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Effects of Planting and Nitrogen Application Patterns on Alfalfa Yield, Quality, Water–Nitrogen Use Efficiency, and Economic Benefits in the Yellow River Irrigation Region of Gansu Province, China

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Abstract: Appropriate planting and nitrogen application patterns to support high-quality production of cultivated forage in light of issues of water scarcity, extensive field husbandry, and low productivity in cultivated grassland planting areas were investigated in this study. Using *Medicago sativa* L. (alfalfa) as the research object, this study analyzed the effects of planting patterns (conventional flat planting (FP) and ridge culture with film mulching (RM)) and nitrogen level (N0: 0 kg·ha^{-1}, N1: 80 kg·ha^{-1}, N2: 160 kg·ha^{-1}, N3: 240 kg·ha^{-1}) on the growth, yield, quality (crude protein content (CP), acid detergent fiber content (ADF), neutral detergent fiber content (NDF), and relative feeding value (RFV)), the water–nitrogen use efficiency, and economic benefits (EB) of alfalfa in the year of establishment. Results demonstrated that (1) RM might greatly increase the growth of alfalfa when compared to FP. The plant height, stem diameter, and leaf:stem ratio of alfalfa all increased under the same planting patterns before decreasing as the nitrogen application rate (NAR) increased. (2) Appropriate NAR combined with RM could improve the yield and quality of alfalfa. Compared with other treatments, the yield, CP, and RFV under RMN2 treatment increased by 5.9~84.9%, 4.9~28.6%, and 19.6~49.3%, respectively, and the ADF and NDF decreased by 14.0~27.6% and 13.0~26.1%, respectively. (3) Under the same nitrogen level, RM showed better performance than FP in terms of water use efficiency (WUE), irrigation water use efficiency (IWUE), precipitation use efficiency (PUE), partial factor productivity of nitrogen (PFPN), agronomic nitrogen use efficiency (ANUE), and EB of alfalfa. Under the same planting pattern, PFPN decreased as the NAR increased, while WUE, IWUE, PUE, ANUE, and EB first increased and then decreased as the NAR increased and reached a maximum value under the N2 condition. In conclusion, the RM planting pattern combined with a nitrogen level of 160 kg·ha^{-1} can significantly promote alfalfa growth as well as the yield, quality, water–nitrogen use efficiency, and EB of alfalfa, making it a suitable planting management mode for alfalfa production in the Yellow River irrigation region in Gansu Province, China and areas with similar climate.

Keywords: planting patterns; nitrogen level; alfalfa; yield; quality; water–nitrogen use efficiency

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1. Introduction

High yield, excellent quality, robust resistance, and abundant nutrition are all attributes of alfalfa (*Medicago sativa* L.). In addition to currently being the most-cultivated grass in the world, it is the primary source of high-quality protein and energy for herbivores such as cows [1,2]; it is also named the "king of the pasture". Alfalfa has developed roots, abundant leaves, and high surface coverage, which play an important and unique role in enhancing the local ecological environment and reducing soil erosion [3,4]. China has developed and put into effect a number of measures over the past few years, including overall adjustment of grain/economic feed crop planting structure, extension of grain-to-fodder crop conversion trials, and accelerated construction of a modern forage industry system. Based on this, the alfalfa industry has achieved unprecedented development, with the planting area reaching 15% of the world's total area, second only to the United States (36%) [5]. However, alfalfa is grown primarily in China's arid and semi-arid regions, with limited soil and water supplies. Typically, alfalfa produces a relatively low yield of low-quality product, which is in stark contrast to the increasing alfalfa yield and quality demands in animal husbandry [6]. Therefore, finding ways to promote the efficient use of water and fertilizer resources while improving alfalfa yield and quality is an urgent problem that must be solved in order to ensure the sustainable and healthy development of the alfalfa industry in China [7].

The growth of alfalfa depends on its genetic characteristics and environmental conditions, and water is the most important environmental impact factor [8]. Appropriate planting patterns can be used to reduce soil evaporation and plant transpiration in agricultural production so as to improve the soil water status in the root zone of crops. Ridge culture with film mulching technology combines ridge culture and film mulching to provide rain collection, evaporation reduction, moisture preservation, and other functions. By changing the microtopography, this technology can increase surface area and solar radiation as well as diurnal temperature variation, making it an essential agronomic measure for achieving highly efficient use of rainfall resource availability in arid and semi-arid areas [9–11]. Ridge culture with film mulching has had wide application in the production of grain and economic crops. According to previous research, ridge mulching with furrow planting can improve soil structure, water and heat conditions, and thus create a suitable microclimate environment for crop growth, thereby improving the nutrient absorption capacity of roots, the photosynthetic characteristics of leaves, and the water use efficiency of crops [12,13]. The RM planting pattern has been gradually introduced into forage production in recent years. Primary studies demonstrated that, when compared to traditional ridge culture in the hilly loess regions of northwest China, ridge culture with film mulching had better performance in promoting the elongation of alfalfa root crowns, which could improve cold tolerance and wintering rate [14], and significantly improved soil water availability, alfalfa yield, and water use efficiency. The effect reached optimum when the ridge:furrow ratio was 60:44 (cm) [15]. In the northeastern margin of the Qinghai-Tibet Plateau, ridge culture with film mulching can significantly increase the emergence rate of alfalfa, the yield of the current year and the following year, and significantly reduce the number of weeds [16]. Nutrient availability is another important environmental impact factor for alfalfa growth. Nitrogen is an important nutrient and structural element required for plant growth, and it has a direct impact on plant metabolism, material circulation, and nutrient distribution [17]. It was discovered that the introduction of nitrogen could balance the nutrient composition of grasslands, improve soil nutrient cycling, and increase soil enzyme activity [18]. Since alfalfa has weak nitrogen fixation ability in the year of establishment and after cutting, it must obtain nitrogen from the soil to maintain normal life activities [19]. Reasonable nitrogen addition could improve photosynthetic characteristics and photosynthate allocation in leaves, increasing alfalfa yield and quality [20]. The combined application of organic and inorganic nitrogen fertilizer can significantly increase soil nitrogen supply, improve biological nitrogen fixation capacity, and reduce nitrogen leaching losses [21]. Suitable planting and nitrogen application patterns can promote the combined utilization of water, fertilizer, air, and heat, which is a vital way to improve alfalfa growth as well as water–nitrogen use efficiency.

There is currently a scarcity of systematic research on the effects of planting patterns and nitrogen application levels on alfalfa growth, particularly research on regulating soil water status through ridge culture with film mulching, as well as connecting nitrogen addition to improving alfalfa productivity. Gansu Province has emerged as a major producer of high-quality alfalfa in China in recent years, with a bed area of 15 million acres for alfalfa by 2022 and a commercial planting area accounting for more than 60% of the country. The Yellow River irrigation region in Gansu Province is rich in light and heat resources, with a large diurnal temperature variation and excellent irrigation facilities, making it ideal for development of the alfalfa industry. However, this region has a quite dry climate and poor soil, with a single planting pattern of alfalfa and a relatively low level of fertilization management, which leaves room for alfalfa production improvement [22]. Under the rigid constraint of water resources and the backdrop of the Action Plan for Zero Growth of Chemical Fertilizer Use by 2020, comprehensive research on planting patterns and nitrogen levels may improve alfalfa productivity and resource utilization rate and may help to promote structural reform on the supply side of agriculture and animal husbandry. Therefore, our objectives were to (1) quantify the effects of planting patterns and nitrogen application levels on the growth, yield, quality, water–nitrogen use efficiency, and economic benefits (EB) of alfalfa and (2) explore a yield-enhancing, quality-improving and efficiency-increasing combination pattern of planting and nitrogen application for alfalfa in the Yellow River irrigation region of Gansu Province, China.

2. Materials and Methods

2.1. Description of the Experimental Site

The experiment was carried out at the irrigation station (37°23′ N, 104°08′ E, altitude 2028 m) of the Jingtaichuan Electric Power Irrigation Water Resource Utilization Center from April to October 2021 in Gansu Province, China. The experimental area has a temperate continental climate, with annual sunshine hours of 2652 h, a radiant quantity of 6.18×10^5 J·cm^{-2}, precipitation of 185 mm, evaporation of 3028 mm, a temperature of 8.3 °C, and a frost-free period of 191 d on average. The soil type of the experimental area was loam, and the 0~100 cm soil layer had an average dry bulk density of 1.61 g·cm^{-3}, a field capacity of 24.1% (mass water content), and a pH of 8.11. The nutrient contents of the topsoil in the experimental area were as follows: 1.3 g·kg^{-1} of organic matter, 1.6 g·kg^{-1} of total nitrogen, 1.3 g·kg^{-1} of total phosphorus, 34.0 g·kg^{-1} of total potassium, 55.2 mg·kg^{-11} of available nitrogen (including inorganic nitrogen, such as ammonium nitrogen; nitrate nitrogen; and hydrolyzed organic nitrogen, such as amino acids), 26.3 mg·kg^{-1} of available phosphorus, and 173.0 mg·kg^{-1} of available potassium. The meteorological data were monitored by a small smart agricultural meteorological station (Davis) installed in the experimental station. The total precipitation and daily average temperature during the experimental period were 199.7 mm and 16.9 °C, respectively (Figure 1).

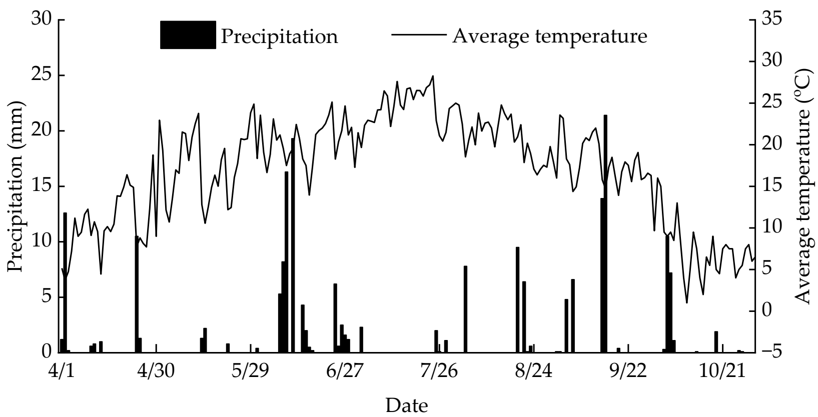

Figure 1. Distribution of daily precipitation and average temperature during the experiment.

2.2. Experimental Design and Field Management

Longdong alfalfa (alfalfa for short) was chosen as the test variety in this study. The experiment was conducted using a randomized complete block design with two impact factors: planting pattern and nitrogen level. Specifically, the planting patterns included conventional flat planting (FP) and ridge culture with film mulching (RM); the nitrogen levels (pure nitrogen) included 0 kg·ha^{-1}(N0), 80 kg·ha^{-1}(N1), 160 kg·ha^{-1}(N2), and

240 kg·ha^{-1}(N3). As shown in Table 1, there were a total of 8 treatments, each repeated three times, which comprised 24 plots, each measuring 42.9 m^2 (5.5 × 7.8 m^2). Deep tillage and leveling were carried out on the test field 10 days before sowing, followed by furrows dug for the RM plots and alfalfa seeds planted on both sides of the ridge and in the furrow with a row spacing of 20 cm. The row spacing in the conventional flat planting plots was 30 cm (Figure 2). All plots received 22.5 kg·ha^{-1} of seeding, and the mulch used in the test had a width of 100 cm and a thickness of 0.008 mm. The nitrogen fertilizer used in the test included urea (mass fraction of N: 46.4%), phosphate fertilizer (calcium superphosphate, mass fraction of P_2O_5: 16%), and potash fertilizer (muriate of potash, mass fraction of K_2O: 60%). Urea was applied before sowing, after the first cutting, and after the second cutting according to an application ratio of 6:2:2, respectively. During sowing, 50 kg·ha^{-1} of phosphate and potash fertilizer were applied once as the base fertilizer. Moreover, drip irrigation was utilized. The dropper spacing in the RM plots was 40 cm, and the dropper spacing in the FP plots was 60 cm. All drips had a flow rate of 2 l·h^{-1}, with valves and water meters (accuracy 0.001 m^3) installed on the water pipes to control the irrigation amount. Irrigation and other field management measures were the same as for the general cultivated grassland in the region. Alfalfa was planted on 7 April and mowed three times: 17 July, 29 August, and 8 October 2021.

Table 1. Experimental design.

Treatments	Planting Pattern	Nitrogen Level (kg·ha^{-1})
FPN0	Conventional flat planting (FP)	0 (N0)
FPN1		80 (N1)
FPN2		160 (N2)
FPN3		240 (N3)
RMN0	Ridge culture with film mulching (RM)	0 (N0)
RMN1		80 (N1)
RMN2		160 (N2)
RMN3		240 (N3)

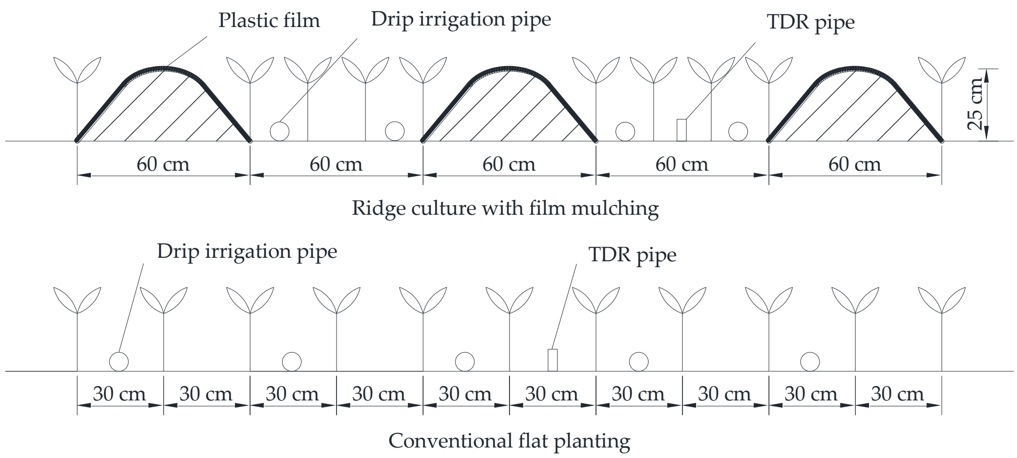

Figure 2. Schematic diagrams of the experimental layout.

2.3. Indicators and Methods for Measurement

2.3.1. Plant Height and Stem Diameter

Each time the alfalfa was to be cut, 10 plants with uniform growth were chosen in each plot to measure the plant height from the bottom and the stem diameter at a distance of 5 cm from the ground using tape and a vernier caliper, respectively.

2.3.2. Leaf: Stem Ratio

When harvesting alfalfa, 20 plants with similar growth were randomly selected from each plot and cut off 5 cm from the ground. The leaves and stems were separated and baked to constant weight at 75 °C after 0.5 h of fixation at 105 °C. After cooling, the leaves and stems were weighed separately to calculate the leaf:stem ratio.

2.3.3. Yield and Quality

(1) Yield (kg·ha^{-1}): Each time the alfalfa was cut, 1 m^2 (1 × 1 m^2) quadrats with uniform growth were selected in each plot and cut 5 cm above the ground. They were baked to constant weight at 75 °C after 0.5 h of fixation at 105 °C. After cooling, the dry weight was used to calculate the hay yield.

(2) Quality: To determine the quality index, the dried sample was crushed for sieving (0.4 mm). The crude protein content (*CP*) [18] was determined using an automatic Kjeldahl apparatus (KjeltecTM8400), and the acid detergent fiber (*ADF*) and neutral detergent fiber (*NDF*) [23] contents were determined using a semi-automatic fiber analyzer (F800) based on the Van Soest method. The average value of three cuts was used to determine alfalfa quality.

Relative feeding value (*RFV*) [23] can be calculated through the following equations:

$$RFV = (DMI \times DDM)/1.29 \tag{1}$$

$$DMI = 120/NDF \tag{2}$$

$$DDM = 88.9–0.799 \times ADF \tag{3}$$

2.3.4. Water–Nitrogen Use Efficiency

Water use efficiency (*WUE*) can reflect the efficiency of water conversion into yield in the process of crop production. Nitrogen use efficiency is the ratio of nitrogen absorbed by crops, which can be used to reflect the utilization degree of nitrogen by crops. They are important indexes for judging agricultural production measures. In this study, we selected *WUE*, irrigation water use efficiency (*IWUE*), and precipitation use efficiency (*PUE*) [7] to evaluate water production effects, and partial factor productivity of nitrogen (*PFPN*) and agronomic nitrogen use efficiency (*ANUE*) [24] to evaluate the nitrogen production effects of different planting patterns and nitrogen levels.

(1) Soil moisture content: In the center of each plot, a 150 cm long time-domain reflectometry (time-domain reflectometry, TDR) probe tube was arranged between the alfalfa rows (Figure 1). Every 3–5 days, the PICO-BT TDR instrument (IMKO, Germany) was used to measure the moisture content of the 0–120 cm soil layer (at 20 cm intervals). Additional measurements were taken before and after irrigation and after precipitation, and the drying method was used on a regular basis for verification.

(2) Evapotranspiration (*ET*, mm): The water balance method was used for calculating *ET*.

$$ET = 10\sum_{i=1}^{n} \gamma_i H_i (\theta_{i1} - \theta_{i2}) + I + P + K - R - D \tag{4}$$

where i is the soil layer number; n is the total number of soil layers; γ_i is the dry bulk density of the ith layer of soil, g·cm^{-3}; H_i is the thickness of the ith layer of soil, cm; θ_{i1} and θ_{i2} refer to the initial and final soil moisture content of the ith layer, %, which is calculated by a percentage of dry soil mass; I is the irrigation amount, mm; P is precipitation, mm; K is groundwater recharge, mm; R is surface runoff, mm; and D is the deep leakage, mm. The surface of the test region was flat. Moreover, the buried depth of groundwater was deep with small single precipitation, so K, R, and D were ignored.

(3) *WUE* (kg·ha^{-1}·mm^{-1})

$$WUE = Y/ET \tag{5}$$

where Y is the yield of alfalfa, kg·ha^{-1}.

(4) *IWUE* (kg·ha^{-1}·mm^{-1})

$$IWUE = Y/I \tag{6}$$

(5) *PUE* (kg·ha^{-1}·mm^{-1})

$$PUE = Y/P \tag{7}$$

(6) *PFPN* (kg·kg^{-1})

$$PFPN = Y/F \tag{8}$$

where F is the nitrogen application rate, kg·ha^{-1}.

(7) *ANUE* (kg·kg^{-1})

$$ANUE = (Y_{NPK} – Y_{PK})/F \tag{9}$$

where Y_{NPK} is the annual yield of alfalfa with nitrogen application, kg·ha^{-1} and Y_{PK} is the annual yield of alfalfa without nitrogen application, kg·ha^{-1}.

2.3.5. *EB*

An economic analysis of alfalfa production was performed after harvest [25].

Total revenue (*TR*, Yuan·ha^{-1}) was calculated as:

$$TR = Y \times P \tag{10}$$

where P (Yuan·t^{-1}) is the price of alfalfa. The alfalfa price was 2500 Yuan·t^{-1} for the 2021 growing seasons.

Net return (*NR*, Yuan·ha^{-1}) was calculated as:

$$NR = TR - TC \tag{11}$$

where TC (Yuan·ha^{-1}) includes input cost and labor cost.

2.4. *Data Analysis*

Microsoft Excel 2019 (Microsoft Crop., Raymond, WA, USA) was used for data collation, Origin 9.0 software (Originlab Corp., Northampton, MA, USA) was used to draw graphs, and IBM SPSS Statistics 26 software (IBM Inc., New York, NY, USA) was used for variance analysis (two-way ANOVA), significance test, and multiple comparison (Duncan). The least significant difference (LSD) test at $p < 0.05$ was used to compare mean differences between treatments.

3. Results

3.1. *Effects of Planting Patterns and Nitrogen Levels on Alfalfa Growth*

3.1.1. Plant Height

Planting patterns and nitrogen levels were observed to have extremely significant effects on the plant height of three alfalfa cuts ($p < 0.01$), but there was no interaction effect between the two (Table 2). The overall plant height of alfalfa was in the following order: first cut > second cut > third cut (Figure 3). Under the same nitrogen level, the plant height of the RM pattern was higher than that of the FP pattern, with an average increase of 8.8%, 7.9%, 7.8%, and 7.1% under N0, N1, N2, and N3 conditions, respectively. Under the same planting pattern, the plant height was in the order of N2 > N3 > N1 > N0, with N2 higher than N0, N1, and N3 by 27.0%, 11.6%, and 6.4%, respectively. Overall, the plant height of RMN2 was the highest among all treatments, with an average increase of 6.7% to 37.5% compared with other treatments.

Table 2. Variance analysis of planting pattern and nitrogen level impact on the plant height, stem diameter, and leaf:stem ratio of alfalfa.

Factors	Plant Height			Stem Diameter			Leaf:Stem Ratio		
	First Cut	Second Cut	Third Cut	First Cut	Second Cut	Third Cut	First Cut	Second Cut	Third Cut
Planting pattern (P)	**	**	**	**	**	**	**	**	**
Nitrogen level (N)	**	**	**	**	**	**	**	**	**
P × N	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note: ** indicates an extremely significant difference ($p < 0.01$); ns indicates no significant difference ($p > 0.05$).

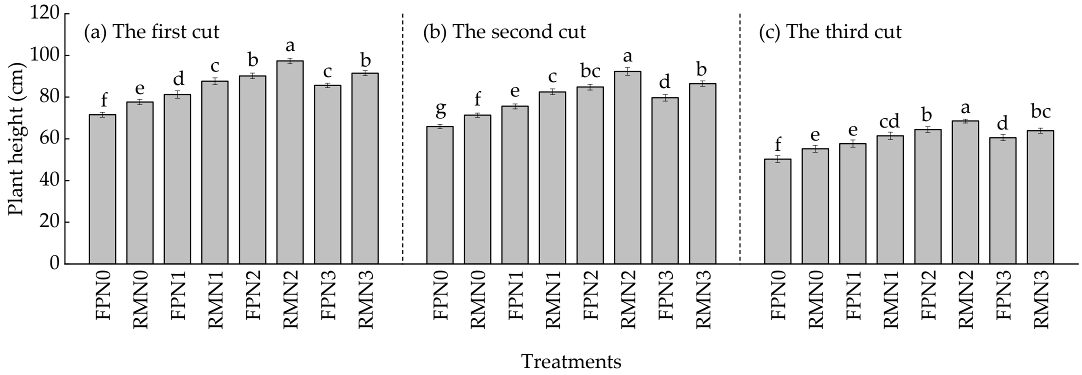

Figure 3. Impact of planting pattern and nitrogen level on the plant height of alfalfa. FP and RM refer to conventional flat planting and ridge culture with film mulching, respectively. N0, N1, N2, and N3 refer to nitrogen application rates of 0 kg·ha^{-1}, 80 kg·ha^{-1}, 160 kg·ha^{-1}, and 240 kg·ha^{-1}. Different lowercase letters indicate significant difference among treatments ($p < 0.05$).

3.1.2. Stem Diameter

Planting patterns and nitrogen levels also had extremely significant effects on the stem diameter of three alfalfa cuts ($p < 0.01$), but there was no interaction effect between the two (Table 2). Alfalfa stem diameter reduced as the number of cutting times increased (Figure 4). Under the same nitrogen level, the stem diameter of the RM pattern was larger than that of the FP pattern, with an average increase of 16.6%. Under the same planting pattern, the stem diameter first increased and then decreased as the nitrogen level increased, and there were notable variations between the four levels. Overall, the stem diameter of RMN2 was the largest among all treatments, with an average increase of 4.6% to 39.0% compared with the other treatments.

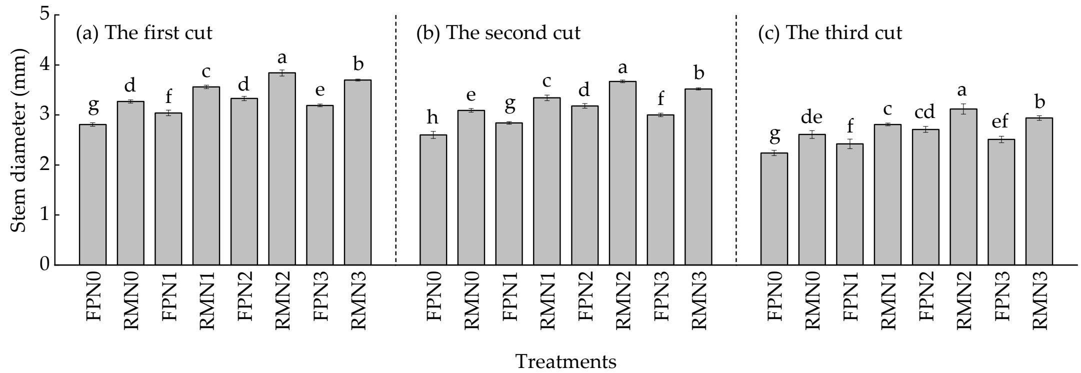

Figure 4. Impact of planting pattern and nitrogen level on the stem diameter of alfalfa. FP and RM refer to conventional flat planting and ridge culture with film mulching, respectively. N0, N1, N2, and N3 refer to nitrogen application rates of 0 kg·ha^{-1}, 80 kg·ha^{-1}, 160 kg·ha^{-1}, and 240 kg·ha^{-1}. Different lowercase letters indicate significant difference among treatments ($p < 0.05$).

3.1.3. Leaf:Stem Ratio

Similar to plant height and stem diameter, planting patterns and nitrogen levels had extremely significant effects on the leaf:stem ratio of three alfalfa cuts ($p < 0.01$), but once again there was no interaction effect between the two (Table 2). As illustrated in Figure 5, the leaf:stem ratios of the three alfalfa cuts were 0.85~1.05, 0.82~1.01, and 0.70~0.88, respectively. Under the same nitrogen level, the leaf:stem ratio of the RM pattern increased by 14.9% on average over that of the FP pattern. Under the same planting pattern, the leaf:stem ratio of alfalfa first increased and then decreased as the nitrogen level increased, with a peak under the N2 condition, which was 1.3% to 7.8% higher than the other three treatments. In all treatments, the leaf:stem ratio of RMN2 was the largest, with an average increase of 1.4% to 24.1% compared with other treatments.

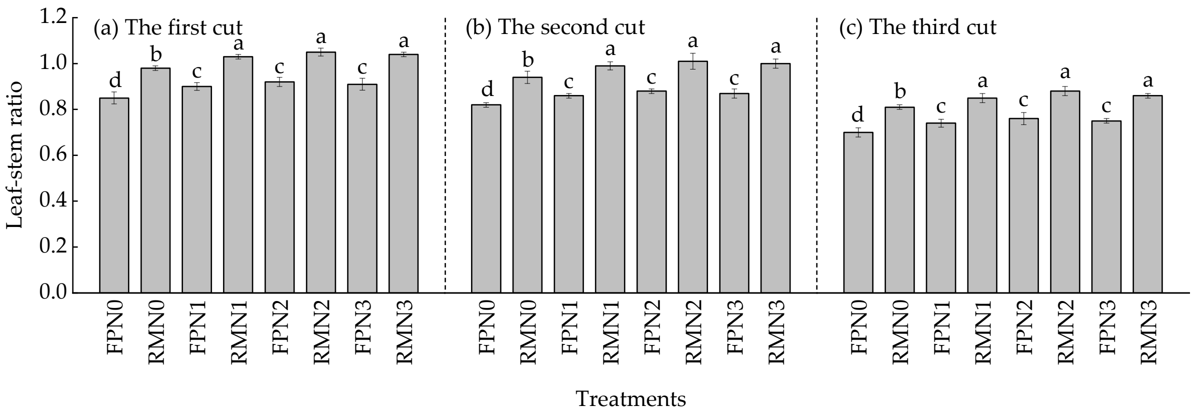

Figure 5. Impact of planting pattern and nitrogen level on the leaf:stem ratio of alfalfa. FP and RM refer to conventional flat planting and ridge culture with film mulching, respectively. N0, N1, N2, and N3 refer to nitrogen application rates of 0 kg·ha^{-1}, 80 kg·ha^{-1}, 160 kg·ha^{-1}, and 240 kg·ha^{-1}. Different lowercase letters indicate significant difference among treatments ($p < 0.05$).

3.2. Effects of Planting Pattern and Nitrogen Level on Alfalfa Yield and Quality

3.2.1. Yield

Planting patterns and nitrogen levels had extremely significant effects on the yield of the three alfalfa cuts, and their interaction had a large impact on the annual yield (Table 3). The yield of the three alfalfa cuts was in the following order: first cut > second cut > third cut (Figure 6), accounting for 35.2%, 33.0%, and 31.7% of the total yield, respectively. Under the same nitrogen level, the annual yield of the RM pattern was 43.3% higher than the FP pattern on average. Under the same planting pattern, the alfalfa yield first increased and then decreased as the nitrogen level increased, with a peak under the N2 condition. In terms of annual yield, N0, N1, and N3 decreased by 22.4~46.0%, 11.5~38.3%, and 5.6~33.9% compared with N2, respectively. In all treatments, the yield of each cut and the annual yield of RMN2 were the largest (22,668.0 kg·ha^{-1}).

Table 3. Variance analysis of planting pattern and nitrogen level impact on alfalfa yield.

Factors	First Cut	Second Cut	Third Cut	Yearly Yield
Planting pattern (P)	**	**	**	**
Nitrogen level (N)	**	**	**	**
P × N	ns	ns	ns	**

Note: ** indicates an extremely significant difference ($p < 0.01$); ns indicates no significant difference ($p > 0.05$).

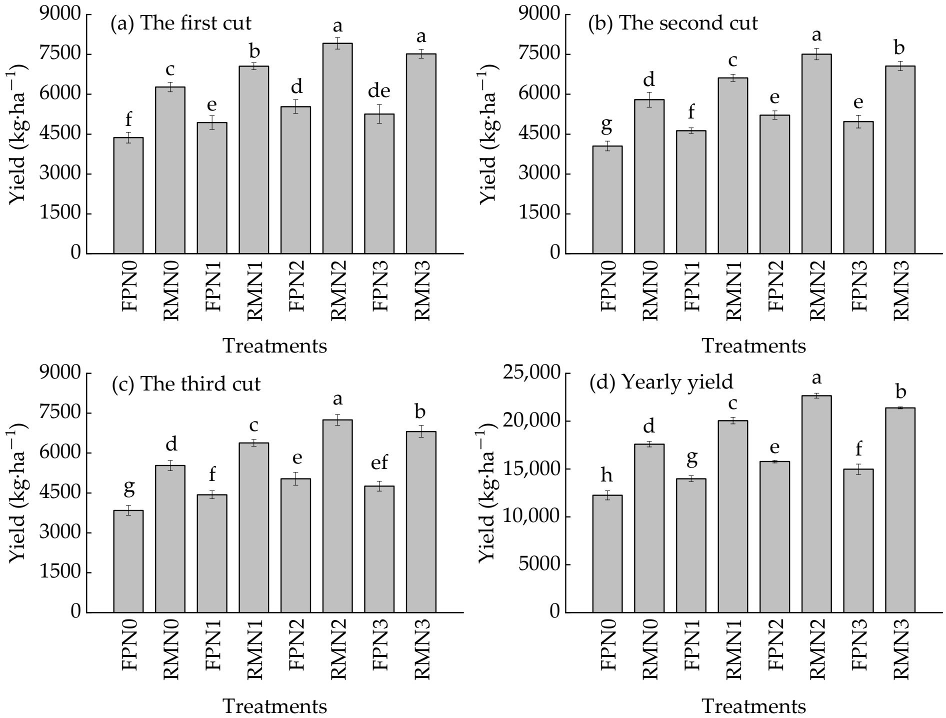

Figure 6. Impact of planting pattern and nitrogen level on alfalfa yield. FP and RM refer to conventional flat planting and ridge culture with film mulching, respectively. N0, N1, N2, and N3 refer to nitrogen application rates of 0 kg·ha^{-1}, 80 kg·ha^{-1}, 160 kg·ha^{-1}, and 240 kg·ha^{-1}. Different lowercase letters indicate significant difference among treatments ($p < 0.05$).

3.2.2. Quality

Planting patterns and nitrogen levels had extremely significant effects on the quality of the three alfalfa cuts, and their interaction only had a large impact on the NDF content and RFV (Table 4). Under the same nitrogen level, CP content and RFV were higher in the RM pattern than the FP pattern, while ADF and NDF contents were higher in the FP pattern than in the RM pattern. Moreover, compared to the FP pattern, the CP content and RFV of the RM pattern increased by 7.8~13.7% and 13.7~28.3%, respectively, while ADF and NDF contents decreased by 5.7~16.5% and 10.2~18.1%, respectively. Under the same planting pattern, the quality of alfalfa at the four nitrogen levels was significantly different. As the nitrogen level increased, CP content and RFV showed a trend of first increasing and then decreasing, while ADF and NDF contents showed a trend of first decreasing and then increasing; each quality index was better under the N2 condition. The quality indexes of the RMN2 treatment were higher than those of all other treatments. Specifically, CP content and RFV increased by 4.9~28.6% and 19.6~49.3%, while ADF and NDF contents decreased by 14.0~27.6% and 13.0~26.1%, respectively. Therefore, it can be concluded that the RM pattern with an appropriate nitrogen application rate can result in high CP content and RFV and low fiber content.

Table 4. Impact of planting pattern and nitrogen level on alfalfa quality.

Planting Pattern (P)	Nitrogen Level (N)	Crude Protein Content (CP, %)	Acid Detergent Fiber Content (ADF, %)	Neutral Detergent Fiber Content (NDF, %)	Relative Feeding Value (RFV)
Conventional flat planting (FP)	N0	18.2 ± 0.4 c	31.5 ± 0.8 a	47.1 ± 0.7 a	127.3 ± 0.5 e
	N1	19.8 ± 0.6 bc	29.2 ± 0.7 abc	45.4 ± 0.4 b	135.7 ± 1.5 d
	N2	21.7 ± 0.8 ab	27.3 ± 1.0 bc	42.5 ± 1.2 c	148.2 ± 4.5 c
	N3	20.5 ± 0.9 bc	28.6 ± 1.0 abc	45.0 ± 0.7 b	137.6 ± 0.6 d
Ridge culture with film mulching (RM)	N0	20.7 ± 1.1 bc	29.7 ± 1.7 ab	42.3 ± 0.9 c	144.8 ± 1.7 c
	N1	21.4 ± 1.4 ab	27.0 ± 2.6 bc	40.3 ± 1.1 d	156.5 ± 2.9 b
	N2	23.4 ± 2.6 a	22.8 ± 3.0 d	34.8 ± 0.6 e	190.1 ± 3.1 a
	N3	22.3 ± 1.9 ab	26.5 ± 0.5 c	40.0 ± 0.5 d	158.9 ± 1.0 b
P		**	**	**	**
N		*	**	**	**
P × N		ns	ns	*	**

Note: The data in the table are mean ± standard deviation. Different lowercase letters indicate significant difference among treatments ($p < 0.05$). ** indicates an extremely significant difference ($p < 0.01$); * indicates a significant difference ($p < 0.05$); ns indicates no significant difference ($p > 0.05$).

3.3. Effects of Planting Pattern and Nitrogen Level on the Water–Nitrogen Use Efficiency of Alfalfa

The planting patterns, nitrogen levels, and their interactions (other than ANUE) all had an extremely significant impact on the WUE, IWUE, PUE, PFPN, and ANUE of alfalfa (Table 5). Under the same nitrogen level, the WUE, IWUE, and PUE of the RM pattern were higher than the FP pattern, with an increase of 45.5%, 43.3%, and 43.2% on average, respectively. Overall, WUE, IWUE, and PUE first increased and then decreased as the nitrogen application rate increased, with maximum values under the N2 condition that were higher than other treatments by 4.3~23.2%, 5.8~28.9%, and 5.7~28.8%, respectively.

Table 5. Impact of planting pattern and nitrogen level on water–nitrogen use efficiency of alfalfa.

Planting Pattern (P)	Nitrogen Level (N)	WUE ($kg \cdot ha^{-1} \cdot mm^{-1}$)	IWUE ($kg \cdot ha^{-1} \cdot mm^{-1}$)	PUE ($kg \cdot ha^{-1} \cdot mm^{-1}$)	PFPN ($kg \cdot kg^{-1}$)	ANUE ($kg \cdot kg^{-1}$)
Conventional flat planting (FP)	N0	18.2 ± 0.7 g	33.3 ± 1.3 h	61.4 ± 2.4 h	-	-
	N1	20.6 ± 0.5 f	38.0 ± 0.8 g	70.1 ± 1.5 g	175.0 ± 3.9 b	21.7 ± 9.8 ab
	N2	22.4 ± 0.2 e	42.9 ± 0.4 e	79.0 ± 0.7 e	98.6 ± 0.8 d	22.0 ± 3.7 ab
	N3	21.6 ± 0.8 e	40.7 ± 1.5 f	75.0 ± 2.7 f	62.4 ± 2.2 f	11.4 ± 3.9 b
Ridge culture with film mulching (RM)	N0	26.6 ± 0.4 d	47.8 ± 0.7 d	88.1 ± 1.4 d	-	-
	N1	29.8 ± 0.5 c	54.5 ± 0.9 c	100.4 ± 1.7 c	250.7 ± 4.2 a	30.8 ± 7.4 a
	N2	32.8 ± 0.4 a	61.6 ± 0.7 a	113.5 ± 1.3 a	141.7 ± 1.6 c	31.7 ± 2.8 a
	N3	31.3 ± 0.1 b	58.1 ± 0.3 b	107.1 ± 0.5 b	89.1 ± 0.4 e	15.8 ± 1.4 b
P		**	**	**	**	*
N		**	**	**	**	**
P × N		*	**	**	**	ns

Note: The data in the table are mean ± standard deviation. Different lowercase letters indicate significant difference among treatments ($p < 0.05$). ** indicates an extremely significant difference ($p < 0.01$); * indicates a significant difference ($p < 0.05$); ns indicates no significant difference ($p > 0.05$).

The trend of ANUE and PFPN in alfalfa differed depending on the nitrogen application pattern. Under the same nitrogen application level, both PFPN and ANUE were higher in the RM pattern than the FP pattern, with an average increase of 43.3% and 41.5%, respectively. Under the same planting pattern, the PFPN of three alfalfa cuts was in the order of N1 > N2 > N3, with N1 increasing by 77.2% and 180.9% compared to N2 and N3, respectively. The ANUE was in the order of N2 > N1 > N3, with N2 increasing by 2.2% and 96.8% compared to N1 and N3, respectively.

3.4. Effects of Planting Pattern and Nitrogen Level on the EB of Alfalfa

The planting patterns and nitrogen levels significantly affected the EB of alfalfa (Table 6). Under the same nitrogen level, the net revenue of RM was larger than that of FP, with an average increase of 50.0%. Under the same planting pattern, the net revenue of alfalfa first increased and then decreased as the nitrogen level increased, with a peak under the N2 condition, which was 8.1~31.6% higher than the other three treatments. In all treatments, the net revenue of RMN2 was the largest, with an average increase of 8.1~97.4% compared with other treatments.

Table 6. Impact of planting pattern and nitrogen level on alfalfa economic benefits.

Factors		FP				RM			
		N0	**N1**	**N2**	**N3**	**N0**	**N1**	**N2**	**N3**
Total revenue (Yuan·ha^{-1})		30,644	34,993	39,455	37,457	43,983	50,144	56,670	53,489
Input cost (Yuan·ha^{-1})	Seed	530	530	530	530	530	530	530	530
	Urea	0	480	960	1440	0	480	960	1440
	Superphosphate	120	120	120	120	120	120	120	120
	Muriate of potash	382.5	382.5	382.5	382.5	382.5	382.5	382.5	382.5
	Rotary tillage	1500	1500	1500	1500	1500	1500	1500	1500
	Insecticide	850	850	850	850	850	850	850	850
	Mulching film	0	0	0	0	641	641	641	641
	Total input cost	3382.5	3862.5	4342.5	4822.5	4023.5	4503.5	4983.5	5463.5
Labor cost (Yuan·ha^{-1})	Weeding	1350	1350	1350	1350	900	900	900	900
	Mulching and residue removal	0	0	0	0	730	730	730	730
	Other (planting, fertilization, etc.)	1130	1130	1130	1130	1130	1130	1130	1130
	Total labor cost	2480	2480	2480	2480	2760	2760	2760	2760
Net revenue (Yuan·ha^{-1})		24,782 g	28,651 f	32,632 e	30,155 f	37,200 d	42,880 c	48,927 a	45,265 b

Note: Different lowercase letters indicate significant difference among treatments ($p < 0.05$).

4. Discussion

4.1. Proper Planting and Nitrogen Application Patterns to Promote Alfalfa Growth

The RM pattern can accumulate precipitation, particularly microprecipitation (<5 mm), by changing the underlying surface structure, regulating the distribution and redistribution of soil moisture, and raising the temperature of topsoil by increasing net surface radiation, thereby effectively improving soil water and heat conditions and promoting crop growth [26–28]. Jing et al. [29] conducted research in the alpine and semi-arid area of Tianzhu, Gansu Province, and discovered that the plant height of alfalfa treated with RM was 4.1% and 34.3% higher than that of film mulching parallel to the ground and ridge–furrow planting, respectively. Yang et al. [30] conducted research in the Guanzhong area of Shaanxi Province and discovered that when ridge culture with film mulching was used instead of flat planting without mulching, the plant height, stem diameter, and aboveground dry matter mass of summer maize were significantly improved. Zheng et al. [31] studied the semi-humid arid areas in northwest China and found that the aboveground dry matter accumulation of corn planted using ridge culture with film mulching increased by 9.4~49.1% over that of corn planted using flat planting without film mulching. Similarly, this study also found that the plant height, stem diameter, and leaf:stem ratio of alfalfa under the RM pattern increased by 7.9%, 16.6%, and 14.9% compared with the FP pattern, respectively. However, Li et al. [32] investigated the irrigation area of the northwest desert and found that the leaf:stem ratio of alfalfa planted with film mulching for 2, 3, and 4 years decreased by 5.8%, 13.4%, and 12.3% compared to those without film mulching, respectively. This may be related to alfalfa varieties, ridge formation, and planting years.

Nitrogen accounts for more than 40% of the main mineral elements required for plant growth [33]. Insufficient nitrogen addition can not give full play to its effect. Excessive addition will harm the soil microenvironment, impede nitrogen uptake, and possibly even cause environmental pollution [34]. Proper addition can fully enhance the growth potential of crops by adjusting nitrogen metabolism intensity and efficiency. The findings of this study demonstrated that the plant height, stem diameter, and leaf:stem ratio of alfalfa all increased and then decreased as the nitrogen application rate increased, with maximum values under the N2 condition. However, an investigation by Liu et al. [19] in Qinwangchuan, Lanzhou, revealed that nitrogen fertilizer significantly promoted the plant height of alfalfa, which increased with the application rate. This might be connected to the setting range of the nitrogen application rate. The maximum nitrogen application rate in the study by Liu et al. was 103.5 kg·ha^{-1}, between N1 and N2 in this study, and had not reached the threshold for excessive application. The research results of Lu et al. [35] in the coastal saline-alkali area illustrated that the plant height of alfalfa reached a maximum value when the nitrogen application rate was 225 kg·ha^{-1}. On the one hand, this may be related to the precipitation in the study area, where there was abundant rainfall with an average annual precipitation of up to 1000 mm, about 5 times the annual precipitation in the study area of this study. The nitrogen available in the soil and the nitrogen absorption capacity of alfalfa were both improved due to the high water content, which increased the threshold of nitrogen demand. On the other hand, it may be related to the basic nutrient status of the experimental field. The low basic nitrogen content of the soil in the experimental field in the study (0.72 g·kg^{-1}) made alfalfa growth more reliant on exogenous nitrogen, so the appropriate nitrogen addition was higher.

4.2. Proper Planting and Nitrogen Application Patterns to Promote Alfalfa Yield and Quality

Yield is the product of assimilated accumulation, and quality is the outcome of assimilated transformation between various forms. Both are essential for measuring crop production levels and the foundation of agricultural production measures [36]. The RM pattern effectively combines rainfall collection, moisture conservation, and temperature regulation, which assists plants in quickly establishing a reasonable canopy structure to make the most of available light and heat to enhance crop yield and quality [37]. Regression research by Yin et al. [38] revealed that the average alfalfa yield created by the RM pattern was nearly two times higher than that of the FP pattern. According to research by Kou et al. [39], RM could considerably boost the nutritional value of alfalfa, increasing the crude protein and crude fat contents by 29.8% and 9.3%, respectively, while decreasing the crude fiber content by 8.0% compared to flat planting without film mulching. The results of this study demonstrated that, in comparison to the FP pattern, the average yield, CP content, and RFV of alfalfa planted using the RM pattern increased by 43.3%, 9.6%, and 18.2%, respectively, while the average ADF and NDF contents decreased by 9.3% and 12.7%, respectively, which are consistent with previous research.

A proper nitrogen supply is a key factor in elevating crop yield and quality. Through meta-analysis, Yin et al. [40] investigated the impact of nitrogen addition on alfalfa yield and quality and discovered that the yield and CP content of alfalfa with nitrogen addition increased by an average of 12.6% and 7.3% compared to that without nitrogen addition, respectively, while ADF and NDF contents decreased by an average of 5.6% and 3.0%, respectively. The relationship between alfalfa yield and nitrogen application rate can be described by a downward parabola, according to research by Yin et al. [41] in the oasis irrigation region of Hexi. This study also found that as the nitrogen application rate increased, the yield, CP content, and RFV of alfalfa first increased and then decreased, while ADF and NDF contents first decreased and then increased, and all reached a better value under the N2 condition. However, research by Wen et al. [42] in the Hexi Corridor, Gansu Province, revealed that the CP content and ADF of alfalfa first increased and then decreased as the nitrogen application rate (0~120 kg·ha^{-1}) increased, while NDF increased. This may be due to the dose effect of nitrogen on alfalfa quality, which is closely related to the planting years. For instance, since the nitrogen fixation capacity of root nodules is weak in the year of establishment, the addition of nitrogen fertilizer can help meet the needs of plant growth, which is conducive to improving alfalfa quality. The nitrogen fixation capacity increases two years after establishment as alfalfa grows vigorously, reducing its reliance on exogenous nitrogen. As a result, excessive nitrogen fertilizer application will hinder alfalfa growth. Luo et al. [43] conducted research in the Loess Plateau region and discovered that the CP content of *Bromus inermis* L. increased while ADF and NDF contents decreased as the nitrogen application rate (0~160 kg·ha^{-1}) increased, which may be related to the smaller gradient of nitrogen application and the forage type. *Bromus inermis* L. is a gramineous forage that relies heavily on exogenous nitrogen, while alfalfa is a leguminous forage that can provide nitrogen through root nodule nitrogen fixation in addition to obtaining nitrogen from the soil.

4.3. Proper Planting and Nitrogen Application Patterns to Promote the Water–Nitrogen Use Efficiency of Alfalfa

The RM pattern can form a relatively closed water circulation system in farmland, effectively blocking vertical evaporation of soil moisture to the atmosphere and causing more soil water to move laterally. This significantly improves the soil water status of farmland, increases soil nutrient availability, and thus improves the water–nitrogen use efficiency of crops [44]. Wu et al. [45] found that the WUE of corn with mulch drip irrigation was significantly higher than that of straw-returning drip irrigation in the semi-arid areas of the Northeast Plain, and that the nitrogen absorption efficiency and yield stability of corn with film mulching were better. According to research by Mak et al. [46] in the northwest semi-arid areas, the WUE of alfalfa planted using the RM pattern was increased by 19.8% compared to the FP pattern. Similar to prior studies, this study concluded that the RM pattern could significantly improve the water–nitrogen use efficiency and net revenue of alfalfa. However, research by Ren et al. [47] in the arid and semi-arid areas of northwest China revealed that under conditions of 230 mm and 340 mm rainfall, the WUE of summer maize (*Zea mays* L.) planted using the RM pattern increased by 73.3% and 40.2% compared to the FP pattern, respectively, while under the condition of 440 mm rainfall, there was no significant difference between the two patterns. Based on this, it can be inferred that the effect of film mulching on WUE improvement is closely related to rainfall during the growth period of crops. The benefits of film mulching for crop growth cannot be fully appreciated with high rainfall or when rainfall distribution is highly consistent with water demand.

Proper nitrogen application can effectively promote nitrogen transport and absorption in plants, improve the contribution of plant nitrogen uptake to yield, reduce soil nitrogen leaching losses and volatilization, and form a good sink–source balance [20], and thus improve the water–nitrogen use efficiency of crops. According to research by Kamran et al. [48] in the Hexi Corridor, Gansu Province, the IWUE of alfalfa with a nitrogen application rate of 150 kg·ha^{-1} was 35.1% and 42.2% higher than that with a nitrogen application rate of 225 kg·ha^{-1} and 300 kg·ha^{-1}, respectively. According to research by Feng et al. [49] in the Hexi Corridor, as the nitrogen application rate (0~120 kg·ha^{-1}) increased, the WUE of alfalfa first increased and then decreased. Similarly, it was found in this study that, as the nitrogen application rate increased, the WUE, IWUE, PUE, ANUE, and EB of alfalfa first increased and then decreased, while PFPN decreased significantly. However, research by Hu et al. [24] in the Yellow River irrigation region, Ningxia, demonstrated that the WUE and IWUE of alfalfa decreased gradually with increasing trickle irrigation and decreasing nitrogen application rate, which might primarily be due to water–nitrogen coupling effects. When the water supply was low, the relatively high nitrogen application rate could not be fully absorbed by crops; when the water supply was high, the relatively low application rate could not meet the needs of crop growth. Similarly, in this study, due to the limited available water in the soil under the RM pattern, when the nitrogen application rate was 240 kg·ha^{-1}, water and nitrogen supplies were not coordinated. Therefore, a large amount of nitrogen in the soil could not be absorbed by plants, which limited yield and quality improvement and reduced the water–nitrogen use efficiency of alfalfa.

In addition, alfalfa is a perennial forage with a growth period of 7~10 years, among which the rapid growth period is 1~2 years after establishment and the prosperous growth period is 3~5 years after establishment, followed by the decline period [50]. There are differences in the nitrogen fixation capacity and nitrogen demand of alfalfa in different years, resulting in different requirements for exogenous nitrogen. In the practice of alfalfa production, nitrogen should be added according to the specific year so as to maximize the effect of nitrogen application. To improve the production level and EB of alfalfa, we should adopt not only appropriate planting patterns and timely addition of nitrogen but also cultivate high-efficiency alfalfa varieties, thus realizing high-quality production of alfalfa based on both environmental conditions and genetic characteristics.

5. Conclusions

(1) The growth of alfalfa could be greatly accelerated by the use of ridge culture with film mulching (RM) compared to conventional flat cropping (FP). Under the same planting pattern, the plant height, stem diameter, and leaf:stem ratio of alfalfa all first increased and then decreased as the nitrogen application rate increased. Moreover, the RMN2 treatment group had the highest plant height, stem diameter, and leaf:stem ratio, which were 6.7~37.5%, 4.6~39.0%, and 1.4~24.1% higher than other treatments, respectively.

(2) The yield and quality of alfalfa could be improved by the RM pattern in concert with a proper nitrogen application rate. When compared to other treatments, the RMN2 treatment increased the yield, CP content, and RFV of alfalfa by 5.9~84.9%, 4.9~28.6%, and 19.6~49.3%, respectively, while ADF and NDF contents decreased by 14.0~27.6% and 13.0~26.1%, respectively.

(3) The RM pattern had a better performance than the FP pattern in terms of WUE, IWUE, PUE, PFPN, ANUE, and EB. As the nitrogen application level increased, PFPN decreased, while the other five indexes first increased and then decreased, with the maximum under the N2 condition.

In conclusion, the yield, quality, water–nitrogen use efficiency, and EB of alfalfa exhibited exceptional performance in the RM pattern with a nitrogen application rate of 160 kg·ha^{-1}, which has been proven to be a suitable pattern for alfalfa planting in the year of establishment in the Yellow River irrigation region of Gansu Province, China.

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