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Research Article

Effect of Seeding Rate on Forage Quality Components and Productivity of Alfalfa in Alpine Area of Korea

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ABSTRACT

The optimal determination of seeding rate is critical to minimizing uncertainties about the large variations observed in forage quality and productivity when alfalfa is cultivated under different geographical areas and growing conditions. The objective of this investigation was to provide information about the proper seeding rate according to harvest timing for alfalfa cultivation in the Northern regions of Korea. Alfalfa was sown in September 2018 at a seeding rate of 20, 30 or 40 kg/ha and harvested four times in 2019: May 3, July 2, September 11, and October 13. Regardless of seeding rate, alfalfa plant height was longest at the third harvest (113 cm) and the shortest in the last annual harvest (43.8 cm). However, seeding rate had no effect on alfalfa plant height at any harvest. Forage relative feed value was increased in the first cutting but decreased in the third cuttings as seeding rate increased. However, seeding rate had slight effect on alfalfa forage quality components at the second and fourth cuttings. Total annual DM and crude protein production (in 4 harvests) was greater at higher seeding rates. Plots seeded at a rate of 40 kg/ha produced on average 1,257 and 2,620 kg/ha more forage (DM basis) than those seeded at a rate of 30 or 20 kg/ha, respectively. Forage DM production at the first, second, third, and fourth harvests accounted for 36.1, 24.0, 27.1, and 12.8 % of total annual DM production, respectively. Overall, small differences were seen when alfalfa seeding rate was different but maximum forage DM production (in four harvests) was detected when seeding rate was 40 kg/ha. These data could be useful to the alfalfa growers by allowing them to make more accurate trade-offs between seed price and the expected magnitude of forage yield gains in order to select the best seeding rate.

(Key words: Alfalfa, Productivity, Forage quality, Seeding rate)

Ⅰ. INTRODUCTION

Alfalfa (*Medicago sativa* L.) is leguminous forage with unique agronomic characteristics such as positive effects on soil fertility and erosion, and because of the high nutritive quality of its forage, it is an excellent forage source in ruminant rations (Robertson et al., 2015; Baxter et al., 2017; He et al., 2017; Baxevanos et al., 2021). Therefore, accurate information on identification of factors influencing alfalfa forage quality and yield is needed to improve the profitability of alfalfa production systems (Brink et al., 2010; Berti and Samarappuli, 2018).

Proper seeding rate is crucial in successful alfalfa establishment, and thus optimization of productivity and forage quality (Lloveras et al., 2008; Lu et al., 2019; Atis et al., 2019). Although there is some information in the literature reporting the relationship between seeding rate and alfalfa forage productivity (Mike, 2008; Barney et al., 1974), the response to seeding rate regimens has been largely variable in different locations and growing conditions, making it difficult to provide a solid recommendation for the proper seeding rate. A seeding rate ranging from 4 to 40 kg/ha has been recommended depending on management strategies and climatic conditions (Lloveras et al., 2008; Berti and Samarappuli, 2018; Hakl et al., 2021). Hakl et al. (2021) identified that in drought-prone areas, lower seeding rates would support the root traits development, which was associated with increased alfalfa productivity. In contrast, in areas with favorable soil and water conditions, a higher seeding rate could be more effective in alfalfa stand establishment and forage yield. However, it has been demonstrated that when alfalfa is seeded at excessive rates, intra-specific competition among plants increases, elevating the risk of plant mortality (Dhont et al., 2004; Hall et al., 2004,

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2010). Contrary to these recommendations, Nelson et al. (1996) and Hall (1993) reported a weak relationship between seeding rate and alfalfa forage dry matter (DM) yield after the seeding year.

In general, the majority of research on the relationship between alfalfa seeding rate and forage DM yield has been conducted in Canada and the United States, where winters are cold and growing seasons are relatively short. Owing to a high degree of variability within the different geographical locations and climatic conditions, the optimum seeding rate in alfalfa still remains a source of debate among alfalfa growers (Lloveras et al., 2008). Alfalfa producers may seek to reduce establishment costs by lowering seeding rate in order to increase farm profit margins. However, other producers may alternatively be willing to minimize the risk of establishment failure by increasing seeding rate, thereby increasing costs associated with seed price (Min et al., 2000; Lloveras et al., 2008; Hall et al., 2010). Therefore, quantifying the magnitude of difference in alfalfa forage productivity and quality components originating from seeding rate regimens will allow the growers to make more accurate trade-offs between seed price and the expected productivity. Therefore, this experiment was designed to determine the optimum seeding rate according to forage yield and quality components over four harvest periods in alfalfa grown in the Northern regions of Korea.

Ⅱ. MATERIALS AND METHODS

1. Experimental location and alfalfa management

Alfalfa (var. P5444) was sown 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, Pyeongchang-gun, Gangwon-do. Seeding rate was 20, 30 or 40 kg/ha and seeding distance was 15 cm. Plots were harvested when alfalfa was at the flowering stage (30% flowering). Harvesting dates occurred in 2019: May 3, July 2, September 11, and October 13. Cutting height was set at 15 cm above the soil surface. The chemical properties of soil in the experimental field are presented in Table 1. The N–P_2O_5–K_2O fertilizers were applied at a concentration of 18–180–120 kg/ha. Nitrogen and phosphate fertilizers were distributed on the seeding date and potassium fertilizer was divided into each harvest time. The soil chemical properties of the experimental location are presented in Table 1.

2. Measurements

At each harvest, alfalfa plant height was measured from the ground to the topmost part of plant. Alfalfa samples were randomly collected at harvest time from each plot and dried to constant weight in a forced-air oven of 65°C for 72 h for determination of DM content. Dry matter yield was calculated as the product of the DM content and total fresh forage production per cultivation area (hectare) (McDonald et al., 2021). Fresh forage mass was obtained after the entire fresh forage mass in each plot was harvested and weighted. The dried samples were milled using a Willey mill with a 1-mm screen. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were measured following the method of Van Soest et al. (1991) with using an Ankom^{2000} Fiber Analyzer (Ankom Technologies, Inc., Macedon, NY, USA). Nitrogen content was quantified using the Dumas method, as described by Jean-Baptiste Dumas (1884), and crude protein (CP) was calculated as nitrogen × 6.25. Total digestible nutrient (TDN) was calculated using the following equation as TDN = 88.9 – (0.79 × ADF%) (Holland et al., 1990). Relative feed value (RFV) was estimated as [(dry matter intake × digestible dry matter)/1.29] according to the equation of Rohweder et al. (1978).

Ⅲ. DATA ANALYSIS

The experiment was a randomized block design with three

Table 1. Chemical properties of soil in experimental field

pH (1:5)	OM (g/kg)	TN (%)	Av. P_2O_5 (mg/kg)	Exchangeable cation ($cmol^+$/kg)				CEC ($cmol^+$/kg)
				K	Ca	Mg	Na	
6.08	45.4	0.18	153.7	6.08	4.29	2.07	0.08	36.3

*OM= organic matter, TN = total nitrogen, CEC = cation exchange capacity.

replications (2 × 3 m^2). Data were analyzed by the general linear model (GLM) procedure of SAS (version 9.0, SAS Institute Inc., Cary, NC). The complete random design was used for effect of seeding rate on alfalfa productivity and quality, and the split-plot design was used for effect of harvesting (main plot) and seeding rate (sub plot). Treatment differences were considered significant when *P* value was less than 0.05.

Ⅳ. RESULTS

A detailed illustration of meteorological data is shown in Fig. 1. July and August were the hottest months, with average temperatures exceeding 22 °C, and then progressively declining below 20 °C from September. Average temperature was slightly lower than the long-term average. Total precipitation was generally higher in July to September and declined suddenly in October. Average precipitation rate was generally lower in 2019 than in the long-term average.

1. Forage component quality

Plant height and alfalfa forage quality according to seeding rate and harvesting time are shown in Table 2. Seeding rate had no effect on plant height at each harvest. Alfalfa plant height was the highest at the third harvest (113 cm), intermediate in the first and the second harvests (mean 81.2 cm), and the shortest in the last harvest (43.8 cm).

Forage CP content remained unaffected by seeding rate with exception for the third harvest, when CP content decreased as seeding rate increased. Seeding rate had no effect on forage NDF content at any harvest ($P > 0.05$). However, ADF content declined in the first harvest as seeding rate increased, but an opposite trend was seen in the third harvest. Seeding rate had no effect on ADF content in the fourth harvest (27.8 % in DM). Higher RFV was seen in the first harvest as seeding rate increased, but an opposite result was observed in the third harvest. Seeding rate had no effect on RFV index at the second and fourth cuttings. Seeding rate had minimal effect on forage TDN content at the fourth cutting (mean 68.7 %), but declined in the third harvest as seeding rate increased. An increase in seeding rate during the first harvest resulted in an increase in forage TDN content. At

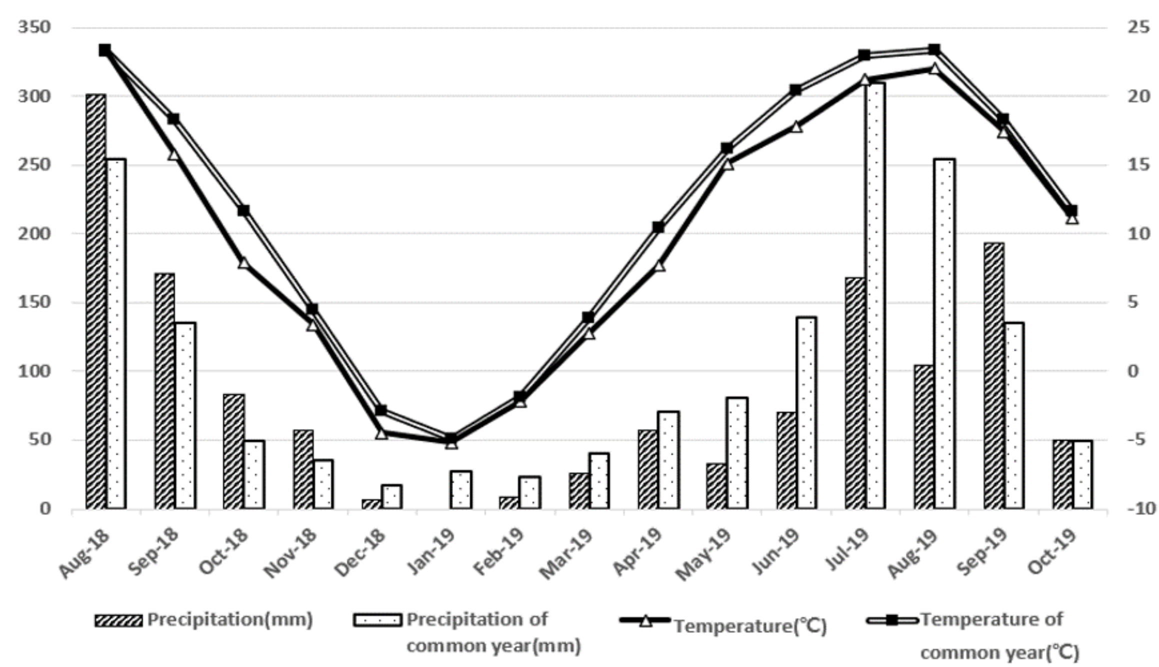

Fig. 1. Monthly meteorological data around experiment period in Pyeongchang (Korea Meteorological Administration).

Table 2. Plant height and forage nutritive quality of alfalfa according to seeding rate and harvesting time

Treatments		Plant height, cm	Forage quality components, %				
Harvest time	Seeding rate, kg/ha		CP	ADF	NDF	TDN	RFV
1st (May 3, 2019)	20	77.3	15.3	35.3^{a}	47.7	61.0^{b}	120^{b}
	30	80.6	15.5	31.8^{b}	45.7	63.8^{a}	131^{ab}
	40	83.6	15.8	30.3^{b}	42.3	65.0^{a}	144^{a}
	Average	80.6^{B}	15.5^{C}	32.4^{C}	45.2^{C}	63.3^{B}	132^{B}
2nd (July 2, 2019)	20	82.5	17.1	35.0^{a}	49.9	61.3^{b}	115
	30	81.4	18.3	32.7^{b}	46.4	63.1^{a}	127
	40	81.5	17.4	34.8^{a}	50.1	61.4^{b}	115
	Average	81.8^{B}	17.6^{B}	34.2^{B}	48.8^{B}	61.9^{C}	119^{C}
3rd (September 11, 2019)	20	110.3	15.9^{a}	41.8^{c}	58.5	55.9^{a}	90^{a}
	30	112.8	13.7^{b}	45.6^{b}	60.8	52.9^{b}	82^{ab}
	40	114.7	12.8^{b}	48.0^{a}	62.0	51.0^{c}	77^{b}
	Average	112.6^{A}	14.1^{D}	45.1^{A}	60.4^{A}	53.2^{D}	83^{D}
4th (October 13, 2019)	20	46.0	27.4	25.5	44.9	68.8	143
	30	41.3	27.8	24.6	43.4	69.4	149
	40	44.0	28.1	26.5	43.5	68.0	147
	Average	43.8^{C}	27.8^{A}	25.5^{D}	44.0^{C}	68.7^{A}	146^{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; TDN = total digestible nutrients; RFV = relative feed value.

the second harvest, TDN content was highest (63.1 %) when seeding rate was 30 kg/ha, which was on average 1.75 percentage units higher than plots harvested at a seeding rate of 20 or 40 kg/ha.

At each harvest, regardless of seeding rate, RFV and TDN concentration followed a similar pattern and from highest to lowest was as follows: fourth > first > second > third harvests. For example, alfalfa obtained from the fourth cutting had a mean RFV of 146, which was 63 and 27 units higher than the third and second harvests, respectively. Forage NDF content (% of DM) was greatest when alfalfa was harvested at the third harvest, intermediate in the second harvest (48.8), and lowest at the first and fourth harvests (mean 44.6). Crude protein content from highest to lowest was as follows: fourth > second > first > third cuttings.

2. Alfalfa forage productivity

Effects of seeding rate according to the harvest dates on alfalfa forage productivity are presented in Table 3. Seeding rate had no effect on alfalfa DM content at each harvest. Alfalfa DM content was greatest at the first cutting (27.9 %), intermediate in the second and third cuttings (mean 21.6), and lowest at the fourth harvest (15.7 %). Alfalfa productivity expressed as forage production (fresh, DM, or TDN basis) per hectare was not affected by seeding rate at each harvest. Forage DM production varied by harvest, with the first, second, third, and fourth harvests accounting for 36.1, 24.0, 27.1, and 12.8% of total forage DM production, respectively. Total TDN production in the first harvest was on average 35, 37, and 39% higher than in the second, third, and fourth cuttings, respectively.

Annual total DM yield (in 4 harvests) of alfalfa according to seeding rate is shown in Fig. 2. As seeding rate increased, total DM yield also increased. The total DM production of alfalfa seeded at a rate of 40 kg/ha was 1,257 and 2,620 kg/ha higher than that of alfalfa seeded at rates of 30 and 20 kg/ha, respectively. There was no harvest timing × seeding rate interaction on total DM yield.

Annual total CP production of alfalfa according to seeding rate is shown in Fig. 3. In general, the total CP production was

Table 3. Dry matter content and forage yield of alfalfa according to seeding rate and harvesting time

Treatments		Dry matter, %	Yield (kg/ha)		
Harvest time	Seeding rate, kg/ha		Fresh matter	Dry matter	TDN
1st (May 3, 2019)	20	27.1	23,389	6,343 [b]	3,869
	30	28.4	24,167	6,867 [a]	4,384
	40	28.2	26,111	7,358 [a]	4,782
	Average	27.9[A]	24,556[A]	6,856[A]	4,345[A]
2nd (July 2, 2019)	20	20.8	20,278	4,197	2,572
	30	21.7	21,333	4,629	2,921
	40	22.7	21,444	4,859	2,985
	Average	21.7[B]	21,019[B]	4,562[C]	2,826[B]
3rd (September 11, 2019)	20	21.4	22,389	4,798	2,681
	30	21.8	23,222	5,059	2,674
	40	21.0	26,389	5,539	2,823
	Average	21.4[B]	24,000[A]	5,132[B]	2,726[B]
4th (October 13, 2019)	20	15.7	14,833	2,327	1,601
	30	15.5	15,944	2,463	1,711
	40	15.8	15,889	2,509	1,707
	Average	15.7	15,555[C]	2,433[D]	1,673[C]

[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.

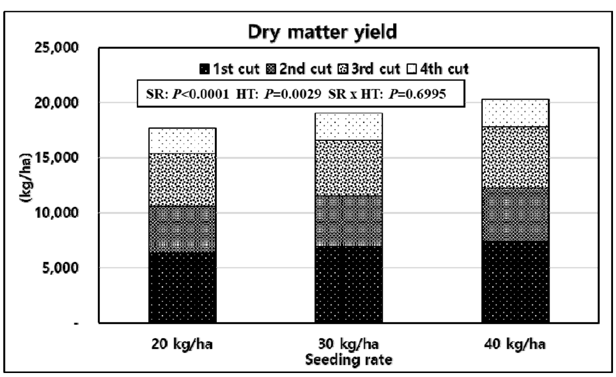

Fig. 2. Annual dry matter yield of alfalfa according to seeding rate and harvest timing. *SR: seeding rate, HT: harvest time.

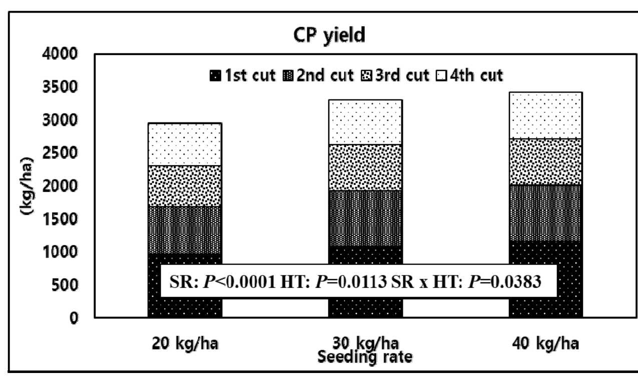

Fig. 3. Annual crude protein (CP) yield of alfalfa according to seeding rate and harvest timing. * SR: seeding rate, HT: harvest time.

generally greater when alfalfa was seeded at a higher rate. The total CP production of alfalfa seeded at a rate of 40 kg/ha was 446 and 1,049 kg/ha higher than that of alfalfa seeded at rates of 30 and 20 kg/ha, respectively. There was a harvest timing × seeding rate interaction on total annual CP yield, suggesting that relationship between seeding rate and the CP yield was different among the harvesting dates.

V. DISCUSSION

1. Forage productivity

Several studies have suggested no measurable benefit in alfalfa productivity with increasing the seeding rate (Nelson et al., 1996; Hall, 1993; Lloveras et al., 2008). For example, Lloveras et al. (2008) investigated the effects of different seeding rates (10, 20, 30, or 40 kg/ha) on alfalfa DM production under irrigated conditions in a Mediterranean climate, and concluded less justifications for increasing seeding rate to higher than 10 kg/ha. However, other studies have reported that alfalfa productivity responds positively to increasing seeding rate (Cooper et al., 1979; Volenec et al., 1987; Stout, 1998; Abdel-Rahman and Abu-Suwar, 2012). These uncertainties imply the importance of determining the proper seeding rate for each location with specific climatic and growing conditions. Geographical location and climatic conditions, seedbed condition, and crop establishment method have been identified as influential factors to alfalfa germination and establishment, resulting in the different responses to seeding rate (Lloveras et al., 2008; Bolger and Meyer, 1983).

Seeding rate is an important factor controlling plant density dynamics, the success of stand establishment and, ultimately productivity of alfalfa production systems (Hakl et al., 2021). In the present experiment, the maximum yield response was observed when alfalfa was seeded at the highest seeding rate (40 kg/ha), possibly because of the proportionally higher number of plants (higher plant density). Previous studies suggest a near-linear relationship between seeding rate and plant density (Hall et al., 2004). For example, Hall et al. (2010) reported significant yield reductions when alfalfa was seeded at a lower rate, which was associated with lower plant density. In contrast, the higher plant mortality rate in the seeding year may occur when alfalfa is seeded at an excessive seeding rate, lowering plant density and yield (Rowe, 1988; Hall et al., 2004; Lloveras et al., 2008). Excessive plant density is usually associated with reductions in available air and soil for plants, increasing the between-plant competitions for soil nutrient, light, and carbon dioxide (Abdel-Rahman and Abu-Suwar 2012). More recently, Hakl et al. (2021) explained the lower forage productivity associated with seeding rate by the reduced root development. Hakl et al. (2021) suggested that in drought-stress regions, a higher seeding rate resulted in no benefits in forage yield in subsequent harvests. In the present experiment, it appears that even the highest seeding rate (40 kg/ha) had no significant adverse effect on alfalfa productivity, as evidenced by the positive response of alfalfa forage production to increased seeding rate and a minimal difference in alfalfa plant height at each harvest (Table 2).

A decreasing trend in alfalfa production (fresh or DM basis) was seen from the first to last annual cutting (fourth harvest). For example, DM yield in first and fourth cutting accounted for 36.1 and 12.8% of total annual DM production, respectively. In support, Djaman et al. (2020) also recorded a similar pattern in alfalfa forage production. The interval between the third and fourth cutting was much shorter than other harvests, resulting in less time being available for alfalfa regrowth and biomass production (Brink et al., 2010; Rimi et al., 2012).

2. Forage quality components

Although several studies have primarily investigated the relationship between alfalfa seeding rate and forage yield but generally less attention has been paid to the forage nutritive quality. Although the effect of alfalfa seeding rate on forage nutritive quality is not clearly understood, there is some evidence that a higher seeding rate is associated with reduction in stem diameter and thus differences in cell wall chemical constituents (Volenec et al. 1987; Lloveras et al., 2008). Lloveras et al. (2008) found that seeding rate (10 to 40 kg/ha) had no effect on alfalfa forage nutritive quality, as measured by leaf to stem ratio and CP concentration, and that it was only changed with harvesting time. Berti and Samarappuli (2018) did not observe any difference in forage nutritive quality (CP and fiber fractions) when alfalfa was seeded at rates ranging from 1 to 25 kg pure live seed/ha. Glaspie et al. (2011) also identified that seeding rate of 9 to 18 kg/ha had no effect on alfalfa forage nutritive quality. In the present experiment, alfalfa cell-wall components were not generally affected by seeding rate, but as seeding rate increased, ADF increased and NDF increased only numerically in the third harvest. It has been proposed that as seeding rate increases, intra-specific competition among alfalfa plants increases, causing plants to increase stem length and, thus stem-to-leaf proportion (Kallenbach et al., 2002; Hall et al., 2010). As a result, alfalfa seeded at a higher rate accumulates more cell-wall constituents. Wang et al. (2017) investigated the forage quality and productivity of alfalfa seeded at 15, 22.5, or 30 kg/ha and found that as seeding rate increased, CP and RFV index increased, but cell-wall fractions (NDF and ADF) diminished. Iwaasa et al. (1998) also reported the slight effects of increasing seeding rates on cell wall constituents (NDF and ADF) of the alfalfa stem.

The higher forage NDF concentration in the third cutting compared to other harvests could be explained by the longer harvest duration (71 days between the second and third cuttings) and the warmer weather from July to September, which may have accelerated alfalfa plant maturation. A longer duration between harvests results in increased plant maturation, which is associated with accumulation of cell-wall faction (NDF and ADF) originating from an increase in stem to leaf proportion. This usually causes a progressive decline in alfalfa nutritive quality (Veronesi et al., 2010; Sulc et al., 2021).

Ⅵ. CONCLUSIONS

This study provided information about forage quality and productivity of alfalfa seeded at different rates over four harvests. In general, slight differences were quantified in alfalfa regrowth rate as well as forage quality components when seeding rate was different. However, forage productivity expressed as annual dry matter or crude protein production increased as seeding rate increased. The findings of this study may help alfalfa growers make better decisions about selecting an optimal seeding rate, taking into account the trade-offs between seed price and forage quality and yield.

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