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

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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

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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.