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

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1. Background

1.1. The Nutrient Challenge in the Global Context

The exponential growth of human activities has changed the biogeochemical cycles worldwide in the last century (Sutton et al. 2013b). The scale of these changes has increased the necessity to develop joined-up approaches that optimize the planet's nutrient cycles for delivery of our food and energy needs, while reducing threats to social and economic well-being, including threats to climate, ecosystem services and human health. The emissions of nitrous oxide (N_2O), nitrogen oxides (NO_x) and ammonia (NH_3) to air, and loss of nitrogen (N) and phosphorus (P) compounds to water is a direct consequence of these changes. These losses of N and P to air and water contribute to a web of interlinked environmental problems such as climate change, particulate matter in air, eutrophication, threatening the human health, biodiversity and ecological integrity.

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. Eutrophication processes and even climate change is accelerated with the increase amount of nutrients. 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.

In the Latin America (LA), agriculture practice had a marked growth in soybean cultivation in the 1990s (Austin et al. 2006) and recent expansion of the sugar cane cultivation and biofuel market (Janssen and Rutz 2011). Soybean cultivation in LA is 40% of global production, larger than any other world region alone (Austin et al. 2006). The impacts of the fast changes on the nutrient cycle in LA and the interactions with other altered biogeochemical cycles are still open issues (Martinelli et al. 2010). Therefore, address the effects of changing nutrient cycles in the region is central for understand the current state of the terrestrial and aquatic ecosystems, with key linkages to food and water security, ecosystems, and human health (Bustamante et al. 2015). Currently, the geographic extent and timing of anthropogenic enhancement of nutrient inputs in both terrestrial and aquatic ecosystems of LA are poorly constrained, and the impacts of these changes have not been comprehensively assessed (Austin et al. 2013). Consequently, a key challenge for many LA countries is to further improve nutrient management, including the reduction of nutrient pollution.

1.2. Nutrient use efficiency for food and nutrition security

According to the Food and Agriculture Organization (FAO) of the United Nations, food and nutrition security consists of having physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. The definition suggests, that food security is the product of following dimensions:

(1) *Food availability*: the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports;

(2) *Food access*: access to food through growing it; purchasing it; being gifted it; bartering or trading for it etc. The access includes a package of entitlements that allows an individual to acquire and maintain appropriate foods for an adequate diet and nutritional level.

(3) *Biological Utilization*: biological use that brings about a state of nutritional health in which physiological needs are met, entailing access to safe drinking water, sanitation and medical care.

(4) *Stability*: stability on the access of food. Population should not risk losing access to food as a consequence of sudden shocks (e.g. an economic or climatic crisis) or cyclical events (e.g. seasonal food insecurity). The stability can therefore refer to both the availability and access dimensions of food security.

Food supply has always been one of the main focuses of government policies, but after the apparent success of the Green Revolution, government officials became convinced that food security would take care of itself (Godfray and Garnett 2014). However, there is no way to separate the ideas of sustainable development, resilient cities, adaptation to global environmental change and promotion of food security, from the idea of sustainable diets. In an increasingly urban world, where the urban population depends almost exclusively on food systems in order to gain access to food, it becomes urgent to understand the configuration of food systems and identify their fragile points, in order to promote production, supply and consumption systems that are sustainable and resilient to global environmental change.

Ensuring access to nutritious food for the world's population, estimated to reach 9 billion by 2050, is one of the greatest challenges of the 21st century (UN 2015). The depletion of natural resources is one of the challenges for establishing sustainable food systems. Agricultural land use in Latin America and the Caribbean regions has increased 34% in the last 50 years, while the area covered by forests has decreased by 9% since 1990, which is an undesirable sign of environmental pressure from the current production and consumption patterns (FAO and PAHO 2017).

Among many options that society has in achieve high nutrient use efficiency and low negative impacts of nutrient, food production and consumption choices represent a key area that may have major implications for nutrient fluxes (Reay et al. 2011). It is important to notice that potential gains by future adoption of low nutrient emission practices in certain sectors and regions can be lost by an increase in consumption of high- nutrient foods, especially livestock products, in another (Steinfeld et al. 2006).

The challenge of ensuring global food and nutrition security in future requires that we continue to increase the agricultural output. To this end, we must (a) intensify crop production on land already under cultivation, while preserving ecosystem services, and preventing further land degradation, and (b) carefully expand the area planted. We need to ensure that smallholder farmers have affordable access to the inputs needed to produce crops successfully for subsistence and for sale in local markets, as food insecurity is often caused by inadequate household income, rather than inadequate global food supply.

At national level, the agricultural production in Brazil, especially from small-scale agriculture, is marked by a lack of reliable data on the number of producers, on cultivation methods and use of natural resources, and on the knowledge about the human dimension in this system (Nolasco 2016). Incorporate mechanisms to identify inefficient use of nutrients at local and regional scale, not only in agriculture, but along all food system that can affect ecosystem services is essential to promote food and nutritional security, not only in Brazil but, also, in others Latin America regions.

1.3. Nutrient use efficiency in the Sustainable Development Goals Agenda

Agricultural system has been identified as a playing a key role in the SDGs due to the numerous challenge to produce enough food to feed an increasing population. The way people produce, process and consume food are directly or indirectly linked with at least 10 of the SDGs (more than half). The implementation of policies or other mechanisms to achieve SDGs have to consider faster development and a wider adoption of new technologies.

A more sustainable agriculture is the only way to achieve the SDGs, however, it is among the most complex and challenging because it means implementing an agriculture that provides viable livelihoods for small farmers and businesses along the whole production process. Furthermore, it is necessary that the entire production system provides nutritious food for population that guarantees not only an adequate supply of energy, but also proteins with essential characteristics, micronutrients, fat, etc. In the context of climate change, agriculture must comprehensively reduce GHG emissions, energy consumption and deforestation, developing resistance to an ever-changing planet (environmental and climatic). Finally, there is a need to reduce environmental and social damage from agricultural practices (soil degradation, habitat destruction, chemical pesticide and herbicide pollutants, etc.) without significantly degrading local culture, landscape, cuisine etc.

The success of addressing these challenges will largely depend on how consumers change and whether rural places can become attractive places to live and work, particularly for younger generations (Dobermann et al., 2013). In addition, not all of these outcomes can be addressed at the same time everywhere, so, each region, state or country will need to analyze and develop policies and technologies that enable them to achieve high priority targets.

Although there are many scientific papers and reports of many aspects of nutrient use efficiency in agricultural systems published, the progress in reducing the output of nutrient from agricultural systems to a desirable level seems to be far from the current situation. Many of these publications consider large scale analysis and, when a local approach is presented, they are related to European, Asian or American regions. Furthermore, some countries have improved their nutrient use efficiency (NUE) and agro-environmental performance, whereas in many others this has not yet happened or agricultural production is even limited by a lack of nitrogen (Luis et al. 2014; Zhang et al. 2015). Consequently, targets to improve nutrient use efficiency need taking into account the current situation of each region as well as all other SDGs and priorities. In Brazil and other countries in Latin America, the unavailability/inaccessibility of data and the lack of long-term monitoring systems are others aggravating factor that limits an integrative analyze about multiple current and future influences on food production, as loss of ecosystem services, GHG emissions, climate change and NUE. In such situation, there might not have enough data and knowledge to answer many questions more precisely, and there is a risk that wrong indicators or poor data may lead to wrong directions being taken.

Theoretical and empirical bases of policy measures related to nutrient management are still small or inexistent, even for Europe and North America (Oenema et al. 2011), 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

2.1. Challenges in the local context

The Pantanal wetland and the rivers from the Upper Paraguay catchment represent a unique study model of a large complex freshwater system. The current conservation status allows to understand the role of different natural biophysical components such as the flooding regime on maintaining biodiversity and providing crucial ecosystem services at different spatial scales (local, regional and global). On the other hand, certain areas are affected by dam construction and land use changes and can thus be used to study the impact of these threats on the natural conditions.

The Pantanal is the largest freshwater wetland system in the world encompassing more than 160,000 km2 of flooded territory laying within Brazil (87.5%), Bolivia (9.4%) and Paraguay (3.1%; Fig. 1). This system is home to over 1800 phanerogam plant species, 250 aquatic plant species, 263 species of fish, 41 of amphibians, 113 of reptiles, 463 of birds and 132 mammals (Alho et al. 2011). Moreover, the Pantanal region has been recognized as a major hotspot for ecosystem service provisioning at a world scale, ranking this system among the most valuable in the planet (over $5000 ha1 yr1; Costanza et al. 1997; Seidl and Moraes 2000). The Pantanal wetland has an extraordinary role on climate regulation, flood protection, water supply, carbon dynamics and it offers important fisheries, water purification, and cultural services, among many others (Seidl and Moraes 2000; Junk and Cunha 2005; Wantzen et al. 2008).

Despite the enormous importance of the Pantanal in terms of biodiversity conservation and ecosystem service delivery its conservation status is being seriously threatened. The main drivers that are, currently, threatening the Pantanal are climate change, deforestation, development of projects and nutrient loads through untreated urban effluents and agrochemicals (Junk and Cunha 2005; Wantzen et al. 2008). The threat on the Pantanal region is not spatially homogeneous. The wetland itself is still under relatively low pressure (mainly cattle ranching) with less than 10% of its native vegetation modified (Harris et al. 2005). Contrastingly, the Upper Paraguay River catchment (over 620,000 km2), which drains to the Pantanal, has substantial area dedicated to agriculture, producing the majority of the net income of the gross domestic product of the States of Mato Grosso and Mato Grosso do Sul (overall on soybean, cotton, rice and beef production; Wantzen et al. 2011). This has dramatic consequences on the hydrology, nutrient and sediment dynamics of the rivers feeding the Pantanal floodplain. Severe effects have already been reported on several large rivers and their associated wetlands and floodplain lakes (Hamilton 2002). Thus, despite its current good conservation status in comparison to other large freshwater ecosystems in the world, the Pantanal is changing quickly and an integrated catchment management view with participation of the many stakeholders involved should be quickly implemented.

2.2. Agricultural practices in the Upper Pantanal

The Upper Pantanal is inside the Mato Grosso (north portion) and Mato Grosso do Sul (south portion) states, two of the largest commodities producers states in Brazil. The Mato Grosso state has been highlighting each year as one of the most important Brazilian states in agricultural and livestock production. According to CONAB, there was an increase of 27.1% of grain production (soybeans and maize) between 2015/2016 and 2016/2017, which corresponds to 50.6 million tons. In the last harvest (2016/2017), the production estimate is of 237.22 million tons of grains in a planted area of 9.4 million hectares, with an expected growth of 3.7% to the next harvest. Improvements in applied technology and more favorable climatic conditions are the factors that best explain the increase.

In the context of the agriculture challenge to feed nine million people by 2050, Brazil's responsibility to increase its food production passes through the Mato Grosso, that is already the largest state in agricultural production, and has still 16 million hectares of grazing area that can be converted to agriculture, according to the Mato Grosso Agribusiness Institute (IMEA).

The Upper Pantanal inside Mato Grosso is responsible for 20% of the current grain production in the state, therefore, the expansion of the agriculture practices in this area in the upcoming years is also expected. A well manage expansion will be a necessary measure to preserve the ecosystem services provision of Pantanal biome, and, besides a more sustainable nutrients management, regional nutrient policies and more joined-up approach addressing the Nutrient Challenge can play a role in the implementation of a sustainable development in the local context.

2.3. Current environmental problems linked to human activities in the Upper Pantanal

The Pantanal and Cerrado play an important role in the environmental quality, food security and economic development of the country. However, agricultural practices in these two biomes are increasingly changing the landscape mainly in the last three decades (Gil 2017). This is mainly due to the increasing demand for food production resulting in the expansion of agricultural and livestock systems, causing profound socioeconomic and environmental impact with loss of biodiversity and removal of native forests (Foley et al. 2005).

The Pantanal has an increasing livestock practice in flooded areas, with strong effects on aquatic communities and water bodies structure that supply the Pantanal (Lorion and Kennedy 2009). Lima et al. (2015) point out that during the rainy season, chemicals and fertilizers used in the pasture are drained to the Pantanal wetlands, contributing greatly to the degradation of water quality. These practices have substantially changed the local and regional nutrient cycling, with potential effect on the global scale (Martinelli et al. 2010). This is mainly due to the increase in the amount of nutrient added to the ecosystems, especially the nitrogen as it is a limiting factor for the local agricultural crops (Vitousek et al. 1997; Galloway et al. 2008).

The most significant effect of high nutrient transport rates to the aquatic systems is the eutrophication (Schindler 2012). Although there is no evidence of eutrophication impairing ecosystem services in Pantanal (McGlue et al. 2011; Remor 2017), this is a well-established problem in many agricultural lands in the word (Downing et al. 2008) and a growing problem in others (Li and Zhang 1999) and also in other places in Brazil (Matsumura-Tundisi and Tundisi 2005; Pacheco et al. 2017), resulting in major economic and biodiversity losses associated with degradation of water quality. Thus, the agricultural practices that continuous to increase since the beginning of 90s in the Upper Pantanal Region may became a serious threat to many ecosystem services in the future.

According to recent monitoring of the Upper Paraguay Basin, the anthropic area in the Pantanal already corresponds to 15% of the area, while in the higher plateau areas (Cerrado) these changes correspond to about 60% of the area (SOS-Pantanal and WWF-Brasil 2015). The Pantanal plain is more conserved due to the traditional management of extensive cattle ranching, which uses natural pastures as fodder for livestock, in addition to its natural characteristics of periodic flooding and low fertility, which hinders the advancement of mechanized agriculture. Pantanal ranching's model has undergone changes, with the introduction of new tools and management techniques, such as the growth of exotic pastures (ANA 2015).

The advancement of unsustainable agroecosystems in river headwaters in the highlands resulted in higher inputs of water, sediment and nutrients to the Pantanal lowlands, reducing its carrying capacity, resilience and provision of ecosystem services such as nutrient retention and recycling, water purification, fish stocks, among others (Bergier 2013). Highlands has faced a gradual transformation in the pattern of agricultural activities with the increase of mechanized agriculture of soy, maize, sugar cane and cotton (ANA 2015). Besides, Pantanal is being continuously and gradually contaminated by pollutants such as nitrogen, phosphorus and agrochemicals from agricultural activities and there is an urgent need to adopt good practices that minimize these impacts (Calheiros et al. 2006).

Deforestation associated with the implantation of agricultural activities and the natural susceptibility to soil erodibility, especially in the plateau region, has caused impacts related to soil degradation and erosion. Several rivers in the region, such as Taquari and São Lourenço, have high sediment transport capacity and their headwaters are located in the plateau region, which has increased sediment deposition in the Pantanal plain and consequent sedimentation of the rivers (Galdino and Grego 2014). The navigability of the Paraguay River has been affected, requiring regular dredging in some stretches and impediments in navigability. There is a demand for greater use of the strategic potential of the Paraguay River waterways, mainly for outflow of minerals and grain crops (corn and soybean), but this has led to debates about the socio-environmental implications of these interventions in the Pantanal. Flood pulses - annual and multiannual flood and drought cycles - are critical to the functioning of ecological processes in the Pantanal, such as nutrient recycling and fish migration. Infrastructure works can affect ecosystems and alter the composition and abundance of species, harming for example, the fishery production and associated trophic relationships (ANA 2015).

2.4. Nutrients in current Brazilian policies

The municipality of Rondonópolis and Mato Grosso State, has no municipal or state legislation that provides maximum standards for the emission of pollutants. The legislation is applied in the national sphere.

A wide survey has been carried out to search for nutrient in current policies. At large, Brazil has general measures and mechanisms to deal with nitrogen in the National Communications, but only as a greenhouse gas (N_2O). Specific and/or unified policies dealing directly with nutrient emissions were not observed; however, some isolated measures with linkages to nutrients have been considered in the legislation.

Unlike the European Union, where some environmental legislation is imposed to all member states, countries of Latin America do not have common directives or a framework in which nations can create their own regulations. Table 1 presents selected examples of recent policy measures in Brazil for specific nitrogen and phosphorus compounds and their sources/receptors.

As observed in the examples above, policy measures dealing with nutrient loading reflect single compounds, that is: diffuse emissions of PO_4, NH_3/NH_4, NO_3 and NO_2 that affects air and water qualities, P_2O_5, NO_3 and NH_4 related to fertilizers productions and usage. These regulations focus on decreasing emissions and/or concentrations on specific bodies (air, water and soil) to below critical levels based on regulatory references from national or international agencies (i.e. World Health Organization, WHO). Assessment reports to evaluate whether countries have achieved the policy objectives were not found so far.

Table 1: Policy measures related to nutrient compounds in Brazil.

Type / date	Compounds / receptors	Objectives / description
Resolution 357 / 2005	NO_3, NO_2, NH_4, PO_4, TP, TN Water quality	Classify and provide limits as references to nitrogen and phosphorus concentration in water system
Resolution 430 / 2011	NO_3, NO_2, NH_4, PO_4, TP, TN Water quality	Establishes limits and patterns of nutrient concentration (nitrogen and phosphorus) in effluents to water systems
Law 8723 / 1993	NOx Air quality	Provides for the reduction of emission of pollutants by motor vehicles.
Ministerial order 518 / 2004	NO_3, NO_2, NH_4, PO_4, TP, TN Water quality	Establishes the procedures and responsibilities related to the control and monitoring of the quality of water for human consumption and its standard of potability.
Normative instruction 46 / 2016	NO_3, NH_4, P_2O_5 Soil quality	Specifications for the production of simple mineral fertilizers. Mandatory use of a certain percentage of nutrients (nitrogen, among others) in the formulation of fertilizers.
Decree 7.390 / 2010	N_2O	The "ABC Plan" (Low Carbon Agriculture, in Portuguese) aims to organizing and planning actions to adopt sustainable production technologies, in

	Soil quality	order to reduce GHG emissions in the agricultural sector, through Biological Nitrogen Fixation (BNF), among other initiatives.

NO_3 = nitrate; NO_2 = nitrite; NH_4= ammonium; PO_4 = orthophosphate; TP = total phosphorus; TN = total nitrogen; NO_x = nitrogen oxides; N_2O = Nitrous oxide; P_2O_5 = phosphorus pentoxide

2.5. Methods to evaluate NUE and cost/benefits of meeting the nutrient management targets

According to Raun and Johnson (1999), the excess of nutrient use for cereal production worldwide represents $15.9 billion annual loss of fertilizer (N fertilizer). Therefore, works are being carried out in order to evaluate the benefit of find a balance in the nutrient use, aiming, not only at decreasing the economic investment loss, but also at preventing the environmental damage from the nutrient excess that are leached from agricultural system. These studies may support ecosystem management in a way that decision-makers can prioritize the most urgent cases to direct their attention for the effective protection of the public health, ecosystems and climate (van Grinsven et al. 2013).

For this reason, environmental pollution policy decisions are increasingly based on cost-effectiveness analysis (CEA) and cost benefit assessment (CBA). While the CEA supports the selection of policy options to achieve environmental goals, the CBA helps identify options where it seeks to increase human well-being. Decision-making will always involve evaluation and weighting, whose rationale and implications may not be fully understood even by decision-makers. Works are being developed, mainly in Europe, in order to estimate the cost and long-term benefits of nutrient use. The economic value of nutrient harm was based on economic concepts, standard and methods of assessing health impacts (estimation of treatment costs, loss of productivity and willingness to pay to reduce the risk of premature death or pain and suffering), to restore ecosystems or to reduce greenhouse gas emissions (van Grinsven et al. 2013).

The nutrients management in agricultural systems has contributed to a great growth of agricultural and livestock production. In the future, with increasing world population, livestock and agricultural production will continue to play a key role in maintaining food production and economic growth (Alexandratos and Bruinsma 2012). Achieving better nutrient management is therefore an important aspect of improving environmental performance in the livestock and agricultural sector, and in that sense improving Nutrient Use Efficiency has been identified as the main strategy for achieving global food security and sustainability (Meena et al. 2015; Oenema et al. 2014). 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 policies (Gerber et al. 2014; Powell et al. 2010). 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 (Gerber et al. 2014).

NUE does not provide direct information on environmental impacts. The evaluation of NUE is criticized because it has some inconsistencies and biases, which raises questions about its reliability for assessing nutrient efficiency of farming systems (Godinot et al. 2014). However, conducted at aggregate of levels encompassing all processes in the supply chain, NUE interestingly informs about the efficiency with which new nutrients are used (Gerber et al. 2014). Only a few studies have evaluated NUE to understand the overall performance of delivering animal products and agricultural commodities at regional or global level, and these studies do not identify nutrient loss at local hotspots such as the Pantanal. These local scale studies are needed to support nutrient management decisions and improve environmental and social sustainability.

This work was developed to target agricultural (crop and livestock) systems and associated wastewater management systems, linked to nutrient management within the study site – the Rondonópolis agricultural region in Mato Grosso State. The methodological approach was based on consolidated methodology, applied on similar studies in other regions of the world and adapted to local situation. Data was gather, based on availability, considering the applicability to help policy design in supporting agricultural development and maintaining quality of ecosystem services for the study sites. Also, the work presents the applicability limitation of this approach, as well as the possibilities on replicating to other regions. Thus, the work will consider how it will be useful for other study sites 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, as a study case, to the valuation of good nutrient practice within the Rondonópolis municipality in the upper Pantanal region in Brazil, 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, marine, freshwater and terrestrial ecosystems, mitigation of greenhouse gases and other climate threats, and improvement of human health as proposed in the Our Nutrient World (2013) report.

4. Methodology

4.1. Description of the study site

The Upper Paraguay River Basin (UPB, Figure 1) is represented by three large biomes: Amazonia, Cerrado and Pantanal, and has Atlantic Forest enclaves (according to the map area of the Law 11,428 of 2006). The main rivers (and springs) of the UPB are located in the plateau and flows towards the Pantanal plain. The intensive exploitation of the plateau by livestock and agriculture activities associated with the conversion of Natural Areas to Anthropic Areas favors the occurrence of erosive processes and siltation of the fluvial courses in the plateau itself and especially in the plains, given the hydrodynamic conditions of the water courses. The landscapes of the Upper Pantanal suffered heavy deforestation for the implementation of the production of soybean, corn and cotton and sugar cane using modern techniques.

The São Lourenço river is one of the main rivers that feed the Pantanal plain. Inside its watershed, the most dynamic nucleus is the city of Rondonópolis, where there are important agroindustry units that make the processing of the region's agricultural production. This area is the most agricultural area of the Upper Pantanal (Figure 1), although there are other agricultural areas with expansive agriculture in the MT state outside the La Plata basin. The São Lourenço river is usually known as Vermelho river in many places. The Vermelho River is a fifth-order river with an approximate length of 122.5 km from its headwater to its mouth in Pantanal region. The main stream has the tributaries on the right bank the sub-basins of Poxóreu, Grande, Bagaréu, Arareau, Míau and São Lourenço, and on the left bank the sub-basins of Paraíso, Tombador, Aread, Tadarimana, Jurigue and Ponte de Pedra. The Vermelho River is an important contributor to the supply of the Alto Paraguay basin and the portion located in the plateau contributes with about 17% of the inflow into the Pantanal 335 m^2 s^{-1} (Souza 2015; Loverde-Oliveira and Nascimento 2004, Figure 2).

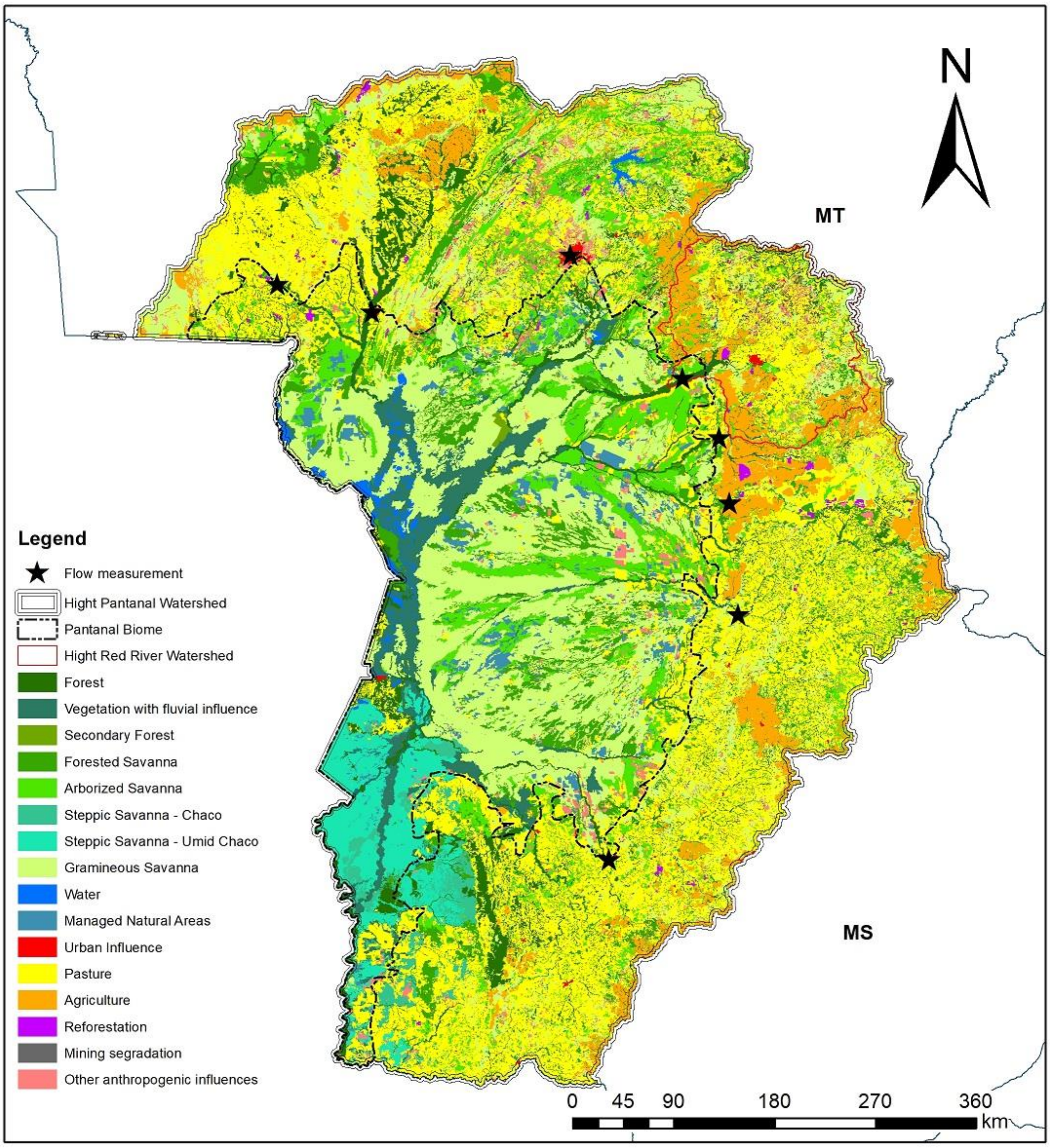


Figure 1: Land Use/Land Cover of the Brazilian Pantanal Biome.

Inserted in the Vermelho river watershed (Figure 3), the municipality of Rondonópolis (Southeast of Mato Gross State) has developed a large importance to the regional agribusiness after the 1970s. Rondonópolis is the second large economy of the Mato Grosso State and is among the 100 largest economies in Brazil with a GDP of $2.3

billion. Agribusiness is one of the main source of economy, and the “driving force” for many other secondary sectors of the local economy. Rondonópolis was once considered the "National Capital of Agribusiness", evolving to adding industrial values to the agriculture commodities products, as soybean and cotton. Today, the diversification of industrial segments has generated important titles for the municipality: the largest pole of crushing, refining and packaging of soybean oil in Brazil, the largest fertilizer mixing pole in the inner Brazil, increased state production of feed and animal supplements, frigorific with international standards and is preparing to consolidate itself as one of the main textile centers of the Midwest by encouraging and investing in the weaving and garment industry.

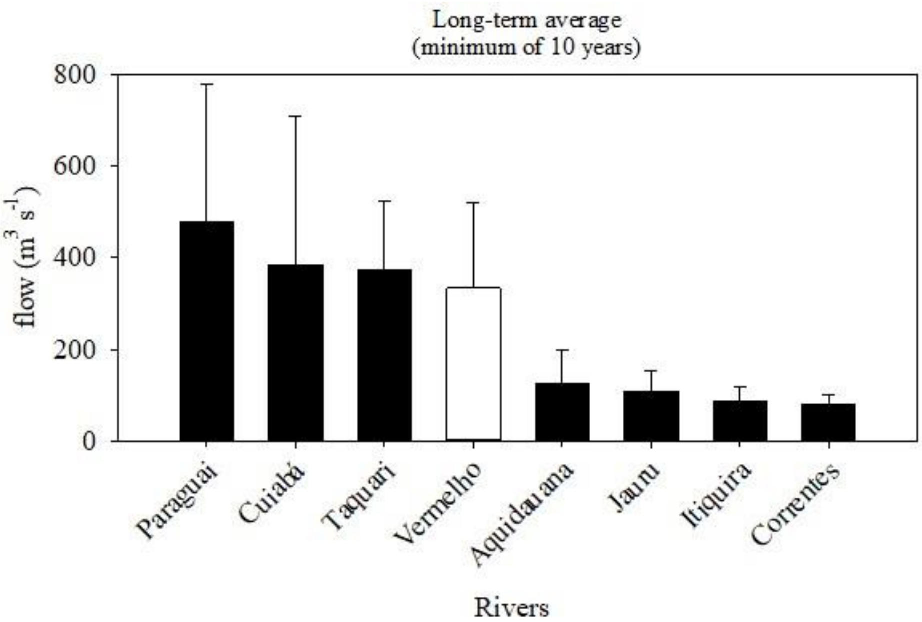


Figure 2: Long-term average of the main rivers water flow. We considered the nearest monitoring station of the Pantanal Biome boarder (Figure 1). The long-term average flow of Paraguay river near the Pantanal border (outflow from Pantanal biome) is 1,889 ± 910 $m^3 s^{-1}$. Source: Agência Nacional das Águas (ANA).

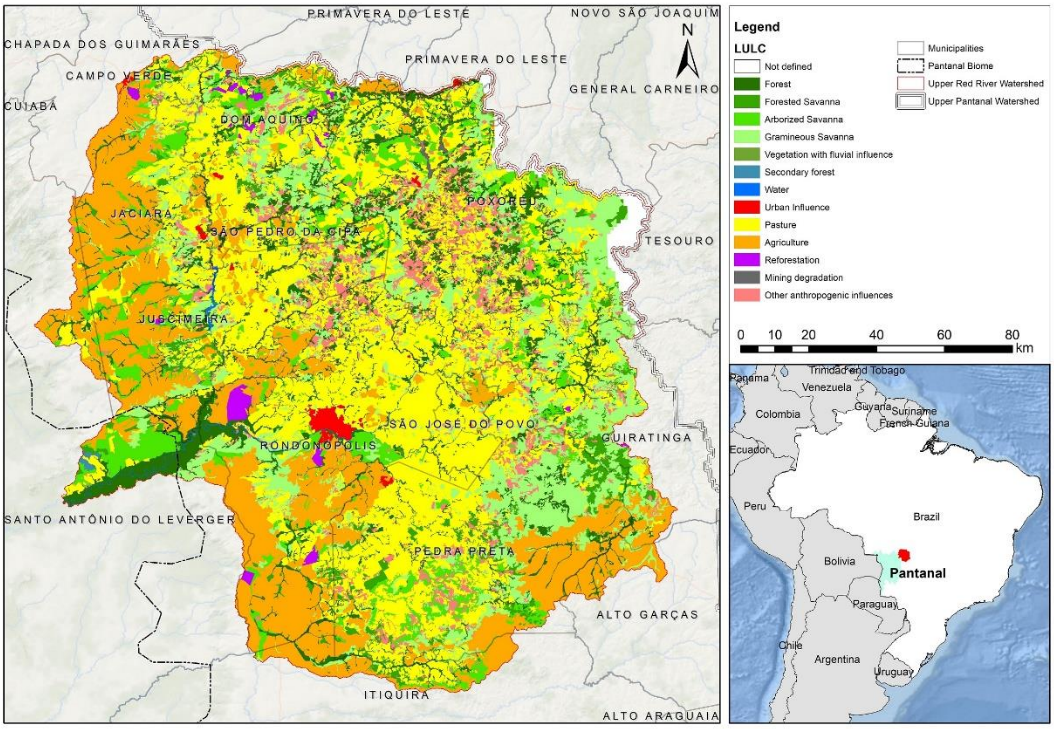


Figure 3: Map of the Upper Vermelho river.

4.2. Target sectors and stakeholders of the case study

The Rondonópolis region has well-placed stakeholders in the production of soybeans, maize and cotton. Soybeans are important commodity represented by several important national and multinational stakeholders. Representatives of Pantanal communities are weakly represented in the discussion about nutrient management, however, where they are present, they frequently focus on water quality and availability. Another important area of attention is family agriculture and smallholders located along the Vermelho river downstream of the study site.

4.2.1. Representatives of Pantanal communities:

The fishing activities are represented by population with low resources and low educational level, composed mainly by women and heads of household. One of the beneficiaries will be the Corumbá Fishing Cooperative (COOPECOR), which regulates fishing operations. The region overfishing has generated high levels of poverty in this group.

4.2.2. National and International Entities:

Intergovernmental Coordinating Committee of the Countries of the River Plate Basin (CIC): is responsible for promoting, coordinating and monitoring the progress of multinational actions aimed at the integrated development of the River Plate Basin, to organize technical and financial assistance with the support of the international organizations and the decisions taken by the Ministers of Foreign Affairs of the five-member countries (Argentine, Bolivia, Brazil, Paraguay and Uruguay). Participating institutions agree on the need to strengthen a common vision of the Basin, seeking to identify and prioritize common problems and their main causes, so as to address them jointly and in a coordinated manner. In Phase 1 of the Framework Program for the sustainable management of water resources in the River Plate Basin (implemented between 2010 and 2016), a diagnosis was made to characterize in a more precise and detailed way the problems of the Basin, obtaining an integral vision of the situation of the systems. Based on this better knowledge, the Transboundary Diagnostic Analysis (TDA) was consolidated and the Strategic Actions Program (SAP) was formulated as a document of policies and priority actions agreed by the five countries to solve the main identified problems.

Brazilian Institute of Environment and Renewable Natural Resources (IBAMA): IBAMA is the executive governmental organ responsible for implementing the National Environmental Policy (PNMA), instituted by Law No. 6.938, of August 31, 1981, and carries out various activities for the preservation and conservation of natural heritage, exercising control and oversight over the use of natural resources (water, soil, etc.). It is also responsible for granting environmental licenses. Locally, the IBAMA needs an adapted governance system that guarantees the conservation of the Pantanal and its ecosystem services. Knowledge, management and planning of existing resources is required. It has a great administrative fragmentation. IBAMA intends to develop an adapted governance system in the region that guarantees sustainable management of resources and encompasses the entire Pantanal.

Ministry of Agriculture, Livestock and Supply (MAPA): responsible for the management of public policies to stimulate agriculture, for the promotion of agribusiness and for the regulation of services linked to the sector. In Brazil, agribusiness includes the small, medium and large rural producers and brings together activities to supply goods and services to agriculture, agricultural production, processing and distribution of agricultural products to the final consumer. In the Pantanal region MAPA needs a system of governance adapted to the agro-livestock activity that cope with the loss of aquatic habitats due to contamination and overexploitation.

Municipal Secretariats of Agriculture and Livestock, and Environmental Secretariat of Rondonópolis and other surrounding cities: its objective is the formulation and implementation of productivity and competitiveness policies for sustainable development.

Federal University of Mato Grosso and the Federal University of Mato Grosso do Sul (UFMT): both universities have great scientific experience and multidisciplinary research groups working on local projects related to agribusiness, ecosystems services, biodiversity etc. Those universities are strengthening applied research and the implementation of extension projects in the region. With local action they are developing greater presence in the region, with the generation of knowledge and extension activities.

Mato Grosso Foundation (FMT): a private company that supports agricultural research, created by several producers from Brazil, headquartered in Mato Grosso. Its goal is to improve logistics along with the development of research on new technologies that give sustainability to agriculture activities. The agronomic research developed and disseminated by FMT is concerned with increasing productivity coupled with Best Management Practices, allowing the same areas to continue producing over the centuries, without degradation and with gains in fertility.

International Plant Nutrition Institute (IPNI): IPNI is a non-profit organization dedicated to developing and promoting scientific information on the responsible management of plant nutrients (N, P, K, Ca, Mg, S and micronutrients) for the benefit of the human family. One of the central strategies of the IPNI Program to support the sustainability of agricultural systems is the dissemination of Good Nutrient Management Practices, which stimulate the application of fertilizers at the right source, at the right dose, at the right time and at the right place. With local action the IPNI has as its main purpose the development and diffusion of new technologies of responsible management of plant nutrients. IPNI Brazil is committed to providing opportunities for farmers, consultants and technicians to achieve greater profitability, food security and environmental sustainability through the appropriate use of fertilizers, taking into account interactions with other management practices.

NGOs (Ecoa-Ecologia e Ação, SOS Pantanal, Ríos Vivos, TNC and WWF): dedicated to the conservation and integrated management of the Pantanal in collaboration with local communities. The main difficulty is the institutional disarticulation that prevents communication between local actors and institutions. They are action to articulate and integrate the region under a common language, based on the knowledge of the existing natural resources and the planning of integral and sustainable solutions.

4.2.3. Agro-industries:

Bom Jesus Group: Bom Jesus Group is one of the largest producers of cotton, soybeans and seeds in the state of Mato Grosso and Brazil. It also operates in the area of transportation, grain and food marketing (seeds, fertilizers and pesticides), livestock and swine farming. The agricultural activities of Bom Jesus Group are located in 19 municipalities of Mato Grosso, Bahia and Piauí, distributed in 20 production centers located in four regions of Mato Grosso and one in Bahia.

4.2.4. National and International ongoing research projects:

International Nitrogen Management System (INMS): INMS addresses the hypothesis that joined up management of the nitrogen cycle will offer many co-benefits that strengthen the case for action for cleaner water, cleaner air, reduced greenhouse gas emissions, better soil and biodiversity protection, while at the same time helping to meet food and energy goals. This is not research in the traditional sense of focusing on fundamental science. It is rather research in how these issues can be brought together to provide tools, approaches, information and demonstration that can support the mobilization of change at a global scale. The INMS has a central role to play in catalyzing the global policy community to develop more effective global and regional strategies to manage the nitrogen cycle. INMS is highly relevant to support several international policy processes. These include the Global Programme of Action for the protection of the marine environment from land-based activities (GPA), the UN Convention on Biological Diversity (CBD), the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP), the UN Framework Convention on Climate Change (UNFCCC), as well as the regional waters and seas conventions, and the programs of UNEP, FAO, WMO, OECD, UNECE and others. This approach is highly relevant as a focused contribution to meeting many of the Sustainable Development Goals, especially as the nitrogen cycle cuts across so many of the different goals

Nitrogen Cycling in Latin America: Drivers, Impacts and Vulnerabilities (Nnet): This project utterly goal is to have an integrated view of nitrogen management in the environment maximizing N essential role in sustaining life and minimizing its environmental affectations for Latin America. The project consists of working groups focusing on various themes related to the N balance in the region. The innovative set up of a network in the region, based on going field measurements in several sites within the region and International collaborations, initial support to new research with potential to rise more funds from other sources, synthesis studies on already publish information, modeling studies capitalizing on already on-going activities within International Scientific Programs (as IGAC, IGBP) and new modeling runs with the synthesis data and new measurements in the region.

4.3. Vermelho river watershed as the unit of study

A watershed is a logical, natural planning unit for agricultural, environmental and socioeconomic research and development (Thurow and Juo 1995). Then, to conduct this study, we considered the Vermelho River watershed as the unit of study and subdivides in 8 sub-basins to facilitate interpretation and represent spatial distribution of the results. These sub-basins are: São Lourenço, Poxoréu, Paraíso, Areia, Tadarimana, Jurigue, Ponte de Pedra and Main Stream. These watersheds comprehend mainly nine municipalities: Rondonópolis, Pedra Preta, São José do Povo, Guiratinga, Poxoréu, São Pedro da Gipa, Dom Aquino, Jaciara e Jucimeira (Figure 4).

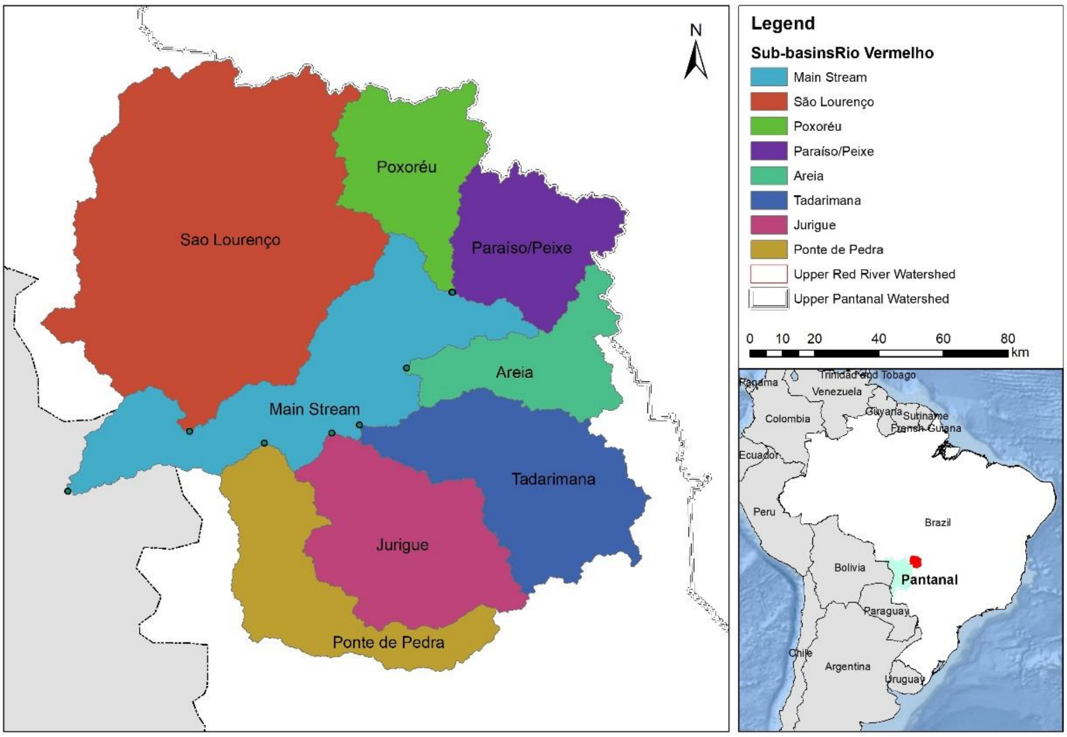


Figure 4: Vermelho River watershed sub divided in the 8 studied watersheds.

4.4. Agricultural practices and crop rotation in Vermelho River watershed

In the beginning of 2000s, there was a scenario with low soybean prices and corn had not market demand yet. Faced with this, monoculture proved to be unfeasible. Producers in the state of Mato Grosso have begun to implement new planting techniques, such as crop rotation, in an attempt to minimize economic losses. At first, grain growers from southern Mato Grosso applied crop rotation in only 15% of their area to 20% and then to 30%. Today, there are areas with up to 40% with crop rotation, and instead of planting 100% of the area with maize crop, part of this area is use to cultivate cotton.

Crop rotation is an economic advance to monoculture production in the region (personal communication). Thus, the producer is not financially dependent on only one crop, and changes in one product price offset losses or gains of the other, which gives more financial security. In addition, rotation practices decrease the risk of pests and diseases development. For example, it improves the physical, chemical and biological characteristics of the soil, as well as reduces the life cycle of insect pests, pathogens and weeds.

Table 2 shows the cultivation practices throughout the year for the Vermelho River basin in a timeline of the last 10 years. Crop rotation practice in Rondonópolis region started at the beginning of 2000s. During these years, there were many crop rotations in the Vermelho river watershed, mainly soybean/maize or cotton, and soybean/maize or *Brachiaria* sp. During the years of 2000 to 2005, the soybean harvest occurred between October and February. Between March and September, the second harvest (known as "safrinha" or "little harvest" in English) usually occurred with the cultivation of corn and/or millet. Between the years 2006 to 2017, the soybean harvest was shortened (starting in the end of September and ending in January). This shortening of soybean harvests was proposed in order to increasing the productivity mainly of cotton. If sown after the beginning of February, there was a significant decrease in productivity of cotton, mainly due to the lack water and low temperatures during flowering and filling of the cotton fruits (Borges et al. 2015). In the second harvest, from 60% to 70% represents maize production and 30% to 40% is cotton.

Table 2: Rotation practices in Vermelho River Basin.

	Hydrological year											
	Rainy Season						Dry Season					
Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2000			**Soybeans**						**Millet or Maize**			
2005			**Soybeans**						**Maize or Cotton**			
2010		**Soybeans**						**Maize, cotton**				
2017		**Soybeans**						**Maize, cotton**				

In Brazil, where no-till technology had been adapted and improved since its early years in the seventies, the set practices centered on no-till planting named “Direct Planting System” (DPS), which includes other important components like crop rotation, crop succession and organic soil covering. The no-till plating embraces sowing practices in which tillage is limited or absent and crop residue is left on surface. Crops are planted in previously unprepared soil through a narrow opening sufficient to proper seed coverage, without performing any other soil preparation. In the region of Rondonópolis, most of the producers uses DPS method and/or an adaptation of this one. There are three principles in adopting the no-tillage system: (i) continuous maintenance of straw on the surface, (ii) non-tillage and (iii) crop rotation. Generally, the rotation with sorghum and millet crops has as purpose increasing straw and, consequentially, the organic matter that is used for the next crop, usually soybeans, which is the main crop in the Vermelho River basin (Figure 5).

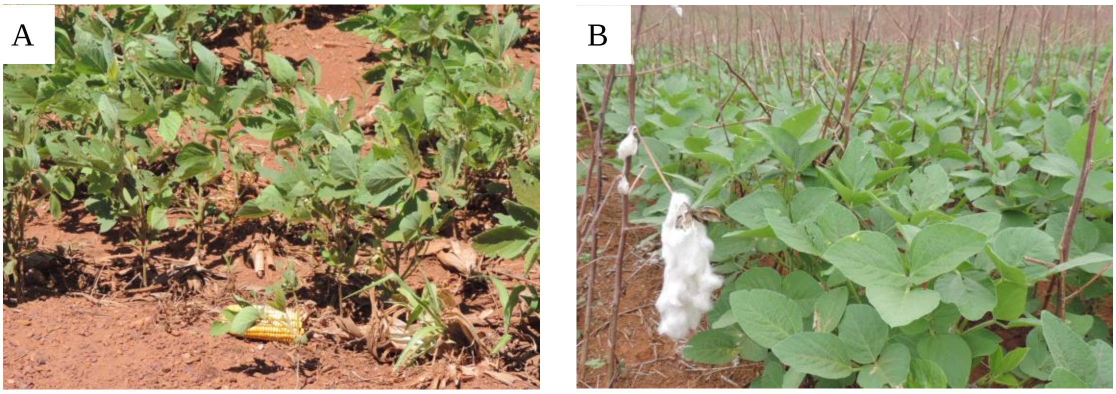


Figure 5: Direct Planting System (DPS). In the Vermelho river watershed, the soybean is planted after the harvest of (A) maize or (B) cotton.

The planting of forage species intercropped with annual crops has proven to be an efficient and economically feasible technique for some producers in the region, especially for small producers. After harvesting the annual crop, the pasture is formed and available for animal production. The inclusion of forage grasses in rotation with soybean has the dual purpose of producing supplementary green mass for animal feed and straw to increase organic matter in the off-season to the next harvest. Usually, small areas are reserved to forage planting in the off-season destined to livestock in the region, mainly in areas of sandier soil and poor in nutrients.

4.5. Methodological approach development and orientations for future studies

The methodology development can be sub-divided in three stages: 1) data gathering procedure; 2) balance calculation; and 3) valuation of costs and benefits (Figure 6). The method is intended to be a simplified approach to facilitate replication to other study sites. In the first and third stage, the stakeholder engagement is a key point to better represent local management practice. However, the methodology was thought to be useful for other region, thus, the method can be adapted using alternative data source as reports, scientific papers, agricultural census and others.

The first stage is focused on providing the basis for a conceptual framework and reviewing the availability of data and experiments results. In this stage, the best strategy is construct of a solid multi-stakeholder partnership comprising of governments, private sector, scientific community, civil society organizations to promote effective data gathering. Furthermore, this stage of stakeholder engagement is important to ensure the post-project actions to apply good practices, and to stimulate trans-disciplinary dialogue between all relevant stakeholders in order to attain the objective of reducing environmental pollution, while delivering financial and social benefits for human health, climate and biodiversity.

Complementary data were used to support spatial analysis of the nutrient balance and come from online free sources provided by national and international institutions. In this study case, we used data from the Brazilian institute of Geography and Statistics

(IBGE), National Institute of Meteorology (INMET), National Water Agency (ANA), National Institute for Space Research (INPE), Shuttle Radar Topography Mission (SRTM), MapBiomas.org.

In the second stage, the nutrient balance components are spatially represented using a Geographic Information System, and a map algebra tool is used to calculate the final soil balance. Details about the methodological procedure to elaborate the spatial analysis is described in the section 4.6.

The third stage represents the application the cost-benefit assessment (CBA) methodology. The application of such assessment was developed in collaboration with GPNM Steering Committee, members of the workgroup focused on evaluate nutrient impacts in Europe and other key GPNM partners (i.e., the INMS project and NNet project). The economic assessment is the most difficult steps in the study since most of the previous studies in the region lack such approach. Details about the method for evaluate costs and benefits of the nutrient management as well as the pros and cons are described in the section 4.9.

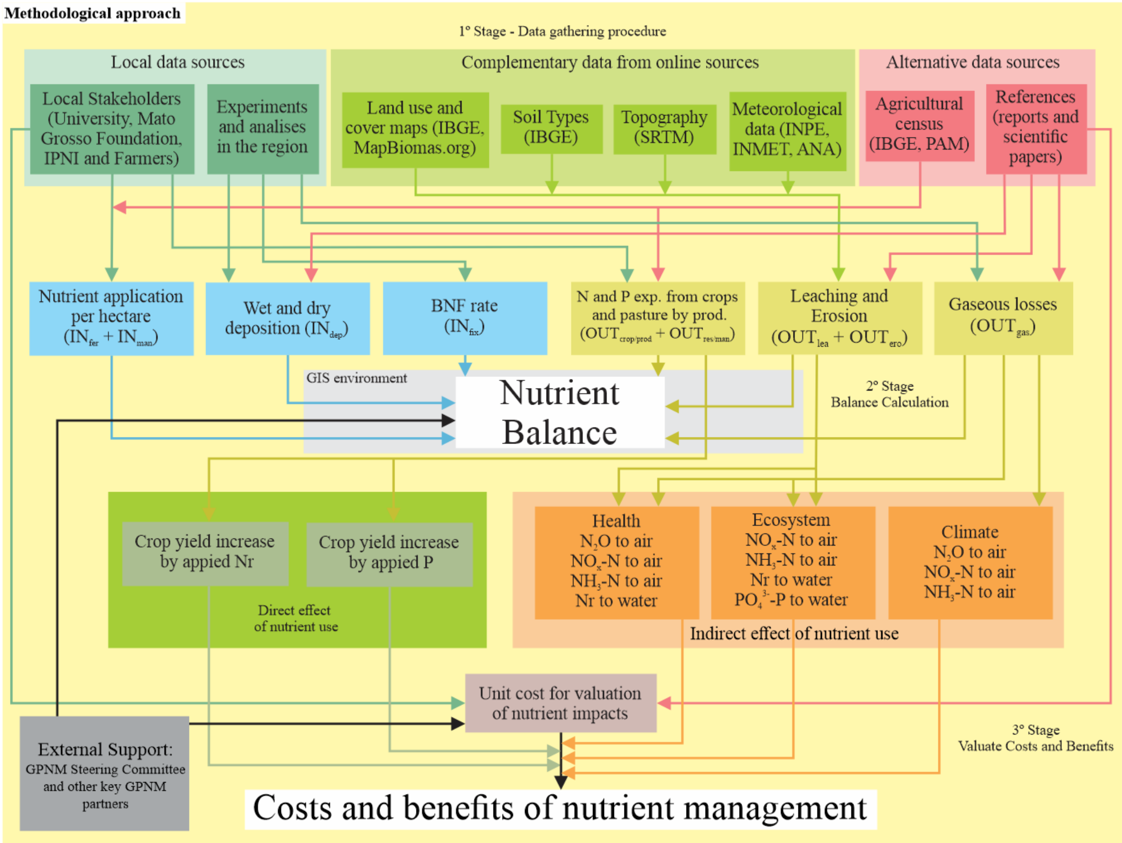


Figure 6: Schematic view of the method development to evaluate nutrient management.

4.6. Data inputs

The spatio-temporal nutrient balance in Vermelho River watershed was undertaken based on the integration of different land use and cover spatially explicit data, nutrient data, and agriculture and livestock census. Crops considered were soybean, maize, cotton and pasture. All data were compiled in a GIS (Geographic Information System) environment and were organized in a Geographic Database (Figure 7).

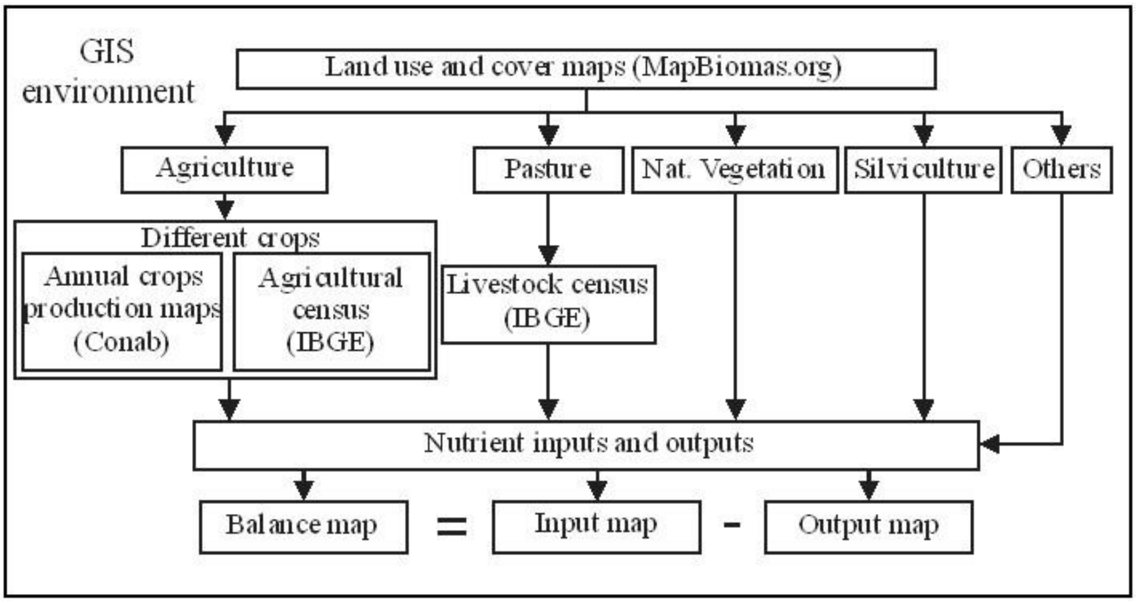


Figure 7: Flowchart of mapping protocol used for the production of spatio-temporal soil N and P balance for Rondonópolis Regions.

4.6.1. Land-use database

In this study, the land use and cover maps were produced by the Project MapBiomas - Collection 2 of Brazilian Land Cover & Use Map Series, accessed through the link: http://mapbiomas.org. These maps include 27 different land-use and land-cover classes considering the years from 2000 until 2015. All original maps were reclassified in order to emphasize the classes of interest:

1) *Agriculture*: agricultural areas, mosaic of agricultural areas with remaining forest, mosaic of forest vegetation with agricultural areas, and mosaic of grassland with agricultural areas;

2) *Pasture*: planted and managed pastureland (e.g. cattle-ranching);

3) *Natural vegetation*: natural vegetation in different stages of ecological succession (e.g. forest vegetation, grassland, wetland);

4) *Others*: urbanized zones, road systems, non-agricultural systems, continental water bodies, and uncovered lands (e.g. rocky outcrops and sand dunes);

The land use and cover maps were decomposed into a regular grid of 30m x 30, then the percentages of each class were computed for each grid. As the *Annual Crops* class do not separate soybeans, maize and cotton distribution, the data for soybean, maize and cotton areas were obtained from the Municipality-based Agricultural Census (IBGE 2000, 2005, 2010, 2015a). The proportion of soybean, maize and cotton was uniformly distributed over the *Agriculture* class. Municipality-based Livestock Census data provided the number of cattle heads (IBGE 2000, 2005, 2010, 2015b), while Agricultural Census of 1996 and 2006 provided the farms areas (IBGE 1996; IBGE 2006). In addition, the ratio of these data was used to calculate the bovine stocking rates (head ha^{-1}) for *Pasture* class for the same period.

4.6.2. Soil nutrient balance

The soil nutrient balance for the land-use systems in Vermelho river watershed was based on the literature (Liu et al. 2010, Stoorvogel and Smaling 1998; Smaling and Fresco 1993) and local data given by local stakeholders. For the analysis we assumed that the 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.

All nutrient inputs and outputs are expressed in kilograms per hectare per year (kgN ha^{-1} yr^{-1}, Table 3). We used the average values of nutrient inputs and outputs from regional survey and literature for the calculation of soil balance (Table 3). In general, nutrient inputs and outputs vary in space and time under Brazilian field conditions due to a diversity of landscape physical elements, soil chemical variety, and climate. However, in this study, a generalization was necessary for establishing soil nutrient balance because the majority of nutrient input and output data are annual.

All nutrient inputs and outputs considered here are referent to productivity average of crops for each sub-basin for the years 2000, 2005, 2010 and 2015. Crops productivity were based on Municipality-based Agricultural Productivity (IBGE 2000, 2005, 2010, 2015a).

Table 3: Average rates of nutrient inputs and outputs fluxes (kgN ha^{-1} yr^{-1}) for crops, pasture, and silviculture for Vermelho river watershed.

INPUTS	Agro system	kgN $ha^{-1}ano^{-1}$	N Reference	kgP $ha^{-1}ano^{-1}$	P Reference
IN1: Mineral Fertilizer	Soybean	0	Regional survey	31.5	Regional survey
	Maize	80	Regional survey	12.9	Regional survey
	Cotton	124.8 ± 19.4	Alves et al. (2006); FNP (2006); Carvalho et al. (2009); Kaneko et al. (2013); Motomiya et al. (2011); Cruvinel et al. (2011); Carvalho and Bernardi (2004)	33.9	FMT (2017)
	Pasture	0	Santos et al. (2002)	0	Santos et al. (2002)
IN2: Organic inputs / Manure from indigenous cattle grazing outside the farm	All	0	Smaling et al. (2008)	0	Smaling et al. (2008)
IN3: Wet and dry deposition	All	5.5	Vet et al. (2013)	0.03	Vet et al. (2013)
IN4: Biological N fixation	Soybean	189.8 ± 40.0	Boddey et al. (1984); Filoso et al. (2006); Alves et al. (2006); Alves et al. (2003)	-	-
	Maize	-	-	-	-
	Cotton	-	-	-	-
	Pasture	25.0 ± 10.0	Boddey and Victoria (1986); Filoso et al. (2006)	-	-
OUTPUTS	**Agro system**	**kgN.$ha^{-1}ano^{-1}$**	**N Reference**	**kgP.$ha^{-1}ano^{-1}$**	**P Reference**
OUT1: Harvested Crop Parts / Animal Products	Soybean	177.0 ± 18.1	Zotarelli et al. (1998); Alves et al. (2006); Hungria et al. (2003); Borkert et al. (1994)	16.0 ± 2.4	Borkert et al. (2004); Riskin et al. (2013); Fageria et al. (2011)
	Maize	94.2 ± 34.0	Zotarelli et al. (1998); Alves et al. (2006); Coelho et al. (2003)	14.0 ± 4.12	Coelho et al. (2003); Resende et al. (2006)
	Cotton	126.0 ± 11.6	Alves et al. (2006); Carvalho et al. (2009); Carvalho et al. (2011)	15.5 ± 3.5	Carvalho et al. (2007); Carvalho et al. (2011)
	Pasture	3.7	Boddey et al. (2004)	1.25	Boddey et al. (2005)
OUT2: Removed Crops Residues / Manure leaving the farm	All	0	Smaling et al. (2008)	0	Smaling et al. (2008)
OUT3: Leaching	Soybean	1.5	Lehmann et al. (2004)	0	Riskin et al. (2013)b
	Maize	17.6 ± 4.7	Wilcke & Lilienfen (2005); Coelho et al. (2003); Andrade et al. (2004); Alves et al. (2006)	0.005	Lourenzi et al. (2014)
	Cotton	8	Alves et al. (2006)	0	Cardoso (2002)
	Pasture	0	Costa (2006)	0	Neill et al. (2001)
OUT4: Gaseous losses	Soybean	0.3	Hungria et al. (2006); Cruvinel et al. (2011)	-	-
	Maize	29.7	Cruvinel et al. (2011); Zavaschi et al. (2014)	-	-
	Cotton	8	Alves et al. (2006)	-	-
	Pasture	6.8	Boddey et al. (2004); Lessa et al. (2014)	-	-

4.7. Estimation of soil nutrient loss rates in the study area thought erosion

The method applied for this estimation is based on Gomes et al. (2017). They applied this method to the Brazilian Cerrado Biome and we adapted it for this study using local information about soil, land use cover, precipitation etc.

For a successful erosion assessment inside a landscape it is essential to have quantitative soil erosion data and its spatial distribution. From these data, it is possible to design and implement appropriate erosion control where conservation measures will have a great impact on reduction of soil loss and water conservation (Shi et al. 2004). There are different methods to assess quantitative soil erosion (Merritt et al. 2003). Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) are the most frequently used. Advantages of these methods are simplicity, effectiveness of the equations, and success in predicting long term average annual soil loss with acceptable accuracy (Zhang et al. 2013). The main objective of the topic is to estimate the spatial distribution of annual soil loss rate using RUSLE model integrated into a GIS, and investigate the relationship between farmland and silviculture uses with soil loss. This method will be used to calculate the spatial distribution of annual soil loss rate for the entire and the output of nutrient from the soil (OUT_{ero}).

All input data for the RUSLE model were stored, analyzed, and visualized within the ArcGIS® environment (version 10.4). The GIS database were georeferenced using World Polyconic projection and SAD 69 (South American Datum 1969). The full database (vector and raster formats) includes the following:

1) Erosivity Map (approximated scale of 1:5,000,000) obtained from (Oliveira et al. 2011);

2) Soil Map from EMBRAPA (Brazilian Agriculture Research Corporation) at the scale 1:5,000,000 (Santos et al. 2011);

3) Digital Elevation Model (DEM) generated from TOPODATA database provided by INPE (Brazilian Institute for Space Research) with spatial resolution of 30m from SRTM data produced by NASA originally (Valeriano 2008);

4) 2000, 2005, 2010 and 2015 Land Use and Cover Maps produced by the Project MapBiomas - Collection 2 of Brazilian Land Cover & Use Map Series, accessed through the link: http://mapbiomas.org. The maps were reclassified in five classes as described in section 4.4.1.

4.7.1. Description of RUSLE model

Estimation of soil loss and its spatial distribution were obtained using RUSLE model integrated into a GIS. RUSLE is an empirical mathematical model developed to estimate soil erosion water (Renard et al. 1997). The evolution and the improvement over the USLE lead to the RUSLE computer program. In the same way as its predecessor, the model does not estimate sediment deposition on the slope (Zhang et al. 1995), but only establishes an estimate of the average annual soil loss caused by rill and interril erosion (Kinnell 2010). As a result, the RUSLE model estimates the potential soil loss rates, which indicate the intensity of the erosion processes. The model is a product of five factors, according to the equation 3:

$$A = R \times K \times LS \times C \times P \qquad 3$$

where A is the annual average soil loss per unit of area (t ha^{-1} yr^{-1}), R is the rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), k is the soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is the slope length and slope steepness factor (dimensionless), C is the crop management factor (dimensionless), and P is the erosion control practice factor (dimensionless). Integrated into a GIS, soil erosion loss was calculated on a cell-by-cell basis in order to recognize the spatial patterns of soil loss. Thus, each factor was calculated taking grid cells of 90m x 90m as reference and an uniform spatial analysis environment for GIS modeling was established (Beskow et al. 2009). In general, grid cells should be as small as possible to allow erosion to be characterized with a better resolution (Beskow et al. 2009). Spatial distribution of soil erosion loss was produced multiplying all factor layers to produce a final map.

4.7.2. Rainfall-Runoff erosivity factor (R)

Erosivity factor (R) represents the erosive power of precipitation in a given soil, regolith or other weathered material. Precipitation is the driving force of erosion and has a direct effect on different phases of the erosional processes including the detachment of soils particles, the breakdown of aggregates and the transport of eroded material by runoff. The R-factor is the kinetic energy of raindrops that fall onto the ground and is affected by rainfall intensity and raindrop size (Wischmeier and Smith 1978).

4.7.3. Erodibility factor (K)

The soil erodibility factor (K) is a property that depends upon two factors; the first one is the infiltration capacity to resist the detachment and transportation by rainfall and the second one is the runoff process (Wischmeier and Mannering 1969). Therefore, K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index for a specific soil (Renard et al. 1997). The K-factor varies from zero to one, in which *zero* refers to soils with less susceptibility to water erosion while *one* refers to soils higher susceptible (Farhan and Nawaiseh 2015). The K-factor map was produced based on soil map and erodibility values published from several studies conducted in different areas of Brazil for the same soil types. The K values for each soil type of the study site can be observed in Table 4.

Table 4: Soil classification and soil erodibility (K) values and their respective sources.

No.	Brazilian Classification	FAO Classification	K (t h MJ^{-1} mm^{-1})	Source
1	Latosol	Ferralsols	0.018	Farinasso et al. 2006
2	Quartzarenic Neosols	Arenosols	0.056	Castro et al. 2011
3	Argisols	Acrisols	0.047	Farinasso et al. 2006; Demarchi and Zimback 2014
4	Plinthosols	Plintosols	0.012 – 0.055	Cabral et al. 2005; Farinasso et al. 2006
5	Litholic Neosols	Leptosols	0.050	Cabral et al. 2005

4.7.4. Topographic factor (LS)

The topographic factor represents the influence of the relief on the erosion process (Renard et al. 1997). The LS-factor depends on the slope steepness (S) and slope length (L) factors considering slopes as uniform profiles. In general, soil erosion increases as the slope steepness increases due to increased runoff flow velocity. As well as, soil erosion increases as slope length increases because of rising accumulation of runoff in downslope (Wischmeier and Smith 1978; Farhan and Nawaiseh 2015). Maximum slope length is seldom longer than 600 ft or shorter than 15-20 ft (Brooks et al. 2012). Both are obtained from Digital Elevation Model (DEM) considering different approaches and methods (Desmet and Govers 1996; Beskow et al. 2009). This study was based on Desmet and Govers (1996) that calculated L-factor using as reference the upslope contributing area of each cell according to Equation 4:

$$Li,j = \frac{[(Ai,j-in + D^2)^{m+1} - (Ai,j-in)^{m+1}]}{[D^{m+2} \times xi,j^m \times (22,13)^m]} \qquad 4$$

where $L_{i,j}$ is the slope length factor for grid cell with coordinates $(_{i,j})$. $A_{i,j\text{-}in}$ is the contributing area at the inlet of grid cell with coordinates $(_{i,j})$ (m^2); D is the grid cell size (m); m is a dimensionless exponent that depends on slope steepness (S); $x_{i,j}$ is flow direction value for the grid cell with coordinate $(_{i,j})$. The exponent m was calculated according to [17] being S < 1%, m = 0.2; 1% ≤ S ≤ 3%, m = 0.3; 3% < S ≤ 5%, m = 0.4; e S > 5%, m = 0.5.

The *S factor* was calculated based on (K. McCool et al. 1987), according to Equation 5 and 6:

$$S = 10.8 \times \sin\theta + 0.03 \; for \; slopes < 9\% \tag{5}$$

$$S = 16.8 \times \sin\theta - 0.50 \; for \; slopes \; \geq 9\% \tag{6}$$

where θ is the slope angle (°). Slope steepness was divided into six categories based on (Ramalho Filho and Beek 1995) as depicted in Table 5.

Table 5: Slope steepness categories for the study site adapted from Ramalho Filho and Beek 1995.

Categories (%)	Relief Classification
0 – 3	Flat Reliefs
3 – 8	Gentle Hillslope
8 – 13	Moderate to Gentle Hillslope
13 – 20	Strongly Undulating Relief
20 – 45	Mountain with Steep Hillslope
45 – 100	Ridge Escarpments

4.7.5. Cover and management factor (C)

The cover and management factor (C) represents an integration of several factors that affect erosion, including vegetative cover, plant litter, soil surface and land management (Wischmeier and Smith 1978; Renard et al. 1997). This is the second most important factor in RUSLE, only after topography, since it represents the conditions that can be easily changed to reduce overland flow and soil erosion (Beskow et al. 2009; Farhan and Nawaiseh 2015). Although treated as an independent variable in the equation, this factor depends upon other factors. The C-factor varies from near zero (for a good erosion protection) to one (for a poor erosion protection) (Ganasri and Ramesh 2016). The C-factor values extracted from literature and percentage of the area to each land use are presented in Table 6.

Table 6: Values of the cover management factor (C) for each land use cover class of the study site.

No.	Land use	C	Source
1	Pasture	0.014	Galdino 2012
2	Natural Vegetation	0.001	Oliveira et al. 2015
3	Annual crops	0.08	Bertol et al. 2001
4	Semi-perennial crops	0.31	Weill 1999
5	Others	0.00	-

4.7.6. Supporting practice factor (P)

The effect of erosion control practice (P) represents the relationship between soil loss with a specific support practice and the corresponding loss with up-downslope cultivation (Pandey et al. 2007). P-factor varies according to soil conservation practices and, thus, it has a strong influence on soil loss (Beskow et al. 2009). Practices characterized by *P* include strip-cropping and terraces and are not applicable to most forested region. The values for P-factor were determined according to (Oliveira et al. 2007) that calculated this factor based on slope angle (α). Thus, the *P* was 0.6 for $0 \leq \alpha \leq 5\%$, $0.69947-0.08991\,\alpha + 0.01184\,\alpha^2 - 0.00035\,\alpha^3$ for $5\% < \alpha \leq 20\%$ and 1.0 for $\alpha > 20\%$.

4.8. Calculation of Nutrient Use Efficiency

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 (Brentrap and Palliere 2010; Norton et al. 2015; Sutton et al. 2013a). 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 (Fixen et al. 2015). 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.

NUE can be defined in many ways depending on the purpose and the interest of the analysis. 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. Methods of NUE determination and their interpretation were reviewed by Dobermann (2007) and the Table 7 shows a summary of common NUE terms, along with their applications and limitations.

According to the International Plant Nutrition Institute (IPNI), the Agronomic Efficiency or Apparent Recovery Efficiency are appropriate performance indicators, however, they require a nil fertilizer application treatment to estimate the extra yield due to the added fertilizer, which mean that the use of such approach is impracticable and useless in a non-research setting (Table 7).

Table 7: Revision of the common Nutrient Use Efficiency terms presented by Dobermann (2007).

Term	Calculation*	Question addressed	Typical use
Partial factor productivity	PFP = Y/F	How productive is this crop- ping system in comparison to its nutrient input?	As a long-term indicator of trends.
Agronomic efficiency**	AE = (Y-Y0)/F	How much productivity improvement was gained by use of nutrient input?	As a short-term indicator of the impact of applied nutrients on productivity. Also used as input data for nutrient recommendations based on omission plot yields.
Partial nutrient balance	PNB = UH/F	How much nutrient is being taken out of the system in relation to how much is applied?	As a long-term indicator of trends; most useful when combined with soil fertility information.
Apparent recovery efficiency by difference**	RE = (U-U0)/F	How much of the nutrient applied did the plant take up?	As an indicator of the potential for nutrient loss from the cropping system and to access the efficiency of management practices.
Internal utilization efficiency	IE = Y/U	What is the ability of the plant to transform nutrients acquired from all sources into economic yield (grain, etc.)?	To evaluate genotypes in breeding programs; values of 30-90 are common for N in cereals and 55-65 considered optimal.
Physiological efficiency**	PE = (Y-Y0)/ (U-U0)	What is the ability of the plant to transform nutrients acquired from the source applied into economic yield?	Research evaluating NUE among cultivars and other cultural practices; values of 40-60 are common.

* Y = yield of harvested portion of crop with nutrient applied; Y0 = yield with not nutrient applied; F = amount of nutrient applied; UH = nutrient content of harvested portion of the crop; U = total nutrient uptake in aboveground crop biomass with nutrient applied; U0 = nutrient uptake in aboveground crop biomass with no nutrient applied; Units are not shown in the table since the expressions are ratios on a mass basis and are therefore unitless in their standard form. P and K can either be expressed on an elemental basis (most common in scientific literature) or on an oxide basis as P_2O_5 or K_2O (most common within industry).

** Short-term omission plots often lead to an underestimation of the long-term AE, RE, or PE due to residual effects of nutrient application.

The method we proposed to calculate NUE is the Partial Nutrient Balance (PNB). This method is recommended by the INPI and the simplest form of Apparent Recovery

Efficiency, usually expressed as removal/use ratio or the output/input ratio. Furthermore, PNB can be measured or estimated in multiple scales from crop producers to regional or national level. Often, the assumption is made that a PNB close to 1 suggests that soil fertility will be sustained at a steady state. However, since the balance calculation is a partial balance and nutrient removal by processes, such as erosion and leaching are usually not included, using a PNB of 1 as an indicator of soil fertility sustainability can be misleading, particularly in regions with very low natural soil fertility and low inputs and production (Naeem et al. 2017). Values well below 1, where nutrient inputs far exceed nutrient removal, might suggest avoidable nutrient losses and thus the need for improved NUE (Snyder and Bruulsema 2007); reachable values, however, are cropping system and soil specific. A PNB greater than 1 means more nutrients are removed with the harvested crop than applied by fertilizer and/or manure, a situation equivalent to “soil mining” of nutrients. This situation may be desired if available nutrient contents in the soil are known to be higher than recommended. However, in cases where soil nutrient concentration is at or below recommended levels, a PNB >1 must be regarded as unsustainable (Brentrap and Palliere 2010). Although we calculated the Whole Nutrient balance in the study area, the calculations of NUE by Partial Nutrient Balance can be an easier tool for stakeholder and a simplest way to evaluate agricultural practice performance.

Then, the NUE was calculated using the PNB and expressed as mass fraction (kg per kg)

$$NUE_{PNB} = UH/F$$

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.

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). The concentrations of N for manure and harvest products are often not known for specific farms, but they can be estimated from regional literature values. At the national and sub-national level, data on production by commodity type (e.g., maize, wheat, rice, other crops, dairy products, and meat) are estimated by governments and the FAO when real data are not available.

A disadvantage of NUE is that it, alone, is often inadequate for assessing agricultural sustainability, so that NUE data must be interpreted in the context of other data. Different crop types are likely to have different NUE, and national and regional NUE values may reflect the particular mix of farming systems within those areas. Maize generally has lower NUE than wheat, and so a country or farmer growing a lot of wheat may report relatively high NUE, not necessarily because of particularly efficient nutrient management practices, but because of the type of crop that the soils and climate best support.

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

The effect of a change in nutrient management on human welfare can be determined, in theory, by comparing its social costs and benefits. Changes in nutrient management can lead to a net improvement in human welfare if the sum of the social benefits exceeds the sum of the social costs. Integrated assessment of multiple impacts is needed to support discussions and decisions, however, considering the complexity of nutrient cycles, identifying, quantifying and comparing the most significant effects in the environment remains a challenge (Sutton et al. 2013a; Keeler et al. 2016). Social Cost-benefit assessment (CBA) has proved its use when comparing alternative options for realization of large infrastructural project and we consider it to be a potentially useful tool to assess economic impacts on changing nutrients management to provide guidance to support policy making. CBA can be used to compare the costs and benefits of different policy options, preferably in monetary terms, from multiple perspectives, such as a private investment decision or considering the whole society, considering the effects related to social welfare (Sutton et al. 2011).

The monetary value of a positive welfare effect can be measured as the amount of money society is willing to give up to secure the improvements to welfare (willingness to pay - WTP), and can be derived from demand for the goods and services traded at different market prices. Because many goods and services are not traded in markets, it is important to use alternative ways to estimate monetary values of changes in environmental quality that affects their provision. Costs represent the monetary value of the negative welfare implications, including all resources a society has to sacrifice of changing practices, such as investment and operating costs and opportunity costs (Sutton et al. 2013a).

Valuation using CBA methodology has been made to assess nitrogen impacts in Europe, based on a set of regional studies reviewed and made comparable by expression in euro (benefit) per kg of nitrogen added in the agriculture and euro (cost of impact) per kg of induced nitrogen emissions. 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. Social costs were estimated using different economic approaches, considering nitrogen damages on human health, ecosystems and climate. Effects on human health were assessed considering unit damage costs for airborne pollution by NOx, NH_3 and its contribution to particulate matter formation, drinking water pollution by NO_3^- and increased ultraviolet radiation caused by ozone depletion associated with N_2O emissions increase. Monetary values were estimated by costs of treatment, loss of productivity and WTP to avoid premature death (value of a life year) or pain and suffering. Climate impacts involve both warming (N_2O emissions) and direct and indirect cooling effects (NOx and NH_3 emissions), as well carbon sequestration driven by nitrogen deposition, which were valuated considering WTP for climate stability, which was approximated using the carbon (CO2-eq) prices resulting from the emission trading system (ETS). Impacts on terrestrial and aquatic ecosystems are related with deposition and nitrogen-loads, and were evaluated by WTP for restoring a healthy ecosystem (e.g. the Baltic Sea) of restoring biodiversity (for terrestrial systems) (van Grinsven et al. 2013).

There are different economic methods to estimate WTP, that can be distinguished whether they are based on actual or simulated price-response data or whether they use surveying techniques to obtain preferences data - stated preference. Selecting suitable methods depends on the driving intentions and it is influenced by conceptual considerations and practical restrictions such as time and budget availability (Breidert et al. 2006). Considering those constraints and the lack of markets for many goods and environmental services, and the flexibility associated with surveys approaches, WTP measurements based on stated preference can be an appropriate tool for economic valuation of changes on nutrients management and its related impacts.

Stated preferences are obtained from direct surveys (contingent valuation), when the respondents are asked to state how much they would be willing to pay in face of changes in the availability of environmental resources and services, to guarantee the improvement in well-being or even how much they would be willing to accept in compensation to tolerate a loss of well-being (Breidert et al. 2006). Direct surveys can consider expert judgements and/or customer surveys and use a questionnaire to create a hypothetical - but realistic – market. Pricing functions can be developed using econometric methods to establish relationships between prices attributed by respondents and affecting factors such as social and economic characteristics and participation in relevant environmental groups (Chen 2014). Indirect survey approaches also can be performed to obtain stated preferences and involve rating or ranking procedures. The respondents are confronted with different possibilities and must apply a preference rating, ordering or select their most preferred choice. The results are used to statistically derive WTP. Different approaches can be used for indirect surveys, depending on the interest in estimate WTP at the individual level based on every respondent's data (conjoint analysis) or at aggregated level (discrete choice analysis) (Breidert et al. 2006).

It is important to note that CBA's are subject to conceptual difficulties and the mix of methods used introduces uncertainties to the estimates. As WTP is based on preferences and influenced by the context, information of the surveys and income, it is a controversial method for economic valuation of ecosystems goods and services. Relationships between nitrogen emissions and related impacts are not always linear and impacts also depend on other factors (e.g. on phosphorus in case of eutrophication), causing dose-response relationships to be uncertain and conditional. Besides, some effects are not considered, such as estimates of benefits of added value that can be created in the food chain using primary agricultural goods (van Grinsven et al. 2013). Despite those inevitable uncertainties the method is relevant to weight and compare multiple effects of nutrients in the environment, and it is a relevant tool for evaluating and building integrated policies (Brink and van Grinsven 2011).

Economic value of a negative environmental impact was linked to nutrients (N and P) by dividing the associated economic loss by the value of the nutrient emissions (implicitly assuming no effect threshold), following methodology described in the European Nitrogen Assessment and further revision (Brink and van Grinsven 2011; van Grinsven et al. 2013). Adaptations to local reality were performed whenever possible. The unit costs (Table 8) 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 (Sutton, 2015) and the concept of purchasing power parity (PPP) based on data provided by the Word Bank (https://data.worldbank.org/). Nutrients fluxes in the Rio Vermelho basin were obtained from the average budgets estimates for years 2000, 2005, 2010 and 2015 as previously presented. Summarized concepts and references used to calculate costs and benefits of nutrients are presented in Table 9 and discussed below. We highlight the lack of more specific data for the study area, which compel us to make some generalizations and increases the uncertainties associated with the calculation methods. In the absence of more accurate data, we strongly recommend caution in the interpretations of results, and we strongly recommend new studies to refine these estimates in the near future.

Table 8: 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

NOx-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

Human health damage is associated with different N-compounds and routes. Skin cancers and cataract are related to reduction in stratospheric ozone layer causing increase of solar ultraviolet radiation at Earth's surface. Nitrous oxides (N_2O) emissions stands out as a dominant ozone depleting substance (ODS). Unit damage cost for those impacts is estimated in terms of years of life lost per kiloton of N_2O emitted (Struijs et al., 2010). Effects resulting from the reduction in the stratospheric ozone layer are dependent on the geographical region, demographic and individual characteristics. Due to differences in the skin color of European populations and those in the state of Mato Grosso, we calculated a three times lower cost value, considering a higher natural protection from solar radiation (Struijs et al., 2010). Nitrogen air-born pollutants - nitrogen oxides (NOx) and ammonia (NH_3) - are responsible for both direct and indirect effects, mainly through formation of tropospheric ozone (O_3) and secondary particulate matter (PM). Those are major contributors to adverse health effects of air pollution such as chronic and premature mortality and morbidity caused by respiratory and cardiovascular diseases (Bickel; Friedrich, 2005; Moldanová et al., 2011). Damage unit cost was derived from dose-response (or exposure-response) functions considering inhalation dose of air pollutants followed by a monetary valuation of damages (Bickel; Friedrich, 2005; Brink et al. 2011). Market and non-market costs were included, such as hospital admissions, medical treatments and willingness-to-pay to avoid suffering.

Mortality from chronic exposure was evaluated in terms of loss of life expectancy using a value of 40000 euros per health life year (Desaigues et al. 2011).

Damages caused by nitrate in drinking water are difficult to estimate, mainly due of scarcity of epidemiological studies. The increase on incidence of colon cancer in population exposed to levels of nitrate exceeding 25 mg L^{-1} was estimated for European countries resulting in a mean unit damage cost of 0.7 euro per kg of N lost (van Grinsven et al. 2010; van Grinsven et al. 2013). Furthermore, a recent study found statistically significant increased risks of colon cancer at drinking water levels above 3.87 mg/L, well below the current drinking water standard of 10 mg/L adopted in Brazil (http://bvsms.saude.gov.br/bvs/saudelegis/gm/2011/prt2914_12_12_2011.html). However, as the level of nitrate found in Vermelho river waters were very low (less than 1 mg L^{-1}) it seems appropriate to consider the unit damage as zero. As highlighted in Brink et al. (2011), unit damage cost could be higher when other chronic health impacts associated with nitrate (Ward et al. 2005) in drinking water are included.

Several climate effects can be attributed to Nr, through processes that act directly and indirectly on the radiative balance of the earth system. Direct effects are related to production and emissions of N_2O, which absorb and reemit infrared radiation, acting as a powerful greenhouse gas. There are multiple indirect effects of Nr, including changes on carbon fluxes, altering CO_2 and CH_4 biogeochemical cycling and changes in the atmospheric chemistry mainly due to increases in aerosol and tropospheric ozone synthesis mediated by NOx and NH_3 (Butterbach-Bahl et al. 2011). Taking into account these multiple effects, van Grinsven et al. (2013) calculated the range of unit cost for climate impact of Nr in Europe, which was used for our estimates. Considering the overall impact on climate changes, no corrections besides currency were made.

Unit benefits of synthetic fertilization were derived from yield curves based on field experiments for maize and soybean production, major agricultural products in Vermelho river basin (Souza et al. 2011; Corrêa et al. 2004; Fageria et al. 2011). Fertilization benefits (net gain) is obtained by the relation between market prices of commodities and the investment costs of the producer for the acquisition and use of the agricultural inputs. We considered N-fertilizer use only for maize cultivation, since N-additions in soybeans are not a common practice in our study area.

In this study, we did not consider the impact of P export from agricultural system due to the lack of studies in the study site that can be used to estimate the costs of its impact.

Table 9: Summarized concepts and data for calculating costs and benefits of nitrogen.

Effect	Explanation and reference
*Human health (increased ultraviolet radiation from ozone depletion) - N_2O	Based on values calculated by van Grinsven et al. 2013 and use on the ENA that considered increased incidence of skin cancer and cataracts from depletion of stratospheric ozone. The unit cost was inferred from a global Life Cycle Assessments study (Struijs et al. 2010). The unit cost for each kg of N_2O-N is approximately 3-fold lower because of the natural protection of the skin due to skin-color (skin reflectance) difference between people from Europe and Mato Grosso State (see Struijs et al. 2010 and Supporting Information).
*Human health (air pollution) - NOx and NH_3	Base on damage unit cost for airborn NOx and NH_3 from ExternE project (Bickel and Friedrich 2005) and calculated by van Grinsven et al. 2013.
Human health (drinking water) - Nr	We considered the value of unit cost for the health impact related to drinking water as zero because the level of nitrate in drinking water is very low (lower than 1 mg/L). Significant increasing risk at drinking water level occurs only above 3.87 mg/L (Schullehner et al. 2018).

Terrestrial ecosystems (eutrophication, biodiversity) - NOx and NH_3	Based on ecosystem damage by deposition of NH_3 and NO_x on terrestrial ecosystem. The methodology to calculate the considered value was based on Ott et al. (2006) representing the cost for restoring the biodiversity loss due to Nr. We considered the restoration cost of the biodiversity changing a degraded area from pasture to forest based on local costs for native forest restoration (Antoniazzi et al. 2016).
*Aquatic ecosystems (eutrophication, biodiversity)	We considered the cost of nutrient load to aquatic system as zero because there is no evidence of eutrophication or ecosystem change (biodiversity and nutrient concentration) in the aquatic system due to nutrient export from land. A deeper investigation is needed to associate degradation of aquatic system to agricultural practices in Vermelho river watershed.
Climate (greenhouse gas)	The unit cost was calculated based on van Grinsven et al. 2013 which considered costs of climate damage based on contribution of N_2O to greenhouse gas balance and CO_2-price, cooling effect of N containing aerosol, C-sequestration in forests driven by N deposition and direct warming and indirect cooling effects by ozone precursed by NOx (Butterbach Bahl et al., 2011).
Crop yield increase (benefit)	We considered results from experiments of crop response to fertilize use (Souza et al. 2010, Corrêa et al. 2004, Fageria et al. 2011). We also used average values from 2010 to 2015 for grain and fertilizer prices. The benefit of each kg of N applied in maize and cotton was estimated under a P basic fertilization of 30 kg P/ha. Since we cannot distinguish benefits of N and P separately for maize and cotton, we considered the benefits of N application in a situation that P is not a limiting factor for maize and cotton production.

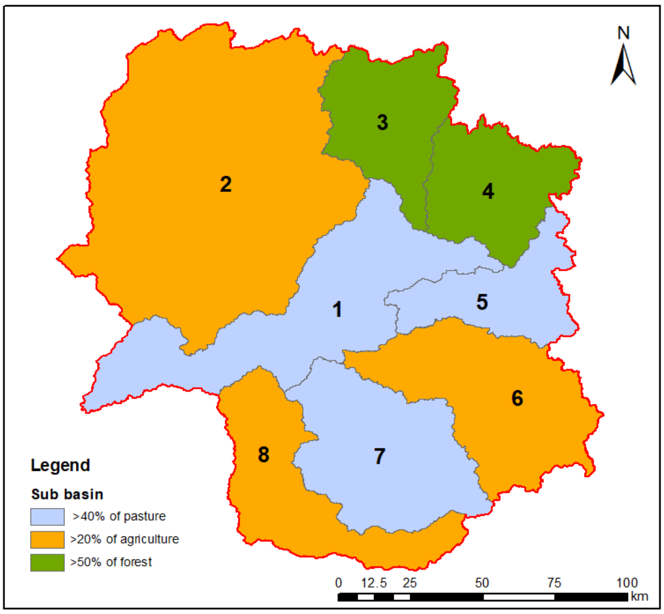
* These unit cost values are estimated from studies from Europe and converted to represent local situation or assigned as zero to the lack of scientific evidences of impacted associated to agricultural practices. We strongly recommend new studies to estimate better values or a deeper investigation at local scale.

5. Results and discussion

5.1. Land cover characteristics of each basin

The land use and cover changes in the Vermelho River watershed has been intense between 2000 and 2015. In this period, natural vegetation areas decreased 9.1% (10,152.9 km^2) whereas agriculture and pasture areas increased 9.2% (3,663.2 km^2) and 8.8% (6,651.7 km^2), respectively. Thus, in 2015, about 44.3% (101,657.6 km^2) of the Vermelho River watershed was natural vegetation, 35.7% (81,917.2 km^2) was pasture and 18.9% (43,339.8 km^2) agriculture areas.

We subdivided the Vermelho River watershed in 8 sub-basins to facilitate interpretation and represent spatial distribution of the results. Thus, the main characteristic of each sub-basin is shown in the Figure 8 and the area of natural vegetation, pasture and agriculture for each sub-basin are presented in the Table 10.



1	Main river course. The river flows southwest passing by Rodonópolis and going directelly to Pantanal. This region is tipically of smallholders livestock farms with low nutrient inputs.
2	Grassland/Pasture and Agriculture. The agriculture production is mainly Soybeans and Maize
3 and 4	Low nutrient inputs and a small portion of crop lands. Most of the are is natural forest and savanna
5 and 7	Mainly livestock production with small areas of Soybeans and Maize.
6	An agricultural basin with production of soybeans. The soybeans in this basin is basically focussed on seed production with a high value added. Crop rotaion is usually Soybean/Cotton
8	The most agricultural sub basin inside the study site. Large farms with Soybean/Maize rotaion practice.

Figure 8: Main characteristics of the 8 sub-basins of the Vermelho River watershed.

Between 2000 and 2015, the expansion of agriculture occurred mainly in the sub-basins 2 (6%) and 8 (7%) due to soybean and maize expansion (see, Table 10). In contrast, the expansion of pasturelands occurred in the sub-basin 5 (10%) and 7 (9%), followed by sub-basins 4 (5%), 1 (4%), 3 (4%) and 6 (2%). In general, pasturelands are expanding mainly over agricultural lands or natural vegetation lands, especially in the sub-basins 3, 4, 5 and 6. In the sub-basins 1 and 7, the pasturelands are mainly over natural vegetation. In general, natural vegetation area increased only in the sub-basins 4 (3%) and 8 (1%) for this period.

Table 10: Area of natural vegetation, pasture and agriculture (relative area) in the eight sub-basins of the Vermelho river watershed.

Relative Area (%)				
	2000	2005	2010	2015
Sub-basin 1				
Natural vegetation	51	45	43	46
Pasture	38	44	43	42
Agriculture	8	7	10	8
Other	4	4	5	5
Sub-basin 2				
Natural vegetation	51	45	42	42
Pasture	34	36	38	36
Agriculture	15	19	20	21
Other	0	0	0	0
Sub-basin 3				
Natural vegetation	60	55	48	57
Pasture	30	38	40	34
Agriculture	9	6	11	8
Other	1	1	1	1
Sub-basin 4				
Natural vegetation	57	56	53	60
Pasture	30	37	37	35
Agriculture	12	7	10	6
Other	0	0	0	0
Sub-basin 5				

Natural vegetation	55	47	51	53
Pasture	32	46	39	42
Agriculture	12	7	10	5
Other	1	1	0	0
Sub-basin 6				
Natural vegetation	43	39	41	43
Pasture	25	29	26	27
Agriculture	31	31	32	30
Other	1	1	1	1
Sub-basin 7				
Natural vegetation	52	42	41	42
Pasture	36	41	40	45
Agriculture	12	16	18	12
Other	1	1	1	1
Sub-basin 8				
Natural vegetation	25	24	26	26
Pasture	29	22	23	21
Agriculture	46	54	51	53
Other	0	0	0	0

5.2. Nutrient balance

5.2.1. Nitrogen Balance

We assessed the nitrogen balance of crop and pasture lands of eight sub-basins of the Vermelho watershed to evaluate the proposed method. We analyzed four years: 2000, 2005, 2010, 2015. In general, the decrease of the nitrogen balance from 2000 to 2015 indicates that the agricultural practices are changing from a framework of positive value (higher inputs and soil accumulation) to a more balanced system (Table 11) with few areas with high rates of nitrogen loss. The decreasing values observed in the study site was also observed by Gomes 2017 in a study made in the Brazilian Cerrado.

Decreasing in soil nitrogen balance were higher in the agricultural sub-basins 8 (72.1%), 6 (70.7%) and 2 (69.0%) between 2000 and 2015 (Table 11). In these sub-basins, the quick advance of annual agriculture is causing decrease in the balance over time (Table 10). In contrast, soil nitrogen decreasing was lower in the sub-basins 5 (33%), 7 (39.6%) and 1 (39.6%) between 2000 and 2015 (Table 11) because pasture areas expansion was higher than agriculture expansion in these sub-basis (Table 10

Between 2000 and 2015, the expansion of agriculture occurred mainly in the sub-basins 2 (6%) and 8 (7%) due to soybean and maize expansion (see, Table 10). In contrast, the expansion of pasturelands occurred in the sub-basin 5 (10%) and 7 (9%), followed by sub-basins 4 (5%), 1 (4%), 3 (4%) and 6 (2%). In general, pasturelands are expanding mainly over agricultural lands or natural vegetation lands, especially in the sub-basins 3, 4, 5 and 6. In the sub-basins 1 and 7, the pasturelands are mainly over natural vegetation. In general, natural vegetation area increased only in the sub-basins 4 (3%) and 8 (1%) for this period.

Table 10). It occurs because in agricultural areas, although fertilizers are used, outputs by harvested products and erosion are causing greater losses of nitrogen, while in pasture areas, nitrogen inputs by biological nitrogen fixation are higher than the other N outputs for this use.

Table 11: Rates of nitrogen depletion (negative) or accumulation (positive) in the soil of the eight sub-basins inside of the Vermelho river watershed.

Nitrogen Balance (kgN ha^{-1} yr^{-1})				
	2000	2005	2010	2015
Sub-basin 1				
Min	-35.7	-42.2	-46.5	-55
Max	21.2	17.8	16.9	16.6
Average	13.9 ± 11.4	10.7 ± 11.9	8.9 ± 12.7	8.4 ± 13.6
Sub-basin 2				
Min	-35.7	-45.4	-49.8	-56.5
Max	21.2	17.8	16.9	16.6
Average	12.9 ± 11.0	8.1 ± 13.1	6.2 ± 14.5	4.0 ± 16.8
Sub-basin 3				
Min	-33.3	-39.6	-56	-55.3
Max	21.2	17.8	16.9	16.6
Average	15.9 ± 8.6	13.7 ± 8.5	9.0 ± 12.1	10.5 ± 11.1
Sub-basin 4				
Min	-33.4	-42.4	-48.5	-52.3
Max	21.2	17.8	16.9	16.6
Average	12.3 ± 12.3	10.3 ± 12.7	7.7 ± 14.3	8.5 ± 14.7
Sub-basin 5				
Min	-33.2	-40.6	-48	-55.3
Max	21.2	17.8	16.9	16.6
Average	11.5 ± 13.1	9.3 ± 13.8	7.6 ± 14.4	7.7 ± 15.4
Sub-basin 6				
Min	-33.9	-42.2	-47	-54.5
Max	21.2	17.8	16.9	16.6
Average	7.5 ± 13.5	5.5 ± 14.8	3.9 ± 15.3	2.2 ± 16.6
Sub-basin 7				
Min	-34.7	-45	-47.6	-55
Max	21.2	17.8	16.9	16.6
Average	14.4 ± 10.8	10.1 ± 11.5	9.3 ± 11.9	8.7 ± 13.0
Sub-basin 8				
Min	-33	-42	-43.5	-55.6
Max	21.2	17.8	16.9	16.6
Average	10.4 ± 9.7	7.5 ± 10.6	8.4 ± 10.7	2.9 ± 12.2

The Figure 9 and Figure 10 shows the magnitude of nitrogen inputs and outputs from agriculture and pasture 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 9). 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. Pasturelands had nitrogen budget of 5.9 (± 3.8) kgN ha^{-1} yr^{-1} (Figure 10), being the BNF (82%) the main nitrogen input and erosion and leaching (49.7%) the main outputs.

Soil nitrogen accumulation or depletion varied, at local scale, as shown in Figure 11. The agricultural sub-basins 8, 6 and 2 have areas with the highest rates of nitrogen accumulation in the soil due to fertilizer application in annual crops. High nitrogen rates in the sub-basins 1, 5 and 7 are especially due to BNF in pasture. Rarely, the pasture areas for livestock in the entire watershed receive addition of fertilizer or any other soil correction.

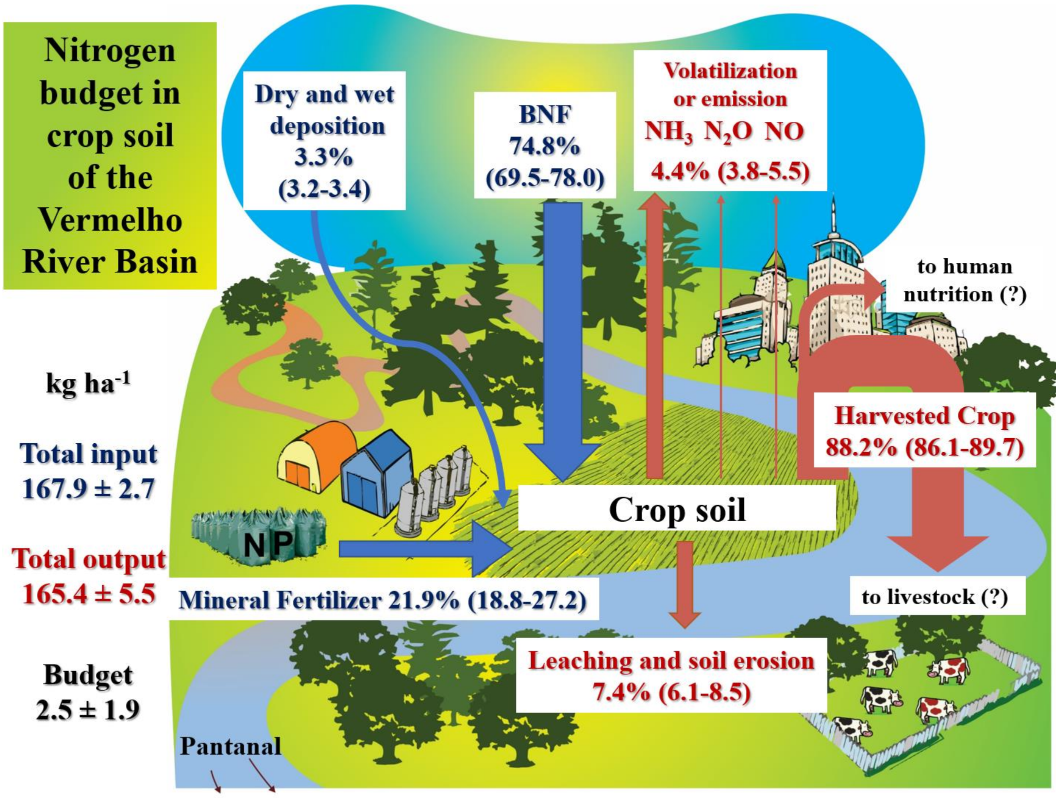


Figure 9: Magnitude of nitrogen inputs and outputs in crop soil in the Rio Vermelho watershed.

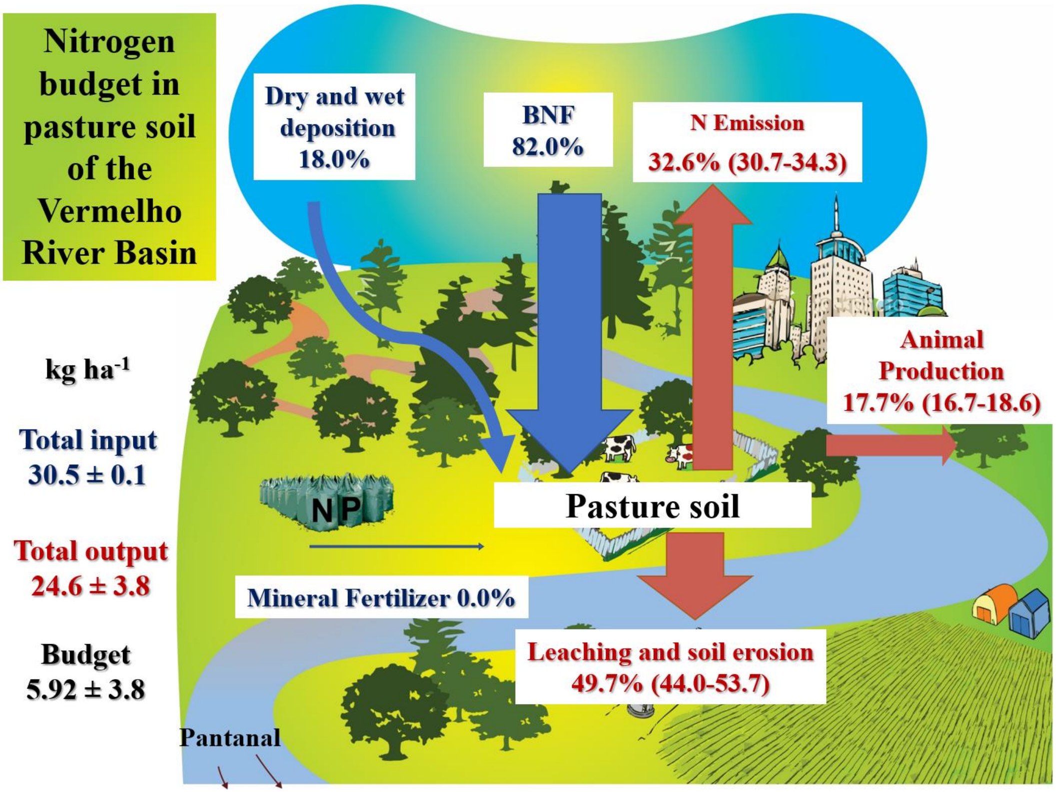


Figure 10: Magnitude of nitrogen inputs and outputs in pasture soil in the Rio Vermelho watershed.

Main drivers of increasing negative soil nitrogen balance in the eight sub-basins showed to be a combination of intensification and extensification of annual crops and livestock production. However, different mechanisms in each sub-basin seems to rule the nutrient balance. While the intensification of crop production in the Ponte de Pedra is the main force that decrease total N balance, in the Areia sub-basin (sub-basin 5), intensification of livestock production is the main drive. Intensification and extensification of these uses is supported by Mato Grosso agricultural policy and international demand for soybean, cotton, maize and meat. Brazilian agricultural policies framed conditions to increase agricultural commodities production by investment in applied agricultural research and incentives to farmers. This has been carried out through financial policies, and rural extension services to incentivize the adoption of modern technologies (Wickramasinghe et al. 2012). However, this preliminary result shows an urgent necessity to engage a more sustainable agricultural practice to control the current framework of nitrogen depletion over time.

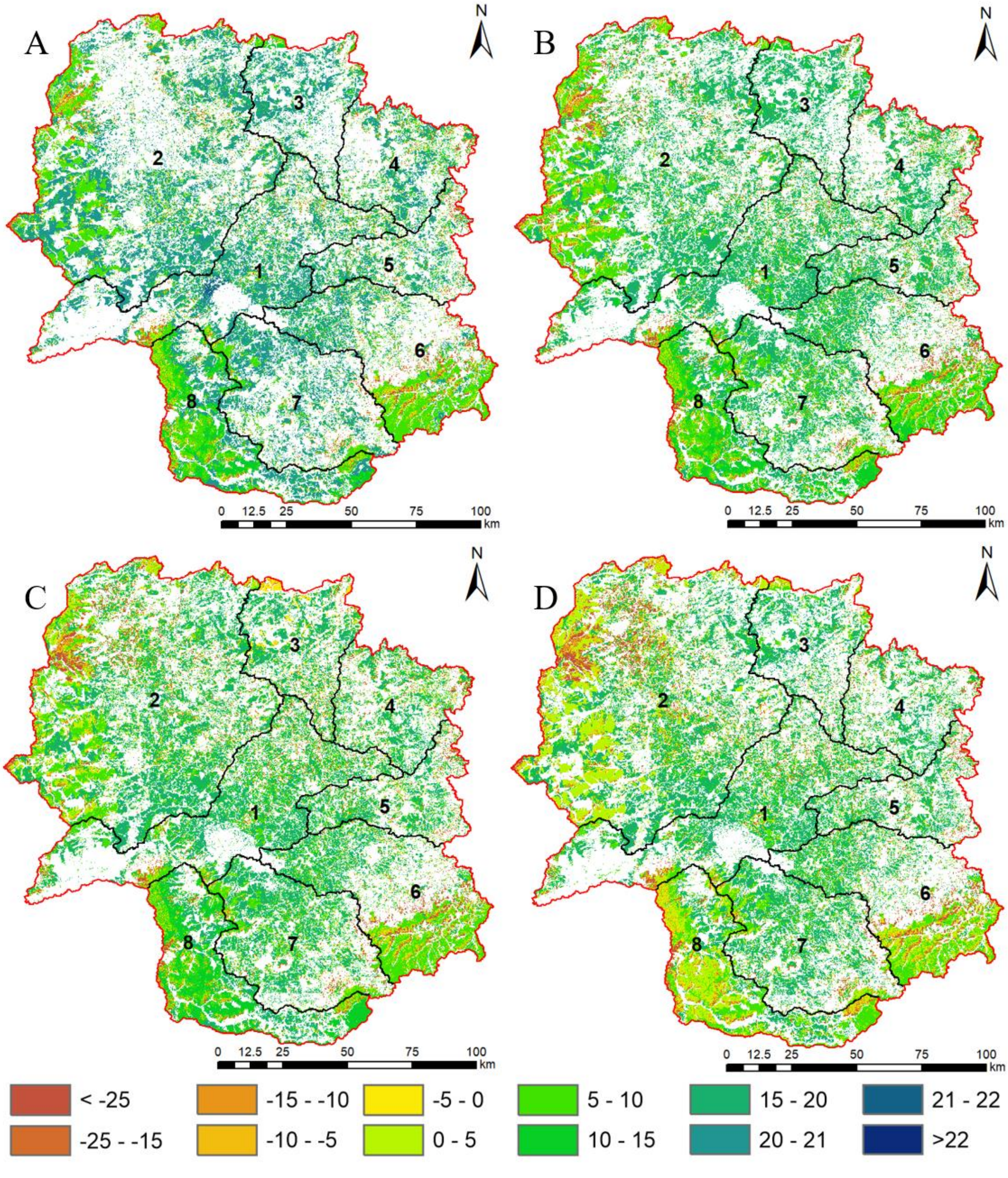


Figure 11: Spatio-temporal variation of nitrogen balance (kgN ha^{-1} yr^{-1}) in the Vermelho river watershed in the four considered years, (A) 2000, (B) 2005, (C) 2010 and (D) 2015. The numbers 1-8 represents the sub-basins described in Figure 8.

5.2.2. Phosphorus Balance

The phosphorus balance of crop and pasture soil in the Vermelho river watershed shows a makeable difference between P use in the crop and livestock production system. As observed in the nitrogen balance, a decrease of the positive balance occurred over time in all sub-basin (Table 12) changing from a framework of positive value to a more balanced system. In sub-basins with predominance of crops there is a very high surplus of phosphorus due to the high level of mineral fertilizer application (sub-basins 2, 6 and 8). On the contrary, the surplus is close to zero in regions with predominance of natural vegetation and pasture lands in the sub-basin 1, 3, 4 and 7 and negative in the sub-basin 5. The negative value of sub-basin 5 is mainly due to the livestock production that is mining P from the soil and due to the non-P fertilizer application or soil correction.

Table 12: Rates of phosphorus depletion (negative) or accumulation (positive) in the soil of the eight sub-basins of the Vermelho river watershed.

Phosphorus Balance (kgP ha^{-1} yr^{-1})				
	2000	2005	2010	2015
Sub-basin 1				
Min	-2.3	-3.0	-3.1	-3.3
Max	19.8	20.9	12.7	14.3
Average	2.0 ± 7.5	1.5 ± 7.7	0.8 ± 5.4	0.6 ± 5.7
Sub-basin 2				
Min	-2.3	-3.0	-3.1	-3.3
Max	19.2	20.8	13.0	14.3
Average	4.7 ± 9.2	6.0 ± 10.6	3.2 ± 6.9	4.0 ± 7.7
Sub-basin 3				
Min	-2.3	-3.0	-3.1	-3.3
Max	20.8	21.2	12.8	13.8
Average	3.5 ± 9.0	1.6 ± 7.9	1.1 ± 5.8	1.0 ± 6.0
Sub-basin 4				
Min	-2.3	-3.0	-3.1	-3.3
Max	20.1	21.1	12.9	14.0
Average	4.2 ± 9.3	1.5 ± 7.8	1.0 ± 5.7	0.1 ± 5.2
Sub-basin 5				
Min	-2.3	-3.0	-3.1	-3.3
Max	21.2	21.2	12.9	13.9
Average	4.4 ± 9.7	1.1 ± 7.3	0.9 ± 5.6	-0.4 ± 4.5
Sub-basin 6				
Min	-2.3	-3.0	-3.1	-3.3
Max	21.1	21.2	13.1	14.6
Average	11.1 ± 11.0	10.3 ± 11.3	6.4 ± 7.3	7.0 ± 8.1
Sub-basin 7				
Min	-2.3	-3.0	-3.1	-3.3
Max	20.6	20.9	12.9	14.4
Average	3.7 ± 9.1	4.6 ± 10.0	2.5 ± 6.6	1.7 ± 6.6
Sub-basin 8				
Min	-2.3	-3.0	-3.1	-3.3
Max	21.1	21.2	13.1	14.4
Average	12.4 ± 10.8	14.6 ± 10.2	8.4 ± 6.8	9.8 ± 7.2

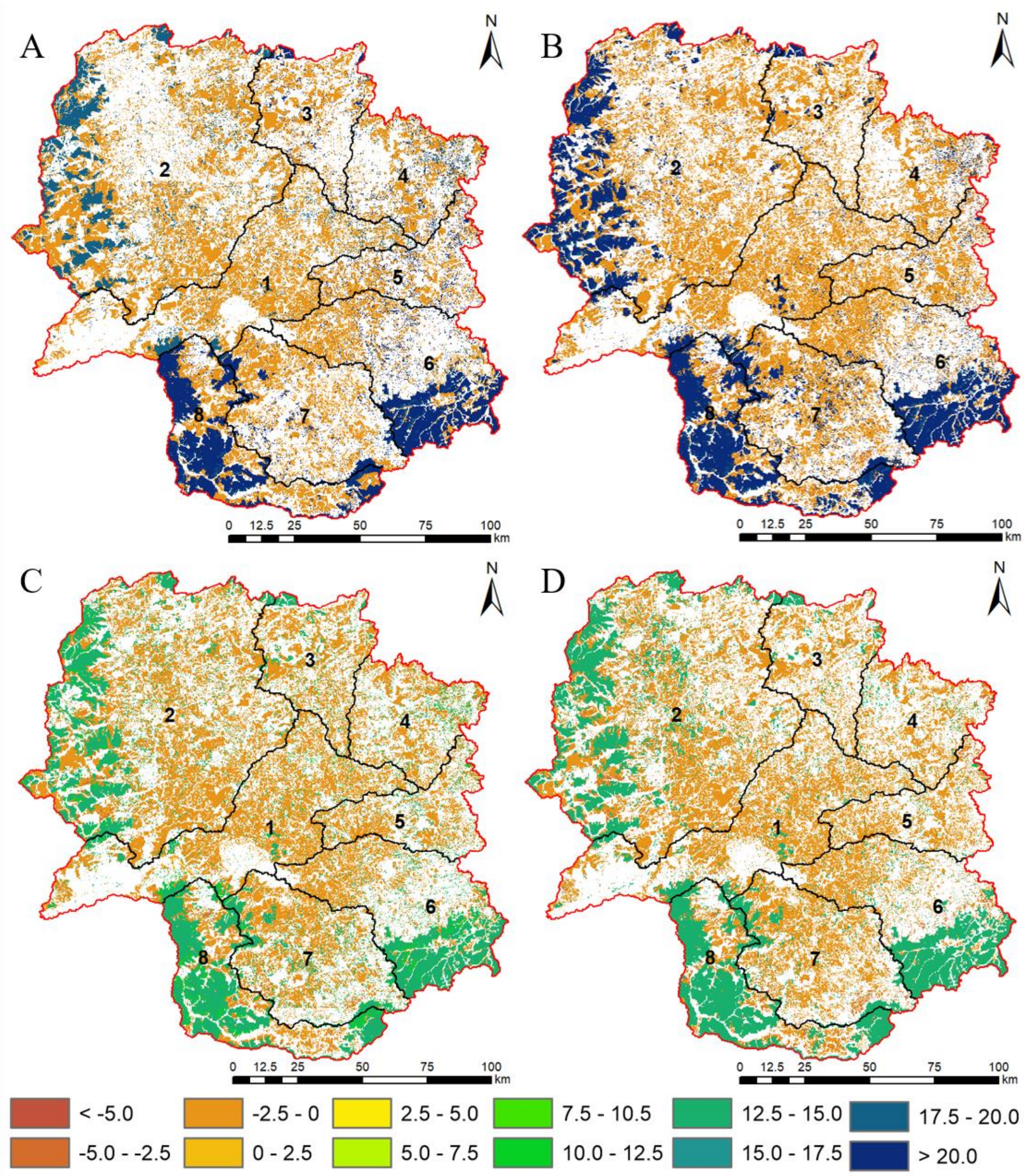


Figure 12: Spatio-temporal variation of phosphorus balance (kgP ha^{-1} yr^{-1}) in the Vermelho river watershed in the four considered years, (A) 2000, (B) 2005, (C) 2010 and (D) 2015. The numbers 1-6 represents the sub-basins described in Figure 8.

Phosphorus depletion and accumulation areas inside the watershed is restrictedly related to the difference of agricultural practice between crop and livestock production (Figure 12). Positive surplus (soil accumulation) occurs in areas of soybean and maize production with positive values of more than 20 kgP ha^{-1} yr^{-1} in 2000 and 2005 and about 13 kgP ha^{-1} yr^{-1} in 2010 and 2015. Negative values (soil mining) occurs in areas of livestock production with about -1.5 kgP ha^{-1} yr^{-1} in all four studied years.

The amount of P flowing through the crop system is about 20-fold the amount flowing in the pasture soil (Figure 13 and Figure 14). I 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 13). In the pasture soil, all the P input comes from wet and dry deposition (Figure 14). Most of the input leave the soil by animal production (87.4%) and the other part leaves by leaching and erosion process (12.6%).

The amount of P input by mineral fertilizer to crop soil is large comparable with other agricultural lands in USA and Argentina (44 kgP ha^{-1} yr^{-1}, Riskin et al. 2013b). Despite this surplus, vertical phosphorus leaching through the soil profile in these soils with high phosphorus-binding capacity is unlikely (Hansen et al. 2002). Given the inputs of P fertilizers to soybean and maize fields, we anticipate that P fertilizer use in crop fields may have to decrease in the coming future to prevent P leaching because some of that capacity would have been saturated by previous fertilizer inputs. However, the consistently high sorption capacities found in previous studies suggest that it may be difficult to saturate the P-sorption capacity of these soils and bring soil P to the ‘critical point’ where only replacement fertilizer inputs are necessary (Riskin et al. 2013a).

In the pasture soil, the negative balance suggests that the livestock production in the watershed is mining P from soil which increases the risk of soil degradation and productivity loses. A protective measure should be proposed to replace P in the soil or decrease livestock production. However, due to the surplus of nitrogen that enters the system a replace measure seen to be more appropriate action to increase NUE and livestock production.

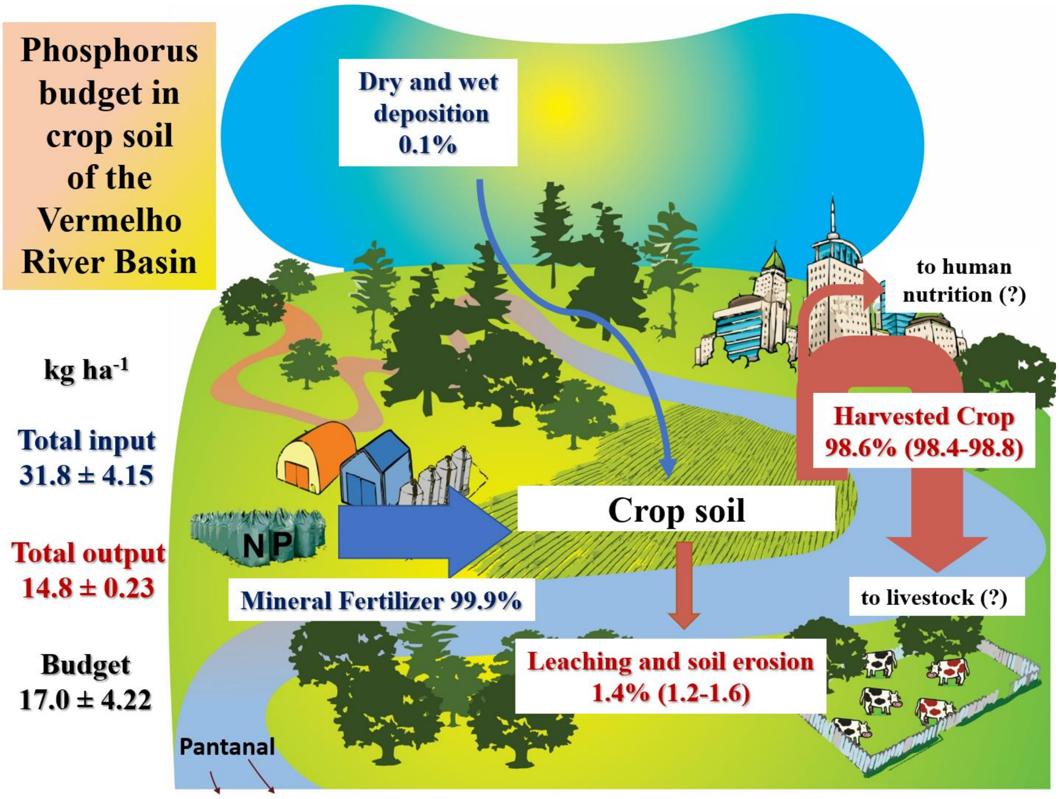


Figure 13: Magnitude of phosphorus inputs and outputs in crop soil in the Rio Vermelho watershed.

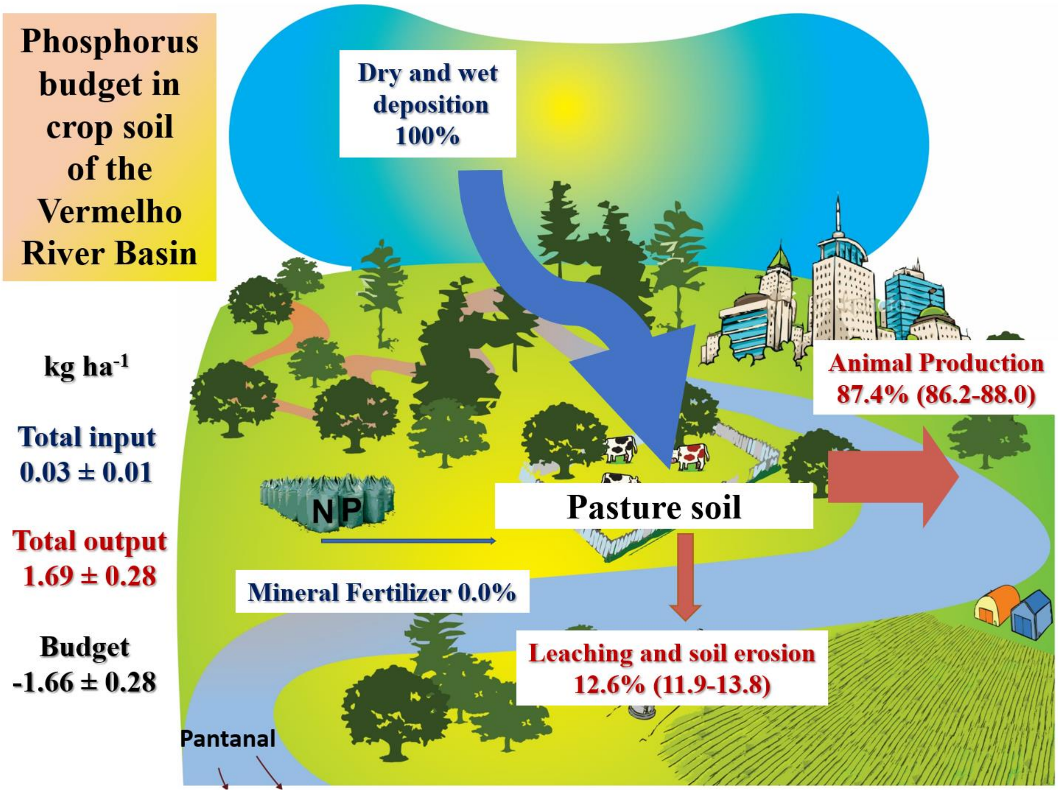


Figure 14: Magnitude of phosphorus inputs and outputs in pasture soil in the Rio Vermelho watershed.

5.3. Water quality longitudinal profile of Vermelho river

The first work on the evaluation of water quality and related factors on the Vermelho River was carried out by Souza (1995) in order to understand the main pollutants of the river within the urban perimeter of Rondonópolis. Later, Loverde-Oliveira et al. (1999), in order to analyze the water quality and the ecological aspects of the Arareau Stream, the main affluent of the Vermelho River, found that changes in the limnological variables are linked to the inadequate soil management. Sette et al. (2002), studied seasonality in the water quality of the river and showed that the episodes of heavy rains provoke an increase in the values of agricultural inputs mainly from the upper parts of the basin. Dotto (2009) indicated that the main changes in the physico-chemical parameters of the waters of the Tadarimana Basin are due to the inputs from agricultural production. Loverde-Oliveira and Silva (2010) showed that the Vermelho River is characterized by being a turbid system with high values of total phosphorus, above the limit established for Class II rivers (stablished by CONAMA resolution 357, Table 1). The Vermelho River is classified as oligotrophic whose nutrient values are limiting factors to the growth and development of planktonic and macroinvertebrate organisms. However, Lima et al. (2015) showed that changes in water quality parameters are related to releases of domestic, industrial effluents, agricultural outflow and transport of sediments by diffuse pollution, generated mainly in agricultural activities that were presented as determining factors of the water quality of the Vermelho River.

The variation of limnological parameters of Vermelho River and its relationship with Land Use and Land Cover were described by Vasco et al. (2011), where they verified that the values of the biochemical oxygen demand and the chemical oxygen demand indicate a greater contribution of organic matter in the urban area due to the lack of basic sanitation, and the higher concentrations of the nutrients (nitrogen and phosphorus) with in the regions close to agricultural activities.

Considering the importance of taking continuous measurements to determine the water quality supplying the Pantanal, there are historical series of water analyzes of the Vermelho River from 2004 to 2014 provided by the National Water Agency (ANA) and Secretary of Mato Grosso State for the Environmental (SEMA-MT) available on the website: www.sema.mt.gov.br/index.php?option=com_docman&Itemid=82. The mean values of the historical series data for total nitrogen and total phosphorus were 0.77 mg L^{-1} for nitrogen and 0.20 mg L^{-1} for phosphorus (Figure 15).

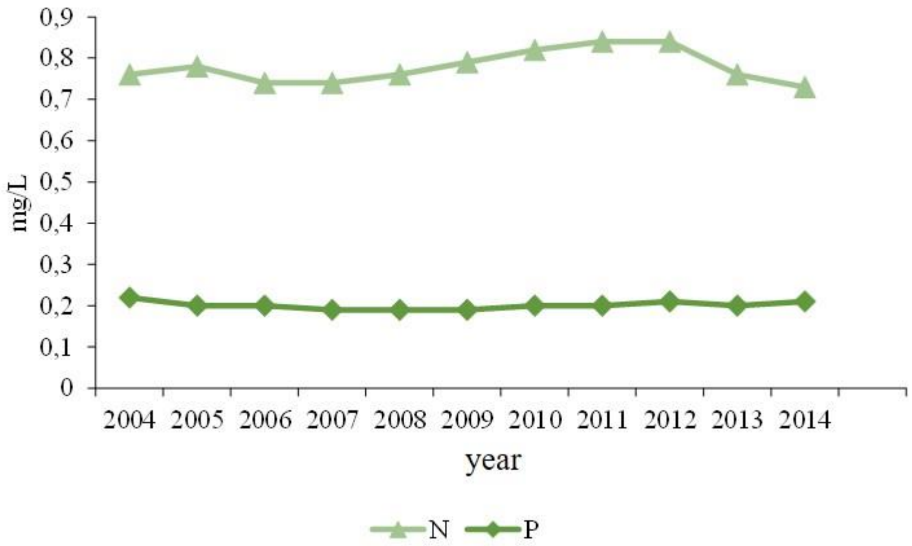


Figure 15: Annual average in mg L^{-1} of total phosphorus (P) and total nitrogen (N) in the Vermelho River inside the municipality of Rondonópolis.

Souza (2015) carried out a water sampling program to analyze the limnological variables in the Vermelho River between 2014 and 2015. The author selected five points of water collection along the entire length of the river. The sampling station 1 is upstream of the Rondonópolis urban area, and sampling station 5 is downstream near the mouth. The others are located between these two sampling stations in the main stream. The results showed that the values for total phosphorus were above the limit established by the regulatory body with a value of 0.19 mg L^{-1} and for total nitrogen of 0.81 mg L^{-1} (Figure 16).

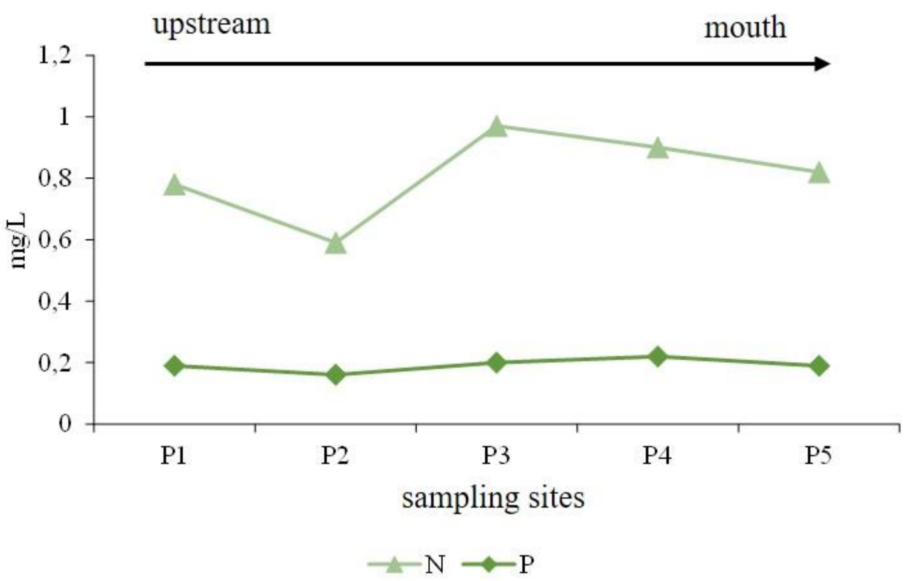


Figure 16: Annual mean concentration of phosphorus (P) and nitrogen (N) for each sampling station in the Vermelho River.

The results in the Vermelho river show that the values of total N and P of the historical series are very close throughout the years without much remarkable change. This suggests that current human activities is not changing these values in the main river in the considered years, but this framework may not be true for small rivers and stream (Dotto 2009). Souza (2015) also states that the high concentrations of dissolved phosphorus indicate an ongoing process of eutrophication in this system due to anthropic activities, such as the dumping of industrial waste and fertilizers from agricultural practices. According to Araújo (2012), phosphorus is essential to the growth of water organisms, especially algae because it is a nutrient that limits their productivity, however, high concentrations of dissolved phosphorus in water can promote algal blooms (Piveli and Kato 2005). The sites with increased nitrogen and phosphorus may have the use of soil mainly for cattle pasture, and since there is no control of the animal manure disposal they can follow to the channel of adjacent streams where cause degradation of the water bodies (García-García et al. 2012). This fact may, in part, explain the high concentration of total phosphorus that was found in this basin, confirming studies of Araújo (2012) in the Cuiabá and São Lourenço river basins, where the concentrations of total phosphorus were above the limits establish by CONAMA 357/2005 for Class II rivers, mainly due to the accumulation of organic matter.

The lack of policies controlling chemical use to improve agricultural production may represent a threat to water resources and service provision. This framework of mismanagement is already contribution to the increasing of suspended solids, inorganic and organic micropollutants, nitrogen and phosphate loading to many agricultural areas in Brazil (Oliveira Filho et al. 2012). In the Vermelho River basin there is evidences of such impact due to the large cultivation of monocultures and pasture areas with large influences to the water quality in protected areas in the Ponte de Pedra sub-basin. Nitrate and potassium are associated with the rural nucleus, where a cluster of temporary crop farmers use fertilizers as inputs (Moura et al. 2010). Although there is no evidence of changes in biodiversity and ecosystem service provision along the main river and downstream of Vermelho river watershed, the nutrient load from human activities may became a serious problem in the coming future.

5.4. Nutrient Use Efficiency

We propose an easy-to-use NUE indicator (see section 4.8), applicable to all agricultural systems. The concept for NUE used here is based on the partial nutrient balance (PNB) principle using nutrient input and output data for its calculation: NUE = output / input.

We will report NUE values as a mass fraction (kg per kg), and nutrient input, output and surplus will be reported in kg ha^{-1} yr^{-1} as suggested to nitrogen use efficiency studies by the EU Nitrogen Expert Panel (Oenema et al. 2015).

The NUE results for N (NUE_N) will be present in a two-dimensional graphic showing the nutrient output (x) and input (y). In addition, for crop systems, reference lines for upper and minimum limit target value represent desirable good management. These reference lines area thresholds of four distinct zones for NUE_N: a zone with low NUE_N values, a zone with a ‘desired’ range of NUE_N values, a zone with high NUE_N values, and a zone inside the desirable NUE_N range but with low production per hectare (Figure 17).

The target values in this study was considered mainly for crop production system that represent the main agricultural practice in the watershed. In other regions where livestock or crop-livestock production system is priority, target and reference values must be adjusted.

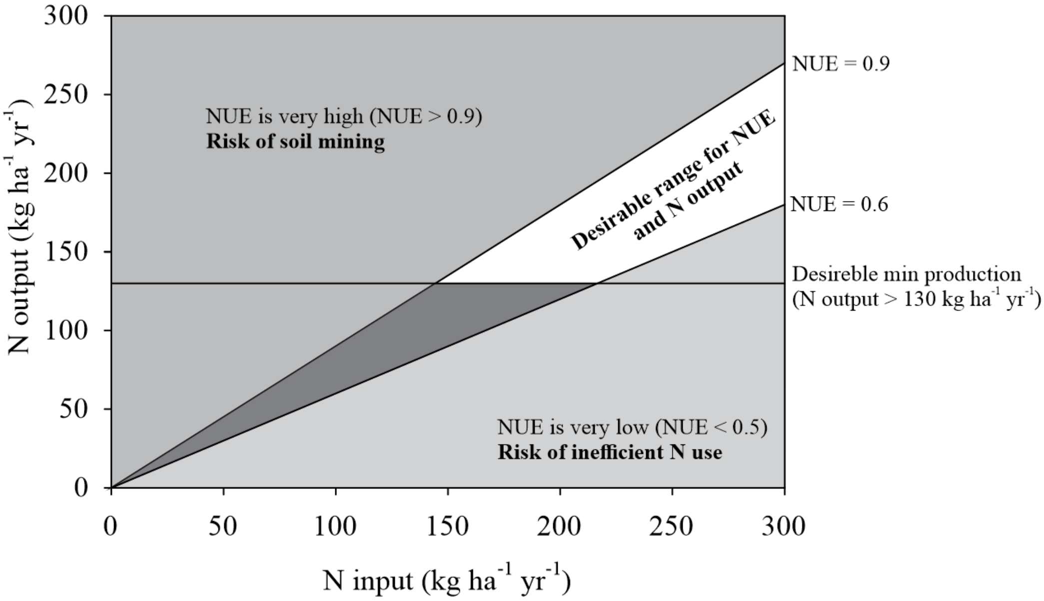


Figure 17: Concept of the nutrient use efficiency indicator for nitrogen (NUE_N) in a two-dimensional N input – N output graphic. The panel shows three ranges of possible NUE_N values, based on possible reference values for NUE_N for crop system (0.6 and

0.9, Oenema et al. 2015). The horizontal line is the desirable minimum production based on the average N output from soybean-maize rotation system in Brazil from 1988-2016.

The target values for NUE will depend on the type of agricultural system and environmental condition. The reference values for the lower desirable NUE limit were proposed based on the averages of NUE for maize crops in Brazil (0.6, Norton et al. 2015), and the minimum desirable value for production was proposed considering the average o N output from the soybean-maize rotation system in Brazil from 1988-2016 (130 kg ha^{-1} yr^{-1}). We considered the maize crop as reference for lower limit because it has the lower average value for NUE among the main crops observed in the watershed (soybean-maize). At the other extreme, when NUE > 0.9, it is likely that efficiency cannot be improved further without risking mining of soil nutrients (Norton et al. 2015, Oenema et al. 2015).

The relationship between N input and output in the agricultural systems of Vermelho river watershed for the years 2000, 2005, 2010 and 2015 is shown in Table 13 and Figure 18. The values of NUE_N in the crop system varied from 0.90 and 0.92 in the considered years. The animal production in the pasture system is less efficient than cropping system in the region and the livestock productivity is very low. However, NUE in pasture system showed to be improved in the last fifteen years changing from the lower value from 0.13 in 2000 to 0.20 in 2015.

The P input, output and NUE for P (NUE_p) is presented in Table 13. The NUE_p in the crop systems ranged from 0.41 to 0.53 in the studied years. The low value of NUE_p in the crop system in Mato Grosso State was already observed by other studies that shows a surplus of P in the region over the past 15 years (Riskin et al. 2013b, Riskin et al. 2013a). This surplus is due to the P inputs to both corn and soybeans to achieve high yields on local farms. Despite this surplus, the high P-sorption capacity of the soil in

Mato Grosso State reduces the P uptake to the root and the risk of leaching of this P surplus (Hansen et al. 2002). In addition to the high P-sorption capacity, the landscape is flat in much of the region; soil infiltration is rapid; and overland flow is minimal, even during intense storms, which reduces the risk of particulate phosphorus loss through water erosion (Hayhoe et al. 2011).

In the pasture system, the values of NUE_p was not calculated because no input of P occurs by fertilizer application. Therefore, the P output from animal production is depleting P stock in the soil, which is 'unsustainable' in the long-term.

Table 13: NUE of agricultural system production by year. Data are derived from N and P balance.

		Years	2000	2005	2010	2015
Nitrogen	Crop	N input (kg ha^{-1})	158.6	164.0	158.3	158.7
		N output (kg ha^{-1})	145.2	150.6	144.6	143.0
		Surplus (kg ha^{-1})	13.4	13.5	13.7	15.7
		NUE (kg ha^{-1})	0.92	0.92	0.91	0.90
	Pasture	N input (kg ha^{-1})	25.0	25.0	25.0	25.0
		N output (kg ha^{-1})	3.3	4.5	4.8	4.9
		Surplus (kg ha^{-1})	21.7	20.5	20.2	20.1
		NUE (kg ha^{-1})	0.13	0.18	0.19	0.20
Phosphorus	Crop	P input (kg ha^{-1})	34.8	35.8	27.5	29.0
		P output (kg ha^{-1})	14.3	14.8	14.6	14.8
		Surplus (kg ha^{-1})	20.5	21.1	12.9	14.2
		NUE (kg ha^{-1})	0.41	0.41	0.53	0.51
	Pasture	P input (kg ha^{-1})	-	-	-	-
		P output (kg ha^{-1})	1.1	1.5	1.6	1.7
		Surplus (kg ha^{-1})	-1.1	-1.5	-1.6	-1.7
		NUE (kg ha^{-1})	-	-	-	-

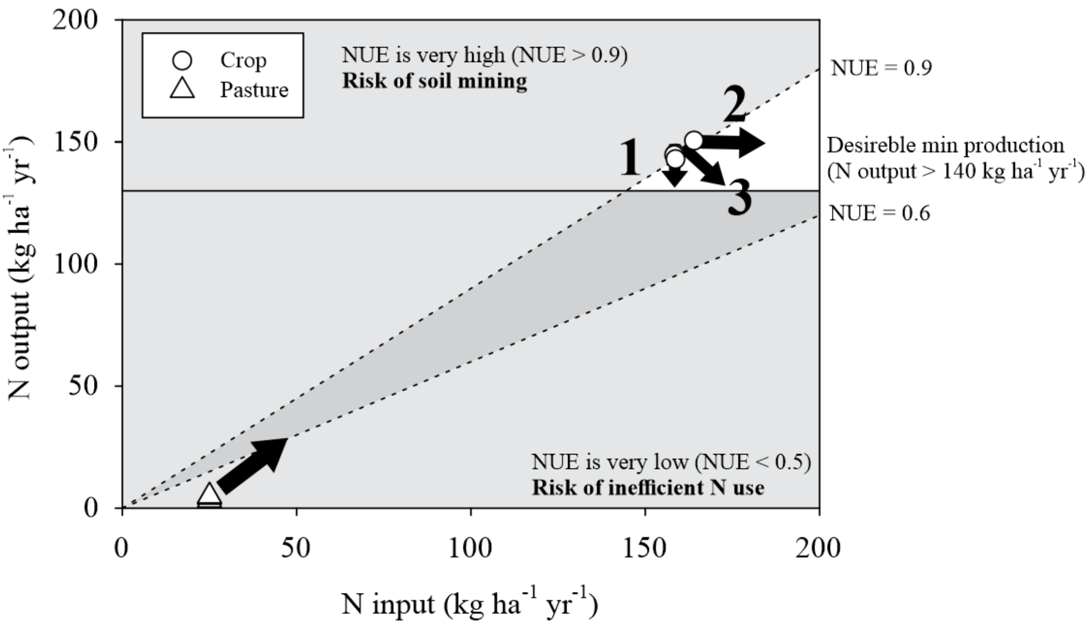


Figure 18: Two-dimensional graphic showing nutrient use efficiency (NUE) for nitrogen (N) of crop and pasture system in the Vermelho river watershed for the considered years (2000, 2005, 2010, 2015). The arrows indicate options to improve NUE in the studied watershed (see text).

The values of NUE_N 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, there is three options that should be applied: 1) decrease output by decreasing the number of individuals per hectare; 2) apply more N-fertilizer to increase input; and 3) a mix of the measures 1 and 2 (Figure 18). In the pasture system, the production is very low with an inefficient nitrogen use. We do not propose the desirable limits for pasture, however, an intensification of livestock production seen to be an option to improve production of pasture land. However, the P deficit already existing in the pasture system (Table 13) should be addressed to support this intensification and avoid soil degradation. If an intensification is not an option for pasture lands, measures to mapping trade-offs in reforestation should be encourage to propose restoration projects to decrease risk of sediment and soil nitrogen loss (Barnett et al. 2016) and increase the capacity of ecosystem service provision.

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

The use of nutrient in agriculture is inevitable to increase production. The damage cost analysis of this use to different sectors can be useful to evaluate if the yield is offset by costs of the emission impact. Aggregating the marginal costs of the nutrient damage (in this case we considered N only, see section 4.9) for the Vermelho river watershed gives an annual cost of about 39 million dollars per year (Table 14). The highest unit and total cost is associated with loss of NH_3 to the air (98% of the total cost). The estimates show wide variations between N compounds and contain uncertainties associated with methods as also noted for EU (van Grinsven 2013) and mentioned in the section 4.9.

Table 14: Nr emissions and associated damage costs in the Vermelho river watershed.

	Emission	Health	Ecosystem	Climate	Total
	Gg (10^6kg yr^{-1})		millions $ yr-1		
N_2O-N to air	0.03	0.01	-	0.36	0.4
NOx-N to air	0.01	0.12	0.04	-0.02	0.1
NH_3-N to air	2.92	16.40	23.41	-1.37	38.4
Nr to water	4.91	0.0	0.0	-	0.0

The first estimates of the direct benefit of N-fertilization was obtained using the response curve and the market price of maize, which is the major crop that uses N for production gain. The benefit of the N-input in agricultural system was estimate in about 36 million dollars per years (Figure 19). This value represents an addition of about 50% to the farmer profit. Minor benefits are observed in Nr influences in climate and reflects the balance between N_2O greenhouse gas and the cooling effect of NH_3 and NOx.

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. Increasing nitrogen use efficiency would reduce N-surpluses and hence all Nr emissions. Attention is needed to future estimates since no damage costs was assigned to Nr emission to the water system. We assumed no damage cost because there is no evidence that the emissions from agricultural systems is affecting aquatic system biodiversity and system service provision. The Vermelho river is currently not showing sign of eutrophication due to agricultural export and the concentration of nitrogen in the water does not exceed values that endanger human health (thresholds were not exceeded). We highlight the lack of more specific data for the study area, then, we strongly recommend caution in the interpretations of these results, and we strongly recommend new studies to refine these estimates in the near future. In addition, we underscore the importance of policies stimulating Good Agricultural Practices (Best Management Practices), and especially those that reduce the significant Nr losses.

Another important issue is the difficulty of considering the cost and benefits of phosphorus use in the agro-system. Due to the soybean productivity in the Vermelho river watershed, the phosphorus fertilization in the crop soil seems to be more important to the crop yield and to the consequent impact of nutrient use than the nitrogen fertilization. Thus far, there is no scientific source that evaluated costs and benefits of P fertilization in Brazil or other regions that can support a feasible evaluation for the Vermelho river watershed.

The findings of the analysis provide the first attempt to evaluate cost and benefits of nutrient use in the Pantanal and these results can provide a strong support for future initiatives to establish emission and concentration targets for nutrient use. As highlighted by van Grinsven et al. (2013), we recognize considerable uncertainties and conceptual challenges in such a monetized valuation of classically noncommensurable issues.

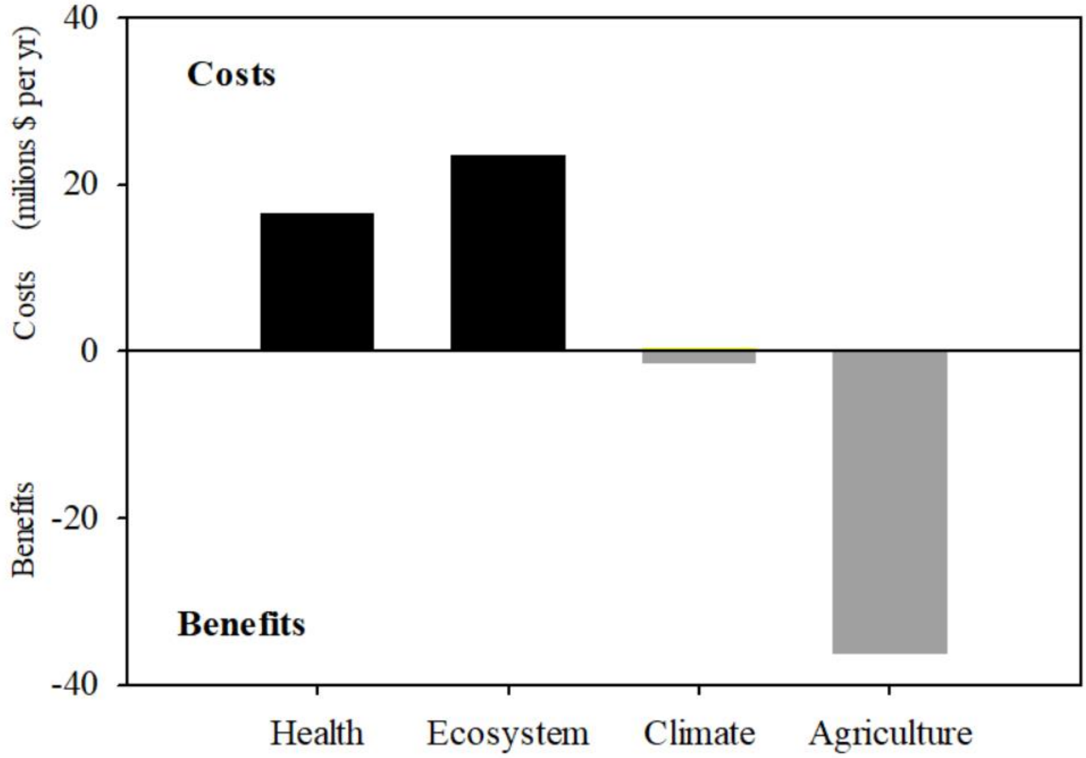


Figure 19: Cost and benefit of nitrogen (N) use in the agriculture sector in the Vermelho river watershed. Negative values mean social benefits of N application and negative values mean costs to human health and ecosystem stability.

5.6. Stakeholder engagement

Efforts towards cross-sector collaboration and stakeholder dialogues is necessary to improve NUE and implement better management practices. Therefore, in this project, the contact with stakeholders in the Rondonópolis region was an important measure to understand agricultural practices, current challenges, and barriers to change at local scale. In the first step, we mapped stakeholders to understand who they are, and through a collaborative process of research, debate, and discussion with local (UFMT, MT Foundation) and regional (IPNI, INPE and EMBRAPA) institutions, we listed and analyzed key stakeholders in multiple sectors (large and small farmers, researcher, institutes etc).

As local initiative, a public meeting was organized by UFMT researchers in order to broaden the dialogue with stakeholders. The meeting was conducted with the purpose of introducing the project objectives and methodology, expand local connection, and gather information about others possible stakeholders (Figure 20A). We invited, professors and students of UFMT, producers/farmers of Rondonópolis, companies and industries focused on agribusiness.

The engagement of the researchers from the UFMT was an important contribution to improving the dialogues with local stakeholders and, also, in obtaining information about local practices. The team from the department of Exact and Natural Sciences of the UFMT coordinated by Dr. Simone Loverde supported the project to improve the understanding about nutrient in the water bodies and the relationship between agricultural system, wastewater and water quality in the Vermelho river. The team from the department of Soil and Rural Engineer coordinated by Dr. Edicarlos Damacena de Souza and Dr. Francine Damian da Silva contributed with the understanding of the fertilizer application practices and crop rotation in agricultural systems, and in obtaining data of nutrient use (Figure 20B).

Figure 20: Public meeting at the Federal University of Mato Grosso for local stakeholders identified in the Nutrient Management Assessment Project in the municipality of Rondonópolis. Photo: Felipe Pacheco, associate researcher at the National Research Institute, UFMT teachers, students and local farmers.

We also have an agreement with the Mato Grosso Foundation (FMT, Figure 21) that contributed by providing information on the nutrients use and practices in the Vermelho river watershed. The FMT is a private research company that works with local farmers since 1993 supporting the increase of productivity and profitability in the region, coupled with the correct agronomic practices of soil use and conservation, with sustainable management of pests and diseases.

Figure 21: Meeting to present the project to the Mato Grosso Foundation.

The engagement of stakeholders as local farmers was, also, important to understand and discuss small details in the production system. In order to understand the nutrient use practice in the Vermelho watershed, a team composed by researchers from INPE and UFMT made some surveys at local farms to have a general view of the crop system in two sub-basins. In the Ponte de Pedra sub-basin, we visited a medium-sized farm that produce soybeans and maize. At this survey, the collaboration of the farmer was important to understand the production and fertilization methods used by a typical farm inside the watershed (Figure 22A). The period of the visit coincided with the beginning of the soybean plantation, according to the administrator. Therefore, the visit to the crop area, was also important to understand the logistics related to the production system, machines typically used, and other practices as nutrient mixing, soil preparation and planting procedures (Figure 22B-C).

We also visited others farms with different production system and rotation: small farms; farms with rotation of soybean and cotton; livestock farms; and also farms with rotation of soybeans and livestock (an increasing practice in the Mato Grosso state). The engagement of stakeholders leading with different production system contributed to understand all practices in the watershed. Understanding all practices will support future actions, because, the implementation of a project or program to propose improvements in the NUE needs to be specifically tailored to the unique context and situation of each production system.

Figure 22: Survey at a typical soybean and maize farm (Guarita Farm). (A) Meeting with Mr. Joel Strobel, owner of Guarita farm located in the Ponte de Pedra sub-basin, (B) visiting to the soybean crop; (C) mixture of fertilizers and preparation of the soil for planting; (D) soybean plantation for the 2018 harvest.

6. Simplification and Limitation of the proposed method

The proposed method to calculate nutrient balance and to evaluate cost and benefits of nutrient use has simplifications and limitations that must be considered. Many of these simplifications and limitations were mentioned throughout the text and were summarized and reported below:

- Some components of the nutrient balance were calculated using values considered for the entire Brazilian Cerrado due to the lack of local information or experiments (see Table 3).
- Nutrient transport by erosion was calculated using average concentrations in the different soil types in the watershed. Local farmers reported that in some regions there is a large range of concentrations in a high spatial resolution and with similar soil type.
- Soil erosion data are not direct measure but from simulated results by model. Then, it can under- or over-estimate soil loss.
- The spatialization of the balance components was considered to be uniform inside each watershed, although it considered LULC characteristics. For example, we considered livestock production uniformly distributed on pasture land. This assumption did not consider the existence of specific areas for animal production or unused pasture lands. The nutrient balance at a farm scale can be under- or over-estimated with this assumption.
- Most of the marginal cost of nutrient use (unit cost) were averages of the values presented in van Grinsven et al. (2013) for the European Union, converted into dollars and transferred to Brazil by using the correlation between unit damage cost and GDP (PPP) of European countries (Sutton, 2015). Adaptations to local

reality were performed whenever possible (e.g. impact to health and ecosystem, benefits on the crop yield).

- The uncertainty of data for each sector of the CBA was not considered in the results. We strongly recommend an uncertainty analyses in future works.
- A broader analysis of the target values for the desirable range of NUE must be made at local characteristics to propose the best alternatives to improve NUE in the watershed with minimum impact on ecosystem services and regional profits.

7. Final Remarks

Given the scale of the nutrient challenge, improving NUE worldwide has become a target of considerable interest as it has indirect benefits for health, environment, and the supply of food and energy (Sutton et al. 2013a). This report is the first study dealing with NUE for both nitrogen and phosphorus in a watershed scale in the Pantanal region. Furthermore, although this method was used at a local scale, it can be widely applied in other regions using multiple scales (state, country and continent), depending on availability of data and experimental results. The developed approach showed to be a useful tool to the valuation of the agricultural practices in the region and also to evaluate cost and benefits of nutrient use to human health, biodiversity and climate. Policy makers can use this tool as a guide for the construction of public policies to increase the NUE at all scales. The increase of NUE of agricultural practices can promote well-being for all by ensuring availability of clean water, protecting natural ecosystem and service provision, and promoting responsible consumption of fertilizers and production. All these benefits can be achieved under the implementation of strengthen relationship between the local stakeholders that was already stablished during the development of this study. Besides the development of a tool to evaluate NUE in the region, the network of stakeholders and institutions may contribute in addressing all these relevant mentioned SDG targets (well-being, clean water, life below water and on land and responsible consumption).

During the development process, the engagement of multi-sector stakeholders (farmers, university, private sector and police makers) was crucial to propose an easy-to-use method, and also to identify limitations as data availability, applicability and functionality of the method. The active relationship with stakeholders, mainly with the Federal University of Mato Grosso and the Mato Grosso Foundation, allowed the understanding of agricultural practices, current challenges, and to identify barriers at local scale. Therefore, to make this methodological approach feasible and to increase reliability for another region, a participative application must be considered. If the engagement with is limited or not possible, published data in reports and papers may be considered as an alternative way to understand practices and nutrient uses at local and regional scale.

At local scale, agriculture has mined soil nitrogen, putting long term soil sustainability at risk. Furthermore, the nitrogen balance in crop soil shows an increase of nitrogen output since 2000 not only due to the increase of production but also gaseous and erosion loses. In the pasture soil, the observed nitrogen surplus is due to the BNF input and the low livestock production. Although there is no fertilizer use in pasture soil in the region, the current input of nitrogen may support the livestock intensification. If livestock production intensification is not a local alternative, restoration project should be encouraged to prevent risk of sediment and soil nitrogen loss and increase ecosystem service provision.

The phosphorus balance in crop soil was positive (input > output) in all studied years. The positive values are due to the high input of mineral fertilization to maintain high yields of both soybean and maize or cotton production. However, the high soil P-binding capacity offsets the high P input and decreases the risk of P leaching. In the pasture soil, the balance is negative due to animal production and no mineral fertilizer addition. Then, P fertilization must be considered to assure sustainability of current production or in an intensification scenario.

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 and optimizing the use of external resources. The benefits of the methodological approach to the study region and a strategy of actions and interactions between institutions is presented in the Figure 23 as an effort to make this method a tool for local stakeholders. We believe that the implementation of such initiative will bring positive results to all stakeholders mainly small farmers and settlements. The UFMT can be the main contact to the developer institutions and send feedbacks to improve the methodology. Likewise, the university can have benefits by using this approach as theme for training people and transfer the technology to the prefecture and other stakeholders. Three others important stakeholders were identified in the region that can be indirect contacts to farmers providing feedbacks to improve methods and local practices. IPNI produces many documents and tools and could implement the methodological approach to farms through reports and presentations. Also, the method can be incorporated to the app already developed by IPNI. The Municipal Secretary of Agriculture and Livestock can work as bridge to small farms providing information about best practice, best management practices and implement the tool to evaluate these practices. Finally, the Mato Grosso Foundation, a private company that support agribusiness and research, could be the bridge to large farms and also use the method to evaluate these practices.

The solidification of all these connections may increase local population well-being by increasing production and opportunities in all agribusiness sectors. Also, giving opportunity and access to information to small local farmers.

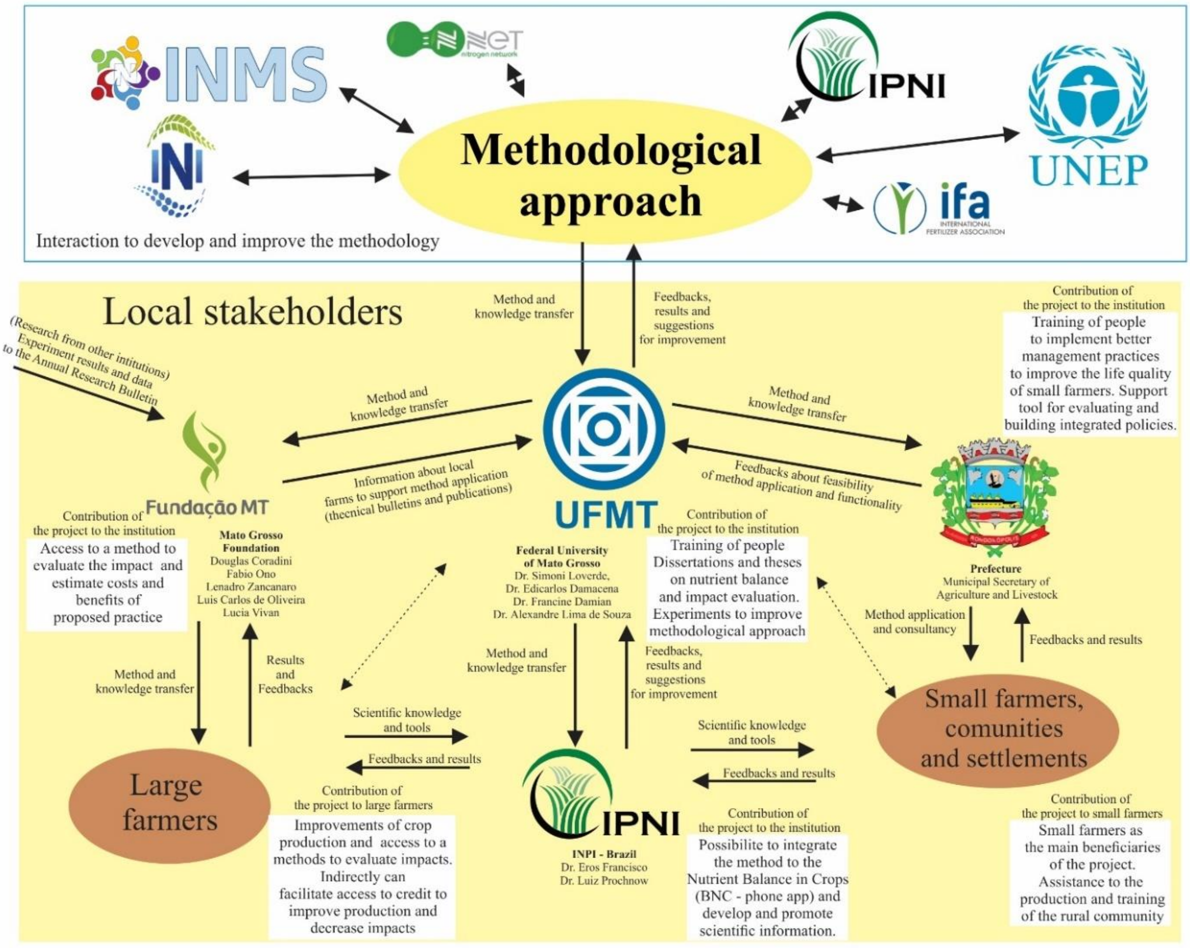


Figure 23: Schematic design of the benefits of the methodological approach development to the study region and a strategy of actions and interactions between institutions.

The CBA analysis represents a first outlook of nutrients impacts to Vermelho river watershed. In Vermelho river watershed major impacts were related with airborne emission of NH3 and NOx, affecting both human health and ecosystems, highlighting the concern that must be given about agricultural practices. Since eutrophication caused by excess nutrient inputs is not a current problem in the study area, there were no costs associated with this, unlike what has been observed for ecosystems in Europe where high costs have been associated. However, we recall the importance of the Pantanal ecosystems, to which ecosystem services have high monetary values attributed. Thus, is relevant that losses of nutrients are monitored and also estimated through environmental modeling, considering land-use changes in the future, and we suggest this could be subject of further studies. Environmental modeling can serve as a basis for discussion and decision-making in formulating laws that benefit the environment in a variety of ways, not only in relation to agricultural productivity, but also quality and environmental protection.

The absence of more accurate local information 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. We believe it will serve as a starting point for deepening and improving the method for application in different regions, allowing comparisons in order to obtaining a global picture of the nutrient management situation.

The methodological approach developed in this study will be constantly updated to improve the applicability in other regions. The development group will continue to work in partnership with the International Nitrogen Management System project to also incorporate other groups around the world which have been developing methods to evaluate nutrient emission in many types of agricultural system and environment. Under the scope of the INMS this method can be carefully tested and adjusted to the special needs of other projects and regions. Finally, the developing group will also propose a solidification of the research group in partnership with the UFMT, FMT and IPNI (local stakeholders) to produce scientific results to improve the capability of the methodological approach to evaluate nutrient practice and investigate options for improvement of NUE at local, regional and national level with a view to reduce negative impacts of nutrient use on the ecosystems.

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