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# Below-ground plant biomass and nitrogen uptake of perennial forage grasses and annual crops fertilized with pig manures

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ABSTRACT

The aim of this study was to determine the importance of below-ground (root) plant biomass and nitrogen (N) uptake with perennial cropping system (PCS) as a mechanism of reducing nitrate leaching. The experimental design was a split plot with main plot being cropping system [annual cropping system (ACS) versus PCS] and subplots being manure treatment [N-based liquid pig manure (LPM), N-based solid pig manure (SPM), and a control with no manure addition (CON)]. The ACS was seeded to barley (*Hurdeum vulgare* L.) and canola (*Brassica napus* L.) in the spring of 2014 and 2015, respectively, whereas the PCS was seeded to a mixture of timothy (*Phleum protense* L.) and orchard (*Dactylis glomerata* L.) grass in the fall of 2013. LPM and SPM were applied to meet N requirement of each crop in spring of each year. In 2014, above-ground and root biomass were collected at harvest and in 2015, above-ground and root biomass were collected at mid-season. The PCS had significantly greater root biomass and N uptake than ACS in both years. Root biomass in PCS ranged from 5.3–9.7 Mg $ha^{-1}$ compared to a range of 1.1–1.5 Mg $ha^{-1}$ in ACS. Consequently, root N uptake in PCS ranged from 43 to 118 kg N $ha^{-1}$ in both years while that in ACS was 9–20 kg N $ha^{-1}$. In 2014, PCS had significantly greater above-ground N than ACS, whereas in 2015, PCS had significantly greater above-ground N than ACS in the LPM only. This study shows that the differences in nitrate leaching between the two cropping systems as previously determined from field core lysimeters at the same plots was mainly due to differences in root N uptake (34–98 kg N $ha^{-1}$) between the cropping systems rather than above-ground N uptake. It is important that studies comparing N losses by ACS and PCS should consider the role of plant root biomass in N recovery.

## 1. Introduction

Nitrogen is an essential plant nutrient that is needed by crops in relatively large amounts for their physiological functions and completion of their life cycle (Delgado and Follett, 2010; Li et al., 2013). Nitrogen is an essential component of many organic compounds in plants such as nucleic acids, proteins, chlorophyll and alkaloids (Maathuis, 2009; McAllister et al., 2012) and N deficiency in plants is the most important nutritional disorder limiting crop yields worldwide (Fageria and Baligar, 2005).

Pig manure is a source of many plant nutrients but it is mostly used to supply N to the crop (Mooleki et al., 2002). Application of pig manure to fertilize cropland can result in nitrate leaching if not properly managed (Nikièma et al., 2013). Pig manure, in either the liquid or solid form, is applied to both annual and perennial forage grasses especially when they are in the vicinity of pig production facilities (The Prairie Provinces' Committee on Livestock Development and Manure Management, 2003; Bork et al., 2013). Continuous use of manure to meet crop N requirement without properly accounting for potential organic N mineralization from previous year(s) manure application has been reported to have a greater potential for nitrate leaching than inorganic N sources (Allen et al., 2006) with a greater risk to water quality when application is followed by surface runoff events (Smith et al., 2007). Ige et al. (2015) found that none of organic N fraction in manure mineralized during the growing season which thereafter may lead to a build-up of soil residual nitrate following its later mineralization if not properly accounted for.

The potential to lose N from ACS is generally high as the recovery of applied N in the above-ground biomass is on average about 50% (Delgado, 2002). Several practices have been proposed to manage manure from livestock production and subsequently improve manure use efficiency without contaminating the environment. These include processing liquid manure by AMAK method on the farm (Makara and Kowalski, 2015, 2018) and incorporation of perennial forage grasses in

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annual crop cycle (Campbell et al., 2006; Karimi et al., 2017). Studies that compared nitrate leaching between ACS and PCS have reported lower nitrate leaching in PCS than ACS (Entz et al., 2001; Campbell et al., 2006; van Es et al., 2006; Karimi et al., 2017), therefore making the use of perennial forage grasses as an alternative management practice to prevent nitrate leaching that occurs in the ACS. Lower nitrate in PCS than ACS has been attributed to the ability of perennial forage grasses to re-grow early in the spring and remain active later into the fall than annual crops, absorbing water and nutrients such as nitrate before they move beyond the root zone (Campbell et al., 2006; Glover et al., 2007).

A 3-year study by Karimi et al. (2017) used field core lysimeters in addition to the traditional soil sampling technique to directly measure the quantity of water and nitrate that was lost below the root zone of ACS and PCS. The study clearly demonstrated that significant amounts of nitrate was leached below the root zone of ACS (20–60 kg N $ha^{-1}$ $annum^{-1}$) whether manure was added to the plot or not while very small amounts of nitrate was leached from the PCS (less than 1 kg N $ha^{-1}$ $annum^{-1}$). These differences in nitrate leaching between the two cropping systems cannot be explained by the differences in their above-ground biomass and N uptake as the ACS had greater N uptake in two of the three years of study Karimi et al. (2017). One would expect lower nitrate leaching in ACS than PCS in the two years when the above-ground biomass and N uptake were greater in ACS than PCS but the result was opposite. This study of Karimi et al. (2017) like many other studies (Randall et al., 1997; Entz et al., 2001; Russelle et al., 2001; van Es et al., 2006) ignored the role of root biomass in N uptake by the two cropping systems thereby making their comparison of N (losses and uptake) between ACS and PCS incomplete. It is possible that differences in root biomass and N uptake will account for the differences in nitrate leaching within the two cropping systems.

Although studies (Monti and Zatta, 2009; Culman et al., 2010; Dupont et al., 2014) have compared the root biomass between ACS and PCS, we are not aware of any study that compares the root N uptake of the two cropping systems on a field that was fertilized with pig manure. Study conducted by Monti and Zatta (2009) that compared root biomass between ACS and PCS used energy crops and their study was only interested in soil water capture capacity by the roots without any reference to root N uptake. Although the PCS had higher water use in the study by Monti and Zatta (2009), Karimi et al. (2017) had demonstrated that there is no direct relationship in the amount of water and nitrate leached between ACS and PCS. Karimi et al., (2017) found that even when similar amount of water was leached in ACS and PCS, nitrate leached was still significant greater in ACS than PCS. Ploschuk et al. (2005) that measured higher root N uptake in PCS than ACS used oil seed crop and their study mainly focused on how perennial oil seeds crop can replace annual oil seeds in terms of biomass and nutrient allocation to different parts of the crops and not in terms of nitrate leaching. With the amount of water and nutrients uptake by crop roots depending on plant species and ecosystem (Ferchaud et al., 2015; Hoad et al., 2001), we are not aware of any study that compares root biomass and N uptake of annual crops and perennial forage grasses in terms of accounting for lower nitrate leaching in PCS especially on a loamy sand that has high potential of nitrate leakage. The objective of this study was to determine the importance of root biomass and N uptake with PCS as a mechanism of reducing nitrate leaching

## 2. Materials and methods

### 2.1. Site description and experimental design

A detailed description of the site and experimental design has been previously provided by Lasisi et al. (2017). Briefly, the study was conducted using the National Centre for Livestock and the Environment study area at the University of Manitoba Ian Morrison Research station, Carman, Manitoba (Lat. 49° 29' 64'' N, Long. 98° 02' 15'' W and 239 m a.s.l). The experimental site was established in 2009 on a Hibsin series soil which is an Orthic Black Chernozerm in the Canadian soil classification system (Mills and Haluschak, 1993) and correlates to an Udic Boroll Mollisol in the U.S.A. classification system (Agriculture and Agri-Food Canada, 2013). Prior to site establishment, physical and chemical properties of the soil at 0–15 cm were determined (Table 1).

**Table 1**
Properties of the soil at Carman.

| Soil Properties | Carman |
|---|---|
| Soil pH (1:2, soil:water suspension)[a] | 5.8 |
| Organic matter[b] (g $kg^{-1}$) | 65 |
| volumetric water content at field capacity[c] (m $m^{-3}$) | 33 |
| Available P[d] (mg $kg^{-1}$) | 20 |
| Bulk density[e] (Mg $m^{-3}$) | 1.2 |
| Soil type[f] | Loamy sand |
| Sand content (g $kg^{-1}$) | 870 |
| Silt content (g $kg^{-1}$) | 50 |
| Clay content (g $kg^{-1}$) | 80 |

[a] Hendershot and Lalande (2008).
[b] Walkley and Black (1934).
[c] Cassel and Nielsen (1986).
[d] Olsen and Sommers (1982).
[e] Hao et al. (2008).
[f] Gee and Bauder (1986).

The experiment was a split-plot design with four replications. Each plot had a dimension of 10 m × 10 m. Main plots were two cropping systems and subplots were three manure treatments. Cropping systems were ACS and PCS and manure treatments were LPM, SPM and CON. The ACS had a canola (*Brassica napus L.*) - barley (*Hurdeum vulgare L.*) rotation from 2009 to 2015 and the PCS was seeded to perennial forage grasses from 2009 to 2012. The perennial forage grasses were a mixture of timothy (*Phleum pretense L.*) and orchard (*Dactylis glomerata L.*) grasses at a seeding ratio of 68:32. In the spring of 2013, the perennial forage grasses were ploughed down and seeded to annual crop (canola) and in the fall of 2013, the perennial forage grasses [orchard grass (var. AC Nordic) and timothy grass (var. Promesse)] were reseeded and maintained until 2015. The ACS was seeded to barley (var. Tradition) in 2014 and canola (hyb. Invigor L140P) in 2015.

### 2.2. Manure application

For this current study (2014 and 2015), manures were applied to the plots in the spring of each cropping year. The liquid pig manure was sourced from earthen manure storage of a commercial pig farm in Manitoba while solid pig manure was sourced from stockpiled pig manure with covered roof at Glenlea Research Station of the University of Manitoba, Manitoba. The ammonium-N concentrations and total N of the manures were determined prior to each application (Table 2) to determine the manure application rates using provincial guidelines with the MARC (2008) software to meet the N requirement of each crop for a target yield of 4.6, 2.2 and 7.4 Mg $ha^{-1}$ for barley, canola and forage grasses, respectively. The manure application rate takes into consideration soil residual nitrate-N at 0–60 cm depth and assumes 25% ammonium-N volatilization loss and 25% organic N in the manure is mineralized during the growing season (Table 3) (MAFRI, 2007). The LPM was metered out using 20 L jugs and manually added to plots while the SPM was applied manually to the plots using a pitch fork and a rake. The manures were rototilled in the ACS plots to a depth of approximately 10 cm before seeding in each year (Nikièma et al., 2016).

### 2.3. Biomass sampling

#### 2.3.1. Above-ground biomass sampling and analysis

For ACS, above-ground biomass was sampled at harvest in 2014 and at mid-season in 2015. Above-ground biomass of PCS was sampled at