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Use of the Nitrogen Index to assess nitrate leaching and water drainage from plastic-mulched horticultural cropping systems of Florida☆

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ABSTRACT

Water quality in Florida is significantly impacted by nitrate (NO_3-N) leaching losses from agriculture in a large part of the state. Horticultural crops are planted across large areas of Florida on coarse sandy soils with low soil water retention and soil organic matter, increasing the potential for NO_3-N leaching. Nitrate leaching losses from the root zone of vegetable cropping systems can negatively impact groundwater. New tools such as the Nitrogen Index (N-Index) are able to quickly assess N use efficiency and losses via NO_3-N leaching from agricultural systems. Furthermore, the N-Index provides technical information about N losses pathways tied to agricultural management practices with a great level of confidence; this information has been used by researchers, growers and policymakers as a decision support system. However, the current version of the N-Index that has been used for different field crops has not been calibrated to be used in plastic-mulched horticultural cropping systems. The aim of this work was to calibrate and validate the N-Index for plastic-mulched horticultural cropping systems of Florida. This study found that the N-Index tool accurately identified and ranked the risk of N losses in the evaluated horticultural systems. The N-Index was calibrated for Florida's plastic-mulched horticultural cropping systems using a sensitivity analysis. The adjusted N-Index was validated using compiled data of vegetables grown under plastic mulching systems during three consecutive seasons. Results from these studies suggest that the N-Index can be an easy-to-use tool capable of assessing nitrogen management practices for vegetable systems. The tool can be used to guide nutrient managers in the implementation of best nitrogen management practices that could contribute to reduced NO_3-N leaching losses from vegetable systems in Florida, contributing to a smaller environmental footprint and conservation of water quality.

1. Introduction

Vegetables are important crops in Florida, and Florida's vegetable crops are important at a national level since Florida's production of fresh-market tomatoes, green peppers, and zucchini ranks second nationally in production value (NASS, 2014). The vegetable production systems in Florida feature the use of raised beds and plastic mulch with the use of drip irrigation. Generally, a few weeks prior to planting, raised beds are constructed and fumigated right before placement of both drip tape and plastic mulch. In order to minimize economic losses from lower yields caused by nutrient deficiencies and water stress, for these high value crops, the N fertilizer and irrigation water application rates are usually higher than the recommended rates (Scholberg et al., 2013). These vegetable crops are also grown during a brief period of time that lasts for about 70–80 days, on sandy, coarse-textured soils with erratic, large rainfall events. The combination of high N fertilizer rates, low plant N extraction rates, low N fertilizer use efficiencies, and large fluxes of water from irrigation and rainfall, greatly increases the potential for high nitrate leaching in these cropping systems. Therefore, leaching of nitrate from cropping systems has been one of the

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nonpoint-sources of groundwater pollution at a regional level (Alva et al., 2005; Chen, Wu, Hu, & Li, 2010; Delgado et al., 2005; Ramos, Agut, & Lidon, 2002; Tei, Benincasa, & Guiducci, 1999).

Nitrogen is an element that is very mobile in soil, and it can be removed from agricultural systems via volatilization of ammonia (NH_3), erosion, leaching, and absorption; and exported by harvesting cultivated plants. In Florida, concerns about N losses from cultivated soil are already longstanding (Oertli & Lunt, 1962), and are influenced by regional management practices (Chen et al., 2010). Nitrate (NO_3^-) is the form of N that stands out in terms of N losses from Florida's agricultural systems (Jadoski, Saito, Prado, Lopes, & Sales, 2010). Nitrate is weakly adsorbed in soil particles and stays in solution. Under typical Florida conditions, most of the N from fertilizers is promptly converted into nitrate and may be lost by leaching because of the inherent poor soil water holding capacity and rapid drainage of sandy soils (Bouwer, 1985). Nitrogen losses are not just seen as a concern from an economic point of view; there are also concerns about risks to human and animal health, and the environment (Rios et al., 2013), especially in Florida.

Nitrogen loss from agricultural systems to the environment can be evaluated by various models. Cannavo, Recous, Parnaudeau, and Reau (2008) reported that there are sixty-two N models reported in the literature that can assess N in agricultural environments. Among the various computer model approaches for modeling N flows reported by Shaffer and Delgado (2002), the new N-Index tool (Delgado et al., 2006, 2008) was selected for the current study because it can be applied more widely and easily than the other models. The N-Index is considered a suitable tool for evaluating agricultural management practices, and it can quantify N losses from the system (Delgado et al., 2006, 2008). The N-Index can accurately perform risk assessments and facilitate the communication between scientists, extension personnel, and farmers about how different management practices may affect N losses (Bolster et al., 2014; Escudero et al., 2014; Figueroa-Viramontes et al., 2011; Saavedra, Delgado, Botello, Mamani, & Alwang, 2014; Saynes et al., 2014).

The N-Index was created by adapting the water leaching index (LI) developed by Williams and Kissel (1991) to conduct an N mass balance (Delgado et al., 2006, 2008). The N-Index approach can be used to conduct a quick assessment of N losses to the environment, including nitrate leaching losses (Delgado et al., 2006; Shaffer & Delgado, 2002; Van Es, Czymmek, & Ketterings, 2002; Van Es & Delgado, 2006). The N-Index is currently being used by technicians at the Natural Resources Conservation Service (NRCS, http://www.nrcs.usda.gov) to estimate the potential nitrate leaching of soils and assess the risk of nitrate leaching (Bolster et al., 2014).

The advantage of the N-Index is that it is a quick tool that integrates management, soil, climate, hydrology and off-site information to assess the pathways for N losses via NO_3-N leaching, surface runoff, erosion, ammonia volatilization, denitrification and N_2O emissions. This quick tool that accounts for leaching, surface and atmospheric losses, can also conduct quick assessments of the effects of N management practices on N uptake by a variety of crops, and can be used to quickly conduct nitrogen balances and assessment of N use efficiencies. It can also be used to assess the potential benefits of increasing N use efficiencies in reducing potential N losses to the air and groundwater, or via surface transport. The N-Index can also consider effects of rotations and be connected to other nutrients for joint assessment of the effects of management on nutrient losses (Bolster et al., 2014).

A disadvantage of the N-Index is that is a tool based on annual information and not an event-by-event mechanistic tool. The tool's assessment of the effects of nitrogen management practices on the risk of nitrogen losses via different pathways is on an annual basis. Users of the N-Index can use the tool to assess the N dynamics during the growing season of the crop by entering the needed annual information (e.g., precipitation during the growing season of the crop and precipitation during the non-growing season of the crop, etc.) and the initial residual soil NO_3-N at planting. The residual soil NO_3-N simulated with the N-Index could be compared to residual soil NO_3-N measured after harvesting the crop at the end of the growing season. Since the N-Index uses annual information (with measured initial soil NO_3-N values collected at planting or twelve months before the harvesting of the crop), this simplifies the entry of information in the N-Index and makes the tool easy to use. Although the N-Index has the disadvantage of not being an event-by-event daily tool, it is a robust tool that can be used to assess the effects of different management practices on nitrate leaching, atmospheric N losses, crop N uptake, and N use efficiencies, with predicted values that are similar to observed values.

The robustness of the N-Index is demonstrated by the fact that it has been adapted to different geographical areas, including several states in the USA (e.g., Wisconsin, Kentucky, and California), and several international regions, including a Mediterranean region of Europe and the countries of Ecuador, Bolivia, Mexico, and Malawi (Delgado et al., 2008; Escudero et al., 2014; Figueroa-Viramontes et al., 2011; Saavedra et al., 2014). Results from earlier publications suggest that the N-Index is a robust tool with good correlation between observed and predicted values (Bolster et al., 2014; Delgado et al., 2008; Escudero et al., 2014; Figueroa-Viramontes et al., 2011; Saavedra et al., 2014; Saynes et al., 2014).

The N-Index assesses the risk of N losses via different pathways. Each pathway can be considered individually. After the evaluation of an agricultural system, the model ranks the scenario as having very low, low, medium, high, or very high risk of nitrogen loss. The tool can assess the effects of nitrogen management using numeric and non-numeric inputs by separating medium, high and very high potential risk for nitrogen leaching losses from low and very low potential risk for nitrogen leaching losses (Delgado et al., 2006, 2008). Scenarios with a ranking of low or very low will have a low potential risk of nitrate leaching, while scenarios with a ranking of high or very high will have a high or very high potential risk of nitrate leaching loss. The tool can also simultaneously assess the risk of nitrogen management for other pathways for nitrogen losses such as atmospheric and surface N losses (Delgado et al., 2006, 2008). This information makes it possible to change the management practices, reducing N losses, as well as increasing fertilizer efficiency (Delgado & Berry, 2008).

To improve its accuracy, the N-Index can be calibrated for each region and production system to attend to specific local conditions (Delgado et al., 2006, 2008; Escudero et al., 2014; Figueroa-Viramontes et al., 2011; Saavedra et al., 2014; Saynes et al., 2014; Bolster et al., 2013). De Paz, Delgado, Ramos, Shaffer, and Barbarick (2009) calibrated the N-Index for vegetable systems of a Mediterranean region of Spain. The N-Index has been adapted for other areas such as Ecuador, Bolivia, Mexico, and several states in the USA using the same formulas but including local information about the crops grown at the site (Delgado et al., 2008; Escudero et al., 2014; Figueroa-Viramontes et al., 2011; Saavedra et al., 2014). Results from earlier publications suggest that the Nitrogen Index is a robust tool with good correlation between observed and predicted values (Delgado et al., 2008; Escudero et al., 2014; Figueroa-Viramontes et al., 2011; Saavedra et al., 2014).

The N-Index uses crop, soil, hydrological, and weather information to conduct nitrogen balances and calculate the nitrate available to leach. The N-Index uses Eq. (1) to calculate the nitrate leaching (Pierce, Shaffer, & Halvorson, 1991).

$$NL = NAL \times (1.0 - \exp(-k \times WAL/POR)) \tag{1}$$

where:

NL = NO_3-N leaching (kg NO_3-N $ha^{-1}\,y^{-1}$) at a specific depth (e.g., root zone);
NAL = NO_3-N available to leach (kg NO_3-N $ha^{-1}\,y^{-1}$);
k is a coefficient (1.2);
WAL = water available for leaching (it can be the LI for an annual NAL);