (6,785 kg/ha), then increased by an average of 2,022 kg/ha in the second and third cuttings, and by 4,536 kg/ha in the fourth harvest. This decreasing trend in forage yield is consistent with the findings of Djaman et al. (2020), who reported a decrease in alfalfa forage yield from the first to fourth cutting, with the first and fourth harvest accounting for 33 % and 16 % of total annual yield, respectively. In agreement, the present experiment identified that the first and fourth cuttings accounted for 29.1 % and 16.3 % of total annual alfalfa yield (fresh basis), respectively. This observation could be explained by the shorter regrowth duration (almost by half) in the fourth cutting relative to the second or third cuttings. The shorter interval between harvests is typically associated with decreases in alfalfa forage yield and fiber components, but an increase in CP level (Putnam et al., 2005; Brink et al., 2010; Rimi et al., 2012).

Additionally, seasonal environmental signals are known to have a significant impact on alfalfa growth and development (Moot et al., 2003). As the daylength and temperature decrease in the early autumn season, the alfalfa plant begins to enter dormancy, resulting in a decline in forage yield (Barnes et al., 1979; Cunningham et al., 2001; Djaman et al., 2021). These seasonal changes result in DM partitioning between shoot and root, which could explain the abrupt decline in DM production from first to fourth cutting (Brown et al., 2006; Khaiti and Lemaire, 1992; Thiébeau et al., 2011). Gosse et al. (1988) documented a 60-kg DM/ha/d reduction in alfalfa growth rate when harvesting time progressed from summer to autumn. As a result, the rapid decrease in DM production in the fourth harvest could be attributed to the occurrence of this harvest in autumn, when higher partitioning of biomass from shoot to root occurs (Ta et al., 2020).

Ⅴ. CONCLUSIONS

This study investigated the relationship between cutting height, forage quality, and yield based on 4 harvesting dates. Under the conditions of this study, alfalfa subjected to a greater cutting height (25 cm) resulted in a superior forage quality than 5- or 10-cm cutting heights, but total forage yield was higher when alfalfa was cut at a lower height. A 5-cm stubble height could be recommended as a proper cutting height as it had no effect on regrowth rate and resulted in a significantly higher DM production per ha. The magnitude of the difference in yield is large enough to offset the quality gain obtained by increasing the cutting height. The information presented in this study could be useful for forage growers by allowing them to have a more precise trade-off between alfalfa crop quality and productivity based on the optimum cutting height and harvesting time.

Ⅵ. Acknowledgements

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