Ecosystem services and life cycle assessment of perennial and annual cropping systems

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Key words: Alfalfa; intercropping; soil organic carbon; nitrous oxide; soil nitrate leaching; global warming potential.

Abstract. Corn cultivation has negative impacts to the environment, such as nitrate leaching, soil erosion, and nitrous oxide emissions. Perennial crops such as alfalfa (*Medicago sativa* L.) reduce annual disturbance of soil, which affects many biogeochemical cycles that are key to provide resilience and stability to cropping systems. Four three-year crop sequences were evaluated. 1) Corn-soybean-corn (CSC); 2) alfalfa-alfalfa-alfalfa (AAA); 3) Corn-spring planted alfalfa-alfalfa (CAA); and 4) Corn-intercropped/alfalfa-alfalfa-alfalfa (CAIAA). Modeling of C and N cycles were conducted with the Denitrification-Decomposition (DNDC) model and global warming potential (GWP) was estimated using life cycle assessment (LCA) methodology. The soil organic carbon (SOC) balance in Year 1 was greater for the CAIAA sequence since alfalfa in intercropping is not removed from the field the first year. In Year 2, CAAIC had the lowest SOC balance due to four harvests of alfalfa removed from the field in Year 2. In Year 3, SOC balances were positive for all sequences but greatest for AAA. This is because in the third-year alfalfa's root mass increases sequestering carbon deep in the soil. The SOC for the sum of the three-years balance was greater for the CAIAC sequence. Nitrous oxide emissions and nitrate leaching for the three-year sequence were the highest for the CSC sequence and significantly lower for the three sequences containing alfalfa. The main driver of emissions was the nitrogen fertilization added to corn. The net GWP was negative for the CAA and CAIAA sequences, indicating these sequences sequestered carbon. The CAIC sequence had the lowest net GWP of -4509 kg of CO_2 e./ha while the CSC sequence had 369 kg of CO_2 e./ha.

Introduction

Intercropping alfalfa with corn can increase corn grain production and alfalfa forage biomass production, as well as greater natural resources conservation than either crop alone (Berti et al., 2021a, Grabber, 2016). In a conventional corn-alfalfa rotation system, lack of vegetation or groundcover between the corn harvest and until after alfalfa seeding the following spring can increase soil erosion and nutrient losses from run-off (Hatfield et al., 2009). Previous research has shown that including alfalfa in crop rotations increases SOC sequestration (Niu et al., 2020), reduces soil erosion (Hatfield et al., 2009; Wu et al., 2011), and nutrients leaching and run-off (Osterholz et al., 2019) in comparison with corn, soybean, and other row crops. However, the impact to greenhouse gases (GHG) emissions when integrating alfalfa into annual or perennial cropping systems has shown contrasting results, from an increase in nitrous oxide emissions to no differences in GHG balances (Graf et al., 2019; Taylor et al., 2013; Tenuta et al.,2019).

Methods

The field experiments were carried out from 2016- 2019 in Prosper, ND. Four three-year crop sequences were evaluated. 1) Corn-soybean-corn (CSC); 2) alfalfa-alfalfa-alfalfa (AAA); 3) Corn-spring planted alfalfa-alfalfa (CAA); and 4) Corn-intercropped with alfalfa-alfalfa-alfalfa (CAIAA). The CAA sequence is the conventional corn-alfalfa system with alfalfa planted in the spring following corn, which has the limitation of a low yield during the alfalfa establishment year (Year 2 in the sequence), which reduces the overall profitability over the 3-year period (Berti et al., 2021b). The corn-alfalfa intercropped system was introduced and assessed due to its potential to bypass the economic constrain during the alfalfa establishment, by establishing the perennial system while growing corn as main crop (Grabber, 2016; Berti et al., 2021a,b). An additional crop sequence (corn-soybean-corn) was added to compare the alfalfa-based sequences with a conventional cropping system in the Corn Belt. A more detailed description of the four sequences analyzed in this study are described in Berti et al. (2021a) for the three alfalfa-base sequences. The CSC sequence description is described in Mohamed et al. (2020).

The SOC, nitrous oxide, and nitrate field emissions from cropped soils were modeled using the Denitrification-Decomposition (DNDC) process-based model. DNDC simulates the biogeochemical processes happening in agricultural soils and provides an estimate of C- and N-related emissions such as GHGs (Giltrap et al., 2010; Gilhespy et al., 2014). Given the limitations of the original version of the DNDC model to assess perennial crops in cold environment such as the US upper Midwest, an advanced version of the model was selected. The Canadian version of DNDC (DNDC 9.5 v. CAN) with an improved alfalfa growth curve was used to model the sequences with alfalfa. This version provides a better simulation of critical parameters for cropping systems with alfalfa such as regrowth after cutting, cold tolerance, fall dormancy, and winterkill effects (He et al., 2019).

The global warming potential was estimated through a life cycle assessment (LCA) methodology, according to the international Standard ISO 14041 (ISO, 2006). The system boundary was set from cradle to farm gate, which allows to account for the environment associated with agricultural inputs, field operations and emissions, and crop yields. The functional unit was kg of CO_2 equivalent per hectare.

Results and Discussion

Cumulative nitrate leaching potential in the three years of the study was significantly greater in the CSC sequence as expected (Figure 1A). This was not surprising since the CSC sequence had the highest total nitrogen fertilizer applied in the corn years. In addition, crop sequences including alfalfa reduced nitrate leaching potential; alfalfa's deep tap root scavenging ability is well documented. Nitrous oxide field emissions were also the highest for the CSC sequence (Figure 1B). Similarly, to nitrate leaching, nitrous oxide emissions are greater with greater applications of chemical N fertilizer as is a common practice in corn. Many previous researchers have shown that nitrous oxide fluxes from the soil increase immediately after nitrogen fertilizer is applied and also after a rainfall event. Nitrous oxide is a potent GHG with 298 times the power to retain heat in the atmosphere than 1 molecule of CO_2.

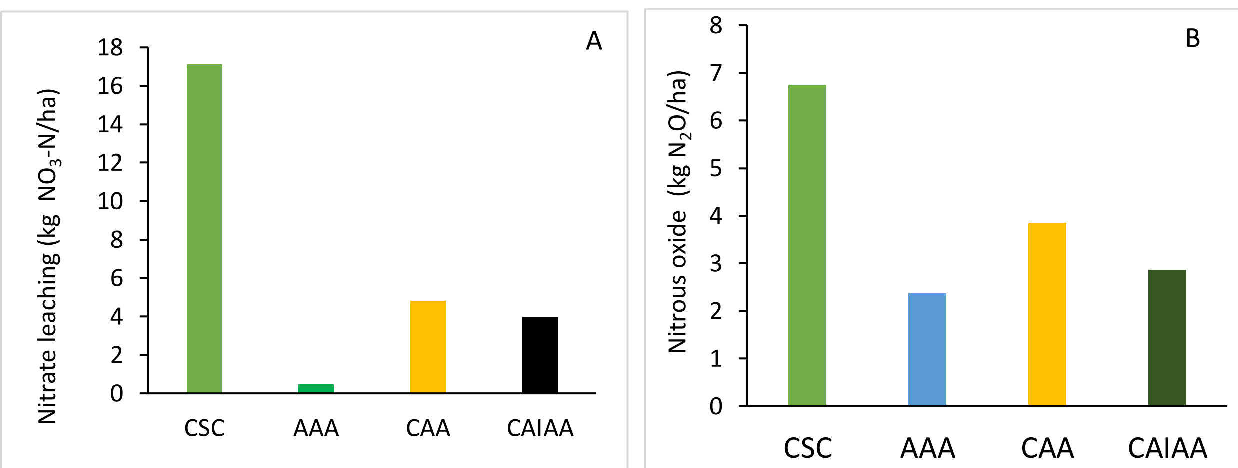

Figure 1. A) Cumulative nitrate leaching potential and B) nitrous oxide emissions of four 3-year crop sequences.

The soil organic carbon (SOC) balance in Year 1 was greater for the CAIAA sequence since alfalfa in intercropping is not removed from the field the first year. In Year 2, CAAIC had the lowest SOC balance due to four harvests of alfalfa removed from the field in Year 2. In Year 3, SOC balances were positive for all sequences but greatest for AAA. This is because in the third-year alfalfa's root mass increases sequestering carbon deep in the soil. The SOC for the sum of the three-years balance was greater for the CAIAC sequence (Figure 2A). The GWP balance for 3 years was positive for the CSC and AAA (Figure 2B). The CSC had the most emissions mainly because of the greater emissions of N_2O in addition to the fuel use for planting, applying fertilizer, pesticides and combining. Alfalfa alone had positive emissions because was harvested two times in the seeding years and three times in Year 2 and 3. The fuels use for cutting, raking, and baling in each cut adds to the CO_2 emissions. In addition, the hay is exported out of the field after harvest thus the C fixed by the plant that is not in the roots is exported out of the field. As alfalfa plants get older the C sequestered in the roots is greater than the exported C, reducing the GWP in the second and third year. In the CAIAC sequence, alfalfa is not harvested in the year of establishment saving the fuel needed for two harvests, reducing CO_2 emissions and keeping the C fixed by the plant sequestered in the soil until the following season.

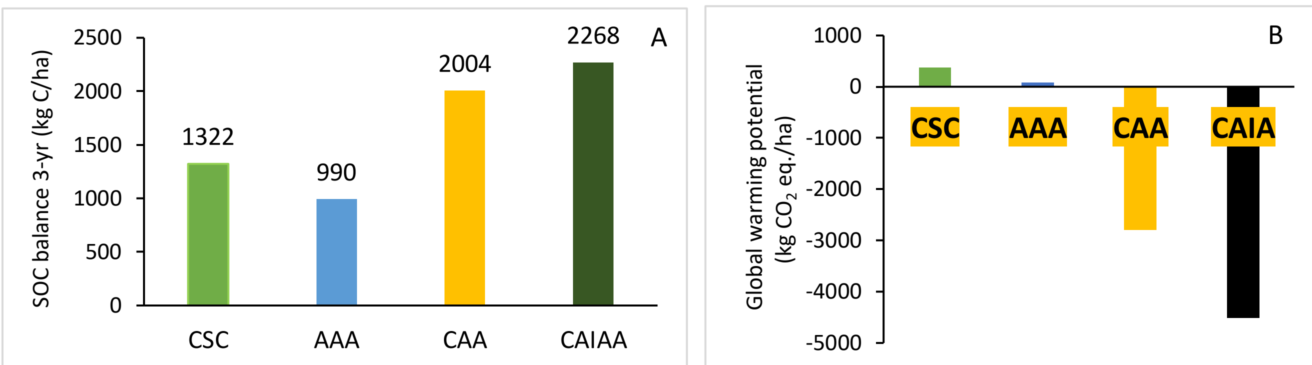

Figure 2. A) Soil organic C balance of four 3-year crop sequences; B) Global warming potential of four 3-year crop sequences.

Conclusions

The estimated soil nitrate leaching potential, nitrous oxide emissions, soil organic carbon, and global warming potential were lower in alfalfa established in intercropping with corn for grain in comparison with a 3-year sequence of corn-soybean-corn. Future research is needed to collect more field data for a better estimation in situ of GHG emissions and nitrate losses from the cropping systems including alfalfa.

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