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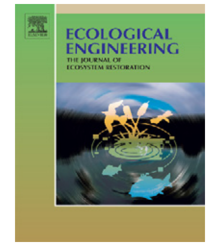

An index approach to assess nitrogen losses to the environment☆

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Nitrogen (N) losses from agriculture are negatively impacting groundwater, air, and surface water quality. New tools are needed to quickly assess these losses and provide nutrient managers and conservationists with effective tools to assess the effects of current and alternative management practices on N loss pathways. A new N-Index tool was developed in spreadsheet format, allowing prompt assessments of management practices on agricultural N losses. The N-Index tool was compared with experimental field data and shown to estimate the effects of management practices on N loss pathways (probability, $P < 0.001$). The N-Index correctly assessed the nitrate nitrogen (NO_3-N) leaching losses when tested against measured NO_3-N leaching data and atmospheric N losses collected over multiple years (annual basis) and locations. The N-Index tool was developed with international cooperation from several countries and there is potential to use this tool at the international level.

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Abbreviations: NIT-1, N-Index Tier-1 spreadsheet tool; NLEAP, nitrate leaching and economic analysis package.

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1. Introduction

Agricultural-related nitrogen (N) losses are negatively impacting groundwater, air, and surface water quality (Antweiler et al., 1996; Follett and Walker, 1989; Follett et al., 1991; McCracken et al., 1994; Mitsch and Day, 2006; Milburn et al., 1990; Owens and Edwards, 1994). The complexities of the N cycle have made estimating these losses extremely difficult (Delgado, 2002). Today nutrient managers and conservationists need faster and more effective tools to assess the effects of current and alternative management practices on N loss pathways. Biologists, applied ecologists, environmental scientists, and nutrient managers interested in assessing the effects of N management on agricultural N losses to the environment could use a N-Index Tier-1 tool to conduct prompt assessments of management practices (Shaffer and Delgado, 2002; Delgado et al., 2006).

Shaffer and Delgado (2001, 2002) described the tier concept for nitrogen management in relation to the complexity of the data needed to develop viable field management practices. In a tier approach, users judge the tool capabilities versus N management requirements for their project. A Tier-1 level will be a system that rapidly conducts an initial qualitative/quantitative screening to separate the potential impacts of medium, high and very high N losses from low and very low potential impacts (Shaffer and Delgado, 2002; Delgado et al., 2006). A Tier-2 level would involve a more complex level of computation of the N dynamics on a daily schedule using application models. A Tier-3 level will involve a detailed research model with supportive field studies.

A potential application of a Tier-1 N-Index is to assess the N losses to the environment to separate the effects of nitrogen management on medium, high and very high nitrate nitrogen (NO_3-N) leaching loss potential impacts from the low and very low levels based on numeric and non-numeric inputs from users. Similarly, the N-Index would be able to separate and rank the effects of nitrogen management on atmospheric and surface N losses. If needed, the N-Index can be calibrated using local/regional data of N uptake, yields, N cycling, N content in manures, and others local parameters to facilitate the decision making process in identifying the potential, local best management practices and alternatives that reduce N losses.

The N-Index can be used to conduct a quick comparison of a basic scenario in different management alternatives. It has been reported that N losses from agricultural systems can be a source of non-point pollution on the environment (Dzikiewicz, 2000; Hofmann et al., 2004; Vagstad et al., 2000; Mitsch and Day, 2006; Hatano et al., 2005). Similarly, several authors have reported that these N losses can be reduced with the implementation of best nitrogen management practices (Bottcher et al., 1995; Delgado, 2001; Shaffer and Delgado, 2002). Expert systems can contribute in making N management decisions that will reduce N losses (Shaffer and Delgado, 2002; Delgado et al., 2006; Palma et al., 2007; van der Werf et al., 2007).

Field and off-site parameters need to be considered when deciding on nitrogen management practices. Off the field practices, such as buffers, can contribute to reduce N losses to the environment (Dosskey et al., 2005; Hefting et al., 2005; Hey et al., 2005). Shaffer and Delgado (2002) and Delgado et al. (2006) recommended that a practical Tier-1 N-Index tool should be able to integrate best management practices with ecological engineering principles and practices such as use of buffers, account for distance to water bodies, deeper rooting systems, distance to aquifers, and others, to help separate and rank the potential effects of nitrogen management.

Rowe et al. (1999) recommended the principle of using trees as a filtering system to reduce NO_3-N leaching. This principle was tested by Allen et al. (2004) for a pecan–cotton alley cropping system in northwestern Florida, and Palma et al. (2007), van der Werf et al. (2007) and Nair et al. (2007) recommended the same type of system for European systems. Deeper-rooted crops were reported to be alternatives to scavenge NO_3-N that has been leached from previous shallower root rotations (Shipley et al., 1992; Delgado, 1998). These deeper-rooted systems were reported to serve as ecological filter strips that recover and even mine NO_3-N from underground water, reducing the net NO_3-N leaching losses to the environment (Delgado, 1998, 2001; Delgado et al., 2001a,b, 2007). The mining of NO_3-N was reported to happen when the amount of NO_3-N leached from deeper-rooted systems was lower than the amount of NO_3-N added with the underground irrigation water.

The concept of an N-Index has been discussed over the last 20 years (Follett et al., 1991; Shaffer and Delgado, 2002; Delgado et al., 2006). Shaffer and Delgado (2002) discussed the possible advantages and disadvantages of having several N-Indexes. The Williams and Kissel (1991) Leaching Index (LI) has been called the N-Index and is being used by USDA-NRCS personnel to estimate potential NO_3-N leaching based on estimated water available to leach (Van Es et al., 2002; Van Es and Delgado, 2006). One advantage of the LI is that it can be computed by using available soil, precipitation, and irrigation databases. The major disadvantage is that the index does not account for N management practices, N dynamics, N sinks, N uptakes, N sources, residual soil NO_3-N, and/or estimates of NO_3-N leaching (Shaffer and Delgado, 2002). Other N-Indexes discussed by Shaffer and Delgado (2002) were the Movement Risk Index, by Shaffer et al. (1991); the Nitrate Available to Leach Index, by Shaffer et al. (1991); the Residual Soil NO_3-N-Index, by Shaffer et al. (1991); the Nitrate Leached Index, by Shaffer et al. (1991); the Nitrogen Use Efficiency Index, by Bock and Hergert (1991); the Annual Leaching Risk Potential Index, by Pierce et al. (1991); and the Aquifer Risk Index, by Shaffer et al. (1991). None of these indexes have all the necessary features that are included in the Delgado et al. (2006) index.

There has been ongoing interest in developing and testing new N-Indexes. Wu et al. (2005) developed the Nitrate Leaching Hazard Index for irrigated agriculture in California. Wu et al. (2005) reported that their Hazard Index can be used to provide information to growers, so they can voluntarily select management practices that reduce NO_3-N leaching. The Wu et al. (2005) Nitrate Leaching Hazard Index was in concurrence with Delgado (1998, 2001), Shaffer and Delgado (2002) with the concept that crop rotations and rooting depths can be used as management tools under commercial operations