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Evaluation of eight alfalfa varieties for their production, quality, and persistence on the Loess Plateau

Bo Han[1,2], Tianming Hu[1*], Peizhi Yang[1], Weize Sun[1]

[1]College of Animal Science and Technology, Northwest A&F University, Yangling, Shaanxi, 712100, China
[2]State Key Laboratory of Crop Stress Biology in Arid Areas, Yangling, Shaanxi, 712100, China

***Corresponding author: hutianming@126.com**

Abstract

Alfalfa (*Medicago sativa* L.) is a high quality perennial legume forage crop in Loess Plateau. This study examined the performance of two domestic and six foreign alfalfa varieties for their yield, quality and persistence on the Loess Plateau. The plant height, fresh-to-dry ratio, stem-to-leaf ratio, and yield were determined for eight consecutive years (2002–2009). The results showed that average plant height of Victoria and Zhongmu No. 1 was greatest, 72.16 and 70.81 cm, respectively; fresh-to-dry ratio of Haygrazer and Victoria was 7.04% and 4.2% respectively lower than the local variety Guanzhong; and stem-to-leaf ratio of Sandity and Guanzhong was relatively higher than other varieties. Average hay production of these alfalfa varieties varied substantially in different years. Haygrazer, Zhongmu No. 1 and Sandity showed 39%–46% higher yield than other varieties. Comprehensive evaluation via the subordinate function method indicated that Zhongmu No.1, Sandity, and Haygrazer had optimal production performance. In addition, these three cultivars showed better persistence and had the optimal duration of use 5–6 years or longer. We propose that these cultivars are suitable for large scale of cultivation on the Loess Plateau for higher yields, which will benefit the rapidly developing local animal husbandry as well as farmers.

Key words: Alfalfa; Loess Plateau; Persistence; Production.

Introduction

The Loess Plateau is the largest loess deposition area in the world. It is located in the north of central China (34°–40°N, 103°–114°S) and covers an area of approximately 640,000 km^2. The elevation is 1,000–1,600 m above sea level (asl), with a semi-arid climate. Annual rainfall is 400–600 mm in the majority of this plateau (Shu et al., 2006). Alfalfa (*Medicago sativa* L.), a widely grown perennial forage legume in the world, has a cultural history of more than 2,000 years on the Loess Plateau (Si, 1975; Min, 2004). Alfalfa is a forage crop of high nutritional value and has positive influences on soil fertility (Tucak et al., 2008). It is the primary species used for regional forage rotation and construction of cultivated grassland on the Loess Plateau. It prevents soil erosion, maintains land productivity and improves environmental quality, thus playing an important role in local ecological management and industrial livestock production (Yang, 2008). Due to the constant emphasis of re-establishing natural ecosystem and sustainable agriculture practice, the acreage of cultivated alfalfa has increased every year. Consequently, appropriate selection of alfalfa varieties has become the key to the successful construction of cultivated grasslands. A diversity of alfalfa varieties have been used on the Loess Plateau, many of which were imported from other countries or introduced from other areas. Therefore, a thorough assessment of their performance on the Loess Plateau is needed in order to identify ones that can be used to achieve the highest yield on the grassland. The above ground biomass production of alfalfa is determined by many characteristics. Among them, persistence of productivity of alfalfa has long been an important topic of relevant research since the production of rotated alfalfa is strongly affected by its age (Kalu and Fick, 1983; Bi et al., 2002). Very limited studies have investigated the introduced alfalfa varieties regarding their duration of use and productivity on the Loess Plateau, leading to certain risks of the development of local alfalfa industry (Davis and Buker, 1966). Several studies have been conducted recently and identified six varieties from 22 introduced varieties in the initial screening based on the production performance (Yang, 2003; Wang, 2005; Zheng, 2005; Niu et al., 2006; Jia et al., 2007). This study examined the production of six introduced alfalfa varieties on the Loess Plateau during an 8-year period, with local variety Guanzhong and domestic-bred superior variety Zhongmu No.1 as control. The aim of this project was to screen for alfalfa varieties with good persistence on the Loess Plateau and provide additional information on these varieties. We hope these new varieties will benefit rapid development of regional livestock industry and can be used for breeding better alfalfa cultivars for this region.

Results

Plant height

From 2002-2009, plant height of alfalfa varieties generally increased first and then decreased with their ages (Table 1 and 3). During the 8-year study period, no consistent differences in plant height were observed between the introduced varieties and Zhongmu No.1. Significant difference in plant height was observed in some specific years. Alfalfa 54 and Derby were both significantly shorter in 2003 and 2004 compared to the domestically-bred Zhongmu

Table 1. Plant heights of eight alfalfa varieties in 2002–2009 (cm).

Variety	Year							
	2002	2003	2004	2005	2006	2007	2008	2009
Haygrazer	65.95±2.35a	75.94±1.72a	76.16±1.13bc	81.60 ±1.95a	75.94± 1.75b	78.10±1.65a	50.58 ±2.09d	52.37±2.02ab
Alfalfa 54	67.39±0.93a	69.54±1.08c	76.82± 1.05bc	80.55±1.58ab	76.74±1.58b	68.73 ±1.92c	56.39±2.05bc	50.74±2.30ab
Derby	67.98±1.66a	73.23±1.17ab	73.57 ±1.12c	75.01± 1.28c	74.63 ±1.90b	64.44 ±1.33d	53.65± 2.1cd	51.27 ±2.10ab
Affinity	65.03 ±2.82a	70.14±1.23bc	76.98 ±1.73bc	78.59 ±1.8abc	80.51±1.97a	68.46± 1.86c	53.97± 1.72cd	49.86 ±2.01ab
Victoria	66.59±3.43a	75.11±1.14a	79.58±1.74ab	81.84± 1.78a	82.48± 1.53a	73.07 ±1.78b	59.37± 1.9b	55.34 ±2.05a
Sandity	60.36± 5.54a	70.79 ±1.80bc	80.79± 1.45a	80.61±1.47ab	80.28±1.11a	70.40±1.95bc	53.06± 2.05cd	52.24± 2.20ab
Zhongmu No.1	70.61 ±1.67a	73.06± 1.39ab	79.95 ±2.02ab	76.81 ±1.69bc	82.26±1.80a	69.76± 1.87bc	64.24 ±2.09a	50.49 ±2.05ab
Guanzhong	51.08 ±6.70b	59.37 ±1.69d	61.74 ±1.21d	63.38 ±2.10d	65.49 ±1.79c	60.94± 2.20e	49.57 ±2.12d	46.87±1.95b

The values in the same column with different letters are significantly different with the LSD test (p<0.05).

Table 2. Yields of eight alfalfa varieties in 2002–2009 (t/ha).

	Dry matter yield in different years (t/ha)							
variety	2002	2003	2004	2005	2006	2007	2008	2009
Haygrazer	14.53±0.35ab	30.77±1.19a	34.50±0.82a	33.70±0.95a	32.23±1.17a	23.43±0.83a	12.89±0.90ef	10.50±0.96d
Alfalfa 54	14.13±0.57ab	26.57±1.70bc	29.13±1.12b	29.33±1.36bcd	27.53±1.15b	15.60±1.65de	12.30±0.56f	9.78±0.45d
Derby	10.97±0.71c	21.50±0.79d	26.27±0.47c	27.63±1.12d	23.70±1.91bc	19.40±1.37bc	15.63±0.25cd	13.80±0.95bc
Affinity	11.80±0.95c	23.40±0.90cd	29.33±1.17b	32.07±1.17abc	24.43±1.14bc	13.50±0.96e	14.67±0.50cde	12.87±0.55c
Victoria	15.10±0.20a	23.36±1.46cd	26.27±0.47c	28.60±0.70cd	24.53±1.58bc	18.33±1.63cd	15.80±0.56c	15.00±0.30b
Sandity	11.53±0.67c	27.27±0.57b	30.57±1.00b	32.40±1.65ab	26.83±1.45bc	22.57±0.96ab	20.70±0.95b	19.43±0.61a
Zhongmu No.1	12.90±1.17bc	24.23±1.17bcd	30.76±0.61b	30.60±1.67abcd	26.60±1.32bc	24.40±0.75a	22.80±0.70a	21.10±0.56a
Guanzhong	8.19±0.66d	17.73±1.04e	22.50±0.66d	23.53±1.06e	23.53±0.97c	17.37±0.56cd	13.70±1.05def	9.65±0.90d

The values in the same column with different letters are significantly different with the LSD test (p<0.05).

Table 3. Average yield and plant height of eight varieties analyzed by Two-way AVONA .

Year	2002	2003	2004	2005	2006	2007	2008	2009
Plant height (cm)	66.9±5.1c	70.9±5.1b	75.6±5.9a	77.2±5.9a	77.2±5.5a	69.2±5.3b	55.1±4.9d	51.2±2.9e
Yield (t)	12.4±2.3h	24.4±3.9d	28.7±3.5b	29.7±3.3a	26.2±3.0c	19.3±3.8e	16.1±3.7f	14.0±4.2g

Mean values in the same row followed by different letters are significantly different ($p < 0.05$).

No. 1 (P< 0.05); Haygrazer and Victoria were significantly taller in 2005 (P<0.05); Haygrazer, Alfalfa 54 and Derby were 7.7, 6.7, and 9.3%, respectively, shorter in 2006; In 2007, Haygrazer was 12% taller and Derby was 7.6% shorter compared to Zhongmu No. 1. The plant height of all introduced varieties was significantly less than that of Zhongmu No.1 in 2008. In contrast, all introduced varieties were substantially taller than the local variety Guanzhong during the 8-year study period, except for in 2009 (P<0.05).

Yield

Of the eight alfalfa varieties, annual production of Zhongmu No.1, Haygrazer and Sandity were greatest, averaging 24.18, 24.06, and 23.91 t/ha, respectively. By comparison, Guanzhong had the lowest production, averaging 17.03 t/ha (Table 4). The hay production of eight alfalfa varieties showed a similar trend during the eight-year cultivation period (Fig 1). The yield was very low in the first year (2002) and substantially increased in the second year (2003), and generally peaked in the 3rd and 4th years (2004–2005). The hay production decreased rapidly with their ages from year 6 to year 8. In particular, the hay production of Affinity dropped to the lowest (13.50 t/ha) in year 6 (2007) and stayed at the low level thereafter. While the yield was decreasing in year 6 (2007), Haygrazer, Sandity and Zhongmu No.1 showed the highest yield among the eight varieties. However, Haygrazer showed a nearly 50% decrease in yield in year 7 and decreased further in year 8. In contrast, Sandity and Zhongmu No.1 only decreased yield slightly in year 7 and 8, producing the greatest amount compared to other cultivars in 2008 and 2009(Table 2). These data indicated that the optimal duration of alfalfa use was about 5–6 years. Statistical analysis showed that with the same ecological factors such as precipitation, temperature and soil, the average hay production of eight alfalfa varieties (Y, t/ha) and the growth year (t) had a quadratic regression relationship: $Y = -1.2398t^2 + 10.285t + 6.4343$ ($R^2 = 0.8398$), where t is 1 to 8 years. When t = 4.15, Y has its maximum value, 27.76 t/ha.

Shoot fresh weight-to-dry weight ratio (fresh-to-dry ratio)

In 2002 and 2003, fresh-to-dry ratio of eight alfalfa varieties was relatively high (Table 5), largely due to the young plants with low dry matter accumulation at the early growth stages. During this period, the plants had a good palatability, thus were suitable for fresh feed or grazing. From 2004 to 2007, plants accumulated more dry matters and fresh-to-dry ratio decreased with growth years or their ages, resulting in a relatively high hay production. However, 2008-2009, the fresh-to-dry ratio increased again. Of the eight varieties, Zhongmu No.1, Guanzhong and Alfalfa 54 had relatively higher fresh-to-dry ratios, indicating that these varieties had a good palatability and were suitable for fresh feed. In contrast, Derby, Victoria and Haygrazer had lower fresh-to-dry ratios, suggesting that these varieties were suitable for modulation of green hay which could be used for livestock as winter reserves.

Stem-to-leaf ratio

The stem-to-leaf ratio of different alfalfa varieties varied with their ages (Table 6). Stem-to-leaf ratios were relatively low in 2002 and 2003, as the alfalfa plants were still establishing the stands, with tender quality and high leaf yield. With the increase in ages, the stem-to-leaf ratios of six introduced varieties increased, reaching the maximum in 2004 and 2005.

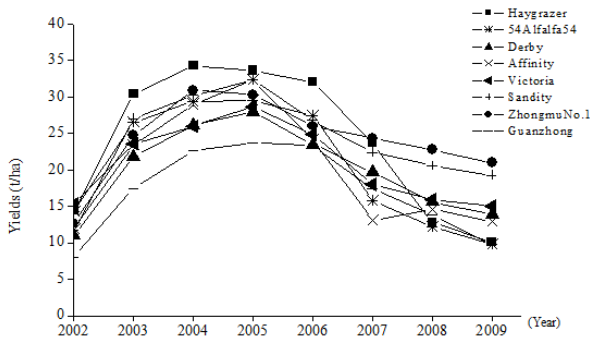

Fig 1. Hay yield of eight alfalfa varieties in different years.

This is corresponding to the two years of the highest hay production. Of these six cultivars, Haygrazer had the highest stem-to-leaf ratio, corresponding to the highest hay production. In the following years, the stem-to-leaf ratio generally decreased slightly then maintained at relatively constant levels. Sandity and Guanzhong showed a great increase in stem-to-leaf ratio during year 2008 and 2009, reaching the greatest stem-to-leaf ratios. Of all seven introduced alfalfa varieties, Alfalfa 54, Victoria and Zhongmu No.1 had relatively constant low stem-to-leaf ratios, suggesting that these three varieties had good feeding qualities due to higher leaf yields and thus protein content.

Comprehensive evaluation

Of the eight alfalfa varieties, Zhongmu No.1 had the highest comprehensive assessment value of 0.75, followed by Sandity, Haygrazer, and Alfalfa 54 with value of 0.65, 0.51, and 0.50 respectively. The comprehensive assessment value of the local variety Guanzhong was lowest (0.30) (Table 7). These data indicated that Zhongmu No.1 is the best for large-scale cultivation on the Loess Plateau. In addition, several introduced varieties are superior to the local variety Guanzhong and can potentially be used for large-scale production on the Loess Plateau. In particular, Sandity and Haygrazer showed not only high production but also good quality of hay.

Discussion

Plant height is one of the main indicators that reflect the status of pasture growth and is positively correlated with production or yield in alfalfa (Frakes et al., 1961; Liang and Riedl 1964; Davis and Buker 1966). Thus, plant height has been used to predict hay production during alfalfa cultivation and breeding. The present study showed that plant heights of alfalfa significantly varied in different years, with no substantial differences among 7 of the 8 varieties examined with an exception of the local variety Guanzhong. These were consistent with previous findings by Kang et al. (2010). Nevertheless, this present study showed again that greater production was achieved from several alfalfa varieties with greater plant height including Zhongmu No.1 and Haygrazer. One exception was Victoria which was one of the taller varieties but without showing advantage of higher yield. This is possibly due to some of the inferior features such as lodging associated with taller plants. The ratios of fresh-to-dry and stem-to-leaf are the primary indicators that have been used for assessment of alfalfa quality (Chacon and

Table 4. Average yield and plant height of each variety during eight years analyzed by Two-way AVONA.

variety	Haygrazer	Alfalfa 54	Derby	Affinity	Victoria	Sandity	Zhongmu No.1	Guanzhong
Plant heights(cm)	69.7±11.6bc	68.4±9.9c	66.5±9.2d	68.3±10.9cd	72.2±9.7a	69.3±11.3bc	70.8±9.7ab	58.0±6.8e
Yield (t)	24.1±9.6a	20.6±8.0bc	19.9±5.8c	20.3±7.7bc	20.9±5.3b	23.9±6.5a	24.2±5.5a	17.0±5.9d

Mean values in the same row followed by different letters are significantly different ($p < 0.05$).

Table 5. Fresh-to-dry ratios of eight alfalfa varieties in 2002–2009.

Variety	Year								Average
	2002	2003	2004	2005	2006	2007	2008	2009	
Haygrazer	4.15b	4.16cd	3.90abc	3.78a	3.50b	3.54a	4.41d	4.23d	3.96
Alfalfa 54	4.21ab	4.44bcd	4.00ab	3.86a	3.63ab	3.27a	5.92a	4.68c	4.25
Derby	4.06b	4.99a	3.57c	3.85a	3.78ab	3.53a	4.86c	4.06d	4.09
Affinity	4.29ab	4.11d	3.80abc	4.12a	3.90ab	3.70a	5.01c	4.37cd	4.16
Victoria	4.14b	4.65ab	3.90abc	3.78a	3.59ab	3.64a	4.24d	4.73bc	4.08
Sandity	4.56a	4.62ab	4.13a	3.80a	3.63ab	3.81a	4.44d	4.15d	4.14
Zhongmu No.1	4.12b	4.51bc	3.74abc	4.10a	3.64ab	3.95a	5.41b	5.25a	4.34
Guanzhong	4.01b	4.62ab	3.70bc	3.86a	4.04a	3.75a	4.97c	5.14ab	4.26
Average	4.19	4.51	3.84	3.89	3.71	3.64	4.91	4.58	

Values were assigned as mean (one-way ANOVA and Fisher's LSD test at $P < 0.05$)

Table 6. Stem-to-leaf ratio of eight alfalfa varieties in 2002–2009

Variety	Year								Average
	2002	2003	2004	2005	2006	2007	2008	2009	
Haygrazer	0.69a	1.11a	1.60a	1.02a	1.26a	1.17a	1.24ab	1.28abc	1.17
Alfalfa 54	0.78a	1.22a	1.50a	1.27a	0.98a	1.04a	0.99b	1.15c	1.12
Derby	0.75a	1.04a	1.40a	1.21a	1.15a	1.25a	1.13ab	1.32abc	1.16
Affinity	0.66a	1.11a	1.28a	1.45a	1.29a	1.21a	1.25ab	1.37abc	1.20
Victoria	0.66a	1.02a	1.48a	1.17a	1.19a	1.08a	1.14ab	1.23bc	1.12
Sandity	0.68a	1.27a	1.35a	1.42a	1.31a	1.25a	1.55a	1.69a	1.32
Zhongmu No.1	0.65a	1.21a	1.25a	1.14a	1.04a	1.15a	1.23ab	1.39abc	1.13
Guanzhong	0.75a	1.45a	1.40a	1.05a	1.13a	1.01a	1.54a	1.67ab	1.25
Average	0.70	1.18	1.41	1.22	1.17	1.15	1.26	1.39	

Values were assigned as mean (one-way ANOVA and Fisher's LSD test at $P < 0.05$).

Table 7. Subordinate function and comprehensive evaluation values of eight alfalfa varieties.

Variety	Subordinate function values					Order
	Plant height	Fresh-to-dry ratio	Stem-to-leaf ratio	Dry matter yield	Comprehensive evaluation	
Haygrazer	0.854 5	0.000 0	0.304 3	0.977 1	0.514 2	3
Alfalfa 54	0.769 5	0.767 4	0.000 0	0.510 2	0.503 6	4
Derby	0.655 3	0.338 0	0.347 8	0.416 0	0.418 3	5
Affinity	0.740 3	0.534 6	0.434 8	0.447 8	0.399 2	6
Victoria	1.000 0	0.327 7	0.058 0	0.553 6	0.387 7	7
Sandity	0.781 4	0.482 2	1.000 0	0.959 4	0.654 3	2
Zhongmu No.1	0.946 4	1.000 0	0.209 9	1.000 0	0.751 3	1
Guanzhong	0.000 0	0.793 7	0.847 5	0.000 0	0.304 2	8

Table 8. The origin of eight tested alfalfa varieties.

Code	Alfalfa variety	Origin
1	Haygrazer	Canada
2	54 Alfalfa 54	Netherlands
3	Derby	Netherlands
4	Affinity	USA
5	Victoria	USA
6	Sandity	Netherlands
7	Zhongmu No.1	China
8	Guanzhong	China

Stobbs, 1976; Chacon et al., 1978; Forbes and Coleman, 1993; Rotili et al., 2001). The fresh-to-dry ratio reflects the degree of forage dry matter accumulation, which directly affects the forage production and quality. It is not only an important indicator for forage palatability assessment, but also a theoretical basis for estimating sun-dried hay or silage production (Smart et al., 2001; Tremblay et al., 2002). The varieties with high fresh-to-dry ratio have poor performance for producing sun-dried hay and are suitable for fresh feed, whereas under the same conditions, those with low fresh-to-dry ratio have excellent performance for producing sun-dried hay and can produce a high yield with high nutrient contents. As crude protein content is 1–2.5 times higher and crude fiber content is 50%–100% lower in leaves than stems, the varieties with lower stem-to-leaf ratio have good palatability and quality (Li and Yan, 1997). Therefore, a large amount of leaves in the forage indicates its good quality and the stem-to-leaf ratio directly reflects the nutritional value of the forage. Our results showed that Zhongmu No.1 and Alfalfa 54 have higher fresh-to-dry ratio and low stem-to-leaf ratio, suggesting that these two varieties are suitable for harvesting fresh for high yield and high protein content. However, Wang et al. (2002) showed that the production performance of Zhongmu No.1 was not so good as introduced alfalfa varieties in Zhengzhou of Henan. The difference could be related to the variations in the soil conditions and climate in different regions. This study showed that several introduced alfalfa varieties had better growth performance on the Loess Plateau and flowered at similar time, compared to the local variety Guanzhong. Currently, a large effort has been made for effective screening and comprehensive evaluation of the production performance of introduced alfalfa varieties as one of the priorities in alfalfa research and breeding (Han et al., 2003). As alfalfa is a directly-applicable perennial feed crop, the evaluation of its production performance could be misleading if only focusing on a single trait. For example, this study showed that Victoria and Zhongmu No.1 were significantly taller than other plants, thus should be preferentially selected when using plant height as the sole evaluation indicator, whereas Haygrazer should be preferentially selected when using yield as the sole evaluation indicator, and Alfalfa 54 and Zhongmu No.1 preferentially selected when using fresh-to-dry ratio and stem-to-leaf ratio as the evaluation indicators. However, when we used the subordinate function for a comprehensive evaluation, it is clear that Zhongmu No.1, Sandity and Haygrazer are the best varieties among the eight examined for cultivation on the Loess Plateau. Most alfalfa varieties are more productive in the 3rd or 4th growth year during the cultivation cycle (Qiao, 1990), and some can sustain a high yield for up to 7 years and even longer (Yan et al., 2001; Sun et al., 2004). Zhongmu No.1 and Sandity showed reasonable yield even in year 7 and 8. Since the present study was conducted under no fertilizer conditions, the duration of use of these alfalfa varieties may be extended for more years via top-dressing and irrigation, but associated cost-effect needs to be further studied.

Materials and methods

Study area description

This study was conducted in Yangling District (108°10E', 34º21'N), Shaanxi Province, China. The study area is located on the Loess Plateau in a semi-humid climate zone. The elevation is 454.8 m above sea level. Average annual sunshine is 2150 h. Average annual temperature is 12–14°C, with the highest temperature of 39–40°C and the lowest temperature of -21– -15°C. Average annual precipitation is 621.6 mm, mainly concentrated in summer months (July, August, and September), with less rainfall in spring. The soil layer is thick, containing 15.0 g/kg organic matter, 56 mg/kg total nitrogen, ≥3.4 mg/kg phosphorus and 165 mg/kg available potassium (pH = 8.26).

Test materials

A total of eight alfalfa varieties were tested in this study, including six imported varieties that were selected based on a preliminary screening for high yield and quality, and one domestically-bred variety (Zhongmu No.1) and one local variety (Guanzhong) (Table 8).

Experimental design

Alfalfa varieties were arranged in random blocks (2 m × 5 m) in triplicate during 2002–2009. Manual ditching and seedling in line were performed on March 31, 2002, with a seeding rate of 0.015 t/ha, sowing depth of 2 cm, row spacing of 30 cm, and 7 rows per block. Irrigation was performed once a year in the reviving period. No fertilization was used throughout the entire growth period, with only simple pesticide spraying for pest control when necessary and timely weeding. Mowing was performed at the early flowering stage for 3 times in the first growth year (2002) and 4 times in the remaining years.

Analytical methods

Plant height measurement

Prior to each mowing, plant heights were measured from 10 plants of each alfalfa variety (in triplicate) to obtain an average value (n = 30).

Fresh weight-to-dry weight ratio and stem-to-leaf ratio

One kilogram of plant samples were randomly collected from each variety before the first mowing in each year. The stems and leaves were separated and air-dried to constant weight, then measured and calculated for fresh weight-to-dry weight ratio and stem-to-leaf ratio (Davis and Buker, 1966).

Hay production

Before each mowing, the production of each alfalfa variety was measured for 1 m^2 of plots in triplicate, then converted to the production of fresh forage per ha. The data were used to calculate the fresh weight-to-dry weight ratio after the fresh materials were dried. Total hay production was considered to be the sum of the production of each alfalfa rotation.

Data analysis

Standard data processing

The subordinate function value of each indicator was calculated for different alfalfa varieties using the formula (1)

$$\mu(X_j) = \frac{X_j - X_{min}}{X_{max} - X_{min}} \quad j=1,2,\ldots\ldots,n \qquad (1)$$

where X_j is the value of the jth comprehensive indicator, X_{min} is the minimum of the jth comprehensive indicator, and X_{max} is the maximum of the jth comprehensive indicator.

Determination of the weight

According to the contribution rates of comprehensive indicators, their weights W_j were calculated using the formula (2):

$$W_j = P_j \sum_{j=1}^{n} P_j \quad j=1,2,\ldots\ldots,n \qquad (2)$$

Where; W_j is the degree of importance of the jth comprehensive indicator to all indicators; p_j is the contribution rate of the jth comprehensive indicator of the alfalfa variety (strain).

Calculation of the comprehensive evaluation value

The comprehensive evaluation values of alfalfa varieties were calculated using the formula (3):

$$D = \sum_{j=1}^{n} [u(xj) \bullet Wj] \quad j=1,2,\ldots\ldots,n \qquad (3)$$

Data were analyzed using SPASS 17.0 and Origin 8.0 software. Values were presented as mean ± SE, and significant differences between mean values were analyzed by one-way and two-way analysis of variance (ANOVA) procedures. Fisher's least significant difference ($P<0.05$, LSD test) was performed to determine the significance of different treatments.

Conclusions

This study evaluated the production performance of two domestic and six foreign alfalfa varieties. Three alfalfa varieties with high production and good persistence were identified, including Zhongmu No.1, Sandity, and Haygrazer. The production of these three alfalfa varieties were 48.2%, 39.2% and 38.6% respectively higher than that of the local variety Guanzhong. Our field observation indicated that the 4th growth year is the peak production period, and the optimal duration of use is 5–6 years for these varieties. We expect that a large scale cultivation of these varieties on the Loess Plateau will lead to higher production of alfalfa and an improvement of income of local farmers. These varieties will also become excellent materials for alfalfa breeding and research in this region.

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