Field Crops Research 164 (2014) 45–53

Contents lists available at ScienceDirect

Field Crops Research

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

Carbon and nitrogen responses of three old world bluestems to nitrogen fertilization or inclusion of a legume

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ARTICLE INFO

Article history:
Received 12 March 2014
Received in revised form 19 May 2014
Accepted 20 May 2014
Available online 6 June 2014

Keywords:
Symbiotic N_2 fixation
N uptake
C uptake
Soil particulate organic matter
Energy cost

ABSTRACT

Old world bluestems [OWB (*Bothriochloa* spp.)] are introduced warm-season grass species commonly used for livestock grazing in the semi-arid Texas High Plains. Interseeding forage legumes into OWB-based pastures can reduce N fertilizer dependency because of symbiotic N_2 fixation, but little is known about their N contribution where water for irrigation is limited. A 4-year study (2007–2010) evaluated N concentration and soil particulate organic C (POC) and N (PON) of three OWB species interseeded with alfalfa (*Medicago sativa* L.), yellow sweetclover (*Melilotus officinalis* Lam.), or sainfoin (*Onobrychis viciifolia* Scop.) compared with 60 kg N ha^{-1} fertilizer and no N (control). Irrigation (maximum of 250 mm $year^{-1}$) was applied uniformly to all treatments. Yellow sweetclover rapidly increased grass N concentration and improved the energy efficiency of forage production more than the other two legumes while N benefits from alfalfa increased over the 4 years. Carbon and N uptake reflected both forage N concentration and production benefits from interseeded legumes and N fertilization. Soil POC and PON concentration was not affected by N fertilization but was increased by interseeding yellow sweetclover. Inclusion of appropriate legumes in this semi-arid region can increase soil POC, PON, and N concentration in the associated OWB grass as much or more than typical rates of N fertilization and cost less energy at irrigation levels of about 33% ET_0. Results have implications for both animal nutrition and the environment.

1. Introduction

The production and transportation of N fertilizer is one of the most energy expensive inputs in agricultural systems (Smil, 2001; Jensen and Hauggaard-Nielsen, 2003; Zilverberg et al., 2012). The unique symbiotic association of legumes with *Rhizobium* strains is well known to decrease dependency on N fertilizer and the importance of this legume-associated biological N_2 fixation has been recognized globally (Westhoff, 2009). Additionally, N fertilized systems have greater emissions of N_2O, a greenhouse gas (Hauck, 1973; Ledgard, 2001), and net global warming potential than legume-based systems (Robertson et al., 2000). As concerns for environmental impacts and energy costs escalate, interest in legumes as an alternative to N fertilizers has increased. Information is needed on C and N budgets in systems that include legumes vs. N fertilization, N transfer from legumes to associated grasses, and contributions of N fertilizers vs. legumes to soil C and N status.

In the semi-arid Texas High Plains, N and water are major limiting factors to plant growth. Here, limited water available for irrigation has discouraged use of legumes that require more water than the warm-season grasses (Fageria et al., 2006) that form the basis of forage systems. Old world bluestems (*Bothriochloa* spp.) are the primary introduced grasses for grazing and pasture improvement in this region (Berg, 1990). The *B. ischaemum* varieties including Sparr (*B. ischaemum* (L.) Keng. var. *ischaemum*) were commonly seeded on non-irrigated lands in the USDA

Abbreviations: CP, crude protein; DM, dry matter; ET_0, reference evapotranspiration; OWB, old world bluestem; POM, particulate organic matter; POC, particulate organic carbon; PON, particulate organic nitrogen; SOM, soil organic matter.

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http://dx.doi.org/10.1016/j.fcr.2014.05.011
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Conservation Reserve Program. Philipp et al. (2005) suggested that Caucasian {*B. bladhii* (Retz.) S. T. Blake [syn. *B. caucasica* (Trin.) C. E. Hubb.]}, which has been recently reclassified by the USDA-ARS-GRIN as *B. bladhii*, may have greater economic potential under deficit irrigation conditions than other OWB species. WW-B. Dahl (*B. bladhii* (Retz) S.T. Blake) is widely planted in this region (Dewald et al., 1995) and may have greater crude protein (CP) concentration than other OWB tested (Philipp et al., 2005). These grasses are often at or below concentrations of N required for animal nutrition (Philipp et al., 2005) but respond in quality and animal performance to N fertilizer. Acceptable yields and forage quality can be achieved with about 60 kg N ha^{-1} and irrigation below reference evapotranspiration (ET_0; Allen et al., 1998, 2012; Philipp et al., 2005, 2007). Berg and Sims (1995) reported that average gains of steers grazing OWB could reach 68 kg N ha^{-1} annually. Cui et al. (2013) showed that both yield and nutritive value of OWB–legume mixtures met or exceeded that of the grass monocultures fertilized once annually with 60 kg N ha^{-1}. Nutritive value was based on CP, cell wall, and estimated dry matter digestibility. Crude protein was consistently increased by legume inclusion compared with N fertilization but differed due to legume species, season of the year, and time after establishment. It is well known that legumes are higher in N concentration than grasses but much less is known about the impacts of legumes on N uptake and concentration in the associated grasses or on the C and N fraction of soil organic matter (SOM).

Many studies have focused on the labile SOM fraction, especially the soil particulate organic matter (POM; e.g., Marriott and Wander, 2006a; Zobeck et al., 2011). The simplicity of its size-based fractionation procedure and the rapid response to different practices make it a popular index for labile SOM. Previous research demonstrated the sensitivity of the soil POM dynamics under different management strategies, including legume association, fertilizer application, and manure-based management practices (Marriott and Wander, 2006a).

The overall objectives of this study were to determine effects of N fertilizer vs. inclusion of legumes (Renumex sainfoin, Madrid yellow sweetclover, and Bulldog 505′ alfalfa) on grass N concentration, energy cost, C and N uptake, and effects on soil POC and PON in the semi-arid Texas High Plains region of USA. Specific aims of this research project were to quantify effects of legumes and N fertilizer on grass N concentration, determine C and N uptake from either grass monocultures or grass–legume mixtures, document changes of labile SOM fraction affected by N fertilizer or inclusion of legumes, and determine how much fossil fuel energy was used for different management practices and energy expenditure for biomass production. It was hypothesized that: (1) weather, particularly water, plays an important role in influencing C and N responses to different treatments; (2) N fertilizer would increase grass N concentration rapidly and the effects of legumes would take much longer time to be detectable; (3) both C and N uptake would be influenced by our treatments and inclusion of legumes would increase uptake more than N fertilizer; (4) labile SOM concentration would be increased by inclusion of legumes; and (5) N fertilizer inputs would cause higher C emissions for biomass production than legumes.

2. Materials and methods

2.1. Site description

This research was conducted from February 2007 to December 2010 (years 1–4) in north-east Lubbock County near New Deal, TX (101°47′W; 33°45′N; 993 m elevation). Research site weather data were obtained from the local National Weather Service Forecast Office in Lubbock, TX. The region has a semi-arid climate with low winter precipitation and relatively greater rainfall distribution during May to late September with a peak in June. Average precipitation during this study was 550 mm $year^{-1}$. Long-term (1971–2010) mean precipitation was 475 mm $year^{-1}$ and average long-term air temperature was 15.5 °C. Average monthly temperatures over the 4 years of this experiment peaked (28 °C) between July and August which agreed with the long-term pattern.

2.2. Crop management and experimental design

This experiment was a randomized complete block design with three blocks, a split-plot treatment arrangement, and repeated measures. Three whole-plot treatments, including three OWB (Caucasian, Sparr, and WW-B. Dahl), were established on Pullman clay loam (superactive, fine, mixed, thermic Torrertic Paleustoll) for a previous study in 1996. Each replicate plot was 15.2 by 46.3 m. In year 1 (2007), five split-plot treatments were superimposed on the three pre-established grasses. These treatments included two monocultures of the three grasses [control (no treatment) and N fertilization (60 kg N ha^{-1})] and interseeding of three legumes (sainfoin, yellow sweetclover, and alfalfa). Thus, there were 45 ($3 \times 3 \times 5$) treatment plots. Grass–legume mixtures received no fertilizer N. For the N fertilized grass, urea was surface broadcast annually in late March. Before seeding, all seeds of the three legume species were pre-inoculated using corresponding *Rhizobia* spp. and were planted using a no-till Tye stubble drill (AGCO, Lockney, TX) in late March of year 1. The seeding rates were 12.1 kg ha^{-1}, 15.6 kg ha^{-1}, and 8.3 kg ha^{-1} (pure live seed basis) for alfalfa, sainfoin, and yellow sweetclover, respectively.

After seeding, all plots were fertilized, excluding N, to ensure that nutrients other than N were not limiting. Irrigation water was applied through a subsurface drip irrigation system (Netafilm®, Tel Aviv, Israel 64922). Irrigation amount was targeted to not exceed 250 mm total irrigation water per year but varied slightly depending on precipitation distribution within each growing season. This irrigation amount did not exceed 33% of ET_0 as described by Philipp et al. (2007). Total actual irrigation supplied was 110 mm, 263 mm, 263 mm, and 230 mm for each of the 4 years, respectively.

2.3. Plant biomass sampling and processing

Plants were sampled in late spring, mid-summer, and autumn. At each harvest, samples were taken from two, 0.24-m^2 quadrats at a 5-cm cutting height within each treatment replicate. Grass–legume samples from interseeding treatments were hand separated in the field into grasses, legumes, and weeds (any plant that was not the target species, which made up an insignificant portion of the total biomass) and were placed in separate paper bags. Late spring samples were taken when all OWB were in a vegetative growth stage. Both Caucasian and Sparr OWB reached an early bloom stage by mid-summer, while WW-B. Dahl remained vegetative. All OWB were flowering by autumn. Depending on environmental conditions, sampling dates were different in each year according to growth stage. The three-season sampling dates for each year were 18 June, 17 July, and 20 October 2007; 15 July, 16 August, and 24 October 2008; 15 June, 16 July, and 23 October 2009; and 16 June, 16 July, and 25 October 2010. No hay was harvested after late spring sampling, which allowed forage to accumulate during the active growing season. The entire plots were harvested for hay immediately after mid-summer sampling, a typical hay harvesting time for OWB in this region (Allen et al., 2005; Duch-Carvallo, 2005). Autumn sampling documented regrowth after mid-summer. Although no hay harvest was performed after autumn, standing dormant biomass was removed before next spring. Total seasonal yield was calculated as the sum