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Full Length Research Paper

Soil water distribution on different number of growing years of alfalfa pasture in the Loess Plateau of Northwest China

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The alfalfa pastureland in the semiarid Loess Plateau region of Northwest China usually has dry soil layers. We studied the soil water variations on alfalfa (*Medicago sativa* L.) grassland with different number of growing years. Seven growing years of alfalfa grassland were chosen in this study: (1) 4-year-old, (2) 6-year-old, (3) 8-year-old, (4) 12-year-old, (5) 14-year-old, (6)18-year-old and (7) 26-year-old. The results showed that the highest soil water content, 12.0 -17.15%, with different number of growing years of alfalfa grassland occurred in 80 -100 cm soil layer, but gradually became stable below 300 cm soil layer. The soil water content with 4, 6 and 8 year alfalfa grassland was in the range of 13.66 - 14.76%, with 12 and 14 year ranged within 11.76 -1 1.87% and with 18 and 26 year within 10.5%. We also found that in 0 - 1000 cm soil layer, the soil water content with different number of growing years of alfalfa grassland had differences due to different soil water conditions and water-supplying capability. The soil water content with 4 and 6 year were 13.85 and 14.22%, respectively, with 8, 12 and 14 year were 12.98, 11.25 and 11.22%, respectively, and with 18 and 26 year were 10.27 and 10.76%, respectively. After alfalfa grew for >18 years, the annual recovery of its soil water at 0 - 200 cm soil depth was 1.49%, whereas the soil water with 18 and 26 year alfalfa pastureland at 200 - 1000 cm soil depth was only 10.10%, dry soil layers occurring in alfalfa pasture. The dry soil layer of alfalfa grassland appears at 160 - 600 cm soil depth in the Loess Plateau. We found that at 250 - 350 cm soil depth, the soil water content with 4 and 6 year alfalfa grassland was in the range of 10.23 - 10.48%, presenting slightly dry soil layer and for more than 8 year, alfalfa was in the range of 7.78 - 8.48%, presenting moderately dry soil layer. In summary, the soil water use of alfalfa would grow with the number of growing years and the depth of desiccated layers will become intensified and thicker.

Key words: Alfalfa grassland, different number of growing years, soil water content, dry soil layers, Loess Plateau of China.

INTRODUCTION

The Loess Plateau of Northwest China is situated in the by an extremely hilly Loess landscape and a semi-arid monsoon climate, which is a most important farming area in China because of plenty of arable land. There is a high risk of land degradation from improper management systems, overstocking and opportunistic cultivation, limiting the development of sustainable agriculture. It is important for sustainable agricultural development and ecosystem upper and middle of the Yellow River (33°43′ - 41°16′N

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and 100°54′ - 114°33′E). It comprises parts of Gansu, Qinghai, Ningxia, Shaanxi and Inner Mongolia provinces with a total area of 624,000 km^2, approximately 6% of the national territory (Liu, 1999). The region is characterized restoration to develop seeded grassland and animal husbandry following the introduction of legumes such as alfalfa (*Medicago sativa* L.) into crop-forage systems (Li, 1999; Li et al., 2003, Jiang et al., 2006).

Alfalfa, a deep-rooted perennial legume, has been planted in pasture/crop rotation system for more than 2000 years in the Loess Plateau. Its planting areas have been gradually increased to meet demand for increasing livestock population and addresses government environmental objectives to prevent soil erosion in this region (Li and Huang, 2008). However, because of limiting water resources, the establishment of alfalfa is slow and its productivity is very low (Yang et al., 2004; Jia et al., 2006). Previous studies show that soil water deficit in the deep profile can be aggravated with the length of alfalfa growing age and thus lead to the decrease of alfalfa grassland in the planting area (Steppuhn and Waddington, 1996; Saeed and El-Nadi, 1997; Matthias et al., 1997; Du et al., 1999; Wang et al., 2000; Fan et al., 2004; Cheng et al., 2005; Zhao et al., 2005; Liu et al., 2005; Joann et al., 2006; Wan et al., 2007).

The Loess Plateau of Northwest China is very deep; at least several dozen meters. Perennial alfalfa often causes severe soil layers (Li, 2002; Wang et al., 2003; Shen et al., 2004). Li (1983) has observed that growing alfalfa continuously for 6 years produces a relatively dry layer in the deep soil profile from 200 to 1000 cm in the Loess Plateau. In this area, the annual rainfall is only 250 - 550 mm, while annual field evapotranspiration is 750 - 950 mm. It is difficult to restore soil water in dry soil layers and the severe dryness of the deep soil influences the regional water cycle on a large scale (Li, 2002; Wang et al., 2008). Many authorities have warned that severe drought after perennial alfalfa would greatly decrease the yield of following crops, or even lead to failure of the harvest. This could potentially damage sustainable development and even influence the stability of the society (Guo and Shao, 2003). From this result, it is, therefore, very important to determine the soil water variations of alfalfa grassland with different number of growing years to attain high pasture yield and keep high soil water storage for subsequent crop.

Although, many studies on soil water consumption and dry soil layers of alfalfa have been done, we still lack adequate information on the dynamic variations of soil water and the extension and degree of dry soil layers with different number of growing years of alfalfa. In response to this demonstrated need, the objectives of this study are: (1) To investigate the soil water consumption on 4, 6, 8, 12, 14, 18 and 26-year-old alfalfa pasture in the same planting area, (2) to determine the soil water content in 0 - 1000 cm soil layers with different number of growing years years of alfalfa grassland and (3) to explore the quantitative indexes of dry soil layer, including the extension and degree of soil dryness.

MATERIALS AND METHODS

Study site description

The soils were from the experimental sites at the Semiarid Ecosystem Research Station on the Loess Plateau run by Gansu Academy of Agricultural Sciences at Zhenyuan County in the Qingyang region (latitude 35°30′N, longitude of 107°29′E, elevation 1279 m a.s.l.), Gansu province, Northwest China. Soil samples were collected in 2006. The climate is typical of a semiarid monsoon environment. Based on data from 1948 through 1988, the annual mean solar radiation is 5489 MJ m^{-2} (Li et al., 2002). The total yearly sunshine duration is 2500 h and the no frost period is 165 days. The annual mean air temperature is 8.3°C and a maximum temperature of 29.2°C (July) and a minimum temperature of -9.2°C (January). The annual mean accumulated temperature above 10°C is 3436°C. The annual mean precipitation is 540 mm, of which about 54% falls from July to September and the average annual free water evaporation is about 1638 mm. The soil is dark Loessial soil (Calcic Kastanozems, FAO Taxonomy), with a field water holding capacity of 21.3% and a permanent wilting coefficient of 6.9%.

Samples used in this study were selected from a farmer's field in 2006 and the cultivar used was Zhenyuan alfalfa. Seven seeded alfalfa (*M. sativa* L.) grasslands with different years of growth were selected: M4, 4-year alfalfa grassland; M6, 6-year alfalfa grassland; M8, 8-year alfalfa grassland; M12, 12-year alfalfa grassland; M14, 14-year alfalfa grassland; M18, 18-year alfalfa grassland; M26, 26-year alfalfa grassland. These alfalfa grasslands were all planted at flat fields in the same region and the distance between two treatments was about 500 m. Three different farm fields were chosen as replicates for the alfalfa grasslands with the same planting years. The alfalfa grasslands are all mowed-grasslands and they are managed using the conventional cultivation technique, being harvested (cut near the soil surface) twice each year except in the first year in which the alfalfa was seeded. The first mowing is in July and the second in October. The area of each alfalfa field is more than 300 m^2 and the whole experiment had a randomization design. In these seven grasslands, the M4 alfalfa was grown along with pea (*Pisum sativum* L.) in the seeding year and pea was in rotation the year before seeding, the other conditions were all monocroping with wheat in rotation before seeding, except M26, which was native grassland (wasteland) before seeding. No fertilizer or manure was applied in soils when these alfalfas were planted.

Sampling and measurements

Soil water content was determined gravimetrically to a depth of 1000 at 20 cm increments at 0 - 200 cm soil layer and at 50 cm increments at 200 -1000 cm from each of the seven grasslands on April 2006. Soil cores taken every 20 cm soil depth from the surface to 200 cm deep and every 50 cm soil depth from 200 to 500 cm deep were taken randomly from seven seeded alfalfa grasslands with different years of growth in April using a cylindrical steel corer (diameter 8 cm, height 20 cm), with three replications. The corresponding field water holding capacity and soil bulk density were determined according to Robertson et al. (1999). The average bulk density was 1.08 g cm^{-3} in soil to a depth of 20 cm and 1.22 g cm^{-3} in the layer of 20 - 40 cm.

According to the value of soil bulk density and field water holding capacity, soil water reserve in mm measured at the vertical of a given point was calculated using Equation (1) as follows (Wang et al., 2002):

$$S_W = h \times d \times b\% \times 10 \quad (1)$$

Where, S_W (mm), the averaged values of soil water content; h (cm), soil layer depth; *d* (g cm^{-3}), soil bulk density in different soil layer and b% was the percentage of soil moisture in weight.

Statistical methods

Analysis of variance (ANOVA) from the statistical analysis system (SAS) package was used to conduct analysis of variance.

RESULTS

Vertical variation of soil moisture

Figure 1 shows the water vertical variation of seeded alfalfa grassland with different number of growing years in 0 - 1000 cm soil profiles. With increasing soil depth, the soil water content increased significantly ($p < 0.05$). The soil water content was 12.00 - 17.15% at a depth of 80 - 100 cm, reaching the highest in the whole soil profile. The water content below 100 cm soil depth began to decline and the soil moisture was 10.03 - 13.94%. The water content below 300 cm soil depth slightly increased but did not differ significantly ($p > 0.05$) among all the treatments. The soil water contents of the field M4, M6 and M8 were between 13.66 and 14.76% below a depth of 300 cm, the values for M12 and M14 were between 11.76 and 11.87% and the water contents for M18 and M26 were 10.50%. The soil water content in 800 cm appeared nadir compared to the upper and lower soil layers (0.20 - 3.00%) but the water content at 750 - 800 cm soil depth slightly increased.

The soil water content of the field M6 was 14.82% at a depth of 0 - 200 cm, but the values for M4, M8, M26, M12, M14 and M18 were 13.22, 12.5, 11.63, 10.90, 10.46 and 10.39%, respectively, indicating that the soil water contents of M12, M14 and M18 were less at 0 - 200 cm than that of M26, corresponding to reductions of 0.74 - 1.25% (Figure 1). The water contents of seven grasslands were all lowest in 0 - 20 cm soil layer due to the evapo-transpiration. For M6, M4, M8, M12 and M14 alfalfa grasslands, the water contents in 0 - 20 cm soil layer were 12.66, 10.32, 10.51, 7.42 and 8.22%. How-ever, the soil water contents of the fields, M18 and M26, were lower than 7.42%. The soil water contents for M4, M6, M26 and M8 were 13.47, 15.6, 13.63 and 12.36% at 0 - 200 cm depth, respectively, but the values for M12, M14 and M18 were lower than 12.00%. The soil water in 100 - 200 cm declined compared to water content in 20 - 100 cm soil depth and the values for M6, M4, M8, M26, M12, M18 and M14 were 14.64, 13.60, 13.09,10.91,10.76, 10.45 and 10.41%, respectively (Figure 1).

The soil water contents of the fields M4, M6 and M8 were more than 11.00% at a depth of 200 - 500 cm, but the values for M12, M14, M18 and M26 were 10.05, 10.48, 9.06 and 9.24%, respectively. The soil water contents in 500 - 700 cm among seven alfalfa grasslands were similar to the soil depth in 200 - 500 cm. That is, with increasing years of growth of seeded alfalfa grasslands, the soil water content decreased significantly. The soil water contents of the fields M4 and M6 were 14.81 and 14.36% at a depth of 500 - 700 cm, respectively, but the values for M8, M12 and M14 were 13.40, 12.60 and 11.93%, respectively and for M18 and M26 were lowest,only 10.66%. The soil water contents for M4, M6, M8, were more than 15.40% in 700 - 1000 cm, but the values for M12, M14, M18 and M26 were 11.93, 12.56, 11.05 and 10.95%, respectively (Figure 1).

The above analysis on the soil profiles in 0 - 1000 cm indicated that after alfalfa grew for >18 years, its soil water content in 0 - 200 cm began to recover in upper layers. In 200 - 1000 cm deep, the soil water became more intensively consumed and the water content decreased in lower layers with increasing years of growth of seeded alfalfa grasslands. However, the soil water content slightly increased with the soil layers deeper for different profiles. Therefore, the soil layer in 0 - 1000 cm could be divided into four layers according to the variation of soil water of alfalfa grasslands growing age: (1) The soil moisture varied drastically at 0 - 40 cm depth due to the strong influence of external warmth and water condi-tions such as rainfall and temperature. As a result, the sharp wet-dry variation of the layer significantly affected the water content in the topsoil and the soil moisture was 6.97 - 13.05%; (2) the soil moisture varied actively at 40 - 100 cm depth. The soil water variation in the layer deceased compared to its upper layer due to the influence of evaporation, rainfall and alfalfa water consumption and the water content varied within 11.93 - 16.32% at a depth of 40 - 100 cm; (3) the soil moisture varied less actively at 100 - 300 cm depth. The soil water variation in the layer significantly deceased due to the influence of alfalfa water consumption and the soil water content ranged from 9.76 - 13.41%; (4) the soil moisture was stable at 300 - 1000 cm. The soil water variation in the layer became relatively stable which mainly affected alfalfa water consumption and its water content ranged within 11.19 - 14.81%.

Soil water reserve in deep soil

The variation of soil water reserve of alfalfa grassland with different number of growing years in 0 - 1000 cm is presented in Figure 2. The distribution amounts and depth of alfalfa roots in soil layer are different for different growing age and there are differences between water consumption by alfalfa in different soil layers. With increa-sing years of growth of seeded alfalfa grasslands, the soil water reserve decreased significantly. The soil water reserve of the field M6 was the highest amounting 1945.6 mm, the values for M4, M8, M12 and M14 were 1878.8, 1784.3, 1542.1 and 1555.0 mm, respectively, and the water reserve for M18 and M26 were the lowest amount-

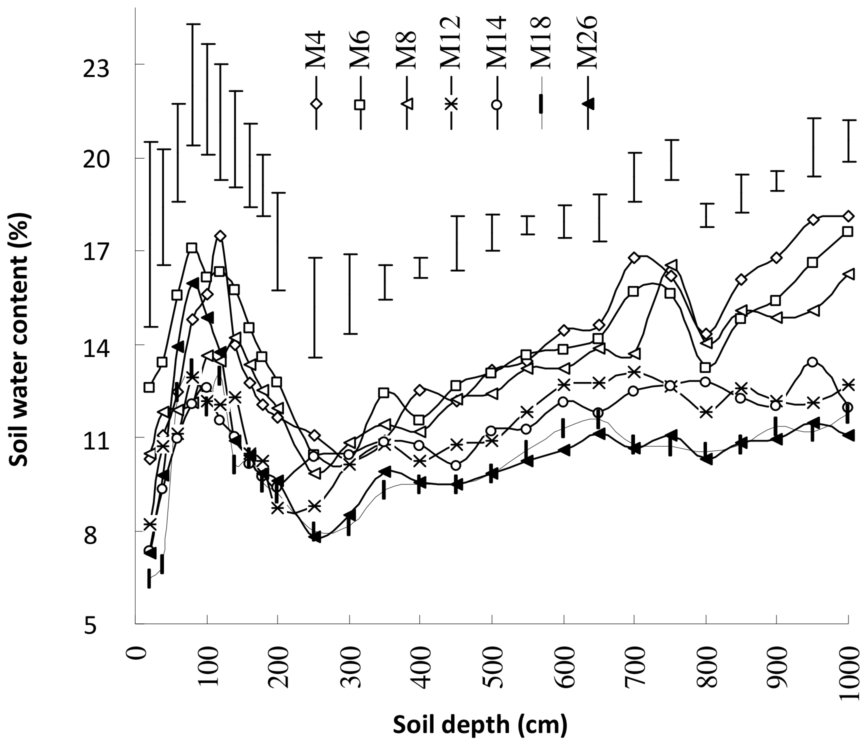

Figure 1. Profiles of soil water variation in 0 - 1000 cm depth for alfalfa (*M. sativa L.*) grassland with different number of growing years. Error bars are the LSD at P = 0.05.

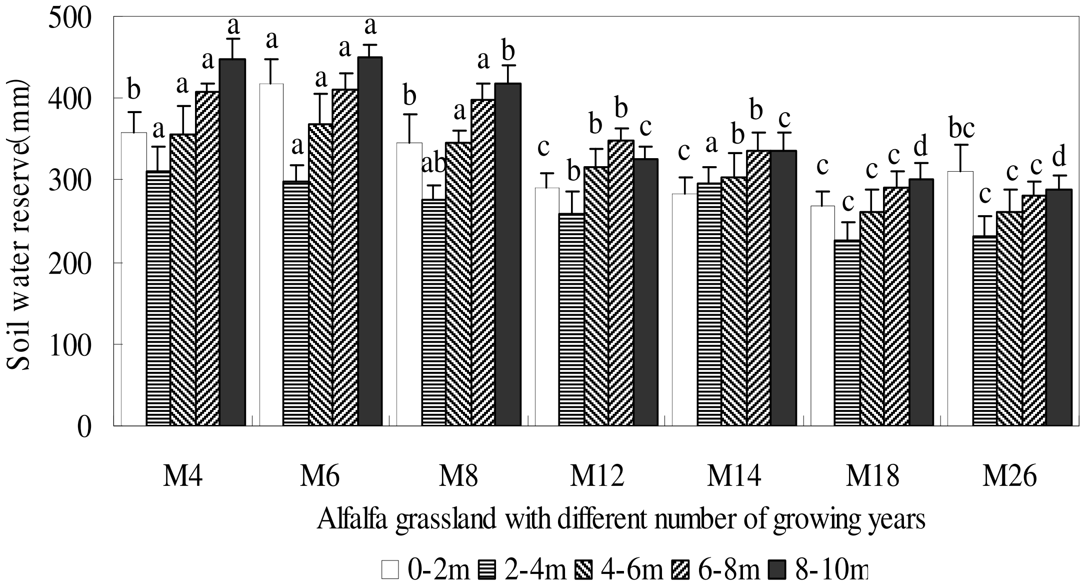

Figure 2. Variation of soil water reserve of alfalfa grassland with different number of growing years in 0 - 1000 cm deep. Means in different soil layers followed by the same letter are not significantly different at P ≤ 0.05.

ting to only 1365.6 mm. According to different soil layers, the soil water reserves for M4 and M6 were lower than 200 mm per meter in 0 - 600 cm and higher than 200 mm per meter below 600 cm depth. The water rese-rve of the field M8 was more than 200 mm per meter below 700 cm soil depth while after alfalfa grew for > 8 years, its soil water reserves were all lower than 200 mm per meter at a depth of 0 - 1000 cm. The soil water

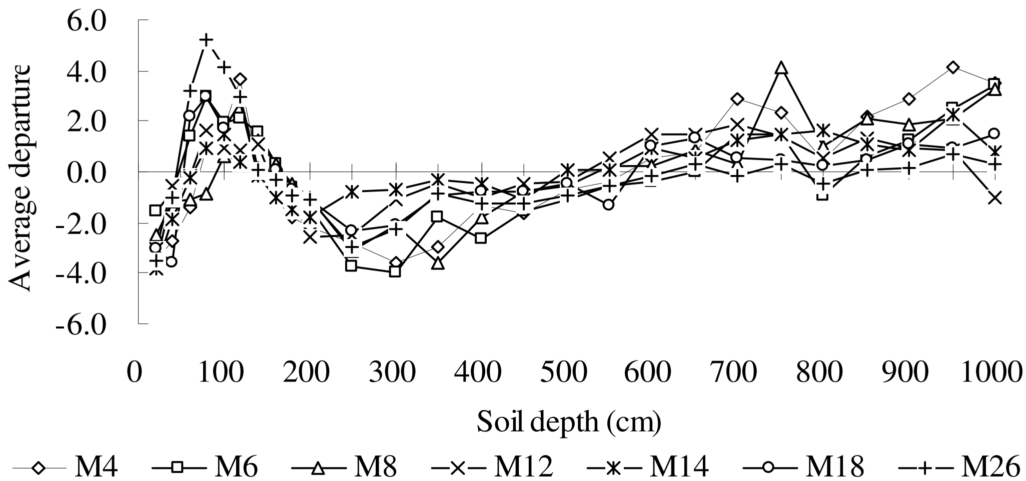

Figure 3. Average departure of alfalfa grassland with different number of growing years in 0 - 1000 cm soil depth.

reserve in different soil layers is also shown in Figure 2. For M4, M6, M8 and M26, the soil water reserve were more than 300 mm per meter in 0 - 200 cm but the values for M12, M14 and M18 were lower than 300 mm per meter. The water reserve for M4, M6, M8, M12 and M14 were more than 400 mm per meter at soil depths of 200 - 500 cm but the values of the fields, M18 and M26, were 354.4 and 357.7 mm, respectively. The soil water in M4 and M6 alfalfa grasslands was the highest surpassing 1030.0 mm in 500 - 1000 cm profile, the values for M8, M12 and M14 were 995.0, 829.0 and 847.0 mm, respectively and the soil water reserves in M18 and M26 were the lowest standing below 730.0 mm.

Departure of soil water content

Since the Loess Plateau has low rainfall and high evaporation and its underground water lies deep below ground, the deep soil is in short supply of water and sometimes reduces its water content close to or to the wilting moisture under the circumstances that high vegetation consumption of water occurs and this will result in its soil moisture standing at a low level for a long time and finally, form dry soil layer. High water consumption of perennial alfalfa and insufficient makeup of soil water will further intensify soil drying and thus prolonged length of alfalfa growth will exacerbate soil drying. The departure of soil water content can be used to demarcate the soil areas with low water content and predict the locations of dry soil layer in alfalfa grassland with different number of growing years. The departure curves of the soil water content for alfalfa growing age are presented in Figure 3. The result showed that the soil area with low water content appeared in 160-600 cm depth, but varied with the lengths of alfalfa growth. The M4 and M6 grasslands presented a negative departure in 160 - 600 cm soil depth and a peak negative departure ranged from 1.38 to 3.99% in 200 - 400 cm. The M8 grassland showed a negative departure in 180 - 500 cm soil depth and a peak negative departure equaled to1.03 - 3.57% in 200 - 400 cm. The M12 and M14 had a negative departure in 160 - 500 cm soil depth and a peak negative departure ranged within 1.02 - 2.54% in 160 - 400 cm. The M18 field presented a negative departure in 180 - 550 cm soil depth and a peak negative departure ranged within 1.10 - 2.3% in 200 - 350 cm. The alfalfa grassland for M26 presented a negative departure in 160 - 600 cm soil depth and a peak negative departure ranged from 1.13 to 2.98% in 200 - 450 cm. In this study, the average water content for seven growing years of alfalfa grassland were different in 0 - 1000 cm soil profile and the values for M4, M6, M8, M12, M14, M18 and M26 were 13.85, 14.22, 12.98, 11.25, 11.22, 10.27 and 10.76%, respectively, indicating that the average soil water content of the field M6 was 3.00 - 4.00% higher than those of M18 and M26. The result also showed that a negative departure of M4, M6, M18 and M26 alfalfa all occurred at a depth of 180 - 550 cm but the soil water content for M4, 11.91% and M6, 12.30%, were much higher in 180 - 550 cm depth than those of M18, 9.10% and M26, 9.42%. Therefore, the departures can function as the indicators of the soil areas with low water content in alfalfa grassland with different number of growing years, but the indicators did not repre-sent dry soil layer limits. However, with increasing years of growth of seeded alfalfa grasslands, the dry layer will inevitably appeared in the soil area with a negative departure.

Comparison of dry soil layers

The dry soil layer was divided into three grades according

Table 1. Dry soil layer occurrences in the grasslands with alfalfas growing for different lengths of time (%).

Soil layer(cm)	4 M	6 M	8 M	12 M	14 M	18 M	26 M
120	17.50	16.35	13.44	12.08	11.61	12.98	13.74
140	13.98	15.81	14.22	12.31	11.07	10.12*	10.87*
160	12.77	14.57	13.32	10.49*	10.19*	10.38*	10.45*
180	12.08	13.62	12.53	10.23*	9.78*	9.57*	9.84*
200	11.66	12.84	11.95	8.71**	9.41*	9.19*	9.63*
250	11.05	10.48*	9.83*	8.79**	10.43*	7.96**	7.78**
300	10.23*	10.23*	10.85*	10.15*	10.49*	8.15**	8.48**
350	10.86*	12.46	9.41*	10.78*	10.91*	9.32*	9.91*
400	12.50	11.59	11.19	10.22*	10.75*	9.49*	9.53*
450	12.17	12.67	12.23	10.79*	10.12*	9.50*	9.51*
500	13.14	13.10	12.41	10.89*	11.27	9.82*	9.85*
550	13.45	13.69	13.24	11.81	11.28	8.91**	10.24*
600	14.43	13.85	13.20	12.71	12.16	11.32	10.61*
650	14.59	14.19	13.85	12.73	11.80	11.61	11.10
700	16.76	15.71	13.32	13.15	12.50	10.78*	10.63*

* Represent slightly dry soil layer; ** represent moderately dry soil layer.

to soil wilting moisture, field water holding capacity, plant growth and moisture deficit in this experiment region: Slightly dry soil layer with a water content ranging within 9.00 - 11.00%; moderately dry soil layer with a water content ranging within 7.00 - 9.00% and highly dry soil layer with water content below 7.00%, respectively. In combination with the varying ranges of the average negative departures of the soil water content, the dynamics of water moisture for alfalfa grassland with different number of growing years in 120 - 700 cm soil depth are presented in Table 1. It is clear from Table 1 that the thickness and drying degree of dry soil layer differed among seven growing years of alfalfa grassland. In this experiment, the alfalfa grasslands had a soil wilting moisture of 7% and their measured soil water contents were above 7%. As a result, these treatments did not have a highly dry soil layer but they all had a slightly dry soil layer. In light of the drying degree, the soil water content of the alfalfa grasslands growing for ≤ 8 years were more than 9.00% and no moderately dry soil layer appeared. In contrast, the alfalfa grasslands growing for > 8 years had a moderately dry soil layer. The soil water content of the field M12 ranged within 8.71 - 8.79% at a depth of 200 - 250 cm and the values for M18 and M26 varied from 7.78 to 8.48% in 250 - 300 cm soil depth.

DISCUSSION

In the Loess Plateau of China, the actual evapotranspiration of alfalfa is always more than precipitation during the growing season. This deficit of water is supplied from stored soil water. Alfalfa extract soil water from deeper soil profile than other crops and used more water and thus, creates a large soil water deficit. In our experiments, there appeared a differentiation among the soil water content of the alfalfa grassland with different number of growing years and the 8 year alfalfa was the demarcation line. The soil water content for growing ≤ 8 years alfalfa grasslands tended to vary consistently and their second peaks appeared in 700 - 750 cm depth. However, the soil water content for growing > 8 years alfalfa varied gently without peaking. The reason was probably that after alfalfa grew for ≤ 8 years, its roots distributed in 0 - 700 cm soil depth, while after alfalfa grew for > 8 years, its roots extended downward and took up water below 700 cm depth so that no peak content of soil water appeared.

Many documents have shown that there exist dry soil layer in the Loess Plateau (Li, 2002; Guo and Shao, 2003; Wang et al., 2000, 2005; Cheng et al., 2005). They reported that alfalfa grasslands will consume the water of soil depth in great quantities because of the higher evapotranspiration in the Loess Plateau when the water in shallow upper soil can not meet with crop requirements. As a result, continuous growing of alfalfa will result in soil drying and finally form dry soil layer. In this study, we found that the water content forming dry soil layer was below 11% and its lowest content of soil wilting moisture was 7%. According to this, the dry soil layer was divided into three layers: Slightly dry soil layer with soil water content raging from 9 to 11%, moderately dry soil layer, with soil water content raging from 7 to 9% and highly dry soil layer, with soil water content raging below 7%. Similar finding was noted by Cheng et al. (2005). However, Zhang et al. (2004) investigated that the dry soil layer for alfalfa grasslands M5, M10 and M15 appeared in 0 - 220, 0 - 240 and 0 - 260cm, respectively, which was different from our results. Liu et al. (2005) also revealed that the dry soil layer gradually moved upward and its thickness tended to decrease with alfalfa growing age. In this experiment, we found that with increasing years of growth of seeded alfalfa grasslands, the dry soil layer widened downward and its drying degree increased, which was consistent with the results by some scholars (Du et al., 1999; Huang et al., 2003; Cheng et al., 2005). The shorter the growing years for alfalfa, the lower the soil water consumption and then slightly dry soil layer occurs in the upper soil. However, the longer the growing years of alfalfa, the deeper its roots distribution which intensified high water consumption at deep soil. Meanwhile, soil drying in deep was intensified and widen downward due to the great accumulative water consumption in early alfalfa growth. Consequently, the alfalfa grassland for growing > 8 years occurred moderately for dry soil layer. The dry layer of the field for the 12 year period reached 500 cm deep and the values of 18 and 26 year even expanded below 600 cm depth.

Considering the times and depths of dry soil layer, this study recommended that the optimal length of alfalfa growing age in the Loess Plateau should not be more than 8 years and its peak growth spanned from the 4th and 6th year. It was reported that it took about 6 - 10 years for purple alfalfa grassland to have secondary grassland vegetations with *Stipa bungeana* populations as dominant populations (Li and Shao, 2005). Therefore, after alfalfa grew for 6 years, the alfalfa-crop rotation system should be practiced to recover soil moisture and to raise land productivity.

Conclusion

In view of the removal of large quantities of forage biomass out of alfalfa grassland systems through mowing for animal fodder, long-term alfalfa forage production can result in the exhausting of soil water and severe soil dryness. The dry soil layer appeared at a depth of 160 - 600 cm in Loess Plateau region for alfalfa grasslands in 0 - 1000 cm soil profile. With increasing years of growth of seeded alfalfa grasslands, the soil water content decreased and water consumption and soil dryness were intensified in deep soil. Considering all the above factors, this study recommended that the optimal length of alfalfa growing age in the Loess Plateau should be not more than 8 years and its peak growth spanned from the 4th and 6th year. Furthermore, after alfalfa grew for 6 years, the alfalfa-crop rotation system should be practiced to recover soil moisture and to raise and sustain land pro-ductivity.

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