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Full Length Research Paper

Variation of productivity and nutritive values of oat (*Avena sativa*) with geographical locations in Gansu Province of Northwest China under irrigation and fertilization conditions

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Field experiments were conducted in low, medium and high sites; Jingqianghe, Huangzangsi and Lanzhou areas of Gansu Province, China from 2000 to 2001 to investigate the effects of geographical locations on herbage dry matter (DM) yield and nutritive values of oat. It was found that the plant growing in Jingqianghe area yielded the highest forages (16046.0 DM/hm2) at high accumulation rate (300 kg ha-1d-1) and within long growing season (120 d), the plant growing in Huazangsi area produced medium quantity of forages (13020.3 DM/hm2) at low accumulation rate (200 kg ha-1d-1) but within long growing season (120 d), and the plant growing in Lanzhou area had the lowest forage yield (12505.7 kg DM/hm2) at relatively high accumulation rate (270 kg ha- 1d-1) but within extremely short growing season (50 d). The highest seed production of 3789.3 kg DM/hm2 annually was observed in Huangzangsi area, the lowest seed production of 933.7 kg DM/hm2 annually was found in Jingqianghe area, and the medium seed production of 1632.7 kg DM/hm2 annually was recorded in Lanzhou area. The plant growing in high site of Jinqianghe area concentrated more ($P < 0.05$) crude fat than that growing in low site of Lanzhou area, and no significant difference in organic matter (OM), crude protein (CP) and crude fibre (CF) concentrations of the plant was observed among different growing sites. No significant difference ($P > 0.05$) in in sacco degradability (ISD) of the plant among different growing sites was observed in the whole growing season. It was concluded from this study forage production should be conducted in high site of Jingqianghe area and seed production of oat should be conducted in low site of Lanzhou area with enough water and fertilizer supply.

Key words: oat (*Avena sativa*), air temperature, solar radiation, forage production and quality.

INTRODUCTION

Oat (*Avena sativa*) is extensively planted as the fodder crop in the vast ranges of northern and northwestern China, especially in the alpine regions such as the Qinghai-Tibetan Plateau (Ma and Han, 2000). Oat is usually harvested as hay and fed as the supplementary feed for the grazing livestock when the animals suffer from inadequate feeds in the long, harsh cold season under the traditional farming system in China (Long and Ma, 1996). Many researchers (Wen et al., 1993; Long et al., 1999) have reported that supplements of oat hay can elicit a response in terms of reduced weight loss, increased growth and milk yield of grazing livestock in cold season.

As one of important feed resources, oat has been extensively studied by Chinese agronomists and nutritionists in the past decades. Some researchers have studied the introduction and selection of oat varieties, watering, fertilizing and harvesting management on oat crop, and supplementary strategies of oat hay for grazing livestock on the basis of forage yield and nutritive value

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analysis (Dong et al., 2001; Long and Ma, 1996). However, the studies concerning the effect of geographical location on productivity and nutritive values of oat are still scarce.

According to Buxton's opinion (1996), herbage maturity influences forage quality and yield more than other single factor, but plant environment and agronomic factors modify the impact of herbage maturity on forage quality and yield and geographical location effects on forage quality even when harvested at the same stage of development. The days to maturity, plant height, growth rate and plant vigour varied with different management practices and environmental situation (Assefa and Ledin, 2001). Assessing the forage production and feeding values of oat in different geographical sites is an important precondition to find the target place for oat cultivation. The present study was thus undertaken to meet this objective by concentrating three locations within different climatic zones in Northwest China.

MATERIALS AND METHODS

Trial sites

The study was conducted from the year of 2000 to 2001 at three geographical locations of Gansu Province, Northwest China, that is, Lanzhou, the low site with arid and temperate climate; Huanzangsi, the middle site with semi-arid and subalpine climate; and Jingqianghe, the high sie with semi-arid and alpine climate. The detailed descriptions for the environment of these three sites are presented in Table 1. The dominant farming systems in these areas are crop farming, crop-pastoral mixture farming and pastoral farm-ing for Lazhou, Huangzangsi and Jingqianghe areas, respectively.

Experimental design

12 plots (2 × 5 m) were randomly established for the oat crop which was treated with different harvest time, i.e., elongating, blooming, heading and fruiting periods of plant growth stage, with 3 replicates for each treatment. The seed rate of oat at three sites was 225 kg/hm2, and soil nutrients and water content were kept at the same level at different sites by monitoring and supplying fertilizer and water according to their supply and requirement balance. All the plots were fenced to protect from grazing and treading of livestock and wild animals.

Measurements

The swards were cut by using hand-held shears to a 2 cm stubble height from a 50 cm × 50 cm quadrates (3 replicates per plot) and weighed according to the method recommended by Moore and Chapman (1986) at corresponding growth period to the trial design. Dry matter yield was determined after drying the harvested material at 65°C for 48 h as described by Ren (1998). The dried forages were separated into 2 parts. One part of the samples was milled through a 1.0 mm screen for chemical analysis, while the other part was milled through a 2.5 mm screen for the in sacco DM degradability studies. Dry matter and ash content were determined as described by AOAC (1984) and the organic matter (OM) was calculated by subtracting the value of the ash content (g kg-1 DM) from 1000. Acid detergent fibre analysis was carried out according to Goering and Van Soest (1970) . Nitrogen was determined using the Kjeldahl method as modified by Davidson et al. (1970) and crude protein was estimated by multiplying N with 6.25. Crude fat was determined by using ether extract method (AOAC, 1984). Each measurement was repeated 3 times. Nitrogen-free extract (NFE) was calculated from NFE (g kg-1 DM) = 1000 – (water content + CP content + CF content + crude fat content + crude ash content). The in sacco degradability analysis was carried out according to the procedure described by Mehrez and Ørskov (1977). About 2.5 g of a sample was transferred into nylon bags and incubated in three fistulated Tibetan sheep (3 replicates per sample). The bags with the forages samples harvested at different growth stage were withdrawn after 6, 12, 24, 48, 72 and 96 h. After removal, nylon bags were washed, dried at 60°C for 48 h and weighed. The 48 h in sacco degradability of DM was regarded as the in sacco degradability of oat hay.

Statistical analysis

Forage yield data of 9 replicates in 2 years are averaged and shown as a symbol in the figures. DM, OM, CP, ADF contents and in sacco dry matter degradability (ISD) data in 2 years are presented as the means of 3 replicates in the tables. Differences among different forages and forages at different harvests in the levels of production, chemical components, ISD were determined by ANOVA (SPSS 10.0, Huang et al., 2001).

RESULTS

Dry matter accumulation rate

The results of this study indicate there were great variations among different locations for dry matter accumulation rate (Figures 1, 2 and 3). Two peaks appeared for dry matter accumulation rate of oat in Jingqianghe Area, with 575.6 kg ha-1d- 1 at the first peak during 17th and 27th of July and 548.9 kg ha-1d-1 at the second peak during 28th of August and 7th of September. Two peaks of dry matter accumulation rate were also observed for oat growing in Huazangsi Area, 450.1 kg ha-1d-1 during 1st and 10th of July and 343.6 kg ha-1d-1 during 21st and 30th of August, however, the plant stopped growing after second growth peak. Only one peak of dry matter accumulation rate, 568.9 kg ha-1d- 1 appeared during 24th and 30th of June. Generally, the plant growing in low site reached their peak accumulation rate much earlier (10 - 20 days) than that growing in high site, but the plant growing in high site had longer growing time and thus possessed higher growth potentials than that growing in low site.

Averages of forage dry matter accumulation rate varied also greatly with growing sites (Figures 1, 2 and 3). The highest value of 300 kg ha-1d- 1 within around 120 d growing season was observed in high site of Jingqianghe area. The lowest value of 200 kg ha-1d-1 within around 120 d growing season was investigated in Huazangsi area. Middle value of around 270 kg ha-1d-1 within only 50 d growing season was measured in Laznzhou area. Therefore, the plant growing in Jingqianghe area yielded

Table 1. Background of trial sites of productivity and nutritive values of oat (*Avena sativa*) with geographical locations.

Sites	Geographical location	Altitude (m)	Climate			Available solar radiation in growing season (MJ/m)	Soil property			
			Precipitation in growing season (mm)	Average temperature in growing season (ºC)	> 0ºC cumulative temperature in growing season (ºC)		type	pH	Bulk (g/cm^{-3})	Total nitrogen (g/kg DM)
Lanzhou	103º53'E, 36º03' N	1525	210	20.2	2816.3	2695.2	Saline soil	8.1	1.42	0.22
Huazangsi	102°01'E, 36°30'N	2394	250	11.2	1874.8	2674.6	Chestnut soil	7.8	1.12	0.27
Jingqianghe	102°13'E, 37°11'N	2960	300	9.5	1080.7	2661.9	Alpine meadow soil	7.6	1.34	0.60

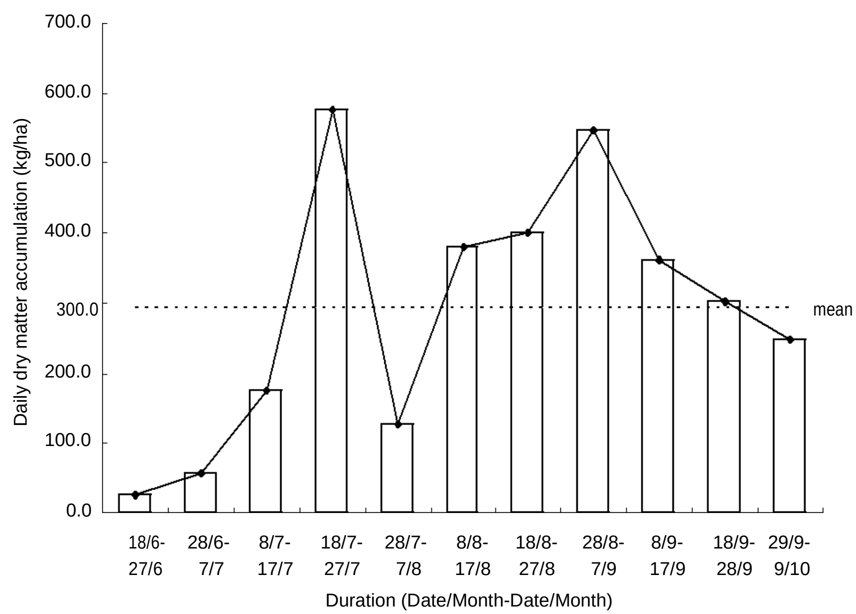

Figure 1. Dry matter accumulation of oat in jngqianghe area.

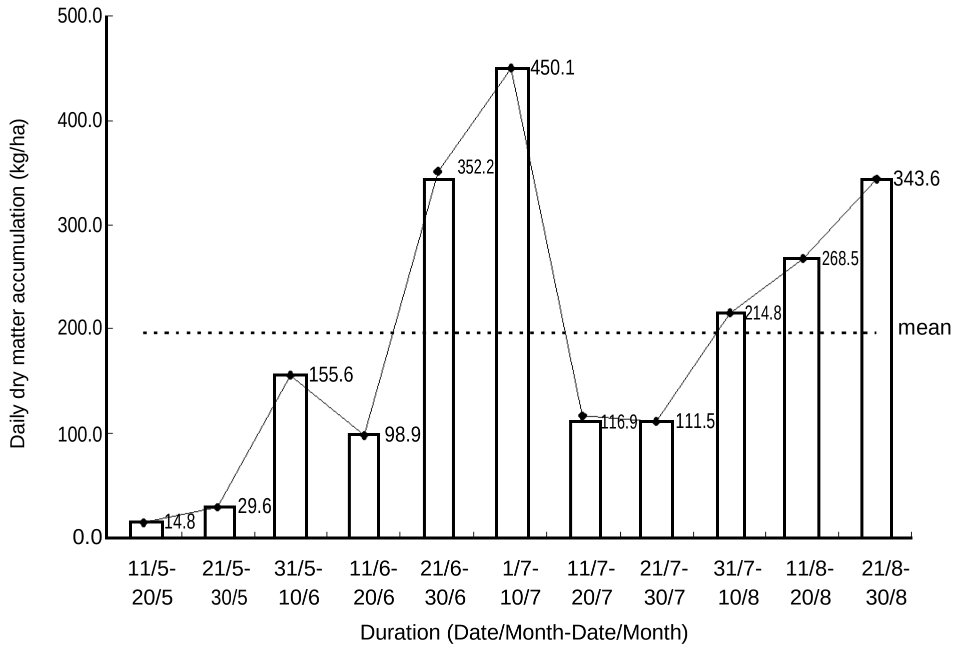

Figure 2. Dry matter accumulation rate of oat in Huazangsi area.

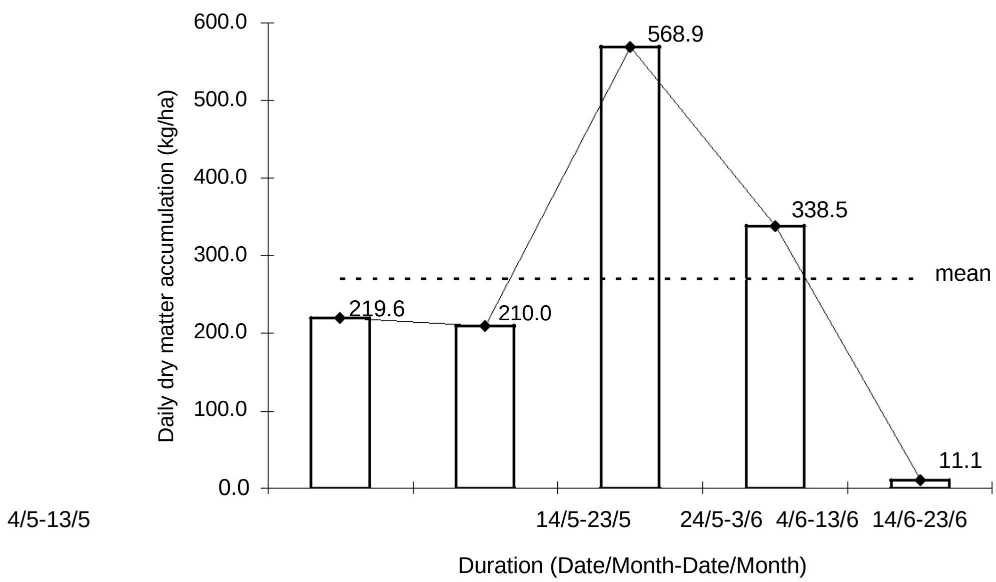

Figure 3. Dry matter accumulation rate of oat in Lanzhou area.

the highest forages (dry matter based) at high accumulation rate and within long growing season, the plant growing in Huazangsi area produced medium quantity of forages at low accumulation rate but within long growing season, and the plant growing in Lanzhou area had the lowest forage yield at relatively high accumulation rate but within extremely short growing season.

Crop forage at different growing stage and seed yield

Forage dry matter (DM) yield of the plant in all sites progressively increased with the growing stages (Table 2). Averagely, 2262.2, 9853.7, 12459.5 and 13857.3 kg DM/hm2 forage can be obtained at elongating, heading, blooming and fruiting of the plant. The peak yield of forage DM at fruiting was 16046.0, 13020.3 and 12505.7kg

Table 2. Seasonal dynamics of forage dry matter production and seed yield (kg DM/hm^2) of oat (*Avena sativa*) in different locations.

Location	Forage yield at different harvest time				Seed yield
	Elongating	Heading	Blooming	Fruiting	
Jingqianghe	2589.9[a]	10812.6[a]	13114.2[a]	16046.0[a]	933.7[c]
Huazangsi	1999.9[c]	9012.3[b]	12921.7[ab]	13020.3[b]	3789.3[a]
Lanzhou	2196.7[b]	9736.3[ab]	11342.5[b]	12505.7[b]	1632.7[b]
Means	2262.2	9853.7	12459.5	13857.3	2118.6
SD	206.4	766.9	674.0	741.3	334.5

Means followed by different letters within a column are significantly different (P < 0.05). SD, standard deviations between means

DM/hm2, respectively, for the plant growing in Jingqianghe, Huazangsi and Lanzhou areas.

Higher (P < 0.05) forage DM yields were observed for the plant growing in Jinqianghe area than that growing in other two sites at each growing stage. Except for elongating stage of the plant, there was no significant (P > 0.05) difference for forage DM yield of the plant in all growing time between Huangzangsi and Lanzhou areas.

Seed yield of the plant varied greatly (P < 0.05) with the growing site (Table 2). The highest seed production of 3789.3 kg DM/hm2 annually was observed in Huangzangsi area, the lowest seed production of 933.7 kg DM/hm2 annually was found in Jingqianghe area, and the medium seed production of 1632.7 kg DM/hm2 annually was recorded in Lanzhou area. Seed yield of oat in Huanzangsi area was twice as that in Lanzhou area and four times as that in Jingqianghe area.

Chemical composition and nutrients production

Chemical compositions of oat harvested at different growing stages in different sites are presented in Table 3. The plant growing in high site of Jinqianghe area concentrated more (P < 0.05) crude fat and nitrogen-free extract (NFE) than that growing in low site of Lanzhou area, and no significant difference in organic matter (OM), crude protein (CP) and crude fibre (CF) concentrations of the plant was observed among different growing sites.

Seasonal variations of chemical compositions were prominent on average. When harvest time shifted from elongating to fruiting, OM content in the plant increased slightly from 862.6 to 902.3 g/kg DM on the average, CF content increased greatly from 212.8 to 360.8 g/kg DM and NFE content increased apparently from 319.0 to 439.8 g/kg DM, while CP concentration declined dramatically from 271.4 to 81.2 g/kg DM and crude fat concentration decreased sharply from 52.8 to 22.7 g/kg DM.

Nutrients production of the plant growing in different sites can be estimated by combining the information of forage DM yield with that of chemical compositions. As shown in Table 4, the plant in all sites produced the highest OM, CF and NFE at its fruiting stage, nearly the end of plant growth, and yielded the highest CP and crude fat at its heading and blooming, the middle time of its life. Table 4 also shows the plant growing in Jingqianghe area produced more nutrients (15210.0 kg/hm2 of DM, 1225.9 kg/hm2 of CP, 5333.7 kg/hm2 of CF, 8281.3 kg/hm2 of NFE) than that growing other two sites at the end of growing season.

In sacco degradability

The 48 h in sacco degradability (ISD) of the plant indicated that ISD degradability of the plant significantly declined with increasing maturity, from 83.8% at elongating of the plant to 53.0% at fruiting (Table 5). No significant difference (P > 0.05) in ISD of the plant among different growing sites was observed in the whole growing season.

DISCUSSION

In mountain areas, the location of field can affect the climatic and vegetative conditions and the operational characteristics of forage conditioning, thus influencing the effectiveness of plant conditioning (Benvenuti, et al., 1995). Plant environment often exerts its greatest influence on forage production and quality by altering growth rate, plant development, and chemical composition of plant parts. The most environmental factors are temperature, water deficit, solar radiation and soil nutrient availability (Buxton, 1996). Herbage biomass was highly correlated with temperature in the alpine region where water stress is absent (Zhong, et al., 1992; Li, 1998; Li and Zhang, 1998). In present study, soil fertility and water supply were controlled as these two factors can be more easily monitored for cultivated plants in most situations. Therefore, temperature and solar radiation were key factors influencing production and quality of oat in different growing sites.

It is reported that rise in temperature normally increase-

Table 3. Seasonal variation of chemical compositions (g/kg DM) of oat in different locations.

Chemical compositions	Locations	Elongating	Heading	Blooming	Fruiting
Organic matter	Jingqianghe	892.0	892.2	929.8	947.9
	Huazangsi	837.4	861.2	878.1	881.5
	Lanzhou	858.5	865.8	882.5	877.5
	Mean	862.6	873.1	896.8	902.3
	SD	47.5	36.7	48.7	59.5
Crude protein	Jingqianghe	229.7	190.4	110.2	76.4
	Huazangsi	281.2	189.7	156.1	83.6
	Lanzhou	303.4	199.7	169.9	83.5
	Mean	271.4	193.3	145.4	81.2
	SD	47.8	7.6	41.3	5.3
Crude fibre	Jingqianghe	199.4	233.1	280.0	332.4
	Huazangsi	209.0	263.7	305.0	341.5
	Lanzhou	230.1	305.5	334.6	408.4
	Mean	212.8	267.4	306.5	360.8
	SD	25.7	46.3	37.3	51.5
Crude fat	Jingqianghe	67.3^{a}	60.9^{a}	31.5^{a}	26.7^{a}
	Huazangsi	51.4^{ab}	45.3^{ab}	30.5^{ab}	23.0^{ab}
	Lanzhou	39.6^{b}	23.1^{b}	18.2^{b}	18.5^{b}
	Mean	52.8	43.1	26.7	22.7
	SD	13.9	12.0	11.4	4.1
NFE	Jingqianghe	391.6^{a}	407.8^{a}	508.1^{a}	516.1^{a}
	Huazangsi	279.9^{b}	346.9^{b}	385.5^{b}	433.4^{b}
	Lanzhou	285.4^{b}	337.5^{b}	359.8^{b}	367.1^{c}
	Mean	319.0	364.1	417.8	439.8
	SD	63.0	38.2	79.3	74.7

Means followed by different letters within a column are significantly different (P < 0.05). SD, standard deviations between means.

Table 4. Nutrients production of oat forages growing in different locations (kg/hm^{2}).

Locations	Harvest time	Organic matter	NFE	Crude protein	Crude fibre	Crude fat
Jingqinghe	Elongating	2310.2	1014.2	594.9	516.4	174.3
	Heading	9647.0	4409.4	2058.7	2520.4	658.5
	Blooming	12193.6	4663.3	1445.2	3672.0	413.1
	Fruiting	15210.0	8281.3	1225.9	5333.7	299.5
Huangzangsi	Elongating	1674.7	559.8	562.4	418.0	102.8
	Heading	7761.4	3126.4	1709.6	2376.5	408.3
	Blooming	11346.5	4981.3	2017.1	3941.1	428.4
	Fruiting	11477.4	5643.0	1088.5	4446.4	394.1
Lanzhou	Elongating	1885.9	626.9	666.5	505.5	87.0
	Heading	8429.7	3286.0	1944.3	2974.4	224.9
	Blooming	10009.8	4081.0	1927.1	3795.2	206.4
	Fruiting	10973.8	4590.8	1044.2	5107.3	231.4

es the rate of plant development but reduces leaf/stem ratio and digestibility, and optimal growth temperatures were near 20 C for cool-season species of forages such as oat (Buxton, 1996). In present study, plants growing

Table 5. 48 h *in sacco* degradability (%) of oat growing in different locations.

Locations	Harvest time				
	Elongating	Heading	Blooming	Fruiting	SD
Jingqinghe	84.1	75.4	66.3	52.1	14.1
Huazangsi	82.3	73.6	61.2	52.6	11.2
Lanzhou	85.0	79.2	64.4	54.3	11.3
Mean	83.8	76.1	64.0	53.0	12.2
SD	2.6	7.5	5.8	2.2	

SD, standard deviations between means.

under higher temperature environment in Lanzhou area had shorter growth time and became mature earlier than those growing in lower temperature environment in Huanzangsi and Jingqianghe areas. Plants in lower temperature environment had longer growing time due to extended vegetative growth. This is consistent with other researchers' findings that the vegetative production is good choice in low temperature environment of alpine region (Ren and Hou, 1999; Liu, 1999).

Many researches on relationship between forage quality and growing site revealed that fibre contents in forages decreased and fat, protein concentrations in plants increased with decreased temperatures at high elevation (Han et al., 1997, 1998; Dong et al., 2004). The similar results were obtained in the present study. These findings can reconfirm Buxton's conclusion (1996) that forages produced at high elevations with their lower temperatures tend to be on higher quality than those produced at low elevations.

It was reported that 1 C increase in temperature will generally decrease digestibility of cool- season forages by 3 - 7 g kg-1 with only minor effects on crude protein concentration (Wilson, 1982; Wilson and Minson, 1983; Ohlsson, 1991; Xu et al., 2002). The depressed digestibility associated with elevated temperatures is usually attributed to higher NDF contents and less digestible NDF of forages grown under lower temperatures because of increased lignification (Buxton and Fale, 1994). Although CP contents of oat growing under higher tempe-rature environment at low site was higher than that grow-ing under lower temperature environment at high site, no effect of temperature associated with elevation on forage digestibility was found in present study.

In this study, solar radiation in Northwest site of Jingqianghe was slight higher than that in other two sites. Increased solar radiation can result in lengthened photoperiod for plants growth (Buxton, 1996). Photoperiod duration has large influence on the development patter of grasses and cereals (Hay, 1990); forage yield is increased substantially with extended photoperiod (Sinclair et al., 2001). Long photoperiod associated with cool temperature in high elevation and latitude site of Jingqianghe may contribute to extended vegetative growth of the plant. Hence, forage production of oat in high site of Jingqianghe area was higher than that in low site of Lanzhou area. On the contrary, the plant growing in low solar radiation and high temperature environment finished vegetative growth in short life span and concentrated more energy for seed production. Thus, the plant in low site of Lanzhou area yielded more seed than that in high site of Jingqianghe area.

Changes in photoperiod can also affect forage quality. Buxton (1996) summarized many researchers' works and concluded that lengthening photoperiod during spring and long photoperiods during early summer have a positive effect on forage quality. This effect is often massed by associated changes in temperature. The positive effect of increasing photoperiod in the spring on forage quality is often dampened by the negative effect of increasing temperature (Buxton, 1996). Work done by Deinum et al. (1981) indicates that an increase of 1 h in day length can increase digestibility by about 2g kg-1. Although no significant effect of solar radiation on forage digestibility was observed in present study, increased nutrients concentrations in forages with increased solar radiation associate with cool temperature can partly support Buxton's viewpoint.

Nutrients production is a very important index in choosing target plant site for forage crops. Without water and fertilizer stress on the plant, more nutrients can be produced in high site of Jingqianghe area, and more seeds be harvested in low site of Lazhou area for oat crop production. Therefore, seed production of the oat is recommended to be conducted in low site of Lanzhou area and forage production be conducted in high site of Jingqianghe area. Further studies are required to investtigate ecological and physiological performance of individual plants and populations of the oat growing under different environments, so as to get a sound explanation for difference in production and nutritive values of the oat influenced by geographic locations.

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