African Journal of Biotechnology Vol. 10(21), pp. 4420-4427, 23 May, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB10.2678
ISSN 1684–5315 © 2011 Academic Journals

Full Length Research Paper

The long-term effects of alfalfa on soil water content in the Loess Plateau of northwest China

Xiaolong Ren[1,2,3,4], Zhikuan Jia[1,2,3,4*], Sumei Wan[2], Qingfang Han[1,2,3,4] and Xiaoli Chen[3]

[1]Agronomy Department, Northwest A&F University, Yangling, Shaanxi 712100, China.
[2]Research Center of Dryland Farming In Arid and Semiarid Areas, Northwest A&F University, Yangling, Shaanxi 712100, China.
[3]Institute of Water Saving Agriculture in Arid Regions of China, Northwest A&F University, Yangling, Shaanxi 712100, China.
[4]The Key Laboratory of Crop Production and Ecology in Dryland, Ministry of Agriculture, Yangling, Shaanxi 712100, China.

Accepted 4 April, 2011

Soil desiccation is the most serious problem in forest vegetations and grassland, which lead to widespread land degradation in the Loess Plateau of China. The soil water variations at 0 to 1000 cm depth of different vegetations were studied to explore the hydrological effects of vegetations and determine the optimal length of alfalfa (*Medicago sativa* L.) phase at the Zhenyuan Agri-ecological Station of the Loess Plateau in China. Eight treatments were designed in this study: waste land, wheat land and six continuous growing alfalfa treatments, including 4-year-old (4 year), 6-year-old (6 year), 8-year-old (8 year), 12-year-old (12 year), 18-year-old (18 year) and 26-year-old (26 year) alfalfa grasslands. Results showed that the wheat field had the best soil water content and no dry soil layer, while slightly dry soil layer occurred in wasteland and 4, 6 and 8 year alfalfa grasslands. After alfalfa grew for > 8 years, moderately dry soil layer appeared in the grassland and expanded beyond 500 cm soil depth. The result also showed that wheat field, wasteland and the alfalfa grasslands growing for 4, 6 and 8 years had no unfavorable impacts on the ecological environments of the soil moisture but the grasslands for 12, 18 and 26 years did exert relatively stronger unfavorable influences on the hydrological effects. Considering all the factors, this study recommends that the optimal length of alfalfa phase should be 8 years.

Key words: Different vegetation, alfalfa grasslands, soil water content, ecological effect, soil desiccation, Loess Plateau of China.

INTRODUCTION

The Loess Plateau is a most important farming area in China. The Loess Plateau of northwest China is situated in the upper and middle reaches of the Yellow River (33°43′ to 41°16′N and 100°54′ to 114°33′E). It comprises parts of Gansu, Qinghai, Ningxia, Shanxi, Shaanxi and Henan provinces with a total area of 624,000 km^2, approximately 6% of the national territory (Liu, 1999). The region is characterized by an extremely hilly Loess landscape and a semiarid 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 (Jiang et al., 2006). From the late 1980s to early 1990s, severe water deficiency occurred in deep soil, which resulted in the collapse of artificial vegetations in large areas, the fluctuation of crop yields and the deterioration of farmland quality (Liang et al., 1990; Li, 2001). Therefore, it is important for sustainable agriculture development and ecological environment rehabilitation in the entire Loess Plateau of China to study the soil water consumption of the different vegetations.

Vegetation dynamics largely depend on soil water

*Corresponding author. E-mail: zhikuan@tom.com or rxlcxl@yahoo.com.cn. Tel: +86 29 87080168. Fax: +86 29 87080168.

availability in dryland and thus, the vegetation restoration needs considering soil water dynamics, which are affected by a number of factors, such as topography, soil properties, land cover, depth to water table and meteorological conditions (Gomez-Plaza et al., 2001; Beate and Haberlandt, 2002). In recent years, many studies on the effect of vegetation upon soil water dynamics have been conducted (Lørup et al., 1998; Domingo et al., 2001; Fernández et al., 2002; Connor, 2004; Shangguan and Zheng, 2006). The relationship between vegetation and soil moisture varying with region showed that vegetation structure was mainly controlled by water supply and demand in semi-arid and semi-humid areas (Grayson et al., 1997; Porporato et al., 2001; Kerkhoff et al., 2004). In the Loess Plateau of China, the groundwater level remains at a depth of about 20 to 300 m precluding any upward capillary flow from groundwater into the root zone. Growing season precipitation and stored soil water at the beginning of the growing season are thus, the critical resources to support plant growth in this region and have an important effect on crop performance and yield (Li and Huang, 2008). However, the deep soil is always short of water and thus, suffers severe dry soil layer because of intensive soil evaporation and plant transpiration in this region. Soil desiccation commonly exists in forest and grassland vegetations and leads to the degeneration of vegetations (Liang et al., 1990; Yang and Yu, 1992; Wang et al., 2002; Li, 2002).

Besides artificial forest and grassland vegetations, dry soil layer also exists in other land use mode. Previous studies showed that, different land use can significantly affect the water content in deep soil and continuous growing alfalfa apple and alfalfa will result in deep soil desiccation and finally impact ecological environments of water (Steppuhn and Waddington, 1996; Saeed and El-Nadi, 1997; Liu, 2000; Liu et al., 2004; Fan et al., 2004; Cheng et al., 2005; Jia et al., 2006; Li and Huang, 2008; Wang et al., 2008). Chen et al. (2005) observed that, there existed differences among water consumptions of different land use modes and the soil desiccation intensities ranked in the order of forestland > high yielding land > low yielding land > bare land. From this result, it is therefore, very important to maintain the balance between the total water consumptions of different land use modes (forestland, grassland and farmland) and the total effective precipitations to counteract or get rid of disadvantageous effects of regional soil desiccation.

Although, many studies on soil water consumption and dry soil layers of different land use have been done, we still lack adequate information on water consumption and ecological effect in deep soil of vegetations. In response to this demonstrated need, the objectives of this study were: (1) to investigate the soil water variation in 0-1000 cm profile of wasteland, wheat field and six continuous growing alfalfa grasslands in the same planting area, (2) to explore the long-term effects of alfalfa on soil water content and (3) to determine the optimal length of alfalfa phase for the alfalfa/crop rotation system using a short-term (2 years) field experiment conducted at Zhenyuan Agri-ecological Station of the Loess Plateau in China.

MATERIALS AND METHODS

Study site description

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

Samples used in this study were selected from a farmer's field in 2006 and 2007 and the cultivar used was Zhenyuan alfalfa. Wasteland, wheat field and six seeded alfalfa (*Medicago sativa* L.) grasslands with different years of growth were taken as the subjects. The experiment consisted of three blocks with 8 plots per block, and the 8 treatments were randomized within each block, for a total of 24 plots per year. All the plots were 10 m × 5 m. The 8 treatments included: (1) waste land, unreclaimed and filled with weeds; (2) wheat land, continuously growing 4 year winter wheat (*Triticum aestivum* L.) field planted in early October and harvested in middle to late July every year; (3) M4, 4 year alfalfa grassland planted in the late September of 2002; (4) M6, 6 year alfalfa grassland planted on October 2000; (5) M8, 8 year alfalfa grassland planted on July 1998; (6) M12, 12 year alfalfa grassland planted in late September of 1994; (7) M18, 18 year alfalfa grassland planted on July 1988 and (8) M26, 26 year alfalfa grassland planted on July 1980. In the 8 treatments, both waste land and wheat land were near the alfalfa grassland. The winter wheat plots were fertilized with mineral nitrogen (119.6 kg ha^{-1} N); half as the basal fertilizer and half as the additional fertilizer and phosphorous (35 kg ha^{-1} P_2O_5) as the basal fertilizer applied at sowing. These six alfalfa grasslands were all planted at flat fields in the same region and the distance between two treatments was about 50 m. The alfalfa grasslands were all mowed-grasslands and were managed using the conventional cultivation technique, harvested (cut near the soil surface) twice each year except in the first year in which the alfalfa was seeded. The first mowing was in July, and the second was in October. The crops (wheat, maize, potato, beans and millet) had been rainfed on all the treatments but were wasteland before they were used as the lands for the experiment plots. The lands were flat in the experiment. All the alfalfa grasslands were not fertilized and alfalfa was harvested manually for livestock. In rainfall-deficit years, alfalfa was cut only two times because of its poor growth, and it was cut three times in rainfall-rich years. No fertilizer or manure was applied to the soils when these alfalfas were planted.

Sampling and measurements

Soil water content was determined gravimetrically to a depth of 1000 cm at 20 cm increments at 0 to 200 cm soil layer and at 50 cm increments at 200 to 1000 cm from each of the six grasslands on April 2006. Soil cores taken from every 20 cm soil depth from the surface to 200 cm deep and every 50 cm soil depth from 200 to 500

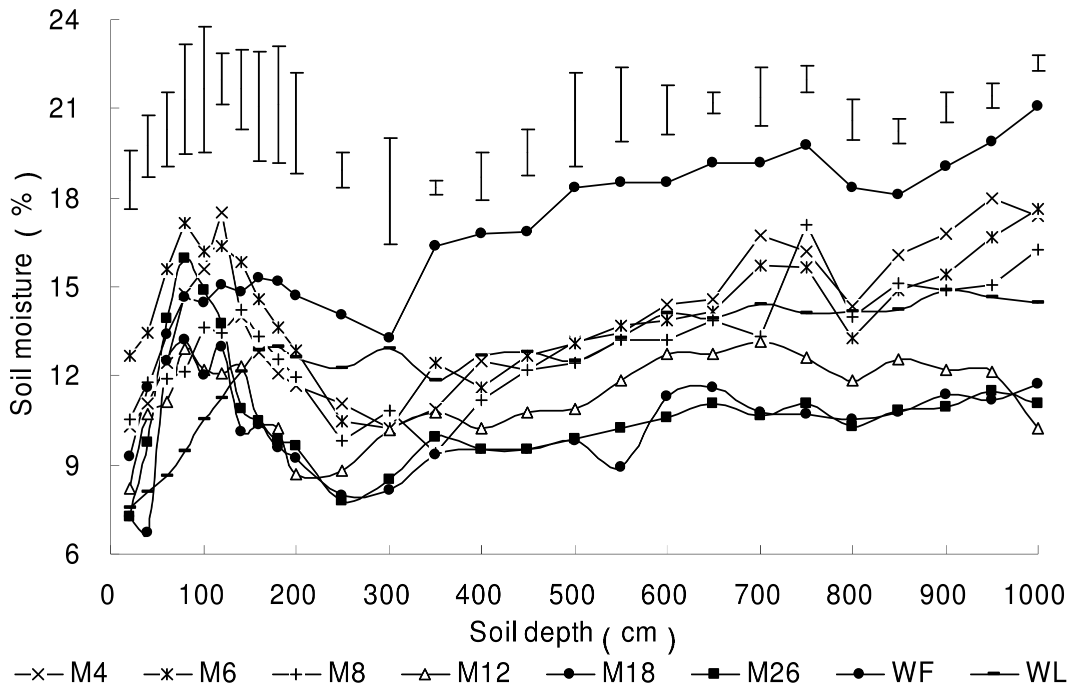

Figure 1. Profiles of soil water variation in 0 to 1000 cm depth under different vegetations. Error bars are the LSD at P= 0.05. M4 to M26 represent 4 to 26-year-old alfalfa grasslands, respectively and WL and WF refer to the waste land and wheat field, respectively.

cm deep were taken randomly from six 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 capacity and soil bulk density were determined according to Robertson et al. (1999). The average bulk density was 1.30 g cm^{-3} in the soil to a depth of 20 cm and 1.35 g cm^{-3} in the layer of 20 to 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):

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

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

Statistical methods

ANOVA from the SAS package was used to conduct the analysis of variance.

RESULTS

Vertical variation of soil moisture under different vegetations

Figure 1 shows the water variation patterns in 0 to 1000 cm soil profiles under different vegetations. There were differences among the soil water contents in the wheat field, wasteland and alfalfa grasslands, but the water variation patterns in the different land use were approximately identical. The soil moisture at a depth of 0 to 300 cm varied greatly, while the value below 300 cm soil layer tended to vary slowly.

The water use in different soil deep is also shown in Figure 1. The field of M6 had the highest water content in the 0 to 200 cm soil deep (14.82%) and then for wheat field and M4, the values for them were 13.85 and 13.22%, respectively. The water contents for M8 and M26 at the same soil layer were 12.5 and 11.63%, respectively, but the wasteland, M12 and M18 grasslands had the lowest moisture content (11.00%). The soil water content for M6, M4, M8 wheat fields and M12 at 0 to 20 cm depth were 12.66, 10.32, 10.51, 9.27 and 8.22%, respectively, but the values for the wastelands, 18 and 26 years alfalfa grasslands only ranged within 7.24 to 7.50%, indicating that the wasteland, 18 and 26 years grasslands had the lowest moisture content and the soil water content of all the 8 land use modes at topsoil were lower because of strong evapo-transpiraton. The soil water content increased with increase in the soil depth. The moisture contents for M6, M26, wheat fields and M4 at 20 to 100 cm were 15.6, 13.63, 13.54 and 13.47%, respectively, the values for M12 and M18 were lower than 12.00%, and wasteland had the lowest soil water content (9.19%), which was 1.90 to 6.41% lower than that of the other land use. The soil water contents for wheat field, M6,

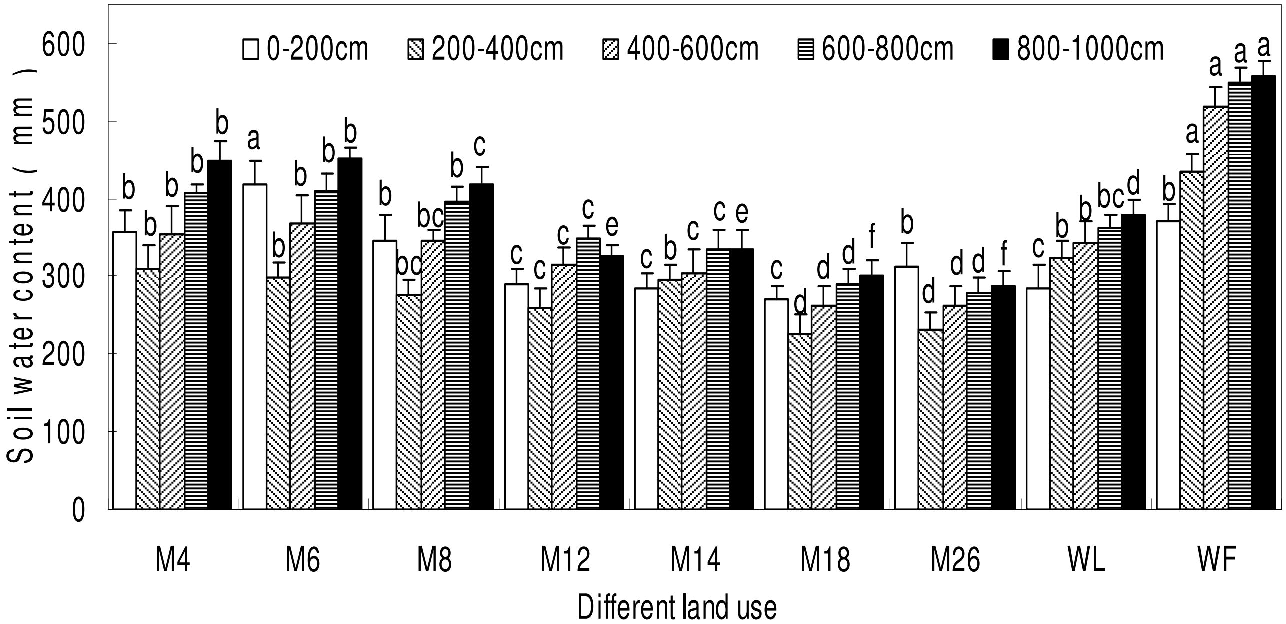

Figure 2. Variation of soil water reserve under different vegetations in 0 to 1000 cm soil deep. Means in different soil layers followed by the same letter were not significantly different at P ≤ 0.05 among the different land use modes. M4 to M26 represent 4-year-old to 26-year-old alfalfa grasslands, respectively and WL and WF refer to waste land and wheat field, respectively.

M4 , M8 and wasteland at 100 to 200 cm were 15.01, 14.64, 13.50, 13.50 and 12.36%, but the values for M12, M18 and M26 only ranged within 10.41 and 10.91%. In 200 to 500 cm soil layer, the water content of the wheat field, wasteland, M4, M6, M8 and M12 were 15.76, 12.50, 11.66, 11.91, 11.03 and 10.05%, respectively, but the values for M18 and M26 were the lowest which was below 9.25%. Meanwhile, the water content for the wheat field at 500 to 1000 cm was 19.16%, the values in 4 and 6 years grasslands were both more than 15.10%, and the soil water contents for M8, wasteland, M12, M18 and M26 were 14.60, 14.22, 12.20, 10.90 and 10.83%, respectively.

In view of the water content at different soil layers, the soil water content of wheat field at 0 to 200 cm was lower than that of the 6 years alfalfa grassland but higher than those of other land use modes. For different number of growing years of alfalfa, the field of M26 had higher water content in 0 to 200 cm soil depth compared to M12 and M18. With the increase of soil depth, the consumption capacities of soil water in 200 to 1000 cm under different vegetations ranked in the order of 18 years alfalfa grassland > 26 years alfalfa grassland > 12 years alfalfa grassland > 8 years alfalfa grassland >wasteland > 6 years alfalfa grassland > 4 years alfalfa grassland > wheat field, which indicated that wheat field had the highest water content and its soil moisture was 3.70 to 7.64% higher than those of other land use modes. We also found that the soil water content in the wasteland was slightly lower than that in the 4 and 6 years alfalfa grasslands but higher than those in 8, 12, 18 and 26 years alfalfa grasslands.

Variations of soil water reserve under different vegetations

The water reserve in 0 to 1000 cm soil profile under different vegetations is presented in Figure 2. The soil water reserve for wheat field, M4, M6, M8, wasteland, M12, M18 and M26 were 2435.5, 1854.2, 1936.5, 1744.4, 1694.6, 1550.0, 1350.1 and 1372.3 mm, respectively, indicating that the wheat field had the highest soil water reserve, than the field for M4, M6 and M8, while the values for M12, M18 and M26 were lower which were 36.4 to 44.6 and 8.5 to 20.3% lower than those for wheat field and wasteland, respectively. For different soil layers, the water reserve of wheat field in each layer except for 0 to 100 cm soil depth was all above 200 mm per meter. The soil water reserve for 4 and 6 years alfalfa grasslands in 0 to 600 cm were both below 200 mm per meter but the values below 600 cm depth were above 200 mm per meter. For 8 years alfalfa grassland, its water reserve below 700 cm soil depth were all above 200 mm per meter and the values for wasteland, M12, M18 and M26 at 0 to 1000 cm were all below 200 mm per meter. Figure 2 also shows that, the 6 years alfalfa grassland had the highest soil water reserve (417.20 mm), the wheat field, M4, M8 and M26, and the field of M12, M18 and wasteland had lower water reserve; all below 300 mm.

The water reserve at a depth of 200 to 1000 cm increased with the increase of soil depth. The soil water

Table 1. Dry soil layer occurrences under different vegetations (%).

Soil depth (cm)	M4	M6	M8	M12	M18	M26	CK1	CK2
100	15.60	16.20	13.60	12.20	12.00	14.90	14.50	10.54*
120	17.50	16.35	13.44	12.08	12.98	13.74	15.07	11.24
140	13.98	15.81	14.22	12.31	10.12*	10.87*	14.84	12.11
160	12.77	14.57	13.32	10.49*	10.38*	10.45*	15.29	12.87
180	12.08	13.62	12.53	10.23*	9.57*	9.84*	15.16	13.00
200	11.66	12.84	11.95	8.71**	9.19*	9.63*	14.69	12.60
250	11.05	10.48*	9.83*	8.79**	7.96**	7.78**	14.02	12.24
300	10.23*	10.23*	10.85*	10.15*	8.15**	8.48**	13.29	12.89
350	10.86*	12.46	9.41*	10.78*	9.32*	9.91*	16.36	11.86
400	12.50	11.59	11.19	10.22*	9.49*	9.53*	16.77	12.68
450	12.17	12.67	12.23	10.79*	9.50*	9.51*	16.86	12.78
500	13.14	13.10	12.41	10.89*	9.82*	9.85*	18.31	12.48
550	13.45	13.69	13.24	11.81	8.91**	10.24*	18.52	13.24
600	14.43	13.85	13.20	12.71	11.32	10.61*	18.49	14.13
650	14.59	14.19	13.85	12.73	11.61	11.10	19.15	13.93
700	16.76	15.71	13.32	13.15	10.78*	10.63*	19.18	14.38

M4 to M26 represent 4- to 26-year-old alfalfa grasslands, respectively and CK1 and CK2 refer to wasteland and wheat field, respectively. *Represent slightly dry soil layer and ** represent moderately dry soil layer.

reserve for wheat field, wasteland and M4 were 434.2, 322.8 and 310.2 mm, respectively, the values for M6, M8 and M12 ranged within 259.4 and 298.8 mm, and the water reserve for M18 and M26 were lowest, (227.1 and 232.0 mm) respectively. Wheat field at 400 to 600 and 600 to 800 cm depth had the highest soil water reserve both of which surpassed 515.0 mm, the field M4, M6, M8, M12 and wasteland had a water reserve ranging within 304.1 and 410.5 mm and the 8 and 26 years alfalfa grasslands had the lowest water reserve (below 300.0 mm). In 800 to 1000 cm soil depth, the water reserve in wheat field was the lowest amounting to 561.0 mm, the values in M4, M6 and M8 grasslands all surpassed 420 mm and the water reserve in wasteland was 378.5 mm; higher than those for M12, M18 and M26 alfalfa grasslands (Figure 2).

Soil desiccation under different vegetations

According to the wilting moisture, field water-holding capacity, plant growth and water deficit of the study area and dry soil layers were classified into three grades in this experiment: slight dry soil layer occurring in the soil with 9 to 11% water content, moderate dry soil layer occurring in the soil with 7 to 9% water content and high dry soil layer occurring in the soil with below 7% water content. The dynamics of soil water content at 120 to 700 cm under different vegetations is shown in Table 1. The thicknesses and desiccation degrees of dry soil layer in the wheat field, wasteland and alfalfa grasslands with different number of growing years differed. In this region, the wilt moisture was 7% and the soil water contents were above 7% in the different soil layers in the wheat field, waste land and alfalfa grasslands, so that no highly dry soil layer occurred. The soil water contents of the wheat field were above 11% in the different soil layers and thus, no dry soil layer appeared. However, slightly dry soil layer appeared in both wasteland and alfalfa grasslands; it appeared in 80 to 100 cm soil depth for wasteland with 10.54% water content, in 250 to 350 cm soil depth for M4 with 10.23 to 10.86% water content, in 200 to 300 cm soil of the grassland with alfalfa growing for six years whose water content was 10.23 to 10.48%; in 200 to 350 cm soil depth for M8 with 9.41 to 9.83% water content, in 140 to 500 cm soil depth for M12 with 8.71 to 10.89% water content, in 140 to 550 cm soil depth for M18 with 7.96 to 10.38% water content and in 120 to 600 cm soil depth for M26 with 7.78 to 10.87% water content. According to the soil desiccation degrees, the soil water contents were all above 9% in the different soil layers after alfalfa grew for ≤ 8 years and thus, no moderately dry soil layer occurred but moderately dry soil Layer took place when alfalfa grew for > 8 years. We found that moderately dry soil layer appeared in 180 to 250 cm soil depth for M12 with 8.71 to 8.79% water content and in 200 to 300 cm soil depth for M26 with 7.78 to 8.48% water content.

Ecological effects of soil water under different vegetations

Compared with alfalfa grasslands, winter wheat consumed water in shallower soil in a shorter time and its soil moisture in 0 to 1000 cm was 16.37%, which was 2.15 to 4.10% higher than those of the other vegetations types and thus, it could not severely affect the ecological environments of the soil water. For wasteland, its water conditions in 0 to 200 cm soil depth were unfavorable and the soil water content was only 10.61%, close to the field of M18 but 0.30 to 4.12% lower than that in wheat field because the compact soil and the weeds made it difficult for the rainfall to penetrate. However, the water content of wasteland in 200 to 1000 cm soil depth reached 13.51%, which was 0.08 to 4.23% lower than those of wheat field, M4 and M6 alfalfa grasslands and 0.46 to 3.41% higher than those of M8, M12, M18 and M26 alfalfa grasslands. Therefore, the water shortage in the upper soil for wasteland was made up by the rainfall and did not affect the ecological environments of the soil water severely. Slightly, dry soil layer for 4 and 6 years alfalfa grasslands occurred at 250 to 350 cm and 200 to 300 cm, respectively, but was small which did not strongly affect the ecological environments of soil water. With increasing years of growth of the seeded alfalfa grasslands, its dry soil layer was deeper and desiccation degrees were thicker. After alfalfa grew for > 8 years, moderately dry soil layer occurred. The dry soil layer for M12 reached 500 cm soil depth and for M18 and M26 expanded below 600 cm. Under the monsoonal conditions characterized by clear cut wet and dry seasons, the consumption and replenishment of the soil water alternated in the 0 to 200 cm soil and the rainfall slightly affected the deep soil of 200 to 1000 cm, whose water was difficult to be supplemented. Thus, once dry soil layer formed, the soil water was not easy to rebound and dry soil layer will remain in the soil deeper than 200 cm below ground permanently.

DISCUSSION

In the Loess Plateau of China, the actual evapotranspiration of vegetations is always more than the precipitation during the growing season. This deficit of water is supplied from the stored soil water but the storage and distribution of soil water are strongly influenced by water use characteristics of the plants. As we know, wheat consumes water in shallow soil for a short time and consequentially, it consumes more water in upper soil than in lower soil. The reason is that, the wheat field went through some farming practices such as plowing and land preparation before planting so that the rainfall could thoroughly infiltrate the wheat field. In our experiments, the water reserve of wheat field at 0 to 200 cm soil depth was lower than that of 6 years alfalfa grassland, but higher than those of wasteland and the other alfalfa grasslands with different number of growing years. The water reserve for wheat field at 200 to 1000 cm was much higher than those of the wasteland and the other alfalfa grasslands. We also found that, the reason for the lower water content in the wasteland with 0 to 200 cm soil depth was that it was unreclaimed and thus, its compact surface made it difficult for the rainfall to infiltrate into soil and its exposed surface led to strong evaporation together with weed consumption of the soil water. A study by Li (2002) revealed that, a clear soil drying tendency and dry soil layer concurred in the wheat field. However, the results of the study indicated that, there was no dry soil layer occurrence in the soil profile in wheat field, which was consistent with what was achieved by Liu et al. (2004). Li (2002) took the 75% of the field water-holding capacity as the ceiling to confirm dry soil layer and in his study, dry soil layer was thought to occur in wheat field when the soil water content amounted to 14.74% in the wheat field. This did not follow the limits that the study formed to confirm dry soil layer. Moreover, the water content of the wasteland in 200 to 1000 cm soil depth was lower than those of the wheat field, than those of the 4, 6 and 8 years alfalfa grasslands but was higher than those of 12, 18 and 26 years alfalfa grasslands, which could be because the long-term weed growth caused the consumption of water at the deep soil was. For alfalfa grasslands with different growing phase, there existed differences among the soil water consumptions. With increasing years of growth of the seeded alfalfa grasslands, the roots distribution of alfalfa became deeper and water consumption in the deep soil was intensified, which caused water deficiency in the deep soil. When alfalfa grew for 26 years and entered into the senescence stage, it reduced water consumption in the upper soil and had higher water storage, while the high accumulative water consumption in the deep soil at the early growth period of the 26 years alfalfa resulted in intensified desiccation at the deep soil. A study by Liu et al. (2005) revealed that, with increasing years of growth of the seeded alfalfa grasslands, dry soil layer gradually moved upward and its thickness tended to decrease, which was inconsistent with our results. In this experiment, we found that as alfalfa growth prolonged, dry soil layer widened downward and its desiccation degree increased, which agrees with the results by many other researchers (Huang et al., 2003; Liu et al., 2003; Cheng et al., 2005; Yang et al., 2006). Alfalfa grassland with short-term growth resulted in low soil water consumption and then slightly dry soil layer occurred in the upper soil, whereas alfalfa with long-term growth led to deeper soil distribution of alfalfa roots and intensified high deep soil water consumption, which along with great accumulative water consumption in early alfalfa growth caused soil desiccation in deeper soil to be intensified and widen downward. Consequently, alfalfa growth phase that lasted for more than eight years led to the occurrence of moderately dry soil layer, its growth phase that lasted for 12 years resulted in dry soil layer below 500 cm and the growth phase that lasted 18 and 26 years caused dry soil layer to expand deeper than below 600 cm. A study by Li and Shao (2005) showed that, it probably took six-ten years for alfalfa grassland to succeed into natural secondary grassland vegetations. Considering all the factors, this study recommends that if alfalfa grasslands are grown for more than six years, grass-crop rotation should be practiced to recover soil moisture in the Loess Plateau of northwest China to raise land productivity and promote agricultural sustainable development.

Conclusions

The soil water variations at 0 to 1000 cm depth of the waste land, wheat land and different growth years of alfalfa grassland were conducted at the Zhenyuan Agri-ecological Station of the Loess Plateau in China to study the long-term effects of alfalfa on soil water content and determine the optimal length of alfalfa phase in the grass-crop rotation system. The following conclusions can be drawn from this study: (1) the soil water content of wheat field below 100 cm soil layer was higher than those of the wasteland and alfalfa grasslands. And when alfalfa grew for over certain years, its root vigor declined and biomass decreased entering into senescence stage, which resulted in alfalfa with lower consumption of soil water in intensity. The soil water content could be recovered to some extent, but the recovery was slow because of soil water over-consumption and low rainfall, which only made water content, rebound slowly and gradually in the upper soil. It was difficult to do so in the deep soil. Moreover, with increasing years of growth of the seeded alfalfa grasslands, the water consumption of alfalfa intensified in the deep soil and soil dry layer occurred. When alfalfa grasslands grew for > 6 years, its soil water content was even lower than that of wasteland; (2) the measured soil water contents in the different soil layers of 0 to 1000 cm indicated that, the consuming capacities of soil water under different vegetations ranked in the order of 18-year-old alfalfa grassland > 26-year-old alfalfa grassland > 12-year-old alfalfa grassland > 8-year-old alfalfa grassland > wasteland > 6-year-old alfalfa grassland > 4-year-old alfalfa grassland > wheat field, which suggested that wheat field had the most favorable water conditions under the different vegetations; (3) in the Loess Plateau, the limits and locations of dry soil layer differed among the different vegetations. No dry soil layer occurred in the wheat field but appeared in both waste-land and alfalfa grasslands with different number of growing years. The wasteland in 80 to 100 cm soil depth, appeared as slightly dry soil layer, alfalfa less than 8 years in 160 to 600 cm soil depth also appeared as slightly dry soil layer and alfalfa over 8 years appeared as moderately dry soil layer, whose dry layer thickness prolonged below and its desiccation degrees intensified with alfalfa growth phase. From the ecological effects of water, winter wheat field, wasteland and the alfalfa grasslands grew for 4, 6 and 8 years had no unfavorable impacts on the ecological environments of the soil moisture but the grasslands for 12, 18 and 26 years did exert relatively stronger unfavorable influences on the hydrological effects. Considering all these factors, this study recommends that the optimal length of alfalfa phase should be 8 years.

ACKNOWLEDGEMENTS

This work was supported by China Postdoctoral Fund Program (20090451406) and Special Financial Aid Program for China Postdoctoral Science Fund (201003687). We are grateful to Professor X.Y. Li and Business Manager John Freitas from Fresno County Library System, USA, for their constructive comments and kind help with the language of this manuscript. We also would like to thank the staff of the research center of dryland farming in the arid and semiarid areas, of the Northwest A&F University.

REFERENCES

Beate K, Haberlandt U (2002). Impact of land use changes on water dynamics-a case study in temperate meso and macroscale river basins. Phys. Chem. Earth, 27: 619-629.

Chen HS, Shao MA, Wang KL (2005). Desiccation of deep soil layer and soil water cycle characteristics on the Loess Plateau. Acta Ecologica Sinica, 10: 2491-2498.

Cheng JM, Wan HE, Wang J (2005). Alfalfa growth and its relation with soil water status in loess hilly and gully region. Chinese J. Appl. Ecol. (in Chinese), 3: 435-438.

Connor DJ (2004). Designing cropping systems for efficient use of limited water in southern Australia. Eur. J. Agron. 21: 419-431.

Domingo F, Villagarcı'a L, Boer MM, Alados-Arboledas L, Puigdefa'bregas J (2001). Evaluating the long-term water balance of arid zone stream bed vegetation using evapotranspiration modeling and hill slope runoff measurements. J. Hydrol. 243: 17-30.

Fan J, Hao MD, Shao MA (2004). Water consumption of deep Soil layers and eco-environmental effects of agricultural ecosystem in the Loess Plateau. Trans. CSAE. 20(1): 61-64.

Fernández JE, Slawinski C, Moreno F, Walczak RT, Vanclooster M (2002). Simulating the fate of water in a soil-crop system of a semi-arid Mediterranean area with the WAVE 2.1 and the Euro-Access-II models. Agric. Water Manage. 56: 113-129.

Gomez-Plaza A, Martinez-Mena M, Albaladejo J, Castillo VM (2001). Factors regulating spatial distribution of soil water content in small semiarid catchments. J. Hydrol. 253: 211-226.

Grayson RB, Western AW, Chiew FHS, Bloschl G (1997). Preferred states in spatial soil moisture patterns: local and nonlocal controls. Water Resour. Res. 33: 2897-2908.

Huang MB, Yang XM, Li YS (2003). Hydro-ecological effect of the soil dry layer as affected by biota use in the Loess Plateau. Chin. J. Eco-

Agric. 3: 114-116.
Saeed IAM, El-Nadi Saeed AH (1997). Irrigation effects on the growth, yield, and water use efficiency of alfalfa. Irrig. Sci. 17: 63-68.
Jia Y, Li FM, Wang XL (2006). Soil quality responses to alfalfa watered with a field micro-catchment technique in the Loess Plateau of China. Field Crops Res. 95, 64-74.
Jiang HM, Jiang JP, Jia Y, Li FM, Xu JZ (2006). Soil carbon pool and effects of soil fertility in seeded alfalfa fields on the semi-arid Loess Plateau in China. Soil Biol. Biochem. 38: 2350-2358.
Kerkhoff AJ, Martens SN, Shore GA, Milne BT (2004). Contingent effects of water balance variation on tree cover density in semiarid woodlands. Global Ecol. Biogeography, 13: 237-246.
Li YS (2001). Fluctuation of yield on high-yield field and desiccation of the soil on dryland. Acta Pedologica Sinica, 3: 353-356.
Li YS (2002). Productivity dynamic of alfalfa and its effects on water eco-environment. Acta Pedologica Sinica, 3: 404-411.
Li YS, Huang MB (2008). Pasture yield and soil water depletion of continuous growing alfalfa in the Loess Plateau of China. Agric. Ecosyst. Environ. 124: 24-32.
Li YY, Shao MA (2005). Degradation process and plant diversity of alfalfa grassland in North Loess Plateau of China. Chinese J. Appl. Ecol. 12: 2321-2327.
Liang YM, Li DQ, Cong XH (1990). The biomass and water use of *Astragalus Adsurgens* Grassland on the semiarid Loess Plateau. J. Soil Water Conserv. 3: 71-78.
Liu G (1999). Soil conservation and sustainable agriculture on the Loess Plateau: challenges prospects, Ambio. 28: 663-668.
Liu G, Wang ZQ, Wang XL (2004). Analysis of dried soil layer of different vegetation types in wuqi country. Res. Soil Water Conserv. 1: 126-129.
Liu PS, Li J, Jia ZK (2005). Soil water study of alfalfa grass water consume disciplinarian and resume effect while grain-grass rotation in the arid regions of southern Ningxia. Chin. Agric. Sci. Bull. 9: 270-274.
Liu WZ (2000). Problems in research on water behaviour, its ecological effect and the optimal regulation of small watershed. Adv. Earth Sci. 5: 65-70.
Liu WZ, Hu MJ, Hou XL (2003). Soil water ecological characteristics in a cross section of small watershed in a semi-arid loess hilly area. Agric. Res. Arid Areas, 4: 95-100.
Lørup JK, Refsgaard JC, Mazvimavi D (1998). Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modeling: case studies from Zimbabwe. J. Hydrol. 205: 147-163.
Porporato AF, Laio F, Ridolfi L, Rodriguez-Iturbe I (2001). Plants in water-controlled ecosystems: active role in hydrological processes and response to water stress. III vegetation water stress. Adv. Water Res. 24: 725-744.
Robertson GP, David CC, Caroline SB, Philip S (1999). Standard soil method for long-term ecological research. Oxford University Press, New York, pp. 75-77.
Shangguan ZP, Zheng SX (2006). Ecological properties of soil water and effects on forest vegetation in the Loess Plateau. International J. Sustainable Dev. World Ecol. 4: 307-314.
Steppuhn H, Waddington J (1996). Conserving water and increasing alfalfa production using a tall wheatgrass wingbreak system. J. Soil Water Conserv. 51: 439-445.
Wang GL, Liu GB, Chang X (2002). A Study on the effect of soil water on vegetation rehabilitation in watershed of Loess hilly area. J. Natural Res. 3: 339-344.
Wang XL, Sun GJ, Jia Y, Li FM, Xu JZ (2008). Crop yield and soil water restoration on 9-year-old alfalfa pasture in the semiarid Loess Plateau of China. Agric. Water Manage. 95: 190-198.
Yang WZ, Yu CZ (1992). Regional management and evaluation in the Loess Plateau. Beijing: China Sci. Press, pp. 292-296.
Yang YH, Zhao SW, Liu NN, Wu JS, Su J, Xu J (2006). Soil moisture characteristics of different vegetation measures in loess hilly region of southern Ningxia. Sci. Soil Water Conserv. 2: 24-28.