Nitrogen transfers and losses in integrated agricultural systems in central Mexico

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Introduction

Agricultural systems in Mexico have become more specialized and more intensive in recent decades; these changes have been accompanied by a greater potential for uncontrolled losses of nutrients. The adoption of more integrated agricultural methods is a priority in food production systems as resource degradation has become a major limitation to sustained output (Ventura *et al.,* 2001). Nitrogen (N) is the single most important nutrient for increasing crop yields and is often lost in different forms due to complex processes of transformation and transfer within components of agricultural systems (Dalton & Brand-Hardy 2003). Nitrogen losses through ammonia volatilization are known to occur in traditional, livestock-based agricultural systems, but little attention has been given to this source of N loss on farms in central Mexico. This study investigated N dynamics in farming systems in the Central Valley of Mexico, in the region of the former Lake of Texcoco, an area characterised by saline and alkaline soils (Beltran-Hernandez *et al.,* 1999).

Within these farming systems, composting is becoming a common method to manage organic wastes in Mexico, and the use of compost and manure as organic fertilizer has increased in recent years (Velasco-Velasco *et al.,* 2004). The practice of composting manure is known to lead to enhanced N losses; for example Martins and Dewes (1992) observed losses of ammonia and nitrous oxide ranging from 21 - 77% of the initial N content during 100 days of composting of farm yard manure. The concept of increasing N use efficiency on farms by minimizing N losses has been studied previously; however, there are still uncertainties and gaps when it is evaluated in a whole farm perspective in Mexico, mainly because of the great diversity of agricultural systems. Parkinson *et al*. (2004) stated that the implementation of cost effective practices for manure handling such as delay turning events during composting could lead to reductions in nutrient loss, composting cost and environmental impact.

The aim of this research was to study the nitrogen dynamics of an integrated agricultural system (IAS) prototype located in the Valley of Mexico with special focus on N losses during the composting process.

Material and methods

The integrated agricultural system (IAS) prototype is located in the Texcoco Region of the Central Valley of Mexico at 19° 29' North latitude and 98° 54' West longitude and 2250 metres above sea level. Mean annual rainfall is 630 mm. Core components of the production system which are typical of the region, are milking goats, vegetable production, fruit trees and grassland. Manure from the goats is composted prior to application to the grassland (see Table 1). Nitrogen inputs and outputs were quantified using a variety of sources: general data from the literature, specific data from the IAS prototype and research conducted in the same region.

In order to establish the magnitude of gaseous N losses from manure management, experimental work was carried out on ammonia-N measurements during aerobic composting (Searle 1984; Chadwick *et al.,* 2001; Misselbrook *et al.,* 2005). Aerobic composting of sheep manure (initial pH 8.3, total N 20 g kg^{-1} DM, total carbon 400 g kg^{-1}

DM) was conducted in a composting facility at IGER, North Wyke, Devon, UK. Feedstock with two C:N ratios (20:1 and 26:1) was created by adding extra straw prior to composting. NH_3-N emission was measured at regular intervals during the composting period (28 days), and total loss was estimated, derived by integrating the area under the best fit polynomial curve ($y = -0.05x^3 + 2.9x^2 - 49.3x + 324$).

Table 1. Characteristics of agricultural systems in the valley of Mexico and in the IAS prototype

Characteristics	Typical attribute values in the region	Selected attribute values in the IAS prototype
Total land area (ha)	1-4	2
Holdings of land	1-2	1
Water supply: rain-fed: irrigated	1:1	1:3
Orchard (number of fruit trees)	0-20	20 (apricot)
Grassland (legume/grass) (ha)	<1	1.5
Goats (number of animals)	15	50
Sheep (number of animals)	15	-
Cow (number of animals)	5	-
Maize (Zea mays L.) ($t\ ha^{-1}$)	6*	3
Alfalfa (cut forage) ($t\ ha^{-1}$) ┴	20*	11**
Lettuce ($t\ ha^{-1}$)	36*	80 ┬
Squash ($t\ ha^{-1}$)	26*	60 ┬
Broccoli ($t\ ha^{-1}$)	28*	60 ┬
Onion ($t\ ha^{-1}$)	20*	80 ┬
Total land for vegetables (m^2)		100

Amounts presented in this table are calculated per annum. ┬ Data obtained in the IAS-prototype under the bio-intensive method. ┴ Dry matter. *Source: (SAGARPA 2005). Note actual area allocated to vegetables = 0.01 ha. ** (Camacho-Garcia & Garcia-Muñiz 2003). In the IAS-prototype 0.1 ha is cultivated with maize, 0.4 ha with alfalfa and only 100 m^2 are dedicated to vegetables (25 m^2 each).

Results and discussion

Ammonia volatilization during composting

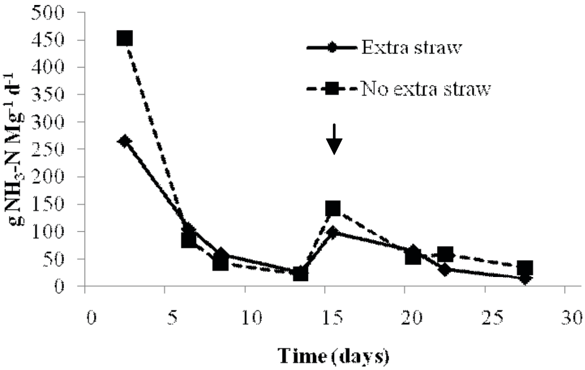
The dynamics of NH_3-N during composting showed that most ammonia volatilization occurred at the beginning of the composting process. The substrate with extra straw added showed less loss of nitrogen (266 g NH_3 Mg^{-1} d^{-1}) compared to the substrate (sheep manure plus bedding) without addition of extra straw (453 g NH_3 Mg^{-1} d^{-1}) (Figure 1). These results coincide with those observed by Liang *et al*., (2006) who mention that 90% of the NH_3 from four paper treatments was emitted within the first 100 h in an experiment in vessels in which he measured the accumulative NH_3 emissions over 300 hr. Similarly, Parkinson *et al*., (2004) confirm that turning manure stacks to aid composting can increase NH_3-N losses during cattle manure storage. A small increase of NH_3-N volatilization was observed following pile turning on Day 15. The proportion of N loss in terms of the initial N content of the substrate was in the order of 15.3% for the substrate with a C:N ratio of 20:1 and 14.0% for the substrate with 26:1 of C:N ratio.

Estimating N balance in the IAS prototype

The main nitrogen inputs to the IAS prototype include: *rainfall and irrigation water, biological fixation, manure, compost, livestock (milking goats), concentrated feed, straw feed*; N outputs include: *erosion, NH_3-N emission, leaching, and vegetables, fruit, milk* and *meat products.* (see Table 2). Reported nitrogen deposition in rainfall in the Central

Valley of Mexico vary widely from to 32 kg N ha^{-1} yr^{-1} depending on the site of the valley, precipitation and industrial activities from Mexico City (Fenn *et al.,* 1999) while N input from irrigation water ranges from 2 to 38 kg N ha^{-1}, depending on the quantity of water applied and its chemistry (Edmunds *et al.,* 2002). Potential N inputs by biological fixation range from 35 – 335 kg N ha^{-1} yr^{-1} (Wheeler *et al.,* 1997; Russelle & Birr 2004). These variations in N deposition depend mainly on particular characteristics of the sites where research was conducted. Data presented in Table 2 was compiled from chemical analysis carried out in the Texcoco region (Beltran-Hernandez *et al.,* 1999; Fenn *et al.,* 1999; Perez-Olvera *et al.,* 2000; Torres-Lima & Burns 2002; Velasco-Saldaña 2002; Camacho-Garcia & Garcia-Muñiz 2003; Velasco-Velasco *et al.,* 2004).

Figure 1. Indicative ammonia-nitrogen losses (NH_3-N) during 30 days of composting of sheep manure plus bedding (SMB) with and without addition of extra straw. ↓= Turning time



The general N balance presented in Table 2 shows that of the total N inputs of 246 kg N in the IAS prototype, 74% comes from N through concentrated and straw feed (56 and 18%, respectively); while 14% (35 kg N) is attributed to biological fixation, and the remainder (12% of N input) corresponds to rainfall and irrigation water (14 and 15 kg N, respectively). Similar percentage values were calculated in the whole-farm nitrogen balance on commercial dairies in Utah and Idaho USA using the University of Maryland Nutrient Balancer (Spears *et al.,* 2003). Large N losses and inefficient N management are apparent according to the nitrogen balance in this case study.

Ranking types of farming system according to nitrogen turnover shows that nitrogen output is directly related to nitrogen input, and that the range of variation between input and outputs is greater in more intensive than less intensive systems (Tivy 1990). According to Tivy's definition, this case study is managed in a semi-intensive manner, in which nitrogen input varies high with respect to nitrogen outputs, and N efficiency is variable. Regarding N output, 65% of the estimated N transfers out of the system corresponds to milk and meat products (102 and 18 kg N, respectively), 23% is lost by ammonia volatilization, 4% is output through vegetables and fruit, and 8% is lost by leaching and erosion. Assessments were made of the reliability of the data in Table 2 on the likelihood of the data source, to be both correct and representative of the agricultural systems intended to describe. Data from chemical analysis and experiments carried out within the valley of Mexico, is rated high (***), but mean values computed from research conducted in a different region in Mexico, are medium (**), while as low reliability (*) was associated to mean values literature data linked to different systems.

Gaseous losses from the IAS prototype

It is important to note that there are still uncertainties regarding gaseous N losses in this system; however, field experiments have shown that approximately 25 kg N a^{-1} are lost through ammonia volatilization during composting in terms of the initial total nitrogen content in goat manure produced per year, and assuming that all manure will be composted for a month. Laboratory experiments measuring NH_3 losses using undisturbed soils from the Mezquital valley (60 km from the valley of Mexico) indicate that 10 kg N ha^{-1} a^{-1} is lost as ammonia from soils irrigated with groundwater, and in general gaseous losses represent from 9 to 12% of the nitrogen applied through fertilisation (Vivanco-Estrada *et al*., 2001). (Estrada-Botello *et al.,* 2002) noted that soil mineral N (ammonium and nitrate) from a tropical region in Mexico was typically partitioned as follows: 60% is utilised by plants, 20% is loss by volatilization and denitrification, 5% through immobilization, 3% by means of surface run-off losses, and 12% by leaching from the unsaturated zone into the water table.

Table 2. Nitrogen dynamics and balance (kg N ha^{-1} per annum) in the IAS prototype in the Valley of Mexico

Input	Reliability	IAS prototype kg N ha^{-1} a^{-1}
Rainfall water	**	14
Irrigation water	***	15
Biological fixation	**	35
Concentrated feed	***	137
Straw feed	***	45
Total		246
Output		
Vegetable and fruit	***	7
Milk and meat	***	120
NH3-N loss by manure composting	***	25
NH3-N loss manure amendment	**	17
Runoff and erosion	***	2
Leaching	**	13
Total		184
Balance		62

Reliability: (*) = low; (**) = medium; (***) = high

The IAS prototype has particular characteristics which make it more vulnerable to gaseous nitrogen losses. The predominance of alkaline soils, and the fact that goat manure has a pH of approximately 8.2 are important factors that enhance ammonia losses either by composting or when surface applied to grassland as an organic fertilizer. Consequently, it was calculated that approximately N losses of 12% of the total nitrogen applied through compost and vermicompost is volatilized as ammonia. Therefore, nitrogen losses through gas emission are considered to be approximately 17 kg N from agricultural land (grassland, cut forage and vegetable production).

Leaching losses of N

Leaching of inorganic N is affected by climate, soil type, geo-hydrological conditions, crop species, timing and rate of fertilizer inputs (McNeill et al., 2005). Amounts of nitrogen lost by leaching in the Mezquital Valley Mexico have been observed to be around 9% of the total nitrogen input either through organic or inorganic fertilization (Vivanco-Estrada et al., 2001). Research conducted in arable systems in the north-western region of Mexico, gives estimates of nitrogen leaching losses ranging from 14% to 26% of the N applied as a mineral fertilizer in wheat under irrigation regime (Riley et al., 2001). Hence, if we consider leaching losses around 9% of the total nitrogen applied to the land; the IAS prototype will lose around 13 kg N ha^{-1} yr^{-1}.

Conclusion

The annual nitrogen balance in the IAS prototype is positive, due mainly to concentrate feed inputs. Gaseous N losses represent approximately 23% of the total N output from the system. However, due to the complexity of internal nitrogen transfer further attention will be given to this aspect because of the potential to underestimate total N losses due to ammonia volatilization, particularly during animal housing. Nutrient management in this system has been managed using good agricultural practices; hence the use of mineral fertilizers has been minimized and the use of compost, vermicompost and crop rotation are management practices followed in order to reach long-term sustainability and self-sufficiency of the system in terms of soil fertility.

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