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A nitrogen index for improving nutrient management within commercial Mexican dairy operations

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ABSTRACT

Some intensive dairy operations in Mexico are contributing to large, negative environmental impacts, especially in regions dominated by high concentrations of animals. Excessive manure inputs plus additional nitrogen (N) fertilizer has, in some cases, resulted in background nitrate–nitrogen (NO_3–N) levels in irrigation water that are so high, it is not safe for human consumption. One reason is that commercial farmers in this region are currently not using any method to rapidly calculate N budgets based on their practices, N inputs and/or crop N uptake. The Nitrogen Index, a quick tool that can be used to conduct an assessment within a few minutes, was developed for Mexico, but needed further testing under commercial field operations. We conducted studies in 2010 and 2011 and collected soil and crop information from several commercial farming operations to test the tool. The index accurately assessed ($P < 0.0001$) residual soil nitrate after harvesting corn (*Zea mays* L.) and oats (*Avena sativa* L.); and also accurately assessed the N uptake of these crops ($P < 0.01$). The Mexico N Index is a tool that can be used to quickly conduct N balances, show when N is being over-applied, and help reduce over-application, thus reducing N losses to the environment and improving management of dairy forage systems in Mexico.

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1. Introduction

The largest environmental impacts from dairy farm operations have been reported to be from excessive nitrogen (N) and phosphorus (P) applications (Sharpley et al., 2003). One reason is that dairy animals have an average N use efficiency that is highly variable and ranges from 17% to 41% (Van Horn et al. 2003; Castillo, Kebread, Beever & France, 2000; Sánchez-Duarte, Núñez-Hernandez, Ochoa-Martinez & Figueroa-Viramontes, 2009). This means that milk production by

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dairy cattle will generally increase in response to dietary inputs that have 13.8–17.5% protein content, but greater inputs simply increase N loss in manure and urea deposition (Brito and Broderick 2006). Currently, the most common practice in Mexico is to apply manure to fields that are dedicated to forage production for the animals (FAO, 2002; Fortis-Hernandez et al. 2009; Figueroa-Viramontes, Núñez-Hernandez, Delgado, Cueto-Wong & Flores Margez, 2009).

The Comarca Lagunera region is located between two states, Durango and Coahuila, and has the largest concentration of dairy animals in Mexico (~423,000 head or 20% of all dairy animals). Due to the high demand for forage in this region, 69% of the irrigated area is devoted to these crops (SIAP-SAGARPA, 2013). The production systems are managed with intensive agricultural inputs that include manure application rates exceeding 80 ha^{-1}, four to eight times the average manure application rate commonly used in the USA. In addition, nutrient managers in the region typically apply additional fertilizer to these forage systems (Fortis-Hernandez et al. 2009). As a result, these practices are threatening water quality, by creating a tremendously high potential for groundwater contamination due to NO_3–N leaching. Recent studies have confirmed this is indeed an emerging problem (Cueto-Wong, Reta-Sanchez, Gonzalez-Cervantes, Orona-Castillo & Estrada-Avalos, 2005; Martínez-Rodriguez, Castellanos, Rivera-Gonzalez, Núñez-Hernandez, and Faz-Contreras, 2006). Commercial field applications of manure in Mexico are not based on any technical studies that account for the N balance, residual inorganic soil N, or mineralizable N that can meet plant N uptake demands. To ensure producer acceptance, it is important to conduct studies within farmers' fields to evaluate methods for increasing N use efficiency using their traditional management practices and thus avoiding over-application of N (Delgado, 2001; Delgado et al., 2007; Cui et al., 2008).

Several researchers have found that it is possible to estimate N availability from manure, and to substitute fertilizer with manure (using manure alone or in combination with inorganic N fertilizer), while maintaining viable crop production and not reducing yields (Figueroa-Viramontes et al. 2010; Ferguson, Nienaber, Eigenberg & Woodbury, 2005; Muñoz, Kelling, Rylant & Zhu, 2008). In addition to the potential environmental impact, this is very important for Mexico, since N fertilizers are imported and the cost is very high, representing 20–40% of the total forage production cost. Using manure to reduce fertilizer use would increase economic returns for farmers in this region and help protect water quality by reducing N losses to the environment. To do so, viable tools that can provide farmers with important information to help them make management decisions that reduce N inputs need to be developed. One such tool, which has been calibrated and validated using data from Mexican field research is the Mexico Nitrogen Index (Delgado et al. 2008; Figueroa-Viramontes et al. 2011).

The Nitrogen Index only requires a small amount of information to run an assessment, and to speed the entry of information, users are given a series of dropdown menus to select practices used at the site. The Nitrogen Index captures information about soils, manures, crops, irrigation management, fertilizer application, and a series of other factors. A detailed description of the Nitrogen Index inputs can be found in Delgado et al. (2006, 2008), Figueroa-Viramontes et al. (2010), and De Paz, Delgado, Ramos, Shaffer, and Barbarick (2009). The Nitrogen Index can also be downloaded from the USDA-ARS Nitrogen Tools webpage (http://www.ars.usda.gov/npa/spnr/nitrogentools) and installed on a desktop or laptop computer. Once installed, the user manual for the Nitrogen Index can be found in the following directory: C:/Program Files/USDA-ARS-SPNR/NitrogenIndex/Example Files & Manual.

The Nitrogen Index outputs include a quantitative estimate of nitrate leaching. De Paz et al. (2009) found an r^2=0.86 between measured and predicted nitrate leaching using the Nitrogen Index. Using plot research data from studies in Mexico, Figueroa-Viramontes et al. (2010) found an r^2 of 0.85 between the residual nitrate measured for the soil profile and residual soil nitrate estimated by the Nitrogen Index. Using quantitative outputs for N loss pathways such as nitrate leaching, ammonia volatilization, and qualitative inputs describing the management practices, the Nitrogen Index tool can assess risk for nitrate leaching losses as very high, high, medium, low, or very low. Our objective was to monitor performance of the Mexico Nitrogen Index tool for commercial dairy farms across the Comarca Lagunera region, in order to validate the tool and transfer the technology to top INIFAP (Instituto Nacional de Investigaciones Forestales, Agricolas, y Pecuarias) personnel working with farmers in this region. If successful, the tool could also be used to help reduce N losses from regional forage production systems.

Table 1
Crop management, soil properties, water inputs, yield and protein content of crops harvested on commercial dairy operations near Comarca Lagunera, MX.

	Site									
	Porvenir	Ampuero	Noacán	Campanario	Granja Ana	Granja Ana	Granja Ana	Chupon	Chupon	Chupon
Forage crop	Oats	Oats	Oats	Oats	Corn	Corn	Corn	Corn	Corn	Corn
Planting date	24/11/2010	4/11/2010	3/11/2010	10/11/2010	4/04/2011	4/04/2011	4/04/2011	18/03/2011	18/03/2011	18/03/2011
Days to harvest	86	96	100	92	106	106	106	109	109	109
Irrigation (mm)	57	84	44	60	75	75	75	90	90	90
[a]Rain GS (mm)	27.9	34.2	34.2	34.2	87.8	87.8	87.8	81.4	81.4	81.4
[b]Rain NGS (mm)	234.1	227.9	227.9	227.9	173.9	173.9	173.9	180.3	180.3	180.3
Texture	clay	clay	loamy	clay	clay	clay	clay	Sandy clay	Sandy clay	Sandy clay
Irrigation NO_3–N (ppm)	0.5	0.5	0.5	0.5	1	1	1	60	60	60
pH	8	8.2	8.1	8.1	8.4	8.4	8.4	8.3	8.3	8.3
Organic matter (%)	2.3	1.7	3.4	1.5	1.1	1.1	1.1	1.5	1.5	1.5
Manure (ton ha^{-1})	0	0	0	0	60	60	60	70	70	70
Fertilizer (kg N ha^{-1})	92	32	42	42	0	60	100	0	60	100
[c] Yield FW (ton ha^{-1})	24.1	44.6	24.9	12.3	62	71	64	74	68	61
[d] Yield DM (ton ha^{-1})	3.8	10.6	5.3	3.8	20	22	20	19	17	17
Protein content (%)	18.2	16.5	17.3	7.7	7.0	6.4	6.3	7.8	6.7	7.6

[a] GS=growing season.
[b] NGS=non-growing season.
[c] FW=fresh weight.
[d] DM=dry matter.