

Article

A Method of Coupling Lucerne Quality with Meteorological Data to Evaluate the Suitability of Hay Harvest

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Abstract: The alfalfa harvest time is determined by the alfalfa growth stage and the weather factors at that time, which will affect the yield and quality of the alfalfa hay. Addressing issues like the lack of precise harvesting timing and underutilized production potential of lucerne, this study is based on the internal (fall dormancy level, crude protein, acid, neutral detergent fiber, relative feed value) and external factors (air temperature, precipitation, wind speed, ground temperature, relative humidity, solar radiation) affecting the quality of lucerne, as well as the relevant experimental data of the existing literature and the weather factors within 24 h after the lucerne harvest. Using principal component analysis to calculate the weights of the above indicators, the harvest suitability score formula was constructed to determine the harvesting time, harvesting method and harvesting stubble. Huanghua City was used as an example to confirm the method's effectiveness in guiding for determining the optimal harvest date of lucerne in the city. Key findings include the following: The hay quality of the first two crops of alfalfa in Huanghua City was higher than that of the third and fourth crops, and the optimal harvest stage of alfalfa was before the precipitation concentration period, which was consistent with other local research results and weather characteristics, and the method was feasible. Precipitation was the most significant factor affecting the lucerne harvest. The effects of other weather factors on hay quality varied with precipitation conditions. The temperature was the second important factor when daily precipitation is less than 1 mm, and the wind speed became the second important factor when the daily precipitation is less than 10 mm and more than 1 mm. Under low suitability and high precipitation, it may be advisable to convert hay harvest to silage to maximize economic benefits. This research could help agricultural decision-makers to develop precise harvesting strategies, and further improve lucerne production efficiency.

Keywords: lucerne; evaluate method; forage management; meteorological data



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1. Introduction

Lucerne, as an important legume forage crop, plays a significant role in global agriculture and livestock production. High protein content and palatability make lucerne a valuable feedstuff for dairy cows. Due to the positive impact on the quantity and quality of produced milk [1], lucerne with relatively constant nutrition is a demand for dairy producers or farmers [2]. Lucerne hay is used as raw material for many kinds of deeply processed grass products, such as grass powder and grass pellets. In order to ensure the quality of these products, it is important to harvest high-quality hay and avoid hay spoilage. Within the critical supply chain, the timing of lucerne harvest is of paramount importance as it directly impacts the quality of forage. The optimal harvest time not only ensures maximum and stable nutrition in forage through the selection of processing methods (i.e., hay making or silage) but also remedies the forage shortage during the nongrowing season.

Additionally, reasonable harvest time could promote lucerne growth and after regeneration, further contributing to the sustainability of pasture [3].

However, lucerne hay harvesting faces several challenges in practical production: (i) Weather factors during the growth period influence the variation of nutrients in lucerne. Thus, research on lucerne cultivation guided by meteorological data has been reported. For instance, Sun et al. calculated the lucerne irrigation quota by using 20 years of meteorological data and the Penman–Monteith model to adjust the irrigation amount in lucerne cultivation [4]. Yang et al. studied the response of lucerne yield to weather changes using field data and APSIM (Agricultural Production Systems sIMulator) to provide guidance for regional lucerne production [5]. Yang et al. conducted a grey correlation analysis of weather factors affecting lucerne yield in Tibet's river valley, which supported adjusting harvesting strategies in practice [6]. (ii) Weather fluctuations during the harvest period affect lucerne harvesting time and methods. Natural drying is the traditional and most common way of lucerne harvest globally [7,8] More particularly, rainfall during harvest may disrupt machinery operations, which could interrupt or delay harvesting progress, whereas silage can improve harvesting flexibility [9]. In recent years, high-moisture baling has gained popularity among farmers, and studies focusing on the influence of additives, fermentation temperatures, and moisture content on dry matter losses and nutrient preservation have increased [10–12]. (iii) Weather conditions during lucerne harvest and hay drying can lead to the loss of nutrients. Meteorological conditions have a significant impact on physiological changes in the drying stage, which is from cutting to drying to a moisture content of approximately 40%. During this stage, lucerne cells are not entirely dead and photosynthesis continues without nutrient supply. It may lead to nutrient consumption in lucerne leaves and further affect forage quality [13,14]. Therefore, minimizing drying time and maintaining suitable drying conditions are crucial for harvesting high-quality lucerne. Rainfall is the most prominent factor limiting the moisture loss and drying rate, and persistent rainfall could cause mildew or rot [15]. Temperature also significantly affects lucerne quality. Higher temperatures can accelerate transpiration and moisture loss but may increase nutrient loss due to cell respiration [16]. Wind speed also has a moderate impact on lucerne harvesting [17]. For example, on windy days, high-temperature drying may accelerate nutrient loss in lucerne, while moderate wind speed can enhance evaporation, facilitate rapid drying of lucerne plants, and prevent mold or rot.

To mitigate the impact of weather factors on lucerne harvesting in different regions, it is crucial to develop lucerne harvesting and processing strategies using meteorological data. In this study, we aimed to combine quality indicators in naturally sun-dried lucerne hay and corresponding weather data in China and then construct a lucerne hay harvesting suitability assessment equation. Local weather data were taken as an example to validate the suitability equation of hay harvesting.

2. Materials and Methods

2.1. Index Selection

Both intrinsic characteristics and environmental factors influence the quality of lucerne hay. In this study, "fall dormancy level", "crude protein content", "acid detergent fiber", "neutral detergent fiber", and "relative feeding value" were chosen to represent intrinsic characteristics, while weather factors during the drying period were chosen to participate in the calculation below.

- **Fall dormancy level:** Lucerne fall dormancy refers to a physiological dormancy phenomenon caused by reduced daylight and declining temperatures in northern latitudes during the autumn season [18]. A fall dormancy level provides essential guidance for lucerne introduction and cultivation zoning [19]. In turn, lucerne with different fall dormancy levels have different nutrient content due to the variations in regional weather; thereby, the fall dormancy level is closely related to the nutritional quality of lucerne hay. For statistical analysis, lucerne varieties in the database are cate-

gorized into five groups based on the fall dormancy level: extreme non-dormancy, non-dormancy, semi-dormancy, dormancy, and extreme dormancy.

- Crude protein content: Crude protein content is one of the most common criteria for evaluating lucerne hay quality [20]. Compared with other forage quality indicators, such as acid, neutral detergent fiber, and relative feed value, natural drying has a more significant impact on the crude protein content of lucerne. Therefore, crude protein content is chosen as an indicator to characterize the influence of climatic factors on hay quality.
- Fiber content: Neutral detergent fiber (NDF) and acid detergent fiber (ADF) content are important indicators of the nutrient content of forages, which is the fiber component of forage, and the NDF and ADF indicators are closely related to the quality of forage, and they are more and more widely used in the evaluation of the nutritional value of forage.
- Weather factors: Harvesting early or late can result in a decline in hay quality, and weather conditions are essential considerations in determining the timing of harvest. As mentioned in the Introduction Section, excessive rainfall and high humidity are the primary causes of poor lucerne hay quality as it is reported that rain could lead to a loss of crude protein losses by approximately 35% [21]. Weather factors such as temperature, precipitation, and relative humidity directly affect the drying rate and quality of hay, especially during the physiological drying stage, which usually lasts for 12 to 24 h. Therefore, average temperature, precipitation, relative humidity, surface temperature, wind speed, and total solar radiation within 24 h of the harvest day have been selected in this study.

2.2. Data Compilation

The data included in the compilation were searched through the China National Knowledge Infrastructure from 2000 to 2023 according to the following terms: “lucerne”, “crude protein”, and “fiber content”. In each study that was selected, we collected regional information (latitude, longitude, and country), and experimental information (sampling time, lucerne variety, and sample drying method). Through these bibliographic searches, a total of 129 paired observations were identified. The distribution of sampled data points is illustrated in Figure 1. The cultivars of lucerne planted in the collected papers and their fall dormant types are shown in Table 1 below.

Table 1. Lucerne cultivars and dormant types.

Fall Dormancy Type	Dormancy Grade	Cultivar
Extreme fall dormancy	1	Xinmu No. 1, Gongnong No. 2, Gongnong No. 3, Longmu 801, Longmu 803, Longmu 806, Gongnong No. 1, Speder, Reindeer
Fall dormancy	2–3	Zhongmu No. 1, Guanzhong lucerne, Algonquin, Golden Queen, Gannong No. 3, King lucerne, Queen lucerne, WL323HQ, Nongbao, Giant, WL232HQ, Polar Bear, WL168HQ, Empress, Xinmu No. 2, Juranen 201, SK3010, Magna graze II, Baimu 202, WL298HQ, Challenger, Pioneer, Knight 2, Zhongmu No. 2, WL168HQ
Semi-fall dormancy	4–6	WL323ML, WL323, WL343, WL354HQ, Adina, Suntory, Phabulous, WL363HQ, MT4015, MF4020, Magnum-Salt Star, SR4030, Yingst, Juneng 7, Wisdom, Magna 401, Magna 551, Konsai, Knight T, WL343HQ, WL354HQ
Non-fall dormancy	7–8	WL324, Sardi 7, CAL-6902, Sardi No. 5, WL656, WL712, WL903
Extreme non-fall dormancy	9–11	West River, Sardi 10

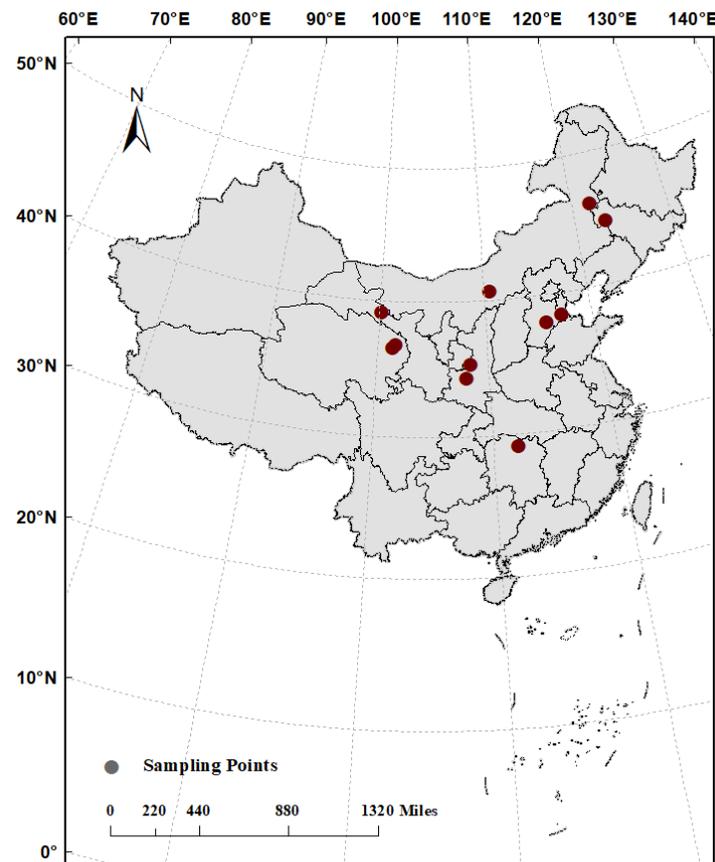


Figure 1. Effects of weather factors on the crude protein of lucerne hay in a database sample distribution map.

The literature included in the compilation met the following criteria: (i) The data on lucerne crude protein content and fiber content were measured on naturally sun-dried, air-dried, or naturally shaded samples, excluding machine-dried samples. (ii) The data on crude protein content and fiber content should belong to the same lucerne variety and the same cutting period, and data from mixed samples were not used. (iii) The literature should provide clear information on the experimental location and harvest time. (iv) The data required for the study should be directly or indirectly obtainable. (v) Duplicate literature with the same experimental year, location, and results was excluded. (vi) All data in the literature used for analysis were obtained through field experiments. (vii) The data on the control group can be selected from the relevant literature regarding stress and fertilization treatments.

The collected data include harvest time, experimental location, fall dormancy level or lucerne variety, weather factors during the drying period, crude protein content, neutral detergent fibers, and acid detergent fibers. Data from tables can be directly extracted, and data from figures have been digitized using the Get-Data Graph Digitizer 8 software. For articles that have not provided daily records of the weather data during the experiment period, the weather data used for analysis in this paper were from ERA5 hourly data on single levels from 1979 to the present. (Copernicus Weather Change Service (C3S) Climate Data Store (CDS)). (Accessed on <22 March 2024>), <https://doi.org/10.24381/cds.adbb2d47>.

County-scale (daily) weather data for the sampling points were obtained using the latitude and longitude of the sampling points. Selected weather data include average temperature, precipitation, relative humidity, surface temperature, wind speed, and total solar radiation within 24 h of the harvest day.

2.3. Principal Component Analysis

In the analysis of lucerne hay quality, there are five internal factors and six external factors, and there is a certain correlation between the factors, which are often used directly to evaluate multiple covariances, resulting in errors in the comprehensive analysis.

Principal component analysis (PCA) is a kind of research method used in a comprehensive evaluation of multiple indicators, with the goal of finding a few representative and comprehensive factors to replace many original indicators to reduce dimensionality so that the few selected factors reflect the information of the many original indicators, with no correlation between them, so that the data can be simplified, objective, and credible [22]. Therefore, we choose principal component analysis as the analysis method of this study.

The preliminary arrangement of test data was completed in Excel (Microsoft® Excel® 2021MSO (Version 2402 Build 16.0.17328.20124) 64-bit). The principal component analysis was performed with SPSS (IBM SPSS Statistics 25). It is used to calculate the eigenvalues and variance contributions of the variance matrix, establish the principal component equations based on the eigenvectors, and find the formula for the composite score of the principal components under the three precipitation levels according to the weight coefficients of the principal components.

2.4. Unified Scoring Dimensions

The principal component analysis is carried out under conditions of different precipitation degrees. In order to evaluate the influence of weather on the quality of harvested hay on a certain day, we considered the number of days where the daily precipitation on the same day in previous years is in each precipitation grade (precipitation $< 1 \text{ mm}\cdot\text{d}^{-1}$, $1 \text{ mm}\cdot\text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$, precipitation $\geq 10 \text{ mm}\cdot\text{d}^{-1}$). We used this number of days to calculate the proportion weights—Q1, Q2, Q3. The weights are calculated as follows:

$$N = n_1 + n_2 + n_3; \quad (1)$$

$$Q_1 = \frac{n_1}{N}; Q_2 = \frac{n_2}{N}; Q_3 = \frac{n_3}{N} \quad (2)$$

where N is the number of years, n_1 is the number of days with daily precipitation less than 1 mm on the same date in N years, n_2 is the number of days with daily precipitation between 1 mm and 10 mm on the same date in N years, and n_3 is the number of days with daily precipitation greater than or equal to 10 mm on the same date in N years.

It should be noted here that when precipitation $\geq 10 \text{ mm}\cdot\text{d}^{-1}$, lucerne harvesting and drying do not normally proceed, and there is little valuable data collected for later analysis with precipitation $\geq 10 \text{ mm}\cdot\text{d}^{-1}$, which are insufficient for principal component analysis, so the data are assigned the value of 0 here, and the subsequent equations are constructed only for the computation of Y_1 and Y_2 . The final scoring formula for calculating the suitability of harvest on a certain day is obtained:

$$Y = Y_1 \times Q_1 + Y_2 \times Q_2 \quad (3)$$

where Y_1 is the principal component score for the same date in the previous year that satisfies the precipitation $< 1 \text{ mm}\cdot\text{d}^{-1}$ condition, Y_2 is the principal component score for the same date in the previous year that satisfies the $1 \text{ mm}\cdot\text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$ condition and Y is the final score.

2.5. Classification of Harvest Suitability

The daily hay quality score is calculated according to the scoring Formula (3), with the highest score being Y_{max} and the lowest score being Y_{min} .

Taking Y_a and Y_b as the boundary values, the suitability of the harvest date can be divided into three grades: highly suitable, moderately suitable, and unsuitable, namely, highly suitable: $Y_b < Y < Y_{max}$; moderately suitable: $Y_a < Y < Y_b$; unsuitable: $Y_{min} < Y < Y_a$.

$$Y_a = Y_{min} + (Y_{max} - Y_{min})/3 \quad (4)$$

$$Y_b = Y_{max} - (Y_{max} - Y_{min})/3 \quad (5)$$

3. Results

3.1. Results of Principal Component Analysis

Precipitation is the most prominent limiting factor affecting the local lucerne harvest and drying rate. Precipitation $\leq 1 \text{ mm}\cdot\text{d}^{-1}$ has no impact on the successful drying of lucerne after harvest [23]. A daily precipitation of 10 mm is the boundary between light rain and moderate rain [24]. Under light rain conditions ($1 \text{ mm}\cdot\text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$), precipitation can affect the quality of lucerne hay and silage [25]. Once the average daily precipitation reaches 10 mm, the ground will be waterlogged, rendering it impossible for machinery to work in the field. And hay harvest data under precipitation greater than 10 are scarce and insufficient for principal component analysis, so in this case, when the precipitation amount is >10 , it is directly assigned a value of 0 and it is not analyzed or calculated. Taking precipitation = $1 \text{ mm}\cdot\text{d}^{-1}$ and precipitation = $10 \text{ mm}\cdot\text{d}^{-1}$ as the thresholds of groups, the influencing weather factor on the quality of lucerne hay is divided into two groups for discussion: precipitation $< 1 \text{ mm}\cdot\text{d}^{-1}$, $1 \text{ mm}\cdot\text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$.

The results of PCA on the seven indexes affecting the crude protein content of lucerne hay are shown in Tables 2–4.

Under precipitation levels of $<1 \text{ mm}\cdot\text{d}^{-1}$ (Table 1), the first three principal components (F1–F3) have eigenvalues greater than 1, with a cumulative contribution rate of 74.16%. This means that 74.16% of the information from the original indicators is retained. The contribution rates of other principal components are negligible in this case.

The first principal component has a high loading on the content of crude protein, acid detergent fibers, neutral detergent fibers, and relative feeding value. For acid detergent fibers and neutral detergent fibers, the weight coefficient of relative humidity (-0.27 and -0.238) is negative, and the weight coefficient for the content of crude protein and relative feeding value is positive (0.215 and 0.284 , respectively). The first principal component can reflect the sample quality information. The loading coefficients for fall dormant, acidic washing fibers, and neutral washing fibers are negative in F1, and it is known that when the dormancy grade of lucerne is higher, the content of acidic and neutral fibers is higher, and the harvested lucerne hay scores are lower.

Table 2. Principal component analysis of quality indicators affecting lucerne hay under precipitation $< 1 \text{ mm}\cdot\text{d}^{-1}$.

Index	Weight Coefficient of Load Value			
	F1	F2	F3	
Internal factor	Fall dormancy level	−0.028	0.204	0.13
	Content of crude protein	0.215	0.006	0
	Acid detergent fibers	−0.27	0.065	0.058
	Neutral detergent fibers	−0.238	−0.009	−0.023
	Relative feeding value	0.284	−0.091	−0.013
External factor	Average temperature	−0.083	0.417	−0.021
	Precipitation	0.147	−0.084	0.322
	Relative humidity	−0.09	0.068	0.452
	Land surface temperature	−0.082	0.414	−0.018
	Wind speed	0.027	0.209	−0.213
	Total solar irradiance	−0.012	0.042	−0.405
Eigenvalue	4.405	1.995	1.758	
Proportion (%)	40.047	18.133	15.98	
Cumulative proportion (%)		74.16		

Table 3. Eigenvector and contribution rate of principal component analysis of each index under the condition of $1 \text{ mm}\cdot\text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$.

Index		Weight Coefficient of Load Value			
		F1	F2	F3	F4
Internal factor	Fall dormancy level	−0.036	0.0390	0.085	0.383
	Content of crude protein	0.01	0.1030	0.502	−0.163
	Acid detergent fibers	0.24	0.0860	−0.047	−0.055
	Neutral detergent fibers	0.106	0.1410	−0.343	−0.002
	Relative feeding value	−0.212	−0.1220	0.274	−0.016
External factor	Average temperature	0.206	0.0010	0.161	0.06
	Precipitation	0.061	0.1060	0.248	−0.754
	Relative humidity	−0.12	0.3960	0.195	0.078
	Land surface temperature	0.216	−0.0540	0.153	0.089
	Wind speed	0.367	−0.2140	−0.109	−0.135
	Total solar irradiance	0.106	−0.4050	−0.065	0.118
Eigenvalue		3.99	2.552	1.599	1.053
Proportion (%)		36.277	23.199	14.538	9.573
Cumulative proportion (%)				83.587	

Table 4. Principal component expression.

Group	Name	Expression
$\text{Precipitation} < 1 \text{ mm}\cdot\text{d}^{-1}$	F1	$F1 = 0.40X_2 - 0.41X_3 - 0.44X_4 + 0.42X_5 + 0.28X_6 + 0.24X_7 + 0.28X_9$
	F2	$F2 = 0.41X_6 + 0.52X_8 + 0.41X_9$
	F3	$F3 = -0.44X_7 - 0.38X_8 + 0.45X_{11}$
	Y1	$Y1 = (40.047F1 + 18.133F2 + 15.98F3)/74.16$
$1 \text{ mm}\cdot\text{d}^{-1} \leq \text{Precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$	F1	$F1 = 0.2153X_1 + 0.2203X_2 + 0.4265X_3 + 0.1782X_4 - 0.3650X_5 + 0.4270X_6 - 0.1021X_7 + 0.3074X_8 + 0.4025X_9 + 0.2723X_{10} - 0.1867X_{11}$
	F2	$F2 = 0.1546X_1 + 0.3336X_2 - 0.0801X_3 - 0.4689X_4 + 0.3349X_5 + 0.2523X_6 - 0.1020X_7 - 0.2748X_8 + 0.3199X_9 + 0.2197X_{10} + 0.4757X_{11}$
	F3	$F3 = -0.3448X_1 - 0.2736X_2 + 0.1843X_3 + 0.2214X_4 - 0.2483X_5 + 0.3013X_7 - 0.4753X_8 + 0.5259X_{10} + 0.2610X_{11}$
	F4	$F4 = -0.2543X_1 + 0.4434X_2 - 0.1588X_4 + 0.1413X_5 + 0.7825X_7 + 0.1481X_8 - 0.2368X_{11}$
	Y2	$Y2 = (36.277F1 + 23.199F2 + 14.538F3 + 9.573F4)/83.587$

The second principal component loaded on the average temperature and total solar radiation has weighting coefficients of 0.417 and 0.414. The third principal component loaded on relative humidity, total solar irradiance, and precipitation has weighting coefficients of 0.452–0.405 and 0.322. The second and third principal components mainly reflect the essential weather information. In the case of precipitation $< 1 \text{ mm}\cdot\text{d}^{-1}$, temperature is the main external factor that most affects the suitability of harvesting hay.

Under the condition of $1 \text{ mm}\cdot\text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$ (Table 3), the eigenvalues of the first four principal components (F1–F4) were all greater than 1, with a cumulative contribution rate of 83.587%. The contributions of the other principal components were negligible.

The load values of the first principal component on wind speeds, acid detergent fibers, relative humidity, and land surface temperature exhibited larger magnitudes, with positive weight coefficients of 0.367, 0.24, and 0.216, respectively. The second principal component demonstrated significant loading in relative humidity and total solar irradiance, with weight coefficients of 0.3960 and -0.4050 , respectively. The third principal component exhibited higher loading in the content of crude protein and neutral detergent fibers, with weight coefficients of 0.502 and -0.343 . Furthermore, the fourth principal component effectively captured the basic information of precipitation by the load value of -0.754 . In

the case of $1 \text{ mm}\cdot\text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm}\cdot\text{d}^{-1}$, precipitation was the main external factor that affected the suitability of harvesting hay the most, with more precipitation being less suitable for harvesting.

The expression for the principal component scores (Table 4) was derived from the standardized data of the original indices, the eigenvalues, and the variance contribution ratio of the principal components. In this context, X1~X11, respectively, represented the following variables: fall dormancy, crude protein content, acid detergent fibers, neutral detergent fibers, relative feeding value, mean air temperature, precipitation, relative humidity, surface temperature, wind speed, and total solar irradiance.

3.2. Validation Results of the Evaluation Method

3.2.1. Overview of the Verification Site

Huanghua City, Hebei Province, located on the western coast of the Bohai Sea ($117^{\circ}04' \text{ E}$, $38^{\circ}08' \text{ N}$), was selected to verify the feasibility of the evaluation method. The region features a flat terrain with saline-alkali land, widely distributed. Huanghua has a long history of lucerne cultivation.

Based on the daily precipitation, temperature, and wind speed records for Huanghua City spanning from 2000 to 2022, we obtained the value of the average monthly temperature, monthly precipitation, and wind speed (Figure 2), and the value of the precipitation concentration degree (PCD) and precipitation concentration period (PCP) in Huanghua (Figure 3).

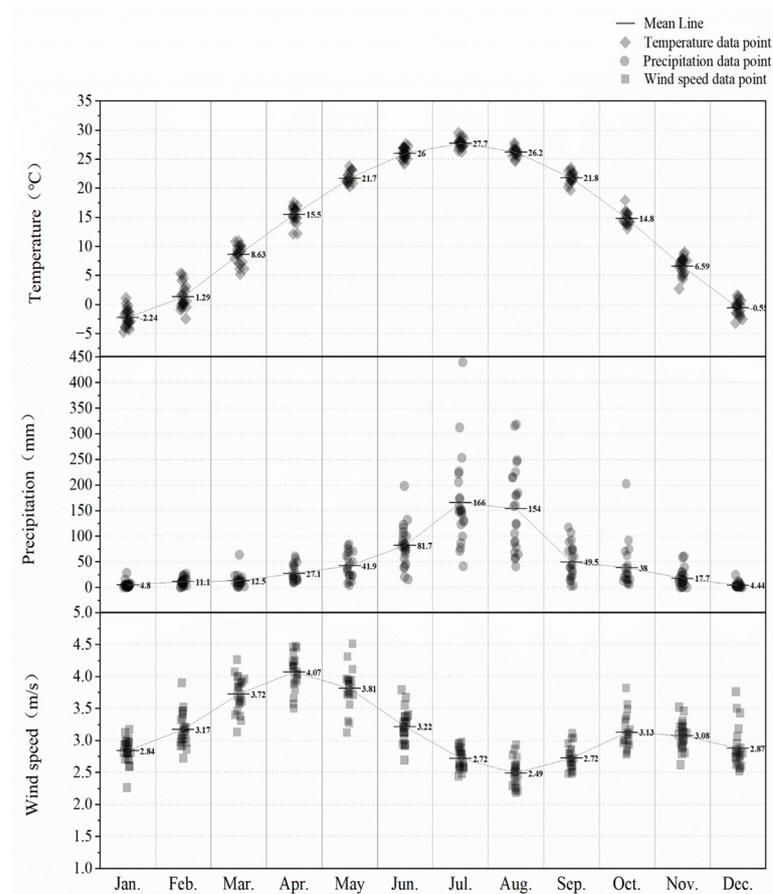


Figure 2. Annual trend chart of meteorological factors in Huanghua City.

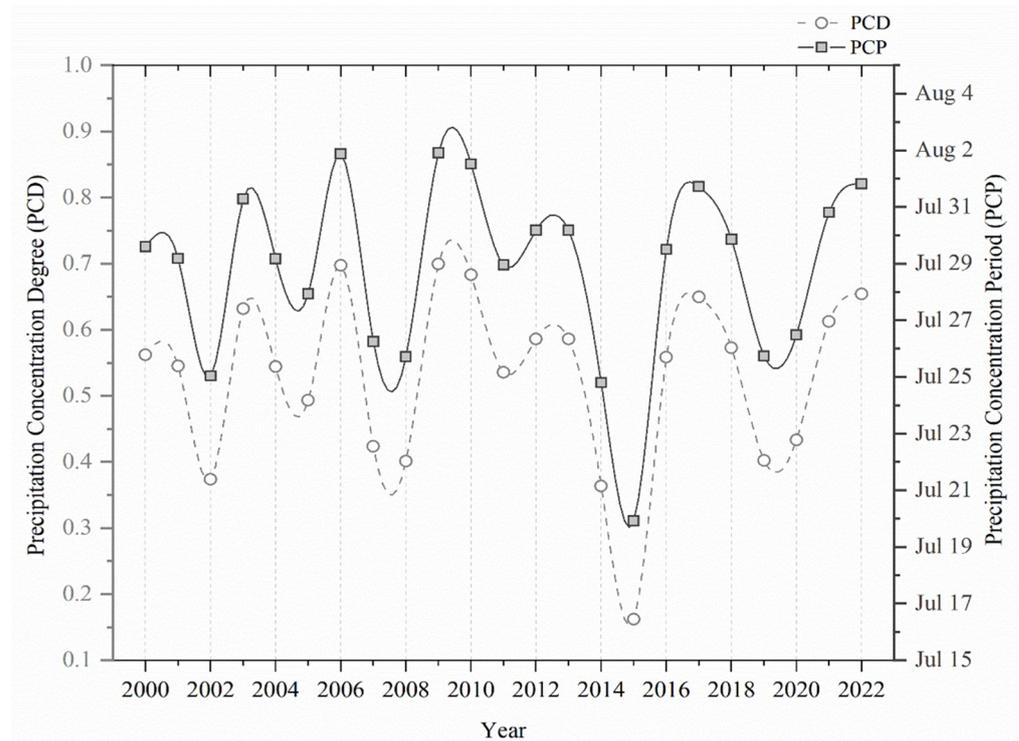


Figure 3. Evolution curve of the precipitation concentration degree (PCD) and precipitation concentration period (PCP) in Huanghua City.

It is noteworthy that Huanghua City experiences a distinctive weather in spring characterized by drought and high winds. The average wind speed in April reaches its peak of the year at 4.07 m/s. The summer weather is characterized by simultaneous rainfall and heat, with rainfall mainly concentrated in July and August. During this period, both precipitation and temperature reach the highest values. July registers the highest average monthly precipitation at 166 mm, with an average monthly temperature of 27.7 °C. But the average monthly wind speed during this period is the lowest of the year, with August recording the lowest wind speed at 2.49 m/s.

3.2.2. Precipitation Concentration Period at the Verification Site

The growth period of lucerne in Huanghua City spans from March to October, during which the lucerne is harvested several times. During the same period, the critical weather factors that impact the harvesting and drying of lucerne hay, including temperature, wind speed, and precipitation, are in a changing state. Thus, the interaction of weather factors should be considered when evaluating the effects of weather on both harvest suitability and hay quality. The temporal and spatial distribution characteristics of precipitation play a pivotal role as determining factors.

The precipitation concentration degree (PCD) and precipitation concentration period (PCP) serve as the parameters of temporal distribution characteristics by employing vector principles. These two metrics hold crucial significance in assessing regional precipitation heterogeneity and offer a quantitative description of the concentration degree and concentration period of precipitation. Hence, the PCD and PCP have been chosen to depict the temporal and spatial distribution of precipitation within Huanghua City.

Using daily precipitation data during the lucerne growth period (1 March to 31 October) from 2000 to 2022, the PCD and PCP were calculated according to the calculation formula provided by Wei et al. [26]:

$$PCD = \sqrt{R_{xi}^2 + R_{yi}^2} / R_i \quad (6)$$

$$PCP = \arctan \left(\frac{R_{xi}}{R_{yi}} \right) \quad (7)$$

$$R_{xi} = \sum_{j=1}^n r_{ij} \sin \theta_j \quad (8)$$

$$R_{yi} = \sum_{j=1}^n r_{ij} \cos \theta_j \quad (9)$$

where R_{xi} is the sum of vertical components of precipitation; R_{yi} is the sum of the horizontal components of precipitation. R_i is the total precipitation in the period (year i); i is the year, $i = 2000, 2001, \dots, 2022$; j is the day order, $j = 1, 2, 3, \dots, 245$ (the total number of days from 1 March to 31 October, known as the total length of time series); r_{ij} is the precipitation of a certain day; θ_j is the azimuth corresponding to each day (the whole study period is $-\pi \sim \pi$).

The PCD mainly reflects the concentration degree of total precipitation during the study period, with the value ranging from 0 to 1. The closer the value is to 1, the more concentrated the precipitation is, and the closer the PCD is to 0, the more uniform the precipitation is. PCD also reflects the occurrence period of the maximum daily precipitation.

The inter-annual changes of the PCD and PCP in Huanghua City from 1990 to 2022 are shown in Figure 3. The PCD ranged from 0.162 to 0.699 with an annual average of 0.529, indicating a high precipitation concentration in Huanghua City. The PCP was assessed for the period from 19 July to 1 August, and the annual average was 28 July. In general, the peaks and the valleys of PCP changed alternately and in the same direction as the PCD.

3.2.3. Suitability Evaluation for Hay Harvesting

According to previous studies, lucerne with a high fall dormancy level (dormancy grade: 1–3) has been identified as the most suitable variety for cultivation in Huanghua City [27]. The records in the database indicated that under varying precipitation conditions (precipitation $< 1 \text{ mm} \cdot \text{d}^{-1}$, $1 \text{ mm} \cdot \text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm} \cdot \text{d}^{-1}$), the average crude protein content of fall dormant and extreme fall dormancy lucerne was 20.36% and 19.43%, respectively.

Under conditions of precipitation $< 1 \text{ mm} \cdot \text{d}^{-1}$, fall dormant lucerne and extreme fall dormancy lucerne had an average neutral detergent fiber content of 31.88%, an average acid detergent fiber content of 40.10%, and an average relative feeding value of 153.88; under conditions of $1 \text{ mm} \cdot \text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm} \cdot \text{d}^{-1}$, lucerne had an average neutral detergent fiber content of 30.39%, an average acid detergent fiber content of 37.24%, and an average relative feeding value of 161.13.

To assess the quality of harvested lucerne hay, daily meteorological data during the growth period of lucerne (1 March to 31 October) from 2000 to 2022 in Huanghua City were utilized. The daily mean value of each meteorological factor was put into the scoring formula to calculate the Y value. Then, heat maps illustrating hay quality scores for different harvest dates were generated according to Y (Figure 4).

The highest score of lucerne harvest suitability in Huanghua City was 66.00, and the lowest score was 26.2 (Figure 4). Taking $Y_a = 39.47$ and $Y_b = 52.73$ as the threshold of suitability grade, the harvest date was divided into three levels: highly suitable ($52.73 < Y \leq 66.00$), moderately suitable ($39.47 \leq Y \leq 52.73$), and unsuitable ($26.0 \leq Y < 39.47$).

A higher score corresponded to better-quality lucerne hay harvested on a particular date and high suitability for harvesting. The harvest suitability of lucerne hay in Huanghua City declined with the months' progress. May stood out as a highly suitable month for harvesting lucerne hay, while October was unsuitable for such operations.

In May, there were 30 highly suitable hay harvesting days, with 9 May being moderately suitable, and the hay quality harvested on these two days was slightly lower compared with other days. Highly suitable periods for hay harvesting in June were 1 June to 8 June, 10 June to 18 June, and 20 June to 30 June, totaling 28 days. The remaining dates were considered moderately suitable for harvesting. July offered a highly suitable hay harvesting

window from 2 July to 7 July, 9 July, 11 July to 12 July, 15 July to 18 July, and 20 July to 23 July, 15–30 July, encompassing 24 days. There were an additional 7 days moderately suitable for harvesting in July. August provided a span of 19 days that were moderately suitable for hay harvesting, 8 days that were highly suitable for harvesting, and 4 days that were unsuitable harvest days. In September, 16 days were moderately suitable, and not a single day was highly suitable for hay harvesting. October offered a 2-day suitable period for hay harvesting. At present, the cutting time of lucerne is not uniform in the coastal saline-alkali area of Hebei Province [28–30]. In general, the best cutting period of lucerne is between the bud stage and the first flowering stage, that is, before the flowering rate reaches 10% [3,31]. The cutting interval is usually 30–35 days. In the Cangzhou area, lucerne can be mowed four times a year. By collecting the harvest time of lucerne in Cangzhou (13 cases in total) in published papers, the distribution map of the cutting time of lucerne with different stubble times in Cangzhou was drawn (Figure 5). For comparison, the harvest suitability obtained by the evaluation method is also shown in Figure 5.

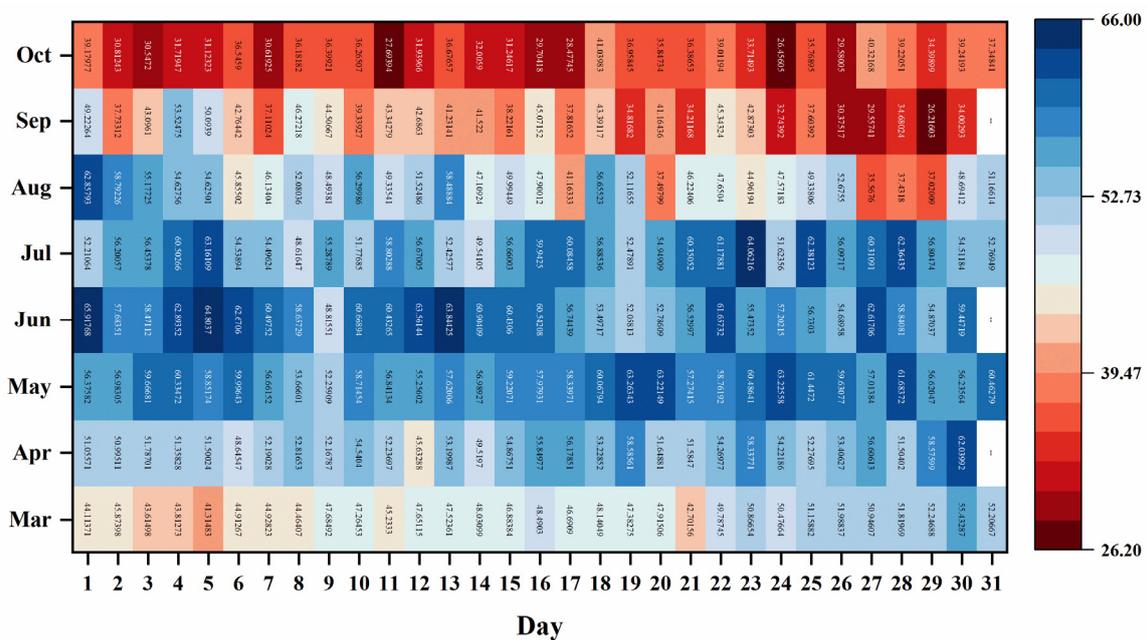


Figure 4. Heat map of the hay quality score of lucerne harvested on different dates.

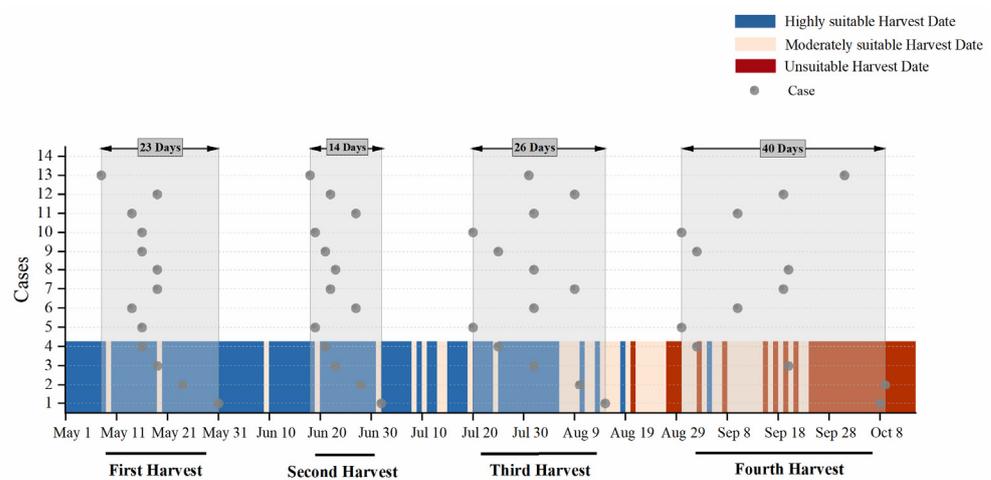


Figure 5. Distribution of actual harvest time and simulated harvest time.

As mentioned above, the precipitation concentration period in Huanghua City was from 19 July to 1 August, which coincided with the harvest time of the third crop of lucerne. In this period, the frequent precipitation prevented lucerne from being harvested as planned. As a result, the harvest time of the third and fourth lucerne crops became more dispersed. It can be seen that precipitation has a significant effect on the harvest of lucerne hay. In current studies, there is no unified standard for the harvest time of lucerne in Cangzhou City [32,33]. More scientific and standardized guidance is needed for the supporting management of lucerne in this area, such as sowing time, cutting time, cutting stubble times, harvesting, and storage methods.

The first harvest time in published papers consistently fell within the optimal period of May. The second harvest time in previous studies was mostly distributed in the generally suitable period of June, while the third harvest gradually experienced a decrease in suitability and included unsuitable periods. The fourth harvest predominantly occurred during an unsuitable period. Similar to the practical harvest situation, the quality of lucerne progressively declined with delayed harvest times. However, by advancing the timing of each crop's harvest, it is possible for the fourth crop to be harvested in August. This adjusted harvesting strategy could improve the quality of lucerne hay compared with previous practices and minimize inconveniences caused by rainy season conditions.

4. Discussion

4.1. Influence of Meteorological Factors on the Quality of Lucerne Hay during Drying Period

The response of lucerne hay quality to weather conditions is the preservation or loss of nutrients during the drying process. In our study, the contribution of weather factors to hay quality varied with rainfall. Under the condition of low precipitation (<1 mm), hay harvest suitability depended largely on the quality of the forage itself: the lower the fall dormancy grade, the higher the crude protein content; the lower the fiber content, the higher the suitability for harvesting lucerne hay; and the higher air temperature was the most beneficial of the weather indicators to improve the quality of hay, followed by ground surface temperature, relative humidity, and total solar radiation. While under the condition of $1 \text{ mm} \cdot \text{d}^{-1} \leq \text{precipitation} < 10 \text{ mm} \cdot \text{d}^{-1}$, the suitability of hay harvesting depended mainly on the influence of weather factors, precipitation became the most significant influencing factor, followed by wind speed, ground surface temperature, and relative humidity. More important, lucerne drying was influenced by the interaction rather than the simple superposition of different meteorological factors. We suggested that less precipitation, a certain level of high temperature and surface temperature, low humidity, and light wind are necessary for obtaining higher-quality hay. Liu et al. found that high temperature, intense light, and gentle breeze are conducive to nutrient preservation during lucerne drying, while humidity and strong winds hinder nutrient preservation [34]. Wang et al. reported that higher temperatures with greater wind speed lead to higher crude protein content, while lower temperatures with greater wind speed result in decreased crude protein content [35]. The following results were obtained from a simulation experiment on the effect of rainfall on lucerne hay quality by You et al. and Xu et al.: the increased precipitation increases the content of acidic and neutral detergent fibers in lucerne and decreases the quality of lucerne hay [36,37]. The relationship between lucerne quality and meteorological factors obtained by this research-developed method is consistent with previous studies. It proved the feasibility of this study's evaluation method.

4.2. The Cutting Period and Stubble Times Were Determined by the Suitability Scoring Formula

Cutting time is one of the key determinants affecting the nutrient composition of lucerne during cultivation. Hu et al. examined the nutritional value of 12 local lucerne varieties with different harvest times and revealed that the quality of all varieties of the first and second harvests was superior to those of the third harvest [35]. Similarly, Du et al. highlighted the superior quality of the first harvest hay in comparison with the second and third [38]. The results of these experimental studies were consistent with the simulation

results of our scoring formulation. Our results showed that hay harvest scores in May and June (i.e., first and second harvests) were significantly better than those in July and August (i.e., third and fourth harvests) in Huanghua, China.

In the analysis of the lucerne quality difference among different cutting times, previous research mostly focused on the impact of weather factors on nutrient accumulation during the growth stage [39,40]. The elevated temperature in summer contributes to premature aging of the lucerne and results in the decline of hay quality [41]. However, our study concentrated on the effects of weather conditions on nutrient loss during the post-harvest drying period. The first harvest of lucerne in May benefits from favorable temperatures and less precipitation, which facilitates the rapid removal of excess water. Conversely, the second and third harvests are usually in July and August. High temperature, great humidity, and frequent rainfall during this period lead to prolonged drying time and, subsequently, nutrient loss and quality decrease [42].

4.3. Adjusting Lucerne Harvesting Methods According to the Suitability of Hay Harvesting

Combining the evaluation scores of forage harvest suitability and local weather characteristics, it can be seen that from the first harvest to the period of concentrated precipitation, the suitability of forage harvest and the quality of harvested forage in Huanghua City decreased with the increase of precipitation.

In the period of precipitation concentration, in addition to not meeting the requirements of natural drying of lucerne, lucerne was also affected by high temperatures, the phenomenon of “summer dormancy” when growth becomes slower, and grass production and quality decreases. In order to avoid this problem, it is advisable to use other alternative methods of forage management during this period. (1) The natural drying of the hay can be accelerated by harvesting the lucerne using a machine capable of crushing the tough stalks that contain a high level of crude fiber. (2) Using silage production can be considered (including semi-drying or wrapped silage) instead of the traditional air-drying and air-drying of the harvest. Moreover, the nutrient losses of silage lucerne are all less than air-drying and air-drying harvests. Nutrient losses for hay made through the air-drying process are about 30%; in addition, if rainfall occurs during drying, losses can be as high as 50%, whereas nutrient losses for lucerne silage are usually less than 15% [43]. In addition, lucerne silage has good palatability and quality, while maintaining high digestibility over a longer storage period. However, it should be noted that traditional low-moisture silage preparation still requires some degree of drying; therefore, high-moisture silage treatments may be suitable for selecting lucerne with general harvest suitability [44]. Another solution for harvesting the fourth swath is to graze the animals. However, this approach may be more suitable for adjacent large pastures and may not be suitable for small areas of artificially cultivated grassland such as the validation area. All of the above methods can avoid the problem of declining lucerne quality during rainfall and the fourth harvest, and have the potential to improve the economic value of grass products and increase farmers’ income.

Even after the period of concentrated precipitation, hay harvest suitability tended to decrease. During this period, the effect of precipitation on lucerne harvesting diminished as precipitation gradually decreased and temperatures began to fall. The decrease in temperature created unfavorable conditions for lucerne growth and the subsequent hay harvest, resulting in generally substandard hay quality. Therefore, it is recommended that the lucerne harvest be completed before the end of the concentrated precipitation period.

This study provides a new method for predicting the suitability of lucerne hay harvesting, which comprehensively considers the influence of lucerne itself and external weather factors during the harvesting period. The main influencing factors affecting the suitability of lucerne hay harvesting in different time periods can also be evaluated. Based on this, the harvesting strategy can be formulated in a targeted manner, and the loss caused by negative factors to lucerne harvesting can be avoided by adjusting the lucerne harvesting method and harvesting time.

For example, in the coastal area of Hebei Province (Cangzhou City), the suitability of lucerne hay harvest in May and June mainly depends on the type of lucerne planted. The suitability is influenced by lucerne's own indexes, and the suitability of the harvest in these two months is obviously greater than in July. In July, precipitation increases, and the main reason affecting the suitability of the harvest of lucerne hay is a change in the weather factors. At this time, high temperatures and humidity are not suitable for harvesting lucerne hay but are suitable for harvesting silage instead. At the same time, it is possible to predict future harvesting conditions by importing future weather data, adjusting the harvesting time and harvesting method, and preparing for subsequent production and trading.

5. Conclusions

This study has improved our understanding of how climatic factors affect hay quality and has identified variations in key climatic factors that affect hay harvest suitability. This provides agronomists with a lucerne harvesting strategy that maximises benefits from a hay quality perspective. This includes the number of harvests per year, the optimum timing for each harvest and the best harvesting method for each stubble. In the future, the methods of this study in combination with weather forecasts can be used to preview changes in annual lucerne hay harvests, or changes in the types of products (e.g. lucerne hay or silage) circulating in the lucerne market, offering the possibility of developing accurate purchasing and selling strategies for different regions.

Furthermore, the study paves the way for sustainable agricultural practices by promoting efficient resource use. While the core scoring formulas are broadly applicable, their final weighting needs to be adjusted based on each region's specific weather data to ensure accurate suitability evaluations.

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References

1. Grant, R.J.; Ferraretto, L. Silage review: Silage feeding management: Silage characteristics and dairy cow feeding behavior. *J. Dairy Sci.* **2018**, *101*, 4111–4121. [[CrossRef](#)] [[PubMed](#)]
2. Ouellet, V.; Tremblay, G.F.; Laroche, J.-P.; Bélanger, G.; Binggeli, S.; Jégo, G.; Charbonneau, E. Modeling whole farm profitability and environmental performance of four alfalfa-grass binary mixtures in eastern Canadian dairy farms. *Agron. J.* **2021**, *113*, 4047–4063. [[CrossRef](#)]
3. Testa, G.; Gresta, F.; Cosentino, S.L. Dry Matter and Qualitative Characteristics of Alfalfa as Affected by Harvest Times and Soil Water Content. *Eur. J. Agron.* **2011**, *34*, 144–152. [[CrossRef](#)]
4. Sun, H.-R.; Yang, X.-J.; Chen, Z.; Zhang, B.-Y.; Ren, Y.-T. Water demand pattern and irrigation quota of alfalfa in Yanyang District. *J. Grassl.* **2017**, *25*, 1227. [[CrossRef](#)]
5. Yang, X. Impacts of Climate Change on Yield, Water Utilisation and Soil Nutrients in Crop Production Systems on the Loess Plateau. Lanzhou University Institutional Repository. 2019. Available online: <https://ir.lzu.edu.cn//handle/262010/337999> (accessed on 3 April 2024).
6. Yang, X.; Liu, L.; Zhu, X.Q.; Yu, C.Q.; Li, J.H. Grey correlation analysis between alfalfa yield and meteorological factors in the Tibet valley region. *J. Grassl.* **2016**, *24*, 198–203.
7. Gallego, A.; Hospido, A.; Moreira, M.T.; Feijoo, G. Environmental assessment of dehydrated alfalfa production in Spain. *Resour. Conserv. Recycl.* **2011**, *55*, 1005–1012. [[CrossRef](#)]
8. Han, K.J.; Pitman, W.D.; Chapple, A. Moisture Concentration Variation of Silages Produced on Commercial Farms in the South-Central USA. *Asian-Australas. J. Anim. Sci.* **2014**, *27*, 1436–1442. [[CrossRef](#)] [[PubMed](#)]

9. Nieman, C.C.; Coblenz, W.K.; Moore, P.A.; Akins, M.S. Effect of Poultry Litter Application Method and Rainfall and Delayed Wrapping on Warm-Season Grass Baleage. *Agronomy* **2023**, *13*, 1896. [CrossRef]
10. Zhong, S.; Zhang, X.; Yang, Y.; Yang, Y. Effects of lactic acid bacteria and cellulase on silage quality of alfalfa with different moisture content. *J. Anim. Nutr.* **2017**, *29*, 1821–1830.
11. Liu, L.Y. Research on the Influence Mechanism of Environmental Factors on Nutrients during Alfalfa Drying Process and Field Regulation Strategy. Ph.D. Thesis, Inner Mongolia Agricultural University, Hohhot, China, 2019. Available online: https://kns.cnki.net/kcms2/article/abstract?v=Ma1nt2RbXaihm3EFfPEvi7bSFz2CQiOU9IWGZZHVdNqMzh6OpbyefK55o24SkrJmMYX5QkLvzLZuMRKo8C7f6xT51xrKHwJ2MjBr1-Rm2_mhfx0tpbv04pNwjvZaKCZYmm1MrjmT1iLaYOhIEYNQ=&uniplatform=NZKPT&language=CHS (accessed on 29 March 2024).
12. Leon-Tinoco, A.Y.; Guimarães, B.C.; Almeida, S.T.R.; Reyes, D.C.; Rivera, S.; Killerby, M.; Wu, C.; Perkins, B.; Knight, C.; Romero, J.J. Effect of lignosulfonates on the dry matter loss, nutritional value, and microbial counts of high moisture alfalfa silage. *Anim. Feed. Sci. Technol.* **2022**, *290*, 115346. [CrossRef]
13. Barr, A.G.; Smith, D.M.; Brown, D.M. Estimating forage yield and quality changes during field drying for hay 1. Model of dry-matter and quality losses. *Agric. For. Meteorol.* **1995**, *76*, 83–105. [CrossRef]
14. Zhong, Y.; Bao, Q.; Sun, W. Research on hay modification and its improvement of utilisation. *Grassl. China* **1997**, *29*, 50–55.
15. Akkharath, I.; Gupta, M.L.; Tullberg, J.N. The influence of weather on the effectiveness of mechanical and chemical conditioning on drying rate of lucerne hay. *Grass Forage Sci.* **1996**, *51*, 96–102. [CrossRef]
16. Wilks, D.S.; Pitt, R.E.; Fick, G.W. Modeling optimal alfalfa harvest scheduling using short-range weather forecasts. *Agric. Syst.* **1993**, *42*, 277–305. [CrossRef]
17. Liu, L.Y.; Jia, Y.S.; Fan, W.Q.; Yin, Q.; Cheng, Q.M.; Wang, Z.J. Study on major environmental factors affecting natural drying of alfalfa. *J. Grass Ind.* **2022**, *31*, 121–132.
18. Standard Tests for Characterising Alfalfa Autumn Dormancy Revised August 1998. Available online: <https://www.naaic.org/stdtests/Dormancy2.html> (accessed on 20 March 2024).
19. Ventroni, L.M.; Volenec, J.J.; Cangiano, C.A. Fall dormancy and cutting frequency impact on alfalfa yield and yield components. *Field Crops Res.* **2010**, *119*, 252–259. [CrossRef]
20. Blume, L.; Hoischen-Taubner, S.; Sundrum, A. Alfalfa—A Regional Protein Source for All Farm Animals. *Landbauforschung* **2021**, *71*, 1–13. [CrossRef]
21. Zhou, Q.; Wei, Y.; Yu, Z.; Wu, Z. Effect of modulation on alfalfa quality after drenching. *Chin. J. Grassl.* **2018**, *40*, 68–72. [CrossRef]
22. Gallo, A.; Moschini, M.; Cerioli, C.; Masoero, F. Use of principal component analysis to classify forages and predict their calculated energy content. *Animal* **2013**, *7*, 930–939. [CrossRef] [PubMed]
23. An, N. Analysis of precipitation suitability during alfalfa mowing in Aluqorqin Banner. *Mod. Agric. Sci. Technol.* **2021**, *24*, 173–175+178.
24. Zhang, F.; Xu, X.; Cheng, J.; Wen, T.; Liu, Z. Characterisation of graded rainy days and rainfall changes in Poyang Lake area. *J. Yangtze Acad. Sci.* **2020**, *37*, 22–28+34.
25. Niu, J.Z.; Shi, D.K. Evaluation of the ecological and climatic suitability of alfalfa harvesting in the Yellow River Delta. *J. Grassl. Sci.* **1998**, *02*, 139–146.
26. Wei, S.-J. Research on Excel calculation method of precipitation concentration and concentration period. *People's Yellow River* **2017**, *39*, 58–61.
27. Wang, S.; Fang, D.; Li, X.; Han, L. Response of alfalfa nutrient quality to autumn dormancy class and stubble size in saline and alkaline land of Hebei Binhai. *Chin. J. Ecol. Agric.* **2022**, *30*, 1630–1637. (In English)
28. Xie, N.; Liu, Z.; Feng, W.; Ji, J.F.; Qin, W.L.; Liu, Z.K.; Wei, L.F. Evaluation of production performance of 29 alfalfa varieties in Cangzhou region. *Hebei Agric. Sci.* **2016**, *20*, 19–26. [CrossRef]
29. Zhao, Z.; Liu, Q.S.; Huang, S.F.; Liu, Z.; Xu, Y.P.; Yan, X.D. Comparison of production performance of alfalfa varieties in Cangzhou, Hebei. *Chin. J. Grassl. Sci.* **2021**, *43*, 92–100. [CrossRef]
30. Liu, Q.S.; Jia, Y.L.; Xiao, Y.; Xu, Y.P.; Zhao, Z.C.; Yue, M.Q.; Wang, X.L.; Liu, Z.M.; Yan, X.D. Effects of balanced fertilisation on alfalfa growth and soil nutrient changes in Cangzhou. *Chin. J. Grassl.* **2022**, *44*, 70–78. [CrossRef]
31. Fan, W.; Ge, G.; Liu, Y.; Wang, W.; Liu, L.; Jia, Y. Proteomics integrated with metabolomics: Analysis of the internal causes of nutrient changes in alfalfa at different growth stages. *BMC Plant Biol.* **2018**, *18*, 78. [CrossRef] [PubMed]
32. Jia, Y.; Gegentu; Wang, Z. Research progress on key technology of alfalfa hay processing. *J. Inn. Mong. Agric. Univ. (Nat. Sci. Ed.)* **2022**, *43*, 80–85. [CrossRef]
33. Tao, Y.; Sun, Q.; Xu, L.; Li, F. Development of alfalfa industry in China and the challenges it faces. *Grassl. Grass Ind.* **2022**, *34*, 1–10.
34. Liu, Q.; Dong, Z.; Shao, T. Dynamics of change in fermentation and fatty acid profiles in high moisture alfalfa silage during ensiling at different temperatures. *Cienc. Rural* **2018**, *48*, e20170605. [CrossRef]
35. Wang, C.; Che, G.; Li, Y. Experimental study on the effect pattern of drying process on crude protein content of alfalfa. *J. Agric. Eng.* **2006**, 225–228.
36. Xu, Q.F.; Wang, B.P.; Dong, K.H.; Yu, Z.; Sun, Q.Z.; Meng, S.F.; Qin, L.G.; Liu, H. Effect of rainfall on alfalfa hay quality. *Grassl. J.* **2010**, *18*, 848–853.
37. You, S.; Liu, Y.; Du, S.; Sun, L.; Gegentu; Jia, Y. Effects of rainfed harvesting on alfalfa nutritional quality and its in vitro digestive properties. *Grassl. Grass Ind.* **2015**, *27*, 32–36.

38. Hu, S.; Wang, H.; Zhao, S.; Gu, M.; Wan, S.; Liu, J. Nutritional value analysis of 12 alfalfa varieties. *Grass Sci.* **2005**, *04*, 22–25.
39. Du, S.; Yang, Y.; Xin, Y.; Wang, H. Effects of alfalfa varieties and mowing stubble on yield and nutritional value. *J. Livest. Ecol.* **2013**, *34*, 44–48.
40. Monirifar, H.; Roudsari, A.M.; Ghassemi, S.; Tavasolee, A. Harvest Time and Cultivar Effects on Growth, Physiological Traits, Yield and Quality of Alfalfa in Saline Condition. *Int. J. Plant Prod.* **2020**, *14*, 453–462. [[CrossRef](#)]
41. Li, Y.; Li, X.; Zhang, J.; Li, D.; Yan, L.; You, M.; Zhang, J.; Lei, X.; Chang, D.; Ji, X.; et al. Physiological and Proteomic Responses of Contrasting Alfalfa (*Medicago Sativa* L.) Varieties to High Temperature Stress. *Front. Plant Sci.* **2021**, *12*, 753011. [[CrossRef](#)] [[PubMed](#)]
42. Burnett, V.; Butler, K.; Clark, S.; Nie, Z.; Zollinger, R.; Seymour, G.; Knight, M.; Mitchell, M. Seasonal growth of lucerne (*Medicago sativa*) under rainfed conditions in south east Australia: Variation of experimental and commercial cultivars sourced from Australia and China. *Field Crops Res.* **2022**, *277*, 108409. [[CrossRef](#)]
43. Wang, L.; Wu, H.; Huo, W.; Feng, J.; Meng, F. Study on the relationship between alfalfa nutritional quality and meteorological factors. *Chin. J. Grassl.* **2017**, *39*, 14–20. [[CrossRef](#)]
44. Jiang, H.; Wang, H.; Bao, B.; Qu, H.; Wang, J.; Sun, L.; Liu, B.; Gao, F. Effect of Compound Additives on Nutritional Composition, Fermentation Quality, and Bacterial Community of High-Moisture Alfalfa Silage. *Fermentation* **2023**, *9*, 453. [[CrossRef](#)]

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