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Optimization of banana crop fertilization using GIS tools.

Optimización de la fertilización del cultivo de banano mediante el uso de herramientas SIG

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Abstract

Precision farming tools have been developed for banana cultivation to meet the needs of monitoring and understanding the status of the product from planting to sale. In recent years, tools have emerged from a precision agriculture perspective, the basic definition of which aims to optimize resources through tools that enable their effective and efficient use. Fertilization in banana crops must be applied to meet the high nutrient requirements of the crops and compensate for the loss of nutrients to the open air. Excessive use of chemical fertilizers is a problem for many agricultural production companies in the country because there is no regulatory agency to control the amount of fertilizers used. The use of GIS tools allows us to control the yield of banana crops, since all previous data, such as crop information, nutritional requirements, availability levels of each nutrient and fertilization strategies are executed manually, which generates inaccurate yield reports and causes economic losses to producers, GIS was implemented because this system is accurate, allowing us to accurately identify crop needs and the amount of fertilizer to use, identify specific areas that require nutrients, and see higher yields and less fertilizer loss.

Keywords: precision agriculture; fertilizers; GIS (geographic information system).

Resumen

Se han desarrollado herramientas de agricultura de precisión para el cultivo de banano para satisfacer las necesidades de seguimiento y comprensión del estado del producto desde la siembra hasta la venta. En los últimos años han surgido las herramientas desde la perspectiva de la agricultura de precisión, cuya definición básica apunta a optimizar los recursos a través de herramientas que permitan su uso eficaz y eficiente. La fertilización en los cultivos de banano debe aplicarse para cumplir con los altos requerimientos de nutrientes de los cultivos y compensar la pérdida de nutrientes al aire libre. El uso excesivo de fertilizantes químicos es un problema para muchas empresas productoras agrícolas del país debido a que no existe un ente regulador que controle la cantidad de fertilizantes utilizados. El uso de herramientas GIS nos permite controlar el rendimiento de los cultivos de banano, ya que todos los datos anteriores, como información del cultivo, requerimientos nutricionales, niveles de disponibilidad de cada nutriente y estrategias de fertilización, se ejecutan de forma manual, lo que

genera reportes de rendimiento inexactos y ocasiona pérdidas económicas a productores, se implementó GIS porque este sistema es preciso, lo que nos permite identificar con precisión las necesidades de los cultivos y la cantidad de fertilizante a usar, identificar áreas específicas que requieran nutrientes y ver mayores rendimientos y menos pérdida de fertilizante.

Palabras clave: agricultura de precisión; fertilizantes; SIG (sistema de información geográfica).

Introduction

In Ecuador, bananas are the country's main production crop and have spread over time, maintaining some obsolete and almost unchanged production characteristics. Air pollution is probably the most worrying problem today, the main reason being the excessive use of fertilizers.

Fontagro in 2010, found that in the last 10 years in commercial banana plantations in Latin America and the Caribbean there has been an impressive decline in productivity efficiency despite the fact that the application of advanced technologies and inputs has been more costly and intensive. This is due to the accelerated change and deterioration of the physical, chemical and mainly biological factors of the soil.

For banana cultivation, precision farming tools were developed to meet the needs of monitoring and understanding the status of the product from planting to sale. In recent years, tools and devices have begun to be profiled from the perspective of precision agriculture, and its basic and fundamental definition aims to optimize resources and assets through devices and tools that enable their use in an effective and efficient manner.

Site-specific management requires that producers know as much as reasonably possible about the soil on their farms. For this reason, intensive and careful soil sampling is necessary. The sampling sites are geo-referenced with the help of GIS (geographic information system). In this way, a guide can be produced in which changes in the soil can be appreciated, which helps to understand fertility.

Adaptation to climate change has become one of the main policies and projects of NGOs, donors and governments around the world. Ecuador's concern for the climate phenomenon is expressed at the international level through its commitment to the United Nations Framework Convention on Climate Change (UNFCCC) in 1994. Likewise, in 1999, it ratified its adherence to the Kyoto Protocol (KP), in 2017 to the Paris Agreement, and in 2021 it reaffirms its commitment in the Conference of the Parties - COP of 2021. At the national level, the country has a regulatory framework that addresses aspects of sustainability and climate change through the 2008 Constitution of the Republic of Ecuador.

Scientific studies point to carbon dioxide (CO₂), the gas that causes the greenhouse effect, as the main culprit in the process of climate change due to the accelerated carbon footprint since the industrial revolution. CO concentrations₂ were in the range of 130 and 320 ppm approximately 800,000 years ago and by the year 2021 levels reached 414.72 ppm.

The carbon footprint is an environmental indicator, which serves to measure the amount of greenhouse gases (GHG) emitted into the atmosphere, allowing to know the impact of human activities on the environment. These studies facilitate the development and strategy to mitigate the effects of climate change resulting from atmospheric emissions, mainly due to anthropogenic activities. (Dias & Arroja, 2012; Torres Ramos et al., 2017)..

Carbon footprint studies on the paper production and consumption process are not indifferent to the scientific community. In this sense; Wencong Yue (2017)) performs an analysis of the life cycle of photocopy paper produced in a factory in China, applying a comprehensive methodology to account for the carbon footprint, as well as to evaluate the effects of reducing pollution percentages. The results show that the carbon footprint per 1000 kg of copy paper reached 647.89 kg CO₂.

Currently, there are many paper industries in different countries that are committed to the preservation of wood, the main raw material for paper, as well as to reducing the carbon footprint. To this end, paper recycling policies have been adopted, preventing paper from ending up in landfills or being incinerated with the consequent emission of greenhouse gases. (Fernandez et al., 2021).

This article focuses on the area of climate change due to CO₂ emissions associated with academic management within universities. The main objective is to estimate the carbon footprint of the Universidad Técnica Estatal de Quevedo (UTEQ) located in Ecuador. The study focuses on the years 2020 to 2022, from which due to the effects of the COVID 19 pandemic there was a transition to online education. These digital transformation processes allowed reducing paper consumption and accounting for the amount of paper generated in the university's teaching activities. Therefore, the aim is to determine what would be the carbon footprint that would have been generated in face-to-face education, where students and teachers printed documents. The study will provide a quantification of the carbon footprint not emitted as a result of UTEQ's online education and its contribution as a Green University.

If in the last 50 years the preservation of the environment has become one of the most important issues in regional and global agendas, environmental education is key to achieve this goal, being one of the pillars that has the ability to redirect and modify the behavior of citizens in order to achieve a balance between man and nature (Fiallos, Mendoza, Escobar & Intriago, 2022). However, with the emergence of the COVID-19 pandemic and in view of the requirement and obligatory nature of social isolation in all regions, the goals set in this regard have had to be rethought and the strategies drawn up by governments and institutions, mainly

educational ones, must include new guidelines to address this new affectation. (López M. , 2020).

Higher education is no stranger to this reality; and in the desire to build sustainable societies, since the beginning of the century it has been working to mitigate the problem, becoming a key element to ensure that the training processes of the citizens of the future, incorporate among its lines of action, environmental awareness and sustainability in their administrative and academic processes. (Muñoz et al., 2017; Nieto & Medellín, 2007)..

If universities are institutions that prepare and train generations to constitute the workforce of a country, countries need "green" universities, oriented to sustainability, for their social and economic development, which at the same time are linked to the processes of innovation, research and problem solving, based on the knowledge of reality, the current circumstances of society. For this reason, the academy plays a very important role in the preparation of responsible citizens and leaders with full social conscience, in charge of projecting and sustaining in some way sustainable societies. (Salas, 2021).

According to Lopera and Duque (2019) the educational institutions themselves should have an academic unit that is at the forefront of projects and programs of clean energy, environmental responsibility, reuse and recycling, preservation of resources, which raises the proposal for changes in the management, participation and management of green universities.

In accordance with the above, the Universidad Politécnica Salesiana, Quito headquarters, south campus, in 2012 conducted a carbon footprint study. Since in that year there were 3870 individuals performing activities within the facilities of the UPS-South, it was possible to establish an annual per capita H-C value of 225.81 kg CO₂ eq, emitted into the atmosphere. To verify these results, the SimaPro 7.3 software was used to obtain a total of 861.03 ton CO₂ eq. (Vilches et al., 2015).

In this same line, the Universidad San Francisco de Quito (USFQ), an HEI seriously committed to the environment, in 2015 conducted a new study to update the carbon footprint CO₂, generated by different items of activities of the university community: students, teachers and administrative staff. The final results indicate that, in 2015, USFQ emitted 6225.4 tons of CO₂ per year into the atmosphere. (Salazar et al., 2019).

With this perspective, the Technical University of Machala, an IES noted for its sustainable performance, through the determination of its carbon footprint as an indicator of environmental impact and climate change, has been conducting studies using the guidelines of the ISO 14064-1:2006 standard and the GHG Protocol (Guide to Designing GHG Accounting Reporting Programs). According to the latest results obtained, the total estimated carbon footprint in 2018, 2019 and 2020 was 16803 ton CO₂/year, 15400 ton CO₂/year and 15203 ton CO₂/year respectively, with Scope 3 being the largest contributor with 94% of the total. It was found 1.66 ton CO₂/student for the year 2018; 1.57 ton CO₂/student for the year

2019 and 1.29 ton CO₂ /student in the year 2020, data that show that emissions are below the national average for both universities and inhabitants of the country. (Ferre-Gutiérrez et al., 2021)..

For its part, the National University (UNA), an institution concerned with improving conditions that promote a positive impact on the environment for its staff and students, conducted a study between 2012 and 2014 to quantify and update the carbon footprint generated by its administrative and academic activities.

For the greenhouse gas (GHG) emissions inventory, it applied the methodology endorsed by the National Meteorological Institute (IMN), using the officialized factors indicated in the Greenhouse Gas Emission Factors Manual, fourth edition of 2014. The results of this study evidenced a 22% increase in the carbon footprint, from 2.91 to 3.57 tons CO₂ equivalent. These results are intended to establish specific environmental strategies or measures for their reduction. (Chavarría-Solera et al., 2016)..

From another angle, the State Technical University of Quevedo has also carried out actions that lead to the optimization of large material, human, economic and environmental resources that contribute to environmental sustainability and therefore to the reduction of the carbon footprint. During the period between 2019 and the first months of 2022, it carried out all academic processes in virtual mode, reducing to 0% the printing of academic documents (Fiallos, et al., 2022).

At present, although UTEQ returned to face-to-face mode, it was decided that 75% of the curriculum will be developed in the face-to-face mode, the policy of 0% of printed documents is maintained, being inserted in the "Green University" initiative which arises with the vision of generating greater responsibility regarding the correct and efficient use of resources, as well as promoting the implementation of good environmental practices by the teaching staff, administrative staff and students of universities and other educational centers in each country. (Ordorika, 2020). This is how this health center contributes to minimize the generation of carbon footprint.

Secondary level educational institutions also conduct research to determine the relationship between carbon footprint levels and students' knowledge, attitudes, and practices. According to Torres Ramos et al. (2017) for the measurement of the carbon footprint in the study population, the Greenhouse Gas Protocol was used, through the emissions calculator of Libélula Gestión en Cambio Climático y Comunicación; as well as, the application of a test of knowledge, attitudes and practices. The results obtained showed that the emissions per year in the educational institution were: 25.36 ton CO₂ eq and the average emission of the population under study was 2.18 ton CO₂ eq with a negative correlation of -0.228 between the carbon footprint and the knowledge, attitudes and practices of the population.

Other HEIs are also aware of the benefits of being environmentally friendly through the reduction of paper consumption, for which they point out the importance of document management as good practices that contribute to saving paper and therefore to sustainable development. The methodology used is synthesis and cause-effect analysis. Good practices of several organizations are analyzed, as well as the problems that paper waste causes to the environment. The result of this work has led to the definition of processes for the implementation of Document Management. (López, 2019; Ramírez, 2020)..

Between the years 2019 and 2021, the world population had to confine itself and maintain physical distance in public spaces, as a result of the global health crisis of COVID-19. As a result, states modified their policies to implement telework and online education at all levels, measures that were possible thanks to technological innovation, precisely the Information and Communication Technology (ICT). (Kem-Mekah, 2020).

Articles published on university teaching during the COVID-19 crisis in Spain, analyze the main teaching resources used by professors, 73.2% of the students who participated in the research indicate that their professors have uploaded files with contents of the subject syllabus, this means being greater with respect to videoconferences and online assignments (Pazos et al., 2020).

At the beginning of the year 2022, after two years of confinement, humanity returns partially to normality, but it left wise lessons at all levels of academia. In the environmental aspect, it contributed to the reduction of the carbon footprint because many IES resorted to digital documents, avoiding the printing on paper of student assignments and administrative reports.

In summary, the change seems appropriate, as technology should be able to be integrated into the day-to-day life of an organization to improve it and contribute to the conservation of the environment (Leiva-Aguilera, 2016)..

In context, currently governments, companies, educational system and individuals converge in the idea of reducing to a great extent the use of vegetable matter in the manufacture of paper, cardboard, as well as reducing the use of chemicals in the manufacture of inks, necessary elements in the printing of documents; in contrast to this, they bet on using digital documents, helping to reduce deforestation, saving time, money and reducing the carbon footprint.

Materials and methods

The type of research carried out for this work was documentary, since we used proposals, theses, research articles, books and reliable solid sources, which helped us a lot to develop the topic.

The use of Geographic Information Systems (GIS), satellite images, aerial photographs, etc., incorporate the field study in the verification process and in the interaction of the verification; in addition, these types of tools allow a more accurate mapping and, by reducing production time, a more "agile" mapping of the crops and their use.

The steps to follow in the general process of developing a thematic map are described below:

- Establish the scale on which you should work
- Identify the different homogeneous Cartographic Units.
- Define the types of nutrients to be addressed and depict
- Assign colors representative of the classes
- Determine overloads and codes
- Relate the Cartographic Units with the types of nutrients and assign them the corresponding color.
- Add to each Cartographic Unit its overburden (if applicable) and its codes.
- Elaborate the legend and publish the map.

Applied research was also used, because it gives us information on the use of GIS and the way in which it can be used in banana cultivation, it practically gives us guidelines for us to put it into practice for the elaboration of thematic maps.

Applied Research

Ponce (2003) expresses: "He is not interested in the increase of scientific theory but in the resolution of practical problems" (p. 65). (p. 65).

The application of new ideas leads the student to enrich their knowledge, since it is not only important to rely on scientific theoretical research without the analysis itself that serves to generate new learning.

Research methods

Descriptive method

It is based on the collection, selection and evaluation of information, based on the fertilization of the banana crop implementing the use of GIS tools. In order to obtain the thematic fertilization maps, we must first have the following information: soil maps, climate data, foliar analysis, soil analysis, crop behavior to fertilizers being implemented, disease monitoring, pest control being implemented, and thus have the option of making fertilization maps for our banana crop, taking into account the evaluation obtained from the requirements of our crop with the above information, as it has been proven that the implementation of GIS has improved performance in crops in which it is implemented, and not only yield improvement, but also in reducing costs and waste.

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Research method

Conducting documentary research is the most competent method of how to carry out and implement the use of GIS tools in the fertilization of banana crops and thus be able to obtain thematic maps of it, so we can have greater control with explicit information on the use of fertilizers and achieve higher yields, lower cost of production, due to the implementation of GIS.

Empirical method

The empirical method is a model of scientific research, which is based on empirical logic and, together with the phenomenological method, is the most widely used in the field of social sciences and hard sciences. (Cobas, Romeu, & Macias, 2010).

Its contribution to the research process is fundamentally the result of experience Its usefulness stands out in the entry into unexplored fields or in those in which the descriptive study stands out.

Therefore, empirical data are drawn from successful trials and errors, i.e., from experience. The procedures used to develop the subject were: data creation, data representation, advantages and disadvantages of raster and vector models, non-spatial information, data capture, raster-vector data conversion. Projections, coordinate systems, through tutorials by the zoom platform, to cite correctly in the APA sixth edition style and to search for valid sources for information.

Result

Thematic maps using the GIS tool with information on the availability levels of each nutrient required by the banana crop.

Elaboration of thematic maps with the availability levels of each nutrient.

Soils are the main means of production in agriculture; and they play a key role in the current economic context, so the application of the high input agriculture model and social reasons such as the separation of human beings from the land has had a decisive impact on soil conditions.

Soil fertility analysis is a procedure by which the stocks of major soil elements are measured for their ability to supply nutrients, which can provide researchers and farmers with an

accurate and reliable basis for making the right decisions on the amendments and fertilizer formulas needed for their experiments or plots.

Soil fertility is assessed by chemical, physical or biological analysis, which is somewhat tedious and provides little or no spatial visualization of soil behavior, making knowledge of soil fertility extremely important for proper soil management. With this problem in mind, thematic maps of essential nutrients for crop establishment and fertilizer management have been created. For this reason, Geographic Information Systems (GIS) have become the ideal tool for this type of analysis, as they allow the use of information of different origins and types, making it possible to process them together.

The main characteristic of GIS is the possibility of working with data located in space and referenced to a system of flat or geographic coordinates, which allows the creation of maps (graphical information) very useful for decision-making. (Puig M. A., 2012)..

Nitrogen

Nitrogen is an important element in the management of banana crop nutrition, it is taken up by plants mainly in the form of nitrate or ammonium, in conditions of ammonium deficiency in the soil the plant increases nitrate assimilation. Its needs are considered high, more than 200 kg ha⁻¹ per year, it is important for the structure of proteins and vitamins, participates in the formation of chlorophyll and is important in plant development (See Figure 1).

Its deficiency in the plant causes stunted growth, yellowing of leaves and small fruits. This element in plants is required in high amounts as it serves as a good constituent of cellular components, including amino acids and nucleic acids, in addition, it is the main mechanism of plant growth. In tropical regions, due to high temperatures and high rainfall, nitrogen losses from the soil are high, so it is necessary to fertilize frequently and in small amounts to ensure an adequate and constant supply for optimal plant growth. (Torres, 2016).

Phosphorus

For banana is a mineral element, which the plant does not need in large quantities, its requirements are less than those of potassium and nitrogen (23 to 34 kg ha⁻¹ year, by the form of storage and distribution in a plant is not a frequent deficiency, it accumulates for a long time, like other mineral nutrients, are lost little during crop development especially at harvest in the fruits and are easily transferred to the son of a succession. The plant absorbs it from the soil in the form of phosphate and phosphite. The highest uptake occurs during the first five months of plant development (vegetative phase) (See Figure 2).

Phosphorus is part of ATP, as well as phospholipids, nucleic acids and coenzymes. Its function is to control starch synthesis, in climatic respiration during fruit ripening, it is a conductor of energy (ATP) and the reduction of NADP to NADPH, releasing energy for respiration needed for fructose synthesis, as well as phospholipid synthesis and cellulose

formation. When the deficiency manifests itself, plants with poor growth and weak root development are formed, sawtooth chlorosis is observed on old leaves, petioles become brittle and break easily, young leaves take on a greenish-blue hue, this deficiency can limit potassium assimilation, and the reaction of plants to its correction is very slow. (Torres, 2016).

Potassium

It is considered the main element of banana mineral nutrition, the plant requires it in large quantities (more than 1100 kg ha⁻¹ yr⁻¹), intervening in processes such as respiration, photosynthesis, chlorophyll formation and regulation of the water status of the plant leaves, which increases resistance to drought, frost and salinity, also a good source of this element helps plants to become less sick. Deficiency of this element usually occurs in soils where its content is low due to its origin or overexploitation. The symptoms of deficiency are chlorosis of the tips of old leaves, inward curling in the later stages of deficiency and subsequent death, stunting resulting in stunting due to shortening of internodes, in some areas this symptom is known as "bolting", bunch deformation, which is usually expressed by stunted fruit that are not full, forming a short bunch, of low weight and very susceptible to early ripening, in addition, the deficiency of this element is a nutritional factor that causes more damage to the banana industry at the national level. (VILLARRUEL, 2016).

Magnesium

Magnesium is required for stem and leaf development as well as for carbohydrate synthesis and accumulation. To ensure maximum yields, a minimum foliar magnesium level of 0.3% (dry matter) should be achieved. Magnesium supply can be increased by using only water-soluble forms and by trying to obtain an optimum cation ratio in the soil. The ratio of magnesium to potassium should ideally be 1:4 in saline soils and 1:2 in clay soils. (Agriculture, 2019).

Calcium

Conditions such as abundant rainfall and high temperatures can cause the origin of deficiencies of different elements such as calcium, especially in periods of rapid growth such as leaf differentiation and fruit development, which can cause the appearance of the physiological disorder maturity spot. In addition, epicuticular wax is responsible for stiffening the cells and appears in the first 14 to 28 days after bunch emergence; consequently, during this period, calcium deficiency is more critical. Forty-two days after cluster emergence, the walls show fractures that vary in size and depth; subsequently, there is discoloration of the cytoplasmic content of the cells that then spread into the intercellular spaces. Calcium is very important in the cell since it is part of the cell wall and acts as a cementing agent that joins the cell walls. (Agriculture, 2019).

Sulfur

Sulfur is required as an element accompanying nitrogen in the formation of proteins and carbohydrates. By supplying sulfur, the uptake and assimilation of any applied nitrogen is maximized thereby improving nitrogen use efficiency. Bananas are generally grown in humid tropical areas with typically high annual rainfall and fast-draining soils. Since sulfur is generally in the form of an anion (SO₄), which is easily leached under such conditions, a regular supply is required to maximize productivity. In many soils, crop sulfur requirements are supplemented by a natural source such as organic matter. However, since most tropical soils are poor in organic matter, sulfur requirements considerably exceed the supply of sulfur from organic matter. Therefore, sulfur fertilizers need to be included in the fertilization program. The critical sulfur concentration in banana leaves (3 leaf) is considered to be 0.23%. In humid tropical areas, the use of non-acidifying fertilizers is recommended so as not to increase the acidity of the soil (See Figure 3).

It is very difficult to correct a soil acidity problem in an established plantation as banana is a perennial crop, which prefers a soil with only slightly acidic pH rising to between 5.5 and 6.5. ESTA Kieserit has no influence on soil pH and is therefore an ideal source of sulfur for bananas. (Agriculture, 2019).

Thematic fertilization maps for banana cultivation with the implementation of GIS tools.

Obtaining strategic thematic maps of fertilization in banana cultivation

In order to obtain the strategic thematic fertilization maps, we must implement site-specific management. Site-specific management seeks to identify and quantify the spatial variability present on the farm, thus being able to determine the impact of variability and yield.

With site-specific management we seek high yields in production, this type of management considers the responses of yield, climate, natural resources and inputs. In this way we can have the specific information of the yield of each lot, since when we start to carefully quantify the yield of the lots it is clearly observed, in this way we can know which are the factors that are limiting our production.

The advantage of implementing this is that it improves profitability by increasing yields and reducing input costs. This does not mean that less inputs will be used, but rather that the use of inputs will be maximized by reducing input losses, better management ensures better quality production and also makes it more profitable.

As a disadvantage we can cite the cost to implement it (equipment, sampling, maps) and training for the use of this technology. (J.Kuruvilla, 2010) .

The devaluation of the peso and the changes in the economic course of our country, originated a return to the consumption of national products. The case of bananas, the fruit with the highest per capita consumption, is paradigmatic. After planting more than 15 thousand hectares a few years ago, the increased competition with the imported product reduced the area to no more than 3 thousand, to supply only the consumption of the north of the country. Currently the situation has been reversed and although the quality of imported products is still superior to the national product, production is much more competitive. Average prices reflect the quality of the origin, while for the national banana you get about \$ 0.40 / kg, the imported banana is paid around \$ 1 / kg (Ecuador: 1.13; Brazil 0.91 or Bolivia 0.84) in the Central Market of Buenos Aires. This forces local producers to strive to achieve a similar quality, for which the adoption of practices, such as fertilization in time and form, aimed at improving the crop are to be taken into account. (MANING & BANMAN., 2010)..

Usual fertilization rates

Nutritional status in the early stages of development, especially K, is very important as it will determine fruit yield. The high K removal rate in banana fruit requires good supplementation even when the soil has levels that could be considered high. Studies conducted in 19 banana growing countries showed that the recommended fertilizer doses would be 211 kg N/ha/year, 35 kg P/ha/year and 323 kg K/ha/year. It is suggested that, to achieve maximum yields, these doses should be doubled.

Nutritional status in the early stages of development, especially K, is very important as it will determine fruit yield. The high K removal rate in banana fruit requires good supplementation even when the soil has levels that could be considered high. This high K demand is associated with site variations with variable and specific responses and recommendations. Thus, recommendations range from a minimum of 500 kg/ha of K₂O when the level of this nutrient in the soil is around 0.5 meq/100 g or, as in the results of the work carried out in Costa Rica, where the best economic response is achieved with doses that vary between 600 and 675 kg of K₂O/ha/year, even in soils with relatively high K content.

In the case of N, banana production around the world uses doses between 100 and 600 kg N/ha/year, depending on the soil and climatic conditions of each zone. In most banana growing areas in Latin America, doses of around 300 kg N/ha/year are used. Table 3 suggests doses for different soil analysis categories. For the interpretation of cation values, it is recommended to combine the quantity and intensity factors, i.e. the data in units of cation load (1 meq/100 g = 1 cmolc/kg) and % saturation with respect to total (GAUGGEL, 2010).

Fertilization practice

It has been shown that the banana plant takes advantage of the nutrients present in the soil from shortly after transplanting for 2 to 3 months, until the beginning of flowering. After flower differentiation, the plant sustains its growth and fills the bunch with stored nutrients. For this reason, in fertilizer management it is recommended to apply nutrients until shortly before flowering, and then concentrate efforts on the succession bud, commonly called "daughter".

The stem should not be fertilized once it has already flowered, since the fruiting process will henceforth be fed by the nutrients stored in the plant. Instead, the daughters should be fertilized in the forward crescent-shaped area, approximately one meter in diameter, which is where the highest density of effective roots is concentrated. It is said that the banana tree "walks", i.e. the daughters appear in a certain direction.

There are no restrictions as to the appropriate types of fertilizers. For their choice, criteria of cost per unit of nutrient, and the appropriate balance in a program that includes all of them, particularly the main ones, N, K, P, S and Mg. For this, the use of physical mixtures and in particular those adapted to each site are recommended. Examples of common formulas in banana areas are 14-2-25-26-7 or 14-4-29-11-6 (corresponding to N-P₂O₅-K₂O, S and Mg). The percentages of nutrients in the formula can be adjusted according to the soil/plant analysis recommendation that allows for some degree of site-specific nutrient management.

The total recommended dose can be divided during the year and distributed in several applications to avoid root burn and nutrient losses by volatilization (N) and leaching (N and K). If the soil has low nutrient retention capacity (low cation exchange capacity, coarse textures, low percentage of organic matter), several applications are recommended. The normal is between 4 and 8 applications per year; but it depends on climate, soil type and labor availability. The advantage of dividing the dosage is the greater efficiency of use and consequently, greater profitability.

N and K can be applied simultaneously with the irrigation shift, thus avoiding possible volatilization losses. The efficiency of this practice can reach 100% to 65% for K and N applied, respectively. (GAUGGEL, 2010).

- Factors determining fertilization in bananas
- Climate (temperatures, cold fronts, winds, rainfall and its distribution, relative humidity)
- Elevation above sea level.
- Soils (morphological, physical, chemical and mineralogical properties).
- Internal and external soil drainage.
- Influence of morphological properties

Structure (medium to fine granular, K absorption severely restricted in massive soils.

- Porosity (size and continuity of pores).
- Optimum loamy to fine sandy texture.
- Friable consistency.
- Effect of Physical Properties
- Bulk density (this must be $< 1.5 \text{ g/cm}^3$ for adequate absorption, the lower the better).
- Infiltration and permeability (these have to be moderate, slow or very fast ones inhibit K absorption).
- Medium to low root penetration resistance.
- Nitrogen Fertilization
- Essential for the formation of proteins, amino acids, nucleic acids, etc.
- In banana essential to obtain a vigorous plant and large, well-formed fruit.
- Deficiency: slow growing plant, small, yellow leaves and small fruit.
- Optimum levels in the leaf are 2.5- 3%.

Nitrogen fertilization continues

Soils with high organic matter content generally require less N ($>8\%$ O.M.) but always require nitrogen. This has been one of the major constraints to organic banana production at the export level.

Doses required 350-600 kg N/ha/year depending on soil texture, sandy soils require more N and applied more frequently.

Phosphorus Fertilization

Its function is as cell pH buffer; control of starch synthesis, in climacteric respiration during fruit ripening; energy (ATP) conductor; reduction of NADP to NADPH releasing energy for respiration, glycolysis and CO_2 fixation; required for sucrose synthesis; phospholipid synthesis and cellulose formation.

P fertilization continues

Essential in storing energy as physis in seeds and fruits and constitutes organic molecules such as cell membrane phospholipids, lipoproteins, etc.

Banana requires relatively small amounts of P since there is a large transfer from mother to child, grandchild etc. and deficiencies of this element are rare after the first generation.

Optimum foliar levels are between 0.25- 0.30%.

P fertilization continues

P is essential in the establishment of the plantation (template) and its application is necessary at this stage, but given the transfer from mother to child, etc., its subsequent application is questionable.

Doses depend on the type of soil, in calcareous and clay soils (soils with poured properties) between 75 to 150 kg of P/ha are required. In acid soils such as ultisols and oxisols, high doses are also required. On loam, sandy loam and slightly acid to neutral pH soils, 50 kg K/ha are usually required.

Experience indicates that it is important to apply phosphorus in the first three generations at the indicated doses depending on the type of soil.

Potassium fertilization

In banana it is essential in keeping the plant hydrated and regulating the opening of the stomata; in the accumulation and translocation of newly synthesized carbohydrates and important in cellulose synthesis.

It can be said to be one of the most important elements in banana nutrition.

Fertility with k continues

K deficiency results in fruit that are underweight, short, thin and very susceptible to early maturity. K deficiency is perhaps the most damaging nutritional factor to the banana industry worldwide.

Optimal foliar levels are between 3.5 and 4.0%, with great benefits in maintaining them around 4% mainly where water stresses and low temperatures are present. (GAUGGEL, 2010)

Fertilization with k continues

The mineralogy and the amount of clay have a great influence on the bioavailability of K and P. In banana, soils rich in Illite significantly fix K as well as clay soils rich in smectic. - The required doses are as follows: Illite-rich soils between 750 to 1200 kg K/ha/year. In smectic clay soils 650 to 900 kg of K/ha. In loam soils of mixed mineralogy, friable 550 kg/ha/year. The most common source of fertilizer is KCL, but in saline and/or sodic soils potassium sulfate should be used and chlorides should be avoided. K uptake as well as P uptake is highly influenced by soil compaction and massiveness, so working with soils with morphological and physical properties is very important. Foliar applications in the form of chelates and metalosates are highly desirable mainly in the dry and/or cold season. (GAUGGEL, 2010)

Calcium fertilization

Ca is essential in the formation of calcium pectate which is an important part of the fruit epidermis and in the formation of new meristematic culture.

In banana its deficiency results in deformed leaves in seedling and in growth deficiency with deformation of the apical meristematic point.

Ca fertilization continues

- Its application in banana depends on the Ca content of the soil and relative humidity. Ca is not absorbed when relative humidity is high and even when the soil has sufficient calcium, deficiencies of this element can occur.

- In acid soils it is necessary to use calcium carbonate or dolomite, depending on the presence of Mg deficiency. At the beginning of planting, the best results have been obtained with foliar application of chelates or metalosates. It is also important to apply them at times when relative humidity is high. (GAUGGEL, 2010)

Site-specific management in banana

In tropical crops such as banana, coffee, cocoa, oil palm, etc. The implementation of this type of management and the use of high technology, which is limited by the high initial cost and low knowledge of the technological tools. However, it is possible to develop systems with less technology with the support of GIS and GPS, but this will depend on the knowledge and experience of the producers.

Knowing the particular characteristics of banana farms, it is possible to design a fertilization system with the site-specific management system with less technology based on GPS and GIS. (J.Kuruvilla, 2010).

Soil map

It is necessary to start from a general soil map which should use a grid system and GPS to permanently locate the sampling site in the field. The general soil map can be made by means of the GIS that exist in the market, in banana it is very important to make a good soil attitude map for banana cultivation. This map clearly delimits the soil units depending on the constraints that are present, for the optimal development of the crop, this system has the advantage of determining the particular soil factors that can limit the banana crop, such as drainage, texture, profile depth, acidity. But at the same time it accumulates the necessary data for a specific map such as nutrient dynamics (see Figure 4).

The information from the foliar analysis complements the information from the soil analysis, which is of great help in determining limiting factors before planting the crop and then being able to monitor over time the changes that could affect the yield. (J.Kuruvilla, 2010).

Yield maps

There must be a way to record the yield of the fruit in order to design a site-specific management system. The fruit is harvested and transported to the processing shed where each bunch is weighed on a computerized scale, recording the weight and the cable from which it originated, in this case a particular system of data accumulation must be developed because all harvesting is manual and there is no passivity to use yield meters linked to GPS, the system of cables for transporting the fruit also delimits the areas and the yield obtained per area (See Figure 5).

"In this way, detailed performance maps can be made." (MANING & BANMAN., 2010)..

Development of a site-specific management system

These yield maps can be overlaid with the soil maps, and in this way determine the variability ratio of the yield.

The analysis of variability allows us to determine which soil factors are limiting yields and thus be able to design a strategy that allows us to minimize these limiting factors and thus increase yields. The purpose of this is to increase the level of yield per area and the use of inputs.

The variability in performance can be affected by an error in the handling of the same, because the activities are usually done manually, there is a possibility that, when performing certain jobs, these are not performed with the precision required by the same. (MANING & BANMAN., 2010).

The following data is entered in these maps:

- Basic data
 - Soil maps
 - Weather data
 - Crop performance
 - Determination of problem areas
 - Disease monitoring.
-
- The following information is included in the soil maps or base maps:
 - Seeding blocks

- Roads
- Drainage
- Rivers.

This should be entered using area photographs and satellite images.

- The following information must be included in the base data:
- Foliar analysis
- Soil analysis
- Performance
- Fertilizer use

In general, soil fertility is assessed from chemical, physical or biological analyses, comparing the results with predetermined calibration scales. This is a somewhat tedious process, with little or no spatial visualization of soil behavior, but the thematic maps allow decisions to be made about banana cultivation and fertilizer management (Puig A. C., 2012)..

GIS is defined as a set of hardware, software, people and methods designed to facilitate the collection, management, manipulation, analysis, modeling and visualization of statistical, spatial and temporal data in order to solve complex land use and management problems. The main objective of GIS is to produce reliable results for decision making by analyzing and interpreting large amounts of biophysical, socioeconomic, and statistical data in spatial and temporal form needed to create flexible, versatile, and integrated information products such as tables and maps. (MANCILLA, 2018).

Soil fertility analysis is a procedure of measuring the stocks of key elements in the soil to determine their ability to supply nutrients, which can provide researchers and farmers with an accurate and reliable basis for making the right decisions on amendments and fertilizer formulations needed for their experiments or plots. Soil fertility assessment is done on the basis of chemical, physical or biological analysis, which is somewhat tedious and provides poor spatial visualization of soil behavior, making knowledge of soil fertility extremely important for proper soil management. Considering this problem, the aim of our work is to create thematic maps of basic soil chemical properties for crop and fertilizer management.

Determination of nutrient requirements of banana crop

Research on mineral nutrition and fertilization of banana has been extensive and effective. This has allowed us to know the general conditions of crop response to nutritional management. (Espinoza & Mite, 2002)..

Table 1. *Tentative critical levels in different tissues of the banana plant.*

Nutrients	Lamina	Ribs	petiole
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N (%)	2.6	0.65	0.04
P (%)	0.2	0.08	0.07
Ca (%)	0.5	0.5	0.5
Mg (%)	0.3	0.3	0.3
Na (%)	0.005	0.005	0.005
Cl (%)	0.6	0.65	0.7
S (%)	0.23	-	0.36
K (%)	3.0	3.0	2.1
Mn (mg/Kg)			
Fe (mg/Kg)			
Zn (mg/Kg)			
B (mg/Kg)			
Cu (mg/Kg)			5

Note: According to research carried out by Lahav and Turner, the tentative critical levels in different tissues of the fully grown banana plant, data taken from (Espinoza & Mite, 2002).

Table 2. *Banana fertilization rates*

Nutrient	Low ground level	Average soil level	High ground level
Phosphorus (mg/Kg)	< 10	10-20	>20
Kg P₂O₅/ha/year			0
Potassium [cmol(+)/kg].	< 0.2	0.2-0.5	>0.5
kg K₂O/ha/year			
Calcium [cmol(+)/kg].	< 3	3-6	>6
kg CaO/ha/year	1160	560	0
Magnesium [cmol(+)/kg].	< 1	1-3	>3
kg MgO/ha/year			0
Nitrogen	Indifferent	Indifferent	Indifferent
kg N/ha/year	350-400	350-400	350-400

Note: Banana fertilization rates according to soil analysis results. (Espinoza & Mite, 2002)..

This table shows a comparison of the results of the potassium (K) dose studies used to determine the critical level and the doses to be applied according to the soil analysis. It is very interesting to note how the same doses of K allow higher yields as time goes by. The highest part of the curves is between 600 and 700 kg/ha of K₂O in all cases.

Meristematic plants with higher production potential were used and it was recommended to divide the application of fertilizers in up to 26 cycles per year (Flores, 1995). K dosage due to the better efficiency of nutrient implementation by the crop; if it is taken into account that the phosphorus (P) requirement of musaceae is low, the disadvantages of extensive implementation of a single critical degree could be manifested with K. In the area there are no K-fixing clays that could hinder the use of a single critical degree. (Espinoza & Mite, 2002).

Table 3. *Banana fertilization rates at high densities*

Nutrients	Low ground level	Average soil level	High ground level
Phosphorus* (mg/kg) kg P₂O₅/ha/year	<8	9-15	>15 0
Potassium (cmol(+)/kg) kg K₂O/ha/year	<0.2	0.2-0.3	>0.3
Calcium (cmol(+)/kg) kg CaO/ha/year	<3	3-6	>6 0
Magnesium (cmol(+)/kg) kg MgO/ha/year	<1	1-3	>3 0
Nitrogen kg N/ha/year	Variable 200-250	Variable 200-250	Variable 200-250

Note: Banana fertilization rates at high densities according to soil analysis results. (Espinoza & Mite, 2002)..

Research conducted in Colombia made it possible to establish critical levels for banana and nutrient recommendations based on soil studies. The same considerations are made for this crop with respect to the behavior of nutrients in the soil, which allows for an elementary recommendation that could be used in all soils where bananas are grown in Latin America. (Espinoza & Mite, 2002). . Soil fertility analysis is a procedure for measuring the stocks of key elements in the soil to determine their capacity to supply nutrients, which provides researchers and farmers with an accurate and reliable basis for making the right decisions regarding the amendments and fertilization formulas needed for their plots. The evaluation of

soil fertility is done on the basis of chemical, physical or biological analysis, which is somewhat tedious and provides little spatial visualization of soil behavior, so knowing soil fertility is extremely important for proper soil management. Taking into account this problem, the objective of our work is to be able to create thematic maps of basic chemical properties of the soil for crop and fertilizer management using G.I.S.

Conclusions

According to the research carried out, we have been able to determine that the most important nutritional elements for banana cultivation are nitrogen (N) and potassium (K). It has also been emphasized that fertilization should be adequate, since the amount of fertilizer varies according to the areas or regions to be fertilized and that the application should be made in the areas of maximum absorption; and that the amounts of fertilizers for banana cultivation should be distributed in 12 annual applications, taking into account the availability of irrigation and the number of tillage of the crop. To make the maps with the levels of nutrient availability we had to perform soil fertility analysis which allowed us to know the availability of nutrients that our soils had and which nutrients were in deficit, this data was entered into the GIS tools to obtain a map which allows us to easily identify the areas that require nutrients and what nutrients each area needs, in order to make the fertilization plan.

Once we had the data from the nutrient availability maps we went on to make the fertilization maps, for which we used site-specific management which helped us to identify and quantify the spatial variability present on the farm, in that way we were able to determine the impact of variability and yield, with this system we must take into consideration the responses of yield, climate, natural resources and inputs and thus we obtained specific information on the requirements and yields of each lot and thus we identified which were the factors that were affecting production, The advantage of implementing this is that it improves profitability by increasing yields and reducing the cost of inputs and by having a better management it ensures a better quality production and also makes it more profitable.

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