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Effects of tillage practices on drainage and nitrate leaching from winter wheat in the Northern Atlantic Coastal-Plain USA

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ABSTRACT

Management strategies for winter wheat (*Triticum aestivum* L., cultivar Pioneer "2548") in the Northern Atlantic Coastal-Plain region of the USA must balance agronomic production with practices to reduce nitrate-N (NO_3-N) leaching, because much of this region lies within the Chesapeake Bay watershed. Winter wheat in this region is commonly grown using no-tillage (NT), but few studies have evaluated the effects of NT on NO_3-N leaching for winter wheat. A four-year lysimeter study was conducted in Beltsville, Maryland by growing winter wheat in eight tension-drained undisturbed soil-column lysimeters (41 cm diameter by 100 cm deep) configured to exclude runoff, to compare the effects of NT vs. simulated plow-tillage (PT) and N fertilization practices on drainage volumes and NO_3-N leaching. Additional data documented wheat total N uptake and bromide leaching. The temporal pattern of drainage showed that NT produced significant, but modestly higher, drainage volumes than PT during fall establishment (mid-Oct. to mid-Dec.), which increased the potential for NO_3-N leaching, especially following high rainfalls. However, the greater risk of NO_3-N leaching with NT during establishment decreased in the spring as tillage effects subsided and wheat water-use and N uptake became dominant. The increased fall leaching risk with NT can be managed by reducing fall-N applications, but both NT and PT can benefit from reduced NO_3-N leaching resulting from spring split-N applications. The final NO_3-N leaching losses depend on the interactions of precipitation timing and amount, fertilizer-N rate and timing, and initial soil water status. Additional winter-wheat NO_3-N leaching research is needed to study to a wider range of soils, to assess high-residue vertical-tillage implements, and to evaluate precision application of spring fertilizer-N.

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1. Introduction

Improving N recoveries for winter wheat is fundamental for lowering N losses to the environment and for improving economic returns to the producer. Fertilizer N costs have increased significantly since 2006, underscoring the importance of efficient N management (Meisinger et al., 2008; Randall et al., 2008). In the Northern Atlantic Coastal-Plain (NACP) region of the USA (McNab et al., 2007), concerns often focus on NO_3-N leaching because the lost N can contribute to increased eutrophication, reduced water clarity, and increased hypoxia in the Chesapeake Bay (Boesch et al., 2001; Carpenter et al., 1998). Cultural practices for winter wheat in the NACP have undergone significant changes over the past 15 years, most notably due to the expanded use of no-tillage. However, the authors could not find any studies directly measuring the effects of no-tillage on nitrate leaching from winter wheat in the humid temperate climate of the eastern USA.

1.1. Leaching in the NACP region of the USA

Managing N for profitable winter wheat production in a humid climate, like the NACP region, is challenging because wheat is grown during the fall–winter–spring water recharge season. Studies at Coshocton, Ohio (USDA, 1958, 1967) used two large gravity-drained monolith lysimeters (Y101A and Y101B), each with an 8 m^2 surface areas by 2.4 m deep, to define the water recharge season in the humid temperate climate of the eastern USA. The well-drained silt loam soil in each monolith lysimeter was seeded to continuous grass over a 25 year period from 1938–1962. The long-term Coshocton percolation data (Fig. 1) shows that the main water recharge season begins in late-fall and extends through May (USDA, 1967). Risser et al. (2005) also reported monthly drainage data from seven gravity-drained lysimeters at the Masser Recharge

Abbreviations: DAP, days after planting; N, nitrogen; NO_3-N, nitrate-nitrogen; NT, no-tillage; PT, plow-tillage; TDM, total aboveground dry matter; NACP, North Atlantic Coastal-Plain.

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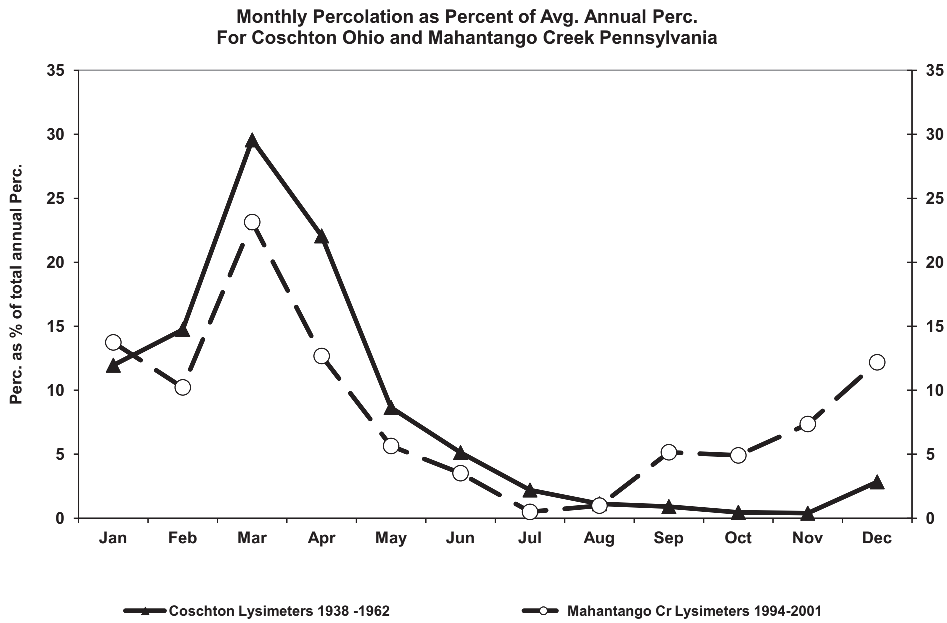

Fig. 1. Monthly percolation, as percent of annual percolation, from long-term large-monolith lysimeter studies at Coshocton, Ohio (solid symbols) and Mahantango Creek, Pennsylvania (open symbols).

Site in the Mahantango Creek watershed in Pennsylvania. These lysimeters were 0.3 m^2 by 1 m deep and were also cropped to grass with monthly percolate measured over eight years (1994–2001). The Pennsylvania data (Fig. 1) shows a similar seasonal pattern of percolation that begins in September and extends through May (Risser et al., 2005). The winter wheat growing season in the NACP is from planting in mid-October through harvest in mid-June. The Coshocton drainage data (Fig. 1) have 95% of the total annual drainage occurring during the winter wheat growing-season, while the corresponding value for the Mahangango Creek is 89%. These drainage data show the basic reason why N management for winter wheat in the NACP is difficult – because it is grown during a season of high potential leaching. Furthermore, the N lost through leaching affects the nitrate concentration of ground water that eventually reaches the Chesapeake Bay through stream base-flow. Bachman et al., 1998 have estimated that base flow makes up about 55% of the total nitrate load for the Chesapeake Bay watershed.

1.2. Nitrogen leaching and tillage

Winter wheat most commonly follows corn in the NACP and is established using either low-disturbance high surface-residue no-tillage, or with traditional high-disturbance low-residue plowing. A survey of Maryland County Extension Agents (pers. comm. Dr. R. Kratchovil, 2010 University of Maryland, College Park, MD) revealed that 50–80% of Maryland winter-wheat acres are now established with no-tillage.

Tillage can have multiple, but contrasting, affects on NO_3-N leaching (Addiscott and Dexter, 1994; Strudley et al., 2008). Compared to plow-tillage, no-tillage generally: (i) increases hydraulic conductivities by preserving root or earthworm preferential-flow channels (Azooz and Arshad, 2001; Benjamin, 1993; Isensee et al., 1990; Palmer et al., 2011b); (ii) increases soil organic N due to reduced decomposition brought about by minimizing soil disturbance and protecting organic N within aggregates (Dolan et al., 2006; Franzleubbers et al., 1994; West and Post, 2002; Wright and Hons, 2005; Zibilske and Bradford, 2007); (iii) slows the rate of residue decomposition by keeping residues on the surface where decomposition is slower than if mixed into the soil (Alvarez et al., 2008; Coppens et al., 2006; Cogle et al., 1987; Douglas et al., 1980); and (iv) increases soil water content (Blevins et al., 1971). Thus, tillage has multi-faceted effects on several soil processes that can impact NO_3-N leaching, especially when tillage occurs shortly before a season of high water-recharge as shown in Fig. 1.

The effect of tillage on NO_3-N leaching will also interact with soil and weather conditions, and N management practices. For example, the timing and amount of rainfall in relation to the time of tillage, can influence total percolation and the percentage of percolation that is contributed by preferential flow, which are two main factors affecting nitrate leaching. Likewise, the timing and placement of fertilizer N can impact N leaching by affecting the size of the soil NO_3-N pool and the distribution of nitrate between rapid-flow and slow-flow drainage domains.

The above factors, and interactions among these factors, illustrates why reviews have concluded that tillage has dynamic and quite variable effects on NO_3-N leaching (Addiscott and Dexter, 1994; Strudley et al., 2008). Therefore, understanding the effect of tillage on NO_3-N leaching from winter wheat using lysimeters in a humid climate, will necessarily involve careful interpretation of the weather conditions after tillage, as well as crop residue and fertilizer N practices. Lysimeters can contribute to our understanding of tillage and NO_3-N leaching by providing a direct measurement of the combined effects of tillage along with the interaction of tillage with the soil N cycle, the soil transport processes, the weather conditions, and the fertilizer N management practices.

1.3. Objectives

The objectives of this study are to utilize undisturbed soil-core lysimeters to: (i) compare the water drainage patterns from winter wheat grown under NT vs. PT under natural humid rainfall conditions and (ii) evaluate the effects of NT vs. PT on NO_3-N leaching and N uptake of winter wheat.