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Forage yield, soil water depletion, shoot nitrogen and phosphorus uptake and concentration, of young and old stands of alfalfa in response to nitrogen and phosphorus fertilisation in a semiarid environment

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ABSTRACT

Alfalfa (*Medicago sativa* L.) is an important forage legume in crop–pasture and animal husbandry systems in the semiarid Loess Plateau of China, but comprehensive studies on forage yield, shoot N and P relationships, and soil water use as affected by nitrogen (N) and phosphorus (P) fertility levels are scarce. The objective of this study was to assess the yield response of alfalfa stands of different ages following N and P fertiliser application in relation to water use in the semiarid region of the Loess Plateau. Field experiments were conducted from 2011 to 2014 in newly-established (young) and well-established (old) rainfed alfalfa stands, planted in 2010 and 2005, respectively, on the semiarid Loess Plateau. Treatments were a factorial combination of two N rates (0 and 70 kg N ha^{-1}) and three P rates (0, 17 and 34 kg P ha^{-1}), applied annually, arranged in a randomized complete block design with three replicates. Forage biomass was measured in mid-July and mid-October each year. The forage yield of the two alfalfa stands increased with N and P fertilisation, but path analysis indicated that it was also affected by rainfall. Water use was greater in the young than the old stand. The water content in the 1–4 m soil layer of the young stand decreased each year from establishment; greater water depletion occurred with N and P fertilisation. In the five-year-old stand, the soil water content changed little over the four growing seasons, and N and P fertilisation did not affect the already depleted soil water content. Shoot P concentration was weakly, but positively, associated with shoot N concentration. The risk of low relative forage yield was greater when the shoot N:P ratio was more than 17. We conclude that N and P fertilisation, particularly P fertilisation, increases forage yield in both young and old rainfed alfalfa stands in a semiarid environment.

1. Introduction

Alfalfa (*Medicago sativa* L.) is an important forage legume in crop–pasture and animal husbandry systems on the semiarid Loess Plateau of China (Jiang et al., 2006). However, the establishment of alfalfa is slow, and its forage yield in the region is very low due to soil constraints and limited rainfall (Jia et al., 2006). Indeed alfalfa has a high water demand but a low water use efficiency compared to other crops (Blad and Rosenberg, 1976). In regions where rainfall is abundant (Hannaway and Shuler, 1993; Berg et al., 2007) or irrigation is applied (Fixen et al., 1983), alfalfa forage yield increases with nitrogen (N) and/or phosphorus (P) fertilisation, but relevant research in semiarid regions with typical rainfed agricultural systems is scarce.

On the semiarid Loess Plateau, Jia et al. (2006) showed that soil available P and soil nitrate-N decreased over a three-year period in an unfertilised rainfed alfalfa field. Moreover, the forage yield of field-grown alfalfa responded positively to an annual surface broadcast of P fertiliser during the first three years after planting in Texas, USA (Sanderson and Jones, 1993) and the first seven years

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after planting in Indiana, USA (Berg et al., 2007), but the response of alfalfa to applied P in semiarid environments has not been widely studied. N fertiliser is essential during the establishment phase if biological N_2 fixation is weak (Hannaway and Shuler, 1993). This could be due to poor nodulation or lack of survival of inoculant bacteria associated with soil conditions (Hannaway and Shuler, 1993). However, in the semiarid Loess Plateau, inoculation is not a common practice and the likelihood of effective nodulation is low (Wang and Hu, 2003). Previous studies at this site showed that the mineral N level in soil decreased over time after alfalfa establishment (Jia et al., 2006). This, combined with the likely absence of effective nodulation, was the reason N fertiliser was used.

In several studies, soil water storage under an alfalfa stand decreased with increasing stand age in semihumid regions of the Loess Plateau (Li and Huang, 2008; Fan et al., 2011; Guan et al., 2013) leading to dry soil zones below 2 m. Two of these studies (Li and Huang, 2008; Guan et al., 2013) were undertaken with no added P or N fertiliser, but the third study (Fan et al., 2011) was part of a 24-year long-term field experiment that included unfertilised plots as well as plots with application of P fertiliser alone or in combination with N fertiliser with or without animal manure. In the semi-arid region of the Loess Plateau (Jiang et al., 2006), soil water storage under an alfalfa stand also decreased with increasing stand age leading to dry soil zones below 2 m, but this study did not include added P or N fertiliser. As far as the authors are aware, no studies of water depletion under alfalfa in the semiarid region of the Loess Plateau have been conducted with applied P and N fertilisers. Because of the lower rainfall in the semiarid region of the Loess Plateau compared with the semihumid region of this Plateau, it is possible that addition of P and N fertiliser could increase depletion of water in the soil profile, even though this was not observed in semihumid regions. Therefore, the present experiment was conducted to determine whether or not water depletion occurred as a result of N and P fertilisation.

Nitrogen and P concentrations in plant tissues are affected by N and P fertilisation. A high ratio of shoot N to P concentrations at both the whole plant level and in single leaves is an indicator of nutrient deficiencies in natural vegetation (Güsewell, 2004) and field crops (Bélanger et al., 2015). Koerselman and Meuleman (1996) reviewed 40 field fertilisation experiments in wetlands, and suggested that shoot biomass is markedly limited by N and P when the N:P ratio of shoot biomass is either low (<14) or high (>16). The stoichiometry between N and P concentrations in shoots and its impact on forage yield has not been determined for alfalfa.

In order to clarify the appropriate fertiliser management practices for alfalfa stands of different ages in semiarid regions of the Loess Plateau of China, the yield response of alfalfa stands of different ages to N and P fertiliser was assessed in relation to water use. Two alfalfa sites, established in 2005 and 2010, were selected to investigate their response to N and P fertiliser application in terms of forage yield, shoot N and P relationships, and soil water use. The following hypotheses were investigated: (i) that the responses of forage yield to N and/or P fertilisation will differ between two alfalfa stands of different ages; (ii) that depletion of water in the soil profile will be greater as alfalfa yield increases with N and P fertiliser application; (iii) the N:P ratios in shoot biomass can be used as an *a posteriori* diagnostic of P and/or N deficiency.

2. Materials and methods

2.1. Site description

A four-year field experiment with alfalfa (*Medicago sativa* L.) was conducted from 2011 to 2014 at the Dryland Agroecology Research Station (36°02′N, 104°25′E, altitude 2400 m) of Lanzhou University at Zhonglianchuan, Yuzhong County, Gansu Province, China. The site has a semiarid climate, with an annual mean air temperature of 4.0 °C, mean maximum temperature of 15.7 °C in July and mean minimum temperature of −12.6 °C in January. The mean annual precipitation over ten years (2005–2014) was 323 mm, of which 83% (269 mm) occurred between early April and mid-October, the growing season for alfalfa. Growing-season precipitation in 2011, 2012, 2013 and 2014 was 11% below, 20% above, 22% above, and 14% above the ten-year average (Fig. 1). Groundwater is unavailable for plant growth because the water table is very deep (>60 m). The soil is a Calcic Kastanozem (FAO Taxonomy) with a field water-holding capacity of 19.7% and a permanent wilting coefficient of 4.5% (Shi et al., 2003). The active accumulated temperatures (AAT) for each growing season, the sum of daily mean temperatures above 10 °C, were 1954, 1832, 2195 and 1853 °C·days in 2011, 2012, 2013 and 2014, respectively.

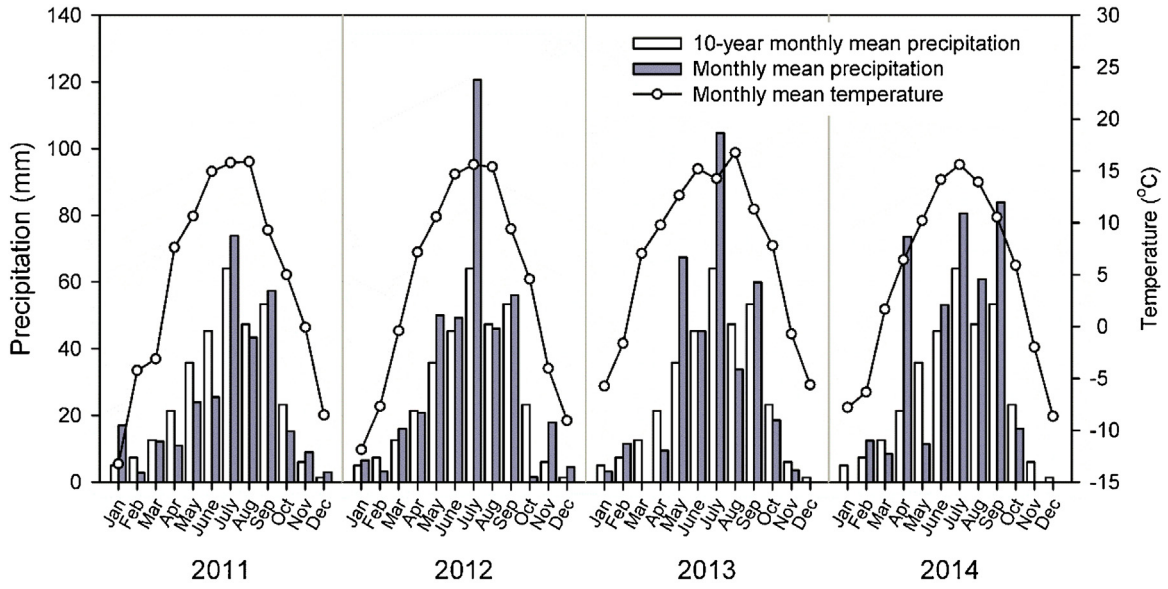

Fig. 1. Monthly mean precipitation and temperature from 2011 to 2014 and precipitation for 2005–2014 at the experimental site at Zhonglianchuan, Yuzhong County, Gansu Province, China.

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