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Crop yield and soil water restoration on 9-year-old alfalfa pasture in the semiarid Loess Plateau of China

Xiao-Ling Wang [a,b], Guo-Jun Sun [a], Yu Jia [a], Feng-Min Li [a,*], Jin-Zhang Xu [a]

[a] MOE Key Laboratory of Arid and Grassland Ecology, School of Life Sciences, Lanzhou University, Gansu Province 730000, China
[b] College of Agronomy, Henan University of Science and Technology, Luoyang, Henan Province 471003, China

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ABSTRACT

The alfalfa pastureland in the semiarid Loess Plateau region of Northwest China usually has dry soil layers. A field experiment was conducted from October 2000 to October 2004 to examine soil water recovery and crop productivity on a 9-year-old alfalfa pasture. This experiment included six treatments: alfalfa pasture for 10–14 years, a conventional farming system without prior alfalfa planting, and four alfalfa–crop rotation treatments. For the rotation treatments, after 9 years of alfalfa selected crops were planted from 2001 to 2004 in the following sequence: (1) millet, spring wheat, potatoes, peas; (2) millet, corn, corn, spring wheat; (3) millet, potatoes, spring wheat, corn; (4) millet, fallow, peas, potatoes. The results showed that dry soil layers occurred in alfalfa pasture. We then plowed the alfalfa pasture and planted different crops. The soil water gradually increased during crop growth in the experimental period. The degree of soil water recovery in the four alfalfa–crop rotation treatments was derived from comparison with the soil water in the conventional system. After 4 years, the soil water recovery from the alfalfa–crop rotation systems at 0–500 cm soil depth was 90.5%, 89.8%, 92.2% and 96.7%, respectively. Soil total N content and soil respiration rate were high in the alfalfa–crop rotation systems. The yields of spring wheat in 2002, peas in 2003 and potatoes in 2004 in the alfalfa–crop rotation systems were not significantly different from yields in the conventional system. In the alfalfa–crop rotation systems, the yields of spring wheat and peas were greatly influenced by rainfall and were lowest in the dry year of 2004; the yields of corn and potatoes had a direct relationship with water use and were lowest in 2003. In summary, soil water in dry soil layers can recover, and crop yields in the alfalfa–crop systems were equal to those of the conventional system.

1. Introduction

The Loess Plateau of Northwest China is characterized by an extremely hilly Loess landscape and a semiarid monsoon climate. Most of the area has steeply sloping land, which is therefore only marginally suitable for cropping. The region has been extremely poor for a long time, and farmers in the region cannot satisfy the primary demands of the population. Because of the poverty of the region, cropland occupies approximately 80% of the total cultivated land (Shan and Chen, 1993). Arable farming, with poor soil and crop management, has been widely practiced in this area, resulting in serious soil degradation and erosion. The rate of soil loss is generally more than 50 t/ha in upland areas (Lu et al., 2003).

Since 1990s, crop yields in the semiarid Loess Plateau have greatly increased due to the use of new technology, including

* *Corresponding author*. Tel.: +86 931 891 2848; fax: +86 931 891 2848.
E-mail address: fmli@lzu.edu.cn (F.-M. Li).
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chemical fertilizers, plastic film mulching and rainwater harvesting (Li et al., 2003; He et al., 2007). In particular, rainwater-harvesting technology has allowed the limitations of drought imposed by the low and erratic rainfall to overcome, providing more consistent crop yields compared with traditional rainfed farming systems. Farmers can use less arable land to provide sufficient food to meet their demands, which can lead to a reduction in the extent of cropland and the use of more land for alfalfa pasture. This can provide an opportunity for pasture–crop rotation.

Pasture–crop rotation is an important sustainable technology. Compared with continuous cereal cropping it can increase the stability of soil aggregates and decrease soil erosion (Jankauskas and Jankauskiene, 2003). In Australia, leguminous forage rotation with crops, adding P fertilizer to alfalfa and canceling summer fallow, has permitted agroecosystems to develop healthily (Cantero-Martinez et al., 1995; O'Leary and Connor, 1997). Forage–grain crop rotation has played an important role in conserving the soil water and fertilizer in dry land agroecosystems in North America, especially following the dust storms of the 1930s. After the introduction of a forage–grain crop rotation, the crop yield improved greatly (Dregne and Willis, 1983; Schwab et al., 1996).

In the Loess Plateau of Northwest China, the Loess is very deep—at least several dozen meters. Perennial alfalfa often causes severe soil dryness (Li, 2002; Shen et al., 2004; Wang et al., 2003). 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). 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 society (Guo and Shao, 2003).

The objective of this research was to explore the feasibility of alfalfa–crop rotation through a 4-year experiment at Zhonglianchuan in the northern mountain region of Yuzhong County, Gansu Province. We sought to answer the following questions: (1) can soil water be restored after long-term alfalfa pasture? (2) How does the yield of the following crop respond to soil water restoration? (3) Which crop rotation will give acceptable yields and achieve soil water restoration?

2. Materials and methods

2.1. Study site description

The study was conducted from October 2000 to October 2004 at the Semiarid Ecosystem Research Station of Loess Plateau (36.03°N, 104.42°E, and 2400 m above sea level), Lanzhou University. The study area is located at Zhonglianchuan in the northern mountain region of Yuzhong County, Gansu Province, China. The area has a moderate semiarid climate, with an annual mean air temperature of 6.5 °C, a maximum temperature of 19.0 °C (July) and a minimum of −8.0 °C (January). The long-term mean annual precipitation is 310 mm, and the long-term average annual free water evaporation is 1326 mm. The ratio of free evaporation to rainfall for the area is 4.28 and about 56% of the precipitation occurs between July and September. The rainfall distribution was measured every month and the total rainfall every year during the experimental period. A wet year occurred in 2002, a dry year in 2004, and normal rainfall occurred in 2001 and 2003 (Table 1). The water table is at a depth of more than 60 m, and thus groundwater is unavailable for plant growth. The field site has a Rusty Dark loessial soil (Chinese soil taxonomy) or Loess Orthic Entisol (FAO taxonomy) (sand 12.3%, silt 66.9%, clay 20.8%), with water content at field capacity of 22.9% (gravimetrically) and at permanent wilting point of 7.5%. Analysis of surface soil (0–20 cm) gives the following results: pH 8.1 (1:2.5 soil/water suspensions), 8.1 g C, 38.65 mg N (nitrate nitrogen and ammonium nitrogen), and 3.9 mg P per kg soil.

2.2. Experimental design and field management

In October 2000, a field that had been planted with alfalfa for 9 years was divided into two parts: one part was plowed, and the other part was maintained under alfalfa (AS). In the spring of 2001, the field plowed in October 2000 was divided into four parts to plant selected crops in the following sequences—(1) RS1: millet, spring wheat, potatoes, peas; (2) RS2: millet, corn, corn, spring wheat; (3) RS3: millet, potatoes, spring wheat, corn; (4) RS4: millet, fallow, peas, potatoes. No fertilizer was applied to these fields during the 4-year experiment. In this region, during May and June, low air temperatures due to the high altitude often result in poor establishment of corn seedlings. Hence, a plastic film covering was used for corn. Near the alfalfa field, a conventional farming field (CS) was chosen in which there had been no prior planting of alfalfa. Spring wheat, peas and potatoes were planted from 2002 to 2004 in this field, to which farmyard manure and chemical fertilizer at 1.5 t/ha of donkey manure, N fertilizer at 90 kg/ha, and P_2O_5 fertilizer at 30 kg/ha were applied. Overall, the 10- to 14-year alfalfa pasture, the four alfalfa–crop rotation systems and the conventional system formed six treatments; each treatment was replicated three times.

In each year from 2002 to 2004, spring wheat and peas were planted on 26 March, and potatoes and corn on 30 April. In the study region, spring wheat, corn, peas, millet, potatoes and benne are the main crops that farms depend on. Each year the farmers plant different crops according to their needs, and each crop has little influence on successive plantings.

2.3. Measurements and data analysis

2.3.1. Soil water content and evapotranspiration

Soil moisture was measured gravimetrically in 20 cm increments to 500 cm depth at sowing and harvest, on 14 April and 14 October each year. Measurement of soil water content at permanent wilting point for alfalfa (WP) has been introduced to identify dry soil layers because alfalfa can tolerate more severe drought than the other crops. This was measured according to the method of Dalgliesh and Foale (1998). Water absorbed from the soil (WAS) was calculated according to the difference in soil moisture content between sowing and harvest in different crops. For each treatment, water use