HORTINVEST
PROJECT

Assessment of the current status of soil fertility and quality, and fertilizer availability in Rwanda's horticultural sector

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List of Acronyms and Abbreviations

CEC	Cation Exchange Capacity
IABM	Iterambere ry' Abahinziborozi Ba makera
KABU	Koperative y' Abahinzi B' imboga n' Ubutunguru
KAIDU	Koperative y' Abahinzi b' Imboga n' imbuto Duhinge neza.
KOABIBIKA	Koperative y' Abahinzi b' Ibigori n' Ibishyimbo ba Karongi
KOGIMUIN	Koperative Girisuku Muhinzi w'Imboga Nyabihu
MINAGRI	Ministry of Agriculture and Animal Resources
MINICOM	Ministry of Commerce, Trade and Industry
UMU	Umurimo w'Umwuga
NPK	Nitrogen, phosphorus, potassium
WUR	Wageningen University and Research Centre
RAB	Rwanda Agriculture Board
MINAGRI	Ministry of Agriculture and Animal Resources

1. Executive summary

This report aims to identify the soil properties at a number of locations in the 6 HortInvest's districts of intervention, the current farming activities that the farmers are performing in those 6 districts and how these are related to soil fertility and soil quality management, and presents the results of a survey on fertilizer availability and their market in Rwanda. Much of the report is qualitative and does not elaborate on for instance nutrient balances.

The work was executed in collaboration with HortInvest's field/office staffs, farmers and agrodealers. Also, some HortInvest project's and some nation publications data were used in order to have a precise and good work done.

Farmers, agrodealers, administrative agronomists and other persons in agricultural extension services have to collaborate, to easily manage the horticulture sector while ensuring a good productivity. Sometimes farmers need a continuation access on their soil's properties information, the type and quantity of the fertilizers they need and their availability on the nearby or general agrodealership market. This information can be provided by persons in agriculture extension services (mostly agronomists), agrodealers and other extension officers in the region. From the interviewees point of views there are some main points identified, and those include but not limited to, the possibility of Nkunganire program to be Harmonized on a point that the farmers can get the inputs from a nearby agrodealer rather than from a sector level based agrodealer, foliar fertilizer were found claimed by a good number of farmers as a source of a good productivity, farmers and agrodealers see the current agrodealership market as a small and expensive sector and that can sometimes affects the access of inputs on time and most of the agrodealers do not have a good capital that can easily satisfy the farmers.

So, a strong partnership between all the concerned people (public and private parties) in this horticulture sector will deliver good services and will positively affect the sector in a good (in quality and quantity) productivity while keeping in mind the good market of the farmers' produces.

2. Introduction

2.1 About HortInvest

The HortInvest project aims to increase farmers' incomes, increase the relative contribution of the horticultural sector to the regional economy in north western Rwanda, and improve the food and nutrition security of the targeted households. HortInvest will help realize the Rwandan National Horticulture Policy to create fast economic growth and reduce poverty and malnutrition. The project covers six target districts in north-western Rwanda.

The HortInvest programme consists of four main components, aligned with Rwanda's National Horticultural Policy's intended outcomes:

1. Domestic & Regional Markets: improving market-led production and supply of fruits and vegetables for domestic and regional markets.
2. Food & Nutrition Security: Enhancing food and nutrition security for rural households involved in horticulture and for urban consumers.
3. Export Development: Developing high-value horticultural supply chains for export markets.
4. Enabling Environment: strengthening the enabling environment for horticulture.

2.2 Why soil quality?

Soil quality is a measure of the condition of soil relative to the requirement of more biotic species and to any human need or purpose. One of HortInvest project's activity is to contribute to improved soil fertility and quality in the project's six selected targeted districts (Karongi, Muhanga, Ngororero, Nyabihu, Rubavu and Rutsiro).

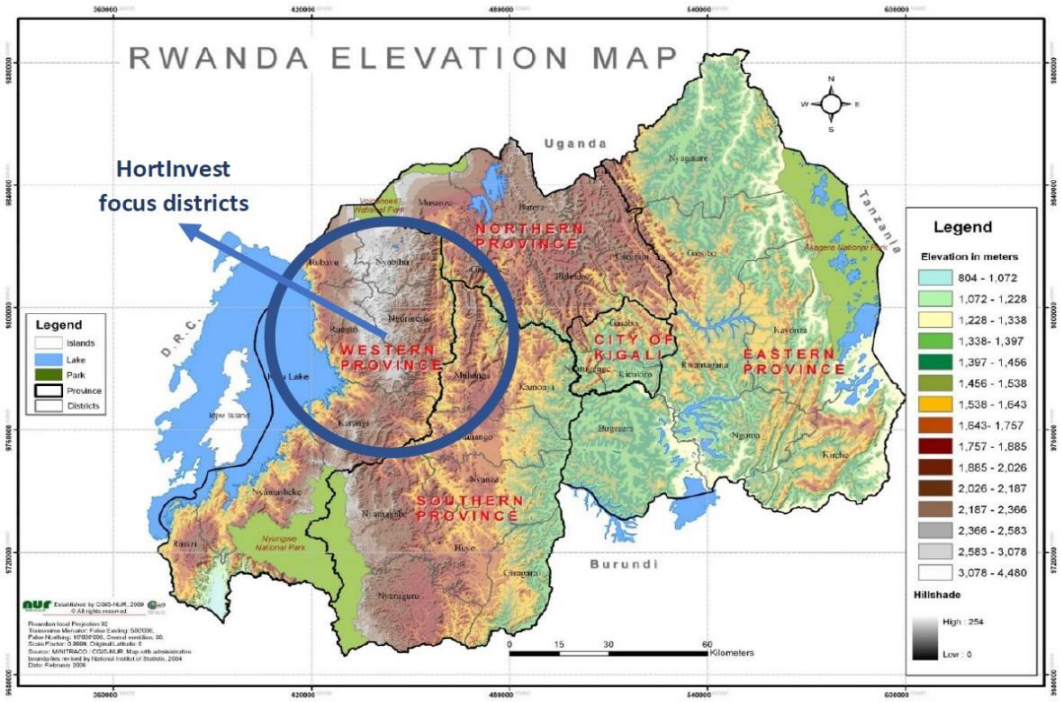


Figure 1. Focal area of the HortInvest project.

2.3 Objectives of the assignment

The objectives of the assignment were to:

1. Provide a quantitative description of soil properties at the locations in the six target districts where HortInvest is active (demonstration plots, business cases, and cooperatives).
2. Describe and quantify current farmers' practices on managing soil fertility & quality.
3. Investigate the availability of fertilizers on the Rwandese market, and give recommendations for improvement of the situation.

2.4 Approach

The following steps were taken:

1. Soil maps were developed using available data from the Rwanda Ministry of Agriculture and Animal Resources (MINAGRI) and soil samples taken during the base line survey of the HortInvest project to identify and the soil properties in the 6 HortInvest districts.
2. HortInvest field Coordinator shared information on current farmers' practices on managing soil fertility and quality.
3. Farmers and agrodealers were interviewed with regards to the fertilizer market.
4. Information from other publications was used (see reference at the end of this document).

2.5 Methods used

1. The questionnaire was developed

2. The survey was done to collect data from farmers and agrodealers in Muhanga, Ngororero, Karongi, Nyabihu, Rutsiro and Rubavu.

3. Soil samples were obtained and analysed for nutrients.

4. The availability and quality of fertilizers on the market was analysed.

5. Recommendations for interventions, and supporting capacity strengthening and knowledge transfer were developed.

6. A quantitative description of current farmers' practices proved not possible. Instead, a qualitative description was provided.

3. Quantitative description of soil properties

3.1 General description of soil properties

All soils contain mineral particles, organic matter, water and air, and their combination determines the soil properties: **texture** (sand, silt and clay particles), **structure** (how particles are mend together), **porosity** (soil's pores and how they influence water and air movement), **chemistry** (soil's nutrients, nutrients solubility and availability to plants, **pH** and **CEC** (a measure of how many cations can be retained on soil particle surfaces) and **colour** (indicating the topsoil type and predict the soil composition).

From all the 12 Soil Classes of the USDA soil taxonomy, Rwanda knows 9, viz. Alfisols, Andosols, Entisols, Histosols, Inceptisols, Mollisols, Ultisols, Oxisols and Vertisols ***(Innoncent N., I., Alfred E., Viollette G., (2014))***

These soils are characterized by different soil properties (see section 3.3 for a more detailed description).

3.2 Soil classification and properties in the 6 target districts

Also HortInvest's 6 target districts know the above mentioned soil types. Except for the Rubavu district, where the soil is mostly characterized by rocks, all districts are dominated by Inceptisols and Ultisols. Besides those two types also Entisols, Oxisols and Alfisols can be found. See Figure 2 for an overview of presence of soil types in the selected districts.

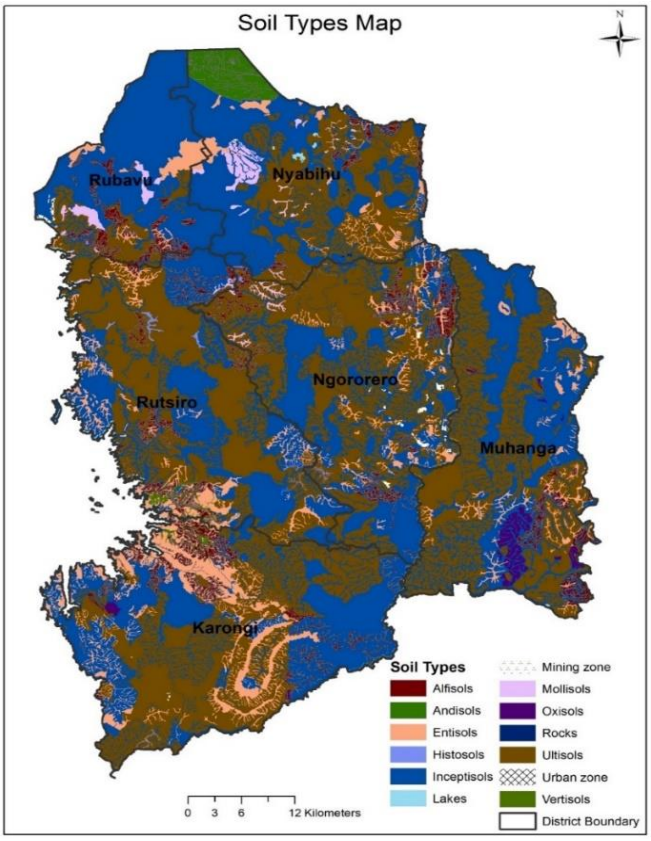


Figure 2. Soil types of the 6 target districts of the HortInvest project (This map were created by me with the help of Eric Nsabimana (Data and GIS Specialist/RAB-RwaSIS project)

3.3 Key characteristics of identified soil types

The soil types identified in the HortInvest region (6 target districts, **Figure 3**) are discussed below. Generally, all these soil types are characterized by low natural soil fertility, and will therefore need fertilization (nutrients inputs) to improve their fertility and productivity of the crops. See "*Tim K., Bill Z., (2020), Soil Classification and Geography, Plant and Soil sciences eLibrary"* for further information.

Ultisols

Ultisols are intensely weathered soils of humid areas. They are characterized by a humus-rich surface horizon (the uppermost layer), by a layer of clay that has migrated below the surface horizon, and by low levels of available calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}). Low in natural fertility, ultisols can be agriculturally productive with inputs of lime and fertilizers.

Alfisols

Alfisols are found under forest and savanna vegetation. They are characterized by clay accumulation in subsoil horizons, and are leached below the topsoil. Alfisols are generally fertile.

Inceptisols

Inceptisols form quickly through alteration of parent material. On the beginning of B horizon may be seen with accumulation of small amount clay, salt and organic matter. They are find all over the world mostly in mountainous regions. The productivity of these soil depends on clay and organic matter content presented and other plant-related factors.

Oxisols

Oxisols are the most weathered soils. They form in hot, humid climates with high annual rainfall, and commonly occur in equatorial latitudes. Oxisols are highly leached, dominated by iron and aluminium oxides, low in natural fertility (basic cations, Ca^{2+}, Mg^{2+}, K^{+}) and high in soil acidity (H^{+}, Al^{3+}). They are physically stable soils, with low shrink-swell properties.

Andosols

Andosols are formed in regions of recent volcanism and are generally high in natural fertility. They are light soils that are easily cultivated, and are potentially very productive.

Entisols

Entisols are sandy mineral soils that are low in organic matter, natural fertility, and water-holding capacity (Weil and Brady, 2016). Entisols are commonly arable if given an adequate supply of plant nutrients and water.

Mollisols

Mollisols are characterized by a thick, dark surface horizon. This horizon, known as a mollic epipedon, results from the long-term addition of organic materials derived from plant roots. They are among some of the most important and productive agricultural soils in the world and are extensively used for this purpose.

Vertisols

Vertisols are clay-rich soils that shrink and swell with changes in moisture content**.** Vertisols are usually very dark in colour, with widely variable organic matter content. Because they swell when wet, they transmit water slowly and have undergone little leaching. They tend to be fairly high in natural fertility.

Histosols

Histosols consist primarily of organic materials with high amounts of organic carbon. Histosols are generally very difficult to cultivate because of the poor drainage. Most are acidic and many are very deficient in major plant nutrients which are washed away in the consistently moist soil.

4. Current farmers' practices with regard to management of soil fertility and quality

4.1 What are soil fertility and quality?

Soil fertility is the ability of soil to sustain plant growth and a good crop yield. A healthy soil has sufficient nutrients that are well balanced, has a proper pH, is fertile, has well-drained (soil with a good moisture content) and is free of toxins (organic and chemical). It will lead to the growth of strong and healthy plants. Healthy plants are relatively resistant to pests and diseases, which is a prerequisite for good productivity. There are several farming methods and activities that can improve and maintain healthy soils, such as the correct application of fertilizers (organic and inorganic), and the use of soil amendments.

4.2 Current farmers' practices in the 6 districts

Based on field visits and the data collection from the demo sites, current practices taking place in the 6 HortInvest districts of intervention:

Land preparation typically involves ploughing, harrowing, and levelling the field to make it suitable for crop establishment. Land preparation releases nutrients to the soil due to destroying /reducing weeds and ant nests, improves the contact of the plant roots with soil and water and can help to reduce the incidence of pests and diseases.

Nursery preparation concerns all activities for raising young vegetable seedlings on a prepared sowing bed until they are ready for permanent planting. Starting with healthy seedlings with good growth and root system means a better uptake of nutrients.

Transplanting is the technique of planting seedlings at its final location in the production field. For a good yield the crop needs fertilization, which is done at transplanting.

Crop rotation helps to manage soil fertility, reduce erosion, increase nutrients availability, and break weed, insects and diseases cycles. It increases water availability to plant and recycle plant nutrients into the soil, e.g., when including nitrogen fixation crops in the crop rotation.

Fertilization is needed for replenishment of nutrients to the soil. Fertilization is supplementing the soil with additional nutrients that are in shortage for good crop growth. Fertilizers can take place in different stages of crop growth, for which both organic and inorganic fertilizers can be used. Out of 141 farmers (from HortInvest baseline survey data), 124 famers use starter solution of NPK at transplanting, and 73 farmers used foliar fertilizer such as easy grow and poly-feed.

Compost and manure. A small number of farmers apply compost, but most farmers use manure as an organic fertilizer. Both compost and manure are used to improve soil nutrient status. Out of 141 farmers, 124 farmers apply manure before seedlings transplanting.

Weeding is the removal of the unwanted plants or shrubs from the field. Weeds are competing with the commercial crop for nutrients. So it is very important to remove those weeds to improve nutrient availability to the commercial crops. 134 out of 141 farmers were maintaining farm hygiene by weeding the surroundings of the vegetables.

Pruning contributes to plant nutrient recycling, enhancement of soil structure, maintenance of soil microbial activities and high soil nutrients status.

Mulching improves soil organic matter and plant growth by increasing root activity and by providing better moisture conditions and nutrient levels in the root zone. 96 out of 141 farmers apply mulching as a mode of soil management practices where possible, or based on the knowledge they have.

Drainage canals are used in areas subject to flooding. They prevent crop loss from flooding and maintain agricultural soil conditions. When constructed correctly they also prevent erosion which can lead to huge losses of soil containing nutrients. From the 141 farmers 77 farmers established the drainage canals where necessary or depending on the knowledge they have.

Harvesting is the process of gathering a ripe crop from the fields. Reduced amounts of crop residues remain after harvest for soil cover and organic matter, or for grazing of livestock (which results in manure). Moreover, where animals graze the residues, even less remains for conservation purposes.

Pest and diseases control: The relation between soil fertility and pest and disease control is complex. Soils with high organic matter and an active soil biology generally show good soil fertility and good crop growth. On the one hand, this may stimulate crop resilience and therefore lower pressure of several insect herbivores, but on the other hand, higher nitrogen contents in the crop may stimulate the development of pests and diseases. Some farming practices, such as excessive use of inorganic fertilizers, can cause nutrient imbalances and lower pest resistance

Variety choice: The farmers also use hybrid seeds, for example for maize and tomatoes. 126 farmers out of 141 farmers adopted hybrid seeds.

4.3 Current fertilizer usage and soil fertility status

Nationwide 64% of farmers use organic fertilizer on their farms (National Institute of Statistics of Rwanda's Seasonal agricultural survey, 2020 season A (from September 2019 to January 2020). Inorganic fertilizers are used by 34% of the famers. Most frequently used inorganic

fertilizers are DAP (Diammonium Phosphate 18-46-0), Urea (Nitrogen 46) and NPK (Nitrogen-Phosphorus and Potassium with different percentage composition) with frequencies of 41%, 36% and 18%, respectively.

However, all 12 farmers we surveyed in the 6 districts used organic fertilizer. The quantity fertilizer used is determined by the amount of money a farmer had, and 100%, 92%, 92% of the farmers applied DAP, UREA and NPK fertilizers, respectively. Most of the interviewed farmers collaborate in the HortInvest project and others are the lead farmers, which may have biased the results. At the other hand it shows how HortInvest through trainings and other facilities has positively impacted the Rwandan Horticultural sector.

From the data analysis done by HortInvest, a large part of the area has low nitrogen phosphorus and potassium content, which explains why most farmers are using NPK, Urea, DAP and other fertilizers containing those nutrients. The maps below show N,P and K nutrient contents in the soil of the 6 districts as determined during the baseline survey.

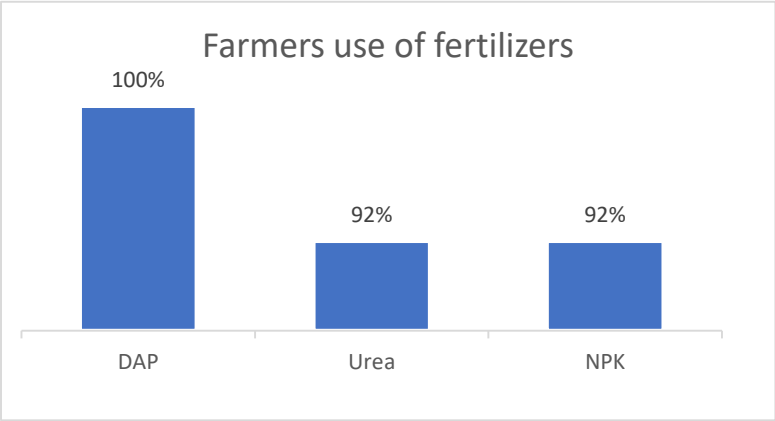


Figure 3. Utilization of the main fertilizers by farmers.

Other fertilizers are also used by the farmers based on the information and knowledge received from sector based agronomists or agrodealers in the farmers' regions but also based on every farmer's point of view and his capacity. The usage differs from one region to another based on region soil types and other factors (see table 4 in the Annex: Fertilizers use and frequency).

Organic fertilizers are the most widely applied fertilizers by farmers; they consider the organic fertilizer to be the basic and the best for their soil and that pushes them to make it a priority. Organic fertilizer is used by all farmers while starting each agriculture season. The quantity used depends on the field surface or the price of the fertilizer. All interviewed famers (12) use cow manure that they mix it with other residues. The application of organic fertilizer is necessary but not sufficient to meet farmers' productivity and let alone to fully improve soil fertility in most of the cases in rural area, maybe this can only work when the target is Organic farming.

Based on the data from soil samples, maps were drawn to indicate the soil fertility for potassium, nitrogen and phosphorus (Figure 4). In case of exchangeable potassium, the soil status for this nutrient is low in the regions of Muhanga and Ngororero but medium to high in Karongi, Rutsiro, Rubavu and Nyabihu. It implies that from Muhanga to Nyabihu the potassium is easily up taken by plants from the soil.

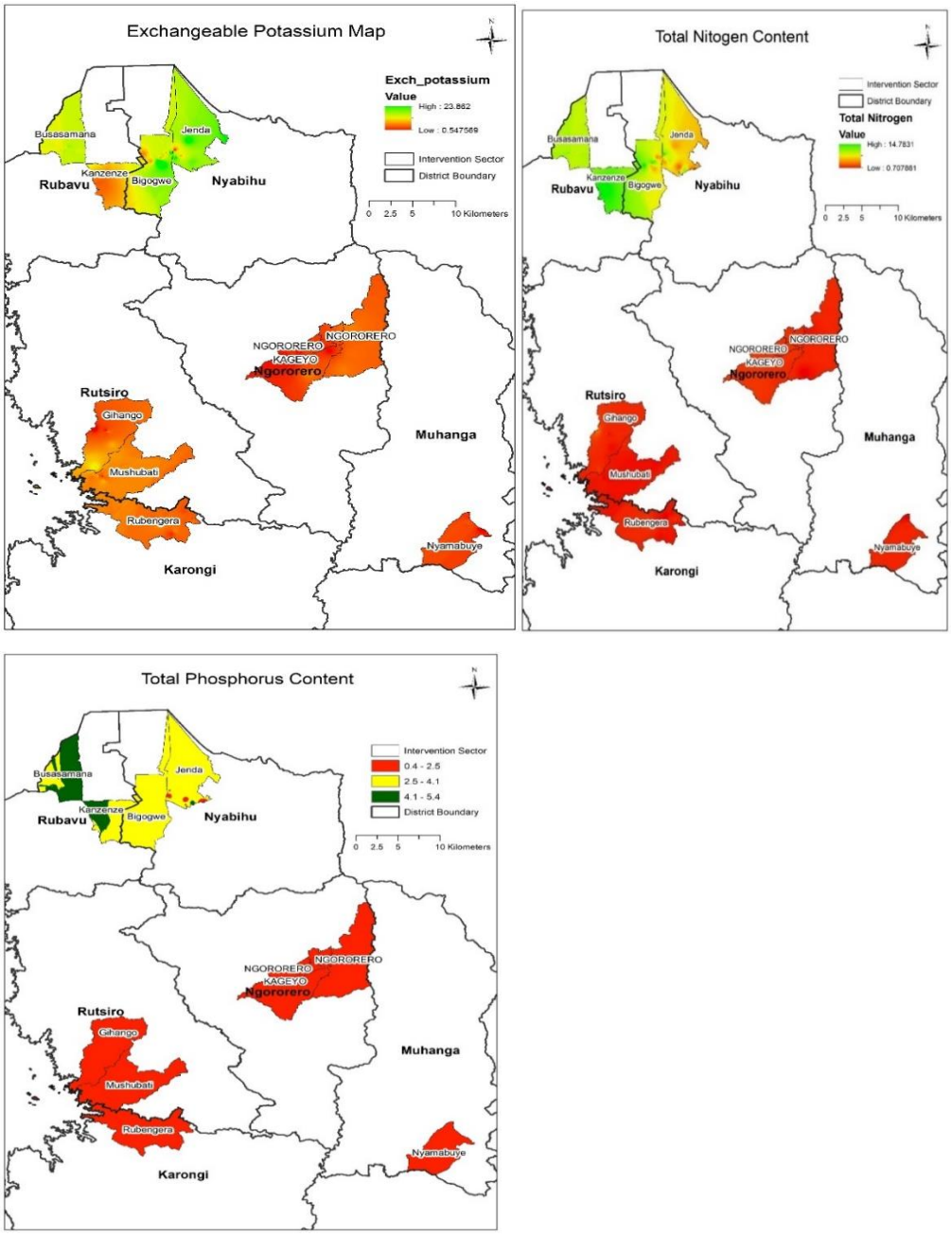


Figure 4: NPK nutrient composition in the 6 districts of the HortInvest project (based on soil samples taken during the February 2020 survey)

Nitrogen shows a similar pattern but the levels are extremely low in the regions of Muhanga, Ngororero, Karongi and Rutsiro. This is also an indication of low organic matter in the soil or low rainfall quantity because nitrogen is added to soil naturally through N fixation by soil bacteria (the higher the organic matter the higher the bacteria composition in the soil) and through atmospheric deposition in rainfall. Additional N is typically supplied to the crop by fertilizers, manure, or other organic materials. Application of organic fertilizers is a good solution to the problem.

Phosphorus levels change from low to high (from Muhanga to Rubavu). The total soil phosphorus is made up by 2 forms of phosphorus. Approximately 30-65% of total soil phosphorus is in organic forms that are not available to the crop, while the remaining 35-70 % is in inorganic forms, which is available to the crop. Soil organisms play a key role in transforming and processing organic forms of phosphorus into forms that are available to plants.

4.4 Other practices suitable to the farmers, and recommendations

The above practices are good and necessary but there are others which can be combined with them to enhance soil quality and fertility.

Cover crops are plants that are planted to cover the soil rather than for the purpose of being harvested. Cover crops manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an agroecosystem.

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals. Trees add organic matter to the soil system in various manners, whether in the form of roots, litter falling, or as root exudates in the rhizosphere. It creates organisms involved in soil biological activity and interactions, with important effects on soil nutrients and fertility.

Drainage canals must be applied in the high-altitude regions to avoid crop damage due to intense rain and flooding by removing excess water.

Liming is the application of calcium- and magnesium-rich materials in various forms, including marl, chalk, limestone, burnt lime or hydrated lime to neutralize soil acidity in acidic soil. Benefits of liming include increased nutrient availability, improved soil structure, and increased rates of infiltration. Limestone application changes the soil from acidic to neutral or basic status (as can be seen on a pH map in the annex, which shows acidic soils in parts of Muhanga, Rutsiro and Ngororero districts).

5. Procedures and limitations for the import, logistics, market availability and price mechanisms of fertilizers

5.1 The processes and limitations for import and logistics of fertilizers

The processes for import and logistics of fertilizers differ from big to small agrodealers. For the big ones who import fertilizers it takes between 15 days (import from African countries) to 60 days (import from outside of Africa) for the fertilizers to reach their shops. For agrodealers based mainly in the local administration sectors or districts (retailers), transport from the importers are short and quick, lasting between 1 to 2 days. For medium-sized agrodealers (wholesale in the districts and Kigali city), it takes a maximum of one week for the products to reach their shops. In general, transport is not an issue in terms of making fertilizers available to the farmers if an agrodealer anticipates on the demands and orders well in advance. But sometimes fertilizers are not available at the sector level or in regional stocks, which can cause a delay of up to a week. To avoid this, farmers are asked to order fertilizers before the start of the agricultural season to ensure availability on the right time. Currently there are some time limitations on availability of fertilizers due to the Covid-19 pandemic, and the fertilizers' importation is delayed and that affects all the dealers from big to small ones.

Other inconveniences like truck break downs and blocked maritime ways or roads can lead to a delay in importation or regional transportations causing periodic shortages in agroshops.

Currently, farmers are only allowed to buy fertilizers from agrodealers in their own sector (local administrative sectors), and they are not allowed to purchase from an agrodealer in a different sector even if that shop is the closest. Farmers only get the fertilizers from the shop they registered in. Most of the time there are only a small number of agrodealers per sector who may be miles away from many farmers of that sector. Keeping in mind that, this policy is a good way of monitoring on fertilizer use on both the farmer and agrodealer side and to follow up on Nkunganire program. The distance and travelling time between farmers and agrodealers threatens fertilizer accessibility.

The limited availability of funds is a big challenge to some small agrodealers in order to access some products needed by farmers.

Foliar fertilizers are directly applied to leaves and essential elements, however, only contribute marginally to soil fertility and crop production based on farmers' experience on their use. All foliar fertilizers are considered expensive by farmers and are not supported by the government Nkunganire program (a public program in which farmers register themselves in advance, to order the hybrid seeds and fertilizers that they will use, the inputs prices are reduced for farmers and the part of the price is paid by the government).

5.2 Market availability and price mechanisms of the fertilizer market

Generally, fertilizers are considered expensive by farmers and agrodealers. The fertilizer market is only partly a free market which is overseen by the government (MINAGRI-MINICOM) and is partly under governmental rules and regulations (that of Nkunganire program). Agrodealers are available at the sector level (those in Nkunganire program). This involves prices, and information on how, when and where and from which supplier to purchase and some other internal rules. Each season, an official communique from the minister is shared with all agrodealers and sector agronomists. This communique includes prices that must be used at the start of the season and agrodealers are required to post these prices in their shops. The observation from the field is that in terms of fertilizers, most agrodealers are selling only fertilizers that are subsidized by this programme. It is hard to find agrodealers selling fertilizers which are not part of this program due to the fact that they are more expensive. The Nkunganire program concerns mainly NPK, DAP and urea. The remaining fertilizers are sold at free market prices without subsidies.

Both systems, free market versus subsidized programs, have advantages and disadvantages.

A. Agrodealership as a free-market

Advantages:

- It is more profitable for the agrodealers since they can fetch higher margins.
- The agrodealers will offer a wider variety of products compared to the Nkunganire program.
- Their clients are big farmers who order large volumes. The agrodealers anticipate these big orders, and farmers do not have to pre-order and do not need to wait for arrival of the fertilizer. This system is an advantage to both parties.

Disadvantages:

- The products are very expensive to farmers.
- To enter the Nkunganire program demands a high capital for agrodealers.
- Agrodealers in the countryside (in rural sectors) have a small number of clients compared to those in the Nkunganire program.
- Some agrodealers are not professional (quality and prices based)
- Free market shops may not have all fertilizers in stock at all times, especially in rural areas. In Kigali, situation is OK. This also goes for large farmers, but they can go elsewhere.

B. Agrodealership as a governmental market (Nkunganire program)

Advantages:

- The farmers obtain agro-inputs (seeds and fertilizers) at a subsidized price.
- It is easy and simple for the agrodealers to get NPK (17,17,17), Urea, KCL/MOP, DAP and other blended including, NPK Cereal (23,10,5+S+Zn+Mg), NPK Winner

(15,9,20+S+B+Zn+Mg+Mn), NPK Traceb (5,7,5+B+Zn+Cu+Mg+Fe+Mn+Mo), Nitrabor (15N+25.6% CaO+B) and Amidas (Urea+Sulfur) fertilizers from the suppliers.

- The agrodealers purchase products based on the number of orders from farmers and will not over-stock. Chemical fertilizers are not perishable, and an excess will not really lead to loss of capital, however, the cash flow of agrodealers is relatively constant and less risky.
- This market is the one mostly targeting the smallholder farmers and they are considered a priority.
- This market is easily accessed by smallholder farmers as they are the one near to them.
- There is at least one dealer per sector, and even they can be far, they can still closer than the private shops.

Disadvantages:

- The agrodealers have a limited range of inputs under the program and the farmers can't get all the needed products for a subsidized price.
- Keeping in mind that it is an easy way of controlling the Smart Nkunganire System, a farmer can only get agro-inputs from an agrodealer from its local administrative sector where he/she is registered, which is a disadvantage considering the distance covered by the farmers. Someone can be in one sector but nearly to the neighbouring sector's agrodealer than his own sector's agrodealer.

5.3 Overview of fertilizer use

Collected field information at the baseline survey and demo site data show that farmers do use fertilizers (inorganic and organic) but also that most farmers do not consider the required quantity, which is determined on the basis of their cash-flow situation. For a good crop production, some smallholder farmers might need more than they can afford to purchase. Some farmers collaborate with OneAcre Fund, which provides them with the agro-inputs (seeds and fertilizers), and at the end of the season, once the crops are sold, the farmers repay to the fund. HortInvest runs a financial literacy program that trains farmers on financial recordings with the aim of financial planning and to help farmers to plan where, when and how to obtain agro-investment (that includes also agro-inputs). In 2020, a financial literacy training pilot has started, which involved the six cooperatives that benefited from the first six HortInvest demonstration sites (KOGIMUIN, KAIDU, UMU, KOABIBIKA, KABU Kageyo and IABM). Per cooperative, one employee and two lead farmers have been trained as farmer trainers for financial literacy through a two-day Training of Trainers (ToT) on financial literacy. These three trainers have so far started to train together a group of 25 farmers from their cooperative to prepare and equip them to record their activities for the crop seasons. In this way, a total of 150 farmers have been trained and have started with financial record keeping. This activity began in the in A season of 2020/2021 and will cover all the 3 seasons of 2020/2021.

For the farmers mostly needed and used fertilizers are available. The most widely available and used fertilizers are those containing N (nitrogen), P (phosphorus) and K (potassium) but they may also contain other micronutrients like Ca (calcium), Al (aluminium), Mg (magnesium), Mn (manganese), Fe (iron) and others (see Table 2 in Annex). Those fertilizers are either for granular or foliar form. In principle, farmers can get fertilizers from sector agrodealers or other private agrodealers around them or from Kigali city. However, the major problems are that some agrodealers (those of Nkunganire Program) are located far away from farmers and that some farmers do not have access to financial schemes for purchasing agro-inputs or others do not know how and where to access them.

5.4 Evaluation of the market: what can be improved?

The agrodealership is partly a governmental and partly a free but small market, and serves many farmers. There are some areas that need some improvements to establish a good and successful collaboration between farmers and agrodealers while ensuring sustainable agriculture.

a. Harmonization of Nkunganire programme countrywide: currently, farmers are only allowed to buy fertilizers from agrodealers registered in their sector, and mostly, there is mostly one agrodealer per sector. This becomes a big challenge for the farmers who are far from the agroshops in their sector but are rather close to other shops in neighbouring sectors. Many farmers are demanding harmonization of Nkunganire lists countrywide so that they can get the fertilizer from any agrodealer who is nearby.
b. As stated above, there is still a limited number of agrodealers in the districts/sectors. There is a need to increase the number of agrodealers and agroshops in each sector so that they can serve a greater number of farmers, especially as they are the first source of information in term of fertilizers use. As some agrodealers said the rules and regulations concerning agrodealership are so demanding and the capital to start that business is high so, that can limit the market expansion.
c. Increase the capacity of small and medium agrodealers through capital accessibility (e.g. linking them to the financial institutions which can help or providing them with some financial literacy trainings) to establish their businesses. That will help farmers to obtain the required fertilizers from the nearby agrodealers.
d. Trainings to farmers, farmers' facilitators and agrodealers on fertilizers and pesticides use can increase their knowledge on how and when to use them.

6. Discussion

Farmers mentioned that the HortInvest project has played a great role in increasing their understanding of agriculture and productivity, but that there always barriers that could be resolved with assistance by the project directly or through any advocacy.

Farmers sometimes do not know the quantity of chemical fertilizers to be used or focus on using organic fertilizers rather than using chemicals because they say that chemical fertilizers are not good to the soil properties. Firstly, this is not true, and secondly, the low amounts of organic fertilizers that most of smallholder farmers in Rwanda apply cannot support and maintain soil fertility. Chemical fertilizers are needed to realize biomass growth, which after harvest can be used to enhance soil fertility. Only excessive fertilizer use can cause problems, just as excessive use of manure and organic fertilizer can.

The continuation of the trainings by the HortInvest project, horticulture extension officers or local agronomists is needed to equip farmers and sector based agrodealers with the necessary knowledge.

The lack of money to buy some inputs including fertilizers remains a problem to some smallholder farmers. They buy fertilizers based on the money they have, and not on the area they cultivate. An advocacy or providing information on how to get some support of money or of the inputs so that they will pay after the season when they will sell their productivity. And having a sure and good market can help them while paying their loans at the end of the season.

Foliar fertilizers are used by some famers who believe that this ensures a good produce, as foliar fertilizers are thought to be directly taken up by crops' target organs. However, firstly foliar fertilizers are more expensive than other fertilizers, and secondly, roots are designed to take up nutrients, and leaves are not. So, it is better to invest in soil fertilizers. Still, that do not mean that foliar fertilizers are not a necessity to plants growth and increase in crop productivity because they correct deficiencies depending on how the farmers are effectively using them.

In the districts of Nyabihu and Rubavu, the farmers claimed to use all the necessary agro-inputs (hybrid seeds, fertilizers) resulting in good productivity but also mentioned that the market is still a big problem. Advocacy on a good market or equip farmers with some season planning skills that would encourage farmers to use all the recommended agro-inputs, to insure a good productivity that will lead to market and income to the farmers. However, an alternative of market regulation is a system in which farmers are provided with market information, knowledge on increasing crop production, and cost-benefit analysis. Then, they can make informed decisions.

Farmers can get the fertilizers at subsidized price only from their local administrative sector agrodealers. Farmers wish to have a harmonized Nkunganire list, where the farmers can get the agro-inputs from a nearby agrodealers regardless of which sectors they are in. It can be good if The HortInvest project invest in advocacy on necessary changes.

Some agrodealers on the sector level may lack the necessary inputs (fertilizers, pesticides and seeds) and that can be a problem to the farmers as it takes them a long time or the unexpected time to get what they need. The agrodealers say that the main problem is that they do not have a good capital to do the business. Maybe an advocacy to some financial institutions on how to get a loan to increase their capitals can help them.

Based on the farmers' interviews conducted and from the demo site data collected, the current farmers' practices are productive but a continuation of training on how those practices affect soil fertility and crop productivity are needed for a better understanding that will lead to an effective application of fertilizer. Some soil tests have been done and the results still have to be shared among famers, local farmer's facilitators, sector agronomists, agrodealers, cooperatives' executive committee and lead farmers, in an attempt to ensure a good soil quality and fertility. sensitization on soil testing before each season, practicing cover crops and agroforestry can help into preventing soil erosion and improving soil fertility.

To summarize the main problems:

- Lack of cash, either capital for agrodealers or investment on the farmers' side to buy inputs.
- Lack of basic information and knowledge on regulations concerning agrodealership.
- A limited number of agrodealers.
- A continuation of knowledge transfers on soil properties and a system to get that information.
- A continuation of knowledge transfers among different farmers on the required amount of fertilizer.

Under the project's collaboration with the Government some measures can be taken to generate solutions. Such as, but not limited to:

- To advocate on or make a good system that keeps and shares information on soil properties of an area and determine the general (even specific if possible) quantity of fertilizer to be used.
- To advocate on a harmonized Nkunganire program which will help the smallholder farmers to get the agro inputs from a nearby agrodealer.
- To train and inform the big number of smallholder farmers about how and when to plan on their investment.

7. Summary and Conclusions

Soil properties differ as a result of several factors including the soil's location, parent materials, leaching capacity of some soils, their past agricultural history, erosion and their natural fertility. Those soil properties are soil texture (the relative proportions of sand, silt, and clay in a given soil), soil structure (the grouping of soil particles into porous compounds), porosity (soil's pores and how they influence water and air movement), chemistry (soil's nutrients, nutrients solubility and availability to plants, pH and CEC (a measure of how many cations can be retained on soil particle surfaces) and colour (indicating the topsoil type and predict the soil composition).

Most of the soil management practices depend on those soil properties. The soil management practices that leads to soil quality and fertility include but not limited to land preparation, nursery preparation, soil amendment and fertilization, crop rotation, Mulching, weeding, transplanting, pruning, establishing drainage canals, harvesting, pest and diseases control, the use of hybrid seeds, cover crops, agroforestry and others. But our focus is on Fertilization. Based on soil information collected from MINAGRI and the samples taken by HortInvest in its six districts of intervention show that the soil needs fertilizers (chemical and organic fertilizers).

Organic fertilizers used by farmers, are mostly made domestically by them or bought from their neighbourhood and are composed with Domestic animal manure and other wastes (see Table 3 in the annex). But Chemical fertilizers are bought by farmers from the nearby agrodealers. These can be private or public agrodealers, based on the famers preferences, knowledge, type of services, type of fertilizer, and location of the agrodealer. All of this to increase crop productivity in quality and quantity while ensuring soil fertility.

Agrodealership market in Rwanda is divided into 2 market's parts (free and public based market). But smallholder farmers get their agro inputs from a nearby local administration sector based agrodealers, who are in Nkunganire program (public based market) where the inputs (fertilizers and Hybrid seeds) are subsidised by the government of Rwanda to support the smallholder farmers to raised their productivity.

There are some challenges faced by the agrodealership on the farmers' side and for the agrodealers as well like, lack of cash; either capital for agrodealers or investment on the farmers' side to buy inputs, A limited number of agrodealers, some farmers lack knowledge on soil properties (as our survey was targeting different farmers, not only those from the project) and continuation of knowledge transfer will help for those already trained. and system to get that information from can be helpful, continuation knowledge sharing on the required amount of fertilizer is key to always make farmers concerned with their daily activity. And those challenges affect indirectly or directly the crop production which hinder the Horticulture sector development. So to overcome those challenges, will need a strong and good collaborative system between the concerned people, organisations or institutions.

8. Annexes

Table 1: Overview of most commonly grown crops per district.

Districts	Horticultural crops	Other crops
Muhanga	• Cauliflower • Cucumber • Beetroot • Eggplants	• Maize • Beans
Ngororero	• Onions • Cabbage • Amaranth • Tomatoes	• Beans • Maize • Yams • Soybeans • Potatoes • Maracuja
Karongi	• Onion • Carrots • Green Pepper • Cucumber • Tomatoes • Maracuja	• Maize • Beans • Yams
Rutsiro	• Tomatoes • Carrots • Eggplants • Courgette • Beetroot • Cauliflower • Tree-tomatoes • Broccoli • Cucumber • French beans • Green Pepper • Chili pepper • Amaranth	• Sugarcane • Beans • Soybeans • Peas • Maize
Nyabihu	• Onions • Garlic • Cucumber • Carrots • Eggplants • Soybeans • Tree tomatoes • Cauliflowers • Broccoli	• Potatoes • Maize
Rubavu	• Onions	• Potatoes

	• Carrots • Cauliflowers • Cabbages • Garlic	• Beans

Table 2: Different Fertilizers used and their nutrient contents.

No	Brand name	Nutrient content (Percentage composition %)
1	NPK	N (17), P(17), K (17)
2	NPK (Cereal)	N (23),P (10),K (5) + macronutrients
3	NPK (Winner)	N (15),P (9),K (20) + macronutrients
4	NPK	N (19), P (19), K (19)
5	DAP	N (18),P (46)
6	Urea	N (46)
7	MoP	KCl (60)
8	TSP	P (46)
9	Codahumus PK	Humic extract (16), humic acid (9), fulvic acid (7), P (7), K (12)
10	Nitrabor	N (15), Co (25), Bro (5)
11	EasyGro Calcium	N (27), P (10), K (16)
12	NPK	N (24), P (24), K (12)
13	NPK	N (13), P (0), K (46)
14	Codahort	Mg (1.75), Fe (2) and other trace elements
15	Codasal complex	Ca (10), Mg (2) and other micronutrients
16	Polyfeed	N (15), P (30), K (15) + other micronutrients
17	EasyGrow (Vegetative)	N (27), P (10), K (16)
18	EasyGrow (Fruits and flowers)	N (14), P (11), K (33)
19	Superfeed High-K	N (18), P (9), K (27) + micronutrients
20	Superfeed plus	N (19), P (19), K (19)
21	Omaxy	N (19), P (19), K (19)
22	Booster	N (12), K (8), Mg (0.2)
23	D.I. Grow	K (35), P (4.44), N (1.75)
24	Wuxal	N (16), P (16), K (12)
25	Multi-NPK	N (13), P (0), K (46)
26	FastGrow	N (19), P (19), K (19)
27	Codafol	N (7), P (21), K (7)

Table 3: Organic fertilizers used by farmers.

Types of Organic manure	Number of farmers (n=12)	% farmers
Cow dung + Plant waste	2	17 %
Cow dung + Plants waste + poultry manure + pyrethrum waste	1	8 %
Cow dung + Plant waste + toilets waste	1	8 %
Cow dung + Plant waste + pig waste + industrial wastes	2	17 %
Cow dung + Plant waste + poultry manure + rabbit and goat manure	1	8 %
Cow dung + Poultry manure + compost	3	25 %
Cow dung + Plant waste + goat and sheep manure	1	8 %
Cow dung + compost	1	8 %

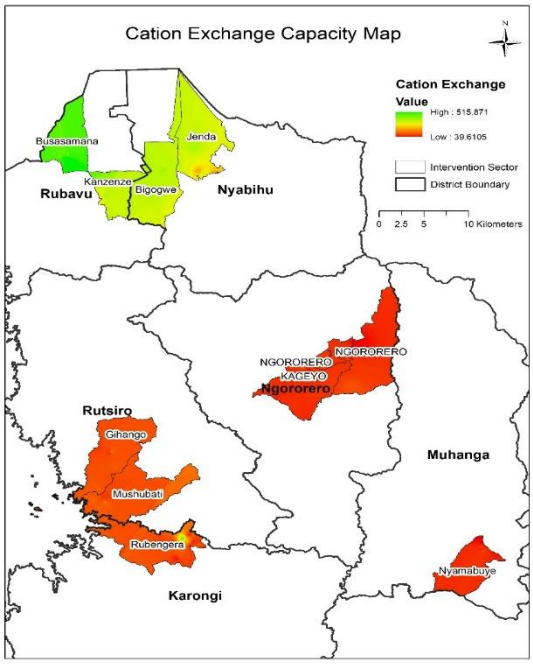
Table 4: Fertilizers use and frequency.

Districts	Fertilizer's type	Quantity used	frequency
Muhanga	• NPK • DAP • Urea • Polyfeed • Easygrow	• 0.5-1 kg / m^2 • 0.5-1 kg / m^2 • 0.5-1 kg / m^2 • 3 spoons / 20 liters • 3 spoons / 20 liters	• 2 times per season • 2 times per season • Once per season • 6 times per season • 6 times per season
Rutsiro	• NPK • DAP • Urea • Polyfeed • Easygrow • Koda • Limestone	• 0.5-1 kg / m^2 • 0.5-1 kg / m^2 • 0.5-1 kg / m^2 • 1kg / m^2 • 1kg / m^2 • 1L/ month • 12.5 kg / m^2	• 2 times per season • 2 times per season • Once per season • 4-8 times per season • 4-8 times per season • Once per week • 1-3 years (on a new field)
Karongi	• NPK • DAP • Urea • Polyfeed	• 0.5-1 kg / m^2 • 0.5-1 kg / m^2 • 0.5 kg/ m^2 • 40ml / m^2	• 2times per season • 2 times per season • Once per season • 2 times per season
Ngororero	• NPK • DAP • Urea	• 0.5-1 kg / m^2 • 0.5-1 kg / m^2 • 0.5 kg / m^2	• 2 times per season • 2 times per season • Once per season
Rubavu	• NPK • DAP • Urea	• 0.5-1 kg / m^2 • 0.1-0.5 kg / m^2 • 0.5 kg / m^2	• 1-2times per season • 1-2 times per season • 1-2 times per season

Nyabihu	• NPK • DAP • Urea	• 0.5 kg / m^2 • 0.5 kg / m^2 • 0.5-0.25 kg /m^2	• Once per season • Once per season • Once per season

Map 1. Cation Exchange Capacity

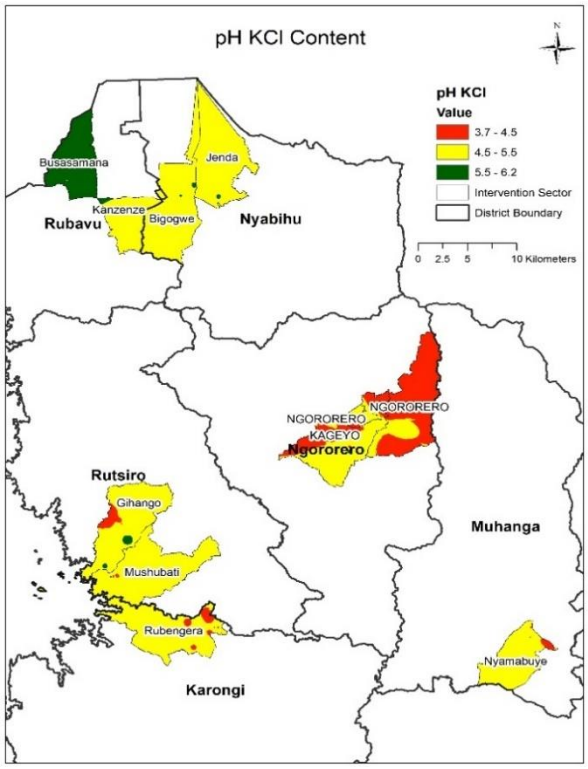
Cation exchange capacity (CEC) is the total capacity of a soil to hold exchangeable cations. It influences the availability for plant and the soil reaction to fertilizers and other ameliorants (Hazleton and Murphy 2007). Most of those exchangeable cations are essential nutrients to plants growth. CEC increases from Muhanga to Rubavu. With others factors constant, Rubavu is more fertile and can better react to fertilizers than the other districts.

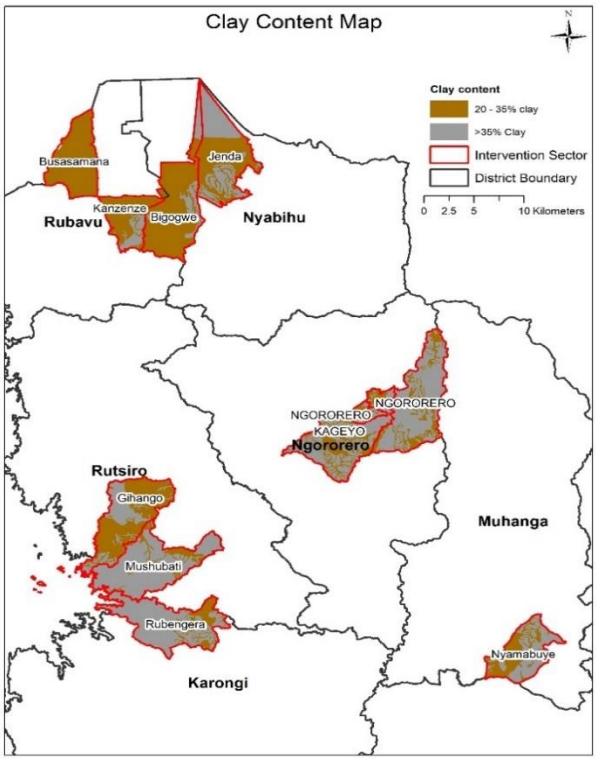


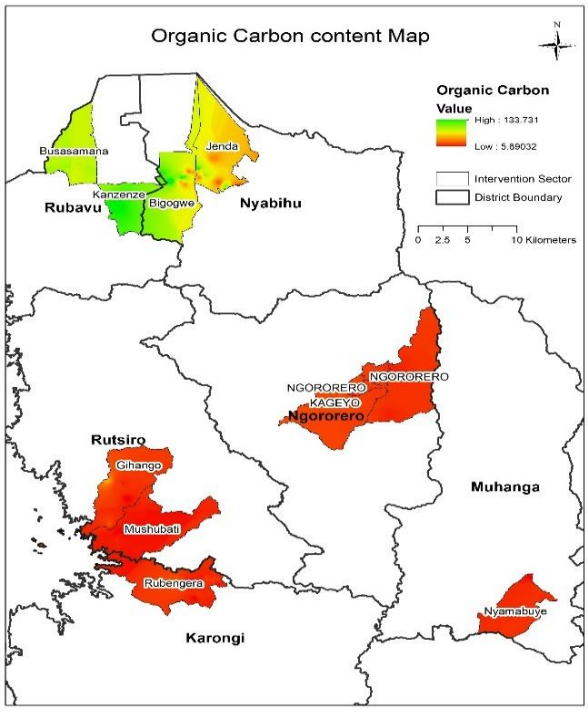
Map 2. The relation between soil pH, soil organic matter and soil clay content

Soil pH is a measure of soil acidity or alkalinity. It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and soil micro-organism activity, influencing key soil processes.

Soils that have a high content of clay and organic matter are more resistant to changes in pH (higher buffering capacity) than sandy soils. The clay content cannot be altered, but organic matter content can be altered by management practices. Sandy soils commonly have a low content of organic matter, resulting in a low buffering capacity and a high rate of water percolation and infiltration. Therefore, they are susceptible to acidification.







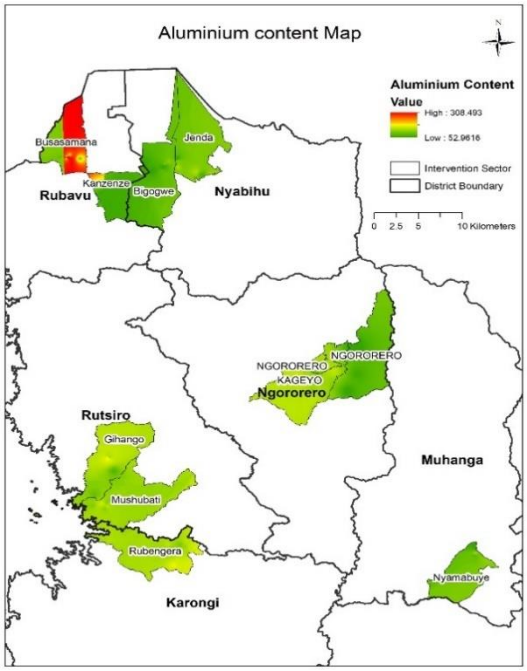
Notes:

- **The pH (KCl):** Its figure refers to the acidity in the soil solution, plus the reserve acidity in the colloids (the finer size fractions of the soil).

- **Organic Carbon:** Soil Organic Matter **(**SOM) is made of organic compounds that are highly enriched in carbon. Soil organic carbon (SOC) levels are directly related to the amount of organic matter contained in soil and SOC is often how organic matter is measured in soil.

Map 3. Aluminium content

Aluminium (Al) is not regarded as an essential nutrient, but low concentrations can sometimes increase plant growth or induce other desirable effects. Aluminium toxicity is an important growth-limiting factor for plants in acid soils below pH 5.0. Al toxicity is manifested only in acid conditions, in which the phytotoxic form Al^{3+} predominates.

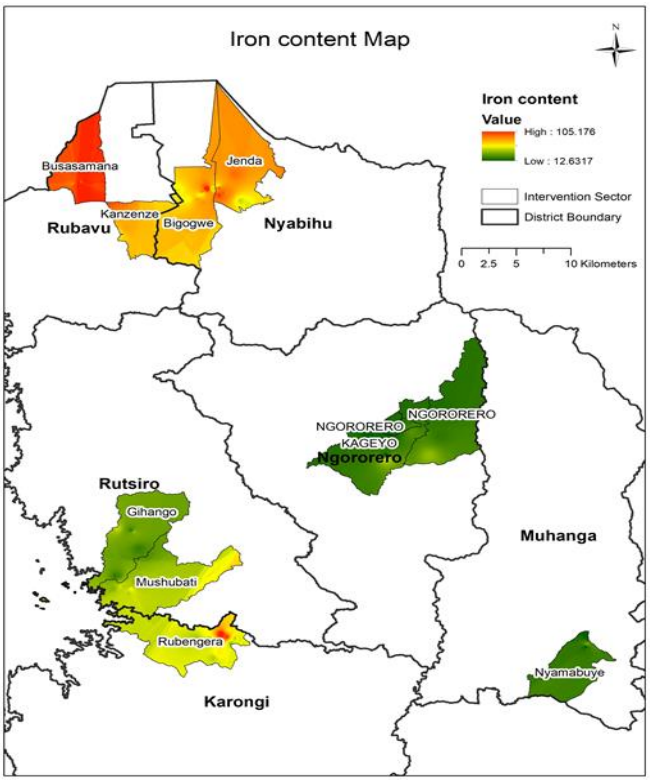


Map 4. Iron content and availability

Iron is the fourth most abundant element found in soil though it is largely present in forms that cannot be taken up by plants. Iron, in small amounts, is essential for healthy plant growth and is classed as a micronutrient. It is important for the development and function of chlorophyll and a range of enzymes and proteins. It also plays a role in respiration, nitrogen fixation, energy transfer and metabolism. As with other nutrients, plants can have too much iron but this primarily affects the uptake of other nutrients rather than producing direct toxicity symptoms. The amount of iron and its availability in soil is influenced by the following:

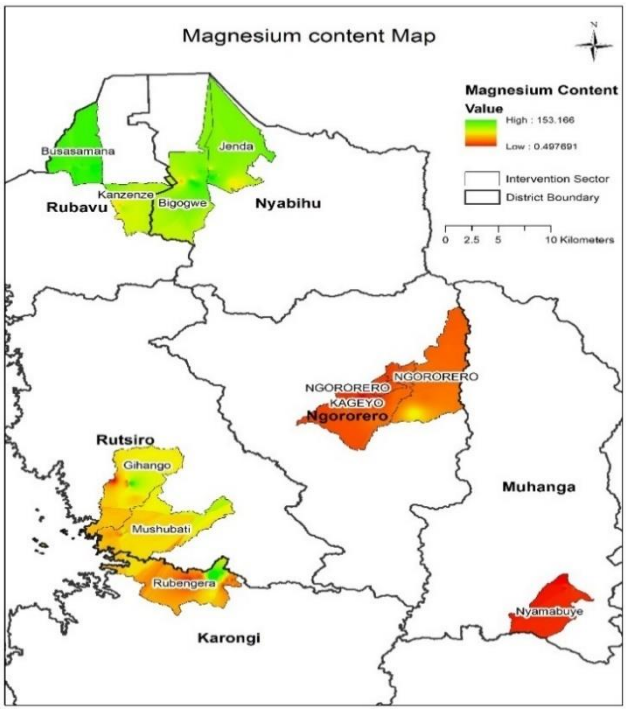
- pH: a high pH reduces iron availability, a low pH increases it
- Organic matter provides iron and makes it more readily available

- Moisture: excess water in the soil, particularly in acidic soils, increases iron availability even to the point of toxicity
- Aeration and compaction: compacted and/or poorly aerated soils have an increased iron availability, particularly if the soil is acidic
- Excesses of those elements mostly in Alkaline conditions inhibit the uptake of iron: phosphorus, nitrogen, zinc, manganese, potassium, molybdenum, nickel, bicarbonate.



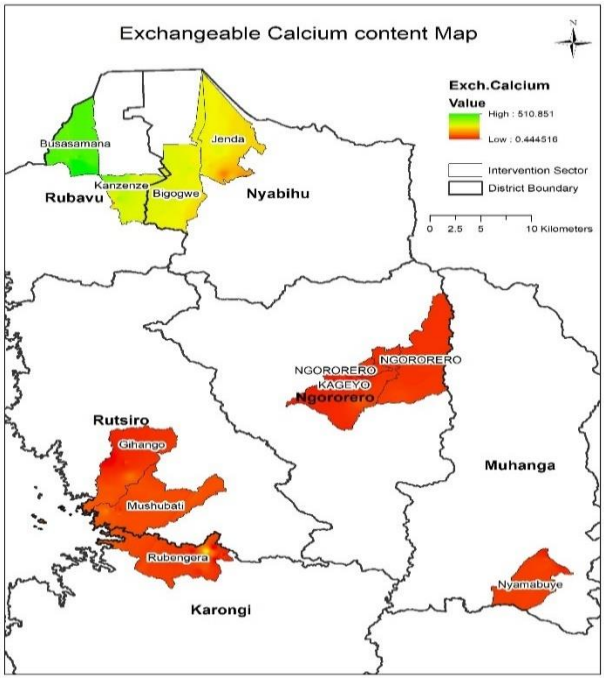
Map 5. Magnesium content

Magnesium is a macronutrient to crops. Magnesium is the central core of the chlorophyll molecule in plant tissue. Thus, if Mg is deficient, the shortage of chlorophyll results in poor and stunted plant growth and it also helps to activate specific enzyme systems. Magnesium is held on the surface of clay and organic matter particles.



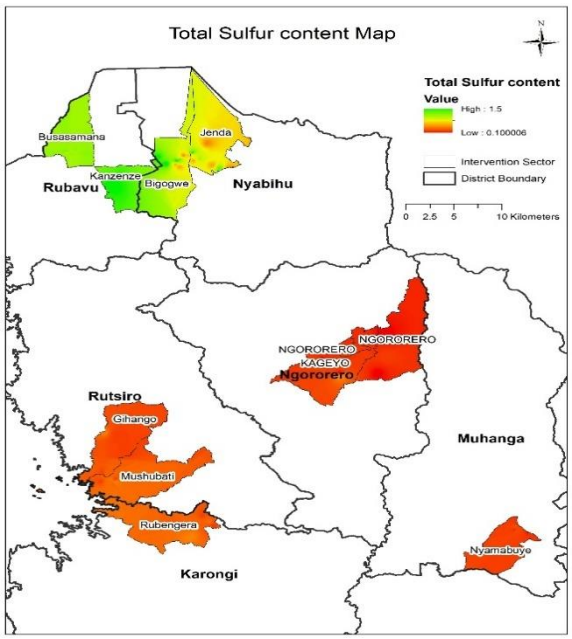
Map 6. Exchangeable calcium

Calcium (Ca) is an essential plant nutrient required by animals and plants in relatively large amounts for healthy growth. In addition to its role as one of the macronutrients in plant nutrition, sufficient Ca has a role in maintaining soil physical properties, and in reclaiming sodic soils. It contributes to soil fertility by helping maintain a flocculated clay and therefore with good aeration.



Map 7. Sulphur content

Sulphur is considered the fourth major nutrient in crop production and is necessary for protein synthesis in a plant Protein synthesis, when supported by sulphur, promotes plant vitality and development, including pollen development. Most sulphur in the soil is located in the organic matter and cannot be taken up by the plant until mineralization, which is when sulphur is converted to sulphate, or SO4-2, by bacteria in the soil.



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