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NUTRIENT SELF-SUFFICIENCY IN AGRICULTURE ON LA REUNION

Analysis of the balance between crop needs and availability of residual fertilizing materials by commune

Corentin Kerdode
Master in Agroecology

Norwegian University of Life Sciences

Isara
23 rue Jean Baldassini
69364 LYON CEDEX 07
TEL.: 02.41.23.55.55

CIRAD, unité SELMET
7 Chemin de l'Irat
97410 Ligne Paradis

Internship supervisor: Jonathan Vayssieres et Manon Alvanitakis

Co-supervisors: Rémi Conrozier et Antoine Versini

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Master thesis

Promotion 121

KERDODE Corentin

Engineer student ESA-NMBU-ISARA
Corresponding teacher: Rim Baccar (ESA) and Charles Francis (NMBU)

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Nutrient self-sufficiency in agriculture on La Réunion.

Keywords: Territorial ecology, nutrients, balances, circular economy.

OUTLINE	The Reunionese context and local MAFOR management are presented, along with a detailed description of the utilized balance method. The results are illustrated through maps and examples of communes, followed by a discussion on the study's limitations and prospects.
OBJECTIVES OF THE STUDY	The objective of this study is to determine if a reduction in synthetic fertilizer imports is feasible while avoiding pollution risks at the communal level. Additionally, it aims to provide insights for the development of future MAFOR valorization platforms by aligning these resources with crop needs.
METHODS	The methodology relies on balances of nutrients under their mineral form at both the island and commune levels, involving a judicious selection of information sources and expert interviews. We have made assumptions about the transportability of each type of MAFOR, which are integrated into the results.
RESULTS	The results highlight a coverage of 39% in Neq, 63% in Peq, and 48% in Keq, with one commune having non-transportable surplus. 900t of Neq could no be imported in La Reunion
CONCLUSIONS	In conclusion, despite identified methodological limitations, this study serves as an initial assessment of MAFOR reserves and requirements on the island. It demonstrates the possibility of reducing nutrient imports, providing valuable insights for stakeholders in achieving better territorial MAFOR management.

NOTICE BIBLIOGRAPHIQUE

AUTEUR(S) : CORENTIN KERDODE
Promotion : 121
ORGALEG

Mots-clés : Ecologie territorial, nutriments, bilans, économie circulaire.

PLAN INDICATIF	Le contexte réunionnais et la gestion des MAFORs locale sont présentés, avec une description détaillée de la méthode du bilan utilisée. Les résultats sont présentés à travers des cartes et des exemples de communes, suivis d'une discussion sur les limites et les perspectives de l'étude.
BUTS DEL'ETUDE	L'objectif de cette étude est de déterminer si une réduction des importations d'engrais de synthèse est possible tout en évitant les risques de pollution au niveau communal. De plus, elle vise à fournir des informations pour la mise en place de futures plateformes de valorisation des MAFORs, en alignant ces ressources avec les besoins des cultures.
METHODES & TECHNIQUES	La méthodologie repose sur des bilans de nutriments sous leur forme minérale à l'échelle de l'île et des communes, avec une sélection judicieuse des sources d'information et des entretiens avec des experts. Nous avons émis des hypothèses sur la transportabilités de chaque type de MAFOR qui sont intégré les résultats.
RESULTATS	Les résultats mettent en évidence une couverture de 39% en Neq, 63% en Peq, et 48% en Keq. Une commune présente en excédent peu transportable.
CONCLUSIONS	En conclusion, bien que des limitations méthodologiques aient été identifiées, cette étude constitue un premier état des lieux des réserves et des besoins en MAFORs sur l'île. Elle montre qu'une réduction des importations de nutriments est envisageable. Ce diagnostic sera précieux pour les parties prenantes en vue d'une meilleure gestion territoriale des MAFORs.

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Acronyms and Abbreviations

AGU: Agricultural Land Used

ADEME: Agence de l'Environnement et de la Maîtrise de l'Énergie (Agency for the Environment and Energy Management)

BOS: Bas d’Occupation du Sol (Land Use Database)

CAU: Coefficient Apparent d'Utilisation (Apparent Utilization Coefficient)

CASDAR: Compte d'Affectation Spéciale pour le Développement Agricole et Rural (Special Account for Agricultural and Rural Development)

CASDAT: Catalogue des Systèmes de Données d'Alerte Territoriale (Territorial Alert Systems Data Catalog)

CONVER: Co-conception d’un Scénario de Valorisation des Biomasses dans une Démarche d’Économie Circulaire (Co-design of a Biomass Valorization Scenario in a Circular Economy Approach)

CORPEN: Comité d’ORientation pour des Pratiques Agricoles Respectueuses de l’ENvironnement (Orientation Committee for Environmentally Friendly Agricultural Practices)

CTEEGI: Coopérative de Traitement des Effluents d'Élevage de Grand Îlet (Cooperative for Livestock Effluent Treatment of Grand Îlet)

DAE: Déchets d'Activités Économiques (Waste from Economic Activities)

DMA: Déchets Ménagers et Assimilés (Household and Assimilated Waste)

FRCA: Fédération Réunionnaise des Coopératives Agricoles (Réunion Federation of Agricultural Cooperatives)

GABIR: Gestion Agricole des Biomasses à l'Échelle de la Réunion (Agricultural Biomass Management at the Scale of Réunion)

GIROVAR: Gestion Intégrée des Résidus Organiques par Valorisation Agronomique à la Réunion (Integrated Management of Organic Residues through Agronomic Valorization in Réunion)

Ha: Hectare

K: Potassium (Potassium)

Kg: Kilogramme (Kilogram)

Keq: Potassium Équivalent (Potassium Equivalent)

LSU: Unité de Gros Bétail (Livestock Unit)

LTECV: Loi de Transition Énergétique pour la Croissance Verte (Energy Transition for Green Growth Law)

MAFORs: Matières d'Origine Résiduaire (Organique ou Minérale) (Residual Origin Materials)

N: Azote (Nitrogen)

Neq: Azote Équivalent (Nitrogen Equivalent)

Peq: Phosphore Équivalent (Phosphorus Equivalent)

P: Phosphore (Phosphorus)

PoVaBiA: Potentiel de Valorisation des Bio-Déchets en Agriculture (Potential of Bio-Waste Recovery in Agriculture)

RDO: Recyclage de l'Ouest (Ouest Recycling Platform)

RGA: Recensement Général de l'Agriculture (General Agricultural Census)

RM: Matière Brute (Raw Matter)

RPG: Registre Parcellaire Graphique (Parcel Register)

SELMET: Système d'Élevage Méditérranéens et tropicaux (Mediterranean and Tropical Livestock Systems)

SERDAF: Système Expert Réunionnais d'Aide à la Fertilisation (Reunionese Expert System for Fertilization Assistance)

TMS: Tonnes de Matière Sèche (Tons of Dry Matter)

Table of Contents

INTRODUCTION

Réunion imports significant quantities of nutrients (N, P, K) every year through synthetic fertilizers (35,000 tons/year) to fertilize crops. However, the island has substantial reserves of MAFOR (MAFORs) from livestock, agro-industry, and waste treatment. Various projects on the island related to the identification, processing, and utilization of these MAFORs demonstrate the willingness of stakeholders to save chemical inputs through the use of these materials, in a circular economy approach.

However, the specialization of agricultural operations, spatial segregation between crops and livestock (sugarcane in the lowlands and livestock in the uplands), and increasing urbanization pose constraints on the use of these MAFORs. Thus, in some areas with nutrient surpluses, livestock farmers face growing difficulties in spreading their effluents. This situation calls for the development of collective solutions for MAFOR management on a territorial scale (co-composting, phase separation, construction of collective spreading plans, etc.) in order to move nutrients from surplus areas to deficit areas at a lower cost.

This study aims, firstly, to quantify the island's self-sufficiency in nutrients N, P, K. It also seeks to identify surplus and deficit areas by conducting a commune-level balance between MAFOR reserves and crop needs in Réunion. The goal is to produce a diagnosis that serves as a basis for discussion among stakeholders to better plan the territorial management of MAFORs, facilitate their spatial distribution, and thus reduce the importation of synthetic fertilizers.

PART I: LITERATURE REVIEW

1.1 Réunionese Agriculture

1.1.1 History of Reunion Island Agriculture: Towards Dependent and Specialized Agriculture

Generalities

The island of La Réunion, located 9,200 km away from metropolitan France, has a total area of 2,520 km², of which only 17% is suitable for agricultural activities due to its rugged terrain and urbanization (see Figure 1). The andosol soils on the island are poor and prone to steep slopes and torrential rains, requiring significant inputs to maintain a certain level of quality of yield.

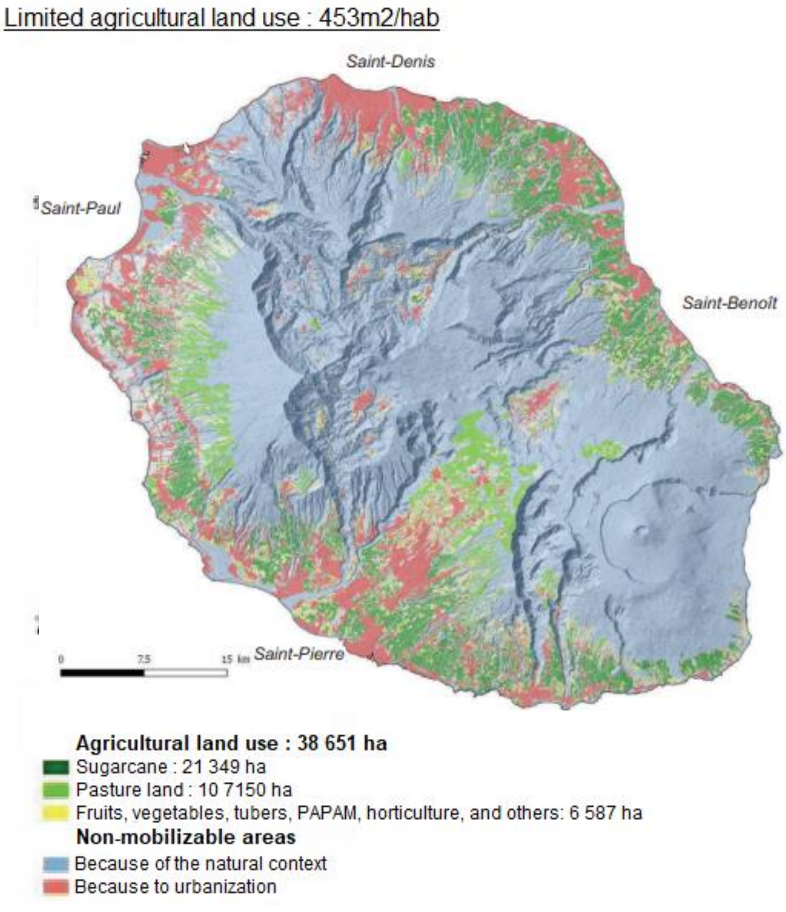


FIGURE 1 : LAND USE IN LA REUNION (SOURCE MÉMENTO 2021)

From the Arrival of the French to Departmentalization

The island of La Réunion is a French island, located 9,200 km away from mainland France. Discovered in the 16th century, it became a French concession in 1642. It then played the role of a "granary" for France with a diversified agricultural production focused on exports (spices, coffee, cotton, vanilla, rice) (DARRAS et al, 2021). The cultivation of sugarcane truly began in the 19th century. By 1860, it occupied 62,000 hectares out of 100,000 hectares of cultivated land. Subsistence farming had greatly declined and was no longer sufficient to feed the population, leading to a food dependency (DARRAS et al, 2021).

Around the 1900s, a crisis in sugar prices pushed producers to diversify once more, particularly by developing the cultivation of fragrant plants and vanilla. In the mid-20th century, three distinct zones emerged: the "sugarcane domain" in the coastal plains, the "tobacco and geranium domain" in the highlands and windward plains, and the "domain of Horticulture/arboriculture shrub crops" in the cirques.

From Departmentalization to Today's Agriculture

The departmentalization of the "old colonies" was approved in 1946, accompanied by a desire to address poverty and health issues among the residents. Large colonial properties were divided and distributed to former agricultural workers, allowing them to become farm owners. In 1975, the development plan for the highlands encouraged the establishment of livestock farming on the former geranium cultivation lands. Geranium cultivation had become difficult due to strong international competition (DARRAS et al, 2021). These new livestock farmers organized themselves into cooperatives and interprofessions, bringing together producers, processors, importers, and distributors of animal products. At the same time, fruit and vegetable production expanded in the West and South, where the climate was more favorable (DARRAS et al, 2021)

Today, agriculture in Réunion is largely based on sugarcane (see figure 1: 21,349 ha), livestock, and fruit and vegetable cultivation (6,587 ha). Most farms specialize in a single type of production (DARRAS et al, 2021). The specialization of production areas has remained unchanged since the 1980s, with sugarcane dominating in the "Lowlands" and livestock farming and forage areas in the "Highlands." This agricultural production relies heavily on imports of inputs: approximately 222,000 tons of animal concentrates and 30,000 tons of chemical inputs for crops (KLEINPETER, 2019).

Agricultural production struggles to feed the growing population. 80% of the protein consumed by the population comes from imported foods (ALVANITAKIS, 2021). This dependence on external imports poses a problem in a context where agricultural land is already limited due to urbanization and natural spaces, and where urbanization is further reducing these areas. The population is expected to surpass one million inhabitants by 2037.

1.1.2 Livestock Presentation

Livestock agriculture is widely practiced on the southern part of the island, and there is strong demand for new installations or expansions. However, there are limitations to this expansion, including available production quotas and regulations regarding effluents. Managing livestock waste is already complex, and there is a shortage of spreading areas in certain communes.

When studying nutrient flows in La Réunion, it is essential to examine the significant role of livestock and the origin of its feed. The nutrients present in animal feed are imported, assimilated by the animals, and then redistributed as livestock effluents. This complex food chain plays a major role in understanding the island's dependence on nutrient imports.

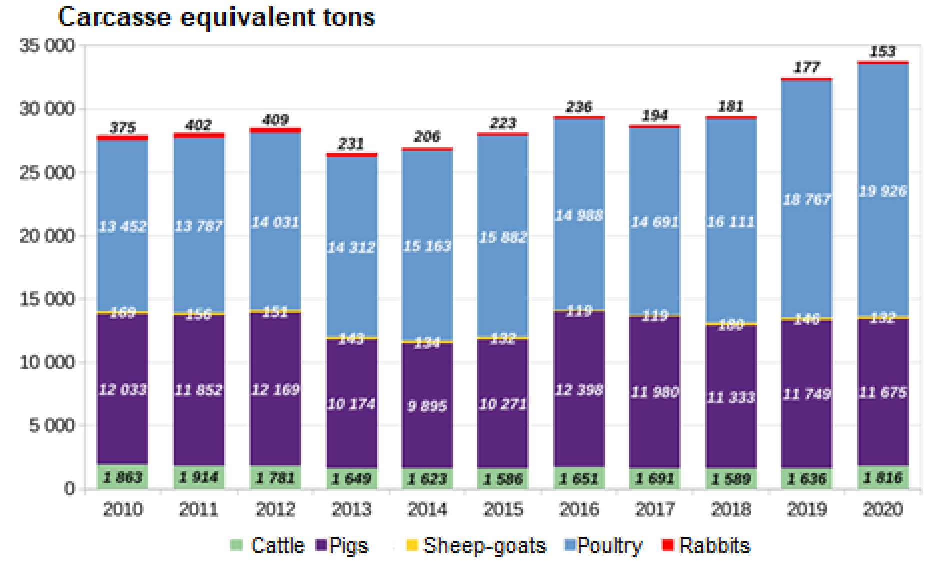


FIGURE 2: EVOLUTION OF MEAT VOLUMES FROM VARIOUS ANIMAL CATEGORIES IN RÉUNION BETWEEN 2010 AND 2020 (IN CARCASS EQUIVALENT TONS) (TRANSLATED FROM: DAAF RÉUNION - ANNUAL AGRICULTURAL STATISTICS)

The primary animal productions in La Réunion are poultry and pork, representing approximately 3 million chickens and 75,000 pigs, respectively, which account for 94% of the local meat production in terms of volume (see figure 2). Currently, all eggs and fresh pork sold in the Réunion market come from 100% local production (AGRESTE, 2021). Half of the poultry products are also of local origin. Animal production has been growing since 2010 (See figure 2), notably in poultry production, which increased from 13,400 to 19,900 tons of carcass equivalents from 2010 to 2020.

This growth exacerbates the dependency on external imports: 222,000 tons of animal concentrates are imported annually, and 70% of the proteins consumed by livestock come from external imports (KLEINPETER, 2023). Only 30% of the proteins are provided by forage and grazing.

Actors involved in various livestock sectors have also raised several concerns, including limited space for grazing and spreading, as well as challenges associated with reducing the consumption of intermediate resources in food production (DARRAS et al, 2021).

1.1.3 Land Use in La Réunion

The population of La Réunion, which stood at 859,960 inhabitants in 2019, is projected to exceed one million inhabitants by 2037, according to demographic growth projections. This has led to competition for agricultural land, as the evolution of urban areas reveals a 2%

increase since 2011 in increasingly dense urban spaces, a 35% increase since 2011 in priority urbanization areas, a 9% increase since 2011 in agricultural and natural areas, and a 4% increase since 2011 in inhabited rural areas (Syndicat du sucre de La Réunion, 2021). This has resulted in a reduction of Potential Spreadable Surfaces due to regulations regarding the distance from residential areas.

The main plant sectors in La Réunion are the sugarcane sector, Horticulture/arboriculture, and forage crops for livestock. They play a crucial role in meeting the local market's needs in terms of quality, quantity, and product diversity (AGRESTE, 2021).

Forage crops

Forage areas rank second in terms of Agricultural Land Use (SAU) in La Réunion, representing a total of 28% (DARRAS et al, 2021). These areas are of great importance due to substantial forage needs for livestock (MAGNIER, 2019). However, the Réunionese forage system has peculiarities: standing grass, although widely produced, seems undervalued, and preserved forages, essential during deficits, face supply tensions in case of drought. Two major challenges emerge: strengthening forage self-sufficiency and optimizing resource utilization by improving grazing practices and creating forage stocks (LORRE, 2019).

Vegetal Production for human consumption

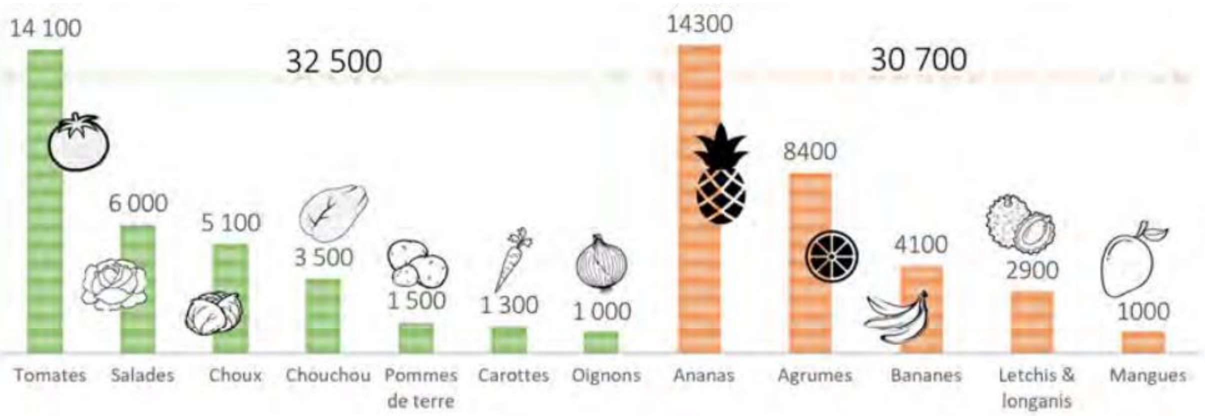


FIGURE 3 : LAND USE FOR FRUITS AND VEGETABLE IN LA REUNION (DARRAS ET AL, 2021)

The sugar cane sector in La Réunion, characterized by its importance in terms of land area, agricultural operations, and revenue, is primarily structured around the French group Tereos (DARRAS et al, 2021). Sugar cane plays a crucial economic role on the island, with a stable annual production reaching 1.70 million tons over the past decade (AGRESTE, 2021). Challenges facing this sector, especially from Tereos' perspective, focus on maintaining the dedicated sugar cane areas and the need to diversify the outlets for this crop (DARRAS et al, 2021).

The Horticulture/arboriculture sector in La Réunion is characterized by significant production of vegetables such as tomatoes, lettuce, cabbage, chayote, potatoes, as well as fruits including pineapples, citrus, bananas, lychees, longan, and mangoes (see figure 3). This diversity of crops contributes significantly to the local market, representing 68% of the fresh vegetable market and 50% of the overall market (including fresh, processed, and frozen products) for vegetables, as well as 58% for fresh fruits and 43% of the overall market (AGRESTE, 2021).The major challenges facing this sector include the need to meet local market demand, gain market share compared to imports, and promote the development of agroecological practices (DARRAS et al, 2021).

Agri-Food Industry

The agri-food sector in La Réunion is essential to the local economy. The agri-food industry accounts for one-third of regional manufacturing turnover and is the island's leading industrial sector. The main industries in this sector are the sugar industry, meat processing, and beverage production (DARRAS et al, 2021).

These sectors enable the development of innovative, high-value-added processed products, such as vanilla. They also represent significant sources of biomass, which can be utilized in various ways, including energy production from wood or sugarcane bagasse, animal feed from molasses, bagasse, and sugarcane straw, soil fertility renewal from vinasse, ashes, lime-chaulée yeast cream, scum, and vinasse digestate, and as bedding for livestock from mulch chips and sugarcane straw (KLEINPETER et al., 2019). Finally, these plant sectors play a key role in promoting tourism and the local culture of La Réunion Island.

1.2 MAFOR

1.2.1 A Variety of MAFOR Already Used in Réunion

Definition of MAFOR

MAFOR, or Residual Origin Materials (see Figure 6), can be used to fertilize crops. They include various materials from different sectors (energy, livestock, agro-industry, etc.).

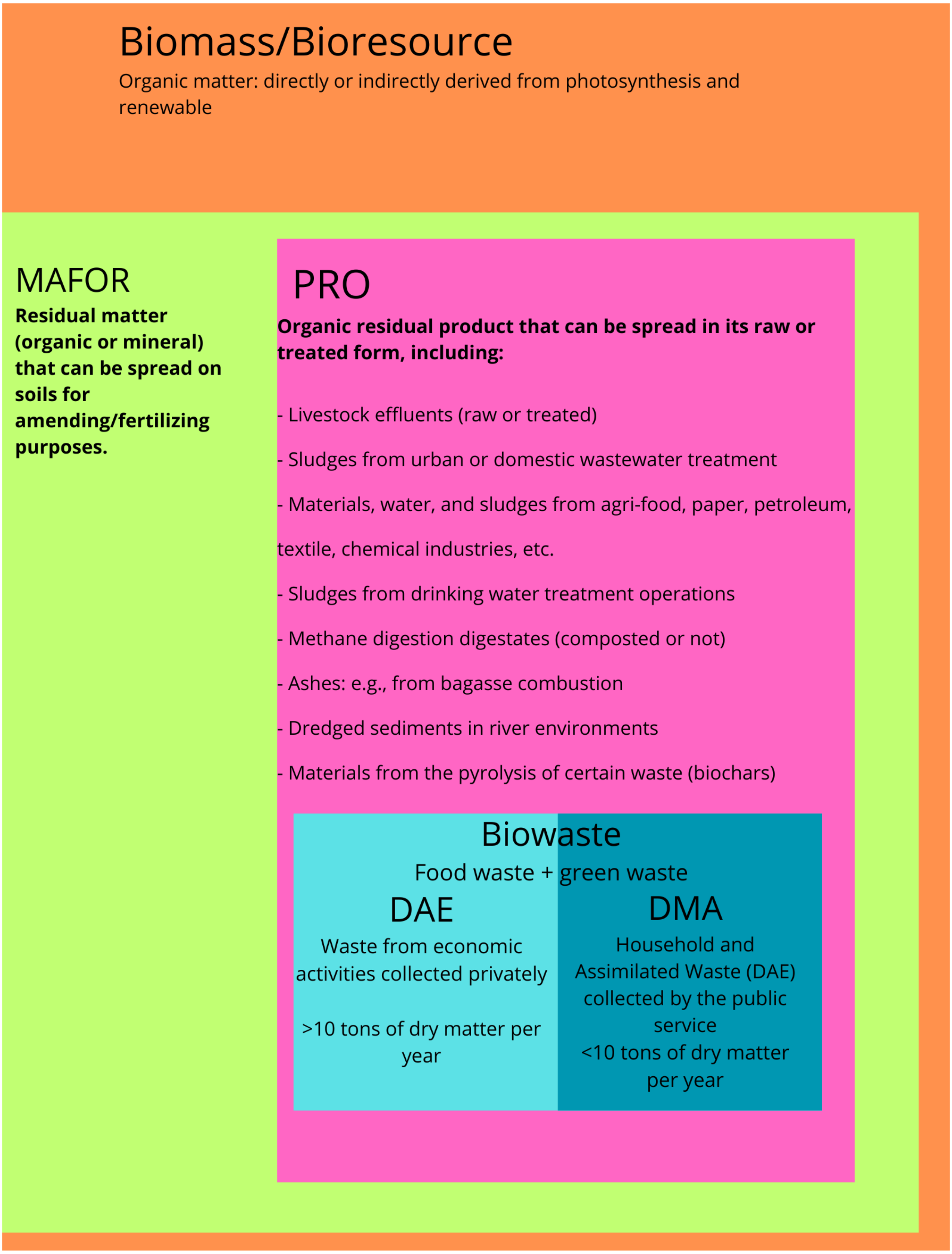


FIGURE 4 : DIAGRAM OF DIFFERENT TERMS FOR ORGANIC MATERIALS USABLE IN AGRICULTURE (PERSONAL SOURCE).

In Réunion, there is a wide variety of MAFOR, each with distinct characteristics in terms of nutrient composition, availability for plants, and impact on the soil (CHABALIER et al, 2006).

Livestock Effluents

Firstly, manures are organic amendments derived from animal excreta and carbonaceous bedding. Bovine, caprine, rabbit, ovine, and poultry manures differ in terms of maturity and nutrient composition. Bovine manures are relatively balanced but contain little directly assimilable nitrogen. Caprine manures are rich in potassium and mature. Rabbit manures are balanced in terms of nutrients and contain calcium. Ovine manures are distinguished by their high potassium content. Finally, poultry manures are characterized by their high concentrations of nitrogen, phosphorus, potassium, and calcium.

Slurries, such as bovine and porcine slurry, are liquid mixtures of animal excreta and urine, along with food waste. Bovine slurry provides readily available nitrogen but has a risk of nitrogen loss through volatilization during spreading. They have low concentrations of nitrogen, phosphorus, and potassium. Porcine slurries are also rich in nitrogen, but they have similar risks of nitrogen loss during spreading, and they contain copper and zinc.

Laying hen droppings are dried and rich in nitrogen, phosphorus, potassium, and calcium. They are excellent as nutrient-rich fertilizers, although their content of humifiable organic matter is limited.

Other MAFOR

For the other MAFOR, we used the categories as described in the GABIR project (KLEINPETER et al 2019) :

MAFORs from the sugar sector:

- Bagasse: Fibrous residue remaining after extracting sugarcane juice.

- Scum: Residues from the sugar sector production process.

- Raw distillation molasses vinasse: Residue from the distillation of sugarcane molasses.

- Paste-like methanized vinasse digestate: Residue from the methanization of vinasse, in paste form.

- Liquid methanized vinasse digestate: Residue from the methanization of vinasse, in liquid form.

- Approved bagasse ashes: Ashes resulting from the combustion of bagasse.

MAFORs from the AAI sector outside the sugar sector:

- Fruit and vegetables residues: Residues from the production and processing of fruits and vegetables.

- Blood and feather meal: Products resulting from the processing of animal feathers and blood.

STEU sludges (sewage sludge):

- Approved granulated and lime-chalked methanized GP STEU sludges: Sludges from wastewater treatment, methanized and granulated with lime, approved.

STEU sludges: Sludges from wastewater treatment.

Green waste:

- Green waste compost: Composting of green waste.

- Green waste shredding: Shredding of green waste.

Multi co-products and waste compost:

- RDO compost: Composting of various co-products and waste.

- Potting soils (universal, garden, anthurium, orchid, seedlings): Potting soils for various gardening purposes.

Transformed livestock effluent:

- Cattle manure compost: Composting of cattle manure.

- Poultry manure compost: Composting of poultry manure.

- Dehydrated granulated layer hen manure: Dehydrated and granulated layer hen droppings.

Biodegradable waste:

- Biodegradable waste from DMA outside DV PAP: Biodegradable waste from municipal and assimilated waste.

- Biodegradable waste from DAE collected privately (excluding known flows): Biodegradable waste from economic activity waste collected privately.

Composts, such as chicken broiler manure compost, pig slurry and bagasse compost, and green waste and sewage sludge compost, are products rich in nitrogen, phosphorus, and potassium, with high concentrations of nutrients. They are used to enrich soils and promote plant growth.

Co-products and waste from the agri-food industry, such as fresh scum from sugar mills and distillery vinasse, are used for crop fertilization, although they have varying nutrient concentrations. For example, fresh scum from sugar mills is rich in phosphorus and calcium, while vinasse is mainly used for potassium fertilization.

Finally, sewage sludge, whether liquid, paste-like, or solid, is derived from wastewater treatment and contains variable levels of nitrogen, phosphorus, and potassium. They can be used as sources of nitrogen for crops, although their impact on soil humus is limited.

1.2.2 Context of MAFOR Management

The issue of MAFOR valorization in Réunion has been the subject of numerous projects involving various local stakeholders since the 1990s.

In 1996, the Agricultural Waste Valorization Mission (MVAD) was created through an initiative of the Chamber of Agriculture, ADEME (Agency for the Environment and Energy Management), the Regional and General Councils, and was subsidized by the European Union. It is managed by the Chamber of Agriculture and has undertaken various actions since its creation, including comparative fertilization trials in sugarcane, mixed crop fertilization advice, spreading plans for livestock farmers, methodological and technical assistance to project leaders for the management, transformation, or valorization of organic materials, as well as studies and the dissemination of technical documents.

CIRAD’s Recycling and Risk and SELMET (Mediterranean and Tropical Livestock Systems) units are partners of MVAD. The Recycling and Risk unit studies the agricultural valorization of organic residual products (PRO), such as lime-chaulée dried sludge from the Grand Prado wastewater treatment plant, pig slurry, and poultry manure, to address questions about the impacts of recycling these PRO on soil quality, plant growth, water quality, and gas emissions from spreading. The unit is also behind the GIROVAR project (Integrated Management of Organic Residues through Agronomic Valorization in Réunion), which aims to co-construct scenarios for organic waste management in 2011. The SELMET unit is particularly focused on the theme of the circular economy, with a significant focus on MAFOR/livestock effluent that led to the GABIR (Agricultural Biomass Management at the Scale of Réunion) project in 2017 (Agricultural Biomass Management at the Scale of Réunion Island), followed by CONVER (Co-design of a Biomass Valorization Scenario in a Circular Economy Approach in Réunion) in 2019 (co-design of a biomass valorization scenario). My internship is directly related to the continuation of these different projects.

Lessons from the GABIR Project

The GABIR project is a territorial ecology project involving 8,000 actors aimed at improving the autonomy of farmers and sectors by promoting biomass transfers. The project started in 2017 for 40 months with 10 partners, funded by the Ministry of Agriculture CASDAR and led by Mathieu Vigne. The results of the GABIR project allowed for the inventory of biomass flows valorized or valorizable in agriculture in Réunion. Quantified MAFOR deposits are estimated at 325,000 tons of dry matter, mainly valorized in agriculture (83%), disposed of (13%), or valorized in the urban sector (4%) (KLEINPETER et al, 2019). Among all the inventoried flows, approximately 80% are operated between stakeholders, demonstrating the existence of a form of circular bioeconomy in Réunion. The room for maneuver regarding agricultural MAFOR valorization still available could mainly concern household biowaste and buried MAFOR. Among the identified MAFOR, it is observed that 140,000 tons of dry matter are used for crop fertilization, including 37% from livestock effluents and biomass from them, 33% from by-products of the sugar industry (scum, vinasse), 15% from green waste shredding and composts, and finally, 12% from co-composts and growing media produced from biomass from the agricultural, urban, and agri-food sectors (KLEINPETER et al, 2019).

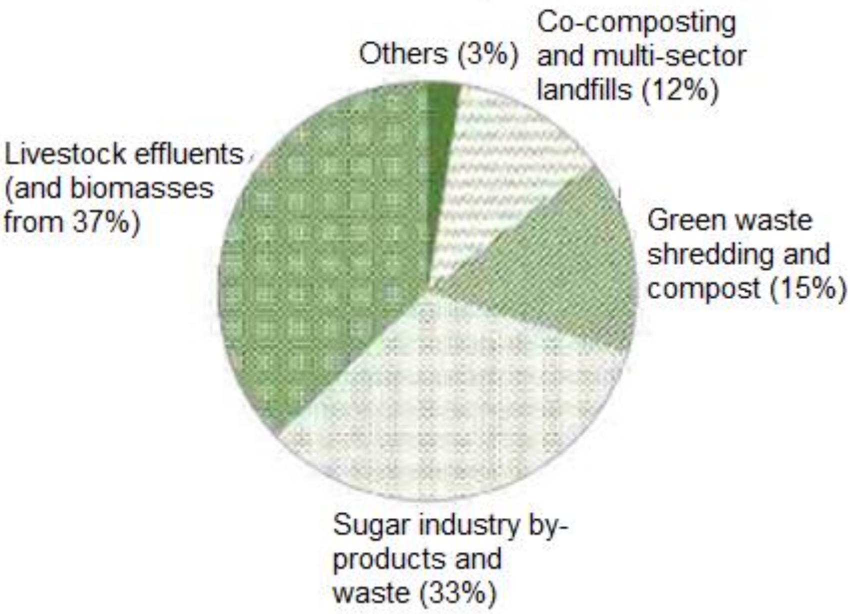


FIGURE 5: TONS PER YEAR IN % OF DRY MATTER OF FLOWS DOWNSTREAM TO PLANT PRODUCTION IN RÉUNION. SOURCE: KLEINPETER ET AL. 2020

The GABIR project quantifies 42,2500 TMS of potentially valorizable biomass sent to landfills (mostly household waste). Waste treatment in Réunion is a major challenge. In particular, household waste is increasing, and its landfill rate is high, reaching 65-70% compared to a national average of 24% (JIQUEL, 2020). To address this issue, the recent LTECV law (Energy Transition for Green Growth Law) requires source separation and valorization of biowaste through composting or methanization. In this context, a technical proposal for Réunion involves the establishment of a Regional Waste Prevention and Management Plan (PRPGD). This would enable better waste management by favoring their valorization rather than burial. The ILEVA ET SYDNE Joint Union is responsible for waste management on the island and collaborates with authorities to implement these new measures.

1.2.3 Spatialization of Nutrient Needs and Nutrient Supply for More Efficient MAFOR Management

The GABIR project has identified a significant amount of MAFOR that is already being utilized or potentially usable in agriculture in Réunion. This offers the potential to reduce the island's reliance on chemical fertilizers. However, the use of these MAFOR materials is subject to several challenges.

Various stakeholders in different agricultural sectors raise significant issues. One of these concerns the limited availability of land for spreading livestock effluents (DARRAS et al., 2021). Farmers in the region face challenges in finding suitable spreading areas, sometimes having to transport their effluents over distances of up to 15 kilometers (JIQUEL, 2020).

These difficulties result from complex regulations, a lack of knowledge about available spreading areas, increasing urbanization that reduces available spreading land, and a lack of coordination among institutions responsible for mapping spreading plans. Consequently, farmers often cannot identify the closest plots, leading to additional costs in terms of time and distance (JARRY, 2019).

For sugarcane growers and market gardeners, there is a lack of information about the origin of available MAFOR, how to use them, and their benefits (DARRAS, 2019). There is also competition between certain MAFOR materials and mineral fertilizers. MAFOR materials require efficient logistics to be competitive due to their high weight, resulting in costly and time-consuming transportation.

These challenges highlight the importance of territorial MAFOR management, which involves implementing collective solutions and supply chains to move nutrients from surplus areas to deficit areas. These solutions can include the establishment of collective treatment facilities for effluents (methanization, composting, co-composting, denitrification, etc.), the construction of collective spreading plans involving farmers, sugar cane growers, or market gardeners, and the implementation of shared transportation for effluents. These strategies would allow for the pooling of equipment and management costs, thereby increasing the competitiveness of MAFOR materials compared to chemical inputs.

The first step in implementing such strategies is to spatialize the supply and demand for MAFOR materials at the territorial level.

Research Questions:

1. Which communes in Réunion have surplus or deficit nutrient levels?

2. Can the currently cultivated areas utilize all the available MAFOR deposits?

3. Furthermore, by how much can synthetic fertilizer imports be reduced due to the availability of MAFOR materials in Réunion?

The objective of this internship is to conduct nutrient balance assessments between MAFOR deposits and crop needs in Réunion, at the commune level, to answer these questions and provide insights into more efficient MAFOR management.

PART II: METHODOLOGY

2.1 Steps in the Creation of Nutrient Balances

Description of the Balance Method

In this section, we will describe the methodology used to create nutrient balances (nitrogen, potassium, phosphorus) by commune on the island of La Réunion for the year 2020. At the core of this method lies the complex task of evaluating, on one hand, nutrient inputs, and on the other hand, the specific needs of different crops (LORIN, 2020). The difference between these two components represents the coverage of crop needs by MAFOR.

At each step of our approach, our main objective was to calculate nutrient supply and requirements in fertilizer equivalents. This methodological choice aimed to simplify the calculation process. This approach is particularly suitable for phosphorus and potassium, but it may introduce some inaccuracies for nitrogen, a significant portion of which mineralizes over the following years (LORIN, 2020) and is not considered in the calculation of a balance for a given year.

This methodical approach aims to provide an overview with balances at the island and municipal levels.

For each crop, we consulted experts to gather the most relevant data. However, it should be noted that this method has certain limitations, which are discussed in section 2.4.

2.2 Methodology for Calculating Nutrient Supply (N, P, K) from MAFOR

In this section, we will begin examining the calculations related to N (nitrogen), P (phosphorus), and P (potassium) inputs, first distinguishing inputs from livestock effluents and then calculating inputs from other MAFOR.

2.2.1 Livestock Effluents

For each animal category and commune, the calculation of nitrogen (N), phosphorus (P), and potassium (K) quantities in fertilizer equivalents was done using the following formula:

*Fertilizer Equivalent NPK Quantity = (Number of Animals * Excreted NPK Quantity per Animal – Losses) * Fertilizer Equivalence Coefficient*

Number of Animals

To obtain the number of animals in each commune, we used data from the 2020 RGA (General Agricultural Census) of La Réunion (see example in appendix 5)

Quantity of Nutrients (N, P, K) Excreted per Animal Category

The estimation of the quantity of nutrients (nitrogen, phosphorus, and potassium abbreviated NPK) excreted by each animal category was based on the CORPEN standards, widely recognized in metropolitan France (DOUBLET et LE GALL, 2013). These standards are available in Appendix 1.

Allocation of Effluent Management Mode

Effluent management mode (in barns, slurry, or grazing) is essential because it determines nitrogen losses in barns or during storage and determines the transportability of effluents leaving the farm.

Cattle

The typology from the 2020 RGA (appendix 5) allows us to associate each age category of cattle with NPK excretion using CORPEN standards. However, this typology does not tell us whether animal excretion occurs in the field, in barns with straw, or without straw. It is important to make this distinction to calculate nitrogen losses in barns/storage and to know the type of effluent produced: slurry, manure, or excrements in the pasture.

The typology and 2018 numbers from (MAGNIER, 2019) are more precise than those of the RGA. It differentiates animals by age category and by type of breeding. According to expert opinion, we assumed that beef cattle in fattening and dairy heifers in growth produce manure, dairy cows produce slurry, and beef cows and replacement animals excrete in the pasture.

An equivalence was established between Magnier's typology and that of the 2020 RGA (Appendix 2), allowing us to calculate, for each age category of cattle in the RGA and by commune, the percentage of animals producing slurry, manure, or excretion in the pasture. By doing this, we assumed that the livestock structure (distribution between beef/dairy/fattening) did not change between 2018 and 2020.

Other Animals

By expert opinion and simplification, we considered that pigs produce slurry, laying hens produce droppings, small ruminants, poultry, and rabbits produce manure for calculation through the CORPEN norms.

Losses in Barns and Storage

Nitrogen losses due to volatilization during barn and storage are based on (DOUBLET et LE GALL, 2013) and depend on the type of animal and effluent management mode. The objective of this calculation is to obtain the quantity of N in effluents leaving storage, which will be spread on the plots.

Equivalent Fertilizer Coefficient

The coefficients come from the Organic Fertilization Guide proposing local measurements (CHABALIER et al, 2006).

2.2.2 Other MAFOR

The evaluation of N, P, K quantity in fertilizer equivalents from non-effluent MAFOR (composts, co-products, and waste from industry) includes two essential aspects.

First, we determined the **quantity in dry matter** (DM) or raw matter (RM) for each type of MAFOR using data from the GABIR project report (KLEINPETER et al, 2019), and we also updated certain MAFOR in collaboration with industry stakeholders identified during the GABIR project.

Secondly, the **composition of nutrients** (N, P, K) and fertilizer equivalence are determined using the Organic Fertilization Guide, which provides local data (CHABALIER et al, 2006) laboratory analyses of MAFOR in La Réunion.

2.3 Methodology for Calculating Crop Needs

2.3.1 Sugarcane Needs

Methodological Choices for N, P, and K Dosing

We estimated the need for N, P, K in fertilizer equivalent for each sugarcane plot using the 2020 sugarcane plot data produced by (RUISSEL et al, 2023) and the SERDAF methodology (SERDAF, 2011). Here's how we proceeded:

Nitrogen

The required nitrogen quantity is calculated using the following formula (SERDAF 2011):

*DoseN(kgN/ha) = -0.000004 * rdt^2 + 0.00172 * rdt - 0.0153 - (0.12 - doseN * coeff_abat_N) + majN * 100 * rdt*

rdt: The yield per hectare is determined from Tereos 2019 data (map from LORRE, 2019: see in Appendix 3) and the plot data from (RUISSEL et al, 2023).

DoseN: This is the base dose for a sugarcane yield of 100 tons/ha. SERDAF (2011) offers a grid based on the nitrogen content of soils. We assume that all soils are "adequately supplied with mineralizable nitrogen." Therefore, DoseN is 120 kg/ha.

coeff_abat_N: This coefficient varies depending on the status of the sugarcane (0.7 for virgin or regrowth). For simplification, we considered that sugarcane plots were in regrowth once every ten times (reasoning based on expert opinion).

majN: The increase considers the export of sugarcane straw and depends on the type of harvest. We assigned an "average" increase to each plot, considering the percentages of harvest practices in the plot's production area (map of LORRE 2019, see in Appendix 3). So, if a plot was in an area where manual harvest accounted for 60% and mechanical harvest for 40%, the majN of the plot is calculated as follows: MajNparcel = 60% * MajN_manualharvest + 40% * MajN_mechanicalharvest

Phosphorus

The required phosphorus quantity is calculated using the following formula (SERDAF, 2011):

*DoseP(kgP/ha) = 0.000092 * rdt^2 - 0.0035 * rdt + 0.25 - (0.12 - doseP * coeff_abat_P) + majP * 100 * rdt*

doseP: This is the base dose for a cane yield of 100 tons/ha. This value depends on the availability of phosphorus (P) in the soil based on the soil's P content (tp class) and the soil's fixing capacity (pf class). An in-depth analysis of soil samples (NOBIL et al, 2023), shows that most cane plots are in a "low" phosphorus availability class. We take a P dose corresponding to this availability class, which is 100 kg of P_2O_5/ha for regrowth and 200 kg of P_2O_5/ha for virgin land.

coeff_abat_P: Coefficient for phosphorus abatement, which is 0.7 for virgin or regrowth sugarcane.

majP: Coefficient accounting for phosphorus losses during application, set to 0.9.

Potassium

The quantity of potassium required is calculated using the following formula:

*Dose K (kg K/ha) = -0.0000073 * rdt^2 + 0.00295 * rdt - 0.029 - (0.2 - dose_K) + majK * 100 * rdt*

dose_K: This is the base dose for a sugarcane yield of 100 tonnes/ha. This value depends on the soil's potassium (K) availability, assessed using the assumption of a fixing class (K_cec) and average potassium content (tk). Therefore, it is 160 kg K_2O/ha for ratoon cane and 200 kg K_2O/ha for virgin cane.

The collected data have allowed for a significant precision at the parcel scale, regarding the nutritional requirements of sugarcane cultivation. The results reveal an average yield of 78 tonnes per hectare, with nutrient requirements of 124 kg N/ha, 52 kg P/ha, and 169 kg K/ha in equivalent fertilizer.

1.3.2 Pasture Requirements

Methodological Choices for N, P, and K Doses

We estimated the fertilizer equivalent N, P, and K requirements for each pasture plot using 2018 pasture mapping data (LORRE, 2019). Initially, we calculate nutrient exportation through mowing or grazing to deduce the requirements. Here's how we proceed:

Calculation of N, P, K Exports

Nutrient exports are calculated at the plot level:

*Nutrient Export N, P, K = area * yield * forage N, P, K content*

Yield is given in dry matter tons (TMS) for each plot by (LORRE, 2019). This report assigns a yield to the plot based on a typology of 26 pasture types, taking into account various factors, including use, species, pedoclimatic zones, and the level of intensification in Réunion.

The nitrogen content is assessed using the nitrogen dilution curve (MIRALLES BRUNEAU et al, 2020), illustrating the decrease in nutrient content as the pasture regrows. Each management method is thus assigned a specific yield and nitrogen content.

In the context of my study, a correspondence was established between the pasture typologies of ARP (MIRALLES BRUNEAU et al, 2020), representing 12 types, and those of LORRE F. (2019) (26 types) to link the different data (See Appendix 4).

Potassium and phosphorus content are also calculated based on yield (MIRALLES BRUNEAU et al, 2020) and nitrogen content.

Nitrogen Requirement

The determination of nitrogen requirements for pastures in La Réunion is expressed in equivalent fertilizer nitrogen and is based on the nitrogen balance method. The idea is to determine the theoretical dose of chemical fertilizer needed to cover pasture nitrogen exportation, taking into account nitrogen already supplied by the soil.

Nitrogen requirements are calculated using the following formula:

Pasture Equivalent Fertilizer Nitrogen Requirement = (Pasture Nitrogen Exportation - Soil Nitrogen Supply) / CAU Urea

Soil Supply: We use the soil supply map for pasture (MIRALLES BRUNEAU et al, 2020).

CAU Urea: The apparent utilization coefficient (CAU) for urea fertilizer is set at 0.3 (CHABALIER et al, 2006).

In cases where soil supply exceeds pasture nitrogen exportation, the pasture equivalent fertilizer nitrogen requirement is reduced to 0.

Phosphorus and Potassium Requirements

The recommended doses are calculated as follows:

P Dose = (Predicted Yield * Phosphorus content in exports) * P Coefficient

K Dose = (Predicted Yield * Potassium content in exports) * K Coefficient

Based on expert opinions and (NOBILE et al, 2023) we established a P Coefficient of 1.5 (See 2.4 for more details).

This methodology allows us to determine the average fertilizer equivalent requirements for pastures in La Réunion, which are on average 116 kg N/ha, 253 kg K/ha, and 40 kg P/ha. These specific data contribute to optimal and sustainable agricultural management of the island's pastures.

2.3.3 Horticulture/arboriculture

Nitrogen, phosphorus, and potassium requirements for horticulture/arboriculture are calculated by commune using the following formula:

*Fertilizer Requirement (kg/ha/cycle) = Developed Area (ha * cycles) * Equivalent FERTIRUN Fertilizer Requirement (fertilizer equivalent units/ha/cycle)*

The fertilizer requirement for horticulture/arboriculture is determined based on the **developed area**, which is the product of cultivated area and the number of crop cycles, according to data from the General Agricultural Census (RGA) for the year 2020 (see appendix 5). Fertilizer requirements are expressed in fertilizer equivalent units per hectare per cycle. Recommendations for **equivalent fertilizer requirements**, expressed in kilograms per hectare per cycle, are derived from FERTIRUN software data (CHAMBRE D'AGRICUTLURE DE LA REUNION, 2018).

Taking the average of different crops, fertilizer requirements for vegetables are 239 kg N/ha, 66 kg P/ha, and 337 kg K/ha. As for fruit crops, the requirements are 105 kg N/ha, 19 kg P/ha, and 189 kg K/ha.

2.4 Review of Some Data Sources Used

We revisit in the following paragraphs the way certain data sources used in the method are constructed, to highlight the limitations involved in their use.

Coefficients P and K for Pastures

Fertilization coefficients for phosphorus (P) and potassium (K) are commonly used in the COMIFER method (DENOROY et al, 2019). These coefficients can vary from 0 to 2 depending on soil type, specific crop requirements, and the number of years without input of these elements. These coefficients are multiplied by the P or K exportation to obtain a recommended fertilization dose.

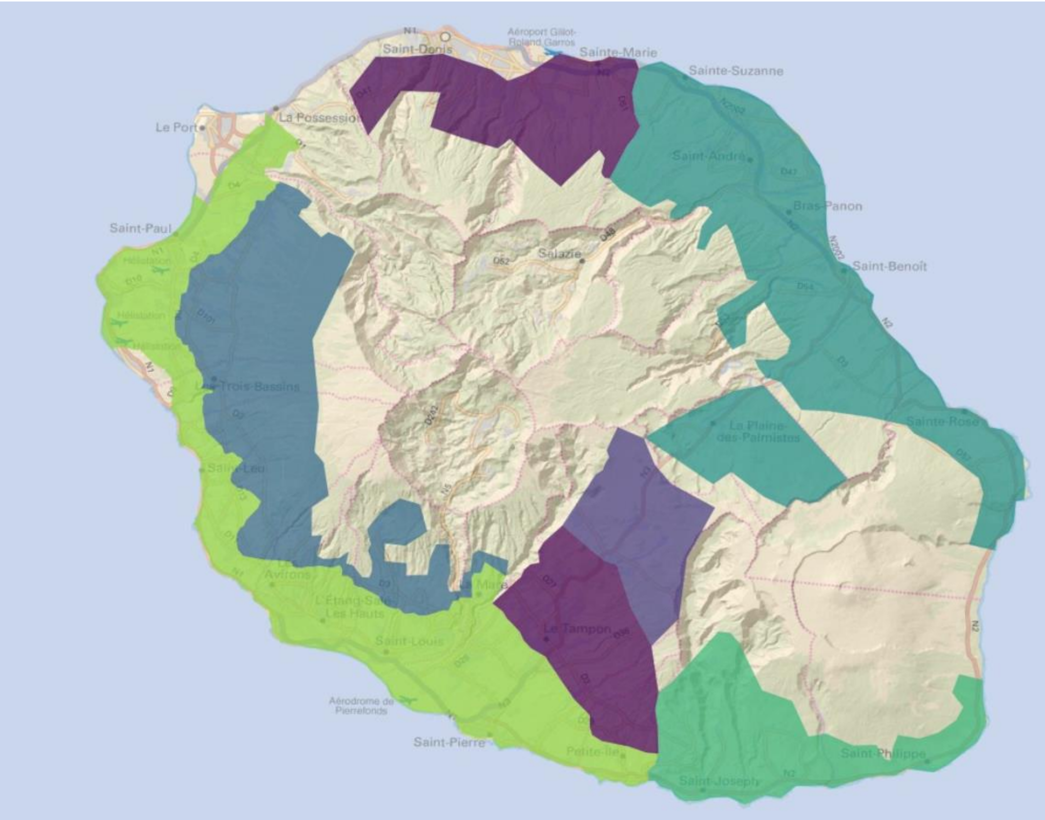
The COMIFER's method does not provide coefficients adapted to Réunion soils. Empirical coefficients were established based on P availability classes in the soil for sugarcane, using the SERDAF method (SERDAF, 2011). No coefficients were established for pastures.

However, a study (NOBILE et al, 2023) shows that most pasture plots are in the "very low" P availability class, according to the classes established by SERDAF. Although these classes were initially established for sugarcane, (NOBILE et al, 2023) suggests that pastures require a higher P input than exports. Therefore, we established a coefficient of 1.5.

Regarding potassium (K), no information is available, and by default, a coefficient Coeff K of 1 is used to estimate potassium needs for the island's pastures.

Mineralization of Soil Nitrogen in Pastures

Analytical work carried out by CIRAD on the island of Réunion from 2005 to 2012 (MIRALLES BRUNEAU et al, 2020) quantified nitrogen inputs resulting from the mineralization of organic nitrogen (see Figure 6) in the absence of external inputs in four different pedoclimatic contexts, covering various altitudes and rainfall levels. On an annual basis, pastures extract over 200 kg of nitrogen per hectare per year, with variations ranging from 200 to 380 kg N/ha/year on the coast and from 170 to 280 kg N/ha/year at 1,600 meters above sea level. However, it is important to note that these data are based on only four collection sites, highlighting the need to supplement this information by including new references. The results should be interpreted with caution due to this limitation in terms of site diversity.



Secteur	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Minéralisation *(kg N/ha/an)*	300	290	230	210	210	100
(min-max)	*(260 - 330)*	*(190 - 370)*	*(170-270)*	*(140-250)*	*(180 - 280)*	*(60 - 150)*

FIGURE 6 : DEGREE OF SOIL NITROGEN MINERALIZATION ACCORDING TO THE SECTOR (=ZONE) IN KG N/HA/YEAR IN LA REUNION (SOURCE ARP 2020)

FertiRun

Fertirun is a fertilizer calculation software for various vegetable and fruit crops, but it has several limitations. It does not incorporate corrective amendments, strengthening inputs, or liming (CHAMBRE D'AGRICULTURE DE LA REUNION, 2018). Additionally, it does not account for residual effects of previous organic fertilizations and lacks precision on the coefficients and reference fertilizers used. These limitations emphasize the need for cautious use and adjustments based on local conditions.

CORPEN Standards

The standards for calculating excreted nutrient quantities, commonly referred to as "CORPEN standards" (DOUBLET et LE GALL, 2013), play a fundamental role in assessing the quantities of nitrogen, phosphorus, and potassium excreted by animals in this report. CORPEN standards evaluate excreted nutrients based on the difference between nutrients ingested through diet and nutrients fixed in meat and milk. These standards are constructed based on assumptions about animal rations and productivity (number of batches in a year for monogastrics, weight at slaughter, annual milk production, etc.). Our calculations follow CORPEN standards based on mainland dietary and productivity data. Currently, there are no plans to recalculate the standards considering specific diets in Réunion.

Pasture Yield and Identification of Plots (Lorre 2019)

To assign a specific yield to each pasture plot, a complex typology and identification of plots were undertaken by LORRE (2019).

Initially, pasture plots for the 2017 reference year were mapped by cross-referencing multiple mapping sources, including existing databases such as the Geographic Parcel Registry (RPG), Land Use Database (BOS), and the Territorial Alert Systems Data Catalog (CASDAT).

Then, yields were defined for a typology of 27 pasture types based on management type (mowing, grazing, wrapped), species, and intensification (mowing frequency, fertilization frequency). Assigning each plot to a plot type is done with the help of local experts, specialized literature, interpretation of aerial photographs, and specific data on selected plots. Like sugarcane, the yields aim to be close to observed real yields on the plots, rather than potential yields, which are often much higher.

It is important to emphasize that this attribution process is complex and requires in-depth expertise to ensure the accuracy of plot type assignment. We lacked the time to re-perform this work with the 2020 reference year.

In terms of area, the pastures identified in 2017 covered a total extent of 10,689 hectares. In 2020, according AGRESTE (2020), pasture areas are estimated at 10,715 hectares, indicating a relative stability in these areas over this period.

2.5 Discussion with Stakeholders

The phase of discussion with stakeholders played a fundamental role in our research methodology. Stakeholders were consulted several times during our study. First, during the calculation of requirements, we consulted experts to obtain their opinions. Additionally, we enlisted researchers specializing in each type of production, including pastures and sugarcane, to obtain relevant information. Ultimately, we were able to access relatively recent sources, allowing us to access up-to-date data. Furthermore, reflections on our results were enriched by discussions with the Chamber of Agriculture, our participation in stakeholder mapping, particularly the stakeholder mapping workshop on circularity (KOUADIO, 2023), and our presence at the final seminar for the Conver co-composting project, enriched our understanding. These interactions provided valuable insights into the results obtained and raised broader questions regarding our work.

PART III: RESULTS

3.1 Quantification of N, P, K from Different MAFOR Sources

The total offer provided by the different MAFOR is of 4,800 tonnes of nitrogen equivalent (Neq), 1,800 tonnes of phosphorus equivalent (Peq), and 7,700 tonnes of potassium equivalent (Keq). (Refer to Figure 7,8,9)

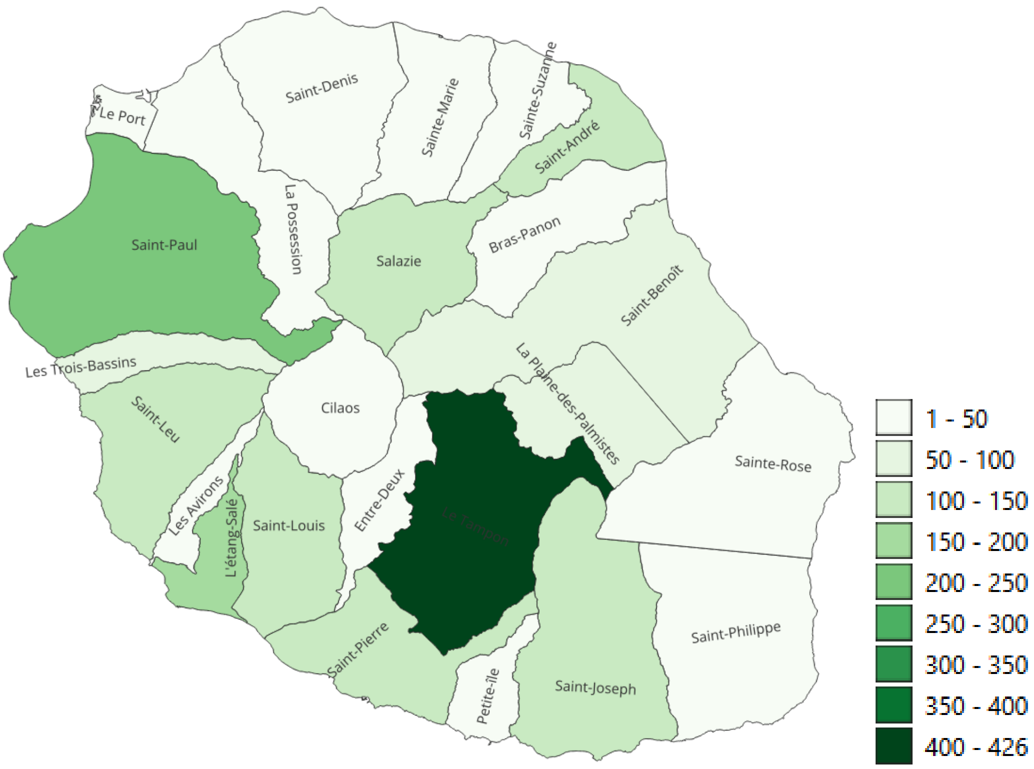


FIGURE 7: OFFER OF NITROGEN IN TONS OF EQUIVALENT FERTILIZER PER COMMUNE IN LA RÉUNION.

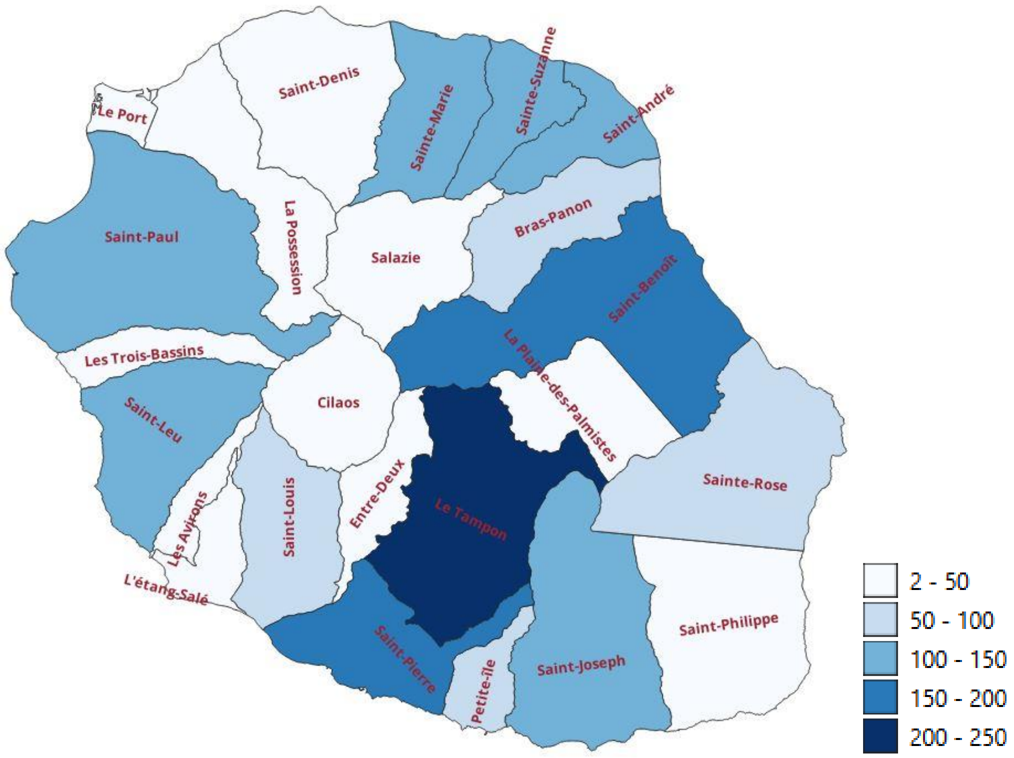


FIGURE 8: OFFER OF PHOSPHORUS IN TONS OF EQUIVALENT FERTILIZER PER COMMUNE IN LA RÉUNION.

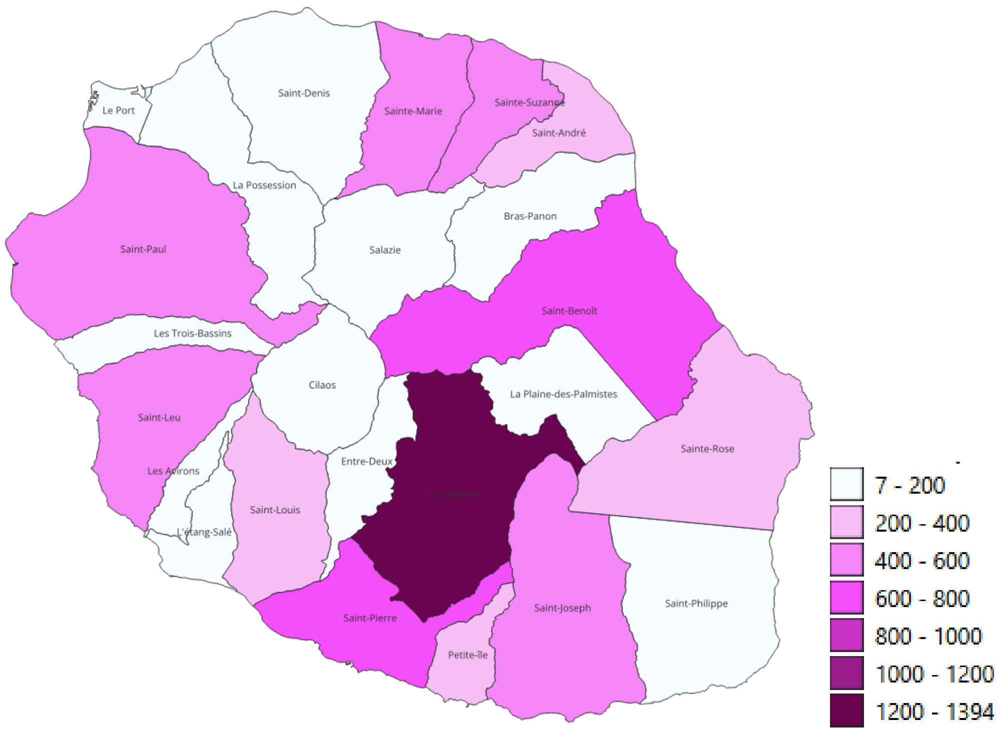


FIGURE 9: OFFER OF POTASSIUM IN TONS OF EQUIVALENT FERTILIZER PER COMMUNE IN LA RÉUNION.

Nitrogen comes from various sources, with 28.2% from cattle grazing (see Figure 10), 24.6% from non-effluent MAFOR, 22.1% from poultry, and 16.7% from pigs.

Regarding phosphorus, non-effluent MAFOR contribute more, accounting for 47% of the total supply, while cattle grazing (16%), pigs (15%), and poultry (13%) also make significant contributions.

For potassium, bovine effluents dominate with 40% of the total K supply, due to their high potassium content, followed by other non-effluent MAFOR at 27.1%, poultry at 12.6%, and pigs at 10.9%.

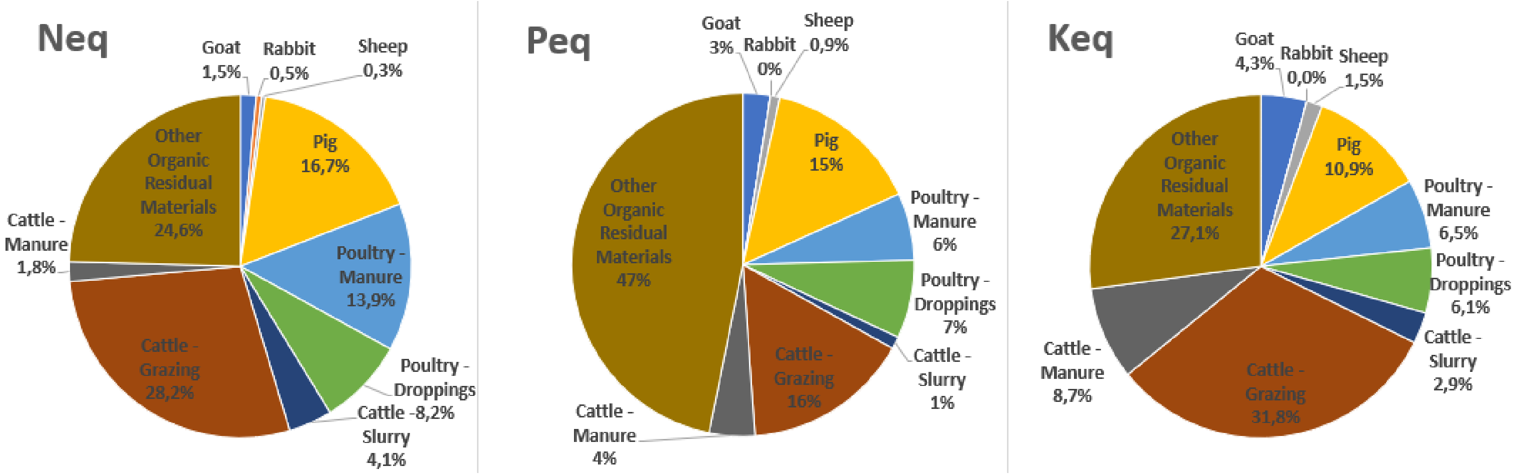


FIGURE 10: PERCENTAGE OF THE TOTAL SUPPLY IN TONS OF LIVESTOCK EFFLUENTS AND OTHER MAFOR FOR NEQ, PEQ, AND KEQ.

An analysis of nutrient delivery per livestock unit (LSU) in different animal categories reveals that despite their low proportion of total LSU (5.39% for cattle and 0.39% for sheep-goats), cattle and sheep-goats significantly contribute in terms of available quantity per LSU, with Neq/LSU indicators of 348 and 257, respectively (while other categories have indicators below 65). This observation can be explained by their ruminant status, which results in the highest effluent production (DOUBLET et LE GALL, 2013).

A closer look at other MAFOR (see figure 11) reveals variable distributions for N, P, or K. Regarding nitrogen, the distribution is balanced among green waste, co-products, waste from the sugar and non-sugar sectors, and multi-co-product and waste composts. Foam, categorized as co-products and waste from the sugar sector, is less represented compared to P and K due to its low equivalent fertilizer coefficient (0.1 compared to 1 for both P and K). Foam is primarily used for phosphorus and calcium (CHABALIER et al, 2007).

For phosphorus and potassium, co-products and waste from the sugar sector play a central role, representing 69% for P and 53% for K of the non-effluent MAFOR inputs. Most of these inputs come from foam produced at the Bois Rouge sugar mill in Saint-André and the Le Gol sugar mill in Saint Louis. For phosphorus, multi-co-product and waste composts are also significant at 16%. Green waste (and derived products) accounts for 30% of these MAFOR (composts and green waste shredding) for potassium, distributed across various green waste platform on the island (Le Port, Saint-Pierre, Saint-Denis, Bras Panon, Sainte-Rose, Saint-André, Le Tampon, and Saint-Leu).

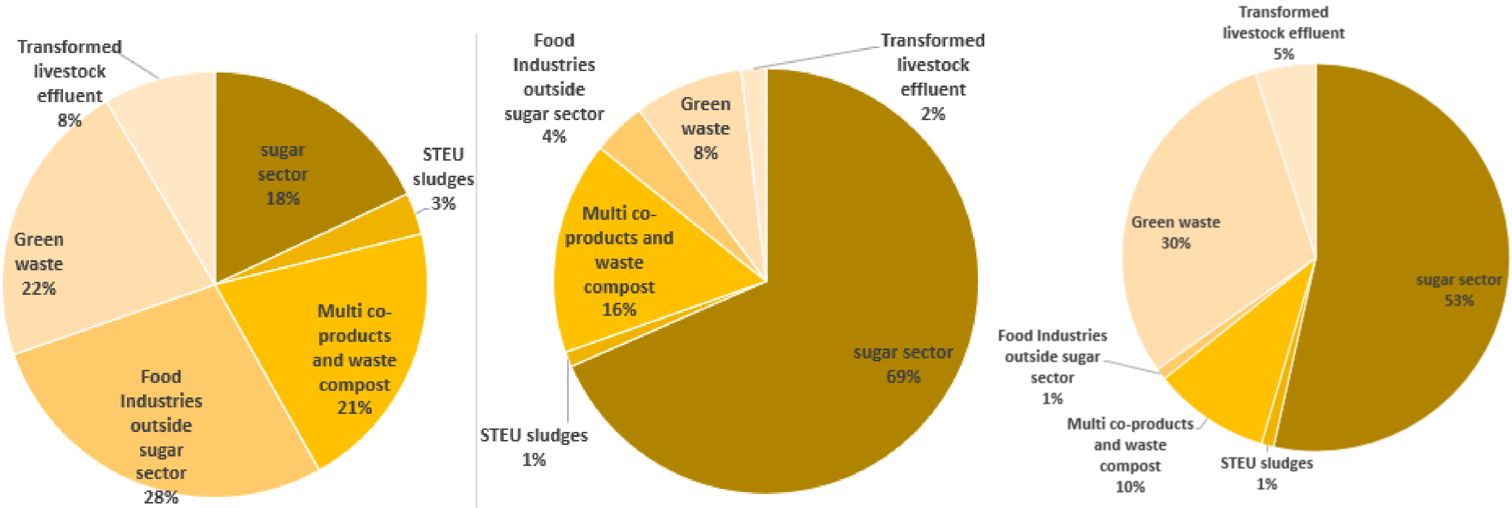


FIGURE 11: PERCENTAGE OF THE TOTAL SUPPLY IN TONS OF OTHER MAFOR THAN LIVESTOCK EFFLUENTS FOR NEQ, PEQ AND KEQ.

3.2 Crop Needs

The total needs for nitrogen, phosphorus, and potassium equivalents for sugarcane, pastures, and horticultural crops have been determined as 1,800 tonnes, 1,130 tonnes, and 7,730 tonnes, respectively (see figure 12, 13 and 14)

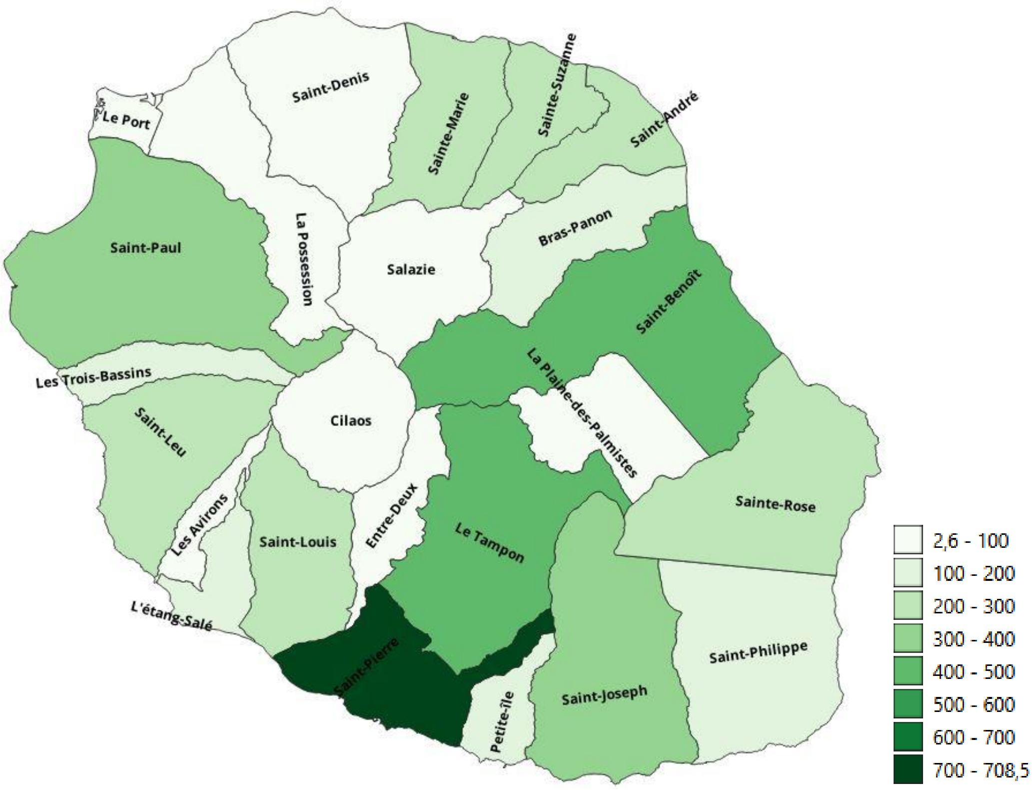


FIGURE 12: NEEDS OF NITROGEN IN TONS OF EQUIVALENT FERTILIZER PER COMMUNE IN LA RÉUNION.

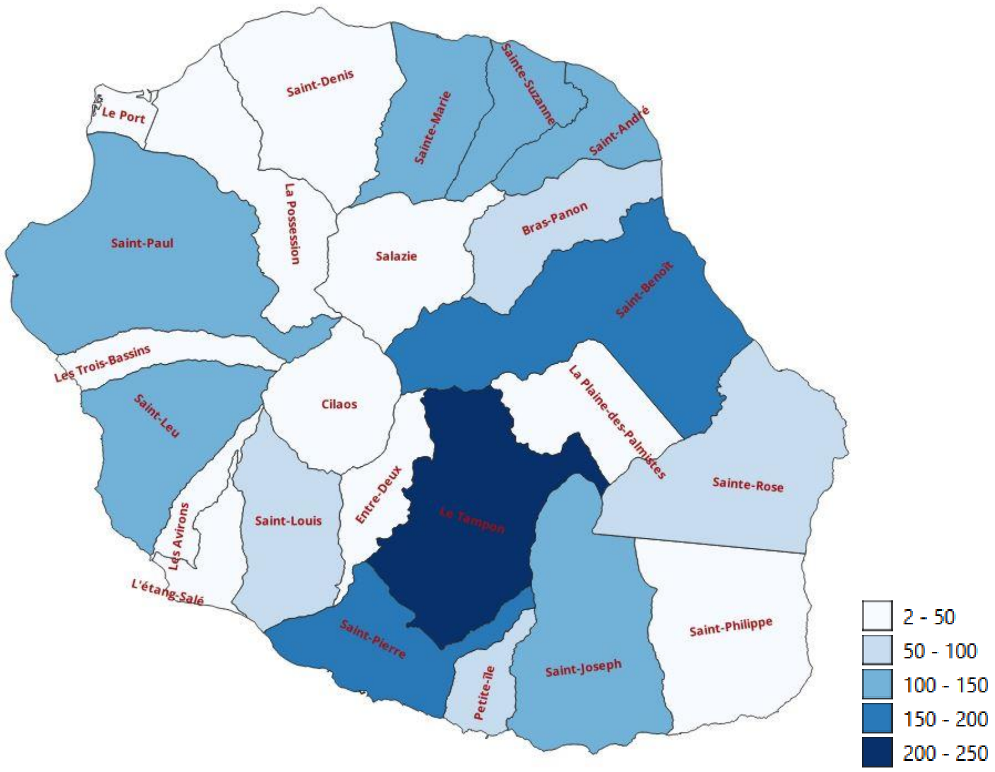


FIGURE 13: NEEDS OF PHOSPHORUS IN TONS OF EQUIVALENT FERTILIZER PER COMMUNE IN LA RÉUNION.

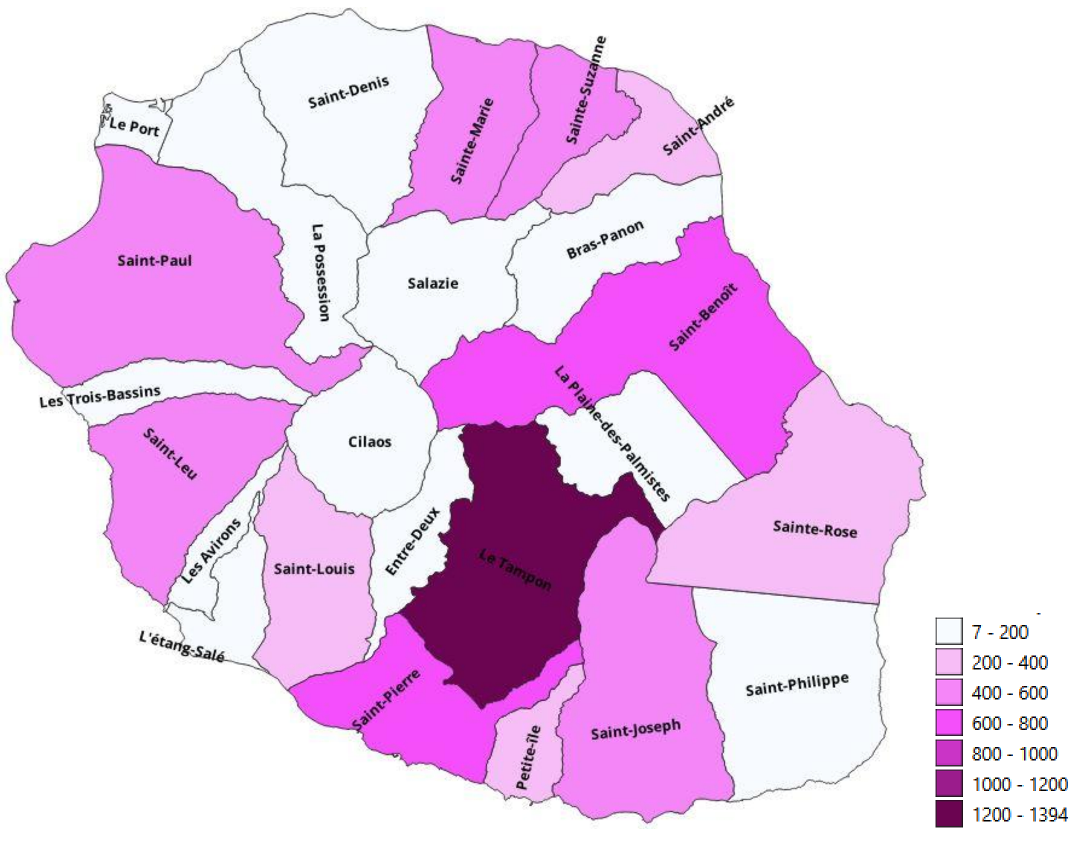


FIGURE 14: NEEDS OF POTASSIUM IN TONS OF EQUIVALENT FERTILIZER PER COMMUNE IN LA RÉUNION.

These needs are distributed interestingly (see table 1). Sugarcane has a particularly high demand for nitrogen and phosphorus, pastures require a significant amount of potassium, and horticultural/arboricultural crops have lower phosphorus requirements. Specifically, sugarcane covers 55% of the agricultural land used (AGU) but contributes to 60% of the nitrogen (Neq), 68% of phosphorus (Peq), and 51% of potassium (Keq) needs. Pastures cover 28% of AGU, but their contribution to nutrient needs is 26% for Neq, 24% for Peq, and 35% for Keq. Horticulture/arboriculture, on the other hand, occupies 17% of AGU but require 14% for Neq, 8% for Peq, and 14% for Keq.

TABLEAU 1: DISTRIBUTION OF DIFFERENT CROPS IN HA, NEQ, PEQ, AND KEQ

	Ha	Neq	Peq	Keq
Sugarcanne	55%	60%	68%	51%
Pastures	28%	26%	24%	35%
Horticulture/arboriculture	17%	14%	8%	14%

As expected, the coastal areas in the west and east, as well as the plains between the two mountainous regions, have the highest representation of nutrient needs due to their larger agricultural land facilitated by flatter terrains. This contrasts with more mountainous communes in the center of the island, such as Cilaos or Salazie, where nutrient needs are less than 100 tonnes.

Regarding nitrogen, the main communes in demand are:

- Saint-Pierre with 708 tonnes
- Saint-Benoît with 497 tonnes
- Le Tampon with 464 tonnes

Saint-Pierre benefits from a mixture of nitrogen from pastures (49%) and sugarcane (41%), while Saint-Benoît relies on sugarcane for 81% of its nitrogen needs, and Le Tampon derives the majority of its nitrogen needs (58%) from pastures.

For phosphorus, the three main communes are also:

- Saint-Pierre (188 tonnes)
- Saint-Benoît (197 tonnes)
- Le Tampon (242 tonnes)

Regarding potassium:

- Le Tampon stands out with almost double the production (1394 tonnes)
- Saint-Pierre (768 tonnes)
- Saint-Benoît (733 tonnes)

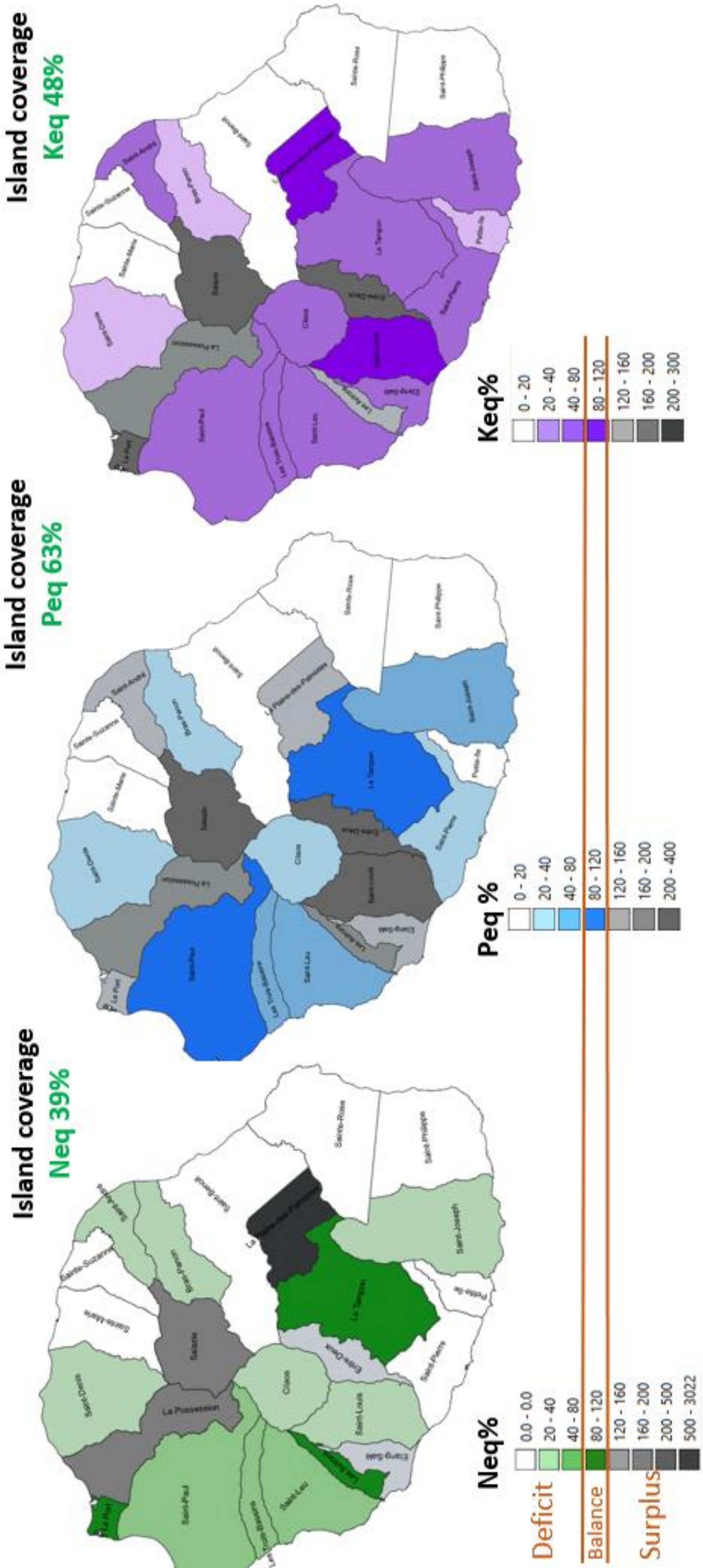


FIGURE 15: MAPS OF (%) COVERAGE IN NEQ, PEQ, AND KEQ PROVIDED BY MAFORS FOR CROP NEEDS/COMMUNE.

The distribution of nutrients in Le Tampon can be explained by the fact that pastures, of which this commune has a significant quantity, generally require more potassium than other crops, with an average demand of 253 kg/ha, compared to 203 kg/ha for sugarcane and 189 kg/ha for phosphorus. Furthermore, the nitrogen needs of pastures are relatively low due to the proportion between exports (as per the method) being relatively low compared to high mineralization in this commune.

In summary, the specific distribution of N, P, and K nutrient needs in communes varies depending on the distribution of different crops and the presence of pastures.

3.3 N, P, K Balances

3.3.1 Island-Wide Results

The analysis of data concerning nutrient supply and demand (Neq, Peq, and Keq) by commune has allowed us to create maps illustrating the coverage provided by MAFOR for crops, as shown in Figure 15. On the scale of the island, this results in a coverage of 39% for nitrogen, 63% for phosphorus, and 48% for potassium. Overall, there is a nutrient deficit on the island. The map identifies communes in deficit (coverage less than 80%), those in balance (80% to 120% coverage), and those with nutrient excess (more than 120% coverage). It should be noted that communes in balance vary for different nutrients (nitrogen, phosphorus, and potassium). Table 1 summarizes the number of communes in deficit, in balance, and in excess, with a predominance of communes in deficit, 16 for nitrogen, 13 for phosphorus, and 17 for potassium.

Number of communes		**Neq**	**Peq**	**Keq**
Deficit		16	13	17
Balance		3	2	2
Surplus	**Transportable**	4	8	4
	Not transportable	1	1	1

TABLEAU 2: NUMBER OF COMMUNES IN DEFICIT, BALANCE OR IN SURPLUS (TRANSPORTABLE OR NOT) FOR EACH NUTRIENT IN FERTILIZER EQUIVALENT.

Figure 16 provides a visual representation of the supply and demand on the island in terms of fertilizer equivalent nutrients N, P, and K, highlighting the transportability aspect of MAFOR. As described in section 2.2.1 of the methodology, bovine grazing effluents and slurry (from pigs and cattle) have been grouped into the "non-transportable" category to emphasize their limited ability to be transported outside the considered communes. This category represents 907 tonnes of Neq (37% of the total supply of MAFOR), 412 tonnes of Peq (36%), and 1848 tonnes of Keq (56%).

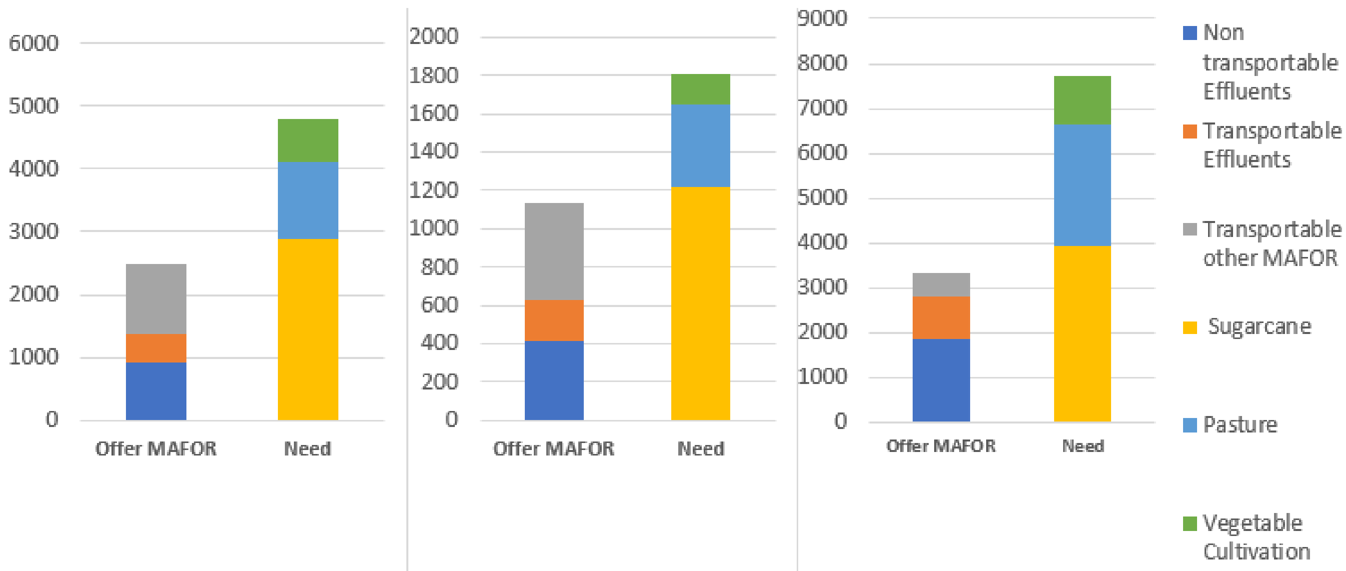


FIGURE 16: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER (IN TONS) PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN LA REUNION

In the following sections, we will examine in detail: the communes in excess, distinguishing those where the transport of excess MAFOR to neighboring communes is possible from those where it is not; communes in balance; and communes with nutrient deficits.

3.3.2 Communes in Excess

As previously observed, several communes have excess nutrients, namely five for nitrogen (N), nine for phosphorus (P), and five for potassium (K) (see Table 2). This section provides examples illustrating various scenarios of excess, including one where livestock effluents are predominant, another where non-livestock related MAFOR are predominant, and a case where excess nutrients cannot be transported.

La Possession: Excess of Transportable Effluents

In La Possession, where poultry farming predominates, poultry droppings and poultry manure, both easily transportable (shown in orange in Figure 17), represent 93%, 92.5%, and 95% of the excess nitrogen (N), phosphorus (P), and potassium (K) equivalent fertilizers, respectively. Although there are excesses in N and P, the majority of these excesses are transportable, leaving a negligible proportion (in this case, from cattle grazing effluents) that could be attributed to local crops.

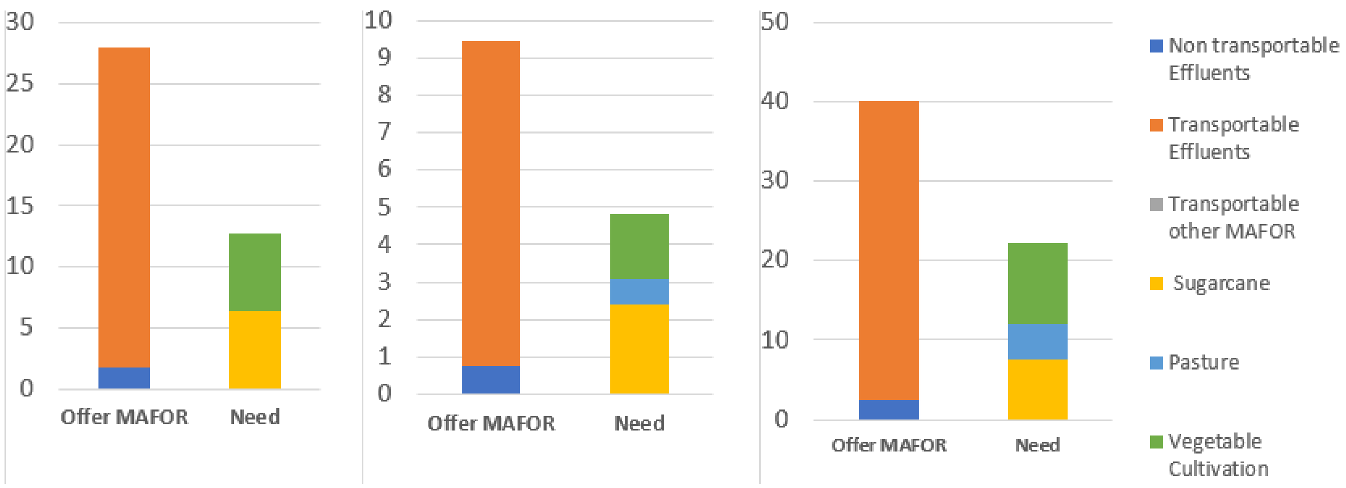


FIGURE 17: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN LA POSSESSION.

Saint Louis: Excess of Non-Effluent MAFOR

In the case of Saint-Louis, there is an excess of phosphorus, with a coverage of 305% (see figure 18), mainly attributable to foam from the sugar sector, rather than livestock effluents. This form of excess is easily transportable.

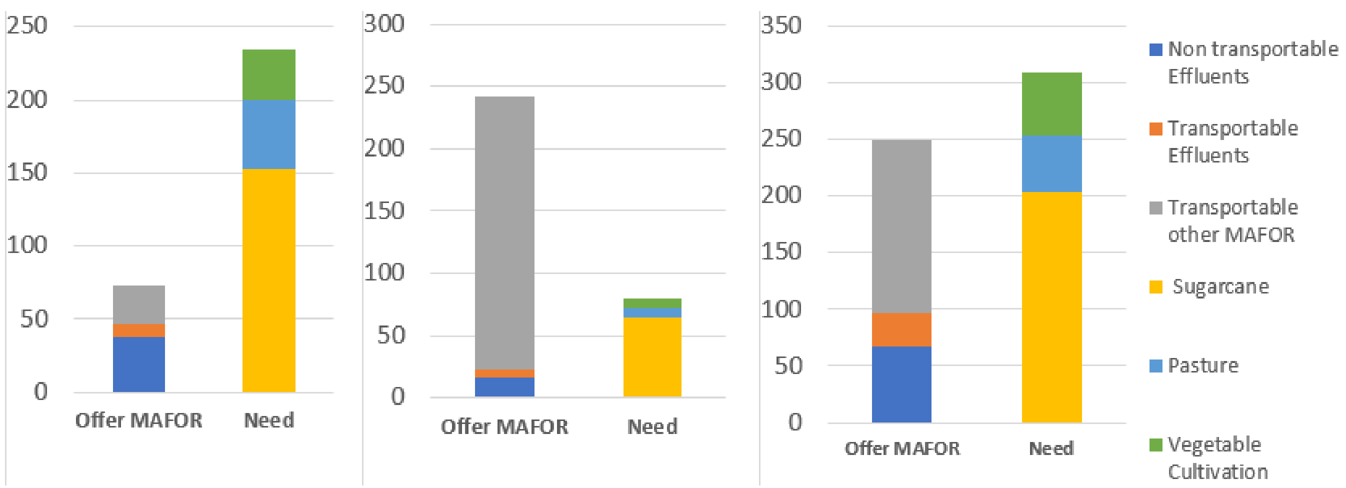


FIGURE 18: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN SAINT-LOUIS.

Salazie: Excess of Non-Transportable Effluents

Take Salazie as another example, where excess nutrients are not transportable. This commune has substantial excesses of nitrogen (148 tonnes), phosphorus (55 tonnes), and potassium (106 tonnes) due to poultry farming and pig slurry. However, the non-transportable excesses (in orange in Figure 19), representing pig slurry, cannot be used in horticulture/arboriculture due to strict sanitary standards. Analyzing these excesses in relation to crops other than horticulture/arboriculture (i.e., pig slurry on sugarcane), a significant surplus is observed, reaching 742% for nitrogen, 680% for phosphorus, and 592% for potassium.

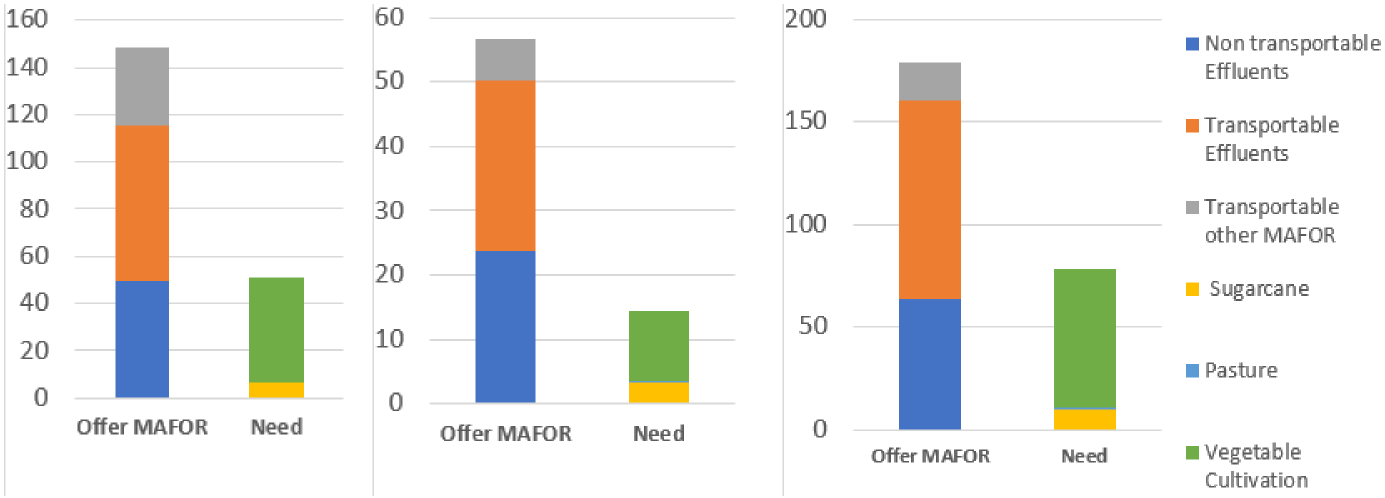


FIGURE 19: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN SALAZIE.

3.3.3 Communes in Balance

The analysis of communes in balance for at least one nutrient reveals a variety of scenarios. Indeed, no commune is in balance for all three nutrients (N, P, K) simultaneously. Imbalances between nutrients vary among communes.

Les Avirons example:

In the case of Les Avirons, although the total nutrient quantity is relatively modest, the commune maintains a satisfactory balance, with a coverage of 109% for nitrogen (N) and 87% for potassium (K), covering 27 tonnes of Neq out of 31 tonnes required (see figure 20). However, a significant excess of phosphorus (P) is observed, reaching a coverage of 185%. It should be noted that the quantity of pig slurry, classified as non-transportable due to its categorization, exceeds the cumulative needs of the commune's different crops by two tonnes. This small quantity could have a limited environmental impact, and its transport could be considered.

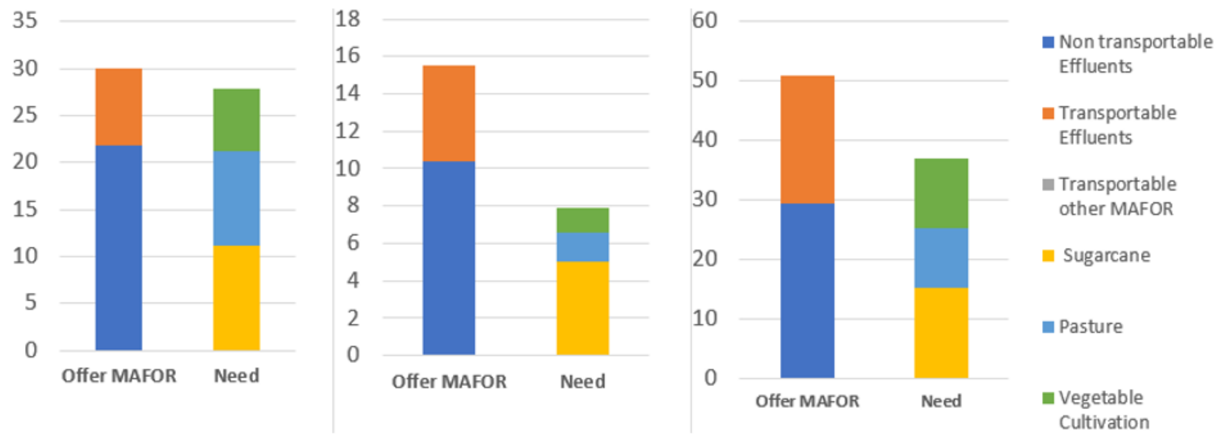


FIGURE 20: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN LES AVIRONS.

Le Tampon example:

The commune of Le Tampon is the only commune with balance for all nutrients, with coverage rates of 92% for nitrogen (N), 82% for phosphorus (P), and 79.6% for potassium (K) in equivalent fertilizers (see figure 21). The balance achieved by Le Tampon is mostly explained by the equilibrium between local pasture's needs and grazing effluents.

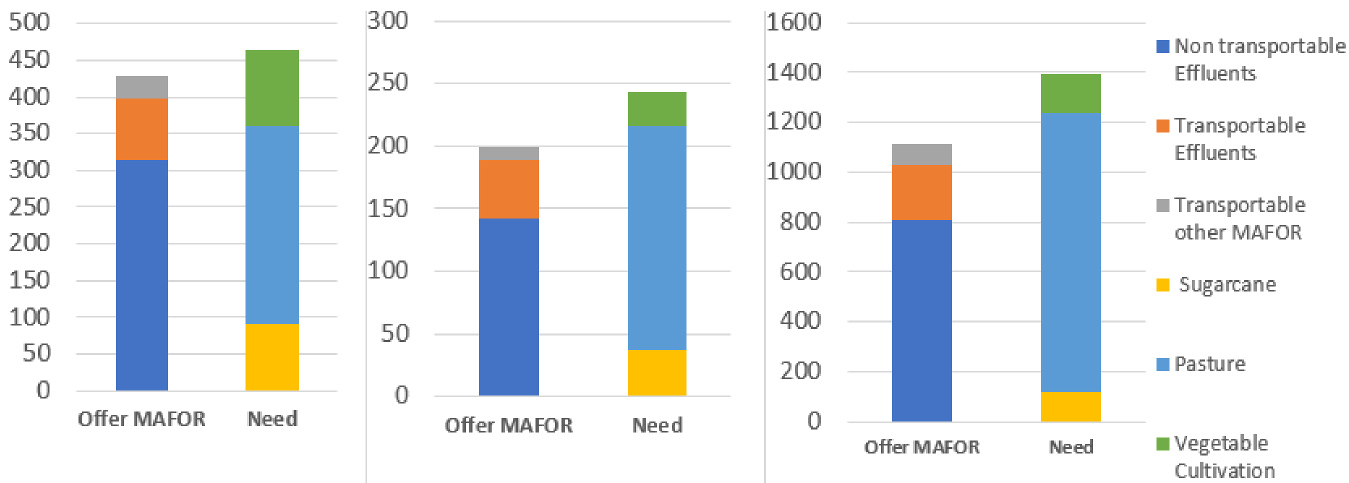


FIGURE 21: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN LE TAMPON.

Similarly, Saint-Paul maintains a satisfactory balance, with coverage of 99% for phosphorus (P), although it shows a deficit in nitrogen (N) with 64% coverage and in potassium (K) with 46% coverage.

Finally, the commune of Le Port is also in balance for nitrogen (89% coverage), but it shows a significant excess of phosphorus (133%) and potassium (218%). This notable disparity is explained by the primary production of green waste mulch and green waste compost, with fertilizer equivalence values of 0.1, 0.5, and 1 for N, P, and K, respectively. This specificity explains the distribution of excesses observed in this commune.

These results highlight the complexity of nutrient dynamics in the different communes studied, reflecting the specificities of their local agricultural and environmental activities.

3.3.4 Communes with Nutrient Deficits

The analysis of communes with deficits in nutrients reveals a variety of scenarios. As expected, deficit communes predominate: 16 for nitrogen, 13 for phosphorus, and 17 for potassium out of 24 communes (see table 2). This is an expected result, given the deficit coverage at the island level (see Figure 14).

Firstly, seven communes, all located on the east coast (except Petite-Île), namely Saint-Benoît (see figure 22), Bras-Panon, Sainte-Marie, Saint-Rose, Sainte-Suzanne, and Saint-Philippe, experience deficits mainly attributable to high nutrient demands associated with sugarcane cultivation, which is prevalent in this region, and low production of MAFOR related to or unrelated to livestock.

Similarly, other communes, such as Saint-Denis and Saint-Joseph, experience deficits due to higher nutrient requirements than inputs, where sugarcane and horticulture/arboriculture are predominant.

For Saint-Leu and Saint-Louis, the deficit results from a combination of excessive needs related to sugarcane and pastures.

Les Trois-Bassins exhibit a deficit mainly attributable to the needs of pastures.

These different scenarios illustrate the complexity of nutrient deficits in the studied communes, reflecting various agricultural dynamics on the island of Réunion.

Saint-Benoît example :

FIGURE 22: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN SAINT-BENOÎT.

Furthermore, more complex situations are emerging where certain communes display different deficits, balances, or surpluses depending on the nutrients. For instance, the

Avirons commune has a surplus in phosphorus and potassium and a deficit in nitrogen (K). In Étang-Salé (see Figure 23), there is an excess of N and P (with a coverage of 144% for N and 150% for N) alongside a deficit in K (55% coverage). In Saint-André, there is a deficit in N and K accompanied by a surplus in P, primarily due to green waste and by-products from the sugar industry. Finally, Saint-Paul experiences a deficit in N and K but maintains a balance in P. These results arise from different combinations of supply and demand. Indeed, as seen previously, crops require varying amounts of N, P, or K (see 3.2.1), and the various MAFORS have different nutrient compositions (see 1.2.1). For example, in Étang-Salé, the excess of N and P can be attributed to the abundance of feather and blood meals, which are rich in these nutrients. In Saint-André, the surplus in P comes from scum (84% of the inputs), which is high in this nutrient and low in N and K.

Example of l'Etang-Salé :

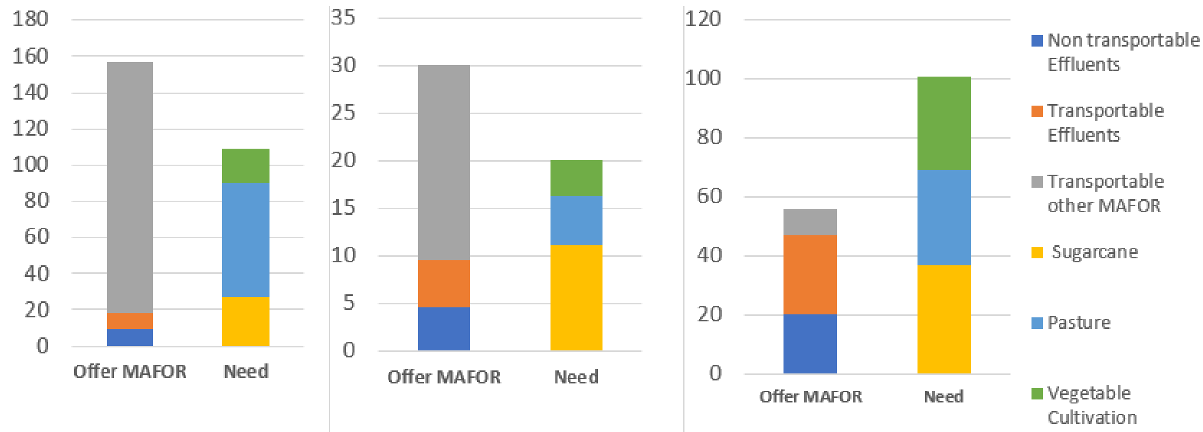


FIGURE 23: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN L'ÉTANG-SALÉ.

PART IV: DISCUSSION

4.1 Partial Nutrient Autonomy

4.1.1 Autonomy at the Island Scale?

In our analysis of nutrient autonomy in Réunion, it is evident that the territory fails to fully meet the nutrient needs of its crops. Our study reveals partial coverage, with only 39% of nitrogen (Neq) needs, 63% of phosphorus (Peq) needs, and 58% of potassium (Keq) needs for crops being fulfilled by MAFOR already used, derived from livestock effluents and listed in GABIR for plant production.

Overall, this situation indicates a nutrient deficit at the island level, with a shortage of 2905 tonnes of nitrogen (Neq), 745 tonnes of phosphorus (Peq), and 4692 tonnes of potassium (Keq) to meet agricultural needs.

According to (KLEINPETER et al., 2023), Réunion imports 3800 tonnes of nitrogen in the form of chemical fertilizers each year, while 2905 tonnes are lacking to cover crop needs. Therefore, theoretically, 900 tonnes of chemical nitrogen could be saved. Other data are currently pending in the SELMET unit to perform the same analysis for phosphorus and potassium.

Comparison of Results with the Chamber of Agriculture

Our results significantly differ from those of the Chamber of Agriculture in 2022. According to them, MAFOR only cover 21% of nitrogen needs, 84% of phosphorus needs, and 30% of potassium needs (CONROZIER, 2022).

The main reasons for these differences lie primarily in the crops and MAFOR considered. This study only considers temporary temperate grasslands (1,768 hectares) and does not account for grazing animals. Our study includes grazing and all grasslands (10,000 hectares).

Different assumptions were made regarding crop needs. For sugarcane, for instance, the study estimates a requirement of 70 kg P2O5/ha/year. In our study, the sugarcane needs are assessed at the plot level, assuming low phosphorus availability in the soil. On average, we calculated a requirement of 116 kg P2O5/ha/year.

Lastly, the effluent calculator used only considered two categories of pigs (sows and piglets). We used three categories (sows, piglets, and fattening pigs), which increased the estimate of nutrient excretion from the pig population.

These discrepancies can be explained by methodological differences and assumptions between the two studies.

4.1.2 Autonomy at the Commune Scale?

The analysis focused on communes reveals a great diversity of situations regarding nutrient balance. It is essential to note that no commune achieves balance for all three essential nutrients, namely nitrogen (N), phosphorus (P), and potassium (K) simultaneously. Conversely, imbalances vary considerably from one commune to another, depending on their specific agricultural activities and the presence of grasslands.

This diversity of situations highlights the complexity of nutrient dynamics in Réunion's different communes. N, P, and K needs vary depending on the distribution of crops and the density of grasslands, reflecting local specificities.

However, a structural problem exists in the commune of Salazie. Nutrient surpluses, mainly from pig slurry, cannot be transported to other areas due to strict sanitary standards. When analyzing these surpluses in relation to crops other than horticulture/arboriculture, such as sugarcane present in the commune, a significant excess is observed, reaching 742% for nitrogen, 680% for phosphorus, and 592% for potassium of coverage. This situation underscores the environmental challenges posed by such surpluses and emphasizes the need to find responsible solutions for managing these excesses. The environmental issue in Salazie related to nutrient surpluses is already well-known. In fact, the closure of the Cooperative for Livestock Effluent Treatment of Grand Îlet (CTEEGI) in Camp Pierrot sparked outrage among pig breeders in Salazie. However, solutions are being explored to manage these surpluses more responsibly. The use of phase separators is one of the approaches being considered. These devices separate undesirable elements from slurry, making it easier to use without causing excessive environmental damage. Co-composting with green waste shreddings from communes is also being considered. Co-composting trials were conducted during the CONVER project. This solution requires the transport of shreddings from surrounding communes to Salazie, followed by the transport of the newly produced compost from Salazie to other communes. Additionally, some breeders are considering switching from slatted flooring to straw bedding to produce manure, which is more transportable than slurry.

4.2 Perspectives on Improving MAFOR Management

4.2.1 Organization of MAFOR Transport

The feasibility of transporting MAFOR, especially livestock effluents, in Réunion is a complex issue that depends on several factors. As we have observed, some communes may have surpluses of one nutrient while showing deficits in others. However, as soon as one of the three essential nutrients is in excess, the spreading of these surpluses becomes prohibited, necessitating their transfer to neighboring communes with deficits, primarily located in the southern and eastern regions of the island.

The road network in Réunion is a crucial element in this equation. The island experiences periods of heavy traffic, especially on the main road that circles the island, which can make transportation problematic during peak hours. However, during working hours, traffic remains relatively smooth, facilitating exchanges between communes.

Another challenge lies in the mountainous regions of the island, where many farms are located. The roads in these areas often have steep slopes and less developed road networks, which can pose problems for effluent transportation. Previous studies have already highlighted concerns of breeders in some communes regarding the time, cost, and environmental impact of effluent transport (JARRY, 2019).

To better understand the implications of MAFOR transport in Réunion, CIRAD is working on spatial modeling of effluent transport using the Ocelet simulation software. (DEGENNE et al, 2019) modeled on Ocelet the transport that would optimally cover crop needs with MAFOR in the commune of Saint-Joseph. This allowed obtaining indicators of distances traveled for effluent transport and the use of different road network segments (see figure 24).

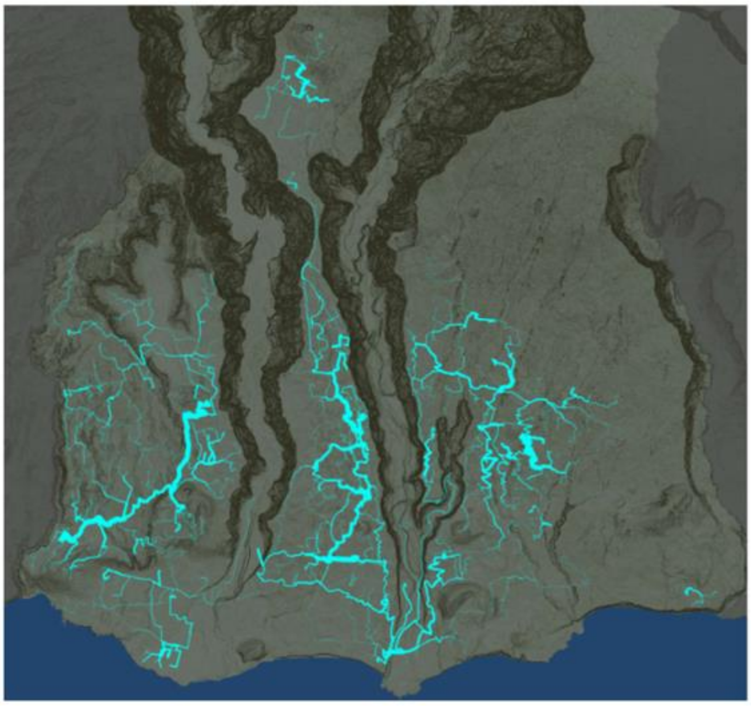


FIGURE 24: SIMULATION OF THE QUANTITIES OF EFFLUENT TRANSPORTED PER PORTION OF THE CURRENT ROAD NETWORK (JARRY R.).

4.2.2 Valorization and Transformation

An interesting solution discussed is the valorization of surplus MAFOR, which would reduce the often-cumbersome transport of these organic materials, including manure and slurry. To achieve this, various stakeholders, such as farmers and haulers, are already working with co-composting techniques. This approach involves mixing livestock effluents with other organic materials to accelerate their maturation and produce nutrient-rich compost.

The surplus of nutrients identified in the results of this study aligns with (DARRAS, 2019) on the valorization and transformation of MAFOR in Réunion through co-composting.

Co-composting offers several advantages, including a reduction in odor nuisances, improved sanitary quality of the final product, reduced spreading distances, and beneficial agronomic use for soil fertility. It also provides economic benefits, such as the possibility of selling compost, and environmental benefits by promoting a circular approach to resources.

Nevertheless, implementing co-composting requires significant material investments and compliance with strict regulatory standards. Choice of transformation facility locations, such as co-composting units, must be strategic to minimize the transportation costs of raw materials, such as shreddings and slurry. Access to funding, particularly from the European Agricultural Fund for Rural Development, is essential for the realization of these projects. Finally, farmers require technical and regulatory support to embark on such initiatives. Breeders, awaiting the Réunion Federation of Agricultural Cooperatives (FRCA), are seeking solutions to optimize these transfers, which could help address the issue of surpluses (DARRAS, 2019).

The approach of valorizing MAFOR, although essential for improving the island's nutrient autonomy, should not be considered automatically sustainable. It is crucial to carefully assess the environmental footprints associated with these input and output flows because in some cases, the benefits of a circular approach may be offset by negative environmental impacts (KOUADIO, 2023).

4.2.3 Considering Buried MAFOR

The results of this study primarily focus on livestock effluents identified by the GABIR project (KLEINPETER et al, 2019) as directed towards plant production. However, the same project has also identified other MAFOR that are currently buried or disposed of but could be valorized to increase nutrient coverage by MAFOR (see figure 25). Taking these additional nutrients into account resulted in an estimated 12% increase in nitrogen equivalent (Neq) coverage, equivalent to 537 tonnes Neq, bringing the total coverage to 50%. Additionally, phosphorus experienced a significant increase, reaching 75% coverage, thanks to an additional 221 tonnes of Peq, while potassium recorded a 4% increase, representing 321 tonnes Keq, with a total coverage of 52%.

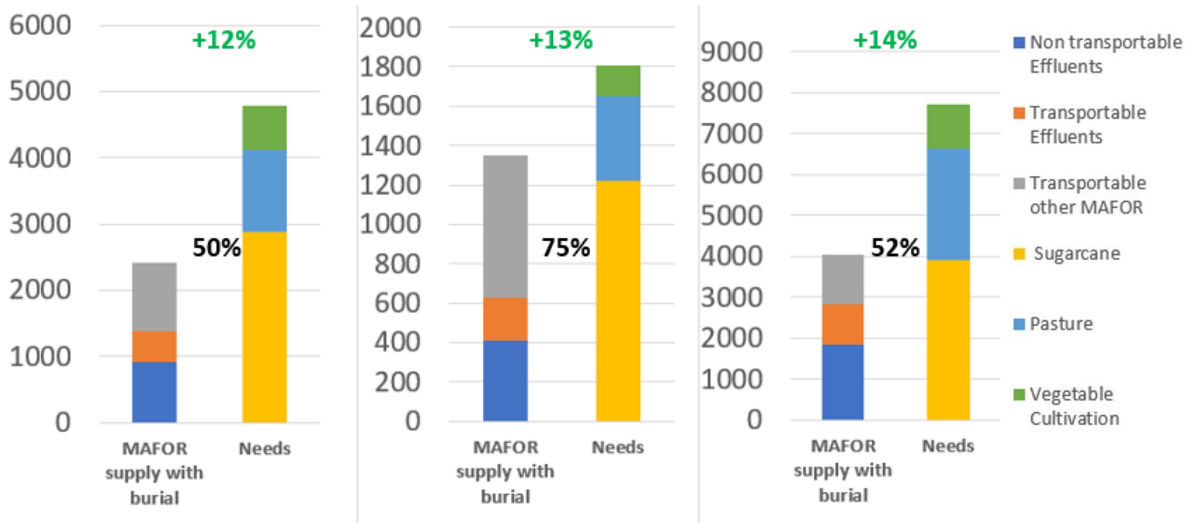


FIGURE 25: QUANTITY OF NITROGEN, PHOSPHORUS, POTASSIUM EQUIVALENT FERTILIZER PROVIDED BY MAFOR SUPPLY WITH BURIAL AND REQUIRED FOR THE NEEDS OF DIFFERENT CROPS IN LA REUNION

It is crucial to note that new laws are now in effect to regulate the management of organic waste in Réunion. The Law for Energy Transition and Green Growth (LTECV), enacted in 2015, mandates source separation and valorization through composting and/or methanization of organic waste by 2025 (KLEINPETER et al, 2019). This regulation applies to all waste producers, including large producers.

Faced with these nutrient surpluses and the new legislation, several solutions emerge for more sustainable management of organic waste. Firstly, it is essential to reconsider current disposal methods, including burial and incineration, which present environmental and capacity problems (JIQUEL, 2020).

To meet the LTECV requirements, Réunion must now develop tailored technical solutions for source separation of organic waste and its recycling. The regulation aims to steer towards valorization pathways, especially organic ones, with a target of 65% by 2025 for non-hazardous non-inert waste (JIQUEL, 2020).

Several options are available for more sustainable organic waste management in Réunion (JIQUEL, 2020). Firstly, methanization is a promising solution that decomposes organic matter into methane gas (biogas) and digestate. Biogas can be used for energy production, while digestate is a nutrient-rich residue suitable for use as fertilizer. The geographical distribution of facilities across the Réunion territory facilitates the implementation of these installations, although it requires infrastructure investments and qualified labor.

Secondly, composting is a proven method for organic waste valorization. It transforms organic waste into compost, a valuable organic amendment for agricultural soils. Réunion already has several composting facilities, but their capacity needs to be adjusted to meet the growing demand. Additionally, the PoVaBiA model offers a way to model compost quality based on incoming materials, which can contribute to improving the use of this product.

Thirdly, composting digestate from methanization is another promising approach. This method allows for obtaining high-quality compost by further valorizing the residues from methanization. Composting digestate can also help reduce nutrient surpluses by transforming waste into a useful agricultural product.

4.3 Methodological Improvement Points for Nutrient Balances

4.3.1 Limitations

In our study, it is important to note that we used various data sources, each with varying degrees of precision (see Section 2.4). For instance, to assess the needs of grasslands and sugarcane, we could use highly precise yield data, but we encountered lower levels of precision in quantifying soil mineralization. Furthermore, horticulture/arboriculture yields are much less well-documented than those of sugarcane and grasslands.

We also chose to adopt a short-term approach, considering only the mineral portion of spread MAFOR. When these MAFOR are spread, the organic portion enriches the soil, contributing to increased nutrient availability in the soil in the following years. This balance is therefore valid only in the short and medium term and should be revised in the long term after soil analyses quantify this change.

Finally, the contribution of legumes was not included in the nitrogen balances due to a lack of reliable sources.

4.3.2 Perspectives

To improve the accuracy of our study, several avenues emerge. Firstly, it is essential to continue accurately assigning MAFOR to specific crops. For example, it is already considered that slurry is unsuitable for horticulture/arboriculture due to existing regulations, while pastures are intended for grasslands.

Additionally, it is crucial to consider local regulations, especially regarding the distance from buildings, as highlighted by JARRY (2019) in her work on the commune of Saint Joseph. Extending this analysis to the entire island would provide a better understanding of the specific regulatory constraints in each area.

Finally, the indicator of nutrient needs coverage by MAFOR provides only a partial view of the island's nutrient autonomy. Indeed, the nutrients from livestock effluents, the majority in the MAFOR pool, are indirectly sourced from imports. (KLEINPETER et al. 2023) shows that 70% of the nitrogen consumed by livestock comes from concentrates imported to the island. Some of this nitrogen is fixed in milk and meat, and another part is excreted as effluent, usable for crops. This raises questions about the actual degree of nutrient autonomy of the island and the need to use multiple indicators to characterize this autonomy (KLEINPETER et al, 2023).

The follow-up to this study will allow for a more precise assessment of the possible reduction in chemical fertilizer imports to the island. As part of M. Alvanitakis' thesis, the environmental benefits of this reduction will be assessed through life cycle analysis (LCA). The study will focus on the environmental impact of nitrogen supply, as nitrogen is often the limiting factor for plant growth and a key component of chemical fertilizers. By reducing chemical fertilizer imports and substituting them with locally available nitrogen from MAFOR, Réunion can potentially decrease its carbon footprint associated with fertilizer production and transportation.

CONCLUSION

In conclusion, the objective of this study was to determine the self-sufficiency of the island of La Réunion in essential nutrients, namely nitrogen (N), phosphorus (P), and potassium (K), both at the scale of the entire island and at the commune level. Our approach relied on a balance methodology, involving the calculation of crop requirements and the evaluation of available MAFORs reserves by commune, using fertilizer equivalent indicators to simplify calculations. This analysis was synthesized in the form of maps and a comprehensive Excel spreadsheet, providing detailed data for each commune.

The results of our study shed light on La Réunion's current situation in terms of nutrient self-sufficiency. At the island level, we observe a significant deficit, with rates of 39% for nitrogen, 63% for phosphorus, and 48% for potassium. This reality partly explains the significant quantity of synthetic fertilizers imported to fill these gaps. We have shown that there is a difference of 900 tons of nitrogen equivalent fertilizer between the total input of fertilizers on the island (organic and chemical) and the total crop requirements. A reduction in the importation of these inputs seems possible.

At the commune level, significant disparities are observed, reflecting the variability of crop requirements and the differentiated nutrient richness of available MAFORs. Overall, communes are naturally deficient in MAFOR reserves compared to their requirements, with 17 communes deficient in nitrogen, 15 in phosphorus, and 20 in potassium. Other communes have an excess of MAFORs. Most of these surplus communes have the possibility to transport their MAFORs, considered transportable, to other communes in deficit. However, Salazie face a structural surplus, where the excess of non-transportable MAFORs (manure and manipulable excretion) compared to plant needs is concerning.

Although methodological limitations have been raised and are expected to be addressed in future projects (matching MAFORs with crops, considering regulations, etc.), this study constitutes a diagnosis of the initial state of MAFOR reserves and requirements on the island. This diagnosis will be useful for stakeholders to consider better territorial management of MAFORs, to transport nutrients from surplus areas to nutrient-deficient areas at a lower cost.

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Appendix

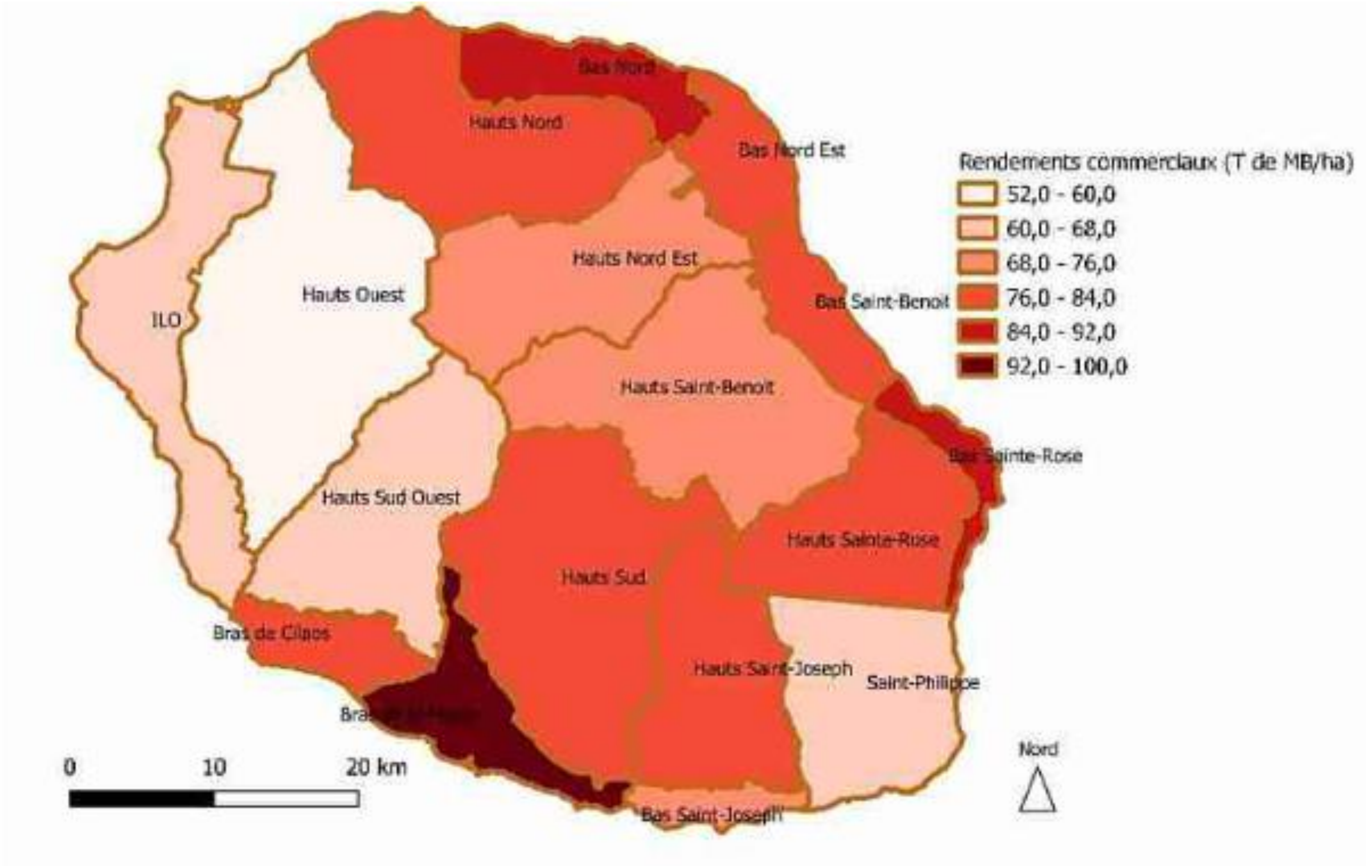
Appendix 1:

Cheptel	Rejet N (t/an)	Rejet N (% total)	Rejet pâture (tN/an)	Rejet bâtiment (tN/an)	Lisier (tN/an)	Fumier Litière (tN/an)	Fumier autre (tN/an)	Fiente (tN/an)
J/01	26 468	2%	20 177	6 201	-	6 201	-	-
Equins	**26 468**	**2%**	**20 177**	**6 201**	**-**	**6 201**	**-**	**-**
J/02/a	23 897	1%	9 744	13 997	543	12 861	594	-
J/02/b	53 284	3%	26 555	26 309	1 002	24 125	1 183	-
J/02/c	5 338	0%	-	5 332	3 066	1 754	512	-
J/03	66 898	4%	46 090	20 076	564	18 740	772	-
J/04	130 776	8%	88 192	41 186	1 552	37 780	1 854	-
J/05	41 586	2%	26 536	14 627	468	13 660	498	-
J/06	133 061	8%	84 646	47 060	1 762	43 657	1 641	-
J/07	442 397	26%	239 063	199 545	17 005	162 381	20 158	-
J/08	428 521	25%	342 308	80 789	4 593	71 560	4 637	-
Bovins	**1 325 760**	**77%**	**863 133**	**448 921**	**30 554**	**386 518**	**31 849**	**-**
J/09/a	75 551	4%	54 310	21 002	-	21 002	-	-
J/09/b	9 482	1%	-	9 482	-	9 482	-	-
J/09/c	6 672	0%	4 785	1 867	-	1 867	-	-
Ovins	**91 706**	**5%**	**59 095**	**32 351**	**-**	**32 351**	**-**	**-**
J/10/a	11 606	1%	2 455	9 140	-	9 140	-	-
J/10/b	2 547	0%	-	2 547	-	2 547	-	-
J/10/c	1 509	0%	237	1 271	-	1 271	-	-
Caprins	**15 662**	**1%**	**2 692**	**12 958**	**-**	**12 958**	**-**	**-**
J/11	14 933	1%	-	14 938	13 868	1 001	69	-
J/12	23 423	1%	-	23 442	20 784	2 267	391	-
J/13	105 122	6%	-	105 187	96 778	7 248	1 161	-
Porcins	**143 478**	**8%**	**-**	**143 567**	**131 431**	**10 515**	**1 621**	**-**
J/14/1	28 483	2%	-	28 483	-	28 483	-	-
J/14/2	15 381	1%	-	15 381	-	15 381	-	-
J/15/a	27 974	2%	-	41 952	-	-	27 974	13 978
J/15/b	3 386	0%	-	3 386	-	1 693	1 693	-
J/16/a11	11 033	1%	-	11 033	11 033	-	-	-
J/16/a12	18	0%	-	18	18	-	-	-
J/16/a21	9 653	1%	-	9 653	9 653	-	-	-
J/16/a22	17 187	1%	-	17 187	17 187	-	-	-
J/16/b1	5 568	0%	-	5 568	-	5 568	-	-
J/16/b2	1 599	0%	-	1 599	-	1 599	-	-
J/16/c1	426	0%	-	426	-	426	-	-
J/16/d1	687	0%	-	687	-	-	-	687
J/16/e1	828	0%	-	828	-	828	-	-
J/16/e2	1 558	0%	-	1 558	-	1 558	-	-
J/17	3 369	0%	-	3 369	3 369	-	-	-
Volailles	**127 149**	**7%**	**-**	**141 127**	**41 259**	**55 536**	**29 667**	**14 665**
Total	**1 730 000**	**100%**	**945 000**	**786 000**	**203 000**	**504 000**	**63 000**	**15 000**

<u>Appendix 2: Table of the % of cattle effluent (l), manure (f), and grazing (p) for each RGA category and commune created by establishing an equivalence between the Magnier J. categories and effluent types (pre-assigned matching between a Magnier J. category and an effluent type) (personal source).</u>

	Categorie RGA correspondante	Categorie < 1 an	Categorie < 1 an	Catégorie entre 1 et 2 ans	Catégorie entre 1 et 2 ans	Femelles > 2 ans	Femelles > 2 ans	Male > 2 ans	Male > 2 ans	Male > 2 ans	Vaches allaitantes	Vache laitiere	Total général
Insee_comr	Type d'effluent	f	p	f	p	f	p	f	l	p	p	l	
97401		0,0%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97402		0,0%	0,0%	0,0%	100,0%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97403		100,0%	0,0%	100,0%	0,0%	100,0%		100,0%	0,0%	0,0%	100,0%	100,0%	100,0%
97404		0,0%	0,0%	65,9%	34,1%	100,0%	0,0%	48,9%	15,6%	35,6%	100,0%	100,0%	100,0%
97405		0,0%	100,0%	62,4%	37,6%	0,0%	100,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97406		22,0%	78,0%	9,1%	90,9%	16,7%	83,3%	0,0%	15,4%	84,6%	100,0%	100,0%	100,0%
97408		0,0%	0,0%	0,0%	100,0%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97409		0,0%	0,0%	0,0%	100,0%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97410		0,0%	100,0%	17,4%	82,6%	0,0%	100,0%	24,0%	0,0%	76,0%	100,0%	100,0%	100,0%
97411		0,0%	100,0%	15,2%	84,8%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97412		47,2%	52,8%	68,2%	31,8%	72,7%	27,3%	11,7%	34,0%	54,4%	100,0%	100,0%	100,0%
97413		6,4%	93,6%	41,6%	58,4%	31,6%	68,4%	0,0%	28,1%	71,9%	100,0%	100,0%	100,0%
97414		0,0%	100,0%	55,3%	44,7%	0,0%	100,0%	25,8%	0,0%	74,2%	100,0%	100,0%	100,0%
97415		2,2%	97,8%	23,1%	76,9%	5,9%	94,1%	0,2%	6,2%	93,6%	100,0%	100,0%	100,0%
97416		4,7%	95,3%	65,0%	35,0%	5,7%	94,3%	3,9%	7,9%	88,2%	100,0%	100,0%	100,0%
97417		0,0%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97418		0,0%	100,0%	85,2%	14,8%	0,0%	100,0%	3,2%	0,0%	96,8%	100,0%	100,0%	100,0%
97419		0,0%	0,0%	53,8%	46,2%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97420		0,0%	0,0%	0,0%	100,0%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97421		0,0%	0,0%	0,0%	100,0%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
97422		14,7%	85,3%	56,4%	43,6%	34,2%	65,8%	8,3%	31,5%	60,2%	100,0%	100,0%	100,0%
97423		5,0%	95,0%	63,0%	37,0%	12,6%	87,4%	0,0%	8,3%	91,7%	100,0%	100,0%	100,0%
97424		0,0%	100,0%	0,0%	100,0%	26,0%	74,0%	0,0%	0,0%	100,0%	100,0%	100,0%	100,0%
Total général		12,0%	88,0%	53,8%	46,2%	26,0%	74,0%	6,9%	15,8%	77,3%	100,0%	100,0%	100,0%

Appendix 3: Sugarcane Yield: Average commercial yields (T RM/ha) by zone (Terreos, 2019)



Appendix 4: the table of equivalence between LORRE F. and MIRALLES BRUNEAU M.'s meadow categories along with their descriptions (personal source).

Typologie LORRE F.	Description	Typologie MIRALLES BRUNEAU M.
Prairie tempérée pâturée	pâturage continu ou tournant très lent (>10 jours sur une parcelle, rotation>4	Pâturage à rotation lente
Prairie tempérée pâturée	Pâturage tournant lent (de 7 à 10 jours sur une parcelle, rotation de 30 jours	Pâturage à rotation lente
Prairie tempérée pâturée	Pâturage tournant (temps de séjour<7jours, rotation 15 à 20 jour selon les sa	Pâturage à rotation rapide ou continu
Prairie kikuyu pâturée	pâturage continu ou tournant très lent (>10 jours sur une parcelle, rotation>4	Pâturage à rotation lente
Prairie kikuyu pâturée	Pâturage tournant lent (de 7 à 10 jours sur une parcelle, rotation de 30 jours	Pâturage à rotation lente
Prairie kikuyu pâturée	Pâturage tournant (temps de séjour<7jours, rotation 15 à 20 jour selon les sa	Pâturage à rotation rapide ou continu
Prairie tempérée fauchée	2 fauches max, en été	Enrubannage tardif
Prairie tempérée fauchée	3-4 fauches en été	Ensilage ou enrubannage précoce
Prairie tempérée fauchée	6-7 fauches tout au long de l'année	Ensilage ou enrubannage précoce
Prairie kikuyu fauchée	2 fauches max, en été	Enrubannage tardif
Prairie kikuyu fauchée	3-4 fauches en été	Ensilage ou enrubannage précoce
Prairie kikuyu fauchée	4-5 fauches, principalement en été, quelques unes en hiver si herbe dispon	Ensilage ou enrubannage précoce
Prairie tropicale fauchée	5-6 coupes étalées sur l'année	Foin tardif
Prairie tropicale fauchée	7-8 coupes étalées sur l'année	Foin précoce
Prairie tropicale fauchée	8-10 coupes étalées sur l'année	Foin précoce
Prairie tempérée mixte à dominance pâturage	1 fauche en été quand surplus d'herbe,pâturage continu ou tournant très ler	Pâturage à rotation lente
Prairie tempérée mixte à dominance pâturage	1 à 2 fauche l'été quand surplus d'herbe. Reste de l'année pâturage tournar	Pâturage à rotation lente
Prairie tempérée mixte à dominance pâturage	plus de 2 fauches l'été, pâturage tournant le reste de l'année	Pâturage à rotation rapide ou continu
Prairie kikuyu mixte à dominance pâturage	1 fauche en été quand surplus d'herbe,pâturage continu ou tournant très ler	Pâturage à rotation lente
Prairie kikuyu mixte à dominance pâturage	1 à 2 fauche l'été quand surplus d'herbe. Reste de l'année pâturage tournar	Pâturage à rotation lente
Prairie kikuyu mixte à dominance pâturage	plus de 2 fauches l'été, pâturage tournant le reste de l'année	Pâturage à rotation rapide ou continu
Prairie tempérée mixte équilibrée	3 fauches max pendant l'été, pâturage continu ou tournant très lentle reste	Ensilage ou enrubannage précoce
Prairie tempérée mixte équilibrée	3-4 fauches penant l'été, reste de l'année pâturage tournant lent	Ensilage ou enrubannage précoce
Prairie tempérée mixte équilibrée	4 à 5 fauches pendant l'été et la mi-saison, pâturage tournant le reste de l'a	Ensilage ou enrubannage précoce
Prairie kikuyu mixte équilibrée	3 fauches max pendant l'été, pâturage continu ou tournant très lentle reste	Ensilage ou enrubannage précoce
Prairie kikuyu mixte équilibrée	3-4 fauches penant l'été, reste de l'année pâturage tournant lent	Ensilage ou enrubannage précoce
Prairie kikuyu mixte équilibrée	4 à 5 fauches pendant l'été et la mi-saison, pâturage tournant le reste de l'a	Ensilage ou enrubannage précoce
Prairie tempérée mixte à dominance fauche	3-4 fauches de septembre à juin.Pâturage continu ou tournant très lent per	Ensilage ou enrubannage précoce
Prairie tempérée mixte à dominance fauche	4 -5 fauches de septembre à juin.Pâturage tournant lent pendant juillet aoû	Ensilage ou enrubannage précoce
Prairie tempérée mixte à dominance fauche	6-7 fauches de septembre à juin.Pâturage tournant pendant juillet août	Ensilage ou enrubannage précoce
Prairie tropicale ensilée	4-5 coupes étalées sur l'année	Enrubannage tardif
Prairie tropicale ensilée	5-6 coupes étalées sur l'année	Ensilage ou enrubannage précoce
Prairie tropicale ensilée	7-8 coupes étalées sur l'année	Ensilage ou enrubannage précoce
Prairie tropicale (bracharia) paturee	pâturage continu ou tournant très lent (>10 jours sur une parcelle, rotation>4	Pâturage à rotation lente
Prairie tropicale (bracharia) paturee	Pâturage tournant lent (de 7 à 10 jours sur une parcelle, rotation de 30 jours	Pâturage à rotation lente
Prairie tropicale (bracharia) paturee	Pâturage tournant (temps de séjour<7jours, rotation 15 à 20 jour selon les sa	Pâturage à rotation rapide ou continu

Appendix 5: example of cattle numbers for different categories in Reunion, based on data from the 2020 General Agricultural Census.

	Total bovins	Total vaches	Vaches laitères	Vaches allaitantes	Mâles et femelles de moins de 4 mois	Mâles et femelles de 4 à moins de 8 mois	Mâles et femelles de 8 à moins de 12 mois	Mâles de 1 à moins de 2 ans	Femelles de 1 à moins de 2 ans	Mâles de plus de 2 ans	Bovins de plus de 2 ans mâles castrés	Bovins de plus de 2 ans mâle non castrés	Femelles de plus de 2 ans
Commune	CHEPTQ_	CHEPTQ_	CHEPTQ_	CHEPTQ_	CHEPTQ_	CHEPTQ_	CHEPTQ_112300	CHEPTQ_	CHEPTQ_113030	CHEPTQ_113020	CHEPTQ_	CHEPTQ_113022_DOM	CHEPTQ_113040
97401	142	54	0	54	7	14	8	11	11	10	1	9	27
97402	81	32	0	32	0	0	5	10	6	16	0	16	12
97403	136	0	0	0	0	0	30	99	54	10	0	10	3
97404	364	119	40	79	17	24	8	20	143	13	10	3	20
97405	270	33	0	33	22	68	55	64	18	1	0	1	9
97406	562	268	136	132	47	49	15	7	64	44	0	44	68
97407	0	0	0	0	0	0	0	0	0	0	0	0	0
97408	23	2	0	2	0	0	0	0	0	10	2	8	11
97409	31	17	2	15	4	2	1	0	1	6	2	4	0
97410	215	106	2	104	4	27	14	6	26	13	0	13	19
97411	58	22	7	15	1	4	0	6	7	14	0	14	4
97412	1255	485	289	196	79	77	133	170	156	56	1	55	39
97413	2635	1360	265	1095	243	287	176	121	230	90	22	68	128
97414	385	273	0	273	51	107	157	153	151	56	7	49	37
97415	1802	907	45	862	128	131	112	100	169	95	10	85	160
97416	1563	390	42	348	73	92	282	229	280	150	15	135	67
97417	89	54	0	54	10	10	0	2	11	2	0	2	0
97418	224	76	0	76	8	20	0	110	5	5	0	5	0
97419	153	53	0	53	0	30	1	0	5	6	0	6	58
97420	69	38	0	38	0	2	3	3	3	15	2	13	5
97421	253	106	0	106	14	26	8	35	23	25	2	23	16
97422	13171	6138	2020	4118	1421	1261	804	564	1584	230	14	216	1169
97423	1249	663	75	588	103	123	91	28	124	46	0	46	71
97424	37	10	0	10	0	0	0	10	3	7	0	7	7
Total	**25427**	**11206**	**2923**	**8283**	**2232**	**2354**	**1903**	**1748**	**3074**	**920**	**88**	**832**	**1990**

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway