Fertilizer recommendation system for crop nutrition

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ABSTRACT

The correct handling of fertilizers in the soil saves time and money. In the market there are computer systems that help farmers in making decisions for fertilizing their crops, but they have a high cost of money, in some cases are unknown in the ambit or are not adaptable to different agricultural species and sectors. The purpose of this work is the development and implementation of a Fertilizer Recommendation System (FRS), with the aim of guiding farmers in the optimal combination of fertilizers, their dosage and budget to apply. FRS was programmed in Python language and the fertilizer recommendation process was solved by a system of equations dynamically constructed according to several input parameters provided by the user as: type of crop, its expected yield (*EY*) and nutrient levels required for the selected crop, plot size, irrigation type and soil/water analysis; the system calculates the dose of nutrients needed to achieve *EY* and performs various fertilizer combinations until it generates the most optimal recommendation. FRS was implemented as a web application, in a university cloud computing in SaaS multi-tenant mode. It was tested on banana crops in the province of El Oro, Ecuador under expert supervision; however FRS is scalable and adaptable to any type of crop and sector. Farmers can access and benefit from this tool to optimize costs and increase crop yields.

Keywords: agriculture, fertilizers, plants nutrition, Recommendation System, TIC

INTRODUCTION

According to the predictions of the United Nations (UN) and FAO, the world's population will approach 9 billion people in the coming decades, in this context, it is estimated that there will be a need for between 70 and 100% more food (Godfray et al., 2010), so agriculture becomes a fundamental pillar for sustaining food in the world (OECD-FAO 2013; García 2006).

In Ecuador, agriculture is the second economic activity after oil exploitation (Vélez, Bravo, & Carvajal, 2017). According to the Survey of Agricultural Surface and Production of the National Institute of Statistics and Censuses of Ecuador (INEC), Ecuador dedicates 5.39 million hectares to agricultural work, of which 42.68% are cultivated pastures, 26.70% correspond to permanent crops and 15.76% to transitory crops (INEC, 2016; Monteros Guerrero, Sumba Lusero, & Salvador Sarauz, 2016). The main crops are: banana, African palm, sugar cane, corn, potato and rice (INEC, 2016; Roibás, Elbehri, & Hospido, 2016), which are destined to meet the demand of national and international markets.

The adequate supply of nutrients for a crop depends on the physical-chemical properties of the soil, chemical properties of the water, climatic conditions, expected crop yield, among others (Redding, Lewis, Kearton, & Smith, 2016). In this context, nutrient deficiency can be remedied by applying nutrients through fertilization that cannot be supplied by soil and water (Mikkelsen, 2017). Fertilizers contain nutrients for plants and can be of animal, mineral, vegetable or chemical synthesis origin (Case, Oelofse, Hou, Oenema, & Jensen, 2017). Proper management of these, is key to efficient production in terms of agricultural yield, given that its proper management favors the increase of soil fertility (Bueno-Delgado, Molina-Martínez, Correoso-Campillo, & Pavón-Mariño, 2016). Therefore, the choice of fertilizers depends on the nutritional supply of soil and water, determined through laboratory analysis, the nutrient requirement of the crop for a production objective and the composition of fertilizers (Manning, 2015; Martínez-Alcántara et al., 2012). In this sense, the prediction and calculation of nutritional needs for crops becomes a complicated task, given the variables considered by its estimation, so its automation would turn this activity into a more efficient and less complex process (Pattison et al., 2008; Ryan, Sommer, & Ibrikci, 2012).

Nowadays, it is essential to use technology for agricultural production (González, Henao, & Torres, 2017; Valin et al., 2014), given the challenge of producing a greater quantity of quality food (Pagán, Ferrández-Villena, Fernández-Pacheco, Rosillo, & Molina-Martínez, 2015), through the implementation of techniques to optimize resources and processes (Aker, 2011; Pérez-Castro et al., 2017).

Among the options to generate processes for choosing nutritional dosages for crops, there are the recommendation systems. These types of systems apply prescriptive data analysis techniques and are implemented when it is necessary to maximize or minimize any business objective in order to optimize resources and increase operational efficiency (Evans & Lindner, 2012; Kopcso & Pachamanova, 2017; Provost & Fawcett, 2013). There are some important contributions of this type of fertilizer recommendation technologies that have been developed for both mobile devices and the web environment e.g., AgPhD (Fertilizer Removal by Crop 2014), DSS-FC (Barradas, 2015) and web based applications Smart-Fertilizer (2017) y Fertilizer Calculator (2012). Each one of them does an individual contribution but it is necessary a software that integrates these solutions and also scalable to more types of crops and different application contexts.

The purpose of this research project was to develop a web-oriented Fertilizer Recommendation System (FRS), where linear programming models and matrices are applied for the solution of dynamic equation systems that are created according to the data of a crop's nutritional requirements and the nutritional inputs provided by soil and water, in order to guide farmers in the optimal combination of fertilizers, their dosage and budget to apply, taking into account the optimization of costs and increase in crop yield (Bueno-Delgado et al., 2016; Pagán et al., 2015; Pérez-Castro et al., 2017).

MATERIALS AND METHODS

This work was accomplished in the Universidad Técnica de Machala (UTMACH), located in El Oro province, south of Ecuador, geographic coordinate: latitude 3°15′30″ S y longitude: 79°57′37″ O

Materials and Tools. For the development of Fertilizer Recommendation System (FRS) PostgreSQL was used as database management system, Nginx for web server, Python programming language (Patel & Cassou, 2015) with Django Framework and additional libraries for mathematical calculations (NumPy). Some input parameters such as soil and water analysis reports were required to identify the required dose of nutrients; and then linear programming techniques were applied to solve equation systems that represent the relationship between the nutrients required for a crop and the fertilizers possessed by these nutrients.. The implementation of FRS was made as an application SaaS multi-tenant on the Internet Of Things platform created by the research group AutoMathTIC of the UTMACH, allowing access to farmers who wish to use the software for fertilizer recommendations. FRS validation was supported by agricultural professionals. FRS has a scalable structure for future upgrades.

Description of the development and implementation of Fertilizer Recommendation System (FRS).

The FRS software was designed to present the minimum dose of nutrients needed to reach the maximum productive potential of a crop (yield). This system applies the rational equation of fertility (Nájera et al., 2015; Salazar Guerrero, 2015), which satisfies the balance between the nutritional requirement of a given crop and the inputs that represent the sum of nutrients, both soil and irrigation water. In addition, the simplified equation (1) considers the efficiency of fertilizer application to the soil according to the type of irrigation used, as well as nutrient supply parameters from the soil.

$$Dose = \frac{requirements - inputs}{efficiency} \qquad (1)$$

The calculation of the required *Dose* allows to know the current need of crops for a given yield, where the nutritional requirement of the crop corresponds to the amount of nutrients required to obtain the yield of production in a given agroecosystem (climate-cultivation-soil system). *Inputs* are the amount of nutrients available in the soil and potentially absorbable, and the *efficiency* of fertilization corresponds to the recovered part of the nutrient applied to the soil of the crop. (Etchevers, Rodríguez, & Galvis, 1991).

Nutritional Requirement

The Nutritional requirement (*NR*) of a crop is obtained by the equation (2),

$$NR = BY \cdot EY \qquad (2)$$

where the base yield (*BY*) is the amount of nutrients needed to generate one tonne of production per hectare (t ha-1) and is multiplied by the expected yield (*EY*) of the crop (t ha-1 year-1) to increase agricultural production (Xu et al., 2017). For example, Table 1 shows the nutrient demand for three types of crops in Ecuador's tropical zone (Vidal, 2007).

Table 1. Demand for nutrients from crops grown in the tropical zone of Ecuador

Crop	N	P_2O_5	K_2O	MgO	CaO	Rango Rdt. (t ha^{-1})
Café	4.50	1.40	5.00	1.50	2.70	15-30
Banana	354.00	29.00	770.00	9.96	3.84	55-100
Cocoa	4.57	0.76	7.20	0.61	1.40	1

Adapted from (Vidal, 2007)

Soil Inputs

The agricultural soils where different types of species are cultivated have multiple nutrients, but only one part is potentially absorbable by the plant in all its growth phases, this is called nutrient availability. In contrast, inputs are all the nutrients that are actually used by the plant, which depend on the absorption efficiency of each crop in reference. For example, a list of nutrients and the optimum level required for a crop is given in Table 2.

Table 2. Nutrient levels in the soil

Element	Símbolo	Optimum Level (ppm)
Macro-Nutrients		
Nitrogen	N	35-60
Phosphorus	P	25-40

Potassium	K	125-320
Magnesium	Mg	45-135
Calcium	Ca	600-1200
Sulfur	S	15 -25
Micro-Nutrients		
Manganese	Mn	6-30
Iron	Fe	20-50
Copper	Cu	1-4
Zinc	Zn	1.2-6
Boron	B	0.15-0.60
Sodium	Na	0-140

Adapted from (Vidal, 2007)

The input also depends on the total amount of nutrient content in one hectare of soil, i. e. the arable layer or volume of soil for a given depth. By multiplying the volume of soil with Bulk density (*BD*), the weight of the hectare is obtained. *BD* is an important variable of soil mass and is defined as the dry soil mass in a unit of volume; this variable is related to the combined volume of pores and solid particles in the soil, and consequently any factor influencing soil pores (agricultural handling) influences *BD*. It is highly necessary to enter the value of *BD* in order to obtain the dose required by the crops. Table 3 shows the textural classes, which directly influence the amount of water that the plant can retain, for example the largest particle of clay has approximately 25 times more surface area, than the smallest particle of sand, therefore as the surface area increases so does the amount of absorbable water, unlike *BD* which is inversely proportional to the size of the surface area (PPI, 2003).

Table 3: Soil textural classes and bulk density

Soil Textural Classes	*BD* (g cm^{-3})
Sand	1.70-1.80
Coarse Sand	1.60-1.70
Sand and Fine Sand	1.55-1.65
Loamy Sand	1.60-1.70
Loamy Coarse Sand	1.55-1.65
Loamy Sand, Loamy Fine Sand	1.55-1.60
Sandy Loam	1.55-1-60
Coarse Sandy Loam and fine sandy loam	1.50-1.60

Loamy Very Fine Sand	1.45-1.55
Loam	1.40-1.50
Clay Loam	1.40-1.50
Sandy Clay Loam and Silty Clay Loam.	1.45-1.55
Sandy Clay	1.35-1.45
Silty Clay	1.40-1.50
Clay (35%-50%)	1.35-1.45
Clay (50%-65%)	1.25-1.35

Adapted from (USDA, n.d.)

Crop Efficiency

The crop efficiency in absorbing nutrients depends on the type of irrigation used. Table 4 shows fertilizer efficiency for nutrients N, P, K.

Table 4: Percentage efficiency of use of N, P, K according to irrigation system used.

Irrigation System	Nitrogen(%)	Phosphorus(%)	Potassium(%)
Furrow	40-60	10-20	60-75
Sprinkler, pivot	60-70	15-25	70-80
Drip, Micro.	75-85	25-35	80-90

Adapted from (Vidal, 2007)

The method used for the selection of fertilizers and their result of the solution dose is done through a system of linear equations by matrices (see equation 3) where [P] represents the concentration of nutrients in the selected fertilizers, [R] represents the amount of fertilizer required to meet the needs of the crop and [Q] is the required dose of nutrients for a crop (Pagán et al., 2015).

$$[P]\cdot[Q]=[R] \Rightarrow [Q]=[P]^{-1}\cdot[R] \qquad (3)$$

where:

$$[\mathrm{P}]=\begin{pmatrix} A_1 & B_1 & C_1 & D_1.. \\ A_2 & B_2 & C_2 & D_2.. \\ A_3 & B_3 & C_3 & D_3.. \\ A_4 & B_4 & C_4 & D_4.. \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix} \ [\mathrm{R}]=\begin{pmatrix} a \\ b \\ c \\ d \\ \vdots \end{pmatrix} \ [\mathrm{Q}]=\begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ \vdots \end{pmatrix}$$

To perform the process of mathematical calculations, the application has a database that stores the most used agricultural fertilizers and their respective nutrient concentration. All the information needed to make the calculations is extracted from this database and the fertilizer combinations are generated from an initial selection of fertilizers to be worked on.

In addition, the application calculates the budget or investment cost of all fertilizers according to the quantities to be supplied and the area of the plot to be cultivated. As mentioned above, if the user selects N fertilizers, the software analyzes all possible combinations of fertilizers [P] that cover the need for the required dose [Q], i. e., for each combination a group of fertilizers with their respective quantities [R] will be obtained as a recommendation, the same ones that will be used in the production of N tons per year of the reference crop. As soon as the iterative process is completed, the program selects the fertilizer combination (s) that fully covers the required dose of nutrients for crop production; if no valid solution is obtained, an error message will be displayed warning of the incompatibility of the adjustment and will recommend a change in the fertilizers initially selected.

Figure 1 shows the procedure used by the FRS application to calculate and generate the fertilizer recommendation for an agricultural crop. The algorithm follows a sequence of steps described below:

Step 1. Enter the general data of the fertilization plan where the name of the plan, the location of the property, a description of the plan and the choice of whether or not to associate a water analysis should be recorded.

Step 2. Choice of the type of crop for which fertilizers are to be recommended and the Expected Yield (*EY*) given in tonnes per hectare per year (t ha^{-1} $year^{-1}$). The FRS database has already registered the base yield (*BY*) for each type of crop, which in turn are used to obtain the values of nutritional requirements (*NR*), described in equation 2.

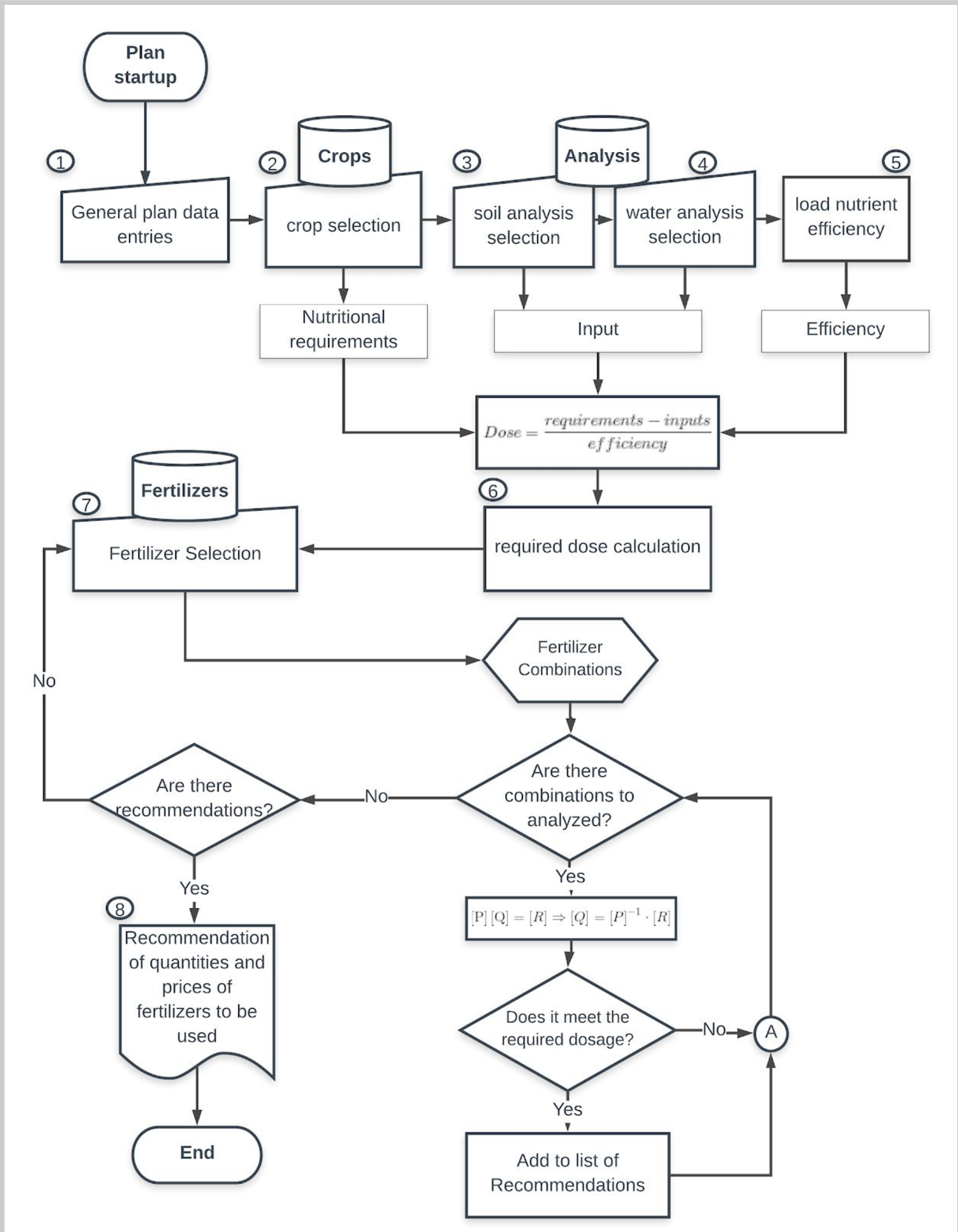

Fig 1. Flow diagram of the methodology implemented for fertilizer recommendation.

Step 3 and 4. Enter nutrient inputs from soil and water. You can select an existing soil analysis or enter a new analysis into the FRS database. Once the soil analysis data have been selected, the nutrient data provided by the water analysis can optionally be added.

Soil weight is a value obtained from the selected soil analysis corresponding to the following formula:

$$SW = BD \cdot SD \cdot 10000m^3 \qquad (4)$$

where soil weight (*SW*) corresponds to the value expressed in tonnes (t) by multiplying the values of Bulk Density (*BD*), Sampling Depth (*SD*) and the size of one hectare of soil.

Step 5 and 6. Efficiency input according to equation 1, You can enter an efficiency manually for all nutrients listed or you can choose depending on the type of irrigation you want to implement (step 5). Once you have the Inputs, Nutritional Requirements and Efficiency you proceed with the calculation of the Dose Required based on equation 1, visualizing the amount of nutrients required for the selected crop (step 6).

Step 7. Choice of the possible fertilizers to work with, where besides visualizing presentation parameters (kg bag^{-1}) and preset costs, it is possible to modify the costs per bag to obtain more accurate results.

Step 8. Recommendation, once the fertilizer selection has been made, the software proceed to make all possible combinations, creating a system of equations that are solved by linear programming (equation 3); in case of finding the solution to the system of equations, it present a list of recommended fertilizers with the quantity in sacks and the required budget, taking into account the parameters generated in the previous steps. If the listed fertilizers do not have any required nutritional elements, it is possible to choose new fertilizers.

RESULTS AND DISCUSSION

In order to validate the operation of FRS, several test cases were carried out; a specific case of fertilizer recommendation for a banana crop on the Santa Inés plot of UTMACH is described below, as well as the results obtained from the software when performing each step according to the algorithm explained in the Materials and Methods section:

A new fertilizer recommendation (step 1) begins with entering general data such as: name of fertilizer plan, location of plot, description and the option to associate a water analysis.

In step 2, the entry of a new fertilization plan (see Figure 2) is selected:

- Cultivated species: Banana
- Phase: General

- Dosage Type: Nutrient Dose for banana cultivation
- Expected yield: 41 t ha-1

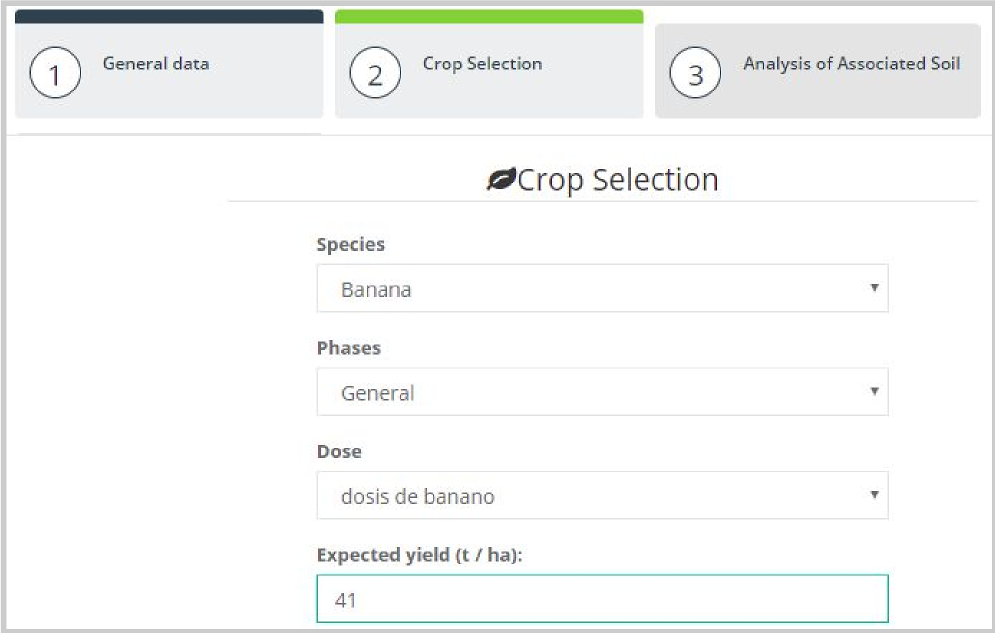

Fig.2. Crop Selection and Expected Yield

The entry of the Nutrient Dosage (see Figure 3) allows the application to identify the nutritional requirement associated with the chosen crop.

See 10 elements   Search:

Ord.	Nutrient	Value	(ha./year)
1	Nitrogen	9	Kg
2	P2O5	2	Kg
3	K2O	14	Kg
4	MgO	1.20	Kg
5	CaO	14.29	Kg
6	Sulfur	2	Kg

Showing 1 to 6 of 6 items   Previous 1 Following

Fig.3. Nutritional Banana Requirement configured in FRS

In steps 3 and 4, which correspond to inputs (soil and water analysis). You can make a new entry or choose from a pre-existing list.

Example of entering a new soil analysis of the plot Santa Inés. The soil analysis shown in Table 5, of the banana cultivation plot used in this test case, was entered into the system as shown in Figure 4 and 5. In Figure 4, the general data and soil characteristics are entered, which allow FRS to know the current state of the crop's soil.

In addition, for the entry of the soil analysis, the user must indicate the value of all nutrients detected as shown in Figure 5. The interpretation criterion is assigned by the system according to the Optimum level (Ol) column in Table 2. Assign "Low" if it is below Ol;"Excessive" if it is above Ol; and "Acceptable" if it is between Ol values.

Tabla 5: Soil analysis of the plot of Santa Inés de la UTMACH banana plantation

Parameters	Results
Sampling depth, m	0.30
Organic Matter, %	4.30
Bulk Density (BD), g cm^{-3}	1.30
Cation Exchange Capacity (CEC), meq $100g^{-1}$	22.40
Electrical Conductivity, mS cm^{-1}	0.09
pH in KCL	5.40
pH in H_2O	6.70
Nitrogen (N), mg kg^{-1}	5.40
Phosphorus (P), mg kg^{-1}	6.20
Potassium(K), mg kg^{-1}	17
Magnesium(Mg), mg kg^{-1}	242
Calcium (Ca),mg kg^{-1}	665
Sulfer (S), mg kg^{-1}	2.20
Manganese (Mn), mg kg^{-1}	53.50
Iron(Fe), mg kg^{-1}	104
Copper (Cu), mg kg^{-1}	8.50
Zinc (Zn), mg kg^{-1}	2.60
Boron (B), mg kg^{-1}	0.39
Sodium (Na), mg kg^{-1}	6.20

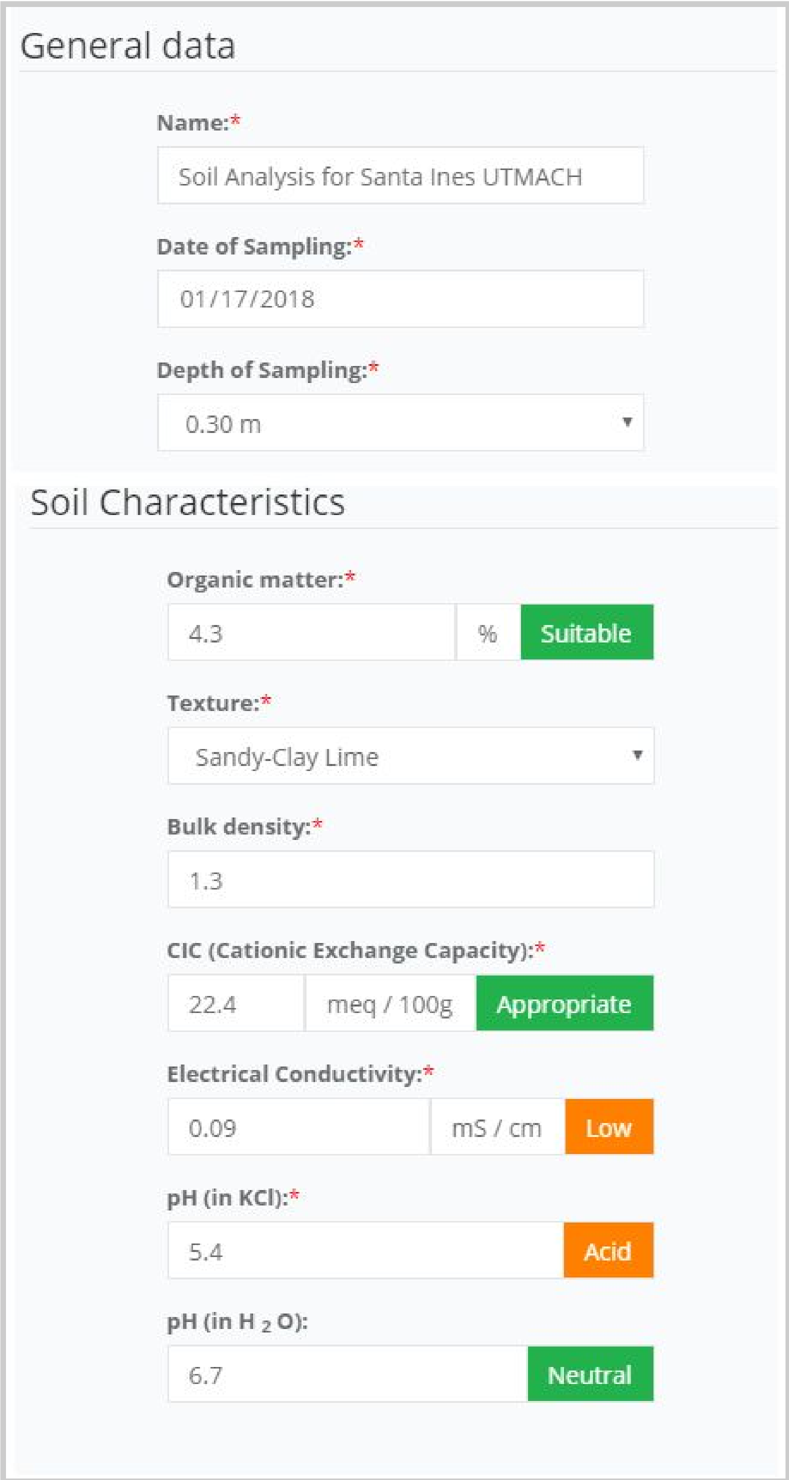

Fig 4. Nutrient composition of the soil analysis of the plot Santa Inés UTMACH

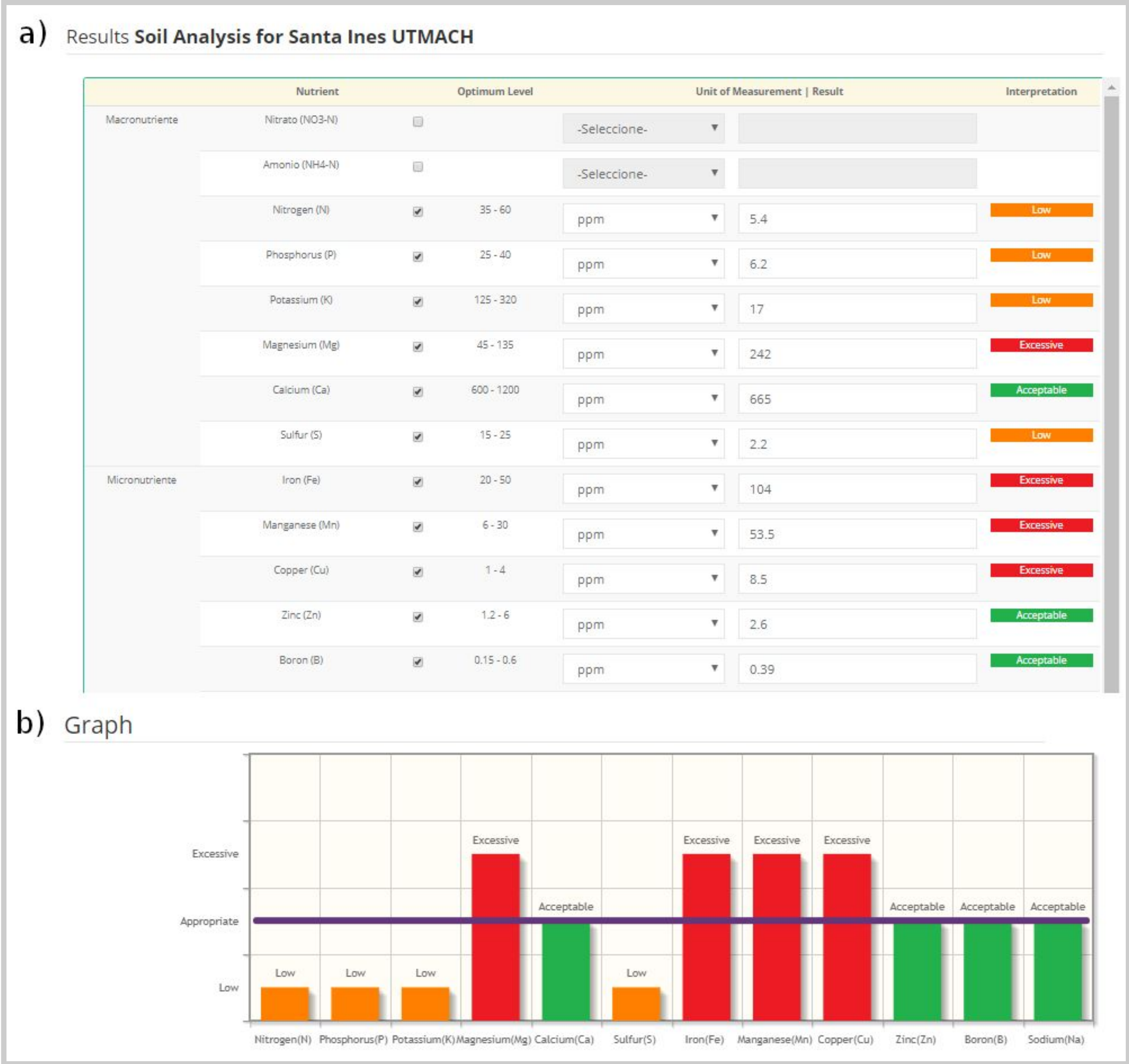

Fig 5. Interpretation of nutrient levels according to the input of soil analysis. (a) the levels entered in MRFs are observed for the nutrients specified in the soil analysis and (b) the interpretation by MRFs according to the configuration values in Table 2.

Selection of a soil analysis. The selection of the soil analysis allows FRS to know the current state of the soil where the crop to be fertilized is located. Once the soil analysis has been selected, a soil weight value of 4200 tons is shown, which is calculated from equation 4 (see Figure 6).

By means of the soil and water analysis (optional) selected, the inputs necessary to carry out the calculation of equation 1 are calculated.

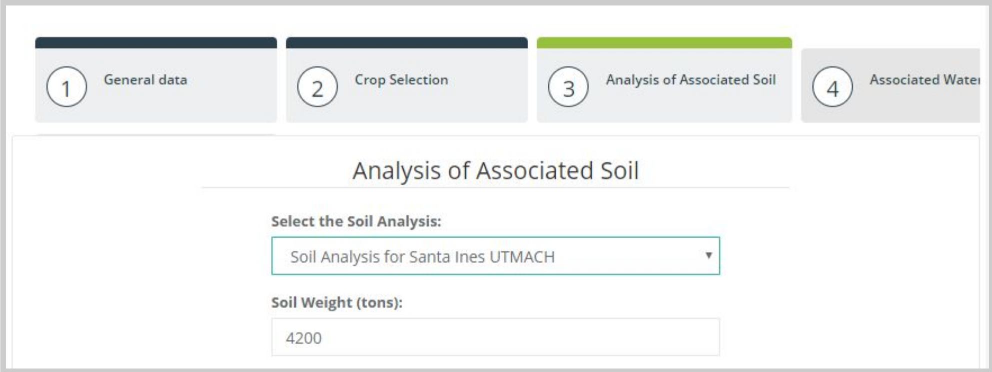

Fig.6. Selection of soil analysis for the test case, plot Santa Inés

Step 5 chooses the nutrient efficiency, where it is possible to enter manually depending on the nutritional requirements of the associated crop (see Figure 3), or you can choose depending on the type of irrigation you want to implement (see Figure 7).

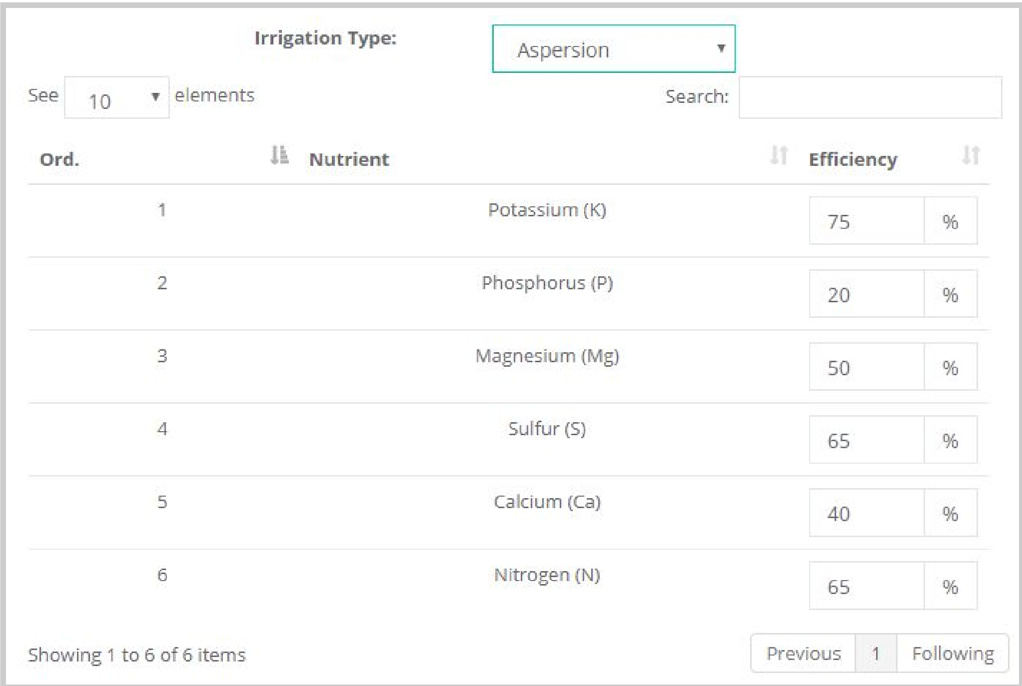

Fig 7. Nutrient efficiency in sprinkler irrigation.

In step 6, once you have the Inputs, Nutritional Requirements and Efficiency, proceed with the calculation of the Required Dose according to equation 1. Figure 8 shows the required nutrient values, together with an observation that indicates if there is any need in the culture of Fertilizing or Not Fertilizing, for this case the needs of K_2O, P_2O_5, MgO, S, and N are identified.

See 10 elements Search:

Ord.	Nutrient	Value	Unit of measurement	Observation
1	K2O	651.09	kg / ha	fertilize
2	P2O5	111.84	kg / ha	fertilize
3	MgO	0.00	kg / ha	do not fertilize
4	Sulfur (S)	111.94	kg / ha	fertilize
5	CaO	0.00	kg / ha	do not fertilize
6	Nitrogen (N)	532.80	kg / ha	fertilize

Showing 1 to 6 of 6 items Previous 1 Following

Fig 8. Required dosage for banana cultivation

Choice of possible fertilizers (step 7). Once observed the dose required for the crop in question, the application shows the configured fertilizers that in their specification have some of the nutrients required to fertilize. You can also choose and configure the price and presentation (25Kg or 50Kg) with which you want to obtain the fertilizer recommendation, as long as the system finds a viable solution (see Figure 9).

Of the fertilizers chosen for the case: Ammonium Sulfate, Diamonic Phosphate (DAP), Potassium Nitrate, Ammonium Nitrate and Urea, all possible combinations are made that can satisfy the need for K_2O, P_2O_5, S and N presented in Figure 8.

See 10 elements | Search:

Cod.	Tradename	Specification	Category	Presentation	Price (Sack)	Select
6	Urea	46.0% N	Acid	50 Kg	19	✔
7	Ammonium nitrate	33.0% N	Acid	50 Kg	19	✔
8	Calcium nitrate	18.57% Ca-15.5% N	Alkaline	50 Kg	1	☐
9	Potassium nitrate	46.0% K-13.0% N	Acid	50 Kg	42.75	✔
10	DAP	46.0% P-18.0% N	Neutral	50 Kg	28	✔
11	Magnesium Nitrate	9.64% Mg-11.0% N	Acid	50 Kg	2.9	☐
12	UAN32	32.0% N	Neutral	50 Kg	1	☐
13	Ammonium sulphate	22.0% S-21.0% N	Acid	50 Kg	16	✔
14	Nitrate Ca and Mg	4.0% Mg-12.0% Ca-13.0% N	Alkaline	50 Kg	1	☐

Fig 9. Filtered fertilizers for selection of the dose required for banana cultivation

Step 8. The recommendations generated by FRS (see Figure 10) generally show how much (%), the nutrient needs of the crop have been covered, as well as the estimated implementation price of each proposed recommendation.

The first two fertilizer recommendations (\$1802.7 and \$1726.75) each meet 100% of all nutrient needs to cover an expected yield of 41 tons per hectare of banana per year. The other options are not viable recommendations because they do not cover all nutrient needs of the crop (it is observed 0% in K_2O, P_2O_5 and S); they are shown to the user to inform that the previous fertilizer selection was not effective and can go back one step to make another choice.

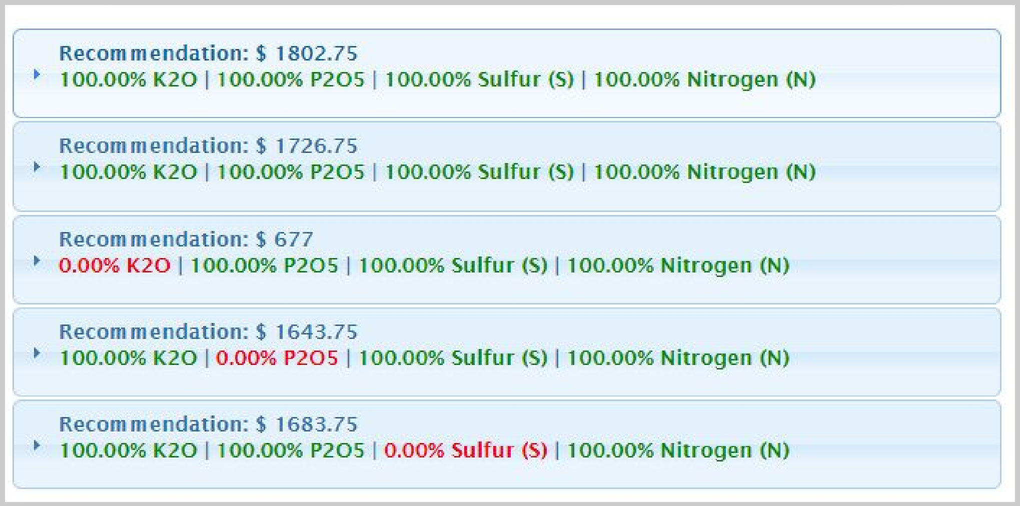

Fig 10. Estimated budget for each recommenda

Recommendation: $ 1726.75
100.00% K2O | 100.00% P2O5 | 100.00% Sulfur (S) | 100.00% Nitrogen (N)

See 10 elements Search:

Cod.	Fertilizer	Quantity	Sacks	Price per Bag	Subtotal
6	Urea	430,828 Kg / ha.	9	$ 19.0	$ 171.0
9	Potassium nitrate	1415.42 Kg / ha.	29	$ 42.75	$ 1239.75
10	DAP	243,135 Kg / ha.	5	$ 28.0	$ 140.0
13	Ammonium sulphate	508,811 Kg / ha.	eleven	$ 16.0	$ 176.0

Fig 11. Detail of Fertilizer Recommendation of 1726.75 for banana cultivation

Among the viable recommendation options, the user can visualize the fertilizer detail, the amount of kg ha-1 year-1 to apply, quantity in bags, the price per bag and a subtotal ($). It is up to the user to choose the option that suits him/her best, in our case we choose the cheapest recommendation of $1726.75 (see Figure 11).

DISCUSSION

Currently in the market there are several Decision Support Systems (DSS) specifically designed to manage and optimize the yield and use of fertilizers (Moreira Barradas, Matula, & Dolezal, 2012). For example, FRC ("Fertilizer Removal by Crop," 2014), is an application for Android mobile devices, designed to calculate the nutrients needed for a crop, the user selects a crop from a list of available crops and enters the expected yield. There are several tools to calculate NPK (Nitrogen N, Phosphorus P and Potassium K), such is the case of NPK Calculator (2017) a mobile application for Android, which optimizes the ratio of nutrients in the fertilizer solution for use in hydroponics or soil. Another case is DSS-FS (Barradas, 2015), a mobile application for iPhone designed to formulate nutrient solutions using a conventional irrigation system, which allows the user to configure the expected yield in t ha-1, select one out of fifteen crops and list the fertilizer mix and its quantities. There are also tools with a Web interface, for example Smart-Fertilizer (“Smart- fertilizer,” 2017) is a tool that offers fertilizer recommendation, dosage and application, but is not free of charge; however, it offers a 14-day trial version with some restricted options; users can enter the analysis of water and soil, choose the type of crop, select fertilizers from a list and calculate the fertilizer combination system. Other options are also available (“Fertilizer Calculator,” 2012), a web application that uses the English unit system, to calculate the user-selected fertilizer dose according to the N, P_2O_5 and K_2O requirements required for a crop, considering a soil analysis report entered by the user.

Each recommended system proposal makes partial contributions, some have common input data such as soil analysis, water analysis, expected crop yield, etc. to come up with a fertilizer combination solution and the recommended dosage; our tool Fertilizer Recommendation System (FRS) integrates the best practices of these tools and proposes others, for example FRS has a scalable and dynamic architecture applicable to any type of crop, allowing the centralized storage of different soil and water analyses, just as it is possible to create new nutritional doses for a type of crop and store it in the database for later uses, it generates the doses and budget of fertilizers recommended for a crop and stores them as fertilizer recommendation plans. For the calculation process, an algorithm was designed (see Figure 1) that guides the sequence of the applied process and was programmed in the Python language with the NumPy extension. FRS creates a system of equations dynamically that relates fertilizers to the nutritional requirements that are calculated based on the inputs provided by the users; this system of equations is solved by matrices and linear programming. FRS was finally implemented in the cloud computing research group AutoMathTIC of the Universidad Tecnica de Machala, as a web application in SaaS multi-tenant mode for the ubiquitous access of users.

CONCLUSION

This work involved the development and implementation of Fertilizer Recommendation System (FRS), a software that allows agricultural producers to obtain recommendations on fertilizers that are required to meet the nutritional needs of their crops; an algorithm was designed and programmed in Python language with the NumPy extension to find the optimal solution to the dynamic system of equations created in FRS, with the information provided by the user. FRS was implemented in the cloud computing of the AutoMathTIC research group of the Universidad Técnica de Machala (UTMACH), as a web application in SaaS multi-tenant mode; that is, for the access of several users from any place and time. FRS was tested in banana crops, however they have a scalable architecture with the ability to adapt to various types of crops.

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AUTHORS' CONTRIBUTIONS

All the authors contributed equally to the writing of this paper. Erik Córdova and Asael Tello developed the FRS software with the computerized advice of Bertha Mazón and the agronomic advice of Diego Villaseñor. Alberto Pan and Dixys Hernández collaborated in the FRS test and correction of the paper.

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