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Nitrogen balance in response to dryland crop rotations and cultural practices☆

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ABSTRACT

Nitrogen balance provides a measure of agroecosystem performance and environmental sustainability by taking into accounts of N inputs and outputs and N retention in the soil. The objective of this study was to evaluate N balance based on N inputs and outputs and soil N sequestration after 7 yr in response to five dryland crop rotations (two 4-yr stacked and two 4-yr alternate-year rotations and one monocropping) and two cultural practices arranged in a split-plot design in the northern Great Plains, USA. Stacked rotations were durum (*Triticum turgidum* L.)-durum-canola (*Brassica napus* L.)-pea (*Pisum sativum* L.) (D-D-C-P) and durum-durum-flax (*Linum usitatissimum* L.)-pea (D-D-F-P). Alternate-year rotations were durum-canola-durum-pea (D-C-D-P) and durum-flax-durum-pea (D-F-D-P). Monocroppping was continuous durum (CD). Cultural practices were traditional (conventional till, recommended seed rate, broadcast N fertilization, and reduced stubble height) and ecological (no-till, increased seed rate, banded N fertilization, and increased stubble height). Total annual N input due to N fertilization, pea N fixation, atmospheric N deposition, crop seed N, and nonsymbiotic N fixation was lower in CD than other crop rotations, regardless of cultural practices. Total N output due to crop grain N removal and N losses due to denitrification, volatilization, plant senescence, N leaching, gaseous N (NO_x) emissions, and surface runoff was lower in traditional CD and D-F-D-P than traditional D-C-D-P and ecological D-C-D-P, D-D-C-P, and D-F-D-P. Nitrogen sequestration rate at 0–125 cm from 2005 to 2011 ranged from 40 kg N ha^{-1} yr^{-1} for ecological D-D-F-P to 52 kg N ha^{-1} yr^{-1} for ecological CD. Nitrogen balance ranged from −39 to −36 kg N ha^{-1} yr^{-1} with CD compared to 9–25 kg N ha^{-1} yr^{-1} with other crop rotations in both cultural practices. Because of reduced reliance on external N inputs and increased grain N removal, N flow, and N surplus, crop rotations with legumes, nonlegumes, and oilseed crops in the rotation can be productive and environmentally sustainable compared with monocropping, regardless of cultural practices.

1. Introduction

Nitrogen is a major nutrient usually applied in large quantity to increase crop yield and quality. Excessive N application through fertilizers and manures, however, can degrade soil and environmental quality by increasing soil acidification, N leaching, and emissions of NH_3 and NO_x gases, out of which N_2O is a highly potent greenhouse gas that contributes to global warming (Franzluebbers, 2007; Herrero et al., 2010). Nitrogen application in excess of crop's need can also result in reduced yield (Smil, 1999; Janzen et al., 2003; Eickhout et al., 2006). Additional N inputs include dry and wet (rain and snow) depositions from the atmosphere, biological N fixation, and irrigation water. Because crops can remove about 40–60% of applied N, the residual soil N (NO_3—N + NH_4—N) after crop harvest can be lost to the environment through leaching, denitrification, volatilization, surface runoff, soil erosion, and N_2O emissions (Smil, 1999; Janzen et al., 2003; Eickhout et al., 2006; Ross et al., 2008). While some of the residual N is immobilized by microorganisms into soil organic N,

Abbreviations: CD, continuous durum; D-C-D-P, durum-canola-durum-pea; D-D-C-P, durum-durum-canola-pea; D-D-F-P, durum-durum-flax-pea; D-F-D-P, durum-flax-durum-pea; STN, soil total N.

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unharvested N in crop residue (stems and leaves) and roots recycle to form the core of soil N storage. By increasing N-use efficiency, enhancing N storage, and reducing N fertilization rate through improved management practices, such losses can be minimized compared with traditional practices (Janzen et al., 2003; Ross et al., 2008; Pieri et al., 2011; Sainju et al., 2012, 2014). An account of N balance using N inputs and outputs and retention in the soil can identify dominant processes of N flow and provides a framework to measure agroecosystem performance and environmental sustainability (Watson and Atkinson, 1999; Ross et al., 2008).

Economically profitable instead of maximum crop yields are determined by recommended N fertilization rates (Schepers and Mosier, 1991). Maximum attainable yield for a crop varies with soil and climatic conditions, nutrient supply, and competitions with weeds and pests (Schepers and Mosier, 1991). Because soil residual and potentially mineralizable N can also contribute N to crops during the growing season, it is necessary to adjust N fertilization rates using these values so that crop production can be optimized and potential for N losses minimized. About 1–2% of soil organic N to a depth of 30 cm is mineralized every year, depending on soil temperature and water content, residue addition (fresh or old residue), and soil organic matter (Schepers and Mosier, 1991; Wang et al., 2014).

Differences in soil and climatic conditions, crop species, and management practices can influence N balance in various agroecosystems due to variations in N inputs, outputs, and retention in the soil (Meisinger and Randall, 1991; Ross et al., 2008; Pieri et al., 2011). Fine-textured soils retain more N and reduce N losses which can reduce N fertilization rates compared with coarse-textured soils, although predominant N losses are gaseous losses and N leaching in fine-and coarse-textured soils, respectively (Meisinger and Randall, 1991; Schepers and Mosier, 1991; Wang et al., 2014). Soil and crop management practices, such as no-till and crop rotation, may result in different N fertilization rates to same or different crops, soil N retention, and N losses compared with conventional till and monocropping (Sainju et al., 2012, 2014).

Weeds and pests are better controlled by using stacked crop rotations which involve same crop types grown successively for a number of years in rotation with other crops compared with alternate-year rotations (Garrison et al., 2014; Nickel, 2014). In the stacked rotation, weeds compete with each other in a similar environment for a longer period of time and the residual herbicide can be used in the first year for effective control of weeds (Garrison et al., 2014). Diversity provided by crop rotation also slows the development of herbicide and pesticide resistance in weed and pest populations (Nickel, 2014). Cultural practices that use higher crop seeding rates, banded fertilization, and delayed planting and harvest can also effectively control weeds compared with traditionally recommended seeding rates, broadcast fertilization, and early planting and harvest (Strydhorst et al., 2008; Nichols et al., 2015). Information on the effects of stacked vs. alternate-year crop rotation and continuous monocropping as well as alteration in cultural practices on N flows and balance, however, is lacking.

Studies on N balance have been reported in several long-term experiments (Davis et al., 2003; Ross et al., 2008; Pieri et al., 2011). Accurate measurement of N balance is, however, difficult because of the complexity of measurement of some parameters and increased time, labor, and cost constraints. As a result, some parameters have to be estimated from the literature which adds uncertainty to the calculation of N balance. We evaluated the effects of dryland stacked and alternate-year crop rotations and monocropping, each under traditional and ecological cultural practices, on N flows and N balance from 2005 to 2011 in eastern Montana, USA. The objectives of this study were to: (1) quantify N flows in crops, soil, and the environment in response to seven years of crop rotations and cultural practices, (2) calculate N balance based on N inputs, outputs, and changes in soil N storage, and (3) determine which crop rotation and cultural practice have N balance that reduce N fertilization rate and sustain crop N uptake and environmental quality. We hypothesized alternate-year crop rotations with ecological practice would have favorable N balance with sustained crop N yield and reduced N loss to the environment compared with other treatments.

2. Materials and methods

2.1. Experimental description

From 2005 to 2011, the experiment was conducted in a Williams loam (fine-loamy, mixed, superactive, frigid, Typic Argiustoll) with 2% slope at the USDA Conservation District Farm, 11 km north of Culbertson, Montana, USA. In April 2005, the soil at the 0–15 cm depth had 660 g kg^{-1} sand, 180 g kg^{-1} silt, 160 g kg^{-1} clay, 10.1 g kg^{-1} soil organic C, 7.2 pH, and 1.27 Mg m^{-3} bulk density. Mean monthly air temperature (115-yr average) at the study site ranges from −8 °C in January to 23 °C in July and August and a mean annual precipitation of 341 mm, 70% of which occurs during the growing season (April to August). Previous cropping history for 12 yr was continuous durum under conventional tillage.

Crop rotations included 4-yr rotations of two stacked and two alternate-year rotations and monocropping. Stacked rotations were durum-durum-canola-pea (D-D-C-P) and durum-durum-flax-pea (D-D-F-P), alternate-year rotations were durum-canola-durum-pea (D-C-D-P) and durum-flax-durum-pea (D-F-D-P), and monocropping was continuous durum (CD). Each phase of the crop rotation was present in every year. All crop rotations were under two cultural practices (traditional and ecological practices) that included combinations of various tillage practices, seed rates, N fertilization rates and methods, and stubble heights at crop harvest for durum, pea, canola, and flax (Table 1). For instance, durum in the traditional practice was planted under conventional tillage with 2,223,870 pure live seeds ha^{-1}, broadcast N fertilization, and 19 cm stubble height. In the ecological practice, durum was planted under no-tillage with 2,965,159 seeds ha^{-1}, banded N fertilization, and 33 cm stubble height. Plots under the traditional practice were tilled in the spring before crop planting with a field cultivator to a depth of 7–8 cm for seedbed preparation and weed control. Plots under the ecological practice were left undisturbed, except during planting and fertilization in rows. Treatments in the experiment were set up in a split-plot arrangement with cultural practice as the main plot and crop rotation as the split-plot treatment in a randomized complete block design with three replications. Plot size was 36 m × 12 m.

Canola and pea were planted in early to mid-April, durum in late April, and flax in late April to early May in each year from 2005 to 2011. Crops were planted with a no-till drill equipped with low-disturbance Barton double-shoot disk openers on 20-cm centers. At the same time, N fertilizer at various rates (Table 1) was applied as urea (46% N) and monoammonium phosphate (11% N, 23% P). In addition, canola received N fertilizer from ammonium sulfate (21% N, 24% S), which also supplied 27 kg S ha^{-1}. Pea received N from monoammonium phosphate while applied as a P fertilizer. The rates of N fertilizers were based on yield goals of 1402 kg ha^{-1} for canola and flax and 2355 kg ha^{-1} for durum. To account for N supplied by soil, N rates were adjusted by deducting soil NO_3—N content to a depth of 60 cm measured in the autumn of the previous year from desired N rates. In the traditional practice, N fertilizers were broadcast and incorporated to a depth of 8 cm into the soil due to tillage. In the ecological practice, N fertilizers were banded to a depth of 5 cm below and 5 cm to the side of the seed. Phosphorus from monoammnium phosphate and K from muriate of potash (60% K) at rates shown in Table 1 were banded as above to