Agricultural Water Management 138 (2014) 10–16

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Mulching effects on water storage in soil and its depletion by alfalfa in the Loess Plateau of northwestern China

Fan Jun[a,b,*], Gao Yu[a,b], Wang Quanjiu[b], Sukhdev S. Malhi[c], Li Yangyang[a,b]

[a] Northwest Agriculture and Forestry University, Yangling, Shaanxi 712100, China
[b] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences, Yangling, Shaanxi 712100, China
[c] Northwest Agriculture Research Foundation (NARF), Melfort, Saskatchewan, Canada

ARTICLE INFO

Article history:
Received 21 June 2013
Accepted 27 February 2014
Available online 16 March 2014

Keywords:
Forage yield
Straw mulch
Loess Plateau
Soil temperature
Soil water
Gravel mulch

ABSTRACT

In the dryland region of the Loess Plateau of northern China, alfalfa (*Medicago sativa* L.) is widely grown for animal feed to develop livestock operations, while also reducing soil erosion and improving soil fertility/quality. A field experiment was carried out on a sandy loam soil from April 2007 to October 2012 to evaluate the processes of soil desiccation in the 500 cm soil profiles, and the effects of mulch management on soil water content and temperature in the upper soil layer (5–15 cm), water use efficiency (WUE) and forage dry matter yield (DMY) of alfalfa in rainfed pasture land. Three treatments were: no mulch control, gravel mulch and corn straw mulch. Corn straw and gravel were chosen, because these materials can be obtained easily in this region. Soil depth of water uptake by alfalfa moved down to deep soil quickly and seasonal rainfall became the main contributing factor after 5 years. The presence of straw on the soil surface reduced the maximum temperature, but it increased the minimum diurnal soil temperature. Straw mulch was more effective in regulating soil temperature than gravel in the pasture planting. Straw mulch and gravel mulch both enhanced soil water content at the 15 cm depth. Straw mulch increased forage DMY of alfalfa by 420 kg ha^{-1} (by 6.7%) compared to no mulch control over the four growing seasons from 2009 to 2012, and gravel mulch reduced the forage DMY by 36 kg ha^{-1} (by 0.5%) during that period, but effects were not significant statistically. Straw mulch increased concentration of nitrate-N and available P in the upper soil layer significantly, and improved WUE. In conclusion, the findings suggest that alfalfa could extract water from progressively deeper soil layers and straw mulch was effective in minimizing fluctuations in soil temperature, and increasing water storage in surface shallow soil layers, forage yield and water use efficiency of alfalfa. Mulching grass hedges intercropping or contour hedgerow intercropping should be considered on sloping land.

1. Introduction

Alfalfa has a high evapotranspiration rate and deep roots that give it access to deeper soil water than annual pastures and crops (Scott and Sudemyer, 1993; Crawford and Macfarlane, 1995; Ward et al., 2002). Rainfed land could show about 30% reduction in biomass production compared to irrigated alfalfa. This certainly represents a valuable result for environments with no or low water availability (Testa et al., 2011). Research has shown that irrigated perennial forages use more water than annual crops or pastures at many locations across Australia (e.g., Angus et al., 2001; Latta et al., 2001; Greenwood et al., 2009). As the availability of irrigation water is decreasing and its costs are increasing, deficit irrigation of alfalfa is used as a strategy for providing water in water-short regions (Hanson et al., 2007). But, for rainfed pasture, improving water use efficiency (WUE) is the optimal approach.

Alfalfa is usually planted for a long time to reduce soil erosion and increase soil fertility in the Loess Plateau, China. Alfalfa is also used as primary species in a series of large vegetation restoration campaigns, such as the “Grain to Green”. However, as a deep-rooted perennial legume, planting alfalfa can lead to soil desiccation in the field due to water over-use (Chen et al., 2008; Li and Huang, 2008; Jia et al., 2009; Fan et al., 2010; Wang et al., 2010). Li and Huang (2008) reported that the decreased soil water storage resulted in forage yield responding more vigorously to variations in annual precipitation after continuously growing over 8 years in continuous

* Corresponding author at: Northwest Agriculture and Forestry University, Yangling, Shaanxi 712100, China. Tel.: +86 29 87010162; fax: +86 29 87012884.
E-mail address: fanjun@ms.iswc.ac.cn (F. Jun).

http://dx.doi.org/10.1016/j.agwat.2014.02.018
0378-3774/

alfalfa treatment. Field surveys have shown that dried soil layers were common in some locations on the Loess Plateau (Li and Huang, 2008; Fan et al., 2010; Yang et al., 2012), even the dry soil layers exist in whole region (Wang et al., 2011), but only few experiments were continued for several years to show how soil layers become dry (Fan et al., 2010, 2011). However, understanding the process of soil desiccation in the semiarid region of the Loess Plateau and in similar regions elsewhere enables scientifically based approaches to be used that would alleviate the process of soil desiccation and prolong vegetation productivity.

The use of gravel and straw mulch are two traditional techniques that are still practiced in the dryland farming area of north China. Fields mulched with gravel and sand are mainly distributed in the western part of the Loess Plateau, because the gravel and sand are available in this area. Xie et al. (2010) recommended the use of gravel-sand mulch with particles smaller than 2 cm to improve watermelon yield. In this practice, the labor cost increased significantly, because the gravel-sand has to be removed away when annual crops are planted regularly. Straw mulching is regarded as one of the best practical methods to improve water retention in the soil and reduce soil evaporation (Steiner, 1989; Li and Xiao, 1992; Baumhardt and Jones, 2002). Straw mulch was also found to be an effective approach for sustainable wheat production in upland ecosystems on the Loess Plateau region (Huang et al., 2005; Zhang et al., 2007, 2009). In northern Vietnam and eastern India, straw mulch has also shown increase in yield of oilseed crops groundnut and yellow sarson, respectively (Ramakrishna et al., 2006; Sarkar et al., 2007). However, in the North China Plain, straw mulch delayed winter wheat growth stages and reduced grain yield (Chen et al., 2007). Therefore, the effectiveness of mulching may vary in different climatic zones and cropping systems, and the research information on this topic is limited. Fertilization can postpone the degradation of alfalfa compared to no fertilization according to field observations (Li, 2002; Fan et al., 2011), but it is rarely used by farmers due to economic factors.

It is urgent to explore how alfalfa depletes soil water, and find an alternative method to postpone the degradation of alfalfa in this region. The purpose of this study was to illustrate soil desiccation process and examine the effects of mulching on soil temperature, soil water content and forage dry matter yield (DMY) of alfalfa in pasture land in the semi-arid Loess Plateau of northwest China. We specifically focused on straw or gravel mulching methods that can help forage production in arid and semi-arid regions.

2. Materials and methods

2.1. Site and soil information

A field experiment on alfalfa pasture land was conducted from April 2007 to October 2012 in the highland region of northwestern China in Shenmu County, Shaanxi Province. Mean annual rainfall at the Shenmu field experiment station is 435 mm and mean temperature is 8.4 °C. Precipitation occurs mainly between May and September, when air temperature is also higher during this period. The soil was a coarse-textured loessial soil and 0–500 cm soil profile was separated into four layers. Samples collected at the beginning of the experiment had the following characteristics: SOM (soil organic matter) = 5.6 ± 1.2 g kg^{-1}, total N = 0.36 ± 0.08 g kg^{-1} and total P = 0.42 ± 0.03 g kg^{-1}.

2.2. Field experimental design and measurements

There were three treatments, viz., straw mulch (SM), gravel mulch (GM) and no mulch control (CK). All the treatments were replicated three times in a randomized complete block design. Each plot was 20 m^2 and a 5-m long aluminum tube was installed at the center of each plot. Soil water content was measured once every two months using a neutron probe (CNC, Beijing, China) at 10 cm (0–100 cm) and 20 cm (100–500 cm) intervals down to 500 cm. Two digitized time domain transmissometry (TDT) soil moisture sensors (Acclima Inc., Meridian, ID, USA) were buried horizontally in soil at 5 and 15 cm depths to measure soil temperature and volumetric water content (VWC) automatically, since all 18 sensors were connected to CR1000 data logger (Campbell Scientific, Logan, UT, USA). Measurements were taken daily at 1-h intervals and the accuracy of the TDT sensor for permittivity is ±1% (±1 from the full scale range and the temperature from 1 to 50 °C) and the Topp equation was used to calculate VWC from permittivity. Oven dry method was used to calibrate TDT sensor and parameters were compiled into data logger program in order to give the final results from downloaded data. Each TDT sensor had a thermistor inside to measure soil temperature.

Alfalfa was planted in May, 2007, after cultivation of the experimental plot area with typical local crops for almost 30 years. In spring, 2009, corn straw was cut into 3–5 cm pieces and covered the bare soil almost 90% in the SM treatment. The corn straw was selected because large areas of corn are planted in the terrace in this region, where soil water conditions are better than slope land. The sloping lands have been changed to pasture or shrub under project "Grain to Green" in this catchment. Calcareous concretions (hereafter called "gravel") were used as mulching material to cover soil approximately 90% in the GM treatment, since calcareous concretions are plentiful in the Loess Plateau region.

Alfalfa was cut two times every year in August and October and the forage DMY was determined from an area 1.0 m × 1.0 m in the center of each plot. Majority of DMY came from August cutting, because alfalfa usually starts growth in the middle of April and perishes in early October due to cold air temperature.

The total water use (ET – evapotranspiration) was calculated from the difference between initial soil water content and final soil water content (ΔW), and precipitation (P) during the growing season by using the following equation:

$$ET = P + \Delta W \quad (1)$$

Due to the high infiltration rate of water in soil, runoff was never observed in the field and there was no irrigation of the field. Because of the deep groundwater table (more than 50 m below the surface), capillary rise was considered negligible and not included. Deep percolation below the root zone was negligible, since the maximum depth of infiltration and redistribution was limited to top 200 cm and soil water content was measured down to 500 cm. Rainfall was recorded at a meteorological station 150 m away from the experimental plots. The water use efficiency (WUE, kg DMY mm^{-1} ha^{-1}) was calculated as forage DMY (Y, kg ha^{-1}) divided by ET:

$$WUE = \frac{Y}{ET} \quad (2)$$

Recharge depth and water uptake depth were determined from soil water profile measurements. Recharge depth was the maximum depth of precipitation infiltration and redistribution within the growing season and water uptake depth was the soil layers where soil water decreases were observed within the growing season. This method can only be used in the arid or semi-arid regions where recharge depths are shallower than the depth of root water uptake. Meanwhile, root zone is far away from ground water table, and soil water movements are in the unsaturated soil in most of the time.

Soil samples (0–20 cm depth) for organic matter, total N, total P, ammonium-N, nitrate-N and available P were collected in October in selected years (2010, 2011 and 2012), and then air dried and ground to pass through a 0.25-mm sieve for chemical analysis.

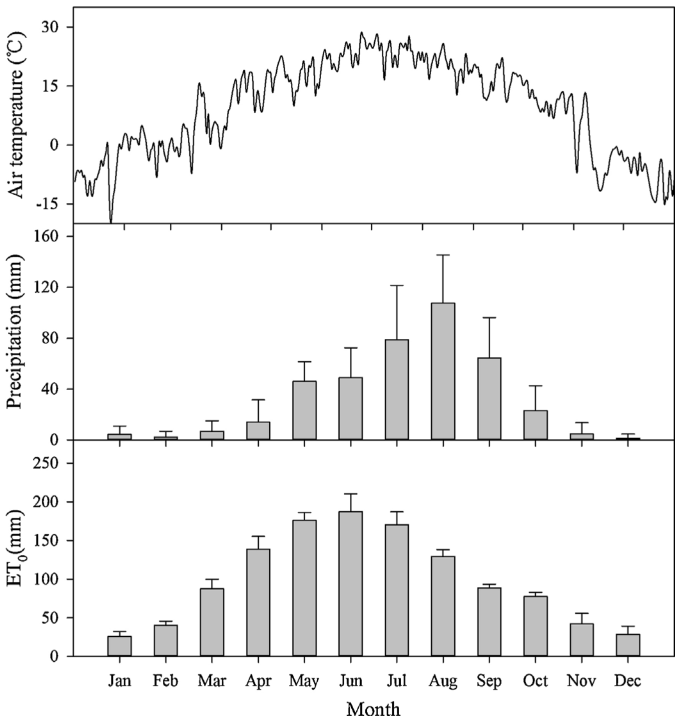

Fig. 1. Daily time series of air temperature, monthly reference crop evapotranspiration (ET_0) and precipitation.

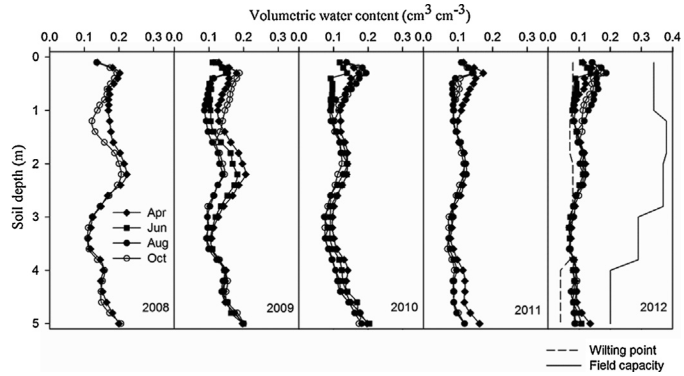

Fig. 2. Soil water content changes in the soil profiles during the study years from 2008 to 2012 in a field experiment on alfalfa pasture land at Shenmu, Shaanxi, China. All data were obtained from the no mulch treatment as a representative.

Standard Chinese methods were used to analyze soil chemical properties (Liu, 1998). Ammonium-N, nitrate-N, available P were determined by extracting soil samples with KCl and $NaHCO_3$, respectively, by using colorimetric methods.

2.3. Statistical analysis

All the data from different parameters were statistically analyzed using analysis of variance (ANOVA) to determine the significant differences in forage DMY and WUE among different treatments. When the *F*-test indicated statistical significance at $P < 0.05$, least significant difference ($LSD_{0.05}$) was used to determine the significance among treatment means.

3. Results and discussion

3.1. Changes of meteorological condition

Meteorological observations in the experimental site showed that mean daily air temperature was 9.0 °C with a maximum of 31.2 °C and minimum of −20.2 °C, suggesting that important features of the climate had large range of temperature variation and short vegetation growing seasons (April–October) (Fig. 1). Mean daily relative humidity was 47%, with a minimum of 8.9% and maximum of 95.7%. Mean daily solar radiation was 16.5 MJ m^{-2} d^{-1}, ranging from 0.9 MJ m^{-2} d^{-1} to 32.5 MJ m^{-2} d^{-1}. Mean daily wind speed was 2.8 m s^{-1}, with maximum of 7.8 m s^{-1}. There were 226 rainfall events during the observation period between 2008 and 2012, of which 49% were less than 5 mm, 39% between 5 and 20 mm, and 12% more than 20 mm. During the study periods, 94% of the total precipitation occurred from April to October (Fig. 1). While soil erosion was controlled by heavy rainfall events and the heavy wind speed also led to wind erosion in this region. Mean annual reference crop evapotranspiration (ET_0) calculated by Penman–Monteith equation (Allen et al., 1998) was 1193 mm over 5 years from 2008 to 2012, but monthly ET_0 distribution did not consistently correspond to precipitation distribution.

3.2. Soil water depletion by alfalfa

Initial and final soil water storage decreased with time in the continuous alfalfa growing, except final soil water storage in 2012 (Table 1). Average annual alfalfa evapotranspiration over 5 years was 491 mm and reference evapotranspiration for a grass surface (ET_0) was 968 mm during forage growing seasons, but average rainfall was 437 mm over 5 years. Alfalfa grew under water stress condition and it had access to deeper soil water which led to negative soil water balance in most years. Since there were no differences of soil water contents in the deep soil profiles among the three treatments, the values of soil water content in the no mulch control treatment are presented to show changes in soil water contents during the study periods (Fig. 2). As affected by soil texture, there was a small peak of soil water content in about 1-m depth. Moreover, the 30 cm soil layer was compacted by former cultivations, so, there also was a peak of soil water content.

Mulching did not affect VWC in deeper soil layers from 2009 to 2012, but alfalfa could absorb soil water from deeper soil layers quickly and the water exchange depth was affected by precipitation and evapotranspiration. Because of its high productivity and a prolonged growing season, alfalfa may consume more water than crops or native grasses. Previous research studies have shown that alfalfa can lead to deep soil desiccation (Chen et al., 2008; Wang et al., 2008; Fan et al., 2010). In our study, field observed data can give soil desiccation processes, which was not shown in previous research investigations.

Alfalfa absorbed 271 mm water from the soil profile during the 5 study years (i.e., 54.2 mm per season) and the ET was underestimated slightly since the root uptake depth has exceeded 500 cm observed depth in 2011 and 2012. Since all access tubes were set up in 2007, there were no observed data in this year. Soil water content distribution in the soil profile showed that maximum depth of water absorption by alfalfa in 2008 was 240 cm, and it was 330 cm in 2009, but the recharge depth was 160 cm only (Fig. 2). The root uptake zone was about 420 cm soil profile and recharge depth was 100 cm in 2010. Precipitation was 460 mm in 2009, which stored in soil and also precipitation was 434 mm in 2010. But, the soil water from depths deeper than the measured depth of 500 cm was absorbed by alfalfa in 2011 and the recharge depth was only 70 cm during the rainfall season. Alfalfa used water from deep soil since the precipitation was 324 mm in 2011, and it is possible to absorb soil water from deeper than 350 cm layers with the water depletion in the measured depth in our study. In 2012, there was 550 mm precipitation, but the soil water recharge depth was about 140 cm. Soil water had decreasing trend at 400–500 cm, which indicated that alfalfa absorbed water from 0 to 140 cm and also may have taken up water from layers deeper than 400 cm. At the same site,

Table 1
Soil water balance from 2008 to 2012 in a field experiment on alfalfa pasture land at Shenmu, Shaanxi, China (soil water content sampling depth was 5.0 m and seasonal balance was calculated in the no mulch treatment as a representative).

Year	Precipitation (mm)	Initial water storage (mm)	Final soil water storage (mm)	Balance ΔW[c] (mm)	ET[d] (mm)	ET_0[e] (mm)	Recharge depth (cm)	Water uptake depth (cm)
2007	423	–[a]	–	–	–		–	–
2008	417	853 ± 29[b]	792 ± 14	−61	478	950	–	0–240
2009	460	761 ± 14	698 ± 13	−63	523	1021	160	0–330
2010	434	661 ± 31	588 ± 12	−73	507	964	100	0–420
2011	324	570 ± 5	480 ± 12	−90	414	980	70	0–120 and below 350
2012	550	496 ± 10	512 ± 15	16	534	928	140	0–140 and below 400

[a] No measurement made.
[b] Standard deviation
[c] ΔW = water storage change.
[d] ET = evapotranspiration of alfalfa.
[e] ET_0 = reference crop evapotranspiration.

the rate of alfalfa root growth was 1 cm per day in the first year and it decreased to 0.6 cm d^{-1} in the second year at the same site (Qi et al., 2009). They suggested that soil water content had significantly impact on above ground biomass of alfalfa, but no effect on root growth (Qi et al., 2009). Therefore, the root depth should be 150, 240, 330 and 420 cm in 2007, 2008, 2009 and 2010, respectively, before parts of soil profile became dry in this study according to the rate of root growing. The estimated root depths data had good correspondence to alfalfa water uptake depth (Fig. 2 and Table 1) and the increasing rate was 90 cm per year, suggesting that root penetrated fast in the coarse soil and depleted soil water quickly. It is possible that the rooting rate may have slowed down after 2011 because of the dry layers between 140 and 400 cm in soil profile. In our other experiment in the semi-humid zone where average annual precipitation is 584 mm and soil had higher water holding capacity under fine soil texture condition than coarse soil, soil desiccation process was very different (Fan et al., 2011). In that study, alfalfa absorbed soil water down to 10 m from 1984 to 2008 and the soil water content decreased continuously and the average rate was 30 cm per year, because the fine soil held more water in soil profile during the study period. Liu et al. (2010) also found a negative relationship between deep soil water content and plant age in this site. In our present study, deep soil water was consumed much faster by alfalfa, because there was a lower amount of rain and thus, less available soil water.

In our study, the method used to calculate recharge depth and water uptake depth according to soil water profiles may have underestimated or overestimated depths, because of the two months interval when soil water increased or decreased during intervals. And also it may have missed accurate results when water uptake depth exceeded observed depth, but it still gave insights of soil desiccation processes. Moreover, our results got verification from estimated root growth as discussed above.

Overall, soil water below 140 cm in the profile was depleted in 4 years when alfalfa was planted. The dried soil layer made different water cycle: available soil water for alfalfa came from annual rainfall, and recharge was blocked below 140 cm. The findings suggest that pasture yield would be controlled by annual rainfall and also the rainfall distribution in year was important to alfalfa growth because deeper soil water may eventually be depleted. Maximizing WUE is the only way to maintain pasture productivity, so it is valuable to test any methods, such as mulching, to improve WUE of pasture in this region.

3.3. Effects of mulching on soil water and temperature in the shallow soil

During the experimental period, soil temperature in alfalfa land varied from −12.2 to 31.2 °C at 5 cm. Soil temperature was affected by surface mulching in the pasture land. Soil temperatures at the 5 and 15 cm depths showed that SM decreased daily mean soil temperature distinctly in the shallow soil layers during the warmer period by 0–4.4 °C, and increased it during the colder period by 0–2.2 °C compared to that of no-mulched control (Fig. 3; Table 2). The results of our study are comparable to other research related to the effects of wheat straw on soil temperature in winter wheat cropping system on the Loess Plateau of China (Zhang et al., 2009). In our study, different mulching materials showed different effects on soil temperature. Gravel mulch increased soil temperature in some cases, especially during the warmer period, while it also decreased soil temperature in some other cases. Moreover, the amplitude of temperature affected by SM was more than GM (Fig. 3). According to daily average temperatures (Table 2), SM decreased soil temperature by 1.0 and 0.9 °C at the 5 cm and 15 cm depths, but GM decreased soil temperature by only 0.3 °C and 0.5 °C at the 5 cm and 15 cm soil depth, respectively.

After daily maximum and minimum temperatures at the 5 and 15 cm soil depths were compared, SM significantly reduced the maximum soil temperature during the warm season. But,

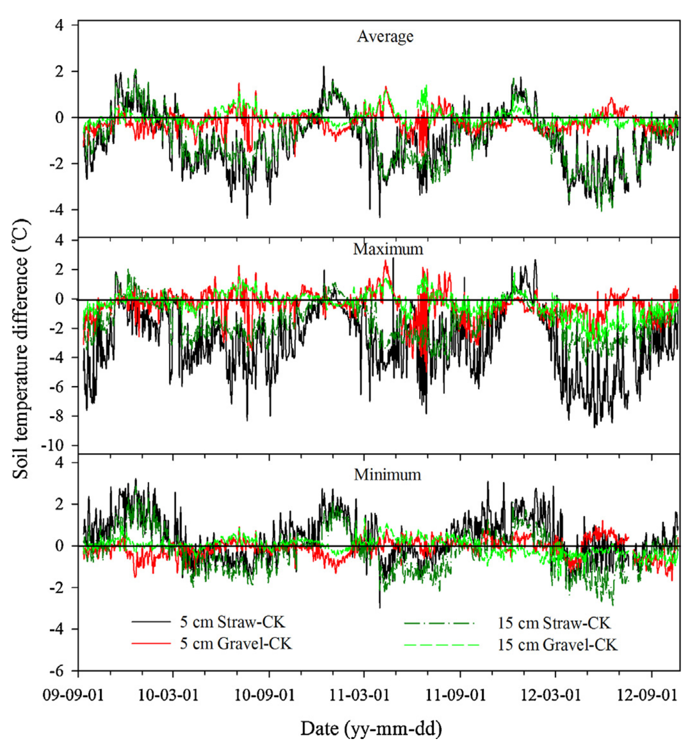

Fig. 3. Temperature differences between straw mulch (SM) or gravel mulch (GM) treatments and no mulch control (CK) at 5 and 15 cm soil depths in a field experiment on alfalfa pasture land at Shenmu, Shaanxi, China. Daily average values calculated from hourly measurements and mean soil temperature was showed in figure from three replications.

Table 2
Effects of mulching on mean soil temperature (°C) at the 5 and 15 cm depths in a field experiment on alfalfa pasture land at Shenmu, Shaanxi, China.

	5 cm				15 cm			
	CK[a]	SM	GM	$LSD^{b}_{0.05}$	CK	SM	GM	$LSD_{0.05}$
Daily average temperature	9.7	8.7	9.4	0.41	9.7	8.8	9.2	ns
Daily maximum temperature	15.0	11.8	14.5	0.20	11.8	10.3	11.0	ns
Daily minimum temperature	6.2	6.2	5.6	ns[c]	7.9	7.7	7.4	ns

[a] CK, control; SM, straw mulch; GM, gravel mulch.
[b] LSD, least significant difference.
[c] ns, not significant.

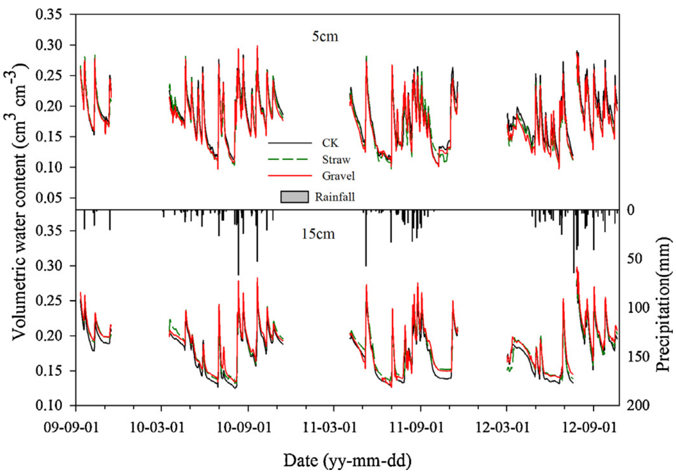

Fig. 4. Effects of no mulch control (CK), gravel mulch (GM) and straw mulch (SM) on soil water content at the 5 and 15 cm depths in a field experiment on alfalfa pasture land at Shenmu, Shaanxi, China. Daily average values calculated from hourly measurements and mean soil water content was showed in figure from three replications. An average low standard deviation (0.01 $cm^3\ cm^{-3}$) indicates that the data points tend to be very close the mean. All data on soil temperatures below 0 were deleted, because soil water content could not be measured by TDT sensor according to the measurement theory when soil water is frozen.

SM increased minimum soil temperature during the cold season distinctly. However, there were no distinct differences in the maximum and minimum soil temperatures in the GM treatment compared to CK. Gravel mulch probably reduced the minimum soil temperature during the cold months (Fig. 3). Straw mulch had more effect on decreasing daily maximum temperature than GM, but SM improved daily minimum temperature at the 5 cm soil depth only. In summary, SM was more effective in regulating soil temperature than GM in the pasture land, like it did in the food cropping systems (Zhang et al., 2009). However, there were no distinct effects of mulching on soil water content at the 5 cm depth (Fig. 4). The shallow soil layer (e.g., 0–5 cm) was wetted by rainfall and dried out after precipitation quickly, because of intense solar radiation and heavy wind speed in the study region. However, soil shallow layers may be affected by forage litters and mulching materials after alfalfa has planted several years, shallow water effects need further investigations. But, the soil water content at the 15 cm depth was increased significantly by mulching ($P < 0.01$) (Fig. 4). Cook et al. (2006) observed that mulch improved water retention in topsoil compared with no mulch. Liang et al. (2011) found that mulch not only changed the soil temperature and water content, but also improved soil physical properties. We did not find any differences between SM and GM, except when soil water moved down into the soil profile after several rainfalls in some cases, which may attribute to reduction in soil evaporation by mulching.

Although mulching had no effect on water content in the deep soil, the effects of mulching on the water content at 15 cm was observed in the four study years. It is valuable to investigate this issue in future over longer time duration and assess the mulching effects on WUE and forage yield.

Table 3
Forage dry matter yield (DMY) and water use efficiency (WUE) of alfalfa under corn straw mulch (SM), gravel mulch (GM) and no mulch control (CK) from 2009 till 2011 in a field experiment on alfalfa pasture land at Shenmu, Shaanxi, China.

	Treatment	2009	2010	2011	2012
DMY ($kg\ ha^{-1}$)	CK	5631	6092	7058	6073
	SM	5902	6186	7302	7142
	GM	5774	5374	6658	6903
$LSD^{a}_{0.05}$		ns[b]	ns	ns	ns
WUE($kg\ ha^{-1}\ mm^{-1}$)	CK	10.2	15.2	17.2	11.8
	SM	10.8	14.8	18.4	13.9
	GM	10.6	13.9	15.6	13.2
$LSD_{0.05}$		ns	ns	ns	ns

[a] LSD, least significant difference.
[b] ns, not significant.

3.4. Forage yield and WUE

Straw mulch increased forage DMY during the four years compared to no mulch control. Gravel mulch also increased forage DMY in 2009 and 2012, but it was lower than the control in 2010 and 2011, but the effects were not statistically significant (Table 3). As mentioned above, soil temperature increase during cold season and decrease during hot season may be beneficial to alfalfa growth in this region. Chen et al. (2007) also observed similar effects on soil temperature in winter wheat in the North China Plain, but SM reduced grain yield of winter wheat. The lower soil temperature under mulching in spring delayed the development of winter wheat up to 7 days, which reduced the gain yield. However, alfalfa has different growth period compared to winter wheat, and the lower soil temperature effect under mulching in spring may be overcome by mulch-reduced soil evaporation during the wet season.

Mulching including straw and gravel could not significantly improve WUE (Table 3) and prevent depletion of water in the deep soil profile during the study years. This was most likely that alfalfa grew in a period with steady high forage yields under local climate conditions when its growth was not limited significantly by water storage and/or availability of nutrients in soil (Fan et al., 2011), even if alfalfa was stressed by water because of high ET_0 (Table 1). With the reduction of the water supply from deep soil, effects of mulching on water balance would be increased because alfalfa will need to survive on annual rainfall. As for the sloping lands on the Loess Plateau, the integrated use of rainfall harvesting and mulching technologies can improve efficiency of harvested rainwater efficiency and subsequently increase crop yield (Wang et al., 2009). Our findings suggest that forage yield in pasture lands can be sustained for many years in this region, and this may imply that the productivity of land can be increased after “Grain to Green” plan is introduced. Our results also suggest that mulch, especially straw mulch, can regulate soil temperature, improve WUE and soil fertility. Since mulch materials like straw or gravel are available in this region, it is convenient to apply mulching in the perennial

Table 4
Effects of mulching on concentration of organic matter, total N, toal P and available nutrients in the 0–10 cm soil layer in a field experiment on alfalfa pasture land at Shenmu, Shaanxi, China.

		Organic matter	Total N	Total P	Available P	Nitrate-N	Ammonium-N
		g kg^{-1}			mg kg^{-1}		
2010	CK[a]	9.8	0.57	0.451	1.49	4.33	27.45
	SM	9.7	0.58	0.454	1.57	3.01	26.16
	GM	8.5	0.50	0.447	1.61	3.37	27.20
	LSD[b] $_{0.05}$	Ns[c]	ns	ns	ns	ns	ns
2011	CK	9.7	0.56	0.43	2.08	1.79	9.17
	SM	9.1	0.56	0.42	2.22	3.27	8.98
	GM	8.1	0.50	0.41	1.76	1.45	8.94
	$LSD_{0.05}$	ns	ns	ns	0.35	0.85	ns
2012	CK	8.4	0.57	0.503	2.90	4.19	7.38
	SM	9.1	0.55	0.499	3.65	6.58	7.13
	GM	7.9	0.51	0.495	2.93	5.88	7.70
	$LSD_{0.05}$	0.34	ns	ns	0.16	0.93	ns

[a] CK, control; SM, straw mulch; GM, gravel mulch.
[b] LSD, least significant difference.
[c] ns, not significant.

forage pasture land. Therefore, it is suggested that the effects of mulch on water content in the deep soil layers should be observed over many years, and also determine the mulching method such as mulching grass hedges or other hedge row intercropping that can be used on sloping lands to prevent loss of soil and water.

3.5. Effects of mulching on organic matter, total n, total P, ammonium-N, nitrate-N and available P in soil

Gravel mulching decreased the concentrations and amounts of organic matter, total N and total P slightly in the upper soil layer compared to CK or straw mulching treatment, but it was not statistically significant (Table 4). Because the build-up of organic matter, total N and total P in soil is a slow process, the effects of gravel and/or straw mulching to increase organic matter, total N and total P in soil may take long time, and also no fertilizers were applied to alfalfa to improve crop growth/production. However, SM increased nitrate-N and available P in soil compared to CK significantly in 2011 and 2012 (Table 4). This suggests that SM can improve soil fertility in the short term, because of its direct benefits for nutrients in straw and indirect benefits from the increase in forage yield (Malhi, 2012a,b). There was no significant beneficial effect of mulching on ammonium-N in soil after 5 years, and this was probably due to rapid nitrification of any ammonium-N released during mineralization of soil organic matter.

4. Conclusions

Soil water was consumed quickly by alfalfa and the dry layers in the soil profile, and soil water content approached wilting point occurred in 4 years in the semi-arid region. Surface soil mulching with corn straw and gravel affected soil water content, soil temperature, WUE and forage DMY of alfalfa, but the magnitude of effects varied with the mulching material. Both mulches improved soil water content at 15 cm depth compared to no mulch control, but had no influence on water content in the deep soil profile. Straw mulch affected soil temperature positively, increased concentration of nitrate-N and available P in the soil significantly, and also it improved WUE and forage DMY, although the results were not statistically significant. Gravel mulch did not display any beneficial effects on soil temperature and fertility, and tended to reduce forage DMY. In summary, our findings suggest that straw mulch would work well to facilitate soil condition (moisture and temperature), forage yield, and WUE of alfalfa. Compared to the use of mulching in annual food crops, it is much more convenient to apply straw or gravel mulch to alfalfa land because it can last for many years. For the sustainability of large-scale vegetation restoration and afforestation in the semi-arid Loess Plateau and other similar regions in the world, controlling the planting density and soil evaporation should be considered. Mulching is optional method, and mulching grass hedges intercropping or other hedge row intercropping should be considered on sloping lands.

Acknowledgments

We acknowledge funding by The National Natural Science Foundation of China (No. 51239009, 41271239, 31070541). Thanks to two anonymous referees for suggestions and helpful comments.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements – FAO Irrigation and Drainage Paper 56, vol. 300. FAO, Rome, pp. 6541.
Angus, J.F., Gault, R.R., Peoples, M.B., Stapper, M., van Herwaarden, A.F., 2001. Soil water extraction by dryland crops, annual pastures, and lucerne in southeastern. Australian Journal of Agricultural Research 52, 183–192.
Baumhardt, R.L., Jones, O.R., 2002. Residue management and tillage effects on soil water storage and grain yield of dryland wheat and sorghum for a clay loam in Texas. Soil & Tillage Research 68, 71–82.
Chen, H.S., Shao, M.A., Li, Y.Y., 2008. Soil desiccation in the Loess Plateau of China. Geoderma 143, 91–100.
Chen, S.Y., Zhang, X.Y., Sun, H.Y., Chen, S.L., 2007. Effects of straw mulching on soil temperature, evaporation and yield of winter wheat: field experiments on the North China Plain. Annals of Applied Biology 150, 261–268.
Crawford, M.C., Macfarlane, M.R., 1995. Lucerne reduces soil moisture and increases livestock production in an area of high groundwater recharge potential. Australian Journal of Agricultural Research 35, 171–180.
Cook, H.F., Valdes, G.S.B., Lee, H.C., 2006. Mulch effects on rainfall interception, soil physical characteristics and temperature under *Zea mays* L. Soil & Tillage Research 91, 227–235.
Fan, J., Hao, M.D., Malhi, S.S., Wang, Q.J., Huang, M.B., 2011. Influence of 24 annual applications of fertilisers and/or manure to alfalfa on forage yield and some soil properties under dryland conditions in northern China. Crop & Pasture Science 62, 437–443.
Fan, J., Shao, M.A., Wang, Q.J., Jones, S.B., Reichardt, K., Cheng, C.R., Fu, X.L., 2010. Toward sustainable soil and water resources use in China's highly erodible semi-arid Loess Plateau. Geoderma 155, 93–100.
Greenwood, K.L., Lawson, A.R., Kelly, K.B., 2009. The water balance of irrigated forages in northern Victoria, Australia. Agricultural Water Management 96, 847–858.
Hanson, B., Putnam, D., Snyder, R., 2007. Deficit irrigation of alfalfa as a strategy for providing water for water-short areas. Agricultural Water Management 93, 73–80.
Huang, Y.L., Chen, L.D., Fu, B.J., Huang, Z.L., Gong, E., 2005. The wheat yields and water-use efficiency in the Loess Plateau: straw mulch and irrigation effects. Agricultural Water Management 72, 209–222.
Jia, Y., Li, F.M., Zhang, Z.H., Wang, X.L., Guo, R.Y., Siddique, K.H.M., 2009. Productivity and water use of alfalfa and subsequent crops in the semiarid Loess Plateau

with different stand ages of alfalfa and crop sequences. Field Crops Research 114, 58–65.

Latta, R.A., Blacklow, L.J., Cocks, P.S., 2001. Comparative soil water, pasture production, and crop yields in phase farming systems with lucerne and annual pasture in Western Australia. Australian Journal of Agricultural Research 52, 295–303.

Li, S., Xiao, L., 1992. Distribution and management of drylands in the People's Republic of China. Advances in Soil Sciences 18, 148–293.

Li, Y.S., 2002. Productivity dynamic of alfalfa and its effects on water eco-environment. Acta Pedologica Sinica 39, 404–410 (in Chinese with English abstract).

Li, Y.S., Huang, M.B., 2008. Pasture yield and soil water depletion of continuous growing alfalfa in the Loess Plateau of China. Agriculture, Ecosystems & Environment 124, 24–32.

Liang, Y.L., Wu, X., Zhu, J.J., Zhou, M.J., Peng, Q., 2011. Response of hot pepper (*Capsicum annuum* L.) to mulching practices under planted greenhouse condition. Agricultural Water Management 99, 111–120.

Liu, G.S., 1998. Soil Physical and Chemical Analysis and Description of Soil Profiles. Chinese Standard Press, Beijing, pp. 24–43 (in Chinese).

Liu, W.Z., Zhang, X.C., Dang, T.H., Ouyang, A., Li, Z., Wang, J., Wang, R., Gao, C.Q., 2010. Soil water dynmics and deep soil recharge in a record wet year in southern Loess Plateau of China. Agricultural Water Management 97 (8), 1133–1138.

Malhi, S.S., 2012a. Short-term residual effects of various amendments on organic C and N, and available nutrients in soil under organic crop production. Agricultural Sciences 3 (3), 375–384.

Malhi, S.S., 2012b. Relative effects of various amendments in improving yield and nutrient uptake under organic crop production. Open Journal of Soil Science 2, 299–311.

Qi, L.B., Fan, J., Shao, M.A., 2009. Simulation and verification of soil moisture of root distribution functions for alfalfa. Transactions of the CSAE 5 (4), 24–29 (in Chinese with English abstract).

Ramakrishna, A., Tam, H.M., Wani, S.P., Long, T.H., 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crops Research 95, 115–125.

Sarkar, S., Paramanick, M., Goswami, S.B., 2007. Soil temperature, water use and yield of yellow sarson (*Brassica napus* L. var. *glauca*) in relation to tillage intensity and mulch management under rainfed lowland ecosystem in eastern India. Soil & Tillage Research 93, 94–101.

Scott, P.R., Sudemyer, R.A., 1993. Evapotranspiration from agricultural plant communities in the high rainfall zone of the southeast of Western, Australia. Journal of Hydrology 146, 301–319.

Steiner, J.L., 1989. Tillage and surface residue effects on evaporation from soils. Soil Science Society of America Journal 53, 911–916.

Testa, G., Gresta, F., Cosentino, S.L., 2011. Dry matter and qualitative characteristics of alfalfa as affected by harvest times and soil water content. European Journal of Agronomy 34, 144–152.

Wang, L., Wang, Q.J., Wei, S.P., Shao, M.A., Li, Y., 2008. Soil desiccation for Loess soils on natural and regrown areas. Forest Ecology and Management 255, 2467–2477.

Wang, Y.J., Xie, Z.K., Malhi, S.S., Vera, C.L., Zhang, Y.B., Wang, J.N., 2009. Effects of rainfall harvesting and mulching technologies on water use efficiency and crop yield in the semi-arid Loess Plateau, China. Agricultural Water Management 96, 374–382.

Wang, Y.Q., Shao, M.A., Liu, Z.P., 2010. Large scale spatial variability of dried soil layers and related factors across the entire Loess Plateau of China. Geoderma 159, 99–108.

Wang, Y.Q., Shao, M.A., Zhu, Y.J., Liu, Z.P., 2011. Impacts of land use and plant characteristics on dried soil layers in different climatic regions on the Loess Plateau of China. Agricultural and Forest Meteorology 151, 437–448.

Ward, P.R., Dunin, F.X., Micin, S.F., 2002. Water use and root growth by annual and perennial pastures and subsequent crops in a phase rotation. Agricultural Water Management 53, 83–97.

Xie, Z.Y., Wang, Y.J., Cheng, G.D., Malhi, S.S., Nera, C.L., 2010. Particle-size effects on soil temperature, evaporation, water use efficiency and watermelon yield in fields mulched with gravel and sand in semi-arid Loess Plateau of northwest China. Agricultural Water Management 97, 917–923.

Yang, L., Wei, W., Chen, L., Mo, B.R., 2012. Respone of deep soil moisture to land use and afforestation in the semi-arid Plateau, China. Journal of Hydrology 475, 111–122.

Zhang, S., Lovdahl, L., Grip, H., Jansson, P.E., Tong, Y., 2007. Modelling the effects of mulching and fallow cropping on water balance in the Chinese Loess Plateau. Soil & Tillage Research 93, 283–298.

Zhang, S., Lovdahl, L., Grip, H., Tong, Y.A., Yang, X.Y., Wang, Q.J., 2009. Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. Soil & Tillage Research 102, 78–86.