Summary Brief

Ecosystems Division/GPA

Case Study on nutrient management valuation in Rondonópolis municipality in the upper Pantanal Region of South America.

Felipe Siqueira Pacheco*[a], Luciene Gomes[a,b], Marcela Miranda[a,c], Karina Tôsto[a], Simoni Maria Loverde Oliveira[d], Dhonatan Diego Pessi[d] and Jean Ometto[a]

Contract
Nº: 2500116256

July, 2018

1. Background

Agricultural system has been identified as a playing a key role in the Sustainable Development Goals (SDGs) due to the numerous challenge to produce enough food to feed an increasing population[1]. The way people produce, process and consume food are directly or indirectly linked with at least 10 of the SDGs (more than half).

The consequences of too much or too little nutrients is one of the central debates about the "Nutrient Challenge". The benefits of supply enough food for mankind brought consequences, the surplus of nutrients causes some imbalance on natural biogeochemical cycles.

Too little nutrient is also an important threat, the insufficient nutrient use increases the risk of land-use change associated with agricultural incursions into pristine ecosystems, and an inability to match crop harvests with sufficient nutrient application leads to depletion of nutrients and organic matter in agricultural soils, leading to land degradation and increasing the risk of erosion.

Theoretical and empirical bases of policy measures related to nutrient management are still small or inexistent, even for Europe and North America[3], however, raising public and institutional awareness of nutrient issues (both the benefits and threats) has the potential to provide an essential basis to develop concrete actions and increase the efficacy of future integrated policies to improve nutrient management and achieve SDGs.

2. Introduction

The Nutrient Use Efficiency (NUE) consists of a broad set of information that addresses the basics of crop nutrition and the 4R Nutrient Stewardship Framework, being a critically important concept for evaluating crop production systems. Estimates of NUE has been widely used as an indicator to evaluate the progress in nutrient management[4,5,1]. The objective of the NUE is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field and supporting agricultural system sustainability through contributions to soil fertility or other soil quality components[6]. Improvements of NUE means to contribute reaching the best management practice (BMP) providing the best combination of economic, social, and environmental performance, the three pillars of sustainability.

Several studies have described the quantification of NUE as a relevant approach to nutrient management or as an indicator of nutrient pressure in agro-environmental system[7,8]. NUE is a dimensionless indicator that is calculated to be the ratio between the amount of nutrient aggregated in the outputs and the system inputs. The NUE can be calculated for different systems, for example, a field with a temporary crop, a herd or an entire chain of system relationships, supporting decision making at many levels[7].

This work was developed to target agricultural (crop and livestock) systems and associated wastewater management systems, linked to nutrient management. The methodological approach was based on consolidated methodology, applied on similar studies in many regions of the world. Also, the work presents the possibilities on replicating to other regions. Thus, the work will consider how it will be useful for stakeholders in Brazil, and other countries, on addressing relevant SDG targets.

3. Goals and objectives

The main goal of this study is to develop a methodological approach to the valuation of good nutrient practice, specifically:

a. investigating options for improvement of NUE (e.g. application of 4R Nutrient Stewardship Concepts), demonstrating social and economic benefits for health, environment, and the supply of food and energy, and;
b. quantifying the multiple costs and benefits of meeting the nutrient management targets for food security, freshwater and terrestrial ecosystems, mitigation of greenhouse gases and other climate threats, and

a. *National Institute for Space Research, Earth System Science Center, São José dos Campos, São Paulo, Brazil.*
b. *University of Leeds, Leeds, England.*
c. *Federal University of Itajubá, Itajubá, Brazil.*
d. *Federal University of Mato Grosso, Rondonópolis, Brazil.*

improvement of human health as proposed in the Our Nutrient World (2013) report.

4. Methodology

The methodology was thought to be useful for any region, thus, the method can be adapted using alternative data source as reports, scientific papers, agricultural census and others.

The methodology application can be sub-divided in three stages: 1) data gathering procedure; 2) balance calculation; and 3) valuation of costs and benefits (Figure 1).

4.1. Soil nutrient balance

For the analysis, soil nutrient balance is the difference between total nutrient inputs (IN) and total outputs (OUT) on agricultural lands; where IN is divided into four factors and OUT is divided into five factors as shown in Eqs 1 and 2. This approach do not take into account the amount of nutrient stored in the soil. A nutrient positive balance, or surplus, indicates inputs that are in excess in agricultural lands, while negative balance indicates excess outputs or nitrogen soil depletion.

$$IN = IN_{fer} + IN_{man} + IN_{dep} + IN_{fix} \quad (1)$$

$$OUT = OUT_{crop/prod} + OUT_{res/man} + OUT_{lea} + OUT_{gas} + OUT_{ero} \quad (2)$$

Where:

IN and OUT - total input and output; IN_{fer}: mineral fertilizer input; IN_{man}: manure input in crops and silviculture (in pasture IN_{man} is not considered an input because it is an internal process); IN_{dep}: wet and dry atmospheric deposition; IN_{fix}: biological fixation.

$OUT_{crop/prod}$: output from crops, wood harvested and animal products; $OUT_{res/man}$: output from crops, wood residues and manure exported from pasture; OUT_{lea}: output from leaching; OUT_{gas}: output from gaseous losses; and OUT_{ero}: output from erosion.

4.2. Calculation of Nutrient Use Efficiency (NUE)

NUE can be defined in many ways depending on the purpose and the interest of the analysis[5]. Therefore, the most appropriate NUE expression is determined by the question being asked and often by the spatial or temporal scale of primary interest for which reliable data are available. The method known as the Partial Nutrient Balance (NUE_{PNB}) is recommended by the International Plant Nutrition Institute (INPI) and usually expressed as removal/use ratio or the output/input ratio. Furthermore, NUE_{PNB} can be measured or estimated in multiple scales from crop producers to regional or national level. An important advantage of this definition of NUE is that the data are generally available at both the farm and national level. On the farm, fertilizer (and imported manure) amounts are usually known, as is the harvest volume or mass (e.g. tonnes/hectare). When the whole balance cannot be calculated, NUE_{PNB} is a good alternative to evaluate agricultural practice.

Then, the NUE_{PNB} and expressed as mass fraction (kg per kg).

$$NUE_{PNB} = UH/F \quad (3)$$

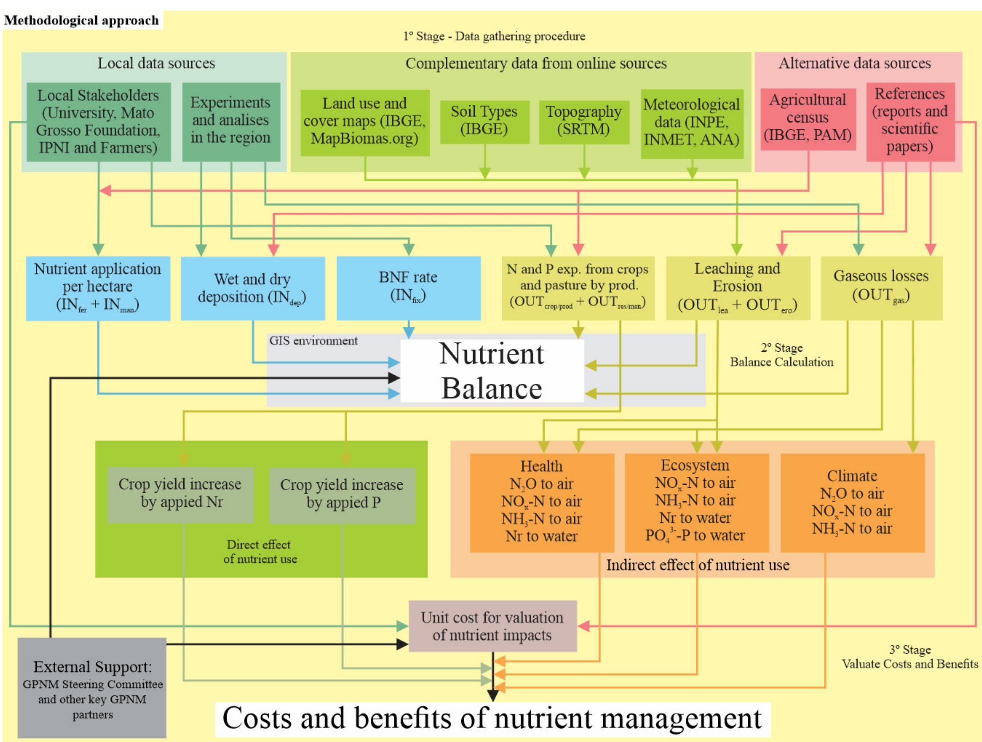

Figure 1: Schematic view of the method development to evaluate nutrient management.

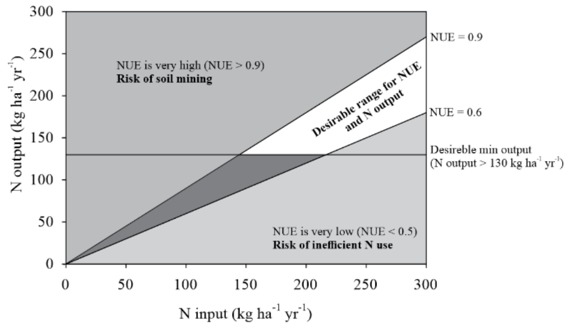

Figure 2: Concept of the nutrient use efficiency indicator for nitrogen (NUE_N) in a two-dimensional N input – N output graphic. The panel shows three ranges of possible NUE_N values, based on possible reference values for NUE_N for crop system 0.6 and 0.9, [2]). The horizontal line is the desirable minimum production based on the average N output from soybean-maize rotation system in Brazil from 1988-2016.

Where, UH is the nutrient content of harvested portion of the crop and F, the amount of nutrient applied. In this calculation, we also considered Biological Nitrogen Fixation (BNF) as part of the nutrient applied both for crop and pasture system.

4.3. Target values and reference lines for NUE

The target values for NUE will depend on the type of agricultural system and environmental condition. Reference lines for upper and minimum limit target value represent desirable good management (Figure 2). The target values in this example was considered mainly for crop production system that represent the main agricultural practice in the studied watershed. In other regions where livestock or crop-livestock production system is priority, target and reference values must be adjusted.

4.4. Methodological approach to evaluate costs and benefits of meeting the nutrient management targets

Social Cost-benefit assessment (CBA) has proved its use when comparing alternative options for realization of large infrastructural project and considered to be a potentially useful tool to assess economic impacts on changing nutrients management to provide guidance to support policy making[9]. Economic value of a negative environmental impact was linked to nutrients (nitrogen) by dividing the associated economic loss

Table 1: Simplified representation of unit cost method for valuation of nutrient impacts in human health, ecosystem and climate, and benefit for crop production. These values were estimated from local data and studies in Europe and United States. Positive values mean cost of the impact to the sector, negative values mean benefits to the sector.

indirect effect of nutrient us			
flux	Health	Ecosystem	Climate
indirect effect	dollar/kg N	dollar/kg N	dollar/kg N
N_2O-N to air	0.31	-	12.26
NO_x-N to air	8.43	2.94	-1.40
NH_3-N to air	5.62	8.02	-0.47
Nr to water	0	0	-

direct effect of nutrient use	
flux	Crop Yield
direct effect	dollar/kg N
Nr applied	-2.49

by the value of the nutrient emissions (implicitly assuming no effect threshold), following methodology described in the European Nitrogen Assessment and further revision[10,11]. Adaptations to local reality were performed whenever possible. The unit costs in Table 1 represent the averages of the values presented in van Grinsven et al. (2013) for the European Union, converted into dollars. Unit cost were transferred to Brazil by using the correlation between unit damage cost and GDP European countries and the concept of purchasing power parity (PPP) based on data provided by the Word Bank (https://data.worldbank.org/). The economic value of direct benefits in agriculture was based on yield response of agricultural goods to nitrogen inputs and current world market prices for major crops and commodities.

5. Results of the method application in Vermelho River watershed.

5.1. Nitrogen Balance

The Figure 3 shows the magnitude of nitrogen inputs and outputs from agriculture in the Rio Vermelho watershed. In general, agriculture systems of the Rio Vermelho watershed showed a nitrogen budget of 2.5 (± 1.9) kgN ha^{-1} yr^{-1} (Figure 3).

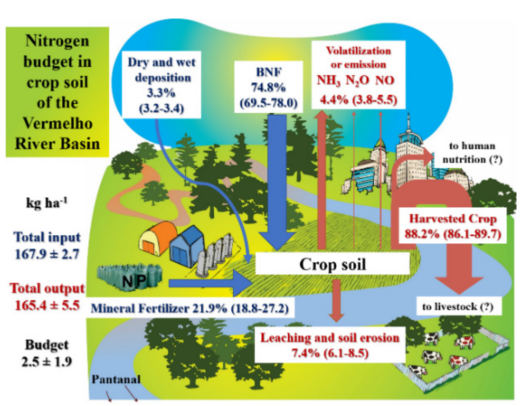

Figure 3: Magnitude of nitrogen inputs and outputs in crop soil in the Rio Vermelho watershed.

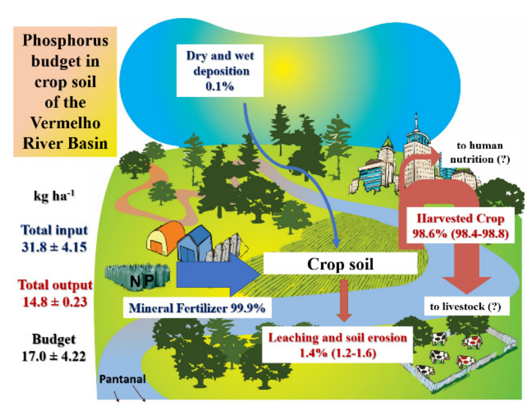

Figure 4: Magnitude of phosphorus inputs and outputs in crop soil in the Rio Vermelho watershed.

BNF (74.8%) and fertilizer (21.9%) are the main nitrogen inputs, while harvested crops (88.2%) and erosion and leaching (7.4%) are the main outputs.

5.2. Phosphorus Balance

The amount of P flowing through the crop system is show in Figure 4. In general, most of the P input to the crop soil in the Vermelho watershed comes from mineral fertilizer (99.9%) and a very small fraction from dry and wet deposition (0.1%). The main P output is the crop production (98,6%) and a small fraction leaves the soil by leaching and soil erosion (Figure 4).

5.3. Nutrient Use Efficiency

The values of NUEN for the crop system is slightly above the target of the desirable range, which mean there is a risk of soil mining. To assure a more sustainable system and avoid soil degradation and nitrogen soil mining, we propose a more sustainable practice preserving the soil (e.g., reducing erosion) and environmental characteristics by improving the effectiveness on the use of fertilizer, maintaining or increasing the productivity (Figure 5).

5.4. Costs and benefits of nutrients use in the Vermelho river watershed

Our estimates of total costs tend to exceed the benefit of N-fertilization by 2.3 million dollars per year. This value is relatively low, then the benefits of N use is offset by the impact of N emission. The obvious options are reducing emissions NH_3 and N_2O, as these Nr emissions generate most social and environmental costs. The common use of urea as fertilizer in the region may represent the main source of ammonium volatilization. Changes in the type of fertilizer use (e.g, ammonium sulphate) may be an option to reduce Nr emissions.

6. Final Remarks

The developed methodological approach can be used as measure to understand the management practices at local, regional and continental scale. Furthermore, it can be used as a tool to propose strategies to improve NUE in crop and livestock production. As improving NUE is a "win-win" strategy, local stakeholders can use this simplified tool to propose nutrient use practices to increase crop production, optimizing the use of external resources and addressing relevant SDG targets.

The absence of more accurate local information of impact costs has made us use estimates based on studies conducted in Europe, where the characteristics of the environment, land use and management may differ significantly from our area of study. Nevertheless, the relevance of this study lies in the effort to compile different data sources to obtaining a unique metric, representative of the impacts that can be associated to the different paths that nutrients, especially Nr, can travel in the environment.

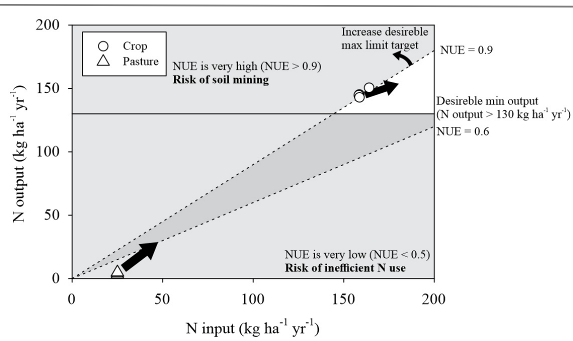

Figure 5: Two-dimensional graphic showing nutrient use efficiency (NUE) for nitrogen (N) of crop and pasture system in the Vermelho river watershed for the considered years (2000, 2005, 2010, 2015). The arrows indicate options to improve NUE in the studied watershed (see text). Increase desirable max limit target of NUE may occur by improving agricultural practices to avoid nitrogen loss by leaching, erosion and emission. This increase may be provided by applying or improving the concept of 4R Nutrient Stewardship.

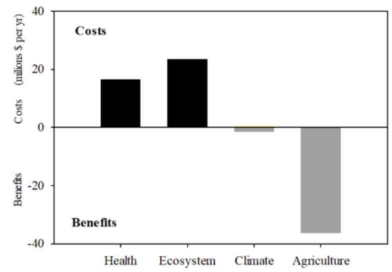

Figure 6: Cost and benefit of nitrogen (N) use in the agriculture sector in the Vermelho river watershed. Negative values mean social benefits of N application and negative values mean costs to human health and ecosystem stability.

7. References

1. M. A. Sutton, A. Bleeker, H. C.M., B. M., G. B., D. V. W. and H. J. M. Van Grinsven, 2013.
2. O. Oenema, F. Brentrup, J. Lammel, P. Bascou, G. Billen, A. Dobermann, J. W. Erisman, T. Garnett, M. Hammel, T. Haniotis, J. Hillier, A. Hoxha, L. S. Jensen, W. Oleszek, C. Pallière, D. Powlson, M. Quemada, M. Schulman, M. A. Sutton, H. J. M. Van Grinsven and W. Winiwarter, *EU Nitrogen Expert Panel - Nitrogen Use Efficiency (NUE) - an indicator for the utilization of nitrogen in agriculture and food systems*, Wageningen University, Alterra, Wageningen, Netherlands, 2015.
3. O. Oenema, A. Bleeker, N. A. Braathen and W. Winiwarter, in *The European Nitrogen Assessment: Sources, Effects and Policy Perspectives*, eds. M. A. Sutton, C. M. Howard and J. E. Erisman, Cambridge University Press, Cambridge, 2011.
4. F. Brentrap and C. Palliere, *Journal*, 2010.
5. R. Norton, Eric Davidson and T. Roberts, *Journal*, 2015.
6. P. Fixen, F. Brentrup, T. Bruulsema, F. Garcia, R. Norton and S. Zingore, *Managing Water and Fertilizer for Sustainable Agricultural Intensification*, 2015, 8.
7. P. J. Gerber, A. Uwizeye, R. P. O. Schulte, C. I. Opio and I. J. M. de Boer, *Current Opinion in Environmental Sustainability*, 2014, **9-10**, 122-130.
8. J. M. Powell, C. J. P. Gourley, C. A. Rotz and D. M. Weaver, *Environmental Science & Policy*, 2010, **13**, 217-228.
9. M. A. Sutton, C. M. Howard, J. W. Erisman, G. Billen, A. Bleeker, P. Grennfelt, J. J. M. van Grinsven and B. Grizzetti, *Journal*, 2011.
10. C. Brink and H. van Grinsven, in *European Nitrogen Assessment*, eds. M. A. Sutton, C. M. Howard, J. W. Erisman, G. Billen, A. Bleeker, P. Grennfelt, H. J. M. van Grinsven and B. Grizzetti, Cambridge University Press, Cambridge, U.K., 2011, pp. 513-540.
11. H. J. M. van Grinsven, M. Holland, B. H. Jacobsen, Z. Klimont, M. a. Sutton and W. Jaap Willems, *Environ Sci Technol*, 2013, **47**, 3571-3579.