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Influence of alfalfa seed belts on yield component and seed yield in mainland China - A review

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ABSTRACT

Alfalfa is widely cultivated and the seed yield differs in different regions due to the climate environment and so on in China. In order to obtain higher yield, alfalfa seed production must choose the most suitable area. Therefore, according to the geographical and climatic conditions, the alfalfa seed production area can be divided into four belts: Hexi Corridor belt, Hetao Plainbelt, the northern slope of the Tianshan Mountains belt and the Hotanbelt in mainland China. Under different cultivation measures, the seed yield of four alfalfa seed production zones, varied in the range of 360-1833 kg/hm^2, 234.96-1560.1kg/hm^2, 179.10-1197.33 kg/hm^2, 225-300 kg/hm^2, respectively. These different cultivation measures can provide theoretical guidance for alfalfa seed production in different production zones.

Key words: Alfalfa seed, Cultivation measures, Production area, Yield.

Alfalfa (*Medicago sativa* L.) is one of the most important forage crops in the world because of its high nutritive quality, yield, good palatability and adaptation to various climatic and soil conditions (Li *et al.,* 2007). For one thing, adding alfalfa hay to livestock feed can significantly promote the growth and development of livestock and poultry, especially improve the milk yield and quality of dairy cows. Thus, it is reputed as the ''Queen of the Forages" and "the first workshop of milk production" (Li *et al.,* 2015). For another, alfalfa also has great ecological value. Planting alfalfa can effectively improve the land salinization and desertification, conserve soil and water and increase soil fertility (Zhu *et al.,* 2014).

The alfalfa planting area in the world was about 33 million ha, in which China had 2 million ha, ranking fifth in the world, and increasing year by year (Yang *et al.,* 2012). At the end of 2015, China's alfalfa planting area increased to 4.7113 million ha (Wang *et al.,* 2017). Although China's alfalfa planting area and commodity production have begun to take shape, China still needs to import large amounts of alfalfa due to the rapid development of China's animal husbandry and dairy industry. In 2014, China imported 0.884 million tons of alfalfa hay, ranking second in the world (Jiang *et al.,* 2016). With the adjustment of the industrial structure and the urgent need of returning farmland to grass and ecological construction (Qi *et al.,* 2008), industrialization of alfalfa is rising rapidly in China and demand for alfalfa seed is increasing as well. However, low seed yield is the main problems in China (Yu *et al.,* 2002) since seed production is usually only a by-product, lacking specialized seed production fields, and the scientific and reasonable management and processing techniques. The average yield of alfalfa seed in China is 225-300 kg.ha^{-1}, which is lower than that in the United States, Canada and other agricultural developed countries (Wang *et al.,* 2004a).

There are numerous factors affecting the alfalfa seed yield components and seed yield, such as varieties, climatic conditions, soil conditions and cultivation management (Wang *et al.,* 2007; Zhou *et al.,* 2009; Mao *et al.,* 2016). It has been reported that the high-yield and high-quality seed can be obtained in areas with a mild climate, abundant light, rare precipitation and favourable irrigation conditions (Wu and Zhang, 2004). According to the optimal climate conditions, the present work was to determine the most suitable areas for alfalfa seed propagation in China.

The effect of location and climateconditions of belts on the suitability for alfalfa seed propagation in Mainland China

According to the climatic conditions and the requirements of alfalfa seed setting, growth and development,there are four optimal areas in China including the Hexi Corridor belt, the Yellow River irrigation belt of Hetao Plain, the north slope of Tianshan Mountain belt and the Hotan belt, respectively.

The Hexi Corridor belt (A), lies in the northwest of Gansu Province and to the west of the Yellow River in China.

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It is a long corridor between the South Mountains (Qilian Mountains and the Altun Mountains) and the North Mountains (Mazong Mountains, Heli Mountains and Longshou Mountains). It starts at Wushaoling Mountains in the east and ends at Yumenguan in the west. The distance from north to south is 40-100km and the distance from east to west is about 1120km (Fig 1). Badin Jaran Desert and the Tengger Desert lie in its northeast.It is mainly sloping plain in front of the mountain. The corridor is divided into three separate endorheic basin according to three big river systems: Yumen, Guazhou, Dunhuang plain, belonging to the ShuleRiver system; Zhangye, Gaotai, Jiuquan plain, belonging to the Heihe River system, a small part of North River; Wuwei, Minqin, Yongchang plain, belonging to the ShiyangRiver system. Cold wave weather is often formed in the spring and winter in the corridor. The invasion of the summer monsoon will bring most of the annual precipitation in this area. Dry climate, the heat and cold change drastically, strong wind with plenty of sands are main climate characteristics. The annual precipitation is decreasing gradually from east to west, and the dryness is increasing gradually. For example, the annual precipitation in Wuwei is 158.4 mm and in Dunhuang is 36.8 mm; the dryness is 4-8 and 8-24 in the east and west of Jiuquan, respectively. The interannual variation of precipitation is great in this area, and the amount of precipitation occupies 50%-60% of total in summer, 15%-25% in spring, 10%~25% in autumn and 3%-16% in winter. Cloudage is small in this area and sunshine duration increased from east to west. Most of regions have 3000 hours of sunshine duration, and the western part of Dunhuang has as high as 3336 hours. The annual average temperature is 5.8 to 9.3°C in this area.The absolute highest temperature is upto 42.8°C, and the absolute lowest temperature is -29.3°C. The average temperature difference between day and night is 15°C. Annual sand storm day in Minqin are more than 50 days, and there are 80 days of windy day in Anxi with 8 or more gales in a year. Wind direction is changeable in the corridor. Wuwei and Minqin surroundings are dominated by northwest wind; Yumen, Anxi, Dunhuang and other places to the west of Jiayuguan are dominated by northeast wind and easterly wind. Hexi Corridor climate is arid continental climate with little precipitation and the annual precipitation is only about 200 mm. However, the development condition of oasis agriculture which is irrigated by ice and snow melt water in the Qilian Mountains are very excellent. It is the most important seed producing areas and commodity grain base with a long history of irrigating agriculture in the northwest of China.

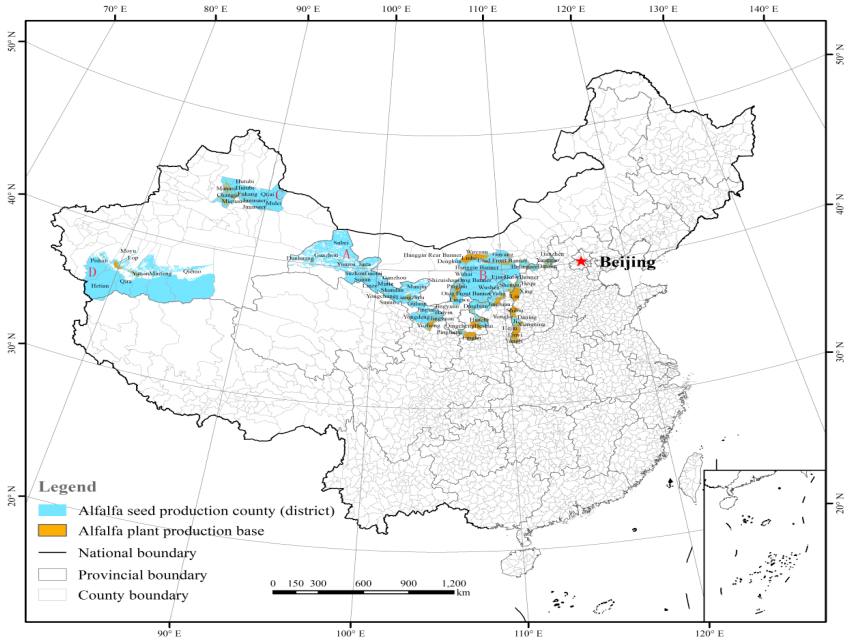

Fig 1: The adaptability and planting regionalization of alfalfa seed production in mainland China. There are four belts marked A (Hexi Corridor belt), B (Hetao Plain), C (The northern slope of Tianshan Mountains) and D (the Hotan region) respectively, each with different numbers of counties. Belt A comprise with Subei, Guazhou, Dunhuan, Yumen, Jinta, Suzhou, Gaotai, Sunan, Ganzhou, Minle, Linze, Shandan, Minqin, Yongchang, Liangzhou, Sunan, Gulang, Jingtai, Jingyuan, Baiyin, Yongdeng, Jingyuan, Yuzhong, Pingliang, Qingcheng, Lingtai, Huachi and Heshui; Belt B include Hanggin Rear Banner, Wuyuan, Linhe, Guyang, Urad Front Banner, Dengkou, Tianzhen, Yanggao, Helingeer, Datong, Hanggin Banner, Wuhai, Shizuishan, Otog Banner, EjinHoro Banner, Pingluo, Wushen, Shenmu, Hequ, Xing, Lin, Yulin, Otogfront Banner, Lingwu, Dingbian, Jingbian, Shilou, Yonghe, Daning, Ji, Xiangning, Hejin, Linyi and Yongji; Belt C consist of Hutubi, Manasi, Changji, Fukang, Qitai, Miquan, Jimusaer and Mulei; Belt D contain Pishan, Moyu, Lop, Yutian, Minfeng, Qiemo, Qira and Hetian.

The Hetao Plain belt (B) which lies in the north of the north latitude 37 degree, generally refers to the area of the east of Helan Mountain, the west of Lüliang Mountains, the south of Yin Mountains and the north of the Great Wall. The Hetao Plain belt including the Yinchuan Plain (Ningxia Plain) and the Ordos Plateau, part of the Loess Plateau, now covers parts of Ningxia, Inner Mongolia and Shaanxi. The Hetao Plain is generally divided into West Tao (i.e. Yinchuan Plain between Qingtongxia and Shizuishan in Ningxia) and East Tao (the part of the Inner Mongolia). The Hetao plain had a continental climate and large temperature differs between day and night. Annual sunshine hours in the Hetao plain is 3000-3200 hours and west of which has more hours than east. The percentage of sunshine ranges from 67% to 73%. Annual total radiation is 627 kJ/cm^2. The annual average temperature is 5.6 - 7.4°C and higher in the west than in the east. The average temperature is -14-11°C in January, and is 22-24°C in July. Activity accumulated temperature above 10°C is 3000-3280°C and frost-free period is 130-150 days. Farmers can plant one crop per year. The precipitation in most areas is 150-400 mm, which is less in the west than in the east. This area belongs to the hot rainy season. The Hetao plain is convenient for irrigation and suitable for alfalfa seed production.

The northern slope of the Tianshan Mountains belt (C) is situated at the northern foot of the Tianshan Mountains, and the southeast of the Junggar Basin, belonging to the area of the east longitude 85°17'-91°32' and the north latitude 43°06'-45°38'. The administrative area is 500 km long from east to west and 285 km wide from north to south, with a total area of 93900 km^2, accounting for 5.7% of the aggregate area of Xinjiang. The territory which is suitable for alfalfa seed production covers Changji, Manasi, Hutubi, Jimsar, Fukang, Qitai and Mulei. The northern foot of the Tianshan Mountains has a arid continental climate and elevation is between 650-5445 m. The annual average temperature is 4.7°~7.0°C. The lowest temperature is -36.0-43. 2°C and the highest temperature are 36.0-43.5°C.The annual precipitation in the plain is 150-200 mm and the annual sunshine hours are 2598.2-3226.4 hours. The frost-free period is 155 days.

The Hotan belt (D) is located in the southern most of the Xinjiang Uygur Autonomous Region, and extends north to south from the Taklamakan desert hinterland and border Awat County of Aksu to the Kunlun mountains east of Qiemo County of the Bayingolin Mongolian Autonomous Prefecture and southwest of Kashmir. The annual average temperature in the plain area is 11.6°C. There is a very abundant heat and the accumulated temperature above 10°C is 4200°C in the period from June to September in the growing season of crops, which are extremely beneficial to the agricultural production. The frost-free period (ground temperature >-1°C, the lowest temperature ≥4°C) is 170-201 days and large temperature difference between day and night is beneficial to accumulate the Photosynthate of crops and increases the sugar content and boll weight of melon and fruit. The plain is dry and rainless and the annual precipitation is 13.1-48.2 mm. The annual evaporation amount is 2450-3137 millimeters, and the dryness is about 20. Thus, it is beneficial to alfalfa seed production and is not conducive to the occurrence of diseases and insect pests.

Analysis on seed yield and yield components of alfalfa in different belts

Alfalfa seed production is influenced by the geographical location, climate, soil, variety, cultivation and management measures and so on. The seed yield and yield components of alfalfa are different in the seed production belts above.

The seed yield of alfalfa in Hexi Corridor belt (A) differs in the range of 360-1833 kg/hm^2. Jingtai is located in the eastern end of the Hexi Corridor portal. As the Yellow River Irrigation region of Gansu Province, this region has a dry climate and abundant heat, which is suitable to produce alfalfa seed. The effects of different amounts of fertilizer and irrigation frequencies on alfalfa seed yield were investigated in this area for two years in succession. The results showed that irrigation had significant effects on alfalfa seed yield, and two-times irrigation is appropriate. The average seed yield was 686 kg/hm^2 and 891kg/hm^2 respectively in 2013 and 2014. The seed yield decreased with the increase of irrigation frequencies and four-times obtained the lowest seed yield, 360 kg/hm^2 and 420 kg/hm^2 in 2013 and 2014. However, the seed yield increased firstly and then decreased with the increase of fertilizer amount. The application of 360 kg/hm^2 diammonium phosphate could obtain the highest seed yield, 631 and 786k g/hm^2 in 2013 and 2014. Further more, the amount of fertilizer and irrigation frequencies had the interaction effect on seed production. Two-times irrigation and 360 kg/hm^2 diammonium phosphate fertilizer were the most economical and efficient irrigation and fertilization conditions in this area (Chen *et al.*, 2016). During the growth of alfalfa, the root system grows continuously to utilize the water stored in the deep soil, so that the plant can grow continuously and slowly, which is the ideal growth mode of seed field (Wang *et al.*, 2004b).Too many irrigation frequencies and too much amount will not only cause the waste of water resources and soil salinization (Fan *et al.*, 2012; Zhang *et al.*, 2014) and also contribute to the excessively vegetative growth. But, on the other hand, too few irrigation frequencies and little irrigation amount will limit the growth and development of alfalfa, which will reduce the seed yield (Han and Wang, 2005). Diammonium phosphate, widely used for phosphorus (P) and nitrogen (N) fertilizer, is a suitable fertilizer during alfalfa seed production (Kuerban *et al.*, 2009). Fertilizer can regulate alfalfa reproductive growth, increase alfalfa stem diameter and

lodging resistance ability (Cheng *et al.,* 2007). Phosphorus deficiency will reduce seed yield, while excess phosphate can result in toxicity. (Hosseinirad *et al.,* 2013). Nitrogen fertilizer was helpful to the growth of the aerial part. (Du *et al.,* 2006). Jiuquan is located in the west end of the Hexi Corridor. It is dry and sunny, and the irrigation system is complete. The average seed yield of alfalfa (300-600 kg/ hm^2) is higher, and Jiuquan is an ideal seed production area (Li *et al.,* 1992). Wang *et al.,* (2006) researched the effects of spacing and intra-spacing under hole-seeding conditions on seed yield of alfalfa in Jiuquan region and the experimental results showed that a spacing increased from 60 to 100cm, alfalfa seed yield decreased from 1240 kg/hm^2 to 982 kg/hm^2, 60cm is the optimum spacing as well. At the same time, with the increase of intra-spacing from 15cm to 60cm, seed yields decreased from 1426 kg/hm^2 to 807 kg/ hm^2. It indicated that the intra-spacing is 15cm, which is better than the other intra-spacing. The best combination of spacing and intra-spacing on seed yield was also the highest, reaching 1833 kg/hm^2 (Wang *et al.,* 2006). The increase of spacing significantly reduced the density of branches, but the number of pods per branch and pods per inflorescence was significantly increased. The density of branches is the only yield constitutes factors that has a significant positive correlation with seed yield, and the differences in seed yield among different treatments is caused by the differences of branches quantity in unit area. The yield of alfalfa seed is reduced because of the high seeding rate and large planting density. In order to reduce plant density and increase seed yield, internal thinning is a common practice or spraying growth some retardants such as Uniconazole and Paclobutrazol. The effects of internal thinning and growth retardants on seed yield were studied in Jiuquan (Wang *et al.,* 2004c). The results showed that the seed yield of alfalfa changed from 563.8 to 571.9 kg/hm^2 when only the growth retardant was applied. The seed yield after row thinning was 763.3kg/hm^2, and the seed yield reached 816.7 kg/hm^2 after spraying the growth retardant. In addition, during the branching period in the second year, the growth retardant was sprayed on the leaves to effectively inhibit plant growth and the plant height was decreased by 19.4% and the pod number was increased by 25.3%. Compared with the control (640.4 kg/hm^2), the seed yield was increased 39.1% by spraying the growth retardant, and the maximum yield was 890.7 kg/hm^2. Thus, for seed fields with too large plant densities, the internal thinning is the key management measure to increase yield. Otherwise, the effect of controlling plant height and increasing seed yield by spraying growth retardants was not obvious. After the treatment of internal thinning, the density of the reproductive shoot was reduced effectively and the height of the plant was controlled. Lodging was reduced through internal thinning. The uprightness and permeability of the plant are better for insects to reach the flowers to do pollination (Dovrat *et al.,* 1969) which contribute to increase the seed yield. After applying the growth retardants, the average height after racemes did not significantly improve and the plant is 137.4-159.3 cm, which is too high to cause plant lodging. Therefore, controlling plant height only by the foliar application of Uniconazole and Paclobutrazol does not fundamentally increase seed yield. Under different plant densities, the effect of growth retardants on seed yield and optimum spraying time and concentration need further study in Jiuquan. The effects of N, P and potassium (K) fertilizers on seed yield and yield components of alfalfa in Wuwei area were studied. When fertilizer amount was 47kg N/hm^2, 120kg P_2O_5/hm^2 and 30kg K_2O/hm^2, the highest actual seed yield reached 875.42kg/ hm^2 (Tian and Du, 2008). N, P and K increase seed yield mainly by increasing pods per inflorescence, seeds per pod and inflorescences per branch.

In Hetao Plain belt (B), spraying boron fertilizer on alfalfa at different growth stages for two consecutive years had a significant effect on seed yield and a definite effect on the seed quality. Seed yield with 0.371% mass fraction of boron is best, the seed yield was the maximum, they were 604.38 kg/hm^2 and 322.76 kg/hm^2 in 2013 and 2014, respectively, which were 71.35% and 37.37% higher than the control. Pods per inflorescence, racemes per pod and seeds per pod had a better correlation with seed yield. B fertilizer treatment showed a higher solid seed rate, and significantly increased the number of normal seedlings (Yuan *et al.,* 2015). B can act directly on the reproductive organs, increase the number of pollen and promote germination and development and the formation of seed to increase seed yield (Li and Zhu, 2009). B is also conducive to fertilization of pollen and reduces seed abortion (Sotomayor *et al.,* 2012). A density experiment was carried out in Ningxia with different density spacing of 15, 20, 25, 30, 35, 42 and 56 cm planting spacing. Under the same cultivation and management measures, little change in alfalfa seed yield components under different densities except for inflorescence or pod number per unit area. The inflorescence number per unit area was 5191, 5363, 5606, 5826, 6249, 6753, 5857 and 5037, pod rate was 77%, 78%, 81%, 83%, 91%, 98%, 86% and 76% at the treatment of 15, 20, 25, 30, 35, 42 and 56cm, respectively.The seed yield was obtained 1102.3^2, 1140.1, 1160.1, 1120.1, 1389.0, 1560.1 1226.1, 1160.1 kg/ hm^2 at the treatment of 15, 20, 25, 30, 35, 42 and 56 cm, respectively. These results demonstrate that the effect of density on yield is mainly achieved through the inflorescence or pod number per unit area (Wu, 2003). Too small or too high density will cause low number of pod and inflorescence per unit area, which will reduce seed yield.

In the northern slope of the Tianshan Mountains belt (C) some of the management measures affecting alfalfa seed production have been focused on irrigation (Chen *et al.,* 2011; Du *et al.,* 2007; Fan *et al.,* 2012; Li and Li, 2006;

Yang *et al.*, 2004; Zhang *et al.*, 2014), fertilization (Chen *et al.*, 2016; Wang *et al.*, 2016; Wu *et al.*, 2007) and planting density (Chen *et al.*, 2005; Li *et al.*, 2012). However, the effect of N fertilization time on alfalfa seed yield has not been mentioned. Therefore, Wang *et al.*,(2005) studied the effect of N fertilizer on alfalfa growth rate and seed yield in alfalfa at different growth stages in Hutubi area.The seed yield was 214.35 kg/hm^2, 641.29 kg/hm^2, 802.16 kg/hm^2, 390.11 kg/hm^2, 390.34kg/hm^2 respectively after top dressing urea 75kg/hm^2 at the green stage, the branching stage, the budding the stage, the flowering stage and applying no fertilizer. The results showed that proper fertilization of N fertilizer could improve alfalfa seed yield and fertilization had significant effects on seed yield at different growth stages (Wang *et al.*, 2015b). It is suitable to apply fertilization at the budding stage. It not only can effectively avoid the competition for nutrients between plant florets, but also effectively avoid unnecessary losses caused by lack of nutrition in plant organs when fertilizing at the budding stage. Moreover, alfalfa increased demand for nitrogen fertilizer from budding to maturity, while the phenomenon of inadequate supply of nitrogen can easily appear at this time since the rhizobia come up aging and nitrogen fixation decreased. At this growth period application of N fertilizer can increase seed yield by 20% to 30% (Lu and Sun, 2013).

The effect of irrigation amount on seed yield was also studied in Hutubi area. In the experimental area, the irrigation method of subsurface drip irrigation was adopted, and 6 irrigation quantities were set to 150, 225, 300, 375, 450 and 525mm. Drip irrigation with 375mm could promote the transformation of alfalfa vegetative growth to reproductive growth and obtain higher reproductive allocation rate for alfalfa plant height, branches per plant, pods per plant and seeds per pod than other treatments. Moreover, with the change of irrigation amount from low to high quantities, the seed yield changed to 179.10, 290.32, 327.21, 1197.33, 1150.99 and 328.26 kg/hm^2. Comprehensive analysis showed that 375 mm treatment was more suitable for alfalfa seed production in Xinjiang Hutubi area than other treatments (Wang *et al.*, 2015a). Water demand of alfalfa differs in the regional climate and growth years and when irrigation time and amount fit water requirement period, it can obtain high yield and quality of alfalfa products (Hou *et al.*, 2013). Suqin Wu, Aiqin Zhang, XinhuiTian and other research results also illustrate this conclusion. Therefore, alfalfa seed fields can get good quality and high yield alfalfa seed under reasonable irrigation conditions (Tian and Du, 2008; Wu, 2003; Zhang *et al.*, 2013).

For the Hotan belt (D), there are few data on alfalfa seed production and its influencing factors.Cao (2002) mentioned that in Xinjiang there were large planting area for alfalfa seed production in Hetian and farmers had a long history to plant local varieties. The seed yield in Hotan was 225-300kg/hm^2(Cao, 2002).

CONCLUSION

This paper presents the alfalfa seed production of four belts and a series of cultivation and management measures affecting alfalfa seed yield, which can provide a theoretical basis for reasonable management of seed fields. Nevertheless, some of the above cultivation management measures mentioned cannot be used as the standard for alfalfa seed production. Scientific cultivation and management measures should be based on the growth of alfalfa and soil conditions in the seed field, as well as the local water and heat conditions to manage alfalfa seed fields scientifically and rationally.

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