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Long-term fencing effects on plant diversity and soil properties in China

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ABSTRACT

Overgrazing reduces plant species diversity, productivity and soil C and N storage due to degradation especially in arid and semi-arid ecosystems. We hypothesized that fencing could significantly reverse these trends in temperate grasslands. The effects of long-term (30 years) fencing on diversity and soil C and N storage were compared with areas where continuous grazing occurred on the Loess Plateau, China. Fencing increased vegetation coverage, height, plant diversity, biomass production and litter, resulting primarily from increases in the ratio of grass species as a percentage of the whole community and photosynthate allocation between above- and below-ground biomass indicated by differences in the root/shoot (R/S) ratios. Fencing significantly influenced soil bulk density (BD), moisture content (SW) and pH. Long-term fencing also led to marked increases in soil organic carbon (SOC), soil total nitrogen (TN), the carbon: phosphorus (C/P) and nitrogen: phosphorus (N/P) ratios, as well as soil C and N storage within 0–100 cm soil profile. The C/N ratio in the surface 0–5 cm fenced and grazed grasslands were also significantly different. Increases in soil C and N sequestration as a result of fencing occurred mainly at deeper soil depths (30–100 cm). These findings have important implications for both protecting and enhancing the resilience of ecosystems, which have been disturbed by grazing and for developing a more effective grasslands management strategy on the Loess Plateau.

1. Introduction

Globally, overgrazing by livestock is one of the most important human induced causes of arid and semiarid grasslands degradation (Su et al., 2005; Liang et al., 2009; Schönbach et al., 2011), lowering both the productivity and resilience of grasslands (Li et al., 2009; Zhou et al., 2011). The effect of overgrazing on the plant community and on soil resources are considered destructive because it reduces vegetation cover (Su et al., 2005; Wu et al., 2010a; Zhou et al., 2011; Louhaichi et al., 2012), increases undesirable species (Louhaichi et al., 2009), reduces species diversity (Li et al., 2006), destroys soil structure (Reynolds et al., 2003), and compacts soil as a direct result of trampling (Manzano and Návar, 2000). These processes increase soil crusting, reduce soil infiltration, and enhance susceptibility to soil erosion (Manzano and Návar, 2000). Therefore, developing ecosystem rehabilitation strategies for severely degraded grasslands is crucial (Li et al., 2009) at a global level.

Degraded grasslands have the capacity for self-recovery if the disturbance ceases for an extended length of time allowing for natural succession (Li et al., 2009). Recovery conditions offer the best overall strategy to restore diversity, ecosystem function and resilience (Palik et al., 2000; Wu et al., 2009, 2010a,b; Medina-Roldán et al., 2012; Bach et al., 2012; Deng et al., 2013a). Grassland management significantly influences plant density and composition, above- and belowground vegetation characteristics and soil properties (Deng et al., 2013a). Fencing is the most common management tool used to reverse grassland degradation throughout the world (Shrestha and Stahla, 2008; Wu et al., 2009, 2010a; Golodets et al., 2010).

Recent research has focused on the effects of fencing on vegetation succession, plant diversity, community structure and productivity (Smith et al., 2000; Gibson et al., 2001; Wu et al., 2009; Golodets et al., 2010; Deng et al., 2013a). Studies have also focused on the effects of fencing on soil nutrients (Mohr and Topp, 2005; Su et al., 2005; Miller et al., 2010; Wu et al., 2010b), soil microbial structure (Stark et al., 2000; Su et al., 2004; Huang et al., 2011), soil enzyme activities (Su et al., 2004), soil C and N cycling (Frank and Groffman, 1998; Stark et al., 2000) and storage

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(Shrestha and Stahla, 2008; Zhou et al., 2011; Medina-Roldán et al., 2012). However, few studies have focused on the effects of long-term fencing on overall plant community composition, diversity and productivity, and other soil properties.

In China, the of the Loess Plateau (~40 million ha) is known for its complex terrain, extreme drought conditions and severe soil erosion (Liu et al., 2007), a result of a combination of overgrazing, the intensification of cultivation and other unsustainable land use practices (Zhou et al., 2006). Grazing exclusion through fencing is regarded as the most effective method available for restoring the ecology of the Loess Plateau (Wu et al., 2010a). Grassland restoration is a long-term and complex ecological process (Hastings et al., 2007).

The Yunwu Mountain reserve, excluded from grazing since 1982, is located in the only remaining grassland region of the Loess Plateau where long-term (30 years) fencing has made it possible to better understand the effect of grazing exclusion on both grassland vegetation and soil properties. Our objectives were to investigate the effects of long-term exclusion on: (1) plant community properties; (2) soil properties; and (3) soil C and N storage. This study contributes to our understanding of the restoration of plant production and soil C and N sequestration in degraded grasslands on the Loess Plateau.

2. Materials and methods

2.1. Study area

The study area is located in the Yunwu Mountain reserve for Vegetation Protection and Eco-environment, Ningxia Province, China (106°16′–106°24′E, 36°13′–36°19′N, 1700–2148 m a.s.l.) (Fig. 1). It is a hilly landscape in the middle of the Loess Plateau with deeply incised gullies and is characterized by a sub-arid climate within the mid-temperate zone. The Yunwu Mountain reserve is a century old protected grassland area. The 4000 ha reserve and most of the surrounding land lies between 1700 and 2000 m in altitude is closely dissected by steep and very steep gulleys. The vegetation is temperate grassland with the primary plant species being herbaceous plants (*i.e.*, *Androsace erecta*, *Artemisia capillaries*, *Artemisia frigid*, *Artemisia sacrorum*, *Heteropappus altaicus*, *Lespedeza davurica*, *Potentilla acaulis*, *Stipa bungeana*, *Stipa grandis*, *Thymus mongolicus*, *etc.*) of which the *Stipa bungeana* community has the most extensive distribution.

The reserve includes three areas: core, buffer, and experimental (Fig. 1), with comparatively similar geographical patterns. The core area has approximately 1000 ha that are totally enclosed and account for 25% of the total area. The buffer area covers 1200 ha and also accounts for approximately 25% of the total area. The role of buffer area is to prevent the effect of human activities on the core area. Outside the core and buffer areas is the experimental area, which encompasses approximately 1800 ha and accounts for 45% of the total area. In the experimental area, crop agriculture and animal husbandry are practiced. No fertilizer is applied as the three areas abut one another. The core area was fenced in 1982 and remains so today.

Before enclosure, the permanent grasslands were used as grazing land. Both the grazed and fencing grassland had similar initial conditions (slope degree, slope direction, topography and altitude) (Qiu et al., 2013), allowing the existing grazed grassland to be used as a control to compare the effects of exclusion on plant diversity and soil properties. In the core area the *Stipa bungeana* community is the most extensive; *Stipa grandis* and *Stipa bungeana* are the dominant grass species, and *Thymus mongolicus* and *Artemisia sacrorum* the dominant forb species. In contrast, freely grazed areas are characterized by a degraded *Stipa bungeana* community. In the grazed grasslands, *Stipa grandis* and *Stipa bungeana* are again the dominant grass species, but *Artemisia capillaries* and *Artemisia frigid* are the dominant forb species. The principle leguminous plant, *Lespedeza davurica*, occurs in both areas.

The study area's soil type is Aeolian soil (silt loam) with a soil pH ranging from 8.0 to 8.6. The area receives a mean annual precipitation of ~410 mm (1960–2010) of which a quarter falls during July and the remainder by September. The area's semi-arid temperate continental monsoon climate produces a mean annual temperature at 6.7 °C (1960–2010), a mean annual total of 2518 sunshine hours, a mean annual evaporation of 1600 mm, and 137 frost-free days per year on average.

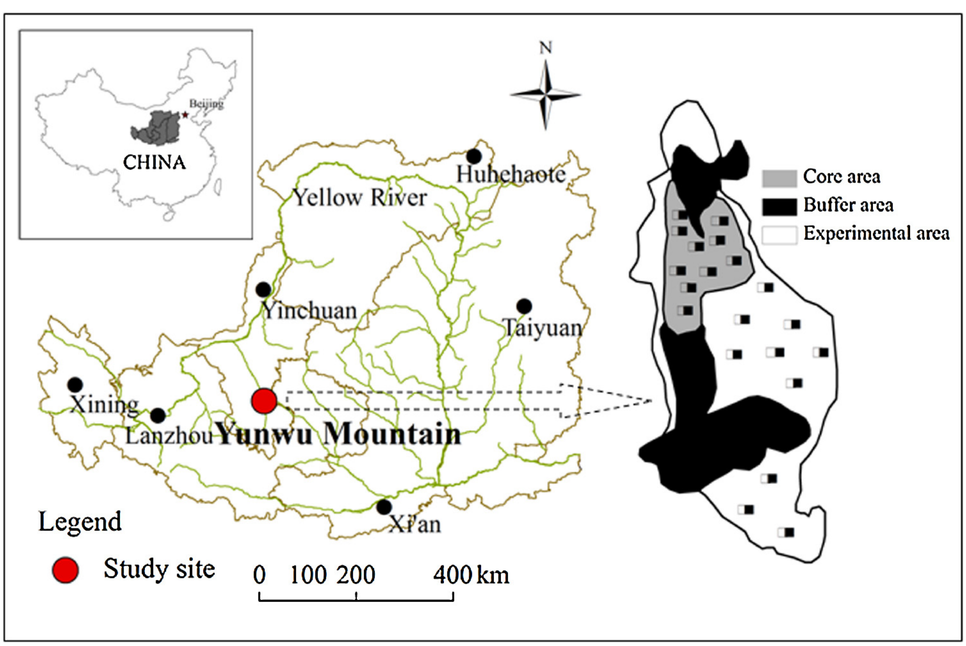

Fig. 1. Location of the Yunwu Observatory on the Loess Plateau. *Note*: the white quadrats in which individual species are divided, and the whole quadrats' species composition and height, density (number of individuals per square meter) and aboveground biomass of individual species are investigated; the black quadrats in which the individual species are undivided, and the whole quadrats' community above- and belowground biomass, canopy coverage and height are investigated.