NITROGEN USE EFFICIENCY IN SMALLHOLDER PRODUCTION SYSTEMS: A CASE STUDY FROM CENTRAL MEXICO

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1 INTRODUCTION

Smallholdings (<5 ha) represent 73% of the total area devoted to agricultural production in Mexico. Velasco-Velasco (2009) argued that many smallholder production systems (SPSs) are of low productivity and little quantitative data has been published on nitrogen use efficiency at farm scale in terms of nitrogen use and management. Nitrogen (N) is the most important nutrient for increasing crop yields. While the benefits from the use of N in terms of productivity are self-evident, low efficiency of N utilization can lead to environmental problems. Nitrogen use efficiency (NUE) at farm scale can be used to indicate the relative balance between the amount of N output from the core components (crops and livestock) versus the amount of N input (Dawson *et al.*, 2008). Nitrogen use efficiency in farming systems is primarily influenced by two factors: the crop and animal themselves and the N loss opportunity, which depends on soil, weather, management strategies and practices (Moll et al., 1982). Nitrogen flow in agricultural systems is commonly used to assess NUE by calculating agri-environmental indicators such as output/input ratio (O/I ratio), N losses (N_{loss}) and change of soil N pool (ΔSNP) (OECD, 2001). From this point of view, several research projects have been conducted in developed countries and Europe to assess NUE of farming systems (Langeveld et al., 2007; Schroder et al., 2003; Spears et al., 2003). In Mexico, there have been few studies on N dynamics in smallholding agricultural systems, and most of them focused in separate processes within enterprises. Aspects which evidence the importance of studying and understanding N flows at farm scale are missing. Therefore this research aimed to quantify and analyze NUE indices such as O/I ratio, N losses and the change of soil N pool (ΔSNP) through the development of a predictive framework for N flows in smallholder systems in the Texcoco region in central Mexico. Typical N management practices were evaluated at farm scale.

2 MATERIAL AND METHODS

The data used was derived from primary sources which included information from an integrated agricultural system prototype located in the Texcoco region and data generated in this research; and secondary sources were those from the literature review and production statistics for the Texcoco region. Due to the characteristics of SPSs in the Texcoco region, general assumptions were defined for each component, and the predictive framework was designed upon the soil surface and system balances methodologies (Öborn et al., 2003; OECD, 2001; Roy et al., 2003). A reconnaissance survey of 15 farms was conducted in the Texcoco region to collect indicative qualitative and quantitative information about nitrogen use and management in SPSs. This survey was carried out following personal field interviews logistics and expert observation as suggested by FAO (1997). Data from the reconnaissance survey was used to characterize the boundaries of SPSs and to define the N management practices analyzed by applying the predictive framework for N flows. Nitrogen input and outputs in the core components (livestock, manure management and cropping system) were defined and computed (
FIGURE 1a). The methodological approach to develop the predictive framework for N flow is summarized in (
FIGURE 1b). A predictive framework for N flows was developed using a worksheet and programming feature of Microsoft Excel to relate N inputs, internal N transfers and N outputs.

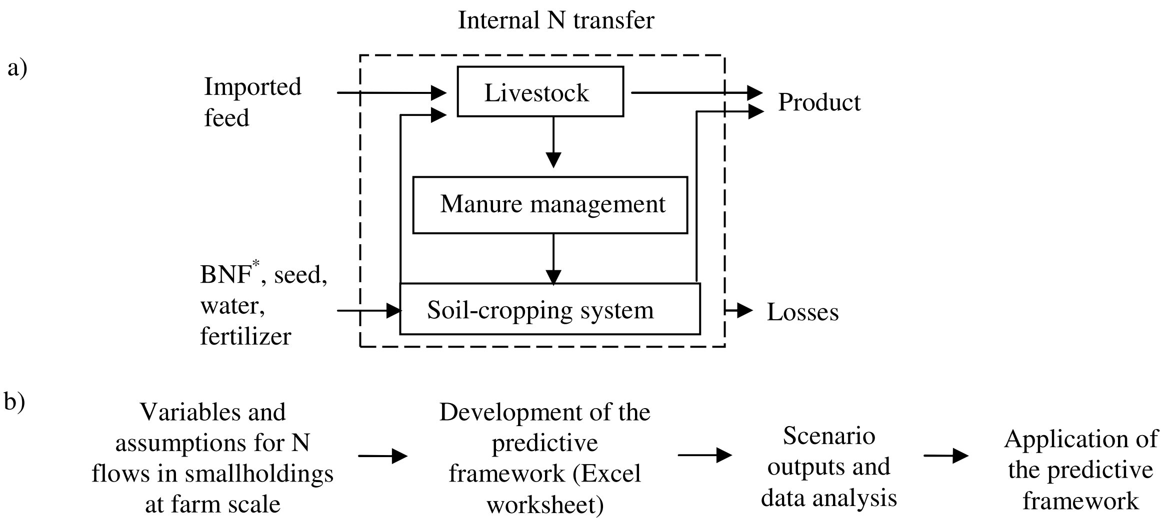

FIGURE 1 Simplified N inputs, outputs and internal transfers for core components a) and methodological approach for the development of the predictive framework for N flows b). *Biological N fixation (BNF)

3 RESULTS

3.1 Key characteristics of livestock, stocking density and manure management practices of surveyed smallholder production systems

According to the surveyed information, seven agricultural producers had farms from 0.5 - 2.0 ha, seven from 2.5 – 8.0 ha and one had a 20 ha farm. This information coincided with data quoted by Madrid-Cordero (2009), who noted that smallholders (<5 ha) represent 73% of farming systems, and 22 and 5% corresponding to medium scale (5 - 20 ha) and large scale farms (>20 ha) respectively. Smallholder farmers are commonly employed in urban jobs to support family income; this is as a common pattern of smallholder farms in the Valley of Mexico (Torres-Lima and Burns, 2002). The Texcoco region is characterized by two seasons of cultivation: Spring-Summer (rainy season) and Autumn-Winter (irrigated agriculture). The main crops are corn maize followed by forage maize, forage oat, alfalfa and vegetables. Nitrogen supply for crops is through manure and mineral N fertilizer. Manure application rates to corn maize and alfalfa ranged from 5 to 180 Mg ha^{-1} (equivalent to 40 – 600 kg N ha^{-1} a^{-1}). The use of manure in the Texcoco region is low when compared to other regions of Mexico e.g. “La laguna” region in Northern Mexico, where application rates range from 200 – 300 Mg ha^{-1} a^{-1} (Salazar-Sosa et al., 2004). Mineral fertilizers most commonly used in the Texcoco region are urea, calcium nitrate and superphosphate, with fertilizer application rates ranging from 10 - 140 kg ha^{-1}.

Dairy cows are the most dominant livestock type held in corrals, with variable stocking density ranging from 1 - 10 LU ha^{-1}. Pigs were the second most common type of livestock, in terms of the number of LU ha^{-1}. Typically, agricultural producers in this region simultaneously manage two or more species. Old manure is defined in this research as that which is stored six months or more before being applied to agricultural land, whereas fresh manure is defined as manure stored for less than six months, usually one month (within or next to the corral). According to the collected data during the reconnaissance survey, 10 agricultural producers store manure from 6 - 12 months before land application, one keeps manure for more than 12 months and four farmers store it for <4 months. Manure management is a key element in terms of N use efficiency at farm scale, and improving N management requires specific on-farm analysis. As noted by Oenema (2006), the study of the complete farming production system is essential to increase productivity and reduce environmental impact from agricultural practices.

3.3 Nitrogen budgets for the case study farms

The data was estimated using the predictive framework and was based upon key management practices such as crop sequence, livestock type, stocking density, manure management (fresh, old and vermicompost), fertilization and manure application rates. TABLE 1 shows N inputs, outputs and NUE indices for three examples of selected SPSs.

TABLE 1 **Nitrogen budgets (kg N ha^{-1} a^{-1}) for smallholder production systems in the Texcoco region.**

Variable\management practice	*Farm A*	*Farm B*	*Farm C*
Crop sequence	Cm/fo*	Alfalfa	Cm/fm**
Livestock type	Pigs	Dairy	Dairy
Stocking density	1.6	4	10
Manure management	Old	Old	Old
Inputs		149	586
Biological Fixation	57	425	11
Seed		3	1
Rain & irrigation water	35	40	35
Imported manure	11	120	0
Fertilizer		0	0
Imported animal feed	42	0	712
Outputs		73	313
Livestock product	64	116	291
Exported crop	10	0	47
Exported animal feed	0	197	0
Exported manure	0	0	735
N losses (N_{loss})	**70**	**241**	**528**
O/I ratio	**0.49**	**0.53**	**0.40**
Change SNP (ΔSNP)	**-35**	**124**	**13**

*corn maize/forage oats (Cm/fo), **corn maize/forage maize (Cm/fm)

The stocking density ranged from 0.4 - 10.0 LU ha^{-1}, and it was observed that manure is typically applied after being stored for more than 6 months. Nitrogen input varied widely, total N inputs ranged from 149 to 852 kg N ha^{-1} a^{-1}. Biological N fixation (estimated from previous research) ranged from 11 – 532 kg N ha^{-1} a^{-1} depending on the crop sequence and the use of fertilizer. The proximity of Mexico city to the Texcoco region is reflected in approximately 33 kg N ha^{-1} a^{-1} deposited in rainfall (Cristobal-Acevedo et al., 2007). Nitrogen inputs such as imported manure, imported animal food and biological fixation strongly influenced the studied variables i.e. O/I ratio. Alfalfa as crop sequence showed positive effect on ΔSNP with values ranging from 43 – 124 kg ha^{-1} a^{-1}. Likewise, SPSs with imported animal feed showed N depletion (TABLE 1). It is important to notice that every surveyed smallholder has particular management strategies that could affect the N flow.

4 CONCLUSION

The effect of selected management practices on O/I ratio was as follows: crop sequence > stocking density > livestock type > manure management. The effect of livestock type on O/I ratio from high to low productivity was observed as follow: pigs > dairy cows/beef cattle > sheep/goats. The effect of manure management on O/I ratio showed that applying vermicompost and fresh manure produced the highest O/I ratios compared to applying old manure. Nitrogen losses decreased as follows: stocking density > livestock type > manure management > crop sequence. The predictive framework can be used as a management tool to highlight NUE indices at farm scale for agricultural systems in central Mexico.

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