Irrigation research on yield and quality in China

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Distributions of Main Alfalfa in China

The areas of alfalfa in China was 4.71 million hectares by 2015 (China, 2016), including cultivated pastures and improved degraded pastures. These degraded pastures, accounting 30% of the total areas, improved the productivity by aero-seeding and artificially planting high quality grass (Li et al., 2015). Since 2009, China has introduced a series of policies to encourage the development of alfalfa industry, which greatly inspired farmers’ passion (Fig.1). The areas of alfalfa were generally increasing from 2001 to 2015, although the areas decreased slightly in some years (Tab.1). However, the production of commercial alfalfa is far from meeting the requirements of animal husbandry due to small areas (0.43 million hectares) and low commodity rate, with 3.67 million tons by 2015. The alfalfa is often considered an extravagant use of water compared with other crops due to its greater evapotranspiration rates. Many studies showed that alfalfa production had high related to the irrigation. Usually, the water requirement of alfalfa is mainly affected by climate region, harvest times, irrigation conditions and other factors. The annual water requirement of alfalfa differs geographically in China. Specially, the annual water requirement of alfalfa is about 500 to 700 mm in Northeast region, 600 to 750 mm in North China Plain, 700 to 900 mm in Loess Plateau and Hetao-irrigated region, and 600 to 1300 mm in the Northwest (Sun et al., 2005). Over 70% of alfalfa areas distributes in the arid and semiarid regions, such as Xinjing, Gansu, Inner Mongolia, Ningxia, etc. (Fig. 2 (a)). The productivity of alfalfa in these areas where the annual rainfall is about 200 to 400 mm (Fig.2 (b)) are extremely limited by the shortage of water resources, with average yield of 6068kg ha⁻¹ (China, 2016). The total alfalfa irrigated areas reached 695,000 ha in China, including underground water irrigated areas of 163,000 ha (China, 2016).

Figure 1: Alfalfa areas from 2001 to 2015 in China

Table 1: Alfalfa hay yield and total production in China

<table>
<thead>
<tr>
<th>Year</th>
<th>Hay yield (kg ha(^{-1}))</th>
<th>Total production (1,000 tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>7500</td>
<td>21360</td>
</tr>
<tr>
<td>2002</td>
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<td>24040</td>
</tr>
<tr>
<td>2003</td>
<td>7785</td>
<td>29890</td>
</tr>
<tr>
<td>2004</td>
<td>8535</td>
<td>33300</td>
</tr>
<tr>
<td>2005</td>
<td>8595</td>
<td>29310</td>
</tr>
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<td>6915</td>
<td>28780</td>
</tr>
<tr>
<td>2013</td>
<td>6690</td>
<td>33250</td>
</tr>
</tbody>
</table>

Figure 2: Distributions of commercial alfalfa (a) and precipitation (b) in China

Alfalfa Water Use Characteristics

Alfalfa is a high-water use crop because it has a long growing season, a deep root system, and a dense mass of vegetation. The amount of water needed is governed by temperature, wind, humidity, and the amount and intensity of light. However, the irrigation requirement for alfalfa is governed by rainfall and the water holding capacity of the soils growing the crop. Commonly cited ranges in water requirements for alfalfa are 400 to 2250 mm of water per season (Sun et al., 2005). It is crucial to yield and quality of alfalfa from branch to bud stage in which should be ensured supply of water (Dong et al., 2006; Yang et al., 2008). Alfalfa is quite tolerant of drought or extended periods without highly available water. As much as 50 to 65% of the available soil moisture can be removed between irrigations early and late in the season, but only 35 to 50% removal will give better results during high water-use periods (Wang et al., 2004; Kou et al., 2014). Maintaining higher levels, especially for slow-draining soils, may cause loss of stand and competition from grass invasion.

Irrigation in Alfalfa

Alfalfa yield and quality are both related to irrigation amount. Irrigation has become one of the major limiting factors for alfalfa production in the main alfalfa areas in China because of severe water shortages. Deficit irrigation has been an effective way to provide irrigation management for water shortage areas (Li et al. 2017; Lindenmayer et al., 2011), although many studies have shown that alfalfa yield benefits from irrigation (Pembleton et al., 2009). Reducing the irrigation amount caused a reduction in yield (Lindenmayer et al., 2011) but improved water use efficiency (WUE) and alfalfa quality. Water stress was generally highly favorable for alfalfa quality because drought delayed alfalfa maturation (Halim and Buxton, 1989). The crude protein (CP) concentration declined when the alfalfa biomass yield significantly increased, especially during the growth period from the branching stage to harvest (Zhang, 2007).
The irrigation methods have high related to growth and WUE of alfalfa by distribution of water and root in soil. The main irrigation methods in China included surface irrigation (pipe irrigation and border irrigation), sprinkler irrigation (center-pivot irrigation, hose-fed traveler irrigation, solid-set irrigation) and drip irrigation (surface and subsurface drip irrigation). The WUE of alfalfa under subsurface drip irrigation, sprinkler irrigation and surface irrigation were 2.03 to 2.47, 1.90 to 2.6 and 1.37 to 2.26 kg m⁻², respectively (Guo et al., 2014; Tao et al., 2015; Sun et al., 2005; Li et al., 2017). Surface irrigation is the most widely used irrigation method in alfalfa irrigation area, although surface irrigation has lower WUE than others. Drip irrigation is considered as one of the efficient water-saving irrigation methods by reducing the loss of water (runoff and invalid evaporation of soil) during the irrigation process. Compared to surface drip irrigation, subsurface drip irrigation is more suitable for alfalfa due to its deep rooted perennial crop. However, there are still a lot of problems in the application of surface and subsurface drip irrigation for alfalfa, such as the clogging of dripper, the damage of drip lines caused by machinery during the harvest and the insufficient water supply at seedling stage (Camp, 1998). Therefore, center-pivot irrigation system has been widely used method of water-saving, especially in the developed countries of alfalfa industry in the world. In recent years, the use of center-pivot irrigation systems has gradually increased in China (Yan et al., 2009) because of advantages in irrigation efficiency, coverage of irrigated area, automation, and labor costs. It was estimated that over 70,000 ha of irrigated alfalfa were equipped with center-pivot systems in the semiarid region of Inner Mongolia, which is one of the largest commercial grass zones of China.

A case of center-pivot irrigated alfalfa in China

This research was conducted in 2014 and 2015 at Saiwusu, Inner Mongolian Plateau, Northwest China (38°56′N, 106°49′E). The climate was a typical temperate continental semiarid monsoon with a summer precipitation pattern. Over 50% of the precipitation occurs from July to September, and long-term average annual precipitation was approximately 250 mm. The soil type was sandy loam with bulk density of 1.3 g cm⁻³ and the pH of 8.5. In the study, three irrigation levels (100%, 80%, 60% ET) were used to evaluate the effects of irrigation amounts on alfalfa yield and quality. For assessing the effects of water distribution variation of center pivot system on alfalfa yield and quality, water application depths, alfalfa yield and quality between the first span, second span, overhang, and end gun were also compared. The results showed there was no significant difference in annual yield between 100% and 80% ET irrigation levels. Compared to the irrigation at 100% and 80% ET level, the irrigation at 60% ET level caused a significant reduction of yield by 10% and 11%, respectively. As the irrigation amounts decreased, total crop water use significantly declined from 617 to 405 mm, and WUE increased from 21.8 to 29.8 kg ha⁻¹ mm⁻¹. The water production functions of alfalfa were parabolic in each harvest. The proportions of seasonal total actual water applied in each cutting were approximately 25%, 32% and 43%, with contributions to annual yield accounting for 54%, 30% and 16%, respectively, indicating that the third harvest of alfalfa had a great potential to improve WUE and save more water. Irrigation levels had noticeable effect on the relative feed values (RFV), but no effect on crude protein (CP) concentrations. The 60% ET irrigation level was conductive to increase CP concentration and RFV of alfalfa but was of no help to improve its grade. The spatial distributions of annual yield and quality were highly related to the water spatial distribution of the center pivot irrigation system. The coefficient of variations (CVs) in annual yield, RFV and CP of the whole system were 5% to 12%, 2% to 8% and 1% to 8% respectively, while the CVs in actual irrigation amounts ranged from 11% to 13%. Over-irrigation caused by end gun slightly increased alfalfa annual yield, but it reduced the quality and WUE. Therefore, an end gun in the center pivot irrigation system should be carefully selected for improving uniformity of the water application. Irrigation level of 80% ET in the first and second cuttings and 60% ET irrigation level in the third cutting were recommended for alfalfa production in semi-arid region such as western Inner Mongolia in China.

Future of alfalfa irrigation in China

Although the China government has established many alfalfa demonstration bases of high production, there is still an important lack of knowledge about the quantification of the effects of management practices on yield and quality. Main alfalfa areas concentrated in arid and semiarid regions of China where the environmental impacts may be more important than yields. It is important to study and take into account the effects of alfalfa management practices in the environment, specially the use of water. Future research should focus on the optimization the decisions on irrigation with limited water resources. The new irrigation technology, like variable irrigation, offers the ability to very precisely apply water, nutrients, and other chemicals in the alfalfa root zone at
the timing and frequency needed. However, the further study on the adaptation and adoption of new irrigation technology is needed. The water-saving irrigation technology, an effective way to solve the problem of water shortage, has been promoted in the alfalfa irrigated regions in China. Many application problems in irrigation engineering, such as poor uniformity, inadequate irrigation facilities, should be attracted attention in the future.

**BIBLIOGRAPHY**


