JAST (Journal of Animal Science and Technology) TITLE PAGE

Upload this completed form to website with submission

ARTICLE INFORMATION	**Fill in information in each box below**
Article Type	Research article
Article Title (within 20 words without abbreviations)	Assessment of growing condition variables on alfalfa productivity
Running Title (within 10 words)	Impact of climate and soil for alfalfa production
Author	Ji Yung Kim1, Kun Jun Han2, Kyung Il Sung1, Byong Wan Kim1, Moonju Kim3
Affiliation	1 Department of Animal Life Science, Kangwon National University, 24341, Korea 2 School of Plant, Environmental and Soil Sciences, Louisiana State University, 70803, USA 3 Institute of Animal Life Science, Kangwon National University, 24341, Korea
ORCID (for more information, please visit https://orcid.org)	Ji Yung Kim (https://orcid.org/0000-0003-3515-1178) Kun Jun Han (https://orcid.org/0000-0002-4842-8829) Kyung Il Sung (https://orcid.org/0000-0003-1232-3520) Byong Wan Kim (https://orcid.org/0000-0001-5047-3912) Moonju Kim (https://orcid.org/0000-0003-0917-7710)
Competing interests	No potential conflict of interest relevant to this article was reported.
Funding sources State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available.	NRF- 2022R1C1C1004618, Ministry of Science and ICT, Korea. RDA- PJ01499604, Rural Development Administration, Korea.
Acknowledgements	NRF- 2022R1C1C1004618, Ministry of Science and ICT, Korea. RDA- PJ01499604, Rural Development Administration, Korea.
Availability of data and material	Upon reasonable request, the datasets of this study can be available from the corresponding author.
Authors' contributions Please specify the authors' role using this form.	Conceptualization: Kim JY. Data curation: Kim JY, Kim M. Formal analysis: Kim JY. Methodology: Kim M. Software: Kim JY, Kim M. Validation: Kim BW, Sung K, Kim M., Han KJ Investigation: Kim JY, Kim BW, Sung K. Writing - original draft: Kim JY, Kim M. Writing - review & editing: Kim M, Kim BW, Sung K., Han KJ
Ethics approval and consent to participate	This article does not require IRB/IACUC approval because there are no human and animal participants.

CORRESPONDING AUTHOR CONTACT INFORMATION

For the corresponding author (responsible for correspondence, proofreading, and reprints)	**Fill in information in each box below**
First name, middle initial, last name	Moonju Kim
Email address – this is where your proofs will be sent	lunardevil@kangwon.ac.kr
Secondary Email address	
Address	Gangwondaehakgil 1, Chuncheon, 24341, Gangwondo, Korea
Cell phone number	010 4904 3536
Office phone number	+82 033 250 8635
Fax number	+82 033 242 4540

Assessment of growing condition variables on alfalfa productivity

Ji Yung Kim[1], Kun Jun Han[2], Kyung Il Sung[1], Byong Wan Kim[1], Moonju Kim[3*]

[1] College of Animal Life Sciences, Kangwon National University, 24341, Korea

[2] School of Plant, Environmental and Soil Sciences, Louisiana State University, 70803, USA

[3] Institute of Animal Life Science, Kangwon National University, 24341, Korea

*Corresponding author: Moonju Kim, Institute of Animal Life Science, Kangwon National University, Kangwon National University, 24341, Chuncheon, Korea, Tel: +82-33-250-8635, Fax: +82-33-242-4540, E-mail: lunardevil@kangwon.ac.kr

Abstract

This study was conducted to assess the impact of growing condition variables on alfalfa (*Medicago sativa* L.) productivity. A total of 197 alfalfa yield results were acquired from the alfalfa field trials conducted by the South Korean National Agricultural Cooperative Federation or Rural Development Administration between 1983 and 2008. The corresponding climate and soil data were collected from the database of the Korean Meteorological Administration. Twenty-three growing condition variables were developed as explaining variables for alfalfa forage biomass production. Among them, twelve variables were chosen based on the significance of the partial-correlation coefficients or potential agricultural values. The selected partial correlation coefficients between the variables and alfalfa forage biomass ranged from -0.021 to 0.696. The influence of the selected twelve variables on yearly alfalfa production was summarized into three dominant factors through factor analysis. Along with the accumulated temperature variables, the loading scores of the daily mean temperature higher than 25℃ were over 0.88 in factor 1. The sunshine duration at temperature between 0 ~ 25℃ was 0.939 in factor 2. Precipitation days were 0.82, which was the greatest in factor 3. Stepwise regression applied with the three dominant factors resulted in the coefficients of factors 1, 2, and 3 for 0.633, 0.485, and 0.115, respectively, and the R-square of the model was 0.602. The environmental conditions limiting alfalfa growth, such as daily temperature higher than 25 ℃ or daily mean temperature affected annual alfalfa production most substantially among the growing condition variables. Therefore, future cultivar selection should consider the capability of alfalfa to be tolerant to extreme summer weather along with biomass production potential.

Keywords: Forage, Biomass, Weather, Factor analysis

Introduction

Research has indicated environmental influences such as temperature, precipitation, and soil physical and chemical characteristics on alfalfa (*M. sativa* L.) biomass production [1-5]. Kim et al. [6] were able to develop an alfalfa yield prediction model with climate and soil variables. Although the variables could explain the alfalfa yield variance at a marginal level, soil texture and growing degree days (GDD) were the most critical among the tested variables to explain the yield variance at around 63 and 32%, respectively. In an attempt to interpret delayed fall harvest's impacts on alfalfa productivity in the following year, the accumulations of carbohydrates and amino acids in the alfalfa root system were evaluated at several fall GDD levels [7]. The research was able to propose a late fall harvest window based on GDD. When developing alfalfa production models, researchers consider the impacts of weather and soil conditions at the same time. Shroyer et al. [8], Park et al. [9], Glenn et al. [10], and John [11] confirmed the effectiveness of precipitation, soil pH, and drainage class as the significant environmental factors affecting alfalfa production.

Some specific weather conditions, such as winter temperatures, are meaningful information to predict first-cut alfalfa yields in Michigan, USA [4]. The research valued the potential of the winter weather-related alfalfa yield prediction model as a management development tool. The performance of the alfalfa growth prediction model varies depending on the target component variables. The prediction models for alfalfa biomass production and crude fiber contents were reported to be more accurate than crude protein content [5].

Kim et al. [6] proposed a possible overestimation of weather influences on forage biomass because of the mutual relationships between the weather variables, as shown in sunshine duration and rainfall variables. Sunshine duration positively influences the phyllosphere bacterial diversity and community structure of the alfalfa field, along with soil temperature [7]. The soil moisture is mainly balanced by evaporation and rainfall; those variables must be involved in enhancing alfalfa productivity. Furthermore, these beneficial effects should be validated based on more research data.

Evaluation of alfalfa growing condition variables, for instance, some accumulated temperature and GDD estimated at ranges of aerial temperatures, had a chance of being eliminated in stepwise regressions even though the variables are some agricultural values. Therefore, consideration for preventing removals of associated weather variables will be necessary to maintain those kinds of variables in alfalfa prediction models.

Considering soil's physical conditions as growing condition variables is challenging even though research adopted soil variables to interpret alfalfa yield variance [12]. Generally, soil physical properties are nominal or categorical data. For example, soil textures are categorized by the combinations of three different soil particle size groups; therefore, the soil texture data provided by the Korean Soil Information System (KSIS, soil.rda.go.kr) are discrete variables and cannot be analyzed by a general linear model approach. Furthermore, these physical characteristics may cause an overestimation of the soil impacts on alfalfa biomass due to possible overlapping of the texture effects. Therefore, data transformation is required to convert nominal soil variables into continuous values [13].

Annually, South Korea imports more than 220 kilotons of alfalfa hay from the USA by paying an approximately similar amount as the logistics costs. Also, the demand for high-quality alfalfa hay is steadily growing in neighboring countries such as Japan and China, which challenges securing the necessary alfalfa hay for the country's dairy industry. Therefore, enhancing the production capacity of domestically produced alfalfa is required to achieve a more sustainable livestock industry. This study assessed alfalfa production potential using specifically coined weather and soil property variables.

Materials and Methods

1. Alfalfa trial data collection and compilation

A total of 197 alfalfa field trial data were acquired from the database of the National Agricultural Cooperative Federation or Rural Development Administration of South Korea between 1983 and 2008 after eliminating some field trial data having missing information. The field trial data covers sites between 35° 00' 58" N, 126° 42' 39" E and 37° 22' 15" N, 128° 23' 25" E in central and southern regions. The meteorological information corresponding to each trial location, including daily temperature, precipitation, and sunshine duration, was collected from the Korean Meteorological Administration (KMA, Weather data service available at MET data portal, data.kma.go.kr). Along with the weather data, soil physical information, such as soil texture, drainage class, and slope, was acquired from the Rural Development Administration (RDA, Soil database (available at Korean Soil Information System, soil.rda.go.kr) of South Korea. After collecting the related data, the data file was arranged by year, location, planting date, harvest date, forage biomass, and corresponding weather and soil data.

2. Development of growing condition variables

Twenty-three environmental variables potentially affecting alfalfa biomass productivity were developed in accumulated temperatures, sunshine duration, daily temperature higher than 25 ℃ January temperature, precipitation, and soil property.

Accumulated temperatures were calculated using several different base temperatures [14, 15] at daily temperature ranges.

$$AT = \sum((T_{high} + T_{low})/2 - T_{base}),$$

The T_{high}, T_{low}, and T_{base} are daily high, daily low, and base temperatures, respectively. The daily mean temperatures higher than 0, 0 ~ 25, and 0 ~30 ℃ were accumulated using 0 ℃ as a base temperature. The base temperature 5℃ was also applied for daily mean temperatures above 5, 5 ~ 25, and 5 ~ 30 ℃. Another base temperature of 10℃ was applied for the ranges of 10, 10 ~ 25, and 10 ~ 30 ℃.

Sunshine duration was counted by the hour or day within daily temperatures between 0 and 25, or 5 and 25 ℃. Since optimum alfalfa root and shoot growth were reported around 25 ℃ [16, 17], the two variables related to the daily temperature higher than 25 ℃ were added to the model in the form of duration day and accumulated temperature. The temperature causing daily temperature higher than 25℃ was calculated by adopting 25 ℃ as a base temperature [1, 8, 18]. For the evaluation of winter temperature impact, the daily mean and daily low temperatures of January were considered.

The precipitation variables were developed by counting the number of days or the total amount when precipitation was greater than 0 or 5 mm. The physical properties of soil were compiled using a categorical scale [19]. The 3 soil textural classes (sandy loam; 0-20 % of clay content, silt loam;0-27 % of clay content, loam; 7–27% of clay content) were used among the total 12 classes. The clay content was considered as a representative soil texture. Based on the slope, the drainage was considered for six levels, from 1 (low) to 6 (high). Finally, the soil properties were transformed into quantitative data using jitter-transformation [20]: $J = X \pm runif\ (n, -a, +a)$.

The X and J are soil variables, respectively, before and after the transformation. The *runif* is a uniform density function to generate a random value for each category, *n* is the sample size, and $\pm a$ is the range of noise considering individual categories.

3. Statistical analysis

Variables demonstrating high correlations with forage biomass productivity were selected among the variable categories [21]. Due to multiple range applications and mutual associations, there is multicollinearity among the climate variables (e.g., accumulated temperature, growth period, precipitation, and sunshine duration). Therefore, the overlapping correlations of weather variables with alfalfa productivity were controlled by excluding the correlations in variable selections. Since there are also probabilities of eliminating some variables containing agricultural values due to the multicollinearity, those variables were included in the model regardless of whether the partial correlation coefficients or factor scores were not high enough to be selected [22].

The factor analysis was referred to assess the relationship between variables and alfalfa production as follows:

$$X_{1\times n} = L_{1\times k}F_{k\times n} + \delta_{1\times n}, \quad (1)$$

$$Y_{1\times n} = \beta_{1\times k}F_{k\times n} + \varepsilon_{1\times n}, \quad (2)$$

Where X denotes the variables containing the selected climate and soil variables, F is the weather and soil property factors, L is a matrix of the loading scores, and δ is the residual effect. The forage productivity (Y) is modeled with β and ε for matrix coefficient and residual effects, respectively. Meanwhile, the R^2 of the multiple regression model was used to assess the performance of the models explaining alfalfa productivity with the selected climate and soil variables. The relationship between the variables and the factors was quantified as a score using the varimax rotation of factor analysis [20]. The jitter-transformation was performed with soil Accumulated temperatures were calculated using several different base temperatures [14, 15] at the ranges of daily temperature. properties using R 3.6.0 statistical analysis [23]. Finally, the partial correlation, factor, and multiple regression analysis were performed using SPSS 24.0 (IBM Corp., New York, [24]).

Results

1. Compiling alfalfa growing condition data during the field trial years

The average rainfall distribution and aerial temperature from 1983 to 2008 are presented in Fig. 1.

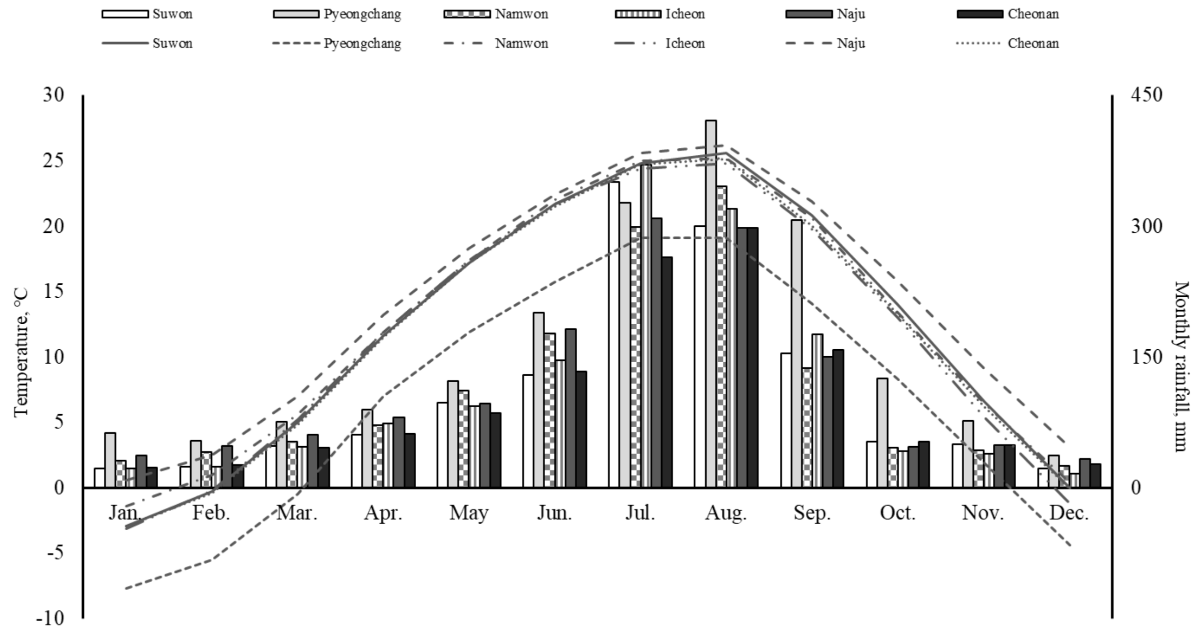

Fig. 1. The Mean monthly aerial temperature and rainfall by the alfalfa field trial locations throughout the data collection period from 1983 to 2008.

The rainfall demonstrated symmetrical distribution beginning from January to December. Rainfall is concentrated in the summer three months from June to August, which overlaps with the monsoon season in South Korea. Although monthly rainfall demonstrated a random pattern in the field trial locations, Pyeongchang (the eastern region) has more rainfall than other locations. After the monsoon, summer temperature frequently rises higher than 25℃ in July and August at the field trial locations except for Pyeongchang. Winter begins in late December and lasts until March. The soil conditions corresponding to the field trial sites vary in the trial locations (Table 1).

Table 1. Summary of soil properties after jitter-transformation from 1983 to 2008

	Mean	Minimum	Maximum	CV
		Before transformation		
Clay content, %	14.6	10.0	17.0	0.22
Drainage, Nominal	5.1	4.0	6.0	0.08

The mean alfalfa production was 13.7 Mg ha^{-1}, and there were no significant trends in biomass production throughout the data collection years (Fig. 2). The means of alfalfa production obtained from the trial vary depending on the research purpose [25].

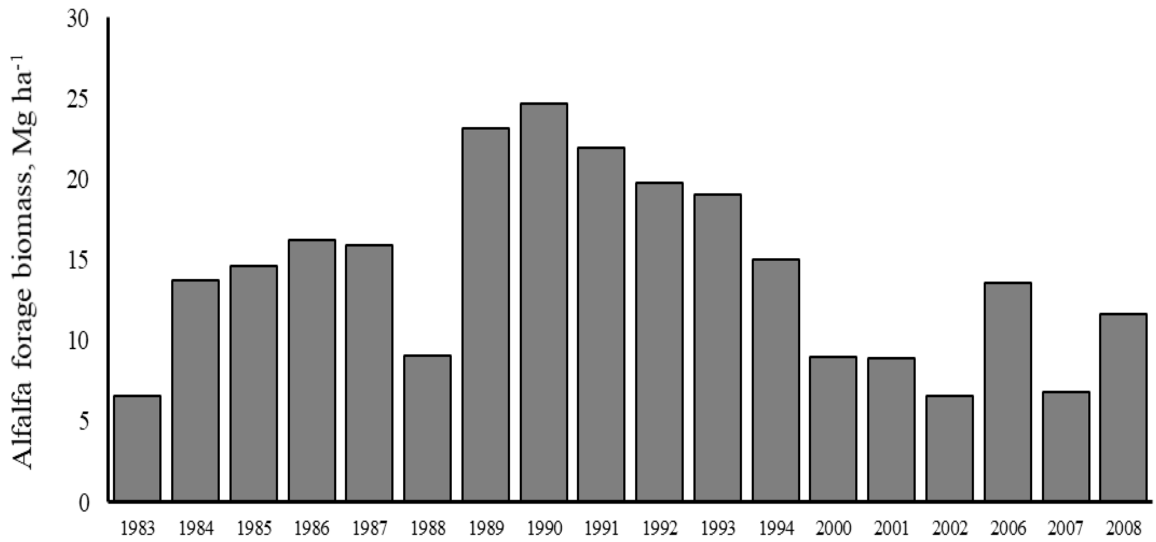

Fig. 2. Means of annual alfalfa forage biomass production in the field trials throughout the data collection period from 1983 to 2008.

The variables assessed for estimating their impacts on alfalfa productivity were accumulated temperatures, sunshine duration, daily temperature higher than 25 ℃, January temperature, rain day, precipitation amount, and soil properties as presented in Table 2. The accumulated temperatures within the ranges of mean aerial daily temperature were approximately 1000 to slightly over 5000 when calculated at 5 ℃ as a base temperature. The difference in the sunshine duration hours between the daily mean temperature ranges from 0 to 25 and 5 to 25 ℃ was approximately 339 hours. The daily temperature higher than 25℃ was approximately two months long, and the accumulated temperature during this period was around 650 ℃. Contrasted to the daily temperature higher than 25 ℃, cold temperatures affect alfalfa's winter survival. The January temperatures indicated subzero temperature even though the daily high was slightly above freezing temperature. The sum of rainy days averaged around 100 days. If the rain days were counted for more than 5 mm, the total rain day was reduced to half.

Table 2. Growing condition variables and data range during the field trial data collection period from 1983 to 2008

Growing condition variable	Low	High	Mean	CV§
Accumulated temperature within temperature range†				
0 to 25 ℃	3181	4838	4334	0.12
0 to 30 ℃	3181	5037	4387	0.12
Above 0 ℃	3181	5051	4387	0.12
5 to 25 ℃	2003	3383	2954	0.14
5 to 30 ℃	2003	3582	3006	0.15
Above 5 ℃	2003	3596	3006	0.15
10 to 25 ℃	1096	2178	1837	0.18
10 to 30 ℃	1096	2377	1889	0.19
Above 10 ℃	1096	2391	1889	0.19
Sunshine duration, hour				
0 to 25 ℃	1294	1892	1586	0.11
5 to 25 ℃	955	1495	1291	0.12
Duration of temperature, day				
0 to 25 ℃	246	304	275	0.05
5 to 25 ℃	193	242	220	0.05
Daily mean temperature > 25℃				
Days > 25℃	Na	63	23	0.65
Accumulated temperature > 25℃	Na	1801	659	0.65
January temperature, ℃				
Daily mean	- 8.9	1.1	- 3.4	-0.76
Daily low	- 13.7	-3.0	-8.2	-0.34
Rain day, day				
Over 0 mm per day	80	150	103	0.15
Over 5 mm per day	30	73	48	0.20
Precipitation amount, mm				
Accumulated rainfall (over 0 mm)	841	2482	1347	0.27
Accumulated rainfall (over 5 mm)	752	2384	1257	0.29
Soil property‡				
Clay content, %	0.2	26.8	14.3	0.45
Drainage, Nominal	3.4	6.5	5.2	0.09

†, the base temperature was 5℃
‡, Jitter-transformation applied values.
§CV, Coefficient of variation.

The amount of precipitation difference between over 0 and over 5 mm was about 120 mm. Since soil properties are nominal data, jitter-transformation was applied to make the variables continuous variables. However, the post-transformed soil properties, such as clay content and drainage, indicated substantial variations. In particular, the higher value of the jitter-transformed clay content indicated closer to sandy loam and loam than the lower value. Furthermore, the lower drainage value indicated less slope and drainage conditions.

2. Growing condition variable selections based on the relationship with alfalfa productivity

The selection of growing condition variables potentially impacting alfalfa productivity is presented in Table 3. The two selection strategies were applied to the growing condition variable selections for factor analysis.

Table 3. Partial–correlation coefficients and variable selection decisions on growing condition variables based on the field trial data collected from 1983 to 2008

Growing condition variable	Partial-correlation coefficient	Decision
Accumulated temperature within the temperature range†, ℃		
0 to 25 ℃	0.696**	Selected
0 to 30 ℃	0.685	Eliminated
Above 0 ℃	0.685	Eliminated
5 to 25 ℃	0.555**	Selected
5 to 30 ℃	0.542	Eliminated
Above 5 ℃	0.536	Eliminated
10 to 25 ℃	-0.484	Eliminated
10 to 30 ℃	-0.530**	Selected
Above 10 ℃	-0.527	Eliminated
Sunshine duration, hour		
0 to 25 ℃	0.148*	Eliminated
5 to 25 ℃	0.237**	Selected
Duration of temperature, day		
0 to 25 ℃	0.576**	Selected
5 to 25 ℃	0.481**	Eliminated
Daily mean temperature > 25℃		
Days > 25℃	0.483**	Selected
Accumulated temperature > 25℃	0.488**	Selected
January temperature, ℃		
Daily mean	0.410**	Eliminated
Daily low	0.466**	Selected
Rain day, day		
Over 0 mm per day	0.154*	Selected
Over 5 mm per day	0.092	Eliminated
Precipitation amount, mm		
Accumulated rainfall over 0 mm	-0.021	Selected
Accumulated rainfall over 5 mm	-0.015	Eliminated
Soil property‡		
Clay content, %	0.322**	Selected
Drainage, Nominal	0.089	Selected

†, the base temperature was 5℃
‡, Jitter-transformation was applied to transform the soil characteristics into continuous variables.
*,**, significant at $p < 0.05$ and $p < 0.01$, respectively.

The selections were based on the high partial correlation coefficients with alfalfa productivity and also based on agricultural impact potential. The correlation coefficients of the growing condition variables, such as accumulated temperatures within the ranges of temperatures from 0 to 25, 5 to 25, and 10 to 30 ℃ were significant and highly correlated with alfalfa productivity ($p < 0.01$). The variable counted by hours for duration of sunshine between 5 and 25 ℃ was selected. The counting of days for the temperature duration between 0 and 25 ℃ was also selected ($p < 0.05$). The daily temperature higher than 25 ℃ was counted by total days or accumulated temperature ($p < 0.01$). Although the low winter temperature variables in January by daily mean or by daily low were significant ($p < 0.01$), the daily low temperature variable was selected because of the slightly higher correlation coefficient. Rain day counted for over 0-mm was selected due to the significance ($p < 0.05$), even though the coefficient was not as high as the other variables. Although not statistically significant, the accumulated rainfall variable counted for greater than 0-mm precipitation was also intentionally considered in the assessment model. The partial correlation coefficient of the clay content in the field trial location soils was significant ($p < 0.01$), while drainage was not.

3. Assessment of the selected growing condition variables on alfalfa productivity

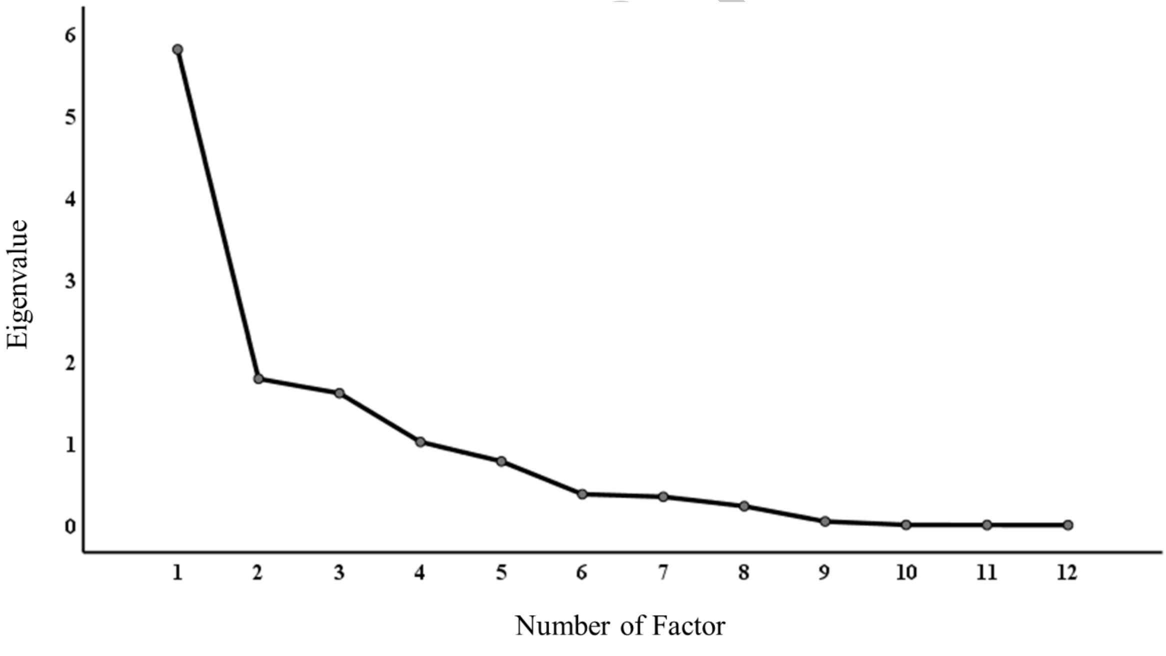

Fig. 3. Scree plot of factor analysis including alfalfa growing condition variables during the field trial data collected from 1983 to 2008.

The impact of the selected growing conditions was summarized into dominant factors (spatial component) based on the eigenvalue of the scree plot (Fig. 3). The first three factors were selected.

Table 4. Loading scores of the selected growing condition variables in the factor analysis, showing dominance of the selected variables in the field trial data collected from 1983 to 2008

Selected growing condition variable	Loading scores of factor		
	Factor 1	Factor 2	Factor 3
Accumulated temperature within temperature range†			
0 to 25 ℃	0.889	0.380	-0.202
5 to 25 ℃	0.896	0.333	-0.246
10 to 30 ℃	0.907	0.259	-0.273
Sunshine duration			
Hour within 5 to 25 ℃	0.030	0.561	-0.557
Duration of temperature 0 to 25 ℃	0.133	0.939	0.042
Daily mean temperature > 25℃			
Days > 25℃	0.942	-0.162	-0.086
Accumulated temperature > 25℃	0.937	-0.164	-0.088
January temperature			
Daily low	0.518	0.486	-0.026
Precipitation			
Over 0 mm per day	-0.359	-0.005	0.820
Accumulated rainfall over 0 mm	-0.080	0.012	0.750
Soil property‡			
Clay content	0.310	0.171	-0.036
Drainage	0.132	0.084	0.066

†Daily temperature higher than 25 ℃, the temperature higher than 25℃

Table 4 indicated around 0.9 loading scores of the variables, such as accumulated temperature in the ranges of temperatures and daily temperature higher than 25 ℃ in factor 1, while those of duration of temperature and January low-temperature variables were higher than any other selected growing condition variables in factor 2. In factor 3, the loading scores of the two precipitation variables were high. As shown in Table 5, the regression model's three components were significant ($p < 0.05$). For the coefficient of determination (R^2), Factor 1 could explain the variance of alfalfa production at 37.9%, which was improved up to 60.2% by including factors 2 and 3 in the regression model.

Table 5. Stepwise regression with the dominant factors against alfalfa productivity based on field trial data collected from 1983 to 2008

Parameter	Standardized Coefficient	*p*-Value	VIF†	R^2 change	R^2
Factor 1	0.633	0.000	1.002	0.379	0.602
Factor 2	0.485	0.000	1.001	0.210	
Factor 3	0.115	0.012	1.001	0.013	

†VIF: Variance Inflation Factors

Discussion

The impacts of weather and soil property variables on alfalfa productivity were assessed through a series of statistical analyses such as partial correlation, factor analysis, and stepwise multiple regression. In the growing condition variable selections, all the accumulated temperature variables demonstrated relatively high partial correlation coefficients with alfalfa productivity (Table 3). Since the inclusion of more than several growing condition variables within the same category may cause an overestimation of the correlation with the alfalfa productivity, three accumulated temperature variables were selected among them. Also, due to the substantial variations in yearly growing conditions and alfalfa production responses, some strategic analysis approach was necessary to keep the potentially meaningful growing condition variables. Although rainy day, accumulated rainfall, and clay content were not highly correlated to the alfalfa productivity, those variables were also included in the factor analysis to balance the evaluation of growing condition variables on alfalfa production.

In this study, the impacts of climate and soil property variables on alfalfa productivity were approximately 60.2%, where the three dominant factors were identified. The daily temperature higher than 25℃ was most contributing to the alfalfa biomass along with the accumulated temperature variables in factor 1. The duration of sunshine at daily temperature at a range of 0 ~ 25 ℃ and rainfall were most contribution in factor 2 and 3, respectively, which indicated those two variables are perpendicular to each other as anticipated. Factor 3 explained only 1.3% of the alfalfa production variance (Table 5). The actual data points of alfalfa forage biomass spread more from the biomass prediction line between 5 and 12 Mg DM ha^{-1} than the higher production levels, 15 Mg DM ha^{-1} (Fig. 2).

In this study, extreme aerial temperature conditions such as daily mean temperature higher than 25℃ and winter January temperature were presumed to influence alfalfa biomass accumulation negatively. However, the evidence of the negative impacts could not be confirmed with the collected alfalfa data because of the insignificance of the partial correlation coefficients of those two extreme weather conditions. Although winter hardiness of alfalfa cultivars has been crucial in alfalfa cultivar selections in the USA [26], the partial correlations of the winter temperatures with the alfalfa productivity remained positive in this study, suggesting that the temperature did not behave as a critical factor for winter survival. Some information about winter survival in the USA indicated winter dormant varieties can survive at -15℃ [18]. However, the monthly average is -5.5℃ in January [27]; the daily low rarely drops to -15℃ in South Korea. Therefore, winter survival should not be a major factor determining alfalfa production in the next growing season [6].

Another reason for the lack of the presumed negative impacts might be explainable by the alternating winter aerial temperature changes by 3- or 4-days intervals between the freezing and mild winter weather. Also, the presumed adverse effects of summer temperatures higher than 25 ℃ could not be confirmed in the study. According to KMA [27], the daily mean temperatures from July to August were around 29 ℃. Therefore, stunts in alfalfa growths could occur in summer, as possibly noticed in cool-season grass. However, the positive partial correlation coefficient between daily temperatures higher than 25 ℃ and biomass productivity indicated a lack of evidence for heat stress in South Korea. The temperature above the ideal cool season grass growth did not evidence any production reductions. Perhaps, the accumulated rainfall demonstrated a negative correlation, however, the values were low and insignificant ($p = 0.78$).

Alfalfa seems to start growing even below 5 ℃ in Korean environment which is supported by a growth chamber study [26]. Therefore, it is necessary to study the alfalfa growth response in early spring in South Korea. Although 5℃ has been frequently adopted as a base temperature in alfalfa GDD calculation [15], considering 0 ℃ as a base temperature could be meaningful by extending the available growing season by 60 days longer than reported cool season grass [28]. The advantages of the greater GDD may be realized in improved alfalfa production capacity in South Korea [29].

Since alfalfa is a high-water demanding forage crop [30–32], the leading alfalfa exporting states on the west coast of the USA depend heavily on irrigation. Unlike those states, the amount of rainfall or soil moisture did not appear as a significant alfalfa production limiting factor. On the contrary, the high temperature and high humidity in conjunction with the strong wind in summer monsoon may be the more challenging growing conditions in South Korea. The current study did not assess the impact of seasonal growing conditions possibly affecting alfalfa production. Although the alfalfa productivity models have limited values as prediction tools due to weather data availability before a particular time, the quantified influences of the growing condition variables provided a substantial understanding of each variable’s influence on alfalfa production. These aspects can be further realized in planning alfalfa cultivar selection, harvest frequency, and seasonal utilization adjustment in the diverse regions of South Korea.

In this study, the impact of two variables on the daily temperature higher than 25℃ was positive on alfalfa production. It implies that aerial temperature higher than 25℃ did not negatively influence alfalfa growth, although 25℃ was reported as optimum root and shoot growth for alfalfa [16]. The degree of heat stress differs by the available soil moisture, and the stress is hard to measure in the separation of drought stress. As reported [16, 17, 26], alfalfa can grow in various temperatures, such as from 0 to 40 ℃, if irrigation is available. Since KMA [27] indicated the hottest summer months, July and August temperatures rarely rise above 35 ℃, alfalfa production loss due to heat stress must be rare in Korea. The distribution of rainfall is critical for enhanced biomass production [33]. However, the impact of rainfall was insignificant in this study (Table 4). As presented in an arid area that requires irrigation [34], available soil moisture balance is critical in alfalfa production rather than rainfall amount during the growing season.

CONCLUSIONS

Since the tested growing condition variables could explain the variance of alfalfa biomass production at around 60 %, the model performance is marginal as a prediction model. Probably, this level of the model performance can be reasoned from some heterogeneous characteristics of alfalfa field research settings and the lack of standardization of obtained data under the various study goals. However, this study could quantify the impacts of large numbers of weather and soil variables on alfalfa productivity through specifically coined weather and soil variables using statistical analysis approaches. Since this modeling effort is novel, adding more standardized alfalfa field trial data or considering seasonal aspects is required in future modeling works.

Acknowledgments

The Basic Science Research Program supported this study through the National Research Foundation of Korea, funded by the Ministry of Science and ICT (NRF- 2022R1C1C1004618, Ministry of Science and ICT) and the "Damage assessment in forages and development of cultivation technology for their damage reduction according to extreme weather (PJ01499604)" through Rural Development Administration, Korea.

References

1. Kim DA. Forage crop - its characteristics and management method. Sunjinmunhwasa. Seoul. Republic of Korea. 1983;91-126.

2. Alex R, Brain A, Misha M. Alfalfa stand establishment. PSS2089. Oklahoma State University. Cooperative Extension. OK. USA. 2019.

3. Anderson B and Volesky J. Seeding alfalfa. G2247. University of Nebraska. Extension. NE. USA. 2014.

4. Durling, J. C., Hesterman, O. B., & Rotz, C. A. (1995). Predicting first-cut alfalfa yields from preceding winter weather. Journal of Production Agriculture, 8(2), 254-259.

5. Bourgeois, G., Savoie, P., & Girard, J. M. (1990). Evaluation of an alfalfa growth simulation model under Quebec conditions. Agricultural Systems, 32(1), 1-12.

6. Kim JY, Kim MJ, Jo HW, Lee BH, Jo MH, Kim BW, Sung KI. Assessment of contribution of climate and soil factors on alfalfa yield by yield prediction model. Journal of the Korean Society of Grassland and Forage Science. 2021;41:47-55. https://doi.org/10.5333/KGFS.2021.41.1.47.

7. Dhont, C., Castonguay, Y., Nadeau, P., Bélanger, G., Drapeau, R., & Chalifour, F. P. (2004). Untimely fall harvest affects dry matter yield and root organic reserves in field-grown alfalfa. Crop Science, 44(1), 144-157.

8. Shroyer JP, Amand PC, Thompson C, Lamond RE, Peterson DE, Regehr DL, Alam M, Higgins R, Sloderbeck PE, Bowden RL, Duncan S, Taylor RK, Fritz JO, Blasi D, Langemeier LN. Alfalfa production handbook. Kansas State University. Cooperative Extension Service. KS. USA. 1987;12-16.

9. Park BH, Kim SD, Kim TH, Sung KI, Lee BH, Lee JS, Jung BT, Jo IH. Forage resource science. Hyangmunsa, Seoul, Republic of Korea. 1997;137-143.

10. Glenn ES, Allen RG, Neibling WH. Alfalfa irrigation and drought. University of Idaho College of agriculture and life Science. Pocatello ID. USA. 2013.

11. John J, Establishing alfalfa for forage. FSA15. University of Arkansas. Agriculture and Natural Resources. AR. USA. 2021.

12. Kim CY, Seo YJ, Kwon TY, Park JH, Heo MS, Ha SK. Correlation between the factors of soil physical property in upland soil. Korean Journal of Soil Science and Fertilizer. 2010. 43;6:793-795.

13. Kim M., Peng JL., Sung KI. Causality between climatic and soil factors on Italian ryegrass yield in paddy field via climate and soil big data. Journal of Animal Science and Technology. 2019. 61;6:323-332.

14. Wolf DD, Blaser RE. Leaf development of alfalfa at several temperatures. Crop Science. 1971; 11:479-492. https://10.2135/cropsci1971.0011183X001100040005x.

15. Sharrat BS, Sheaffer CC, Baker DG. Base temperature for the application of the growing-degree-day model to field-grown alfalfa. Field crops research. 1989;21:95-102.

16. Teuber L, Jernstedt J, Foord K. Alfalfa growth and development. *In*: The 18th California Alfalfa Symposium. 1988 Dec 7;7-8.

17. Matthews C, Arshad M, Hannoufa A. Alfalfa response to heat stress is modulated by microRNA156. Physiologia plantarum. 2019 Apr;165(4):830-42.

18. Undersander D. Hall MH, Vassalotti P, Cosgrove D. Alfalfa germination & growth. A3681. University of Wisconsin-Extension. Cooperative Extension. WI. USA. 2011.

19. NICS. Soil investigation theory and practical techniques. Rural development administration. National institute of crop science. Wanju. Republic of Korea. 2003;40-74.

20. Chamber JM, Cleveland WS, Kleiner B, Tucky PA. Graphical methods for data analysis. Wadsworth and Brooks/Cole. California. USA. 1983.

21. Brown BL, Hendrix SB. Partial correlation coefficients. *In*: Encyclopedia of statistics in behavioral science. John Wiley & Sons. NJ. USA. 2005. https://doi.org/10.1002/0470013192.bsa469.

22. Johnson RA, Wichern DW. Applied multivariate statistical analysis. Upper Saddle River, NJ: Prentice Hall. 2002.

23. R 3.6.0. R foundation. 2019.

24. SPSS. IBM SPSS statistics ver. 24.0. IBM Corp., Somers, New York, U.S.A. 2019.

25. Kim CJ, Kim HK, Park GJ, Shin CN, Lee SK, Lee ID, Lee JS, Jeon BT, Jung YK, Jo IH, Han HJ. An introduction to grassland science. Hyangmunsa, Seoul, Republic of Korea. 1995;143-179.

26. Baron VS and Belanger G. Climate and forage adaptation. *In* : Forages volume II –the science of grassland agriculture 6th edition. Blackwell publishing. Ames. IW. USA. 2007;83-104.

27. KMA. Weather data service-Open MET data portal. Korea Meteorological Administration. URL : https://data.kma.go.kr/cmmn/main.do. Accessed:2022.03.02.

28. Kim DA, Lee KJ. Analyses on the seasonal productivity and summer depression of cool-season pasture crops. Journal of Animal Science and Technology. 1968;10:97-104.

29. Undersander D. Cosgrove D, Cullen E, Grau C, Rice ME, Renz M, Sheaffer C, Shewmaker G, Sulc M. Alfalfa management guide. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. WI. USA. 2011.

30. Putnam DH, Orloff SB. Forage crops *In* : Van Alfen NK. Encyclopedia of agriculture and food systems. Elsevier, Sandiego. CA. USA. 2014;381-405. doi:10.1016/B978-0-444-52512-3.00142-X.

31. Saeed IAM, Ei-Nadi AH. Irrigation effects on growth, yield, and water use efficiency of alfalfa. Irrigation Science. 1997;17:63–68.

32. Blad BL, Rosenberg NJ. Evaluation of resistance and mass transport evapotranspiration models requiring canopy temperature data. Agronomy Journal. 1976;68:764–769. https://doi.org/10.2134/agronj1976.00021962006800050020x.

33. Baral R, Lollato RP, Bhandari K, Min D. Yield gap analysis of rainfed alfalfa in the United States. Frontiers in Plant Science. 13:931403. doi: 10.3389/fpls.2022.931403.

34. Hancock DW, Buntin GD, Ely LO, Lacy RC, Heusner GL, Stewart RL. Alfalfa management in georgia. University of Georgia. UGA Extension. GA. USA. 2015.