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Vetch-rye biculture is a sustainable alternative for enhanced nitrogen availability and low leaching losses in a no-till cover crop system

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ABSTRACT

The reliance of current farming systems on synthetic fertilizers caused concerns about their sustainability, and alternatives to supply nitrogen through biological processes have to be adapted to practical conditions. The present study compared a pure legume and legume-grass biculture as cover crops for sorghum in their supply of nitrogen (N) to the cash crop and their N leaching losses during fallow. A three-year field experiment under no-till with sorghum (*Sorghum bicolor* Moench.) as main crop and cover crop treatments (C- control = bare fallow; R-rye *Secale cereale* L.; V-vetch *Vicia villosa* sp *dasycarpa;* VR-vetch-rye biculture) was established with a completely randomized block design (four replicates) in semiarid central Argentina. Aerial biomass (AB) and N contents were determined for all crops. Soil moisture to 1 m and nitrate-N to 0.60 m depth were determined. Water use- and nitrogen use efficiencies (WUE and NUE) were calculated and biological nitrogen fixation (BNF) estimated. BNF depended on nitrate-N contents of the soils; highest values (11 and 10 g BNF m^{-2} for V and VR respectively) were reached at 1.3 g N m^{-2}. Sorghum responded to higher N availability with an average of +299 and +512 g AB m^{-2} for V and VR compared to C, with higher WUE. The relationship between WUE and nitrate-N was positive with an optimum of 0.048 g N m^{-2} mm^{-1} where WUE reached a maximum of 4.9 g AB m^{-2} mm^{-1}. Potential N losses by leaching were highest in control, while all cover crop treatments had lower losses. Our results support the hypothesis that a legume-grass biculture was more efficient in the trade-off between nitrogen provision to the cash crop and prevention of N losses by leaching. Although the amount of BNF was lower in the biculture than in pure vetch, it covered sorghum N requirements with less potential leaching losses even in high rainfall fallows.

1. Introduction

Agriculture is facing new challenges to combine and harmonize the delivery of several ecosystem services that are apparently conflicting. Specifically the trades-offs and balance between high agricultural productivity and services such as water infiltration, flood- and erosion control, water purification, habitat preservation and nutrient cycling need to be studied and accounted for (Cong et al., 2014; Verburg et al., 2013). An alternative approach for agricultural production has been termed “ecological intensification” (Cassman, 1999), where the central paradigm is the use of biological regulation to manage agroecosystems, at field, farm and landscape scales. Some authors have suggested that “mimicking” natural ecosystems could provide solutions for designing agroecosystems that rely more on natural processes and that could harness land productivity and ecosystem services (Doré et al., 2011). In this context the strong reliance of current farming systems on synthetic fertilizers has created concerns about their sustainability (Bennett et al., 2015; Zimmerer and Vanek, 2016).

It has long been stipulated that legume cover crops can supply nitrogen to subsequent cash crops and thus reduce the amount of fertilizer required under no-till (Ebelhar et al., 1984). On the other hand there is evidence about high levels of NO_3^- leaching during fallows which implies low nitrogen use efficiency and the risk of water pollution in agricultural systems (Drinkwater and Snapp 2007). While legume cover crops have been demonstrated to reduce nitrate leaching relative to a bare fallow system (e.g. Tonitto et al., 2006), for cases where N-fixation brings excessive N into the system relative to crop demand, legume cover crops may exacerbate system N losses during the short fallow period between their termination and planting of the cash crop. Legume-grass bicultures managed as cover crops have the potential to

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reduce leaching losses by scavenging mineralized N during fallow, while at the same time supplying nitrogen to the following crops (Ranells and Wagger, 1997, 1996, 1994). However, there is evidence that the ecological integrity of legume-based agroecosystems is only marginally greater than that of fertilizer systems (Crews, 2004; Crews and Peoples, 2005). This is mainly due to the problem of synchronizing the release of mineralized N with the demand of crop growth in legume cover crop rotations (Restovich et al., 2012). This may lead to high proportions of nitrogen leached beyond the rooting zone, reducing the proportion of uptake by the subsequent crop (Fernández et al., 2012; Kramberger et al., 2009). There is still little evidence about the contribution of cover crop derived nitrogen to cash crops and the nitrogen use efficiency of these systems. However, a meta-analysis on ^{15}N recovery showed that agronomic practices that recoupled C and N cycling had a relatively higher impact on improving the N recovery than those based on commercial fertilizer (Gardner and Drinkwater, 2009).

Although fertilizer use is currently very low in the semiarid Pampas, farming systems tend to become more input-intensive as declining yields and soil N-depletion create the need for improved nitrogen availability. Cover crops, especially legumes, might be a viable alternative for synthetic N fertilizer applications, specifically for sorghum which is usually cultivated without N fertilizer input in this region. We hypothesized that legume-grass bicultures used in rotation with summer cash crops would result in greater nitrogen use efficiency and improved system nitrogen retention relative to pure legume cover crops despite their lower nitrogen contribution. The objective of this study was to elucidate the nitrogen budget and −efficiency of agroecosystems that include legumes as cover crops with the goal to substitute part of the crops' nutrient requirements by a natural source.

2. Materials and methods

2.1. Site description and experimental design

The experiment was established during three years (2010–2013) under no-till on a petrocalcic Paleustoll (USDA and NRCS, 2010) with a calcium carbonate hardpan at depths between 0.6 and 1.5 m, located in INTA Experimental Station at Anguil, La Pampa, Argentina (S 36° 36′ 37.95″; W 63° 58′ 48.22″). The area belongs to the semiarid Pampa region with annual rainfall average of 759 mm and mean temperature of 15 °C (1973–2016). Rainfall, radiation and temperatures for the 3-year experimental period are shown in Fig. 1. The soil is a sandy loam with clay + silt content of 43%, 2% of organic matter, 0.2% of total N, bulk density of 1.2 g cm^{-3}, pH 5.8 and available P 8 mg kg^{-1}. Cropping history at the experimental site was annual cropping for livestock fodder under conventional tillage (disk and harrow) for more than 70 years. The rotation was sorghum (*Sorghum bicolor* Moench.) as summer crop with different combinations of cover crops during winter months (*Secale cereale* L. and *Vicia villosa* ssp *dasycarpa*). Treatments were rye (R), vetch (V), vetch + rye biculture (VR) and a control (C) without cover crop (bare long fallow). The experimental design was a completed randomized block design with 4 replicates. Plot size was 10 × 50 m. At end of March, cover crops were drilled at a density of 200 seeds m^{-2} for both species and a 60/40 proportion of vetch and rye for VR treatment. Distance between lines was 0.17 m. Before cover crop seeding, all treatments were fertilized with 20 kg ha^{-1} of phosphorus (triple superphosphate) to prevent any deficiency of this element. Cover crops were killed beginning of October by application of glyphosate (3 L ha^{-1}) and 2,4-dichlorophenoxiacetic acid (0.4 kg ha^{-1}). Phenological status of cover crops at termination were 50% of flowering in vetch and half of inflorescences emerged for rye, equivalent to Z5.5 of Zadoks decimal code for winter cereals (Zadoks et al., 1974). Sorghum was planted during mid- November in all plots at a density of 15 seeds m^{-2} and a row spacing of 0.52 m. No fertilizer was applied to the summer crop. A sorghum hybrid with an ultra-short cycle was used and harvested for silage at soft dough-hard dough phenological stage (R7-R8) (Vanderlip and Reeves, 1972). Daily air temperature, solar radiation and rainfall data were recorded with an agrometeorological station located near the experimental plots at INTA Experimental Station.

2.2. Plant and soil sampling and analytic determinations

Dry matter production was determined by manual harvest of three sub-samples of each plot representing 1 m^2 for sorghum and 0.25 m^2 for cover crops (Table 1). Aerial biomass for rye and vetch was measured separately in VR treatment. Sub-samples were oven dried at 60 °C during 72 h and milled for chemical analysis.

Soil gravimetric water content was determined at seeding and harvest of cover crops and sorghum. Soil samples were taken at 0.2 m depth intervals to a total depth of 1 m, with three replicates per plot. Consumptive water use (U_w) was estimated as the difference between soil water content at seeding and harvest of sorghum (W_i, W_f) and

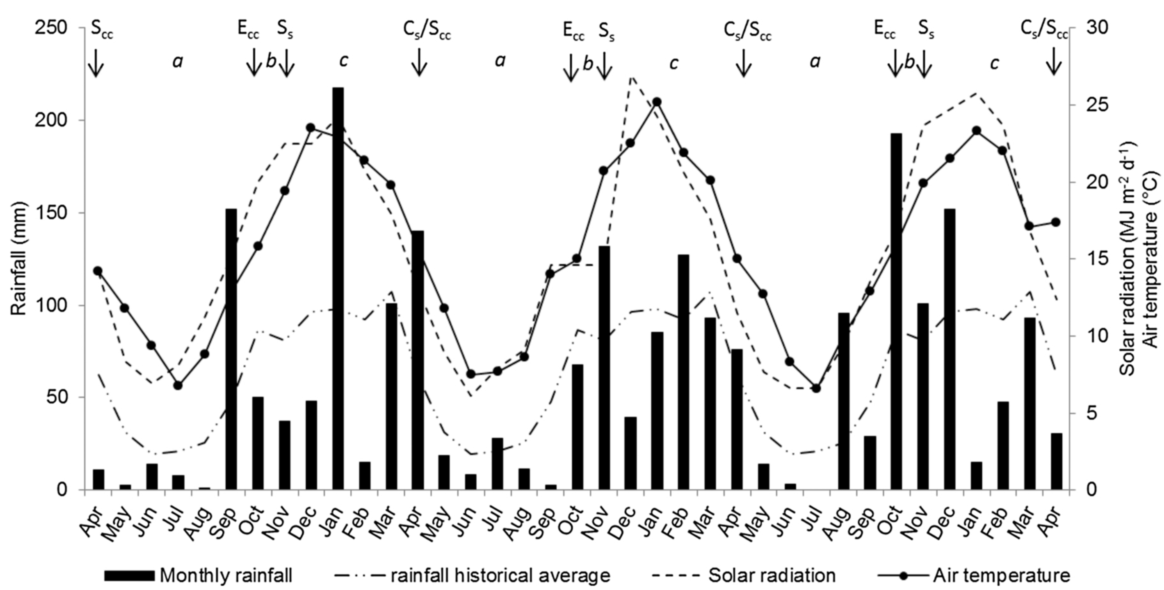

Fig. 1. Monthly accumulated rainfall (mm), monthly averaged daily solar radiation (MJ m^{-2} d^{-1}) and air temperature (°C) between sowing and harvest during the 3-year experiment. Letters "*a*" and "*c*" indicate growing seasons of cover crops and sorghum respectively; letter "*b*" indicates fallow. The arrows show cover crops and sorghum sowing (S_{cc}, S_s), termination of cover crops (E_{cc}), and harvest for silage sorghum (soft dough-hard dough stage, C_s).