UNIVERSIDADE TECNOLÓGICA FEDERAL DO PARANÁ
PROGRAMA DE PÓS-GRADUAÇÃO EM TECNOLOGIAS
COMPUTACIONAIS PARA O AGRONEGÓCIO

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WEB APPLICATION FOR GENERATION OF THEMATIC MAPS AND DETERMINATION OF PROXIMAL SENSOR PLACEMENT LOCATIONS FOR USE IN PRECISION AGRICULTURE

DISSERTAÇÃO

MEDIANEIRA-PR

2018

GABRIELA KAROLINE MICHELON

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Dissertação apresentada ao Programa de Pós-Graduação em Tecnologias Computacionais para o Agronegócio – PPGTCA – da Universidade Tecnológica Federal do Paraná – UTFPR – Campus Medianeiraa, como requisito parcial para obtenção do título de Mestre em Tecnologias Computacionais para o Agronegócio / Área de Concentração: Tecnologias Computacionais Aplicadas à Produção Agrícola.

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MEDIANEIRA-PR

2018

TERMO DE APROVAÇÃO

WEB APPLICATION FOR GENERATION OF THEMATIC MAPS AND DEFINITION OF SENSORS PROXIMAL SENSOR PLACEMENT LOCATIONS FOR USE IN PRECISION AGRICULTURE

Por

GABRIELA KAROLINE MICHELON

Essa dissertação foi apresentada às treze horas e trinta minutos, do dia oito de novembro de dois mil e dezoito, como requisito parcial para a obtenção do título de Mestre em Tecnologias Computacionais para o Agronegócio, Linha de Pesquisa Tecnologias Computacionais Aplicadas à Produção Agrícola, no Programa de Pós-Graduação em Tecnologias Computacionais para o Agronegócio - PPGTCA, da Universidade Tecnológica Federal do Paraná. A candidata foi arguida pela Banca Examinadora composta pelos professores abaixo assinados. Após deliberação, a Banca Examinadora considerou o trabalho aprovado.

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A via original com as assinaturas encontra-se na secretaria do programa.

I dedicate this work, first, to God, because I know that my willpower to not give up and believe in my dreams came from him. Secondly, to my family, but especially to my mother, Lenir Michelon, because by her understanding, confidence and assistance, I was able to devote all my time to the studies.

ACKNOWLEDGMENT

"Do not confuse defeats with failure or successful with victories. In the life of a champion there will be always some defeats, just as in the life of a loser, that there will be always victories. The difference is that as the champions grow in defeats, the losers settle into the victories."

Roberto Shinyashiki

ABSTRACT

MICHELON, Gabriela Karoline. WEB APPLICATION FOR GENERATION OF THEMATIC MAPS AND DETERMINATION OF PROXIMAL SENSOR PLACEMENT LOCATIONS FOR USE IN PRECISION AGRICULTURE. 123 f. Dissertation – Postgraduate Program in Computational Technologies for Agribusiness, University Federal Technological of Paraná. Medianeira - PR, 2018.

Soil is fundamental for the development of life on earth, being essential for human activities such as food production, construction and agricultural cultivation. There is a great diversity of soil types resulting from physical, chemical, biological and anthropogenic events, which are responsible for the spatial variability of soil that directly interferes with agricultural production. The productive potential of a soil depends on its nutrients and their proportions. When soil management is inadequately performed, it can not only impair its quality, but also affect the development of the plant, the quality of the water, the air and contribute to the increase in the emission of greenhouse gases. Therefore, precision agriculture practices are indicated for sustainable development and for prolonging life on Earth planet, since the techniques made available by precision agriculture help in the proper and localized management of the soil. In order to encourage the reduction of environmental impacts and help to obtain higher final income to the producer, this work aimed to provide a Web tool for the control and management of agricultural properties, allowing to register and to gather the necessary information to analyze the spatial variability of the soil and of the plant. The tool was developed in the Web platform due to the greater ease of access for users in relation to desktop software, since the Web tool developed is free and can be accessed from any location and device, without the need to perform any previous installation. It is only necessary to be connected to the Internet and to have a Web browser. By means of experimental data it was possible to validate the operation of the tool to select suitable locations for the installation of sensors according to the samples and the number of sensors predetermined in the definition process. In addition to enabling the generation and visualization of thematic maps, data can be interpolated by three types of interpolators, inverse of the distance to a power, moving average and ordinary kriging. In addition to the features available for the practice of precision agriculture, the application allows synchronization with an Application Programming Interface - API that stores and integrates agricultural data, data samples, thematic maps on a platform that aims to integrate easily by other developers through the communication between a system and the API. This API stores data from a project called AgDataBox-API that includes the integration of the data registered by both the web application developed in this work and a mobile application. So, when it is in the user's interest, the data can be saved by the mobile application and then get it in the web application and vice versa, by means of the synchronization of it in API. Therefore, the web application proved to be effective for precision agricultural practice, and a free tool that is easy to use and with satisfactory performance.

Keywords: sustainable development, computational tool, localized management, spatial variability

RESUMO

MICHELON, Gabriela Karoline. Aplicação web para geração de mapas temáticos e definição de locais para instalação de sensores em agricultura de precisão. 123 f. Dissertation – Postgraduate Program in Computational Technologies for Agribusiness, University Federal Technological of Paraná. Medianeira - PR, 2018.

O solo é fundamental para o desenvolvimento da vida na terra, sendo essencial para as atividades humanas como na produção de alimentos, na construção civil e no cultivo agrícola. Há uma grande diversidade de tipos de solos resultantes de eventos físicos, químicos, biológicos e antropogênicos, os quais são responsáveis pela variabilidade espacial do solo que interfere diretamente na produção agrícola. Desse modo, o potencial produtivo de um solo depende dos nutrientes e suas proporções em que este os possui. Quando o manejo do solo é realizado de maneira inadequada, pode prejudicar não só a sua qualidade, mas também o desenvolvimento da planta, a qualidade da água, do ar e contribuir para o aumento da emissão de gases do efeito estufa. Portanto, práticas de agricultura de precisão são indicadas para o desenvolvimento sustentável e para prolongar a vida no planeta Terra, pois as técnicas disponibilizadas pela agricultura de precisão auxiliam no manejo adequado e localizado do solo. Afim de incentivar a redução de impactos ambientais e auxiliar na obtenção de maiores rendimentos finais ao produtor, este trabalho objetivou fornecer uma ferramenta Web para o controle e manejo de propriedades agrícolas, permitindo cadastrar e levantar as informações necessárias para analisar a variabilidade espacial do solo e da planta. A ferramenta foi desenvolvida na plataforma Web devido a maior facilidade de acesso para os usuários em relação a softwares desktop, pois a ferramenta Web desenvolvida é gratuita e pode ser acessada de qualquer local e dispositivo, sem a necessidade de realizar qualquer instalação prévia, basta apenas estar conectado à Internet e possuir um navegador Web. Por meio de dados experimentais foi possível validar o funcionamento da ferramenta para escolha de locais adequados para instalação de sensores de acordo com as amostras e número de sensores pré-determinados no processo de definição implementado, além de possibilitar a geração e visualização de mapas temáticos, podendo ser interpolados por três tipos de interpoladores, inverso da distância elevado a uma potência, média móvel e krigagem ordinária. Além das funcionalidades disponibilizadas para a prática da agricultura de precisão, a aplicação permite o sincronismo com uma Application Programming Interface - API que armazena e integra dados agrícolas, amostras de dados, mapas temáticos em uma plataforma que objetiva a integração de forma fácil por outros desenvolvedores por meio da comunicação entre um sistema e a API. Esta API armazena dados de um projeto chamado AgDataBox-API que inclui a integração dos dados cadastrados tanto pela aplicação Web desenvolvida neste trabalho quanto de um aplicativo desenvolvido para dispositivo móvel. Assim, quando for de interesse do usuário, poderá salvar dados pelo aplicativo do celular e depois obtê-los na aplicação Web e vice-versa, a partir do sincronismo dos mesmos na API. Portanto, a aplicação Web se mostrou eficaz para prática da agricultura de precisão, e uma ferramenta gratuita de fácil utilização e com desempenho satisfatório.

Palavras-chave: desenvolvimento sustentável, ferramenta computacional, manejo localizado, variabilidade espacial

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LIST OF ACRONYMS

AgDataBox	Agricultural Data Box
Al	Aluminum
API	Application Programming Interface
B	Boron
C	Carbon
Ca	Calcium
CASE	Computer-Aided Software Engineering
Cl	Chlorine
CSS	Cascading Style Sheets
CTC	Cation Exchange Capability
Cu	Copper
CV	Coefficient of Variation
DBMS	Database Management System
Fe	Iron
FPI	Fuzzy Performance Index
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite Systems
H + Al	Hydrogen + Aluminum
H	Hydrogen
ha	hectare
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transference Protocol
ID	Inverse of Distance
IDE	Integrated Development Environment
IDW	Inverse Distance wWeighting
IoT	Internet of Things
ISD	Inverse of Square Distance
ISI	Interpolation Selection Index
IT	Information Technology
jdk	Java Development Kit
JSPs	Java Server Pages
K	Potassium
KPa	Kilopascal
MA	Moving Average
MAPA	Ministry of Agriculture, Livestock and Supply
ME	Mean Error
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
MPE	Modified Partition Entropy Index
MVC	Modelo Visão Controlador
N	Nitrogen
NN	Nearest Neighbor
O	Oxygen

OK	Ordinary Kriging
OLS	Ordinary Minimum Square
OM	Organic Matter
P	Phosphorus
PA	Precision Agriculture
pH	Hydrogenion potential
PWS	Plant Water Status
RS	Remote Sensing
S	Sulfur
SB	Sum of Bases
SDI	Spatial Dependence Index
SDME	Standard Deviation Error
SDUM	Software for Definition and Evaluation of Management Units
SDUM	Software for Definition of Management Units
SPR	Soil Penetration Resistance
SWP	Stem Water Potential
TB	Terra Byte
UML	Unified Modeling Language
URI	Uniform Resource Indentifier
URL	Uniform Resource Locator
VRA	Variable Rate Application
VRT	Variable Rate Technologies
WebApp	Web Application
WLS	weight least squares
Zn	Zinc

LIST OF SYMBOLS

μ	Estimated location
Z^*	Inverse of distance estimated at a estimated point
n	Number of sample points
λ_i	Sample point
d_i	Euclidean distance between estimated location and sample point
p	Exponent
$\hat{\gamma}$	Semivariation
N(h)	Number of pairs of measured values
$z(u_a)$	Measured sample point value
h	Vector
$\hat{\gamma}(h)$	Semivariogram plot
$\hat{Z}_i$	Interpolated value
γ_i	Weight assigned to sampled value
Z_i	Value of attribute sampled
w	Number of neighbor points
C_0	Nugget effect
C_1	Partial sill
y_k	Vector feature
R^p	P-dimensional space
C	Number of groups
$P^{(t)}$	Elements partition
t	Iteration number
v_i	Group Center
A_i	Weighted average of data
j	Semivariograms models

1   INTRODUCTION

The level of soil fertility is crucial to provide good yielding crops. There are different types of soils due to the high degree of spatial variability that occurs with the interaction of physical, chemical, biological, and anthropogenic processes (ARTUR et al., 2014).

To increase the productive potential of a given soil, the application of agricultural inputs are essential in right quantities and at necessary places. Besides maintaining or improving soil quality, conscious and optimized management practices help to improve water and air quality and reduce emission of greenhouse gases (OMOWUMI et al., 2014).

Performing the necessary and localized soil maintenance includes using techniques that measure the physical, chemical and biological properties of the soil. These techniques are currently provided by Precision Agriculture (PA), which is prioritized by many farmers, environmentalists and government authorities as techniques to assess and improve soil quality, promoting sustainable development (CAMPOS et al., 2007).

One of the widely used and considered essential PA practices is the construction of thematic maps, since they represent the spatial variability of an attribute in a specific field. Thematic maps can be generated with data information obtained from chemical and/or physical laboratory analysis of the soil or also by means of productivity data of the sample points collected from a given field (BETZEK et al., 2017).

To obtain a reliable soil and plant data from a growing field, depending on the attribute of interest, it is necessary to obtain such data on dense sampling grids in the field, manually and/or with a mechanical devices, which is an exhaustive and costly process for the intensive acquisition of field data. An alternative to be adopted is the autonomous data collection devices, such as sensors, which often provide information automatically. The choice of strategic locations for data acquisition is indispensable for both manual and sensor based sampling, since parcels of fields that do not have their data collected should be represented by collection points (CAMILLI et al., 2007).

The sensors are tied to the advent of a new era for farming, the Agriculture 4.0, which will no longer depend on applying water, fertilizers, and pesticides uniformly across the entire fields. Instead, farmers will apply the right amount necessary for a healthy growth of the crop. For that a new generation of sensors, which are intelligent interconnected through a network, known as Internet of Things (IoT), where "Things" includes sensors, actuators, hardware, software and storage spread across a number of fields, such as precision agriculture(GUBBI et al., 2013).

The concept behind this technology is to automate tasks through Internet-connected

electronic devices that capture information, which is sent from the collection site to the storage cloud, where all the information collected can be viewed and analyzed for later decision-making (BURHAN et al., 2018).

This set of PA techniques is actually used with the aid of computational tools that allow the farmer to register the data of his agricultural property and generate thematic maps (HEDLEY, 2014). For this, it is necessary to have computational tools that allow the integration of this information and contribute to the effective practice of these PA techniques.

1.1 PROBLEM

Can a Web application make PA practice more accessible and simple to control and manage an agricultural property?

1.2 JUSTIFICATION

The world's population has been steadily increasing. Accordingly to Bogue (2017), an overall population is expected to increase from 7.4 billion (current population) to approximately 9.55 billion by the 2050s. Hence, there is great concern about how to increase world food production according to the population demand without devastating and attacking even more the environment.

The agriculture is an important source of food for the population, so it is essential that the food producing use PA techniques along with modern technologies that aid in the measurement and interpretation of inter and intra-field variability. Because, with adequate and localized management, it is possible to increase the production of every piece of land to its productive potential in existing agricultural fields and to achieve sustainable development from an economic and, especially, an environmental point of view (KATALIN et al., 2014).

However, small producers, with lower purchasing power, have greater difficulties in applying PA (MAOHUA, 2001) techniques. Some PA techniques require producers to purchase modern agricultural machines and equipment such as Global Navigation Satellite Systems (GNSS), sensors, cameras and displays.

The need to invest, the lack of agronomic knowledge, the lack of technical skills and problems of compatibility between hardware and software, as well as the complexity of using some computational tools and the time necessary to learn to use them are limiting factors to

producers for adoption of PA (ANSELMI, 2012; BAMBINI et al., 2013).

An important PA technique is the generation of thematic maps, which represent soil and plant infield variability. However, it is necessary to use software to generate thematic maps, and to use interpolation techniques to estimate non-sampled data in a field. Therefore, free and easy-to-use software can make PA feasible even for small farmers (BIER; SOUZA, 2017).

Data collection devices, such as sensors, are able to provide information on spatial variability of soil and plant often at a relatively low-cost, which makes it possible to make correct management decisions to obtain high yields from a crop (AN et al., 2015; KIM et al., 2009; ROJO et al., 2016).

However, in order to make the use of sensors economically feasible, it is important that the producer knows the most suitable locations for its installation, in order to obtain information that helps to reduce waste with agricultural inputs application and increase the productivity of the plant (BAZZI et al., 2018).

Finally, there are ways to expand the practice of PA to more farmers, by simply having the low-cost tools that make PA techniques viable. Knowing that software with free versions have limited functionality, and that there are only a few Web tools, it is important to provide the user with a free, simple, practical and complete Web application, such a tool should allow greater control of agricultural properties, so that it can be managed in a way more secure and organized, applying PA techniques to analyze and raise the necessary information to verify the causes of spatial variability of soil and plant.

1.3   OBJECTIVE

The objectives of this work include the development of a free Web application that provides tools to register, to control, to analyze and to interpret the soil and plant features in a simple and practical way for the user.

1.3.1   General Objective

Develop a Web application to register information of the soil and plant, to generate thematic maps and to choose the appropriate place for installation of data collection devices, aiming to improve the management of agricultural fields.

1.3.2   Specific Objectives

a) Implement computational procedural functions that allow the selection of the most suitable locations for the installation of data collection devices;

b) Develop Web application with friendly, simple and objective interface;

c) Integrate the Web application with the resources made available by R statistical software for the spatial analysis of data and the generation of thematic maps;

d) Validate the operation of the developed Web application and its usefulness for the practice of Precision Agriculture by using data collected from experimental fields.

1.4   HYPOTHESES

Using the Web application, make the application of PA techniques feasible and enable adequate soil management to obtain higher yields and less wastes with agricultural inputs.

1.5   WORK STRUCTURE

This work is divided into five chapters in which: the second chapter has the theoretical fundamentals that covers the subjects of precision agriculture, thematic maps, interpolation methods and sensors in agriculture. Chapter 3 presents the materials and methods that were required for the development of the Web application. Chapter 4 compiles the results and discussions. In the fifth and final chapter, includes the conclusions obtained and possible future applications that can advance this work and lead to new research and tools for the PA.

2   THEORETICAL FOUNDATION

This chapter discusses the PA and the techniques that assist in its effective practice, such as thematic maps, interpolation methods, Internet of Things, and Web programming. At the end of this chapter related work involving the importance of the computational tools for the PA are presented.

2.1   PRECISION AGRICULTURE

PA consists of practices of localized management of agricultural production field, which aims to optimize the use of agricultural inputs, improve the productive efficiency of the field and reduce the environmental impact (KOUNTIOS et al., 2018; SANTOS et al., 2017). This has become possible and efficient by integrating resources such as tools, technologies, and information management systems that have recently emerged (KHANAL et al., 2017).

According to Chen et al. (2015), the PA has been promoted because of the advances in theories and technologies in recent years and many authors have different ways of defining it. However, the purpose of PA in all definitions is always the same: use strategies to address the problems of heterogeneity of an agricultural property (INAMASU et al., 2011).

The main difference between PA and conventional agriculture is the way the soil management is accomplished, because PA involves application of right amount of inputs at the right place at at the right time taking into account the spatio-temporal variability of the cultivation field (MCBRATNEY et al., 2005; CAMICIA et al., 2015).

Bongiovanni and Lowenberg-Deboer (2004) discuss the concept of PA as sustainable agriculture, described by the intersection of three disciplines: ecology, economics and sociology. According to Aubert et al. (2012), PA technology can reduce the use of environmental contaminants by more than 90%.

PA practice is summarized in Aubert et al. (2012), as the use of information technology applications (IT) to electronically monitor soil and crops conditions, and assist farmers in decision making. However, this requires the owner of agricultural fields to be willing to learn new techniques that may have a high degree of complexity, as well as involve financial investments.

The PA has great potential to protect the environment, not only by reducing the application of soil nutrients and by controlling the use of agricultural inputs, but also because it assists in controlling soil erosion and soil compaction (BONGIOVANNI; LOWENBERG-

DEBOER, 2004).

Currently, in Brazil, the practice of PA has a greater focus on the variable rate application of fertilizers. However, PA is not only the application of localizes inputs in the soil, but also includes the study of productivity variability, soil (physical and/or chemical characteristics), weed infestation, diseases and pests (MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO, 2009).

In general, PA provides field information to the farmer, allowing it to be analyzed and interpreted to make the most appropriate management decisions for each type of soil and plant. The essential process for the effective practice of PA, can be described in three fundamental stages: data collection, data processing and interpretation, and application of agricultural inputs (Figure 1).
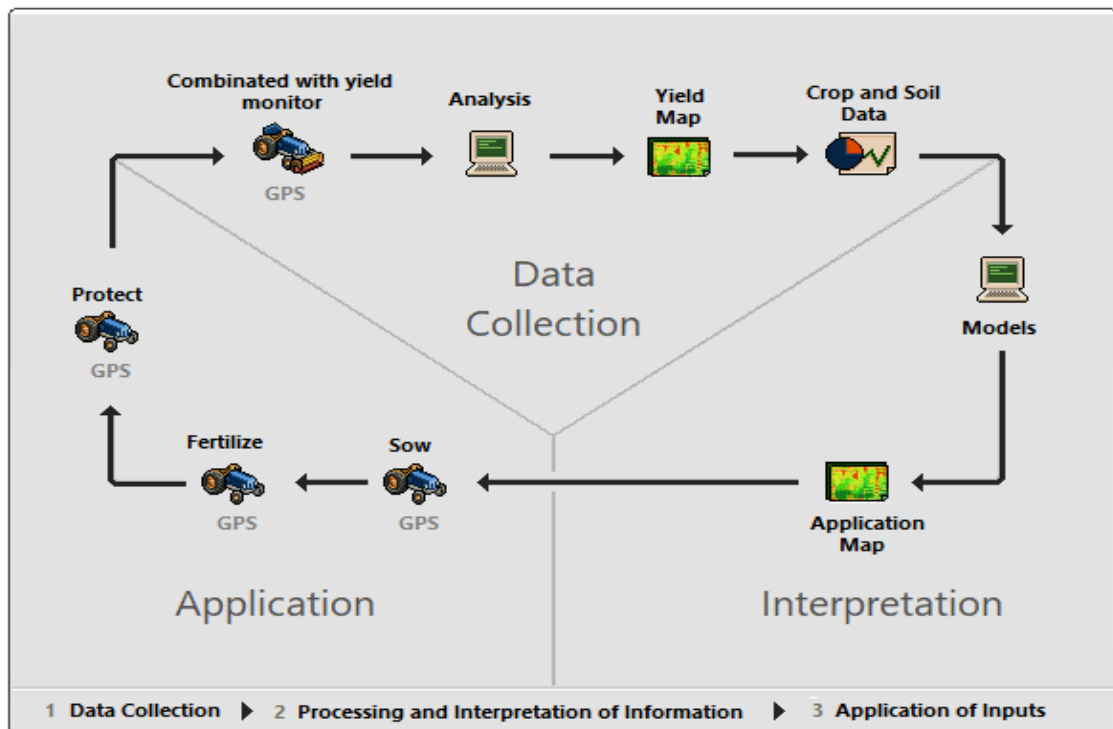
Figure 1 ─ Essential stages to practice the precision agriculture.

Source: Adapted from Chartuni et al. (2007).

Among the PA techniques, the yield map is considered by Camicia et al. (2015) and Ortiz et al. (2010) as essential, because it represents its spatial distribution in an field, allowing variables that influence higher and lower yields to be analyzed. With the yield map, it is possible to analyze which fields need more fertilizers or if they have other limitation for a better crop development (CAMICIA et al., 2015).

According to Franzen and Mulla (2015), PA is a form of management of the whole agricultural process that takes into account the variability in agricultural properties and

considers thematic maps as the most complete and true information to evaluate and quantify the variability of an agricultural field, and to later manage it efficiently.

The variability of soil and plant in PA can be classified, according to Blackmore and Larscheid (1997) as: spatial, temporal and predictive. Spatial variability is the variability observed in the field and can be easily analyzed through thematic maps; temporal variability is the variability observed when comparing attribute maps of more than one year; and the predictive variability, is the result of the difference between the prediction of the value of some attribute and the value actually obtained.

Also, according to Zhang et al. (2002), the factors that influence agricultural production that can be analyzed through PA techniques are divided into six groups:

a) production variability: historical and current distribution of productivity;

b) field variability: altitude, slope, landscape aspect, terrace proximity to border and rivers and lakes;

c) soil variability: soil fertility, soil chemical and physical attributes;

d) crop variability: planting density, plant height, nutritional stress, water stress, biophysical properties of the plant (e.g. leaf field index and biomass), leaf chlorophyll content and grain quality;

e) variability of anomalous factors: weed infestation, pest attack, presence of nematodes, frost and hail;

f) variability in management: sowing rate, crop rotation, application of fertilizers and pesticides.

2.1.1 History of Precision Agriculture

There have been reports of working with PA since the beginning of century XX. According to Franzen and Mulla (2015), researchers began to investigate soil spatial variability by concentrating on crop nutrient management. To accomplish this, they obtained soil samples.

According to Stafford (2000), the earliest publication mentioning spatial variability and recommending to take into account this variability in management was published in 1928 by Eden and Maskell. However, the practice of PA began in the 1980s, in North American continent, with the development of the first yield map and implementing out the variable rate application of fertilizer (MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO, 2009).

However, what leveraged the PA was the emergence of GPS, in late 1980s, initially created exclusively for military purposes and managed by the United States Department of

Defense. With the advent of GPS, determination of geographical position and navigation between any two points on the earth's surface becaame possible. In Brazil, the practice of PA gradually began in 1995, with the importation of new equipment and agricultural machinery such as harvesters equipped with yield monitors (BERNARDI et al., 2014).

Conventional agriculture is gradually being replaced by PA. However, there are limitations for many farmers, since it is necessary to manage a very large amount of information, such as soil, crops and environmental factors. In addition, most PA techniques are intensive and costly (such as soil sampling, laboratory analysis, acquisition of machines and equipment for data collection and localized management) (STAFFORD, 2000).

PA practice is possible today, thanks to technological advances such as GNSS, yield monitors, sensors, geographic information systems (GIS), software and variable rate application equipment (VRA). Accessibility to these technologies promotes the consolidation of PA practices, and hence sustainable development (HEDLEY, 2014).

2.1.2 Soil Attributes and Yield Relationship

The soil physical, chemical, textural and topological attributes can affect crop development and consequently its yield. Thus, these attributes can be considered indicators of soil quality (REIS et al., 2017).

The chemical analysis allows measure the quantity of some soil attributes, as well as identify possible nutritional problems that may influence productivity, as Hydrogenion potential (pH), Organic Matter (OM), available Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Potential Acidity (Hydrogen + Aluminum (H + Al)), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn) and exchangeable Aluminum (Al) can be determined. So, the soil chemical analysis purpose is to determine how much nutrients the soil will be able to provide to the plants and in which quantities and characteristics of the input should be applied to have high crop yield. The soil analysis also can be used to verify if there is superficial acidity, which hinders or prevents root growth, so that the crop does not absorb the applied input or the elements of the soil by itself (WOLLENHAUPT et al., 1997).

According to Ferreira (1993), the physical attributes interact with the water and air fluids and depending on the way these constituents are associated, their movement in the porous system is variable, depending on the soil type and/or on the management conditions to which it is submitted.

Since water and air occupy porous soil spaces, there is a relationship between water and air factors, which causes changes in moisture content to affect soil temperature. Making the

availability of nutrients influenced by the balance between soil, water and temperature (LOPES, 1998).

According to Lopes (1998) Carbon (C), Hydrogen (H) and Oxygen (O) are non mineral attributes, and they are found at the atmosphere and in the water, and participate in photosynthesis process. Photosynthesis accounts for most of the plant's growth. Among the nutrients, minerals can be divided into primary nutrients: Nitrogen (N), P, K; secondary nutrients: Ca, Mg, and Sulfur (S); and micronutrients such as Boron (B), Chlorine (Cl), Cu, Fe, Mn, Molybdenum (Mo) and Zn.

The primary nutrients are the most absorbed by the plant, also known as macronutrients and the secondary nutrients (also called macronutrients) and micronutrients are such important as the primary nutrients are for proper soil fertility, but are less absorbed by plants.

According to Prezotti (2013), pH influences many soil attributes, and when less than 5.5 may decrease the availability of some micronutrients and macronutrients, in addition to increasing the solubility of $Aluminum^{+3}$ (siglaAlAluminum^{+3}, toxic form of aluminum). In soils with a pH greater than 6.5, a marked reduction in the availability of some micronutrients may also occur.

To perform a good soil management, besides being necessary to know the available physical and chemical nutrients, is necessary also to know the soil texture and structural form. The texture corresponds to the size of the mineral particles and the structural form deals with the structure by which the particles are grouped together determined by parameters as density and porosity. These features provide support to determine the supply capacity of nutrients and water and air supply, important for the development of plants (BAZZI, 2011).

Staff (2017) shows the soil texture classification by the attributes sand, clay and silt in twelve texture classes: sands, loamy sands, sandy loams, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. Subclasses of sand are coarse sand, sand, fine sand, and very fine sand. Subclasses of loamy sands and sandy loams that are based on sand size are named similarly (Figure 2).

The soil felief is a responsible factor for changing its humidity, the intensity of erosion and leaching, its microclimate and the level of the water table. Thus the soil altitude in the landscape influences the variability of the attributes (FRANZEN et al., 2006).

Slope and pedoform affect flow, transport, uptake and storage capacity of water, organic matter content and nutrients resulting in changes in soil attributes in a way that affects crop development (SILVA et al., 2007).

According to Inamasu et al. (2011), the main attributes that determine the productive potential of the soil are those responsible for maintaining water in the soil and providing

nutrients as: texture attributes, structure, macro relationship and microporosity, degree of soil compaction and density.
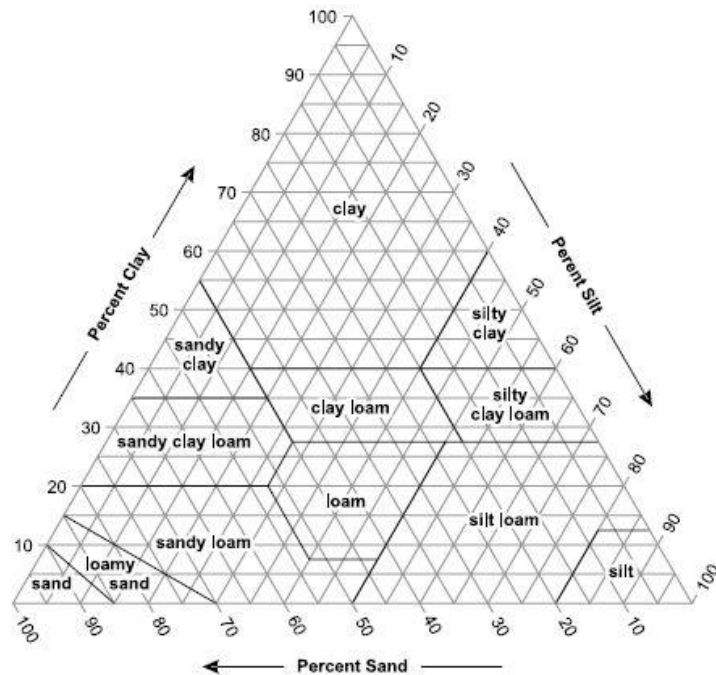
Figure 2 − United States Department of Agriculture textural triangle showing the percentages of clay, silt, and sand in the 12 basic texture classes.

Source: Staff (2017).

2.2 THEMATIC MAPS

Thematic maps can be used to represent yield data, soil chemical and physical attributes, plant growth, and other factors related to crop conditions. The data used in the generation of thematic maps can be obtained from laboratory analysis and/or by field sensors and monitors attached toplanters and harvesters (BIER; SOUZA, 2017; MOLIN et al., 2015).

The thematic yield map is the spatial representation of field productivity that is recorded during harvesting operation (SENA et al., 2014) (Figure 3). However, yield maps are generated by an automatic process, based on sensors installed in the harvesters, and which process a large amount of data with some errors (MENEGATTI; MOLIN, 2004).

The accuracy of these maps is very important for the interpretation of the data, so, some authors such as Menegatti and Molin (2004), Michelan et al. (2007), Molin and Gimenez (2000) and Santi et al. (2013) recommended to remove the errors from data before creating the yield maps. After removing the errors from data, the number of sample points, that is, the

number of the total data within the harvest field, decreases. To recreate the maps, interpolation methods are used to estimate values for non-sampled sites to create a dense and regular grid of sample points and subsequently to generate the thematic map of yield (BIER; SOUZA, 2017).
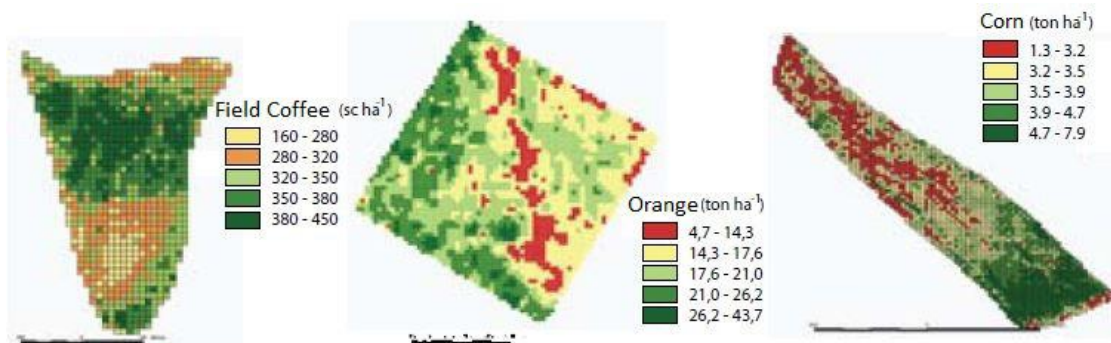
Figure 3 – Yield maps representing the spatial variability of different crops.

Source: Adapted from Ministério da Agricultura, Pecuária e Abastecimento (2009).

Manual data collection always reults in smaller set of data due to cost and time issues. In manual sampling, the producer chooses within an field a small number of sampling points and strategically divides them into a field, which results in a sparse sampling grid. According to Journel and Huijbregts (1978), a sampling grid with 2.5 samples points per hectare (ha) is recommended. Thus, the grid of data collected is irregular and sparse due to the time it would take to collect a lot of samples, besides being economically unviable because of the cost of physical and/or chemical laboratory analysis of the soil and plant attributes (LI et al., 2007).

Therefore, to create thematic maps with a sparse grid of sample points, first, the data must be interpolated to obtain a dense and regular grid of data, to create the map (BIER; SOUZA, 2017).To interpolate the data, it is important to know the interpolation methods that exists and how their calculations works to estimate points non-sampled, since the use of an interpolator influences the estimated values, in the construction of the thematic map and consequently, in the decision making (BETZEK et al., 2017).

2.3 INTERPOLATION METHODS

Interpolation is the name given to the process of predicting the value of a point not sampled from neighboring sample points (HAMED et al., 2015; SCHETTINI, 2009) (Figure 4). The idea of using neighboring sample points is because it is believed that the points that are further apart tend to be disimilar (JOHNSTON et al., 2003; MIRANDA, 2010).

What differs between the various interpolation methods is how the weighting is

assigned to the different samples (FERREIRA et al., 2013). Among the methods of interpolation, the literature divides them into deterministic and statistical methods (BABAK; DEUTSCH, 2009). The deterministic methods are based on the values of the neighboring sample points and/or mathematical formulas applied to these points. While statistical methods include spatial autocorrelation of sample points to estimate a non-sampled point, that is, it analyzes the similarity between samples in terms of distance and direction (BURROUGH, 1986; CARMO et al., 2015).
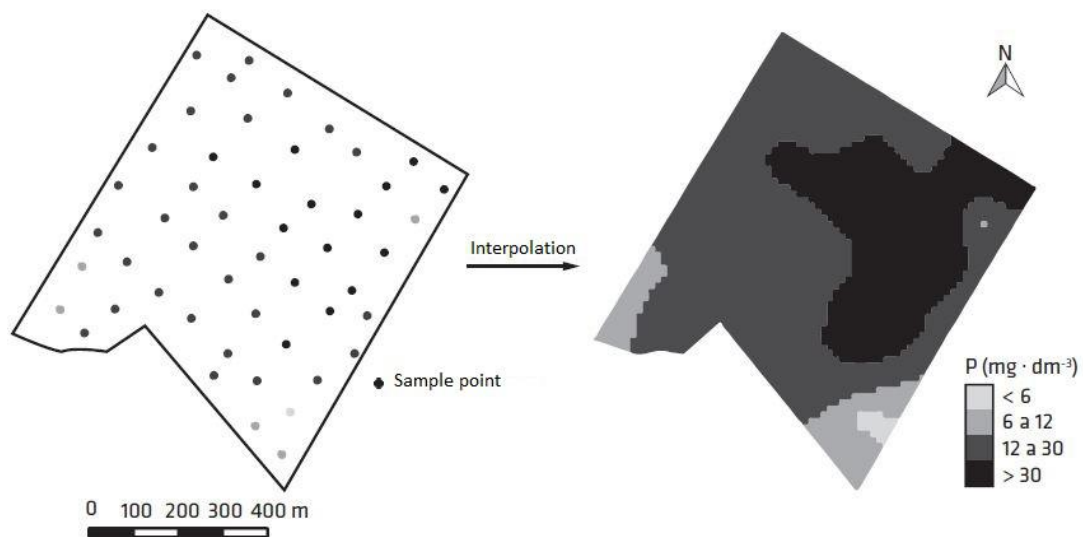
Figure 4 – Thematic map after the interpolation of an irregular grid of sampling points.
Source: Molin et al. (2015).

The most commonly used interpolation methods in the PA are the inverse distance weighting (IDW) and the ordinary kriging (OK) (BETZEK et al., 2017; SOUZA et al., 2016; SENA et al., 2014).

According to Silva et al. (2008), using the IDW is easier because the inverse distance weighting is easier to perform than the OK statistic. On the other hand, OK makes precise description of the data, since it takes into account the spatial autocorrelation of the points used to estimate a non-sampled point. Moreover, the OK seeks to minimize the variance estimated from a selected model, which takes into account the spatial dependence between the data.

Betzek et al. (2017) compares two inverse distance interpolation methods (exponent of 1, ID and 2, ISD) and OK. Both ID and ISD use the inverse distance calculation to estimate non-sample points (where ID uses power 1 and ISD uses power 2), and are the most important interpolation methods of IDW considered in the literature (BIER; SOUZA, 2017).

According to Betzek et al. (2017), ISD was the method that least influenced the behavior of the data, since it practically maintained the original values. While OK was the method that presented the greater influence, because it increased the minimum value and

reduced the maximum value when comparing the interpolated values with the originals. In their study, the best performances were from OK and ISD, but the authors makes it clear that the results of the interpolators vary greatly in relation to the analyzed attribute. Silva et al. (2008) found similar results.

Coelho et al. (2009) used OK, ISD and ID with sample grids of different densities, and concluded that to use the full potential of ordinary kriging it is necessary to have many points in order to generate a semivariogram in the best possible way. The authors noticed that the reduction of the sample data generated dissimilar maps and, IDW was preferred under such circumstances.

Babak and Deutsch (2009) mentioned that IDW is better suited for data interpolation in many situations than OK, since IDW is simple and applicable method with any number of sample points, besides being a robust method that in many cases is more efficient than OK. In addition, they comment on the main advantages of OK in relation to IDW, is its robustness in estimating a non-sampled value in relation to the number of data, and take into account the spatial structure of the data points (anisotropy), and availability of the estimation variance that provides a measure of the accuracy of any single interpolated value.

However, IDW also has its advantages, Li et al. (2007) stated that the IDW is a simple, intuitive and fast interpolator to compute the interpolated values. They also mentioned the few characteristics of this method: the choice of the parameters used in the interpolation are selected empirically (there is no specific theory or logic that brings correct results for any type of data and density of samples); is a very accurate interpolator that does not soften the minimum and maximum values; and is sensitive to *outliers*.

The following are the interpolation methods that are available in the Web application developed in this work: Moving Average (MA), IDW and OK.

2.3.1 Moving Average (MA)

This interpolation method estimates non-sampled point values based on the mean of the sampled points within a predefined radial distance as given i, Equation 1. In this method weights are not assigned to the sample points based on the distance between sampled points and the point to be estimated as in IDW. All points within the predefined radial distance are equally weighted (i.e, weight is 1/n) (BAZZI et al., 2015).

$$\hat{Z}_i = \frac{\sum_{i=1}^{n} Z_i}{n} \tag{1}$$

where: $\hat{Z}_i$ is the interpolated value of the non-sampled point; Z_i is the value of the neighboring sample point; n is the number of neighboring sample points used for interpolation of the non-sampled point.

According to Maleika (2015), the MA interpolation method results in estimated points less accurate compared to other interpolation methods such as IDW and OK. This inferiority of the moving average between the other interpolation methods is given by the comparison of the error rate, however, in relation to the performance in the execution time of the algorithm, Maleika (2015) mentioned that the MM method reached 10-30 times faster than IDW and OK interpolation methods.

2.3.2   Inverse Distance Weighting (IDW)

The IDW is based on the decrease of the weight of a value as the distance between the sample point and the point to be estimated increases as given in Equation 2 (JOHNSTON et al., 2003) (Figure 5).

$$Z^* = \sum_{i=1}^{n} \lambda_i Z(\mu_i) \tag{2}$$
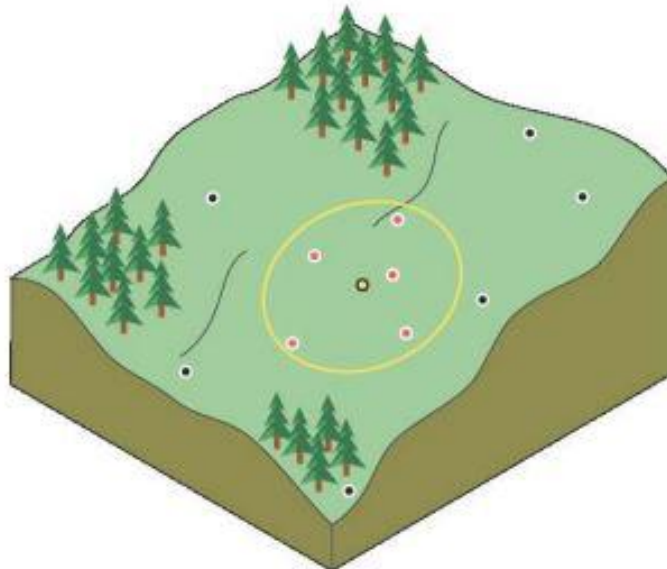
Figure 5 − Point to be estimated (yellow) through the nearest (red) sampled points with weighting inversely proportional to their distances.

Source: Johnston et al. (2003).

where: μ is the location to be estimated, i = 1, ..., n are the sampling point locations

within the neighborhood, Z^* is the estimated value at the point being estimated, n is the number of sampling points, and λ_i are the weights, determined according to Equation 3:

$$\lambda_i = \frac{(\frac{1}{d_i^p})}{\sum_{i=1}^{n}(\frac{1}{d_i^p})} \tag{3}$$

where: d_i are the Euclidean distances between estimation location and the sample points, p the exponent, is the power.

The IDW is not sufficient to provide a visual description of the spatial variation of the points, that is, it does not take into account the type of relief of the location of each point. However, the overall objective of spatial interpolation is to estimate the values at existing sites in a crop field that were not sampled based on sampled points.

2.3.3   Ordinary Kriging (OK)

Kriging is a method of geostatistical interpolation that, unlike deterministic methods, is based on statistical models that includes spatial autocorrelation (relationship statistics between measured points). According to Bier and Souza (2017), geostatistical interpolation methods are the most used in PA.

According to Ferreira et al. (2013), there are many types of kriging, simple kriging, ordinary kriging, universal kriging, disjunctive kriging, indicative kriging, cokriging, among others, but the most commonly used types are simple kriging and ordinary kriging. In simple kriging, the mean is assumed to be statistically constant for the whole field and in ordinary kriging, the mean is floating or moving throughout the field. Therefore, the most commonly used method is ordinary kriging, since it is not necessary to know the mean value to apply it.

Kriging is a method able to predict how the surface of a field behaves, and to provide accurate or almost accurate estimated measures (JOHNSTON et al., 2003). This method provides an objective way to establish the optimum weighting between points in a location to be estimated. According to Olaya (2012), the optimal interpolation of kriging consists of:

a) the prediction error must be minimal;

b) nearest neighbors must have weights greater than the furthest neighbors;

c) the presence of a point in a particular direction must influence points that are in the same direction even though they are distant;

d) very close points with similar values should be grouped in such a way that no over-sampling occurs;

e) the estimation of the error must be due to the structure of the points, not their values.

For the spatial autocorrelation to be quantified, semivariograms are calculated before applying the interpolation using kriging techniques, since the semivariogram allows modeling the spatial dependence between the samples. The weights are determined from a spatial analysis, based on the semivariogram, which produces a surface model of the collected samples (SENA et al., 2014). In order to choose the best semivariogram model, we can use the cross-validation technique, which evaluates the fit of the spatial theoretical models or measures indicated to verify the accuracy of the estimated points, such as reduced average error, standard deviation of mean error and standard deviation of the reduced error (ISAAKS; SRIVASTAVA, 1989).

Equation 4 can be used to calculate the variogram models and their parameters:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{a=1}^{N(h)} [z(u_a - Z(u_a + h)]^2 \tag{4}$$

where: $\hat{\gamma}$ is the estimated semivariance, N(h) is the number of pairs of measured values $z(u_a)$ and $Z(u_a + h)$ are separated by a vector h. The graph of $\hat{\gamma}(h)$ versus the corresponding values of h is called semivariogram.

The parameters required to calculate spatial dependence and variogram are: the sill variance (c + c0) comprises any nugget variance (c0) and the spatially correlated variance (c), and the range (a) a finite distance at which some variograms reach their sill. Some variograms do not have a finite range, and the variogram approaches its sill asymptotically. If the variogram increases indefinitely (unbounded variogram) with increasing lag distance the process is intrinsic only (OLIVER; WEBSTER, 1990) (Figure 6).
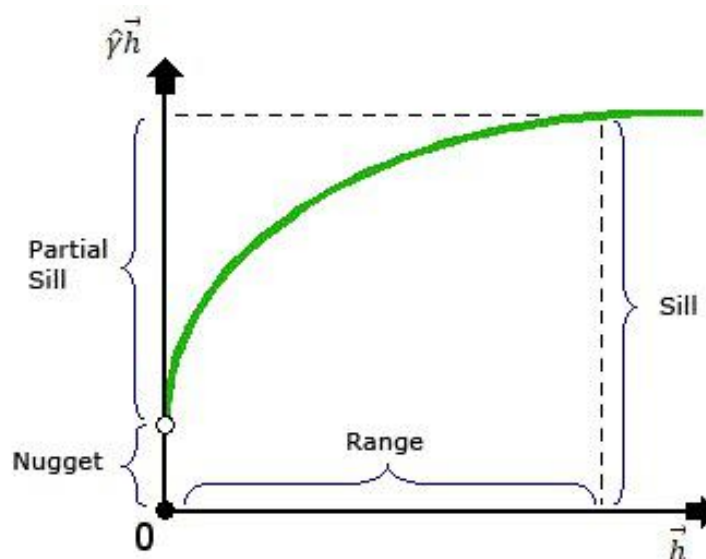
Figure 6 – Semivariogram and its parameters.

Source: Carmo et al. (2015).

It is very important to evaluate the semivariograms models before performing the interpolation by the kriging methods, because if it is adjusted improperly, the interpolation may present distorted information in the thematic map in question (ISAAKS; SRIVASTAVA, 1989).

In order to perform ordinary kriging interpolation, after the adjustment of the variogram model is constructed, Equation 5 can be used to calculate the estimated value at the point of interest (unvisited point):

$$\hat{Z}_i = \sum_{i=1}^{w} \gamma_i * Z_i \tag{5}$$

where: $\hat{Z}_i$ is the interpolated value; γ_i is the weight assigned to sampled values; Z_i is the value of the attribute sampled; w is the number of neighbor points used to interpolate a point, with the constraint that the sum of the weights γ_i must be equal to one.

According to McBratney and Webster (1986), the most suitable models for the majority of situations used by kriging techniques are the spherical, exponential and Gaussian (Figure 7).
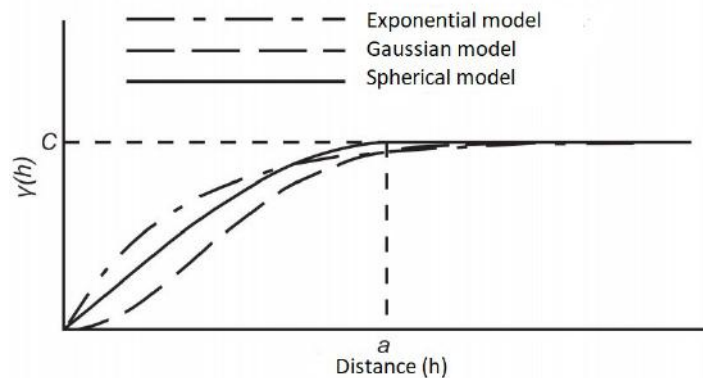
Figure 7 – Behavior of the main semivariogram, spherical, exponential and gaussian models.

Source: Adapted from Isaaks and Srivastava (1989).

After adjusting the semivariogram and obtaining the model parameters, a relation between the plateau and the nugget effect in which the index of spatial dependence (SDI) (CAVALCANTE et al., 2007) is established between the samples and is used to classify the model as the Cambardella et al. (1994) classification, where is weak when $< 25\%$, moderate from 25% a 75% and strong $> 75\%$ (Equation 6):

$$IDE(\%) = \frac{C_1 * 100}{C_0 + C_1} \tag{6}$$

where C_0 is the nugget effect and C_1 is the partial sill.

To use the kriging interpolation method, the parameters required to construct the

semivariogram need to be estimated accurately and if the adjusted model is inappropriate, the interpolation will contain estimation errors that will provide distorted information of the situation in question. Thus, it is interesting that the interpolation tool used brings the result of the interpolation to the most appropriate model as presented by Betzek (2017), thus avoiding erroneous results and the user is not limited to using this method of interpolation that is more complex than the deterministic methods like IDW (ISAAKS; SRIVASTAVA, 1989).

2.4   SENSORS

In recent years technological advances have helped reduce sensor costs, which has also helped the PA gain popularity (KHANAL et al., 2017). Sensor networks are very efficient for data collection, because they are very fast and often get information automatically, while manual collection takes time and labor intensive for the producer (KHAN, 2016).

Sensor networks consists of small, sensing nodes with limited processing capacity, including sensors and their specific conditioning circuits, which communicate over short distances, usually using radiofrequencies (CAMILLI et al., 2007).

There is a wide range of sensors, and Adamchuk et al. (2004) cites some soil sensors such as: electric and electromagnetic sensors that measure electrical resistivity/soil conductivity; optical and radiometric sensors that obtain visible and near-infrared spectra from the electromagnetic waves to detect the level of energy absorbed/reflected by the soil particles; mechanical sensors that measure forces resulting from a tool involved with the ground; acoustic sensors, which quantify the sound produced by a tool that interacts with the ground; pneumatic sensors that assess the ability to inject air into the soil; and electrochemical sensors that use ion selective membranes to detect ion activity.

Sahitya et al. (2017) mention that the widely used sensors in PA are the soil-mixing, light-measuring, temperature-measuring sensors for detecting rain, infrared and ultraviolet energy. Such sensors are becoming more and more common in monitoring the environment and in PA (JOHN, 2016).

According to Khanal et al. (2017), sensor networks have helped farmers to identify soil variability and productivity, as well as to allow the application of localized practices to manage crop characteristics. With frequent data collection it is possible to implement more appropriate management and increase the productive potential of a growing field. According to reports from Maurya and Jain (2016) and Srbinovska et al. (2015), sensors proved to be efficient in monitoring parameters that help increasing the productivity of crops such as pepper, cotton,

grape, and greenhouse crops.

Sensors have also been widely used to measure soil moisture and make timeliness of irrigation decision which in turn can conserve water (NAVARRO-HELLÍNN et al., 2015; PANAGOPOULOS et al., 2014; ROJO et al., 2016).

Authors such as Castello et al. (2010), Khandani and Kalantari (2009), Mouazen et al. (2014) and Singh and Sharma (2016) pointed to a major problem in the use of sensors: there are currently no software packages that provide optimization functions and optimum location for sensors in the field.

As an alternative to subjective choice of appropriate sensor installation sites, Barker et al. (2017) mention the temporal stability analysis to be used as a tool for the objective location of locations for sensor installation for soil water monitoring.

Edwards-Murphy et al. (2016) stated that the modern agriculture is tied to sensor networks (detection, computing and embedded communication devices). The network of sensors, besides being fundamental in the practice of PA, is also responsible for the creation of IoT, which has applications in several fields (health, environment and agriculture) (SAHITYA et al., 2017).

2.4.1 Internet of Things

It is believed that the Internet and objects with detection and actuation capabilities will be connected and integrated into the "Internet of Things" (IoT) in the futre. However, according to Lopez et al. (2017) and Porambage et al. (2016), although it is a social and economic advancement, IoT will be accompanied by concerns about data protection and security, threatening the privacy of people with harmful attacks that can occur when sensitive information is collected or controlled without user consent.

The main goal of IoT is to maximize hardware communication with the physical world and convert the data obtained into useful information without human intervention. According to Kaur and Sood (2017), IoT consists of three elements (Figure 8).

The elements of IoT are: hardware, middleware and presentation. The hardware being sensors with battery, actuators and communication systems. The sensors collect the data from a monitored field and send it to the middleware, which processes this data and analyzes it using tools for extraction and interpretation of characteristics. Finally, the presentation is the upper layer of the middleware responsible for presenting the information processed to the user (KAUR; SOOD, 2017).
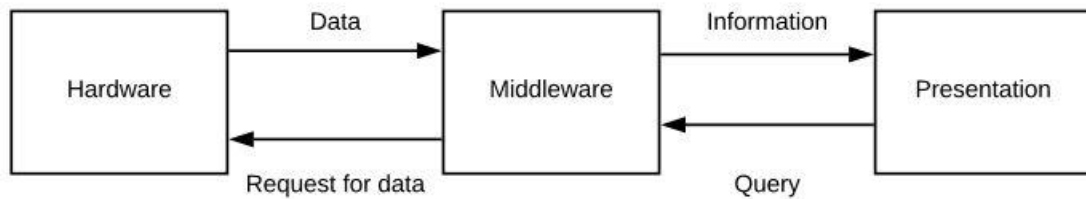
Figure 8 ‒ IoT elements.

Source: Adapted from Kaur and Sood (2017).

In the IoT paradigm, objects that people use to manage, monitor, and optimize the operational aspects of their daily activities are interactive devices connected to the Internet with intelligence capable of detecting, communicating, processing, and storing (CHEN et al., 2017). Ahmed et al. (2017) presented the IoT objects as: computers, smartphones, tablets, wireless sensor networks, handheld devices and appliances (Figure 9).

Figure 9 ‒ IoT sources of information.

Source: Ahmed et al. (2017).

Ziegeldorf and Wehrle (2014) mention that IoT systems will offer advanced services in a completely new way by obtaining data in a densely populated environment. The author gives examples of such IoT systems as generalized health care, building management systems, intelligent city services, public surveillance and data acquisition, or participatory detection applications (BEDI et al., 2016; VIPPALAPALLI; ANANTHULA, 2016).

According to Fernandez-Gago et al. (2017), 26 billion objects will be connected by IoT by 2020. The authors also mention that IoT will be a driver of great economic growth and will help to increase jobs, because is expected that it generates around $1,9 trillion in product production and service delivery.

Systems designed for IoT environments should take into account: interoperability, in which devices with different capacities from different manufacturers must be able to communicate, capable of exchanging information with other systems; dynamicity of IoT systems, that allows new devices and services to enter and leave the system at unpredictable intervals, and fragmented search (FERNANDEZ-GAGO et al., 2017).

Therefore, IoT is a worldwide trend today and promises to bring more development and business possibilities, both in services for people and in their industrial applications. For IoT to materialize it is necessary to use sensors, communication networks and an intelligent system that manages the entire process and the data it generates, as well as a connected database for storing this data. All these developments point to the importance of computational tools in many fields and applications in the world.

2.5   COMPUTATIONAL TOOLS FOR PRECISION AGRICULTURE

The need for extensive use of a large number of data requires the use of data acquisition and analysis systems, computational processing and decision support systems, and automatic equipment for field operations (SEARCY, 1995).

Technology creates significant opportunities to improve efficiency in agricultural operations and contributes to environmental sustainability (AUBERT et al., 2012). For the variables involved in an agricultural property to be monitored, transmitted, stored, analyzed, mapped, a set of electronic, electrical, and information science techniques is required.

Computer science has become increasingly fundamental to perform vital functions in agriculture, such as application of sensors, especially for wireless sensor networks, or for Web systems, and are widely used for precision irrigation, fertilization and harvesting (BATTE, 2005).

Technological advances in geographic systems such as GISs provides an effective way to handle large amounts of spatial data and GNSS and remote sensing are key tools for data collection and application of georeferenced inputs. These tools provide data inexpensively, quickly, and consistently, allowing to diagnose the system, as well as generate information that requires GIS data visualization software (OMOWUMI et al., 2014). Thus the computer science

is of paramount importance for the PA, since computational tools allow to process and visualize the data collected, and subsequently interpret them.

According to (KHANAL et al., 2017), recent advances in technology include GNSS to guide agricultural machinery, yield monitor on harvesters, variable rate technologies (VRT), sensor networks and remote sensing (RS). All of these technologies have become possible with advances in computing, which assist farm owners, identify field variability, and implement agricultural practices in a localized manner.

Whelan and Taylor (2013) described possible tasks to be performed by software packages in PA as:

a) record keeping and agricultural accounting;

b) global navigation satellite system (GNSS) or vehicle navigation data processing, mapping and data storage;

c) treatment, mapping and storage of data, spatial data analysis and development of decision support systems;

d) map and export prescription management maps and control variable rate application devices;

e) evaluation and analysis of crop data.

Among many softwares packages available for PA, ArcGIS[1] is widely used for geostatistical applications, such as to interpolate and generate maps, however, it is a proprietary software (RODRÍGUEZ-AMIGO et al., 2017).

Other widely used software is the SGIS[2] software. In the work of Amado et al. (2006), the software CR-Campeiro[3] SGIS was used for the generation of sampling grid of an experimental field and to create interpolated maps of chemical attributes of each sampling point. The FalkerMap[4] proprietary software also enables the generation of maps.

Another freely available desktop software is the Software for Definition of Management Units (SDUM) (BAZZI, 2011). This software can be used to develop and evaluate management units, in a simple and friendly way. However, this software only interpolates by the IDW method and enables the MZs generation by the Fuzzy C-Means and K-Means grouping methods (BAZZI, 2011).

Bazzi (2011) argued that there are software packages such as TracMaker[5] and PathFinder[6] for input of georeferenced data obtained through communication with GNSS receivers and that can be exported to the computer. He mentioned R[7], GS+[8], Surfer[9] and ArcGis software (the latter three are proprietary software packages) as software available to produce

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[1] http://www.arcgis.com
[2] https://sgis.rnp.br
[3] http://www.crcampeiro.net/c7
[4] http://www.falker.com.br

thematic maps using different interpolation methods. He also noted that the free software FuzMe[10] and Management Zone Analyst[11] are avaiable for the definition of management units using the Fuzzy C-Means technique.

There are several software package available to interface to and apply sensors, manage and visualize data (some need to be purchased, while others can be used with part or all of the features free, Tables 1 and 2).

Table 1 − Softwares to agricultural data and sensor management

Enterprise	Software	Description
AGCO	Falcon II Application Control	Implement VRA
	Direct Command	Implement VRA
AgLeader	Seed Command	Implement variable rate planting and fertilization control
Case IH	AFS Plantes Software	Implement VRA
	AFS Pro600 Advanced	Record harvesting and mapping data
	Farmlap2e	Spraying and localized application of inputs
Farmscan	Grain Yield	Record harvesting and mapping data
	Irrigation Manager	Irrigation
Farm Works	Lexion Yield Tools	Processing and mapping harvester data
John Deere	Field Doc suite	Localized application of inputs
	Harvest Doc Combine	Record harvesting and mapping data
Mapshots	EASi Rx	File Shape Converter for VRA
Micro Trak	Data Trak	Record harvesting and mapping data
Trimble (Greenseeker)	RT200 Software	Variable rate nitrogen management
	Autoboom suite	Implement VRA
Raven	SCS suite	Implement VRA variables
	Viper suite	Implement VRA

Source: Adapted from Whelan and Taylor (2013).

There are currently software or software modules that requires plug-in installation and additional configurations to perform certain tasks and, there are potential problems of possible incompatibilities between software, file formats and hardware used by software when more than one tool needs to be used to perform all tasks of PA (WHELAN; TAYLOR, 2013).

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[5]https://www.trackmaker.com

[6]https://geospatial.trimble.com/products-and-solutions/gps-pathfinder-office

[7]https://www.r-project.org

[8]https://geostatistics.com

[9]http://www.goldensoftware.com/products/surfer

[10]https://sydney.edu.au/agriculture/pal/software/fuzme.shtml

[11]https://www.ars.usda.gov/research/software/download/?softwareid=24&modecode=50-70-10-00

Table 2 – Data management and/or visualization software

Enterprise	Software	Description
Precision Agriculture Laboratory	Vesper	Spatial prediction for mapping
Delta Data Systems	FuzMe	Grouping for Class Management
	Viewpoint	Visualization and basic interactions of thematic map
ESRI		Basic map view and interactions in ESRI file format
	Arcexplorer	
	Map Maker Free	Viewing and editing maps
Map Maker	FOViewer	Reading and exporting harvester data
MicroImages	TNTmips Free	Basic map view and interactions in TNT file format
NSW Lands	GEOD	Coordinate projection conversion between datums in Australia
Pitney Bowes	MapInfo ProViewer	Visualization and basic interactions of thematic map in the MapInfo file format
TerraGo Technologies	TerraGo Desktop	Map visualization
Universisty of Nebraska-Lincol	Yield Check	Processing and cleaning harvester data in text files

Source: Adapted from Whelan and Taylor (2013).

Camargo (2005) has developed a free web page, with features for displaying maps and inserting information indexed to production plots in a remote database. These functionalities are also accessible in the Web application developed in this work, as well as many others such as the registration of fields and samples, interpolation and strategic positioning of data collection within a property.

Although Web applications are more practical for the user, as they can be accessed from any device without previous installation, there are a few, free or entirely free software packages available to users, and do not have all processes considered important (field, sample, sample grid, thematic map and sensor placement registration and visualization), unlike software developed in this study for the management actions required by PA. AgroPrecision[12], for example, has a Web application for crop management, but in order to access the services it is necessary for the user to be a partner of the Agroprecision Agricultura Inteligente enterprise.

Those who wish to apply the management practices of PA have their activities

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[12]https://www.agroprecision.com.br

facilitated with the Web tool developed in this work, because it is a free of charge tool and with the basic functionalities integrated in one application. In the next subsection we will briefly explain exactly what Web applications are.

Although there are some applications available for use in PA, in the resource search carried out in this work, free, easy-to-use, Web software that allows to register properties, fields, samples, thematic maps and location of strategic locations for sensors installation to implement PA practice could not be found.

2.5.1 Web Application

A Web application (WebApp) can be accessed from anywhere at any time, with Internet access only, through any computer or mobile phone. The Web is an abbreviated derivation for the expression World Wide Web and is just one of the features of the Internet - in this case, navigate through the hypertext (BONIATI et al., 2013).

Web applications includes text known as (HTML), use the Hyper Text Transference Protocol (HTTP) and resources accessible through this protocol, known as Uniform Resource Identifier (URI). These components work through browsers, to view and capture information, and it is through the Internet that this information is transmitted (GONÇALVES et al., 2016).

The Internet today offers a plethora of applications with dynamic and personalized content. A Web application is a program that is implemented to run through a browser, the Internet, or private networks (Intranet). To build Web applications with dynamic features requires the use of tools that allow, for example, database queries, integration with enterprise systems, etc (TEMPLE et al., 2004).

When a WebApp is combined with client and server hardware, operating systems, network software, and browsers, a Web-based system emerges. WebApps are considered computer software because they are a collection of executable instructions and data that provide information and functionality for end users (PRESSMAN; LOWE, 2009).

Over the years, Web applications are making users increasingly dependent on their functionality, which requires the development of reliable, quality WebApps (GINIGE; MURUGESAN, 2001). Because of this, the development of WebApps has become a more complex and challenging task, so developers need to adopt software engineering processes as a way to manage the development of complex and large-scale WebApps (SUH, 2005).

2.6   SOFTWARE ENGINEERING

A software is composed not only of computer programs, but also of documentation associated with it and necessary data configuration to the programs so that it operates as expected. To manage all aspects of software production, from the initial specification of the system to the final maintenance phase, the software engineering techniques are used (SOMMERVILLE, 2011).

Software engineering encompasses three key elements: methods, tools, and procedures, where methods provide the details of how to build software that involves project planning and estimation, software requirements analysis, data structure design, program architecture and algorithm processing, coding, testing and maintenance. The procedures maintain the methods and tools and enable the best possible development of the software (PRESSMAN, 1995).

For software development it is necessary to have communication with the client to be able to satisfy the desired requirements in the software. It is also necessary to have planning of how everything will be developed and who will develop each activity to stipulate deadlines that should be reached. Software modeling is another necessary task so that all software developers can understand its operation and develop it correctly. On top of modeling and the development of the software delivery of the software to the client should be considered (PRESSMAN; MAXIM, 2016).

Developing a software, as well as constructing a structure, involves an initial planning. To create a model for development systems that represents, in some way, how the final system will be, helps in the management of complexity by ensuring communication among the people involved resulting in the reduction of development costs and in the prediction of the future behavior of the system (BEZERRA, 2007).

According to Sommerville (2011) and Amo et al. (2010), the models are presented as documentation of the structure of the system and its functionalities. Therefore,

According to Filho (2011) and Sommerville (2011), software engineering can be defined as a tool that assists in the development of a product that satisfies the quality requirements, and includes on-time completion.

For Pressman (2011), there are different categories of software such as system software, application software, scientific (or of engineering), embedded, product line, artificial intelligence and the system that what was used in this work: web application.

For Web applications it is recommended to use a specific software engineering known as Web Engineering. The following subsection explains the reason for its use in developing

WebApps.

2.6.1   Web Engineering

Web engineering was concieved in 1998 to manage the development of WebApps. According to the comparison made by Ginige and Murugesan (2001), the web-based system is like a garden, continues to grow and evolve, because unlike traditional software, Web applications change and grow rapidly in their requirements, content and functionality.

Web Engineering is a way to develop and organize knowledge about Web application to build a WebApp. Within web engineering there are concepts for system analysis and systems design, software engineering, hypermedia engineering, human computer interaction, user interface, testing, modeling and simulation, project management and graphic design presentation (SUH, 2005).

The goal of traditional software engineering as well as Web engineering is to facilitate the development and maintenance of software products by applying methods, techniques, tools, computer-aided software engineering (CASE - used for code visualization and monitoring of software execution according to Cindra et al. (2011)), and specific models that helps in managing the quality of production, deadlines and people involved in the project.

However, although they have the same goal, it is not possible to use the same techniques of traditional software engineering to develop Web applications, since Web applications have faster life cycles. Therefore, Web engineering uses software engineering by adding new approaches, technologies, tools, techniques and guidelines used solely for Web-based systems to avoid design failures that may cause future complications (GINIGE; MURUGESAN, 2001; SUH, 2005).

Gonçalves et al. (2005) discuss that in Web Engineering the content design along with the architecture of the application and the graphic design of the interfaces should be highlighted, besides the use of templates. Ginige and Murugesan (2001) mention that Web engineering deals with all aspects of Web application development, from design to implementation, evaluation and evolution.

According to Offutt (2002) and Denning (2016), Web engineering is used to achieve Web application quality as the reliability (application should work correctly), usability (application should be attractive to users), security (application must have confidentiality and security of the inserted data), availability (application must be available at all times to be used), scalability (application must host large numbers of users and be expanded if necessary) and maintenance (application must be updated to provide improvements and defect repairs).

3 MATERIALS AND METHODS

In this section the technologies used for modeling and developing the Web application, the data to perform the functions proposed in the application, the characteristics of the server for hosting the Web environment, the methods that were used to develop the functionalities of the application, and the data collection methods utilized in the experimental agricultural fields are described.

3.1 CONTEXT AND MOTIVATION

This work is part of an existing software called SDUM - Software for Definition and Evaluation of Management Units[13]. The SDUM is a desktop software developed by Bazzi et al. (2015) and made available for free to enable the creation of management zones in precision agriculture and allowing the generation of thematic maps by the IDW and MA interpolation methods.

SDUM is software available as a desktop application, and requires installation. Therefore, this work arose from the motivation to enable its functionalities in a software Web that can be used without the need for installation of software abd with the use of, only an electronic device, a web browser and Internet connection.

A web computational tool was proposed to reengineer the SDUM desktop, transporting its thematic map generation features and adding new features for PA management practice in a simpler and easier way. This project is part of a larger project called Agricultural Data Box (AgDataBox), which is developed by University Federal Technological of Parana - Campus Medianeira in partnership with the Western Paraná State University and support of the Ministry of Agriculture, Livestock and Supply (MAPA), Coordination for the Improvement of Higher Education Personnel (CAPES), National Council for Scientific and Technological Development (CNPq) and Itaipu Technological Park Foundation (PTI).

AgDataBox includes five integrated modules as shown in Figure 10. It consists of an integrated data environment, obtained from different sources, such as soil sample data, georeferenced images, precipitation, field operations, machines/equipment and thematic maps. It aims to develop and make free available computational tools for those engaged in PA management.

The AgDataBox project not only allows the storage and management of the data

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[13]http://ppat.md.utfpr.edu.br/sdum/sdum-vm.ova

entered in the central database, but also provides features and functionalities such as the generation of thematic maps and management zones, etc. that can be requested by modules that will be built by any developers or companies looking for software resources for PA work.
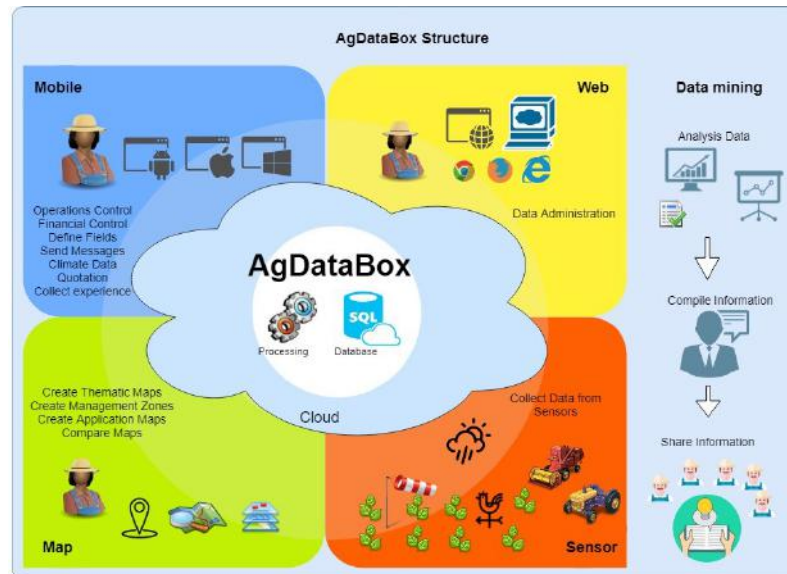

Figure 10 – AgDataBox project architectural model - Server layer and client layer.

Source: Adapted from Jasse et al. (2017).

AgDataBox modules includes AgDataBox Mobile (version for mobile devices), AgDataBox Web and AgDataBox Map (a computational tool developed in this project to make SDUM available on the web platform), the AgDataBox API and a module for handling information obtained through sensors. AgDataBox Mobile, AgDataBox Web, and AgDataBox Map work as clients, while the AgDataBox API matches the server. The module for manipulating information obtained by sensors is still in development.

All the modules that are part of the AgDataBox project can access all information logged by the user on the central storage server, regardless of the application being used.

The AgDataBox API, where (API) means Application Programming Interface, allows the sharing of data in two or more applications, making it possible to exchange data between them through HTTP requests. The AgDataBox API allows to save, edit, delete and search data for areas, samples, sample grids, thematic maps, weather data and operational control.

The Web application communicates with the API, through a sequence of message/information exchange between the client (any application that uses API resources through HTTP requests) and the server, including authentication, where the client performs requests and the server forwards a response to the call (Figure 11).

When the user logs into the Web application, it receives a request by sending the user's credentials to the API, if the user has a registration and the credentials are correct, the Web

application receives a token (Request 0 in Figure 11). The token is then used in all operations that the user makes in the Web application to save, change, edit, and query data in the API.
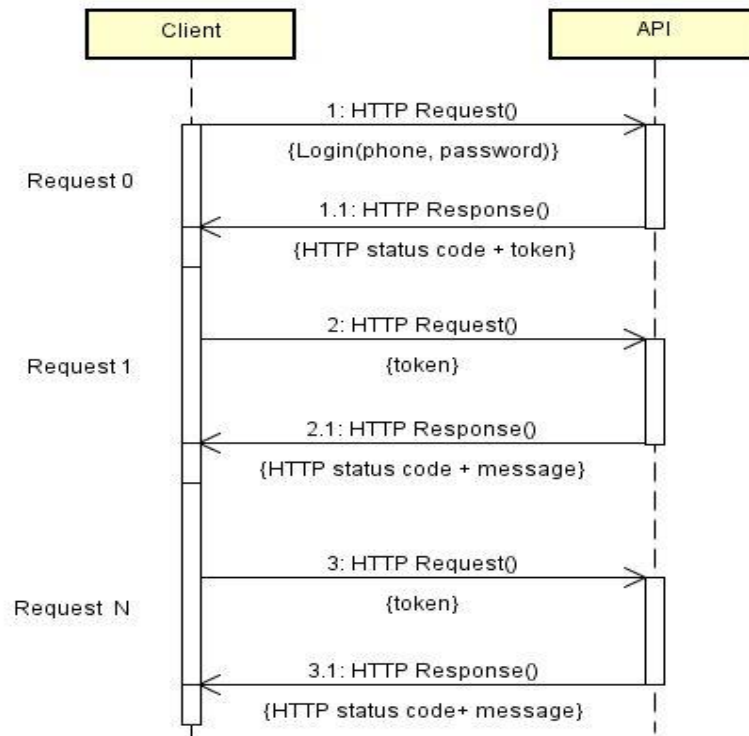
Figure 11 ‒ Sequence diagram of the message swap between the client and the API server.

Source: Authorship.

In Request 1 (Figure 11), the Web application (Client) sends the user's token along with the type of operation to be executed and, upon receiving the request, the API verifies if the token is valid, performs the operation and returns a response to the customer's request.

3.2   TECHNOLOGIES FOR MODELING AND WEB APPLICATION DEVELOPMENT

Only free and open source tools were used for the development of this work since they allow the development and subsequent modifications or additions of new modules in the system, as well as allowing the Web application to be made available for free, so, it can be used by all.

3.2.1   Integrated Development Environment

The integrated development environment (IDE) used was NetBeans, created by means of a project in 1996 by two Czech students at Charles University. In 2000, this project was acquired by Sun Microsystems. Later, with Oracle's acquisition of Sun Microsystems in 2010, it became part of Oracle. The NetBeans open source project is dedicated to providing software development in a fast, easy and efficient way for individuals and organizations, which can also help improve it with source code back to the common source code of the project. (NETBEANS, 2018).

3.2.2   Programming Language and Frameworks for Development

The Java object-oriented programming language was used, since it simplifies the development of complex systems, aids in the automatic management of memory (allocated structures are automatically released) and is a very flexible language with an ample documentation, many libraries and free codes ready to be used (TEMPLE et al., 2004).

The Java language was initially developed by Sun Microsystems, which was launched in 1995 and is currently maintained by Oracle Enterprise. Java is a competing, strongly typed, class-oriented, object-oriented, general-purpose language (GOSLING et al., 2017).

In this project Servlets architecture and Java Server Pages (JSPs) were used, which have the advantages of scalability, can increase or decrease servers according to the use of the application, have efficiency for not starting new processes to meet each incoming request and a structure allocated in memory that can be used to attend requests that reach the same Servlet. Another advantage is that they have automatic recompilation (TEMPLE et al., 2004).

In order to run the Web application developed with Servlet and JSP technologies, the Apache Tomcat server application, which is a Java based open source web container, was used.

HTML hypertext marking language was used for web page construction (paragraphs, headings, tables, images and videos). The Cascading Style Sheets language (CSS), which is composed of layers to define the presentation (appearance) of documents written in a markup language, such as HTML, and Javascript which is a programming language that allows controlling some behaviors of browsers through snippets of code that are sent in the HTML page, were used. It is an interpreted language, processed by the browser itself and dynamically updates the content of the page (MELONI, 2014).

The Hibernate free license framework was used to make the relational object mapping

that is written in the Java language, to perform mapping of attributes within the database tables (HIBERNATE, 2017).

The JavaScript jQuery library, which has many resources for transferring and manipulating HTML documents, event handling, animation and Ajax were used (JQUERY, 2017).

The model-view-controller (MVC) model was used to manage the interaction of the Web-based system. Separate and independent modules are fundamental to the design of architecture, since it allows changes to be made locally. The MVC pattern (Figure 12) makes this separation of the elements of a system, allowing changing them independently.
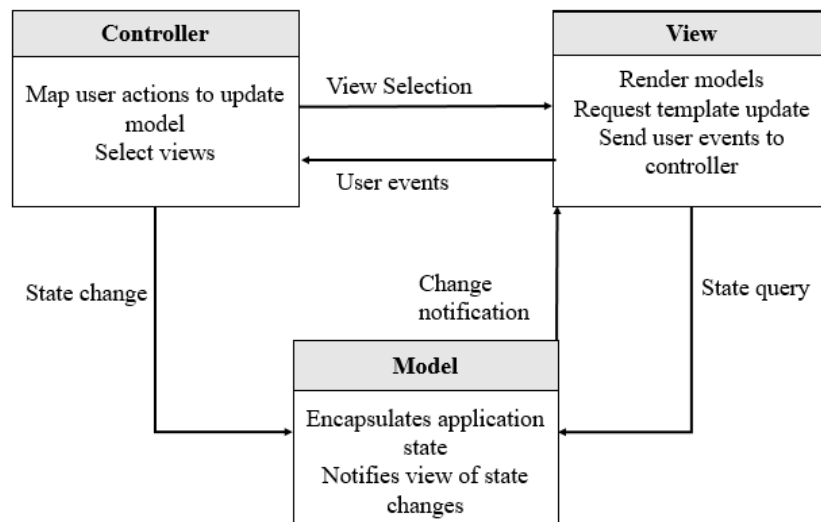
Figure 12 – Organization of the MVC standard.

Source: Sommerville (2011).

According to Sommerville (2011), this layered approach supports the incremental development of systems and the MVC architecture is a widely used standard (Figure 13, MVC when used for managing interactions in a Web-based system).

To apply the MVC standard in the application, the VRaptor framework was used. VRaptor is widely used in Java Web applications because it brings high productivity to development through dependency injection methodology. The basic concept of dependency injection is to not have to search for what you want to access, but to get it easily by the framework (VRAPTOR, 2017).

Figure 13 − Web application architecture using the MVC standard.

Source: Sommerville (2011).

3.2.3 Module for Selecting Strategic Locations for Sensor Installation

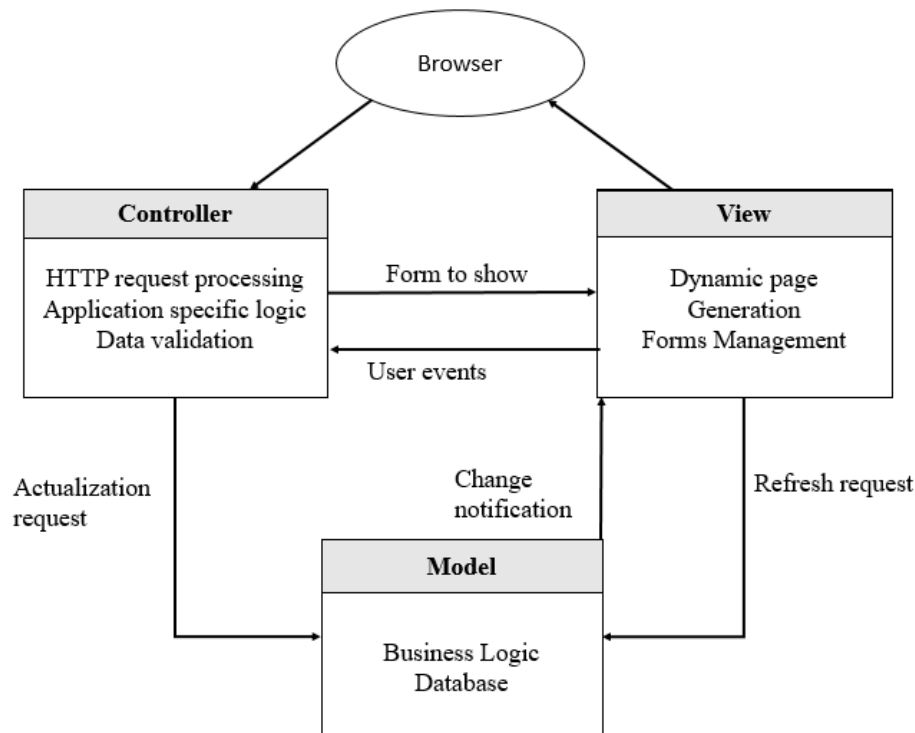To obtain the optimal location for sensor placement in a given area taking into account certain samples, a module was implemented to calculate the most suitable sensor location using the modified Fuzzy C-Means algorithm as explained by Bazzi et al. (2017).

To define the sensor location for data collection, Fuzzy C-Means algorithm with some modifications was used according to Bazzi et al. (2018). The Fuzzy C-Means algorithm minimizes the sum of the quadratic errors within each class or group, following some criteria and the data are iteratively grouped to the nearest group using a minimum distance criterion. The method assumes a group of data $Y = \{y_1, y_2, ..., y_n\}$ where y_k corresponding to a vector feature $y_k = \{y_{k1}, y_{k2}, ..., y_{kp}\}$ ε R^p for each k ε $\{1, 2, ...n\}$ where R^p is the p-dimensional space.

The algorithm aims to find a set of pseudo Fuzzy partitions corresponding to the family of Fuzzy C sets of Y, where the best partition represents the structure of the data and is denoted by $P = \{A_1, A_2, ..., A_c\}$ and satisfies $\sum_{i=1}^{c} A_i(y_k) = 1$ and $0 < \sum_{k=1}^{n} A_i(y_k) < n$, where k ε $\{1, 2, ..., n\}$ and n represents the number of Y elements. The algorithm is characterized by the number of groups C, a distance measure that defines the maximum allowable distance between the points and centroid (m $\varepsilon(1, \infty)$).

Each centroid position is calculated by taking the number of groups C. For each C, $v_1^{(t)}, ... v_c^{(t)}$ (Equation 7) is iteratively evaluated for the partition $P^{(t)}$, where $t = \{1, 2, ...n\}$ is the iteration number. The vector v_i corresponds to the group center A_i and is the Weighted average of data at A_i. The data value y_k is the mth power which is the degree of relevance to their Fuzzy set, A_i.

$$v_i = \frac{\sum_{k=1}^{n} [A_i(y_k)]^m y_k}{\sum_{k=1}^{n} [A_i(Y_k)]^m} \tag{7}$$

All possible combinations of sample points are tested using the Matrix of Relevance given by Equation 8, the Modified Partition Entropy Index (MPE) given by Boydell and McBratney (2002) and Fuzzy Performance Index (FPI) given by Fridgen et al. (2003) (Equations 9 and 10).

$$A_i^{(t+1)}(y_k) = \left[\sum_{j=1}^{c} \left(\frac{\|y_k - v_i^{(t)}\|^2}{\|y_k - v_j^{(t)}\|^2} \right)^{\frac{1}{m-1}} \right]^{-1} \tag{8}$$

Where: $\|y_k - v_i^{(t)}\|^2$ represents the distance between y_k and v_i.

$$FPI = 1 - \frac{c}{(c-1)} \left[1 - \sum_{j=1}^{n} \sum_{i=1}^{n} (u_{ij})^2 / n \right] \tag{9}$$

$$MPE = \frac{-\sum_{j=1}^{n} \sum_{i=1}^{n} u_{ij} \log(u_{ij}) / n}{\log c} \tag{10}$$

Where: C is the group number; n is the number of sampling points in the area; u_{ij} is the element ij of the Fuzzy pertinence matrix.

The lowest values of MPE and FPI are used to find the strategic locations for a given number of sampling points or sensors within a management area. The function implemented to locate sensors can be divided in steps to understand the process of choosing strategic locations for installing sensors or collecting data from an area (Figure 14).
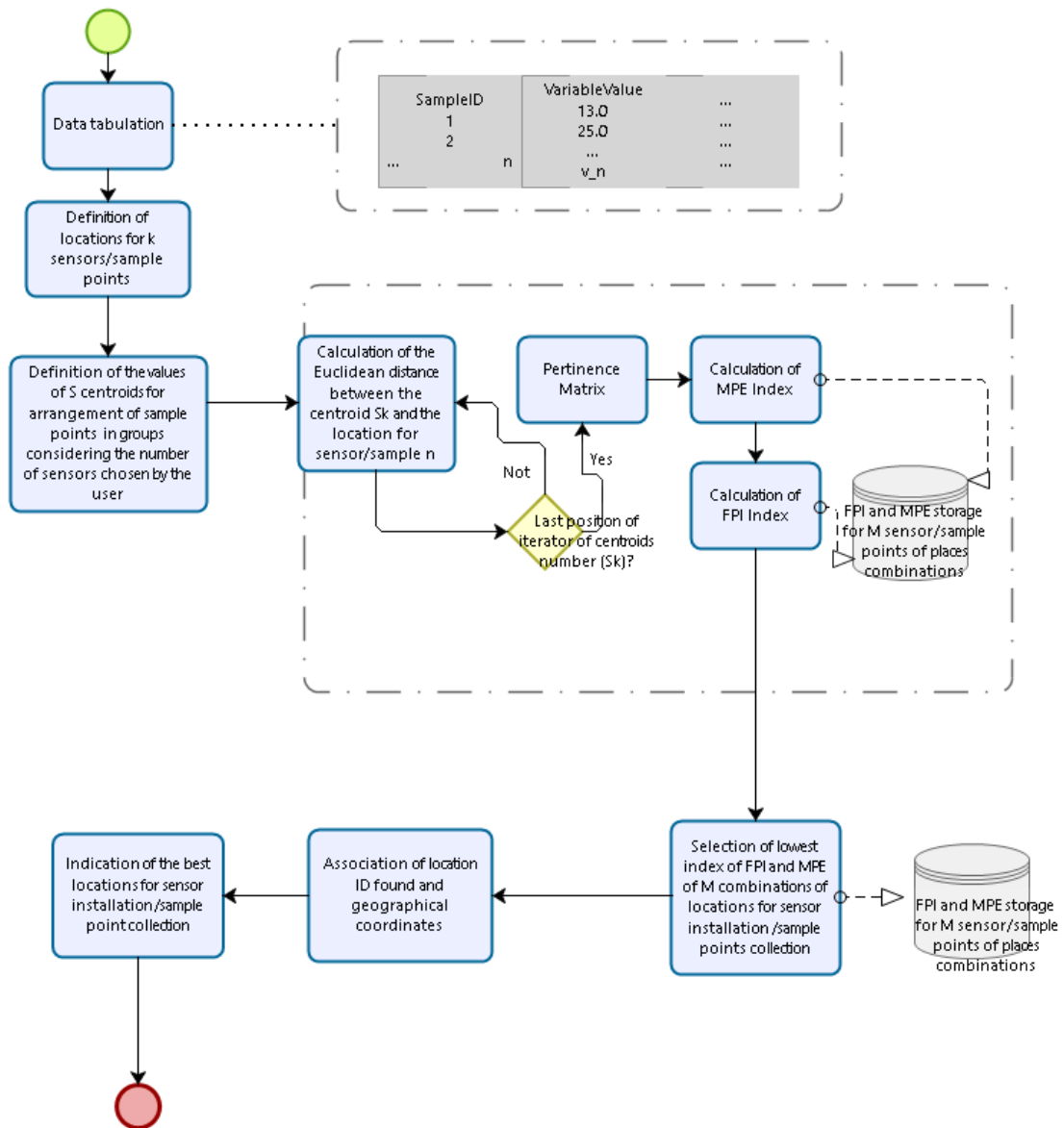
Figure 14 − Flowchart of the process of choosing the locations for sensor installation or for data collection.

Source: Adapted from Bazzi et al. (2018).

3.2.4   Software R

R software scripts developed by Betzek et al. (2017) were used to define the geostatistical analysis procedures and the spatial interpolation of the data by the OK and IDW methods. For the MA interpolation method, procedural functions implemented in PostgreSQL were used.

3.2.5   Interpolation Methods

For OK interpolation, in order to choose the most appropriate model, it is necessary to obtain first the best estimators of the nugget, sill, and range parameters to generate the semivariogram. Two methods were used: ordinary minimum squares (OLS) and the weighted least squares (WLS) method, which are explained in MELLO et al. (2005).

After estimating the parameters of semivariograms models, it is necessary to compare them to evaluate which one fits the sampled data better. According to Faraco et al. (2008), cross-validation is the most appropriate criterion for choosing the best fit spatial variability model.

In cross-validation, one value at a time is taken out from the data set and the value for this sample point is estimated from the remaining sample points (leave one out technique). This process is repeated until all sample points are compared to each other. For each sampling point, the mean error (ME) which can be standardized by the standard deviation of the estimation (SDME) is used (Equations 11 and 12) (FARACO et al., 2008) as follows:

$$ME = \frac{1}{n} \sum_{i=1}^{n} Z(\lambda_i) - \hat{Z}(\lambda_i)) \tag{11}$$

$$SD_{ME} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Z(\lambda_i) - \hat{Z}(\lambda_i))^2} \tag{12}$$

Where: ME is the mean error; SD_{ME} is the standard deviation of the means errors; n is the sample points number; $Z(\lambda_i)$ is the observed value at point λ_i; $\hat{Z}(\lambda_i)$ is the predicted value by kriging at point λ_i.

To select the best semivariogram model adjustment, the interpolation selection index (ISI) (Equation 13) proposed by Bier and Souza (2017), was used. ISI considers ME and SDME information obtained by cross-validation in its calculation, and the best model is the one with the lowest ISI value.

$$ISI = \left\{ \frac{abs(EM)}{max|_{i=1}^{j}[abs(EM)]} + \frac{[DP_{EM} - min|_{i=1}^{j}(DP_EM)]}{max|_{i=1}^{j}[abs(DP_{EM})]} \right\} \tag{13}$$

Where: abs(EM) is the modulus value of the mean cross-validation error; $min|_{i=1}^{j}$ is the lowest value found among j models compared and $max|_{i=1}^{j}$ is the highest value found among the j models compared.

3.2.6   Database Management System

PostgreSQL Database Management System (DBMS), which is an open source package, derived from the POSTGRES written at the University of California at Berkeley, was used (POSTGRESQL, 2017).

PostgreSQL DBMS was chosen, because it has extension for georeferenced data, compatibility with most programming languages, unlimited database capacity, table indexes and line numbers up to 1.6 Terra Bytes (TB), and allows creation of tables with capacity up to 32 TB (POSTGRESQL, 2017). To obtain the processing functions for georeferenced data, the PgAdmin III extension was used.

3.2.7   Satellite Images

To view and, edit geospatial data and satellite images in the Web application, the open source Javascript library OpenLayers was used, which is compatible with browsers such as Firefox, Google Chrome, Safari or Opera. The Javascript OpenLayers library or API is designed to provide web development tools that allows to view or manipulate geographic information (HAZZARD, 2011).

3.2.8   Host Server

The Web application was deployed on a private server that was purchased with financial assistance from the Ministry of Agriculture, Livestock and Supply (MAPA), which is used to host student work of the University Federal Technological of Parana - UTFPR of Medianeira. This server is hosted on the DigitalOcean[14] Cloud Server.

The server has Ubuntu Linux operating system installed, 4 GB of RAM, 60 GB of SSD and Dual Core processor with 2 cores. The server uses the Java Development Kit (jdk) 8 and Apache Tomcat 7 server application. Its development is geared towards distributed systems with technology to perform the integration of more than one application executed in the same environment (with a single application server running for all applications), so that, future modules developed can be integrated.

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[14]https://www.digitalocean.com/

3.2.9 Application Modeling

It is very important to perform software modeling to represent the essential parts of a system. The modeling of a system represents it with some kind of graphic notation. Currently, the most widely used modeling language is the Unified Modeling Language (UML) (SOMMERVILLE, 2011).

For modeling the Classes and Use Cases Diagram, the UML was used to document the application and facilitate the understanding for future developers that will give continuity to the project.

3.3 FIELDS AND EXPERIMENTAL DATA FOR WEB APPLICATION CASE STUDY

To validate the functionalities proposed in this work, tests in the web application with data from three experimental fields were performed (Figure 15). Two fields are located in the municipality of Serranópolis do Iguaçu in the west of Parana (field 1, with 10 ha and field 2, with 23.8 ha), both cultivated under no-tillage system by more than 10 years with succession of soybean and corn for commercial purposes.

The other field (field 3 with 2 ha) used for validating the application, is an almond orchard located in Arbuckle, state of California, USA.
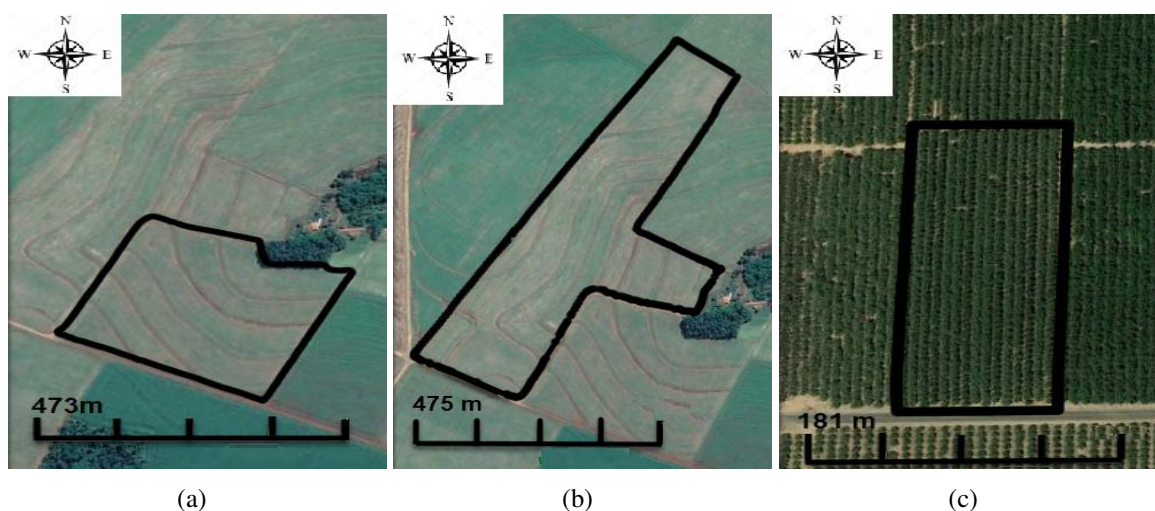

(a)   (b)   (c)

Figure 15 – Experimental fields: (a) Field 1; (b) Field 2; and (c) Field 3.
Source: Authorship.

To validate the WebApp, each field was registered with area, sampling information, and

defined the sample grids. Moreover, interpolation was conducted and the strategic locations for data collection were determined. The choice of strategic places for sensors location is function of the crop structure. Soybean and corn (fields 1 and 2), may have sensors anywhere in the area, however, in crops such as fruit trees (field 3), sensors must be placed on the trees or near it for data acquisition.

In order to determine the chemical and physical elements of the soil of fields 1 and 2, sampling points were collected in the years 2015 and 2016, at depth 0-0,2m, with (8 sub-samples) within a radius of 3 meters from the central point (WOLLENHAUPT et al., 1997), located by means of a GNSS receiver (GNSS Trimble Pathfinder Pro XT). The collected samples were conditioned in plastic bags and sent for laboratory analysis.

The chemical and physical attributes analyzed for field 1 and 2 were: clay, silt, sand, OM, P, K, Cu, Fe, Zn, Mn, pH, H + Al, Ca, Mg, Al, Sum of Bases (SB), Baseline V Saturation (%), Aluminum Saturation (%) and Cation Exchange Capacity (CTC), in this work, soil texture (sand, clay and silt), pH ($CaCl_2$), soil penetration resistance (SPR) in kilopascal (KPa), OM (g dm^{-3}), elevation (m) and soybean 2015-2016 crop and corn 2016 crop yields (Mg ha^{-1}) was used.

The choice of these attributes, was based on the work of Doerge (2000), who recommends temporally stable variables (attributes) for the generation of management zones for localized management, allowing the subareas to be used for more than one year.

The yield data of fields 1 and 2 were used, which were obtained in January/February for soybean and July/August for corn. At each sampling point, two planting rows were collected over a 1m path, representing a portion of about 0.9 m 2 for soybean and 1m^2 for corn. Threshing was done manually and oven-drying procedure was carried out at 105°C for subsequent calculations of the productivity in megagram per hectare, considering the moisture content of 12%.

Due to the arid climate of California (field 3) with minimal periods of rainfall in the summer season, there are a large number of crops that require irrigation. According to Maupin et al. (2014), California is the largest consumer of groundwater in the United States, with 76% of the total used by the state for irrigation in 2010.

According to Fereres and Soriano (2007), irrigation in agriculture is essential to feed the growing number of the world's population, which makes agriculture responsible for using 70 to 80% of the total water in arid and semi-arid zones. Therefore, the withdrawal of water resources combined with drought periods highlights the need to develop methods that increases the efficiency of water use through better management of agricultural irrigation systems.

Bazzi et al. (2018) used the stable attributes of soil texture and elevation with the

addition of the apparent electrical conductivity (ECa) to generate management zones, since according to Sudduth et al. (2005) and Moral et al. (2010) the attributes of soil texture and ECa have a high correlation with each other and a relation with the water supply to the plant and can be used together to generate efficient management zones.

According to Kizer et al. (2016), plant water status in the plant expressed as stem water potential (SWP) can be determined using a pressure chamber. However, this method requires time and a lot of work to perform the measurement of the water potential in the plant, making it impractical to use for irrigation management of a large area. Therefore use sensors and knowledge of strategic locations for data collection can assist in the management of irrigation reduce use of water and increase yield.

As Rojo et al. (2016) and Bazzi et al. (2017), the data of texture, elevation, ECa and SWP were used in order to determine data acqusition sites in the almond orchard that make irrigation feasible in an optimized way. The elevation and ECa data show great relation with the soil texture and its water holding capactity. Bazzi et al. (2018) stated that these attributes were sufficient to determine data collection sites for irrigation.

Therefore, data of sand, clay and silt (%), elevation (m) and ECa in shallow depth (0.3m) and deep layer (0.9m) measured by soil electrical conductivity sensor (Veris model 3150, Veris Technologies of Salina, KS, USA) were used in field 3. Plant water status data - SWP was measured according to the methodology described by Shackel et al. (1997).

The data from fields 1 and 2 was used to evaluate the features of area registration, sample grids, samples and thematic maps and field 3 data was used to verify the functionality of determining optimum location for sensor installation.

3.3.1 Descriptive and Exploratory Data Analysis

To demonstrate the use of the tool, the data used were evaluated using descriptive and exploratory statistics by Minitab software. The measurements of position (mean, median), dispersion (standard deviation, coefficient of variation) and distribution (coefficient of asymmetry and kurtosis coefficient) were calculated. The hypothesis of normality of the data was tested by the Anderson-Darling and Kolmogorov-Smirnov tests at the 5% significance level with the Minitab software too. To determine the homogeneity of the data, the coefficient of variation (CV) was used. The CV is classified as lower when CV $<10\%$ (homoscedasticity); medium, when $10\% < CV < 20\%$; high, when $20\% < CV < 30\%$; and very high, when $CV > 30\%$ (heteroskedasticity) (PIMENTEL-GOMES; GARCIA, 2002).

3.3.2   Data Interpolation

Thematic maps of fields 1 and 2 for various soil attributes were generated by the methods IDW and OK, with number of neighbors equal to ten in the case of IDW and with size pixels of 5m x 5m for both the methods. The size of the pixel X and Y in the thematic map defines the spatial resolution, so, the smaller the pixel size is, greater is the number of points that will be interpolated, and consequently, higher the resolution of the map will be and more clearly the contour curves of the area. However, choosing smaller pixel size takes longer to execute the algorithm, as more computations are required that result in a greater number of interpolated points and creation of a larger number of pixels, taking more time to complete the process of generating a thematic map.

The parameters can be defined according to the user's needs and according to the level of detail of the thematic map required. In this work, the thematic maps were generated to visualize which sites within the fields presented smaller and higher yield according to the soil attributes samples.

3.3.3   Location of Strategic Places for Sensor Installation

The sensor positioning strategy available in the web application developed in this work compared its results to the existing sensors position in field 3, trying to interpret if the application can bring better options for data acquisition compared to the ones used so far Bazzi et al. (2018) and Kizer et al. (2016).

It is necessary to irrigate the almond orchard (field 3), because the climate of the region can cause conditions of water stress to the plant as mentioned before. In order to perform irrigation in this field, a-continuous leaf monitors developed at UC Davis (KIZER et al., 2017; ROJO et al., 2016) that sense leaf and environmental temperature, relative humidity, incidence radiation and wind speed, to estimate Plant Water status were deployed as a mesh network. The plant water status (PWS) reported by the leaf monitors were used to actuate latching solenoid valves to control irrigation in this orchard.

Knowing optimal locations to install the sensors in field 3, can not only help in the optimization of the water use, but also improve the quality of almonds (i.e., deficit irrigation during the hull-split period can help minimize hull rot and promte uniform maturity of nuts). Stable soil and plant SWP data were used to obtain optimal locations for placement of leaf monitors for data collection as reported by Bazzi et al. (2018).

4 RESULTS AND DISCUSSIONS

This chapter introduces the Web application developed and describes how its use can enable PA management practice through its available functionalities.

4.1 MODELING

In order to plan and to verify the functionalities and the structure of the application, the Class Diagram and Use Case Diagram were modeled.

4.1.1 Class Diagram

Through the Class Diagram (Figure 16), it is possible to visualize the attributes of each class and their relationships to enable the operation of the Web application. Since the computational tool was developed using the MVC standard, the operations in the Class Diagram do not appear in the classes, only on the controllers. The classes presented in the Class Diagram have only the getters and setters methods responsible for searching and changing values of particular attributes within classes, respectively.
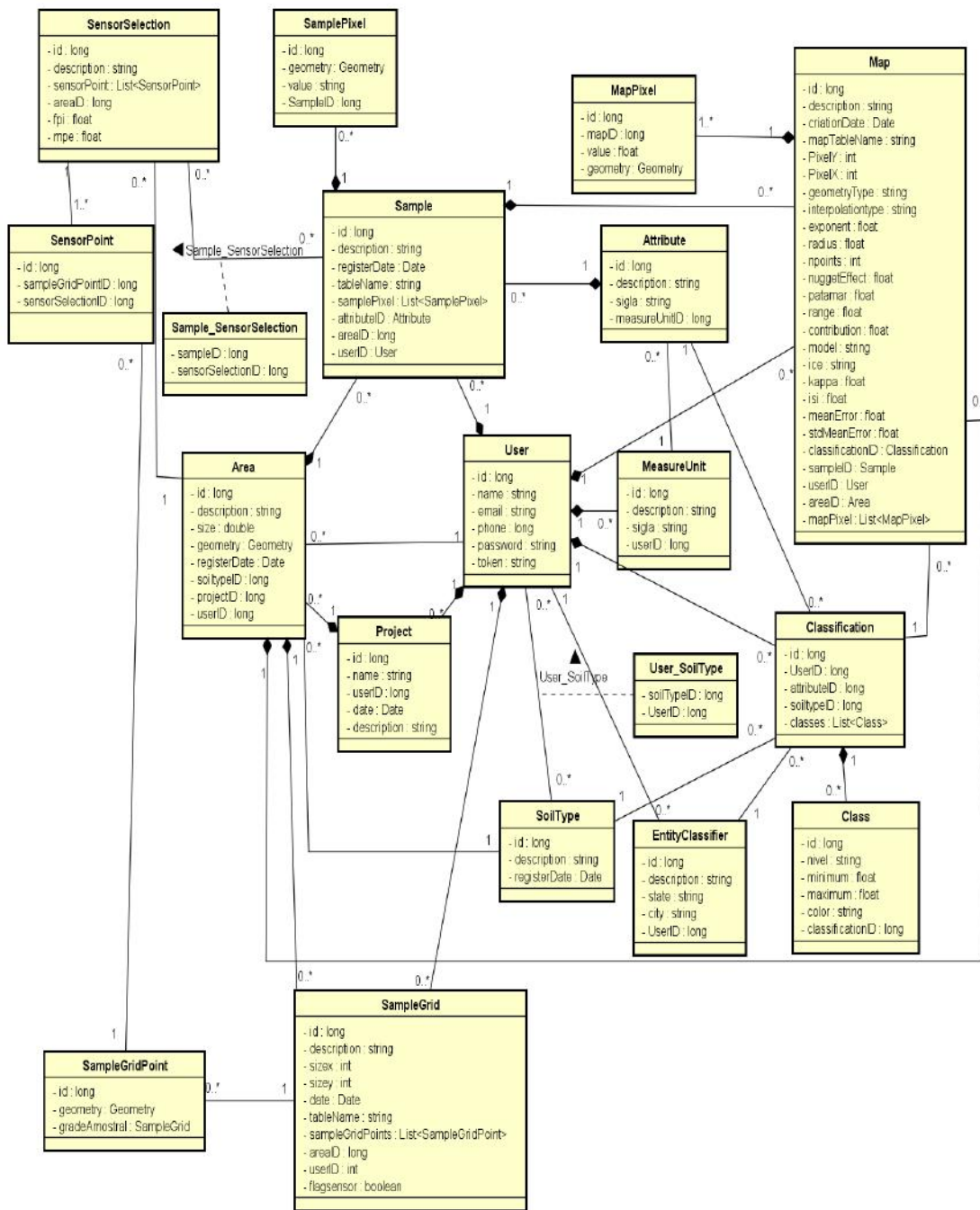
Figure 16 – Web Application Class Diagrams.

Source: Authorship.

4.1.2 Use Case Diagram

The Use Case Diagram (Figure 17) shows the functional requirements of the system, the operations that the actor (user) can perform within the developed web application: manage user registries, login procedure, registration of information and visualization of the registered items.
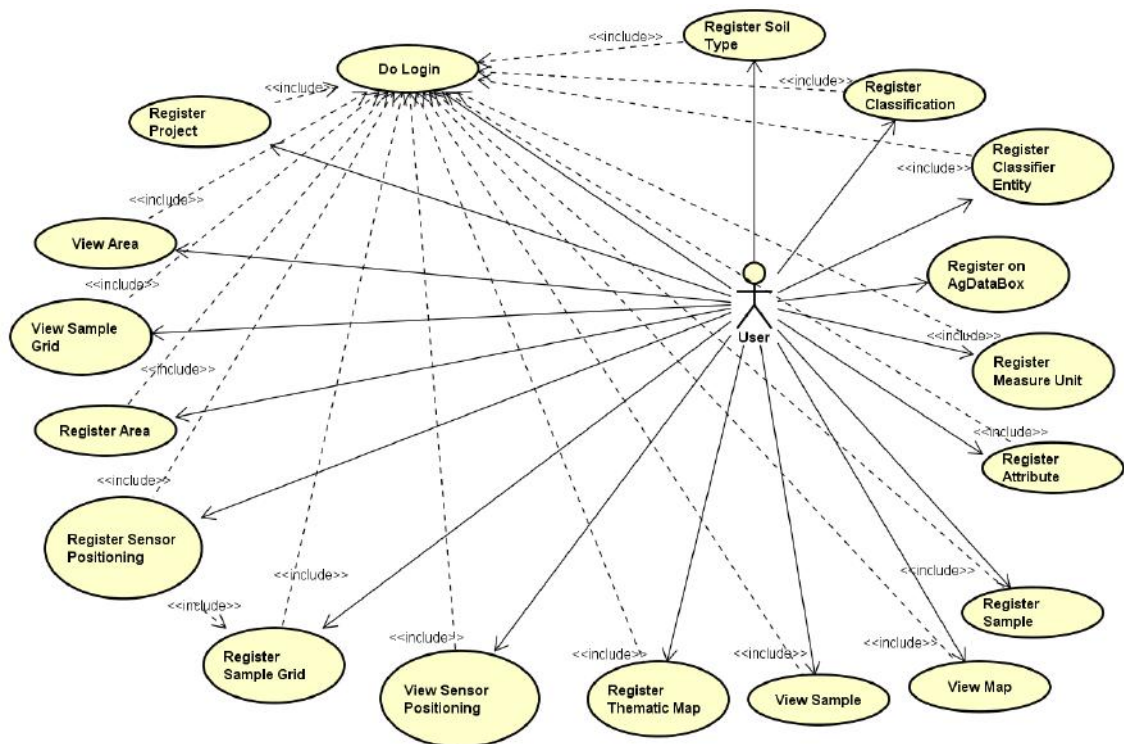
Figure 17 – Web Application Use Case Diagram.

Source: Authorship.

4.2   WEB APPLICATION

All the logic of the Web application developed was done using the Java language. The forms and lists were created using JSP technology - creation of Web pages based on HTML and Javascript languages. The CSS was used to display the Web application appearance. The project division was done in packages, the package "Páginas Web" has the web pages, and each class of the Web application model was split into packages within the JSP package, and for each class package, forms and lists were created to allow registrations, editing and listings. In the "Pacotes de Códigos-fonte" package consists of the control package, the connection package, view and model packages required to structure of all the source code and ensure that the package works well (Figure 18).

The Web application developed in this work can be accessed at `http://www.ppat.com.br/sdum-web`. To access it, connection to internet is necessary and should have a browser on an electronic device.

Using the login form on the home page of the Web application the user can do the login or the registration, if user is not registered.
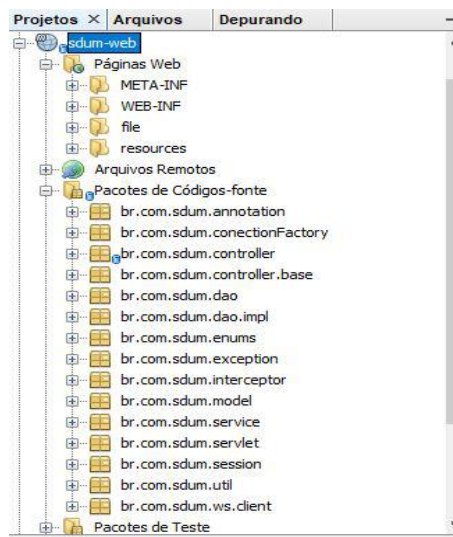
Figure 18 – Web application project divided in packages.

Source: Authorship.

The login connection is done by the exchange of messages from this Web application with the AgDataBox API - the central data server. The application sends the user phone and password to the API by the POST method in the HTTP requisition and the API returns the status code 200 (which represents success in the operation requested) and user's token if the user has already registered in the API. When the user registers in the Web application, it sends the user data entered in the registration form by the POST method in an HTTP request to the API, and the API returns the response with the status code 200 if the registration was executed successfully, otherwise it returns an error status code and the Web application displays a message to the user that it could not register the user. The user's registration will be successful if the information is correctly entered according to the fields requested in the registration form and if the user has not entered a phone and/or an email already registered in the API.

When the user registration was done successfully in the API, the Web application creates a user in its local database. When the user does the login, the project listing is displayed first. A project is created only in the Web application database. The project is a procedure to manage the user's fields, sample data and sample geographic location (grids). In this way, the user can register a field, for example, directly in the API or using the synchronization provided by the Web application. Then, the user can obtain the field registered in the API to the Web application project without a need to register the same field again. The same field can be registered in more than one project.

The synchronization between the Web application and the API occurs as: when the user wants to fetch some field from the API server to the Web application (there is a button specific in the field listing to do the synchronization), the Web application lists all fields of the

user registered in the API through of the method GET using HTTP request, passing the user's token. When the user chooses a particular field listed by the API to save to the Web application, the application uses the method GET through HTTP request, again, passing the user's token and the field code registered in the API. After, the API returns the field information, which is used to store the field in the Web application database, storing an id, which increments in the database sequentially, and stores the area code obtained in the API registration.

The inverse process of writing an field, for example, that is only saved in the application database to the API database requires the code of the soil type registered in the API, so the web application always saves the soils created by the user in the application in the API database also. As for the sample registered in the API, it is necessary that the field, the attribute, and its respective unit are previously registered in the API. At the time of making the HTTP POST request it is necessary to pass some essential parameters so that the API registers the sample, such as the field code, and the attribute (which requires the code of the unit of measurement in its register) in the API.

All the parameters required for Web application synchronization with the API can be found in the API documentation provided at the link: `http://www.ppat.com.br/api/doc.html#/`. However, there are some limitations between the Web application and the API, such as the situation where a user registers a soil type that already has the same description previously registered by another user. So, the user who subscribes to a soil description that already existes in the API (registered by another user) will not be able to edit and delete the soil type. Only those who created the soil type information first will be allowed to do this in the API.

After registering a project, its field and the field's sample, sample grids and thematic maps, the user could visualize it in the world map (Figure 19). The world map appears also in field, sample data and sample grid forms, Figure 20.

The map page is made available through the OpenLayers library[15] making some library imports and code changes. The map is made of layers, with a view to visualize them, and it can interact to modify the map content and has some controls that allows the user interaction.

To register the fields, the user needs to register a soil type. To register a sample data, the user needs to register an attribute and its unit. The soil type, unit of measure and attribute entries are automatically saved to the Web application database and the in the API database. Field, sampled data and sample grids can be registered only in the Web application database or in the API database, which can be defined by the user. Thematic maps and sensor positioning can only be manipulated in the Web application and stored in the local database.

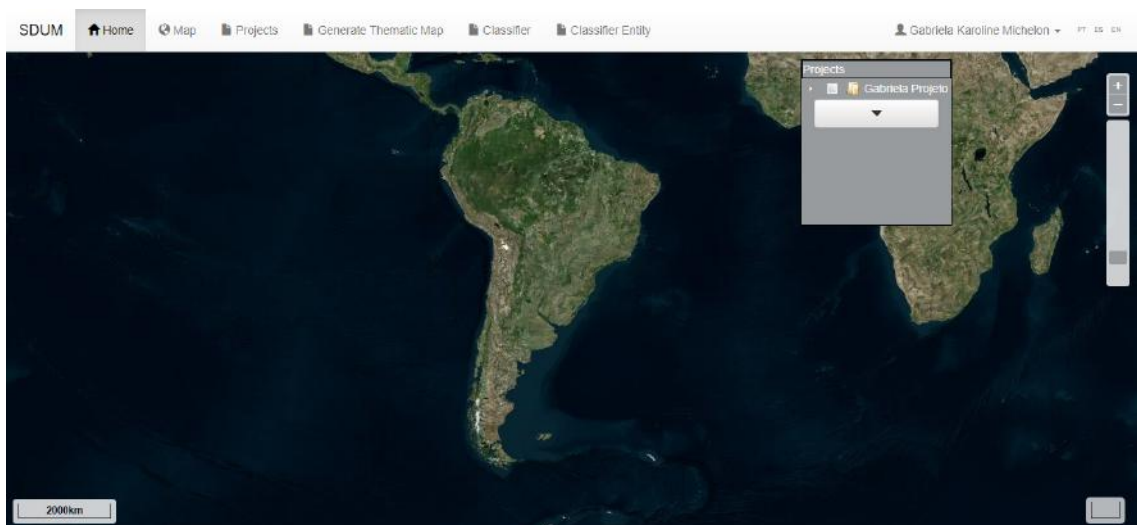
[15]http://openlayers.org/en/latest/apidoc/

Figure 19 ─ Map page after opening a project in the Web application.

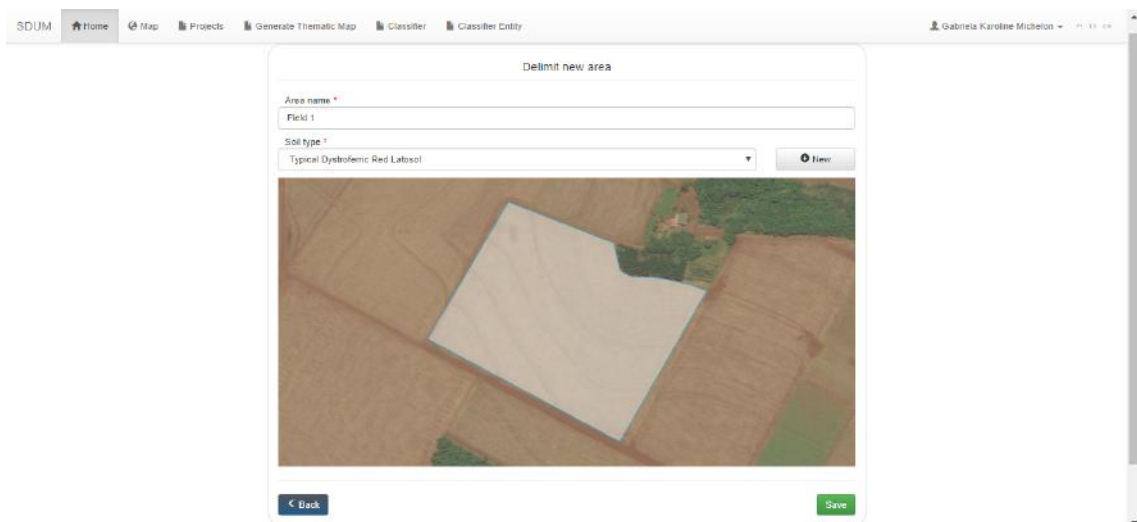**Source: Map avaiable through OpenLayers library, Hazzard (2011).**

Figure 20 ─ Delimited field at registration field form.

Source: Authorship.

Everything that is registered by the user is his/her full responsibility, because the Web application does not provide a listing of units, attributes, and soil types. Thus, the user must be fully knowledgeable before registering anything.

Therefore, the Web application allows the user to manage fields, sampled data, sample grids, thematic maps, and sensor location. The tool developed in this work has the advantage of being free and online, but has some limitations. The time to perform some tasks can be relatively long, as in the case of registering thematic maps, the smaller the pixel size and the larger the field size for data interpolation, the more is the time necessary for the application to perform this task.

The interpolation process generated by the MA method is performed through functions

implemented with the pgSQL language in the PostgreSQL database. While the IDW and OK interpolation methods were implemented in software R and made available through an API, for which it is necessary to pass the points to be interpolated and their respective original values, the area corresponding to the sampled data, and the parameters corresponding to the IDP or OK method in the json format. The API returns a response in json format for the Web application with the estimated points, and when interpolated by OK, also returns some parameters used by the method in the interpolation process. Thereafter, the Web application needs to create the pixels for each point using a function that has been implemented with the pgSQL language in the PostgreSQL database. The pixel is a square formed for each point estimated in the interpolation, and these pixels are used at the time of thematic map generation on the world map display screen, where each pixel has a color according to the classification chosen by the user or by the standard classification determined in the Web application.

Some PA management can be done through the Web application and to know how to use it, it is suggested to read the appendix of this work. The next section presents a case study to demonstrate some possible applications in the PA made available by the Web application developed in this work.

4.3 PRECISION AGRICULTURE MANAGEMENT WITH THE WEB APPLICATION

To apply the PA functionalities provided by the Web application, the descriptive and exploratory data analysis was done first. The procedure used in PA is demonstrated below:

4.3.1 Case Study Descriptive and Exploratory Data Analysis

To test the functionalities of the application developed the data available from the three agricultural fields were used.

The attributes pH, sand, silt and clay for field 1 and the attributes sand, silt, clay and elevation of field 2 did not satisfy normality requirements. The results of the normality tests are indicated by a "*" in Table 3 indicating a p-value < 0.05 or a confidence level greater than 95%.

The CV is classified as very high (heteroscedasticity) for the SPR attribute of 0-0.1m in field 1 and high in field 2. Only OM of field 1 presented high CV. The other attributes presented low CV (homoscedasticity) with the exception of silt in field 1 and field 2 in OM, which presented average CV.

Table 3 – Descriptive statistics of the attributes of fields 1 and 2

	Attribute	Min	$\bar{x}$	Md	Max	AM	SD	K	AS	CV
	OM	18.06	34.03	33.76	48.38	30.32	7.55	-0.55	-0.09	22.19%
	pH*	4.80	5.05	5.00	5.50	0.70	0.19	-0.28	0.60	3.74%
	Sand*	16.25	17.44	17.50	20.00	3.75	0.99	-0.47	0.39	5.70%
	Silt*	12.50	16.13	16.25	21.25	8.75	1.93	0.38	0.46	11.99%
F1	Clay*	58.75	66.43	66.25	68.75	10.00	2.02	3.67	-1.37	3.05%
	SPR_0_10	759.44	2578.57	2452.84	4745.15	3985.71	891.10	-0.17	0.09	34.56%
	Elevation	351.70	362.83	363.21	372.69	20.99	5.46	-0.55	-0.21	1.50%
	Corn2016	7.70	10.03	10.09	12.86	5.16	1.04	0.81	0.12	10.39%
	Soy2015-16	3.35	4.68	4.72	5.74	2.39	0.52	-0.01	-0.06	11.20%
	OM	28.17	35.99	35.69	49.02	20.85	4.39	0.26	0.58	12.20%
	pH	4.80	5.32	5.30	6.00	1.20	0.28	-0.33	0.26	5.27%
	Sand*	16.25	16.95	16.25	18.75	2.50	0.86	-0.47	0.83	5.07%
	Silt*	12.50	15.91	16.25	18.75	6.25	1.31	-0.34	-0.10	8.21%
F2	Clay*	63.75	67.14	67.50	68.75	5.00	1.44	-0.87	-0.37	2.14%
	SPR_0_10	1768.28	3591.97	3530.59	7534.69	5766.41	1012.41	2.12	0.84	28.19%
	Elevation*	344.40	363.60	365.82	372.87	28.47	7.38	0.28	-0.98	2.03%
	Corn2016	6.53	8.98	8.88	10.74	4.22	0.92	0.10	-0.22	10.25%
	Soy2015-16	2.30	4.26	4.25	5.28	2.98	0.50	2.25	-0.40	11.80%

F1 - field 1; F2 - field 2; Soy - Soybean; * Not normality at 95% of confidence; Min - Minimum; $\bar{x}$ - Mean; Md - Median; Max - Maximum; AM - Amplitude; SD - Standard Deviation; K - Kurtosis; AS - Symmetry; CV - Coefficient of Variation.

Source: Authorship.

The attributes OM, pH, sand, SPR, and elevation, of field 1, presented a platykurtic distribution, while the other attributes of field 1, presented leptokurtic distribution. For field 2, the attributes that presented platykurtic distribution were pH, sand, silt, clay, SPR and elevation. The OM attribute showed mesokurtic distribution. Analyzing the symmetry values, all attributes presented symmetry symmetry with the exception of the clay attribute in field 1, which presented negative asymmetry (Table 3).

In field 3, all attributes, except for SWP, do not present normality at 95% of confidence (Table 4). The SWP data of the plant, elevation and soil sand content had CV classified as low (homoscedasticity). For clay and silt the CV was classified as medium and for the attributes of ECa at both depths, it was classified as very high CV (heteroscedasticity). Clay and SWP presented leptokurtic distribution and the other attributes presented platykurtic distribution. The asymmetry coefficients indicated that data of all attributes analyzed in field 3 are symmetrical.

Table 4 – Descriptive statistics of the attributes of field 3

Attribute	Min	$\bar{x}$	Md	Max	AM	SD	K	AS	CV
SWP	7.08	8.79	8.80	10.78	3.70	0.48	1.31	0.19	5.50%
Clay*	6.20	9.03	8.97	12.03	5.83	1.06	0.60	0.39	11.71%
ECa0.9m*	8.28	16.51	14.02	30.91	22.63	6.21	-0.74	0.69	37.58%
Elevation*	55.24	56.50	56.44	57.99	2.75	0.70	-1.05	0.12	1.23%
Sand*	64.09	71.84	72.48	79.11	15.02	3.51	-0.70	-0.34	4.89%
ECa0.3m*	4.63	8.54	7.50	16.29	11.67	3.09	-0.20	0.94	36.17%
Silt*	13.59	19.13	18.76	25.22	11.64	2.87	-0.75	0.39	15.01%

* Not normality at 95% of confidence; Min - Minimum; $\bar{x}$ - Mean; Md - Median; Max - Maximum; AM - Amplitude; SD - Standard Deviation; K - Curtose; AS - Symmetry; CV - Coefficient of Variation.

Source: Authorship.

4.3.2   Generation of Thematic Maps

To generate the maps by IDW, exponent 2 was chose, since according to Betzek et al. (2016), the values estimated by IDW when raised to power 2 suffer less variation in the minimum and maximum values, causing less influence on the original data.

To generate the maps by OK, the method implemented by Betzek et al. (2017) was used, which returns the parameters of the geostatistic model that best fits the semivariogram to generate the interpolation appropriately. The parameters used in each thematic map of the field 1 and 2 interpolated by OK are in Table 5.

The classification used for the attributes of yield, texture and elevation was the standardized classification of the application, in which it takes the value of the amplitude of data and divides into 5 intervals, resulting in 5 classes on the map as suggested by Souza et al. (2018). The classes are presented following a sequence in which the lighter color represents the smallest range of classes and by gradually raising the pitch of the color as the class interval value increases.

According to Souza et al. (2018), it is important to choose an effective color scheme to generate thematic maps, and a sequential color scheme is recommended for numerical data with classes that seek to determine low, medium and high levels, for example. Thus, the colors used in the classes of the standard classification of the thematic maps generated in the web application developed in this work vary from salmon, orange, and brown, but the user can register a different pattern as classifiers and choose the colors according to their objectives.

For the SPR, pH and OM attributes, a classification determined by Canarache (1990), Lima et al. (2006) and Costa and Oliveira (2001) was used to generate thematic maps instead

of use the standard classification available in the application developed in this work.

Table 5 – Parameters used to geostatistic generated by the method of OK

F	Attribute	Method	Model	ICE	Cont	Range	Kappa	ISI	SDME	ME
	Clay	WLS	Sph	0.12	2.55	47.94	0.50	0.10	2.07	0.00
	Sand	WLS	Gaus	0.00	77.16	47.94	0.50	0.00	7.64	0.00
	Silt	OLS	Sph	0.08	4.87	48.70	0.50	0.08	2.04	0.00
	Elevation	OLS	Gaus	1.00	26.77	83.72	0.50	0.04	5.07	0.00
1	pH	OLS	Sph	0.05	0.04	83.89	0.50	0.00	0.19	0.00
	OM	WLS	Gaus	0.00	77.16	47.94	0.50	0.00	7.64	0.00
	SRP	WLS	Sph	0.00	635 K	119.60	0.50	0.10	901.90	0.00
	Corn	OLS	Mat	0.01	1.00	47.94	2.00	0.00	1.04	0.00
	Soybean	WLS	Sph	0.13	0.24	47.84	0.50	0.03	0.53	0.00
	Clay	WLS	Mat	0.08	2.60	422.15	2.00	0.10	1.45	0.00
	Sand	OLS	Exp	0.09	0.53	340.76	0.50	0.10	0.86	0.00
	Silt	OLS	Exp	0.04	1.52	340.76	0.50	0.10	1.31	0.00
	Elevation	WLS	Mat	1.00	93.39	419.22	2.00	0.00	0.28	-0.01
2	pH	WLS	Gaus	0.00	0.07	104.85	0.50	0.00	0.27	0.00
	OM	OLS	Gaus	1.00	22.88	183.5	0.50	0.70	3.93	0.00
	SRP	OLS	Mat	0.04	1 MM	104.81	1.00	0.10	1019.42	0.00
	Corn	WLS	Mat	0.09	0.70	419.40	2.00	0.10	0.90	0.00
	Soybean	WLS	Sph	0.03	0.31	183.41	0.50	0.00	0.55	0.00

F - Field; Cont - Contribution; Gaus - Gaussian; Sph - Spherical; Mat - Mattern; Exp - Exponential; K - Thousand; MM - Million.

Source: Authorship.

The yield maps generated by the IDW and OK methods of interpolation for soybean season 2015/2016 and corn season 2016, for fields 1 and 2, are shown in Figures 21 and 22, respectively. The semivariograms of the best model adjusted to the data in each soybean and corn yield thematic maps generated by OK is shown in Figures 21 (e) and (f) and 22, respectively (e) and (f).

The yield maps of soybean for 2015/16 (Figure 21) were similar using the interpolator IDW and OK method. The maps of corn yield for 2016 (Figure 22) by these two methods were not similar for both fields.

In the thematic maps generated by OK of corn yields for 2016 season of field 1 and 2 (Figure 22 (c) and (d)) there was a large difference between the minimum and maximum values of the original data and the values of the estimated/interpolated data. The maps interpolated by IDW presented the minimum and maximum values of the original data. Thus, the IDW and OK

maps shows differents representation of the yield.

By the OK method, there was a gradual increase in the corn yield of field 1 from the Southwest region to the Northeast region, and in field 2, there was a gradual increase of the interpolated production of the Southeast region towards the northwest (Figure 22 (c) and (d)). Already in the maps interpolated by IDW, in both areas the yields presented has more difficult delimitations to do the localized management (Figure 22 (a) and (b)).

Soil texture attributes of field 1, Figure 23 (c), did not present a spatial dependency, obtaining the same value for all the interpolated data, because the semivariogram for the sand presented a pure nugget effect (Figure 23 (e)). According to Sturaro (1988), the pure nugget effect occurs when there is significant value difference between nearby points, representing a possible regionalization below the sampling mesh scale and/or errors in sample collection and measurement.

According to Isaaks and Srivastava (1989), the pure nugget effect is characteristic of data with great randomness, with marked discontinuity at the origin of the semivariogram. When pure nugget effect occurs, the thematic map generated by OK should be discarded, since geostatistics does not apply when there is no spatial covariance between the samples, as shown by Oliveira et al. (2015). According to Betzek (2017), when the pure nugget effect occurs, thematic maps must be generated by other interpolation methods. In this work, the thematic map of OK with pure nugget effect is presented to exemplify possible occurrences with the data, but this should not be taken into account for analyzes and interpretations for the data in question.

In the thematic maps of the soil texture attributes for fields 1 and 2, is possible to see sites where the silt content is lower is also site where higher in clay and sand content occur (Figures 23, 24 and 25).
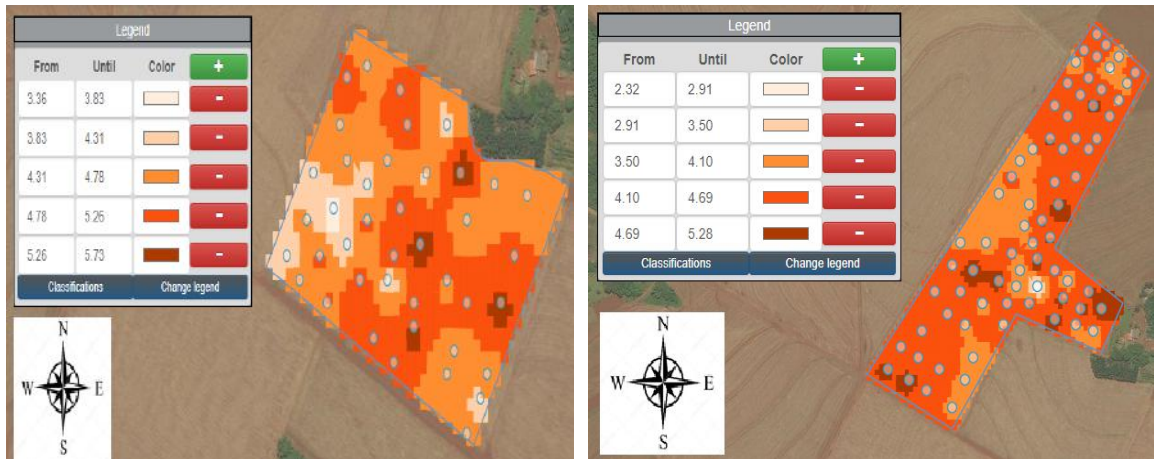
(a)

(b)
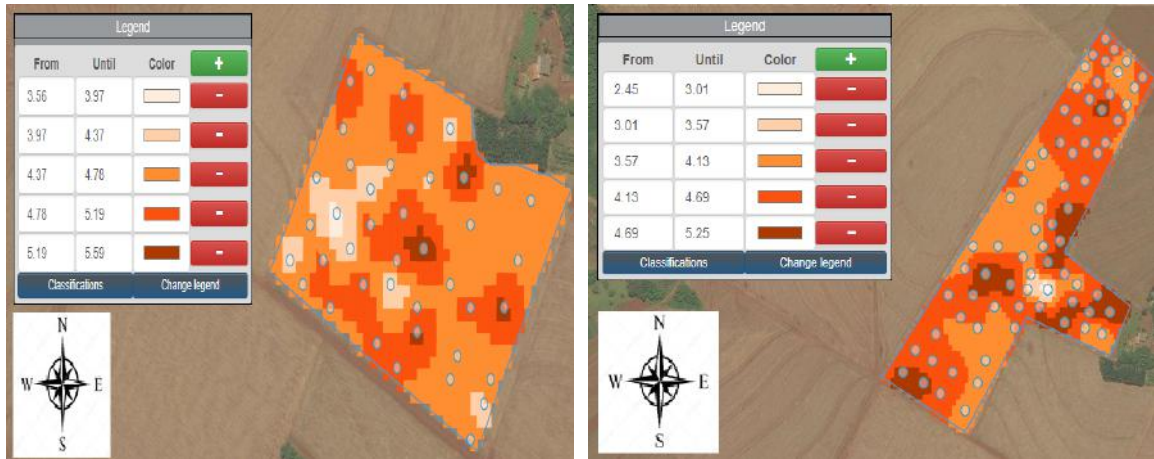
(c)

(d)
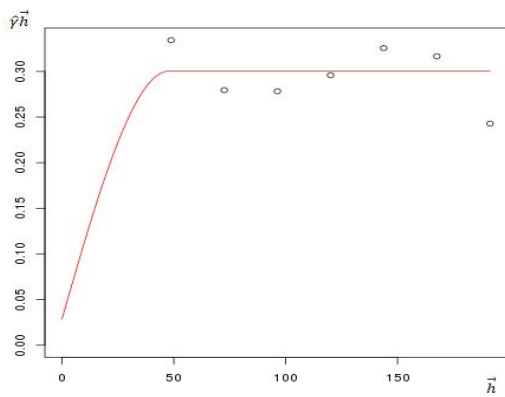
(e)
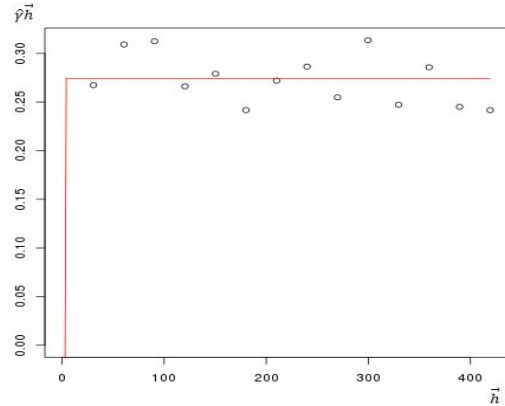
(f)

Figure 21 − Thematic maps of soybean yield for 2015/16 in Mg ha^{-1} and Semivariogram of the best fit model to the OK geostatistic: (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Spherical; and (f) Field 2 - Model Spherical;
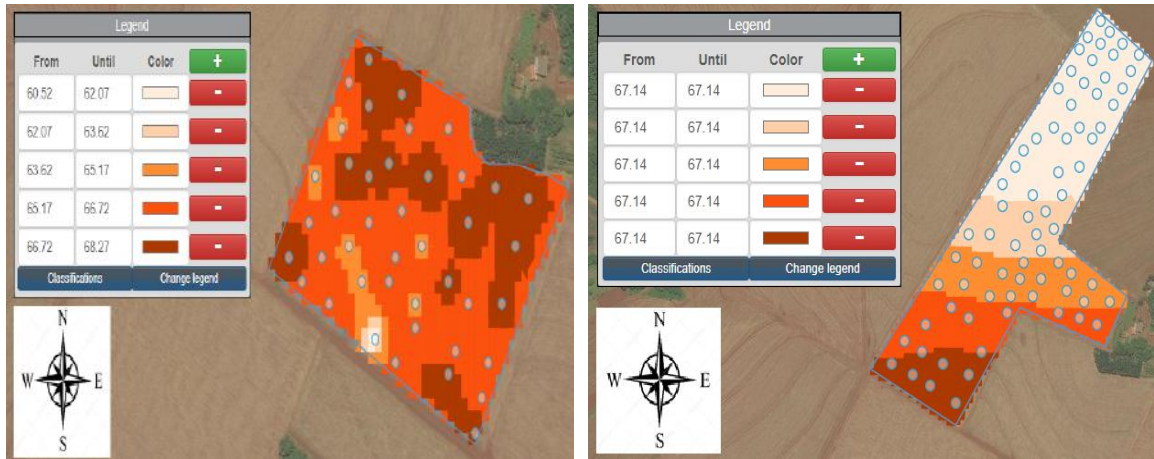
Source: Authorship.
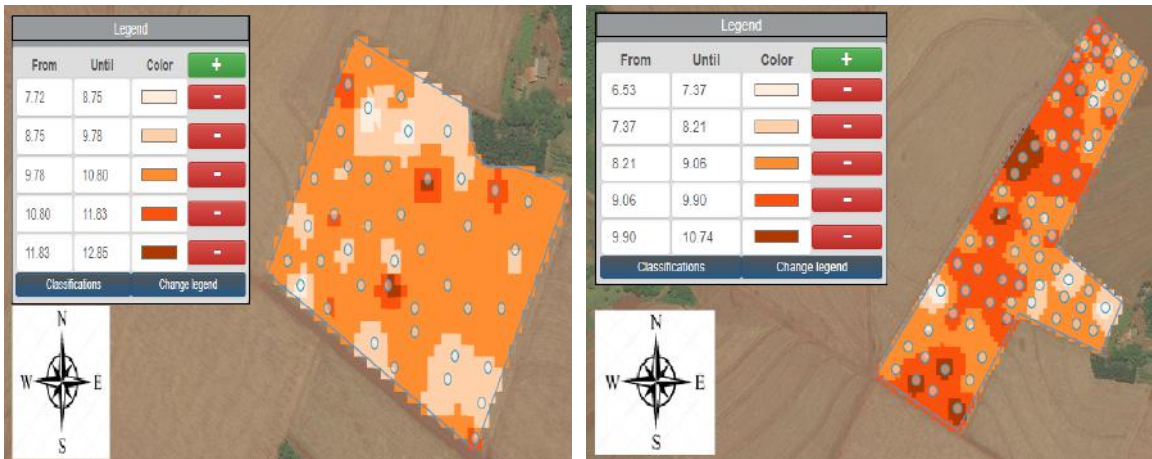
(a)

(b)
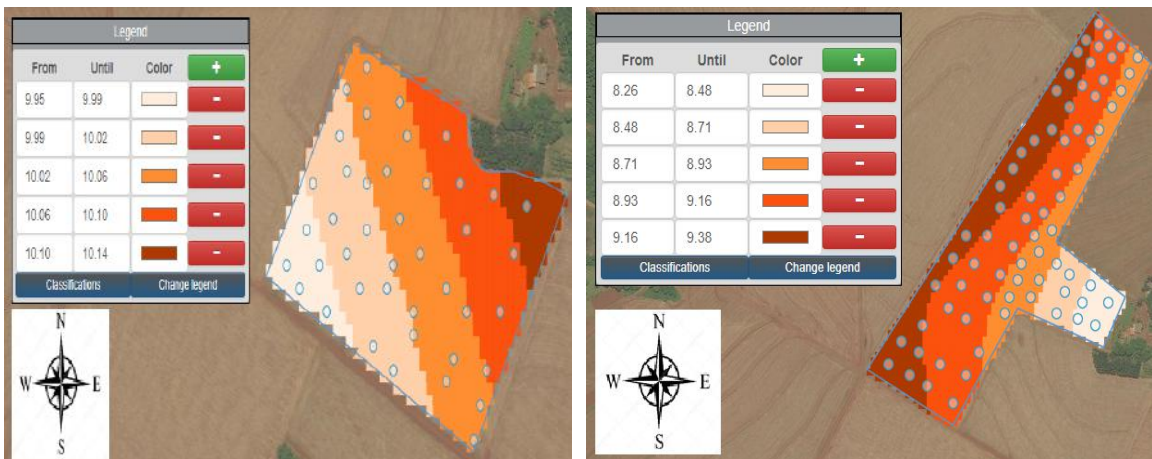
(c)
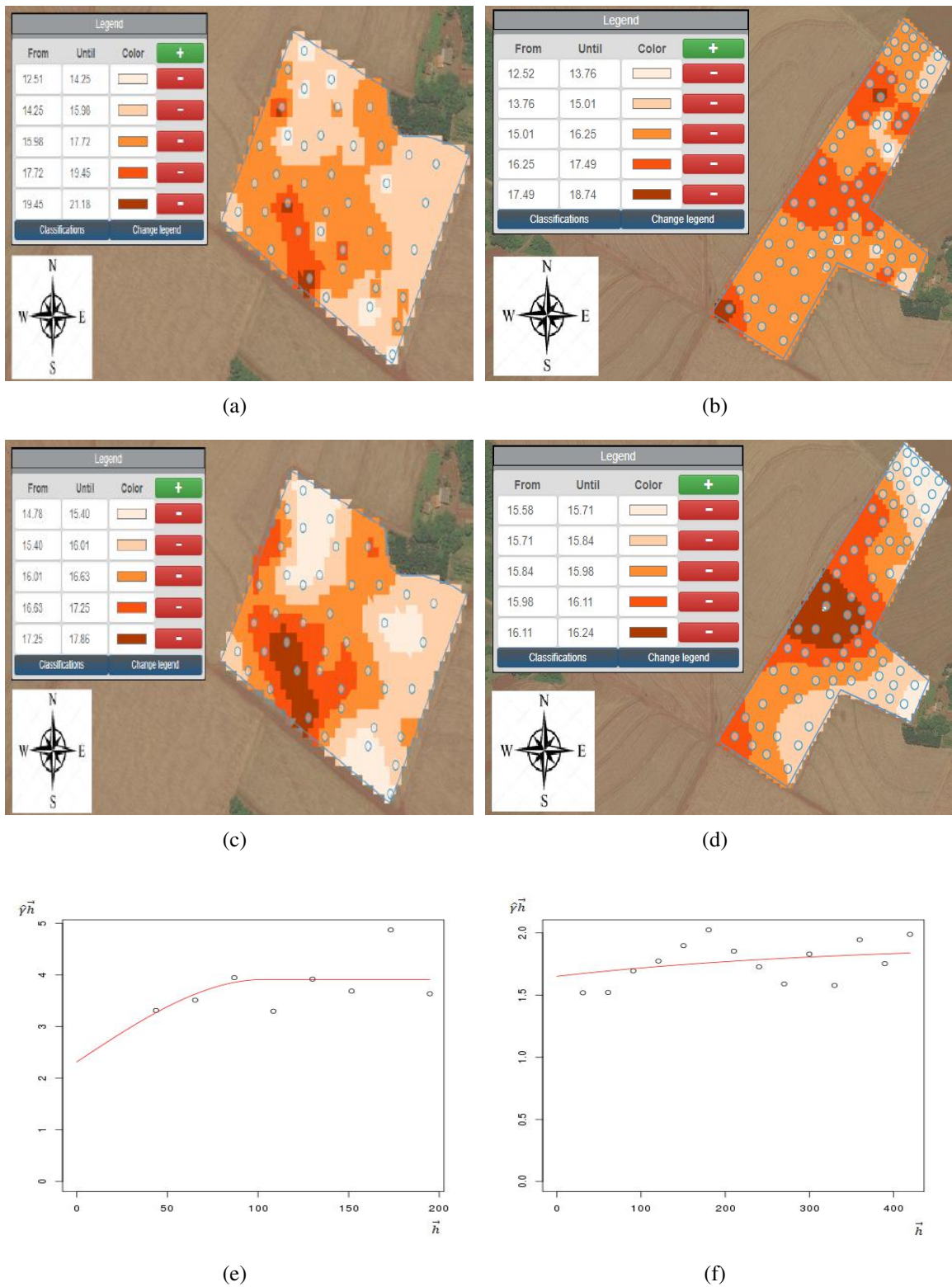
(d)
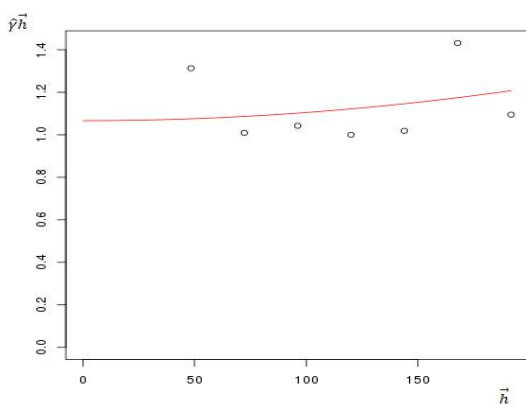
(e)
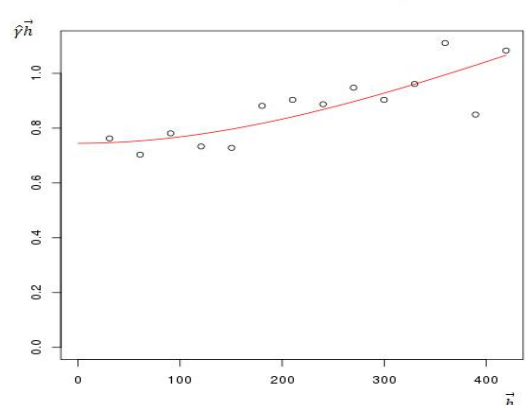
(f)

Figure 22 − Thematic maps of corn yield for 2016 in Mg ha^{-1} and Semivariogram of the best fit model to the OK geostatistic: (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Mattern; and (f) Field 2 - Model Mattern.

Source: Authorship.
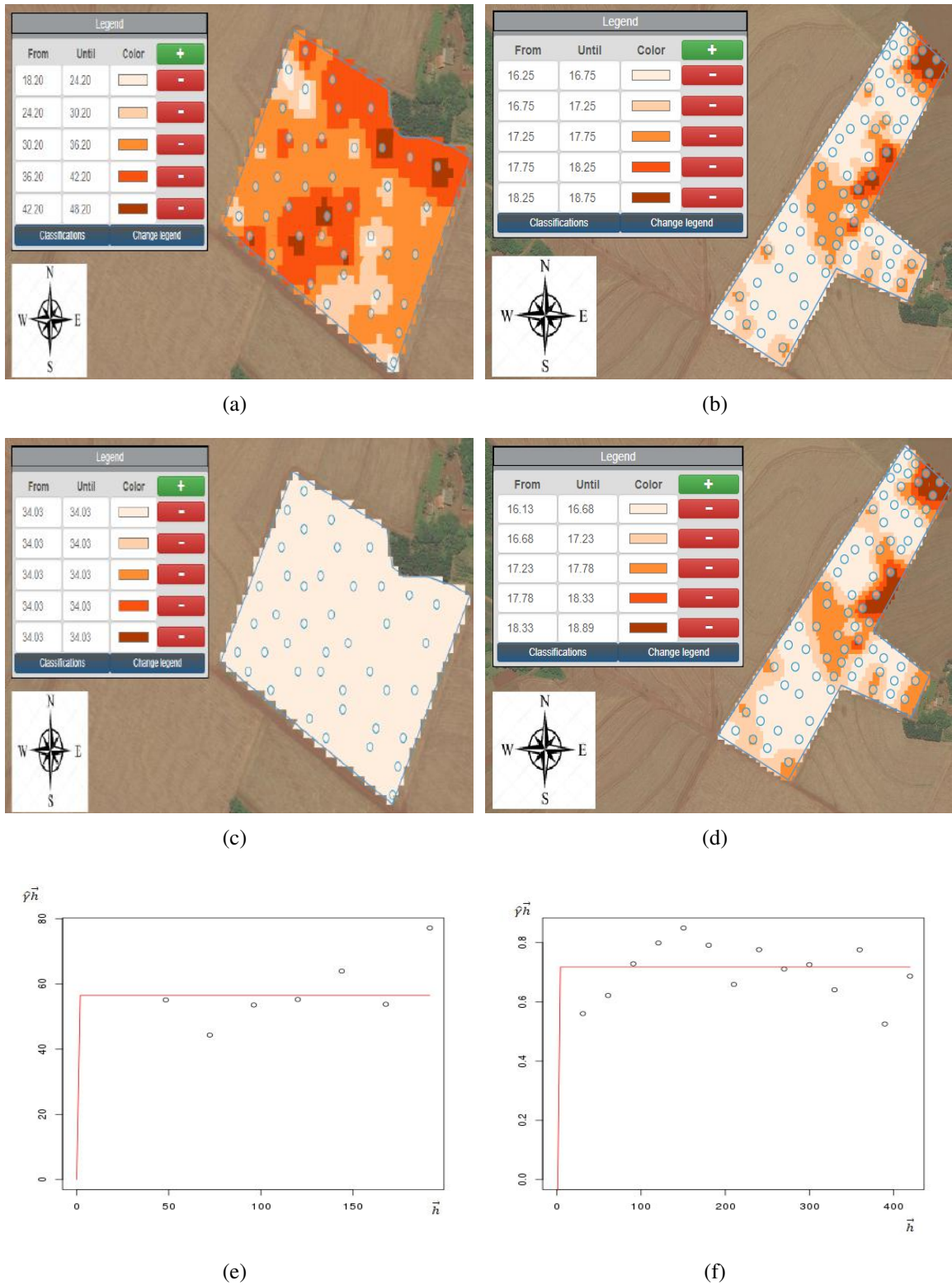
Figure 23 − Thematic maps of sand content in % and Semivariogram of the best fit model to the OK geostatistic: (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Field 1 - Model Gaussian; and (f) Field 2 - Field 1 - Model Exponential.

Source: Authorship.
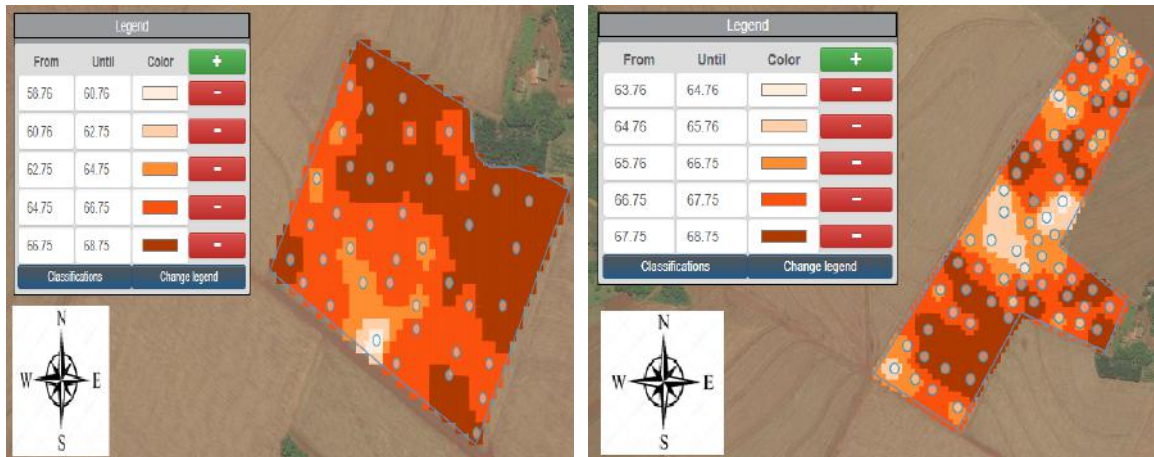
(a)

(b)

(c)

(d)
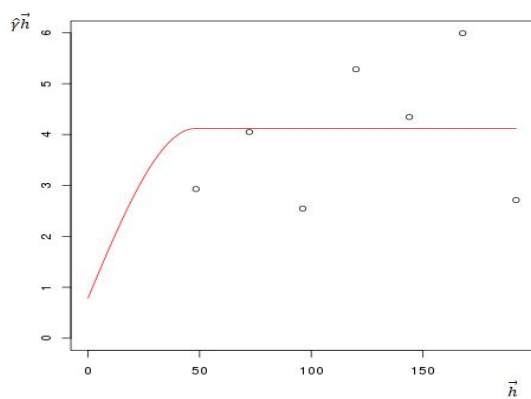
(e)
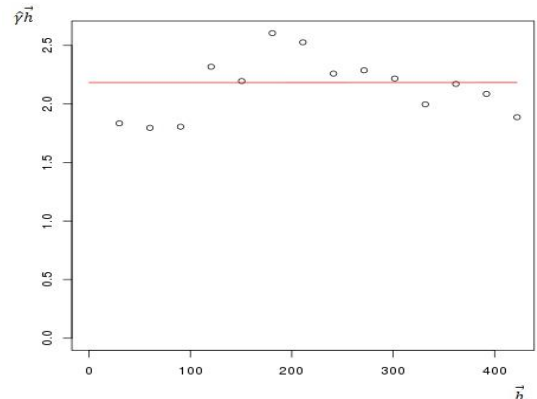
(f)

Figure 24 – Thematic maps of clay content in % and Semivariogram of the best fit model to the OK geostatistic: (a) Field 1 - Method IDW; (b) Field 2 - Method IDA;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Spherical; and (f) Field 2 - Model Spherical.

Source: Authorship.

Figure 25 − **Thematic maps of silt content in % and Semivariogram of the best fit model to the OK geostatistic: (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Spherical; and (f) Field 2 - Model Exponential.**

Source: Authorship.

Canarache (1990) suggests a classification to determine the critical level of SPR for soil root growth (Table 6). In field 1 almost 48% of the SPR data of 0-0.1m were within the average rank and the remaining 52% from low to very low SPR, while field 2 presented approximately 14% of field with low SPR, 80% of field in average SPR rating and approximately 7% of field in high SPR rating, Table 6.

The SRP thematic maps interpolated by OK in field 1 (Figure 26 (b)), presented only two classes (low and medium), increasing the original minimum values. The OK method also reduces the range of the original values of field 2, estimating all sample points within one class (the middle class, in which 80% of the original data were classified), without displaying the original minimum and maximum. The most similar representations with the original values were with the IDW interpolator for both fields (Figure 26 (a) - field 1 and (b) - field 2), where the original values remained at the interpolated values, and it can be seen that in field 1 the greater part was concentrated in the middle class and the smallest part in the very low level class. As in the map of field 2, most of the field was classified as average and the rest of the field, most classified as very low and the smallest part classified as high SPR.

Table 6 – Suggested limits for classes of classification of soil resistance to penetration

Classes	Limits (KPa)	Limits to root growth	Field 1	Field 2
Very Low	$<= 1000$	No limitations	2.38%	0.00%
Low	1001 - 2500	No limitations	50.00%	13.70%
Mean	2501 - 5000	Some limitations	47.62%	79.45%
High	5001 - 10000	Some limitations	0.00%	6.85%
Very High	10001 - 15000	Root growth is not possible	0.00%	0.00%
Extremely High	> 15001	Root growth is not possible	0.00%	0.00%

Source: Canarache (1990).

In the elevation maps of field 1 (Figure 27 (a) and (c)) there was no relationship between yield and elevation. Analyzing elevation maps of field 2 (Figure 27 (b) and (d)), the sites with lower altitudes are at the South end of the field 2 and the highest altitudes at the North end. Comparing the elevation maps (Figure 27) with soybean and corn yield maps (Figure 21 and 22), there is no relation like the higher altitude sites always have higher or lower productivities.

Lima et al. (2006) recommended that for the crops in fields 1 and 2 soil pH should be between 5.0 and 6.5, so that the plant obtains good-availability of nutrients.
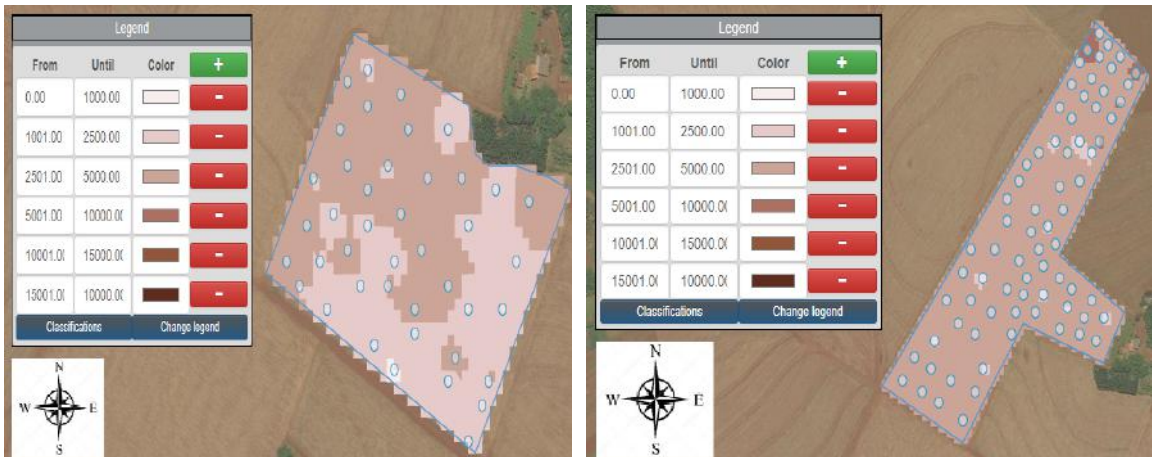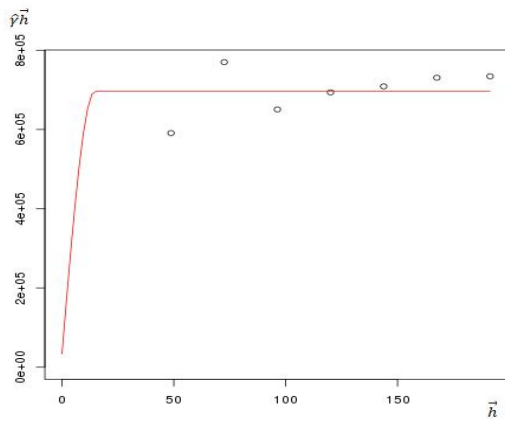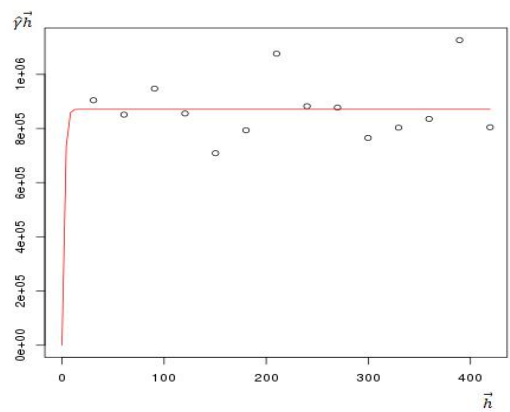
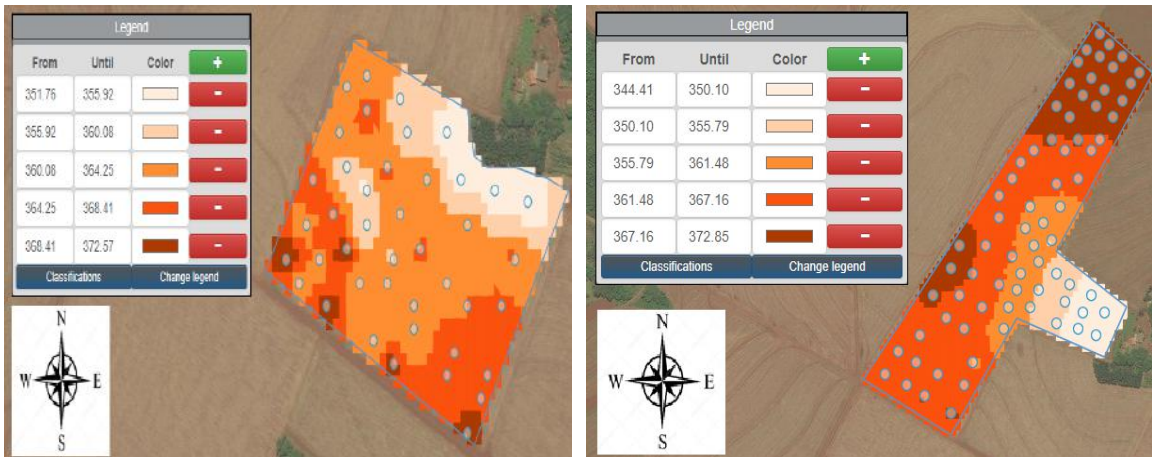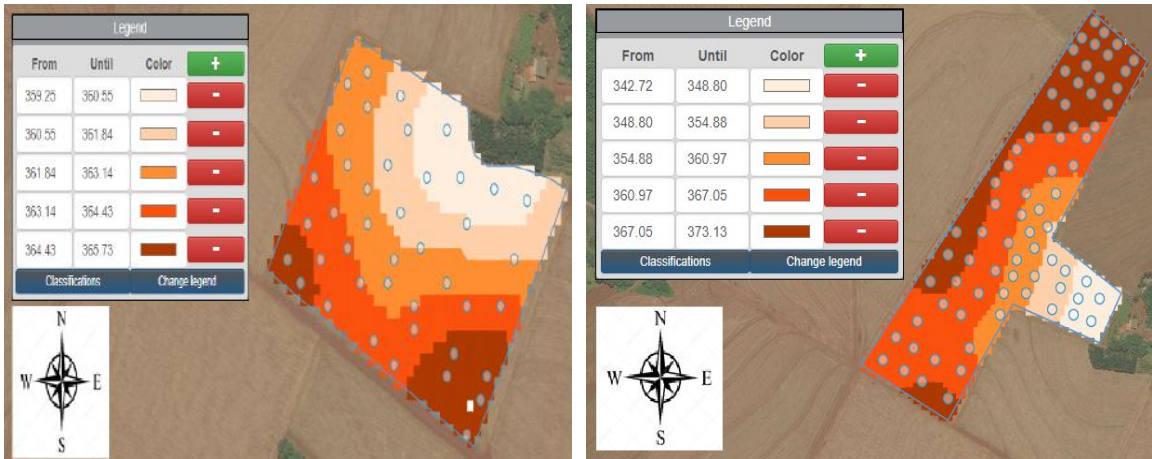**Figure 26 – Thematic maps generated with the classifier of SPR 0-0.1m (KPa) and Semivariogram of the best fit model to the OK geostatistic: (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Spherical; and (f) Field 2 - Model Mattern.**
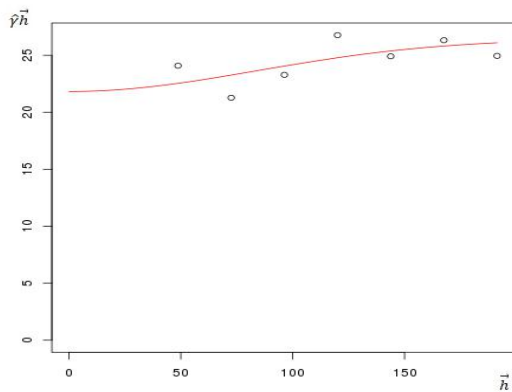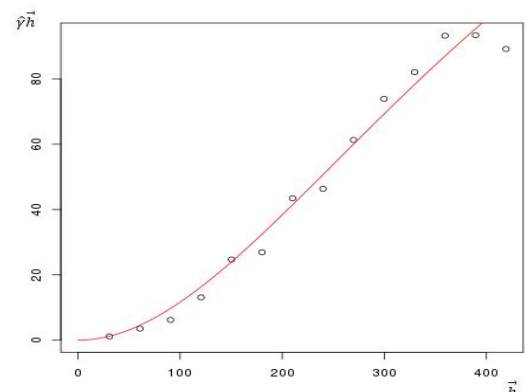
Source: Authorship.

Figure 27 – Thematic maps of elevation (m) and Semivariogram of the best fit model to the OK geostatistic: (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Gaussian; and (f) Field 2 - Model Mattern.

Source: Authorship.

Prezotti (2013) mentioned that soil OM is formed by the above ground and root residues of plants, and microorganisms. Raphael et al. (2016) stated that OM is an indicator of soil quality because it contributes to increased soil fertility and may be the main source of nitrogen in a crop, directly influencing productivity.

According to Inamasu et al. (2011), fields with higher contents of OM are usually located in the lower parts of the field, while the higher parts of the terrain have lower OM contents due to erosion issues.

The OM can be classified according to Costa and Oliveira (2001) and the pH according to Lima et al. (2006) (Table 7). Approximately 85% of field 1 is characterized by a soil with medium and high OM content in field 2 and all sample points collected were within the middle to high OM content. The OM semivariogram for field 1 shown in Figure 29 (c) a pure nugget effect, therefore it was not possible to do an interpolation by OK. The results of interpolation by IDW, Figure 29 (a), show places where field 1 has higher contents and lower OM content. In field 2, Figure 29 (b) and (d) show that all interpolation methods used show high OM content everywhere in the field and that the generated maps were very similar.

Table 7 − OM and pH classification in fields 1 and 2

Attribute		Classification				
		Very Low	Low	Mean	High	Very High
OM[1] (g dm^3)	Interval	< 14.0	14.0 - 25.0	25.0 - 35.0	35.0 - 60.0	> 60.0
	Field 1	0.00%	14.28%	42.86%	42.86%	0.00%
	Field 2	0.00%	0.00%	41.10%	58.90%	0.00%
pH[2] (CaCl$_2$)	Interval	< 5.0	5.0 - 5.4	5.4 - 5.8	5.8 - 6.2	> 6.2
	Field 1	40.48%	52.38%	7.14%	0.00%	0.00%
	Field 2	12.33%	42.47%	38.35%	6.85%	0.00%

Source: [1]Costa and Oliveira (2001) e [2]Lima et al. (2006).

Approximately 85% of field 1 is characterized by a soil with medium and high OM content and in field 2 and all sample points collected were within the middle to high OM content as shown in Table 7. By means of the thematic map of the Figure 29 (a) (map (c) can not be analyzed, because nugget effect occurred), the places where field 1 has higher and lower soil moisture content can be seen. The most of field 2 was classified with high OM content by both interpolation methods (Figures 29 (b) and (d)).

The pH in field 1 can be classified as very low (40%) which is outside the recommended range (between 5 to 6.5) for soybean and corn crop, according to Lima et al. (2006), while field 2 contained only 12% of the field classified as very low and 88% within the

range of low to medium soil pH (Table 7).

The OK method has maintained the classification intervals of the original values (Table 7) in the fied 1 estimated values (28 (c)), whereas the method IDW (28 (a)) only presented the very low and low range in field 1, changing 7% of the field that according to the sampling points, are classified as medium level of soil acidity.

In the field 2, he IDW interpolator presented values overestimated values with respect to the original data presented in four classifications (very low, low, medium and high, Figure 28 (b)). The OK interpolator, smoothed the minimum and maximum values of pH in the thematic map (Figure 28 (d)), showing only one class, with estimated data classified as medium level of soil pH (Table 7).
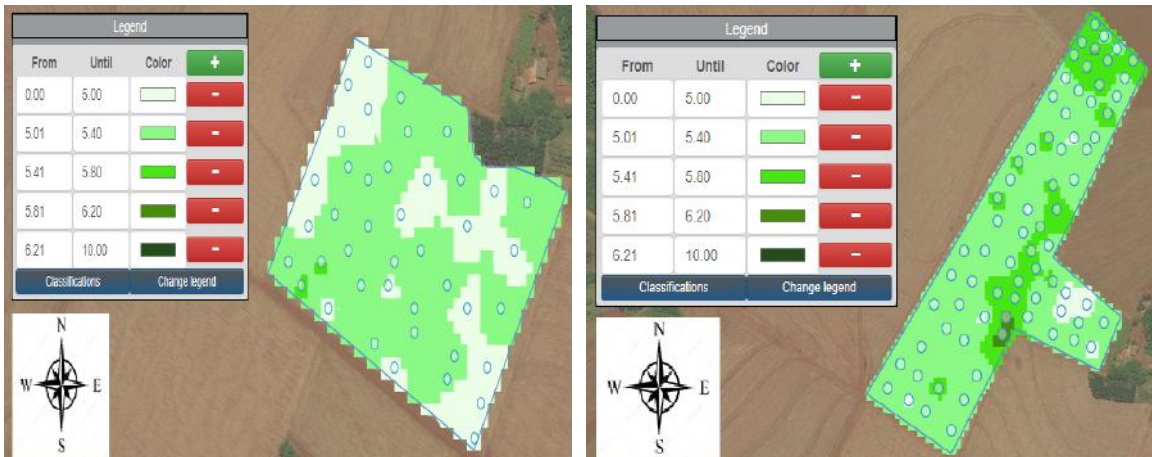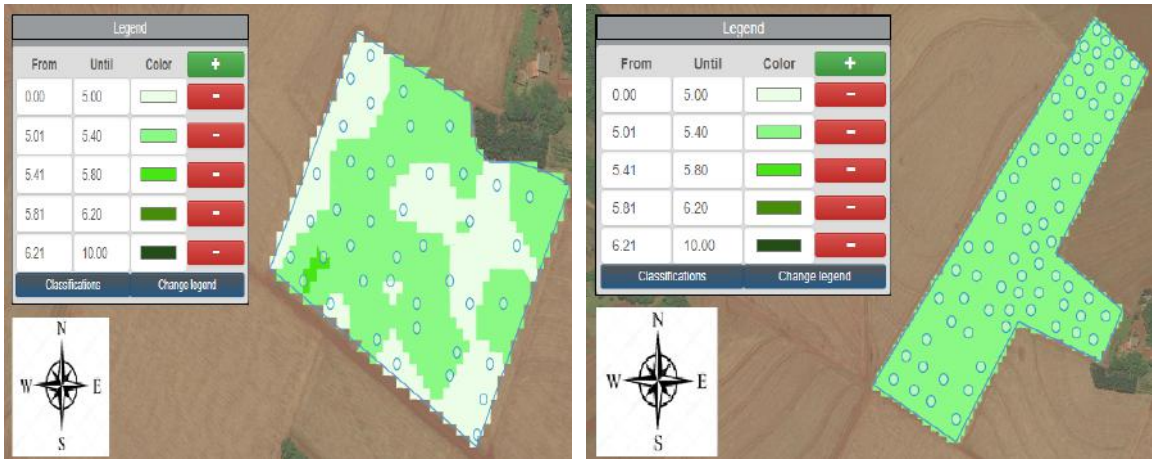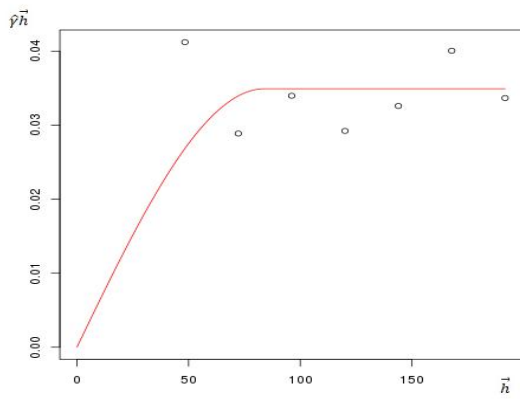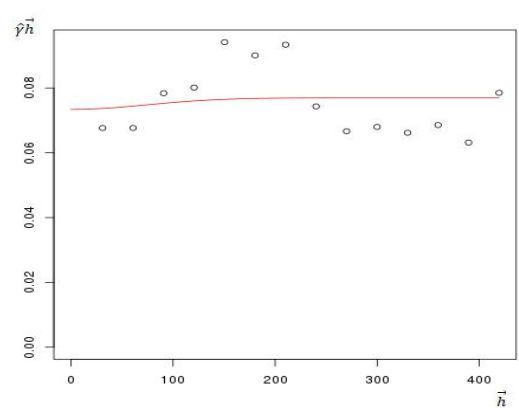
Figure 28 – Thematic maps generated with the pH classifier (CaCl$_2$): (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Spherical; and (f) Field 2 - Model Gaussian.
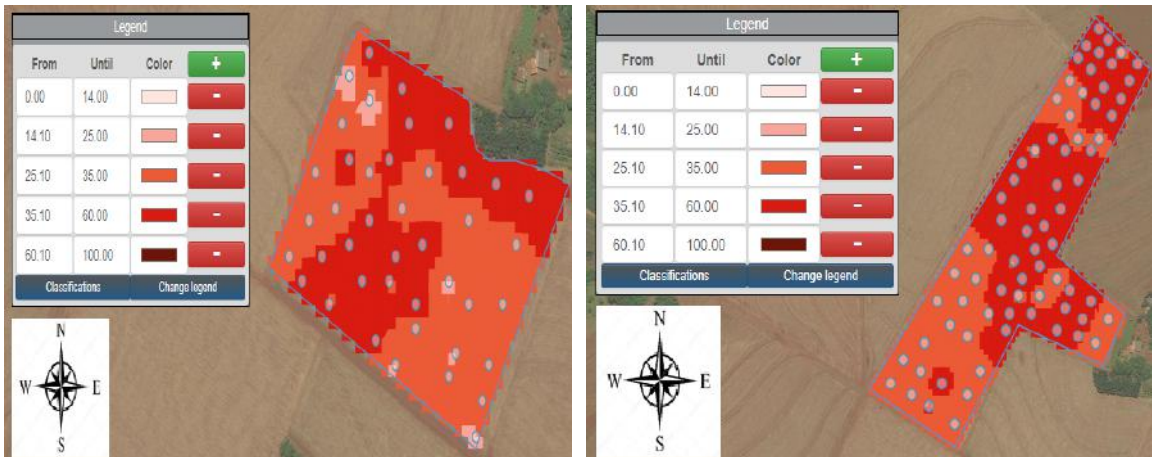
Source: Authorship.

(a)

(b)

(c)

(d)
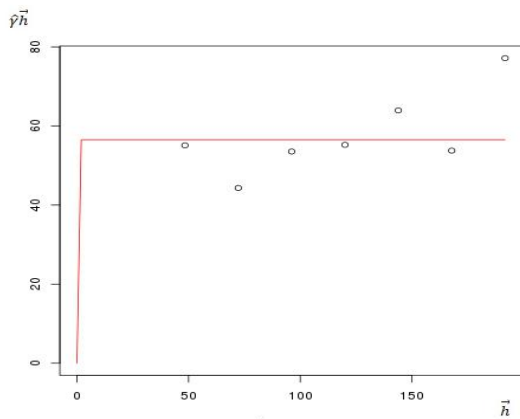
(e)
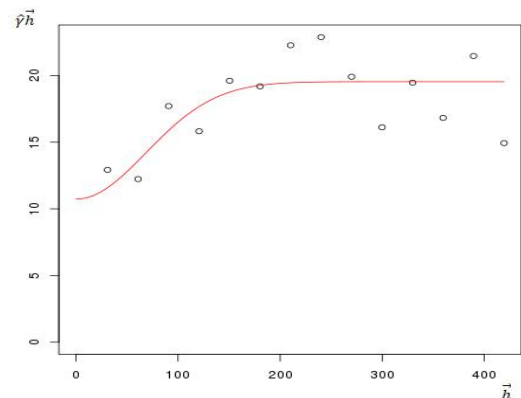
(f)

Figure 29 – Thematic maps generated with the OM classifier (g dm^{-3}): (a) Field 1 - Method IDW; (b) Field 2 - Method IDW;(c) Field 1 - Method OK; (d) Field 2 - Method OK; (e) Field 1 - Model Gaussian; and (f) Field 2 - Model Gaussian.

Source: Authorship.

4.3.3   Optimal Proximal Sensor Placement

To obtain locations for placement of leaf monitors the stable soil following stable attributes of field 3: sand, silt, clay, elevation and ECa at depths 0.3 and 0.9m were selected in the Web application. Moreover, the number of sensors was selected as 50 and an automatic grid with pixel X and pixel Y of 20 m (Figure 30) were used. Following Bazzi et al. (2018), 50 sample locations (Figure 31) were considered and a grid of 21 m X 20 m. The result obtained by the Web application for optimal placement of proximal sensors is presented in Figure 32.

Figure 30 − Register screen to obtain strategic positioning of sensors using attributes of texture, elevation and ECa of the soil.

Source: Authorship.

Comparing the locations used for stable data collection and the optimal locations recommended by this Web application (Figures 32 and 31), respectively, it can be seen that the strategic sites defined by the application form a grid with well positioned points distributed over the field, where there is a division of the points into 5 vertical rows, as well as the regular grid 20mx21m used by the producers. However, in the grid recommended by the Web application developed in this work, there are fewer sampling points in the upper part of field 3 compared to the regular grid used by the producer.

For the positioning of sensors, the 14 sensors were selected, since it is the number of sensors available for the researchers, and the grid used was a regular grid of 20 m X 20

m (BAZZI et al., 2018). To obtain the optimal locations for sensor placement, only the SWP attribute was used, Figure 33.

Figure 31 − Location of 50 sampling points for data collection leading to precision irrigation.

Source: Bazzi et al. (2018).

Figure 32 − Visualization screen of optimal locations for proximal sensor placement using stable soil attributes.
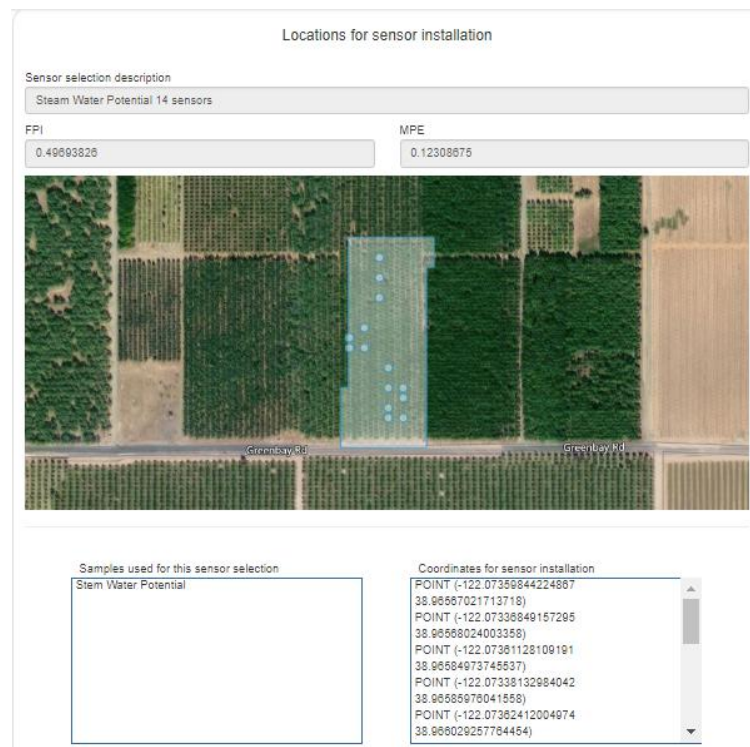
Source: Authorship.

Figure 33 – Registration screen for positioning sensors using SWP.

Source: Authorship.

The locations (trees) where the 14 sensors (leaf monitors) were installed in field 3 (yellow marker) to manage the irrigation process of the almond trees is presented in Figure 34. The leaf monitors were installed in two management zones, which were determined by the characteristics of digital elevation, surface electrical conductivity, soil texture, leaf temperature and canopy cover of the plant. Two types of different treatments for irrigation were applied in each management zone: management based on the plant water stress (Figure 34, rows in red and irrigation entirely managed by the Figure 34, rows in blue) (KIZER et al., 2017).

Repeaters (blue marker in Figure 34) were used to extend the signal distance so that the sensors can send the information through the wireless network to the gateway (red marker in Figure 34) in the data storage center.

Fewer sensors can be used in the upper part of field 3 by the aplication Web sensor positioning (Figure 33) in relation to the grid used by the researchers (Figure 34) to obtain SWP data from the plant. Since many sites were close, the optimal placement of sensors in field 3 was performed with a smaller number of sensors (10 sensors, Figure 35), to verify if a smaller number could represent part of the locations that were close in Figure 33 for irrigation management.

The sensor placement locations obtained in the Web application using SWP resulted in 10 sensors being distributed over the field (Figure 35), but it is necessary to analyze the

other attributes of the soil to determine the optimal locations, since other attributes of the soil and plant can change the availability of water to the plant, as mentioned by Dalchiavon et al. (2011).
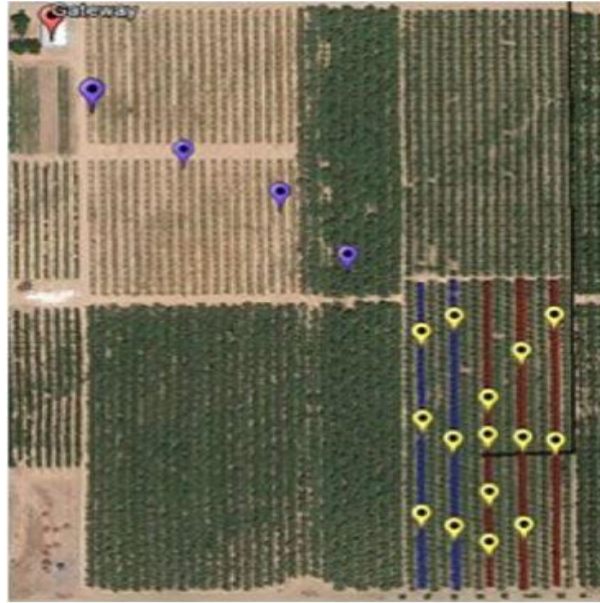

Figure 34 – Locations where the sensors (yellow marker) and repeaters (blue marker) and gateway (red marker) were installed in field 3. Blue rows indicate the water management performed by the producer and red rows indicate management based on the plant water status.

Source: Kizer et al. (2017).

Figure 35 – Locations determined for sensor installation using 10 sensors and SWP sample.

Source: Authorship.

5 CONCLUSIONS

This work provided a free computational tool, easy to access, without the need to be installed on a PC for any interested person in practice the PA management. Through the tool, the user register projects, agricultural areas, sample grids, samples, thematic maps and obtain strategic locations to collect soil and plant data, and also to export this data to txt file.

With this Web application, it is possible to maintain control of the data collected from the farm, the user just needs to login and access the application by the Uniform Resource Locator (URL) in a browser using an electronic device connected to the Internet.

In addition to storing property information, the user can perform soil and plant analysis and interpretations of thematic maps, making decision making simpler and more objective to apply PA techniques.

The Web application provided the creation of thematic maps through the MA, IDW and OK interpolation methods. In addition, the developed tool made it easier to generate OK maps more reliably because the user does not need to choose a model for the semivariogram since the geostatistical procedures are computed and compared in the Web application, and it returns to the user the map interpolated by the best semivariogram model suitable for the data.

The Web application and its integration with the central data server through the AgDataBox API allowed the storage, management and synchronization of information in an organized way, leaving it optional for the user to register, edit and delete areas, samples and sample grids only in the application or in API.

The use of the OpenLayers library was essential to provide the geographic data functionality of the Web application, as it is an efficient tool and can be used for free to do the integration of online mapping services.

The computational tool developed became an alternative to the use of the SDUM software, since it allows to register information of the agricultural property and to generate thematic maps, not only by the method MA and IDW, but also by the OK method, besides providing the new functionality in the software SDUM to obtain optimal location for installation of proximal sensors for data collection.

Therefore, with web application developed in this work, the user can apply PA techniques that contribute to sustainable development and help reduce production costs, increase the productive potential of the growing areas, and consequently increase profitability of producers and reduce environmental impacts.

5.1   FUTURE WORKS

Implementation of a module for generating management zones should be included in the Web application developed in this work, as it is already implemented in the SDUM desktop software. New interpolation methods, other manners to export areas, samples, sample grids and thematic maps can also be implemented, for example creating shapefile format files besides text files.

Updates and improvements are needed to the computational tools. As modifications and updates to the Web application over time will be unavoidable. It is also suggested to conduct satisfaction surveys with the users of the Web application developed in this work and with people who practice the PA to understand their needs and requirements, in order to make this tool better and more suited for PA management.

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APPENDIX A – WEB APPLICATION HANDBOOK

A.1   DO LOGIN

The home page of the Web application has a form for login (Figure 36), where the user will put his phone and password used to do the registration. If the user does not have a registration, it can be done by clicking on the "New user" and filling the field name, phone number, e-mail and password (Figure 37).
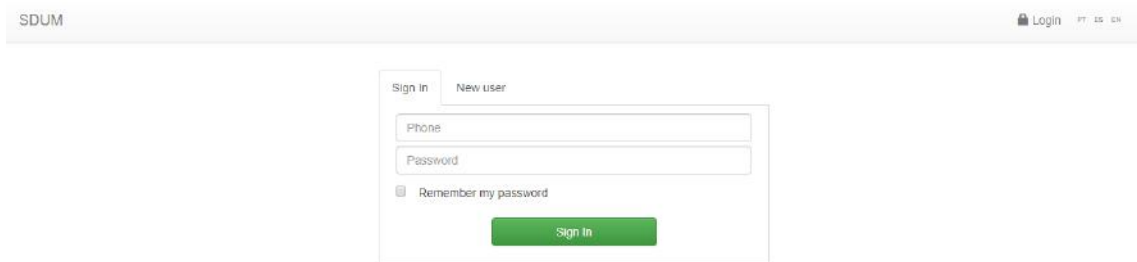
Figure 36 – Login page.
Source: Authorship.
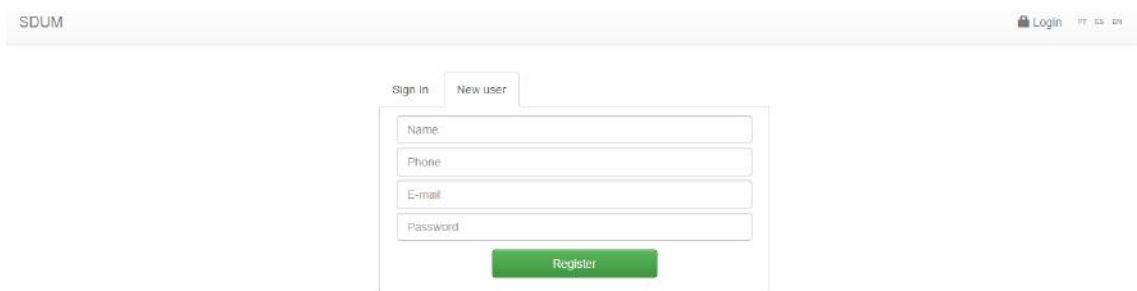
Figure 37 – Registration page.
Source: Authorship.

A.2   REGISTER PROJECT

The application was structured considering the project management in an independent way, since for each registered project, areas that can be registered are: samples, sample grids, strategic location for sensor installation/data collection and thematic maps.

After logging in, the project listing screen (Figure 38) appears for the user to register a new project or open a project already registered in order to use the Web application functions.
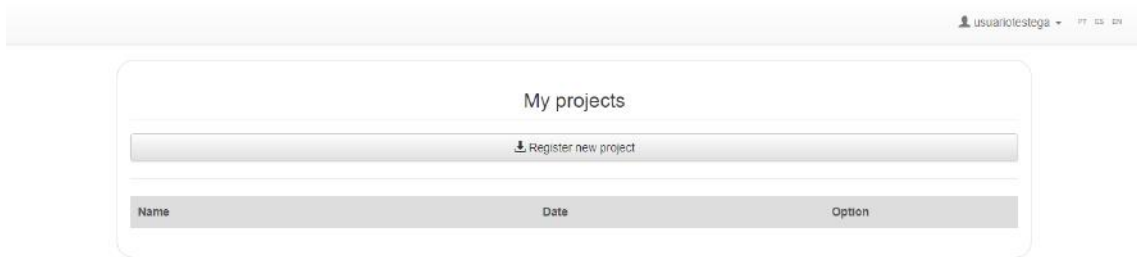
Figure 38 ‒ Project listing page.

Source: Authorship.

To register a new project, simply enter a name and the description of it (Figure 39). After registering a new project, the user is redirected to the project listing (Figure 40).
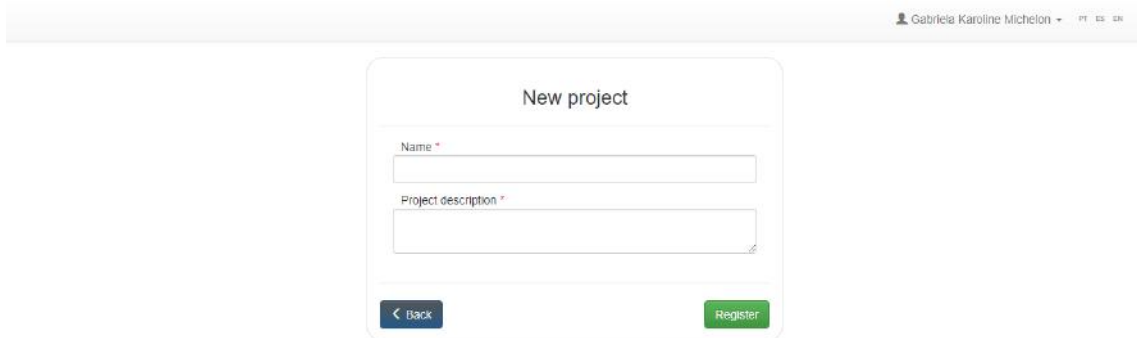
Figure 39 ‒ Project registration page.

Source: Authorship.

Clicking on "Open Project " (Figure 40) opens a new screen with the world map (Figure 41) and a window to display the project, their respective areas, sample grids, samples and thematic maps.
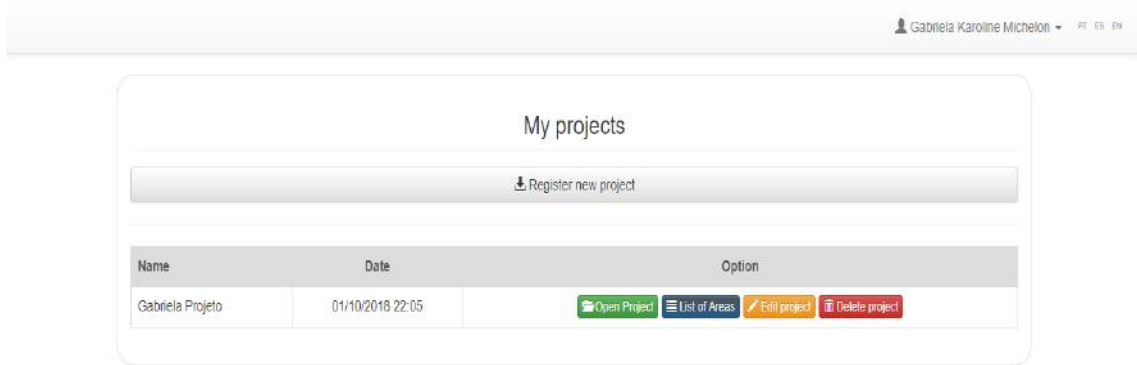
Figure 40 – Project listing page after registration of a project.

Source: Authorship.
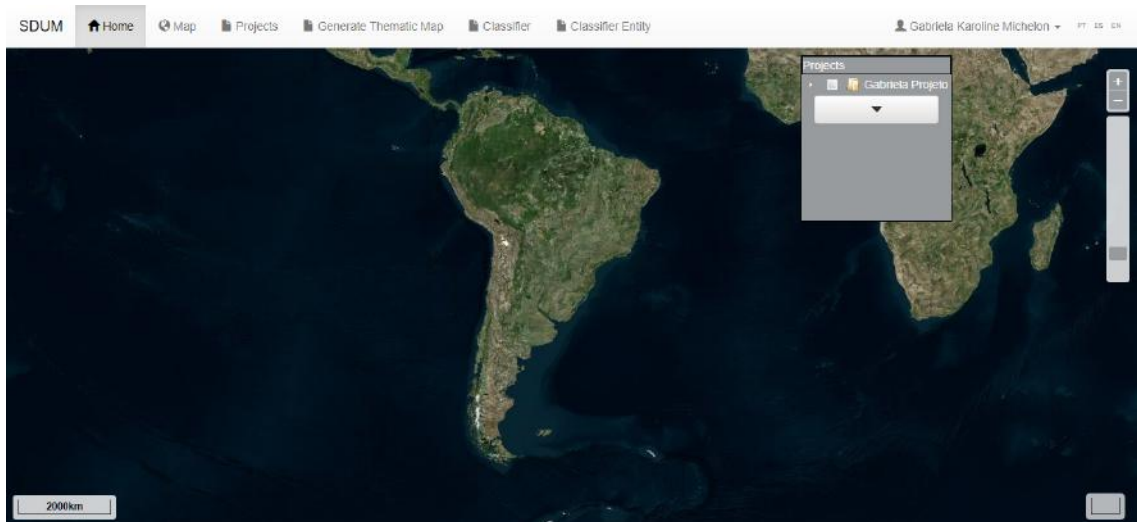
Figure 41 – Map page after opening a project.

Source: Authorship.

A.3   REGISTRATION OF FIELD

To register areas, the user can open the project listing, where he/she can open the listing area and screen to the area registration. To open the project listing again, just click the menu button on the top menu of the map: "Projects".

The user can choose to register a new area from the import of areas already registered in the central data server of the AgDataBox - API, or by means of uploading a file in text format, or, if user prefers, by manual drawing on the map (Figure 42). Areas that are registered and/or edited only in the application, can be synchronized with the server through at button to the right of the area listing screen.

Before registering an area, the user must have registered some type of soil (for more details see the Soil Type section of this chapter) to select in the field "type of soil" in the area

registration form. In area registration form there is also a checkbox ("Save area in the API") which when selected allows to save the area on the central data server (Figure 43).
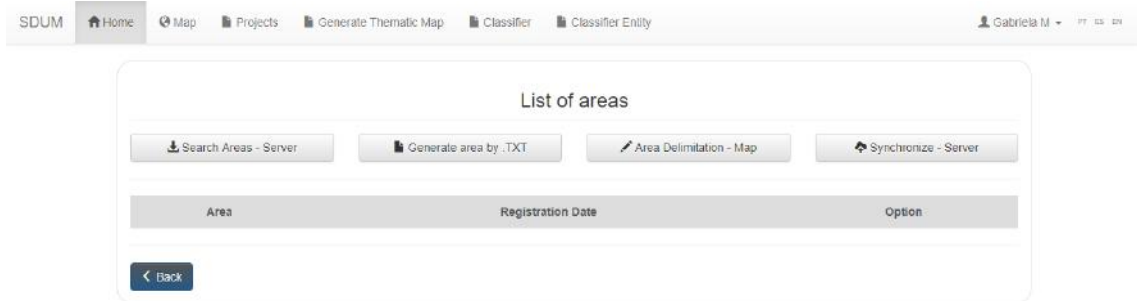
Figure 42 – Areas listing page.

Source: Authorship.
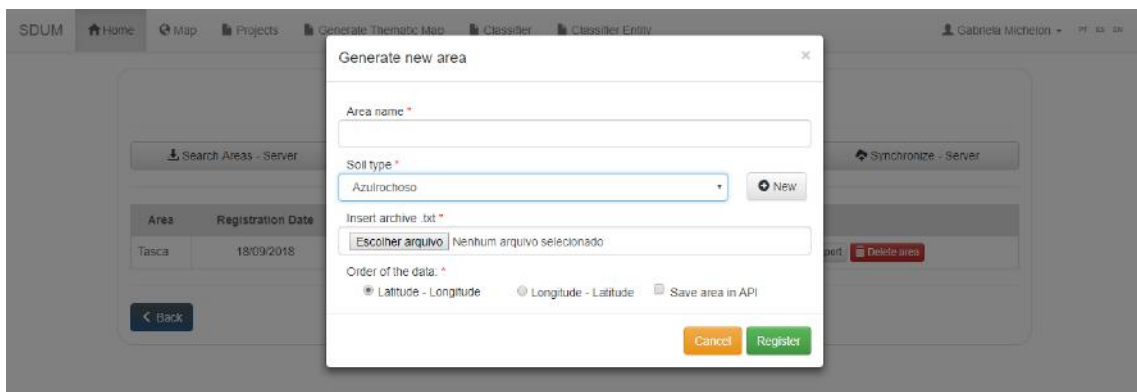
Figure 43 – Form page to register an area from a text file.

Source: Authorship.

The text file should contain the geographical coordinates of the area in decimal degrees, the first row of the file must be the name of the columns (longitude and latitude), these columns being separated by tab space. The decimal values of the geographical coordinates must be number with dot-decimal separator (Figure 44).

If the user chooses to draw the area manually, the screen shown in Figure 45 will appear. The user can zoom the map with the mouse scroll until the desired area is found. After locating the area, to draw it, the user need to click with the left mouse button on the location of the map where the user desires to contour the area and move the mouse in the desired direction. When it is necessary to change the direction of the line it is necessary to give a new click to save that part of the drawing, this procedure must be repeated until a closed polygon is formed. After drawing the area on the map, the user must fill in the fields and save.

```
LONGITUDE          LATITUDE
-54.003644214    -25.406813811
-54.003644871    -25.406815517
-54.003642762    -25.406821901
-54.003637508    -25.406843061
-54.003634822    -25.406853051
-54.003632679    -25.406864985
-54.003631301    -25.406877835
-54.003629429    -25.406891312
-54.003633303    -25.406892014
-54.003629667    -25.406904978
-54.003627832    -25.406918327
-54.003626251    -25.406929894
```

Figure 44 ‒ Application-compatible text file format.

Source: Authorship.
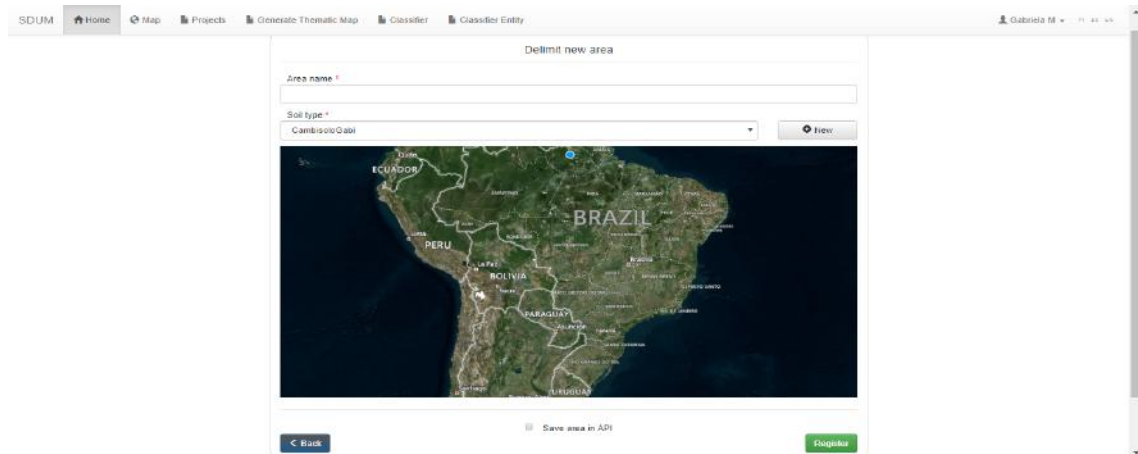
Figure 45 ‒ Form page to register an area delimiting manually on the map.

Source: Authorship.

After registering the areas, the user can synchronize them with the central data server (46). The areas synchronized with the central data server can also be viewed by clicking the "Browse Areas - Server " (Figure 47).

If the user desires to export the area, it can be done by clicking on the button "Export" at the side of the other buttons sensor selection, samples and sample grids. The exportation done is in a text file format. If the user wants to exclude the area, there is a button "Delete" in the listing area page. If the area desired to exclude is stored in API, the user can choose to delete the area just at the application Web, or at the API. To delete the area in the API, the user needs to check the option "Delete in API" (Figure 48).
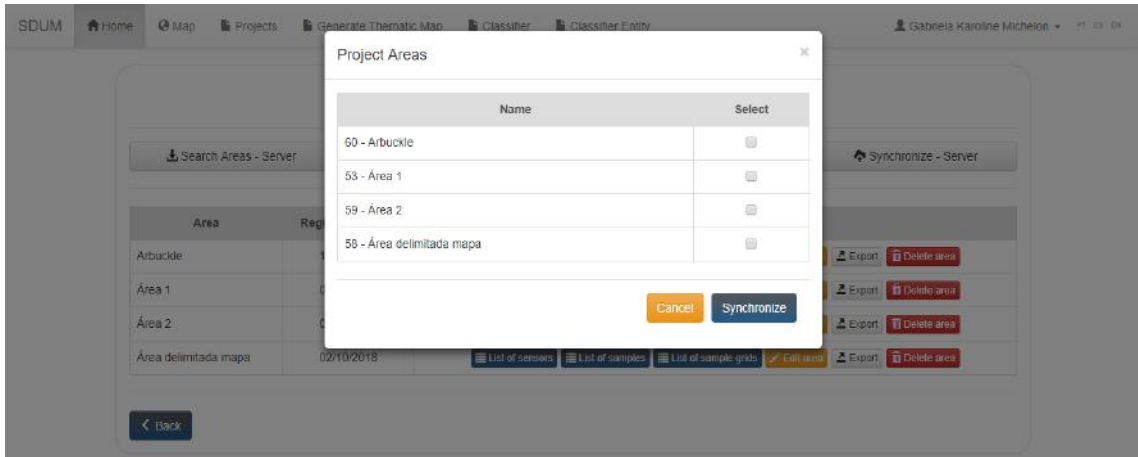
Figure 46 ─ Screen to synchronize saved areas in the application with the central data server.
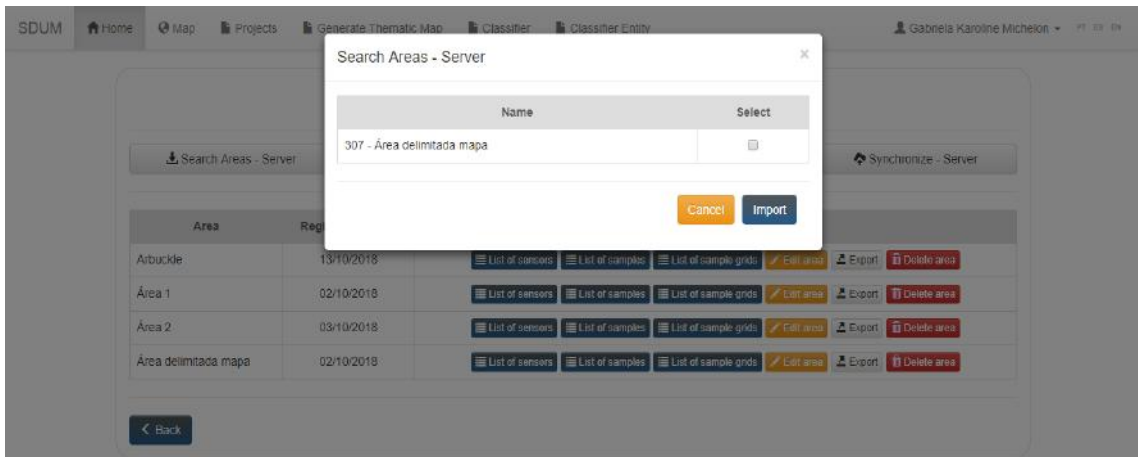
Source: Authorship.

Figure 47 ─ Screen to search for saved areas on the central data server.
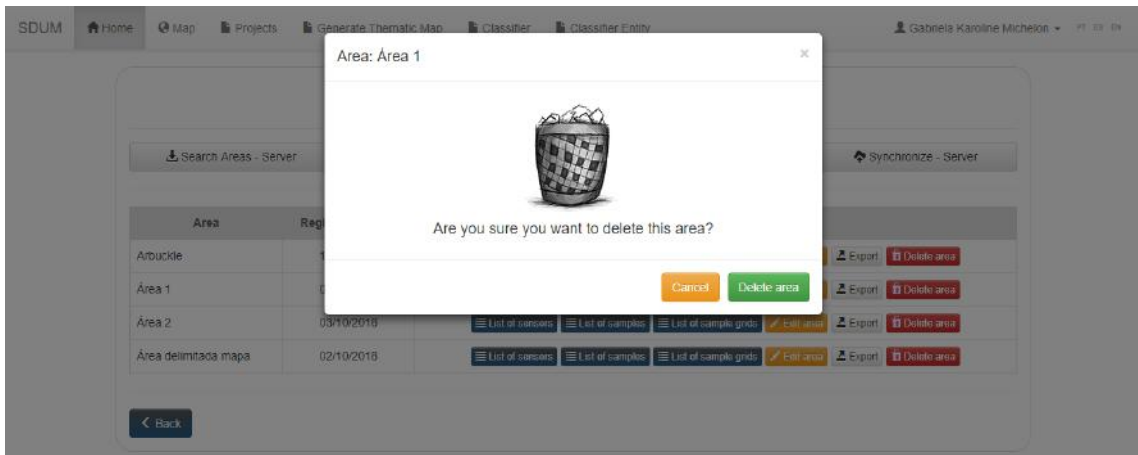
Source: Authorship.

Figure 48 ─ Screen to delete area.

Source: Authorship.

A.4 REGISTRATION OF SOIL TYPE

To register a new area (Figure 49), it is necessary to register a soil type if the user still does not have registered any soil type in the central data server or in the application. To register a new soil type, it is necessary to click the button "New" at side of the soil type selection field (all soil types registered by the user on the central data server will be available in the application, as well as the types of soils that are registered in the application will be automatically stored in the central data server, AgDataBox - API).
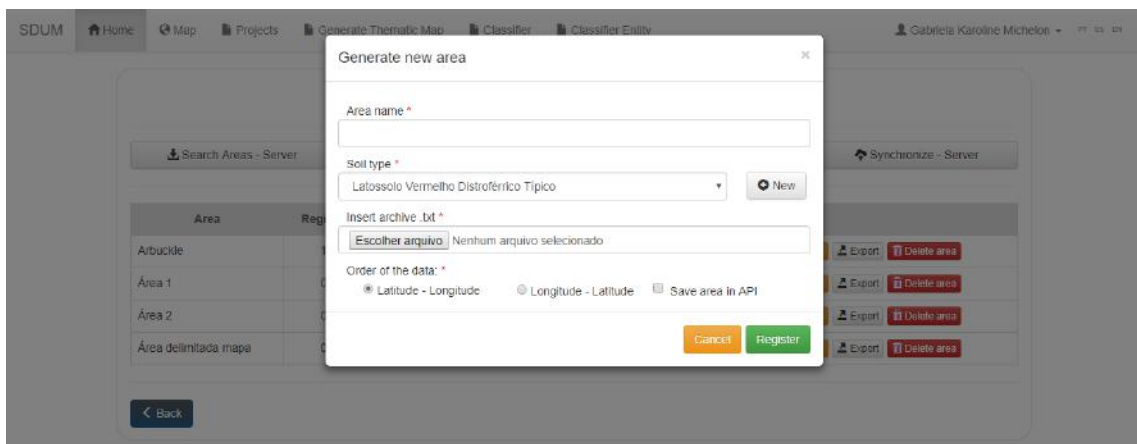
Figure 49 – Area registration age by text file.

Source: Authorship.

The soil type registration screen has only one field for the description/name of it (Figure 50). After the soil type registration, the application redirectes to the list of soil types and the user receives the success message if the registration has been successfully registered (Figure 51). All the listings screens have a button for editing and another for the exclusion of the items registered.
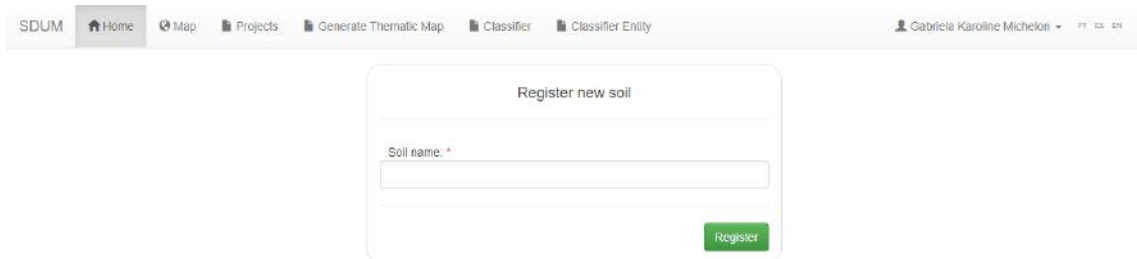
Figure 50 – Soil Type registration page.
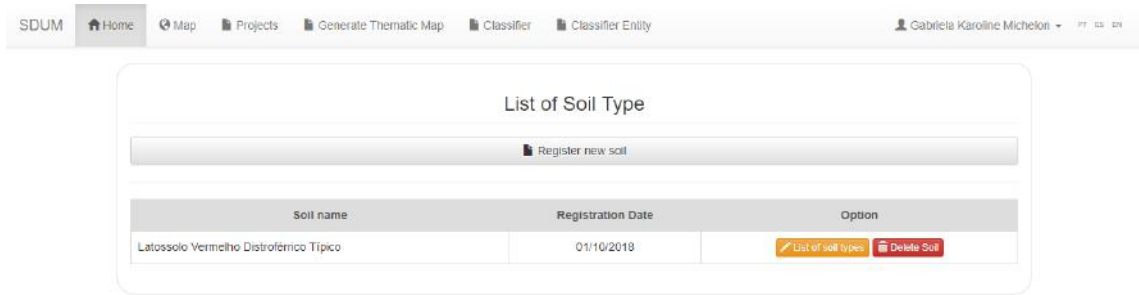
Source: Authorship.

Figure 51 ─ Soil Type listing page.

Source: Authorship.

A.5 REGISTRATION OF SAMPLE

To register a sample, the user must click on the "Sample List" in the area listing screen for the area that he/she wants to register the sample in. Then he will be redirected to the sample listing screen where the user can choose the option sample register from the button "Register new sample" (Figure 52).
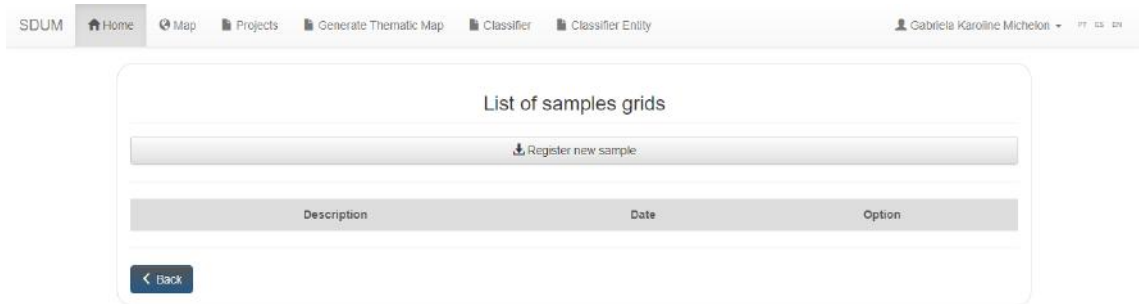
Figure 52 ─ Sample listing screen.

Source: Authorship.

Before registering a sample (Figure 53), the user must have registered attributes. To register a new attribute just click the button "New" next to the selection field for attribute type. On the attribute register screen (Figure 54 has the unit of measure selection field, which can also be registered by means of the button "New" next to the selection field for measure unit (Figure 55).
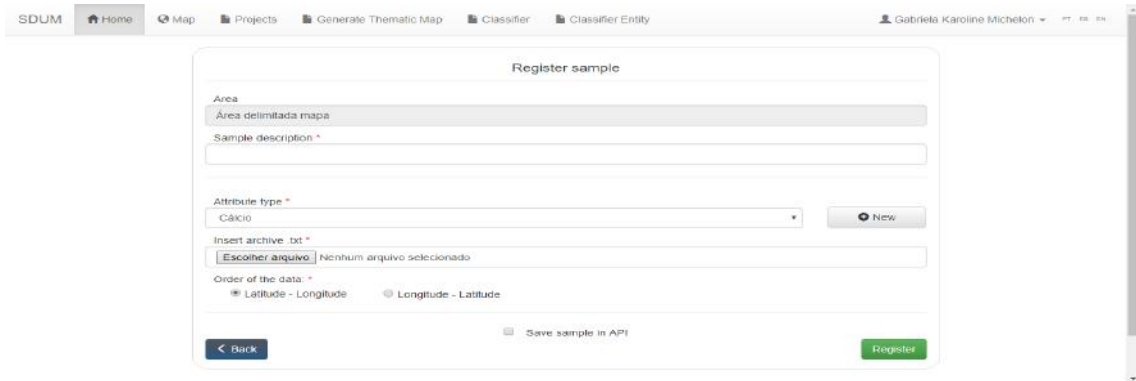
Figure 53 – Sample registration screen.

Source: Authorship.
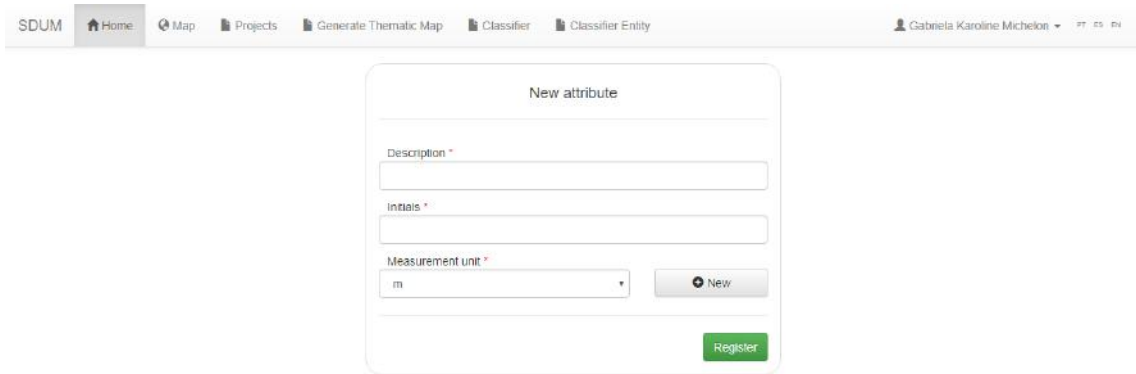
Figure 54 – Attribute register screen.

Source: Authorship.
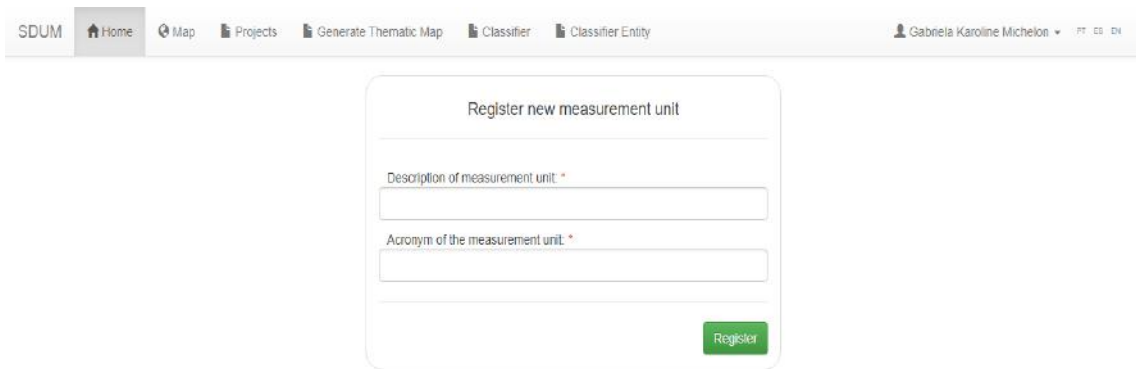
Figure 55 – Measure Unit register screen.

Source: Authorship.

The sample listing enables the user to edit, export the sample to text file, delete or synchronize the sample with API, the user just need to click at the corresponding button (Figure 56). In the form to edit a sample (Figure 57), the user can change the value of sample points, sample description and attribute type. If the user wants to change the value of a sample point,

he must have to click on the point and enter the new value in the field "Sample value", after that he/she must click on the "Update sample" button and then on "Save".
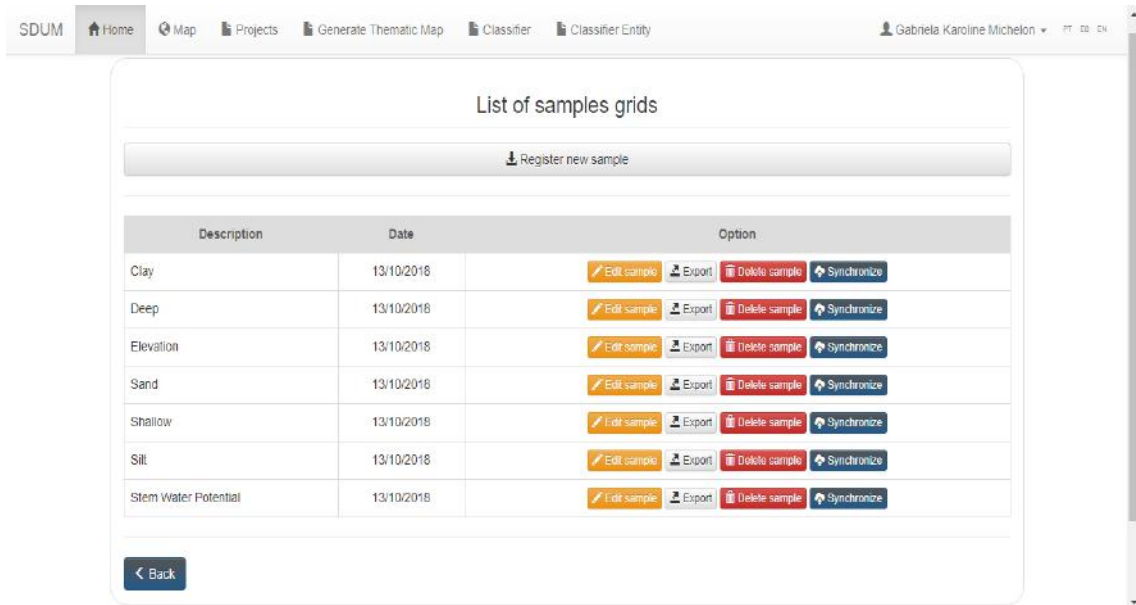
Figure 56 ─ Sample listing screen.
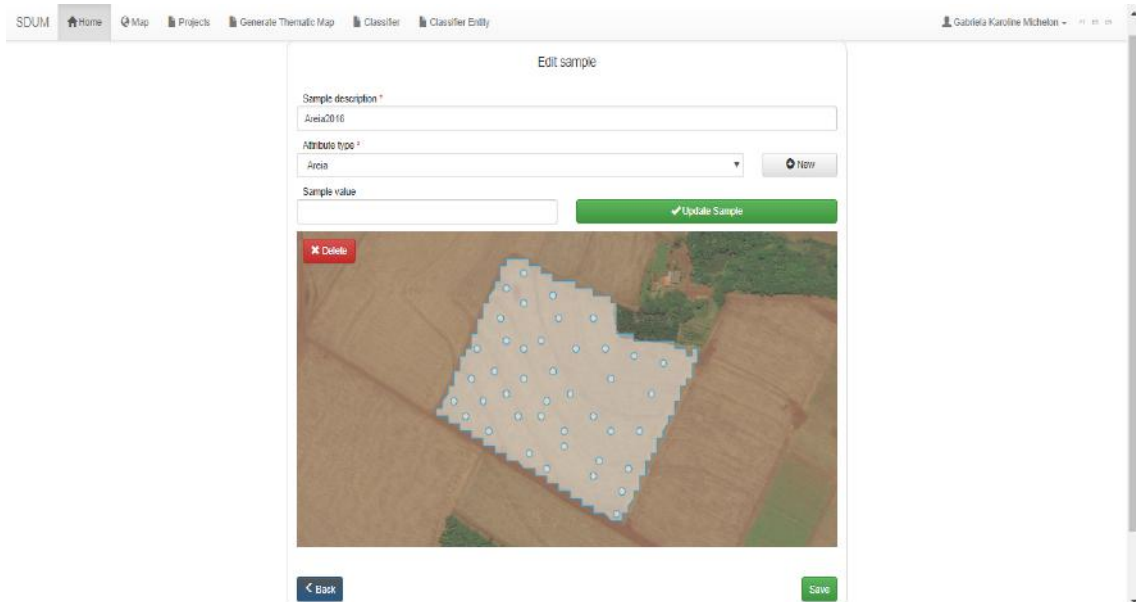
Source: Authorship.

Figure 57 ─ Sample edit form screen.

Source: Authorship.

A.6 REGISTRATION OF SAMPLE GRID

The sample grid registration can be made by means of a fixed grid size, given in pixels (where one pixel corresponds to one square meter), or by means of a text file (Figure 58).

In the sample grid record by text file, the user must be aware in the order in which the coordinates are in the file and select the corresponding order of the data in the form (Figure 59). In the case of taking the grid sample by means of a fixed grid, just inform the size of the pixel X and Y (Figure 60).

Figure 58 – Sample Grid register screen.

Source: Authorship.

Figure 59 – Sample Grid register screen by text file.

Source: Authorship.

Figure 60 ─ Sample Grid register screen by pixel size.

Source: Authorship.

In the figure 61, the sample grid list screen is displayed. The user can edit, export to text file, delete, synchronize with the API the sample grid and the sample too. In the sample grid list, there is one more option in relation to the sample listing screen, where it is possible to register a sample from the points of the respective sample grid chosen. If the user chooses to register a sample from the sample grid, the application will redirect to the sample register screen from the selected sample grid (Figure 62) and after registering, the user is redirected to the sample grid screen where he/she can edit it, updating values of sample points that are initially registered with zero value.

Figure 61 ─ Sample Grid listing screen.

Source: Authorship.

Figure 62 – Sample register screen from a Sample Grid.

Source: Authorship.

A.7 REGISTRATION OF SENSOR LOCATION POSITIONING

To register strategic locations for data collection, the user must click on the option "List of sensors" in the list of areas and then, in the list of sensors, must click on the button "Register new sensor selection" (Figure 63).

In the sensor position register screen (Figure 64), there is the "Sensor Description field" where the user can enter a description for the type of sensor or data desired to get the sensor positioning. The "Description sensors place" is a field to enter the description for the resulting sample grid used to sensor positioning. The field for number of sensors is the number of points that the user wishes to obtain for data collection. Below the map, there are two frames, where the first, determines the type of grid that will be used for the positioning of sensors. In this frame the user can choose the option "Sample grid from selected points", where the grid is a grid chosen by the user, each point being determined manually, or can choose the option "Automatic grid", which will be automatically generated by half of a regular grid obtained by the information of the size of the X and Y pixel. The second table has the samples registered for the respective area, the user can choose the samples that he wants to use together to obtain a strategic location for collecting determined samples data.

After filling in the necessary information to generate the sensor positioning, the user should click on the right button "Register." From the registration, the application directs the user to the sensor list screen (Figure 65. In the sensor list screen, the user can click on the button "View ", where he/she can see the value obtained from the FPI and MPE index and the points for sensor location or data collection (Figure 66). The user can export or delete the points of the chosen location to place sensors by clicking on the button "Export" or "Delete".
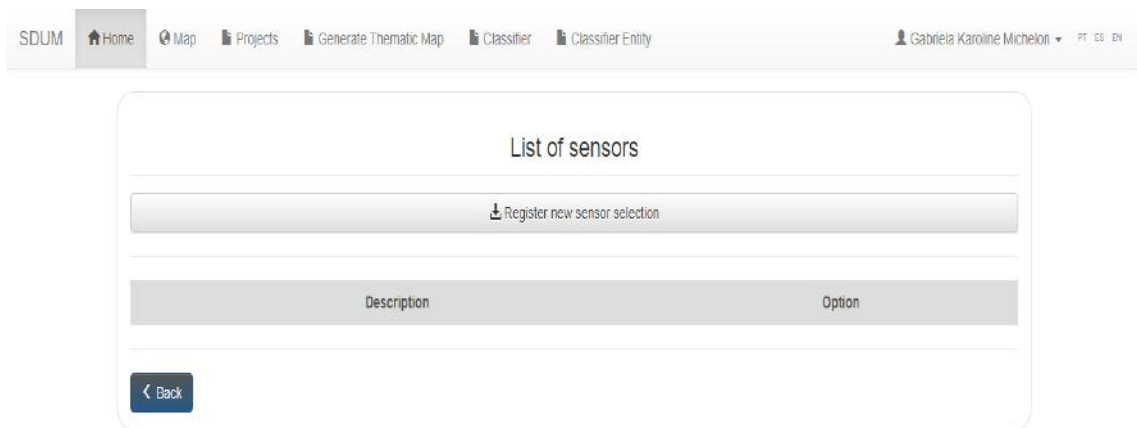
Figure 63 ─ Sensor list screen.

Source: Authorship.
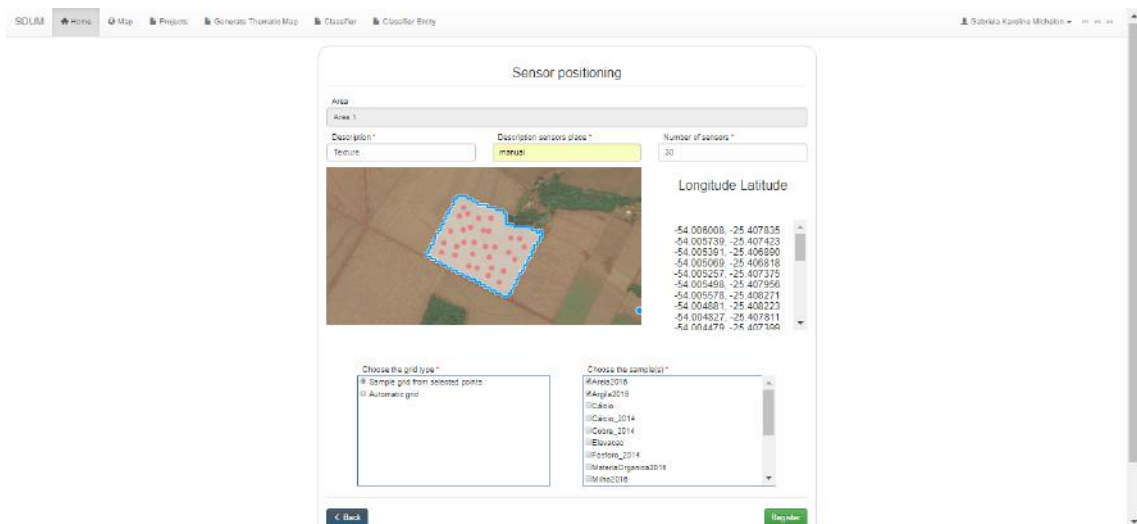
Figure 64 ─ Sensor Positioning register screen.

Source: Authorship.

A.8   REGISTRATION OF CLASSIFIER ENTITY

To generate a thematic map, the user can register a classification, which must have a classifier entity associated with the classification. To register a classifier entity, user just has to click on the top menu of the application button "Classifier Entity" that will take the user to the screen of Figure 67 where it has a button called "Register Classifier" and then, the application redirects to the classifier form page (Figure 68).
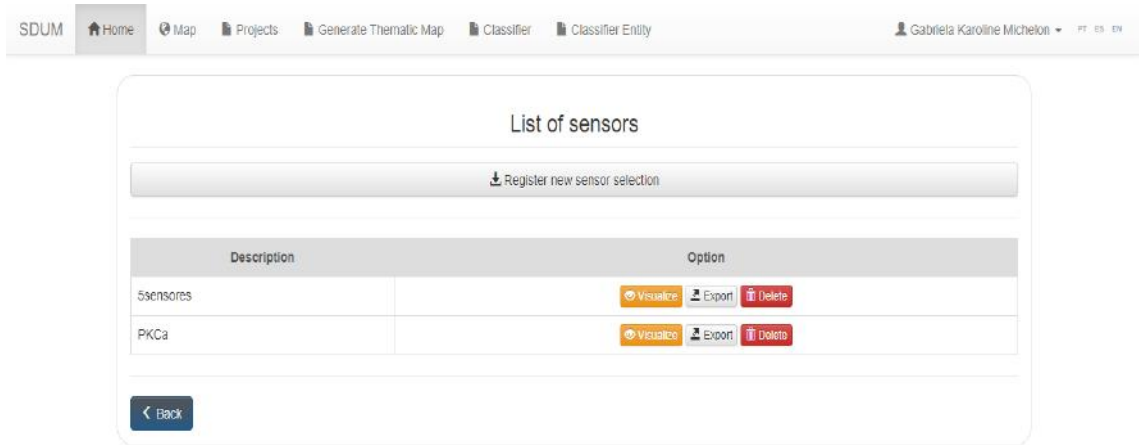
Figure 65 ─ Sensor listing screen after performing Sensor Positioning registration.

Source: Authorship.
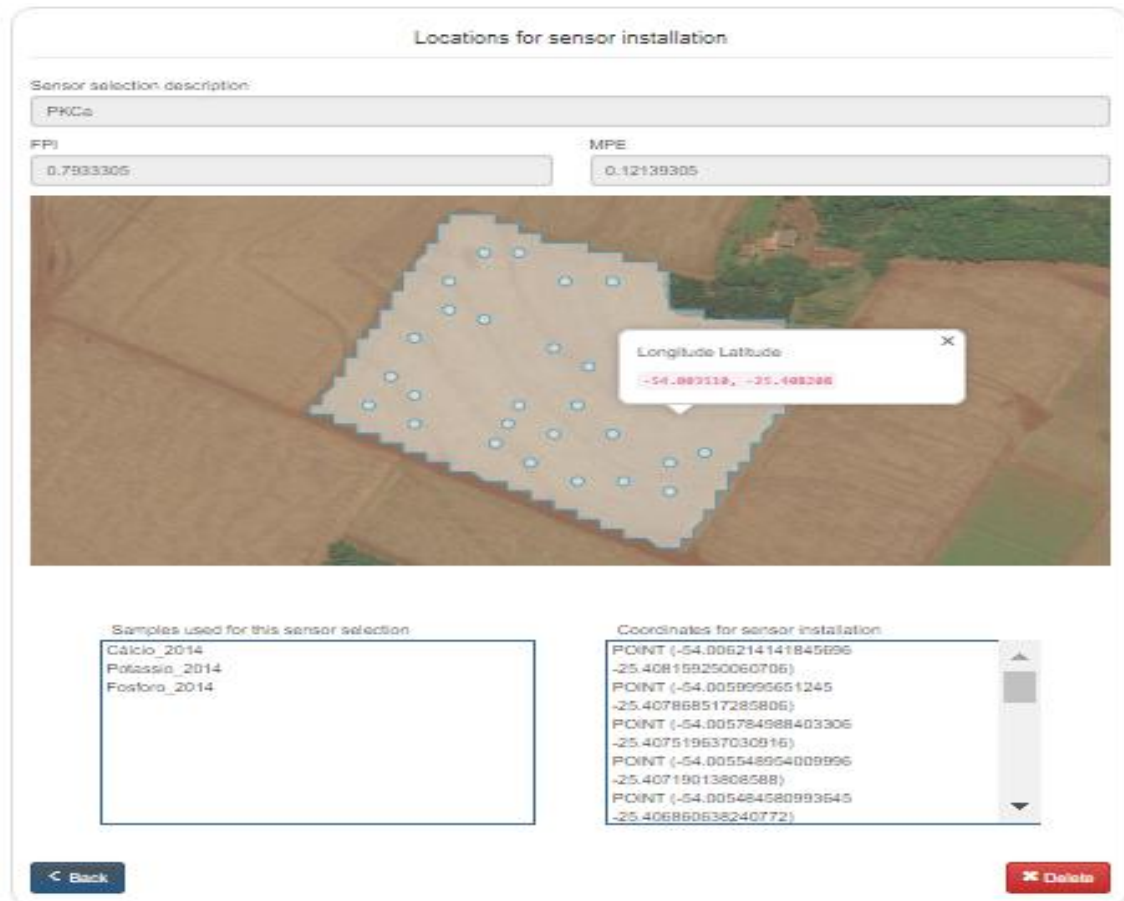
Figure 66 ─ Registered Sensor Position display screen.

Source: Authorship.
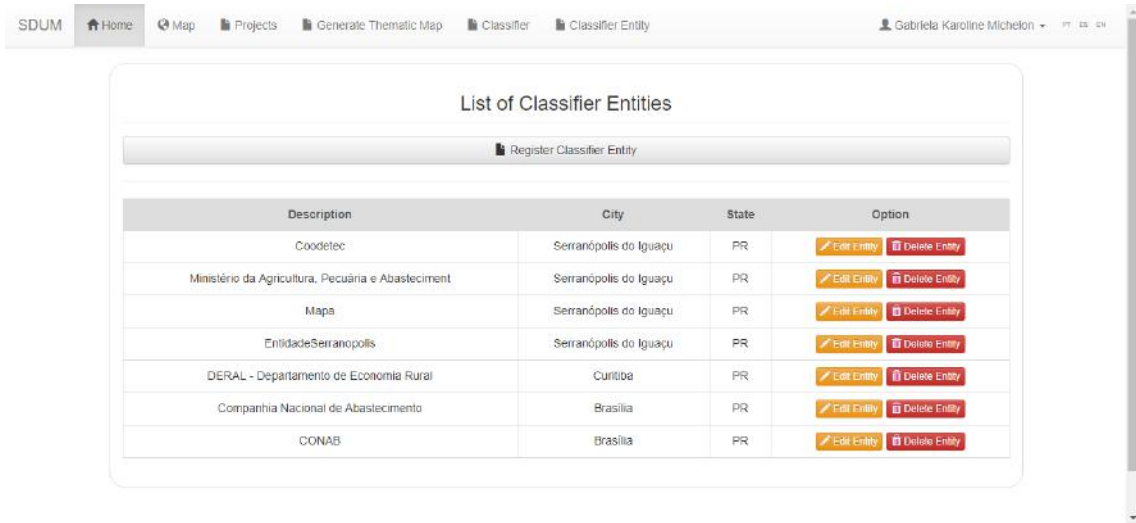
Figure 67 – Classifier Entity listing Screen.

Source: Authorship.
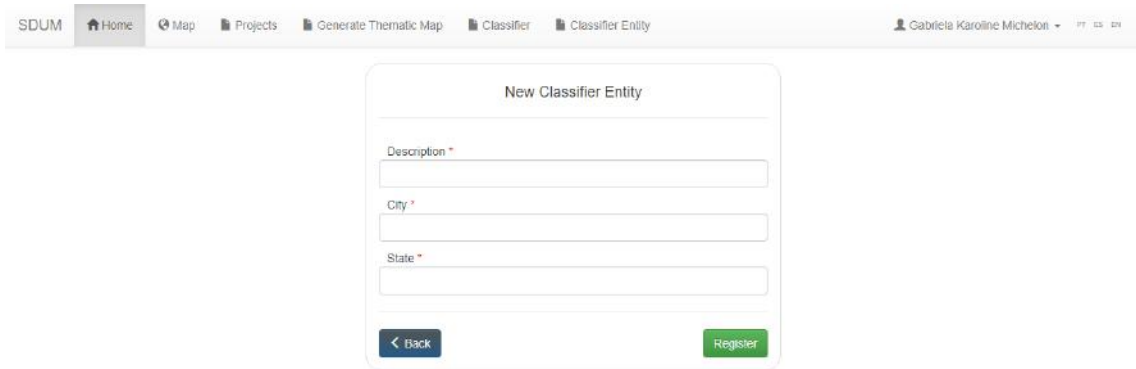
Figure 68 – Classifier Entity register Screen.

Source: Authorship.

A.9 REGISTRATION OF CLASSIFICATION

After register classifier entity, the user can register classification to generate thematic maps based on the intervals registered by the classification. The classification list has a button that opens the form for the new classification register form (Figure 69).

The intervals or classes of the classification can be increased or decreased according to the user's need. The value reported for classes must be numbers, and if necessary, decimal separator represented by period, not comma. The user can choose a classifier entity, an attribute type, a soil type, the range of values and colors to register the classification (Figure 70).
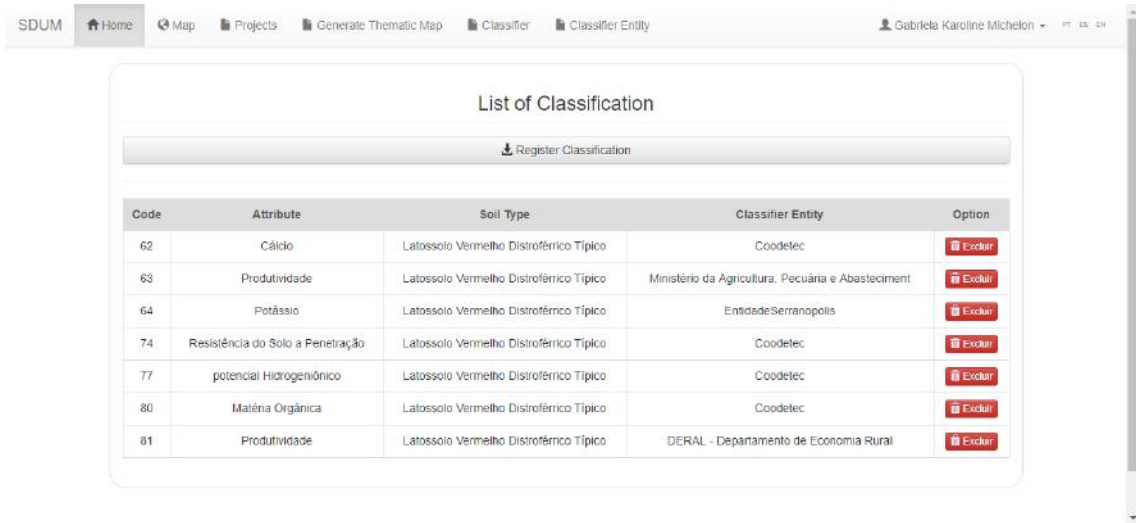
Figure 69 ─ Classification listing screen.

Source: Authorship.
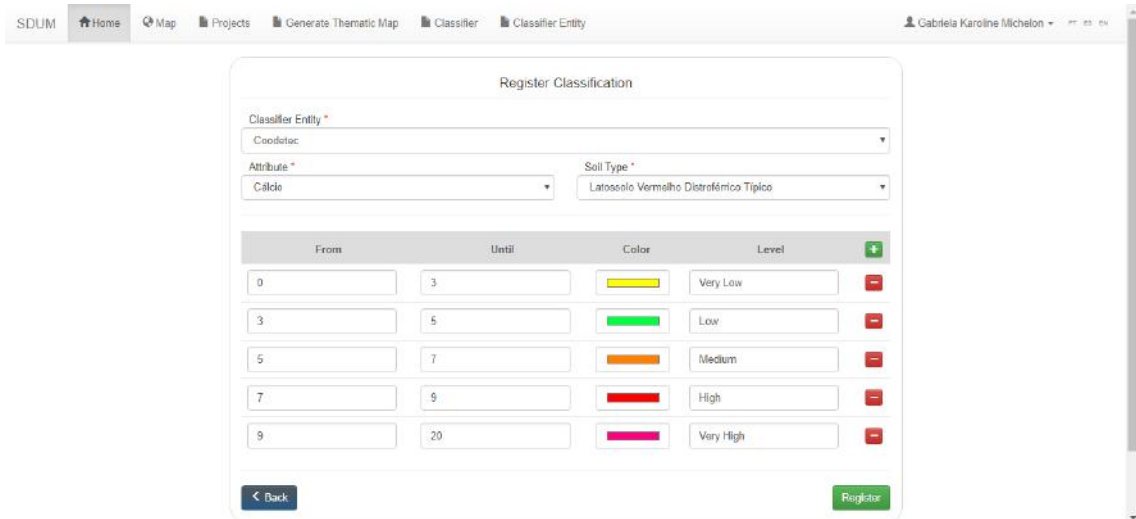
Figure 70 ─ Classification register screen.

Source: Authorship.

The user needs to be careful when registering the classifier because it is not possible to register more than one classifier using the same classifier entity with the same attribute and a certain type of soil in the API if they have already been used together in the registration of another classifier. Therefore, the application will not allow the registration of the classifier and it will be necessary to change the attribute or soil type or classifier entity, or to exclude the previous classification to register another classification using the same parameters (attribute, soil type and classifier entity).

Another important observation is that the user can not register the same description for more than one level in the classification. Each level or class of the classification must have a unique description. Otherwise, the API will not allow the registration of the class and,

consequently, the application will not register it.

A.10   REGISTRATION OF THEMATIC MAP

To register a thematic map, the user should click the top menu button called "Generate Thematic Map" and then in the list of thematic maps, on the button "Register Map Thematic". The user can select the desired interpolation method, OK, IDW or MA.

The form screen for registering thematic map using the MA interpolator (Figure 71) has Pixel X and Pixel Y fields corresponding to the size in meters of the distance between the center of a polygon or between two points that are very close in the vertical and horizontal directions respectively; has a field "Number of neighbors", which is the number of points in the neighborhood that are being considered for interpolation. In this case, it is recommended to leave the parameter "Radius" configured with the value of zero, since the field "Radius " must be nonzero when the user wants to use the distance instead of the number of neighbors. The radius parameter defines the distance within which samples for interpolation of a pixel should be considered.

Figure 71 – Form to generate thematic map by MA method.
Source: Authorship.

If the user chooses to interpolate by the IDW method, he/she will have one more field to fill in the thematic map register form: the exponent to calculating the inverse distance between the point to be estimated and the neighboring points (Figure 72). The IDW interpolator exponent value allows you to prioritize or to giver more importance for neighboring points, that is, greater the exponent is, greater the importance for the nearest sampling points.

Figure 72 ─ Form to generate thematic map by IDW method.

Source: Authorship.

By choosing the IDW interpolation method, is possible to generate thematic maps also by the nearest neighbor method (NN), just fill in the radius fields with value 0, exponent with value 1 and number of neighbors equal to 1.

The NN method is the simplest interpolation method and its main feature is to ensure that the interpolated value is one of the original values. This method is recommended to work with qualitative data because it does not generate new values for the sampled data, it only estimates values for non-sampled data (BAZZI, 2011).

In order to interpolate by OK, the user only needs to enter the name, area, sample and size of the pixels desired to the interpolation process, since the rest of the parameters are calculated by the geostatistics implemented in the R software, which returns the model that best fits the data for later generation of the thematic map (Figure 73).

Figure 73 ─ Form to generate thematic map by OK method.

Source: Authorship.

After the thematic map registration, the application is redirected to the list screen (Figure 74) of thematic maps, where the user can visualize the result of the geostatistics if the interpolation has been performed by the OK method. Otherwise the user will only see a false button with the message "Not applicable".

Figure 74 – Thematic Map listing screen.

Source: Authorship.

If the thematic map has been registered by the OK method, the user can click on the button in the geostatistics column, the list of thematic maps. Clicking this button "Visualize", which opens a window where the result of semivariograms (left side of the screen) and the model that best fit the data (right side of the screen) are shown, besides the parameters used for the interpolation: method, model, ICE, contribution, range, kappa, ISI, standard deviation of the mean error and mean error (Figure 75). The user can export to a text file the coordinates and respective values by clicking on the button "Export", corresponding to the thematic map at thematic map listing. To delete, the user must have to click on the button "Delete" corresponding to the thematic map desired at thematic map listing.
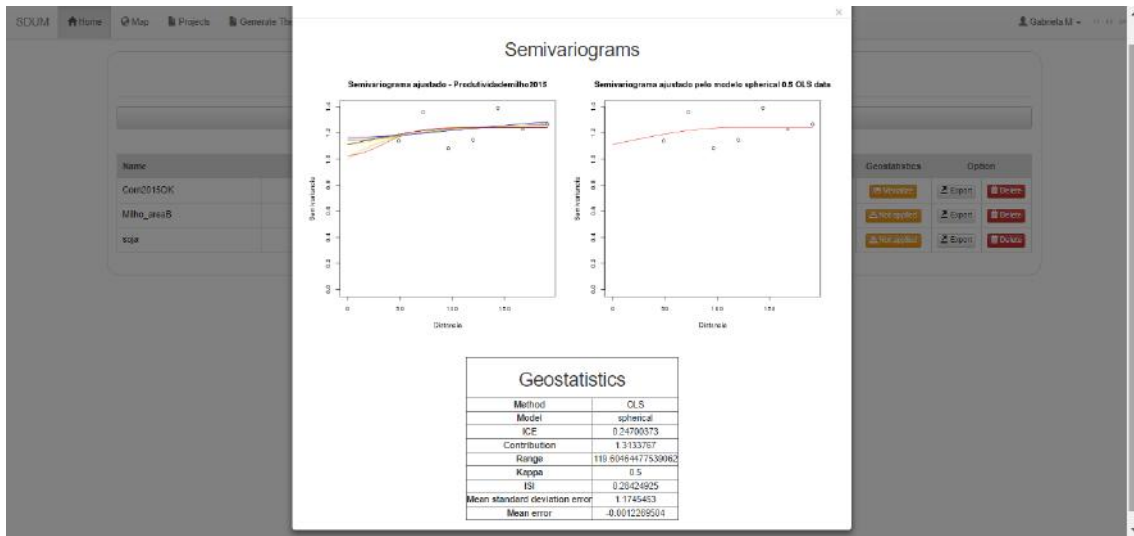
Figure 75 – Geostatistics of the Thematic Map created by the OK method at listing screen.

Source: Authorship.

A.11   VISUALIZATION OF MAP

When the user opens a project, or clicks on one of the top menu buttons "SDUM", "Main", "Map", will open the world map view screen, and a window in the right corner (can be dragged), where the user can list the current project and its respective areas, samples, sample grids and thematic maps appears. The user can select each of the items he/she wants to see by clicking on the respective check boxes next to each name, and to render the layers he/she will have to click on the central button of the project listing window on the map screen (Figure 76).
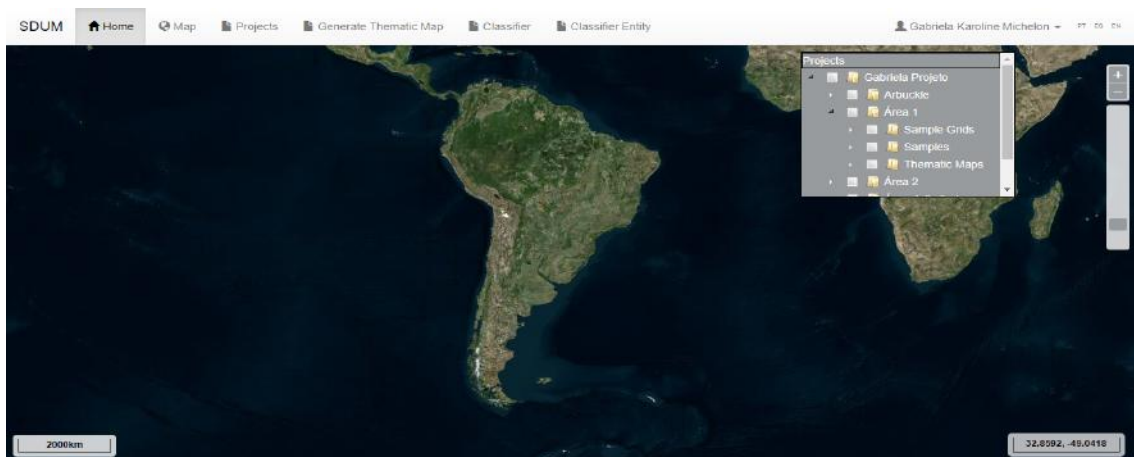

Figure 76 – List screen of Areas, Sample Grids, Samples and Thematic Maps of the Project openned.

Source: Map avaiable through OpenLayers library, Hazzard (2011)..

The figure 77 shows the items that were selected, a sample grid, and a sample. These are displayed in layers, and can be visualized with the sample grid and sample points within the

area. If the user clicks in one of the points, he/she can see a box that displays information about it. If the clicked point is from a sample, the information presented in the box will be the sample information corresponding to the sample point selected (Figure 77). If the point is a point of a grid, the information in the box changes to the grid information respective to the sample grid point (Figure 78).
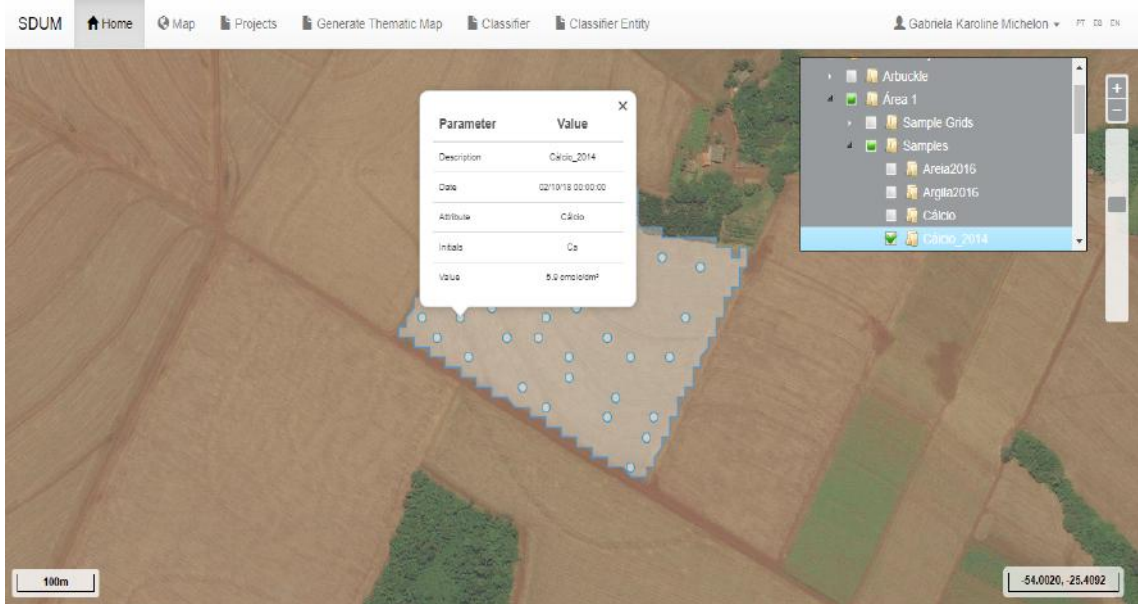

Figure 77 – Screen of Sample Grid and Sample, with Sample Point information box.
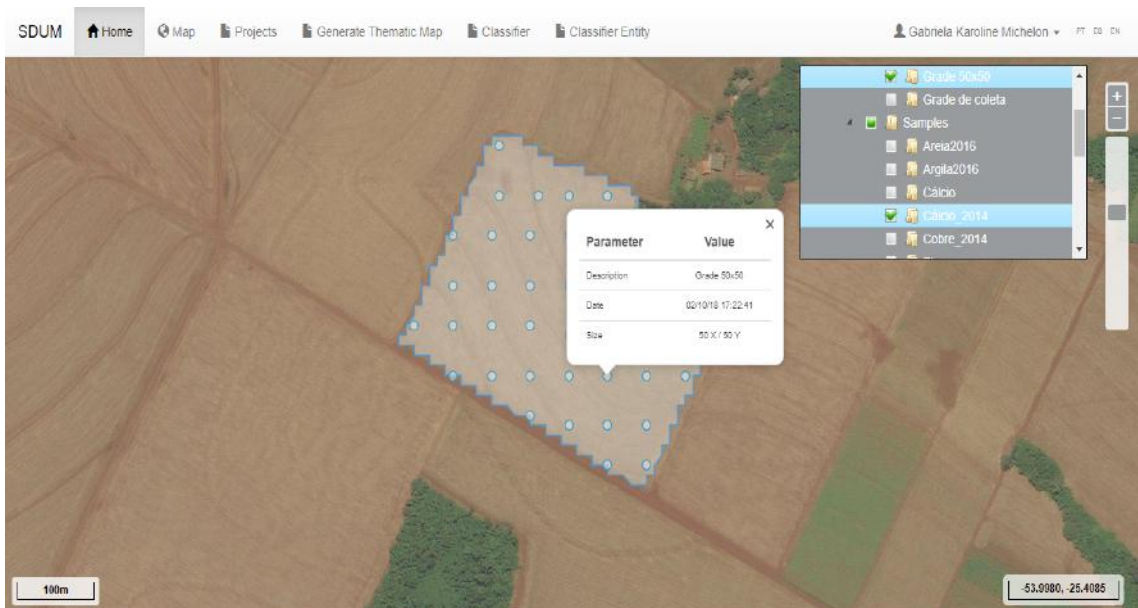**Source: Authorship.**

Figure 78 – Display screen of Sample Grid and Sample, with Sample Grid Point information box.
Source: Authorship.

If the user wants to view thematic maps, he/she simply will have to select them. If

he/she selects more than one thematic map of the same area, only the last thematic map selected in the order will appear in the selection window of the map screen layer. The ranges and colors can be choosen to view the thematic map through the legend box on the left side of the screen (the box can be moved inside the map screen). To increase the number of intervals, the user just has to click on the button represented by the plus sign, as well as to decrease a range, must have to click on the minus button.

In order to change the values of the intervals, the user must write only numbers and if necessary use decimal separator - point, otherwise the application will not apply the classification. After making the desired changes, user just needs to click on the button to the right of the legend box "Change legend" (Figure 79).
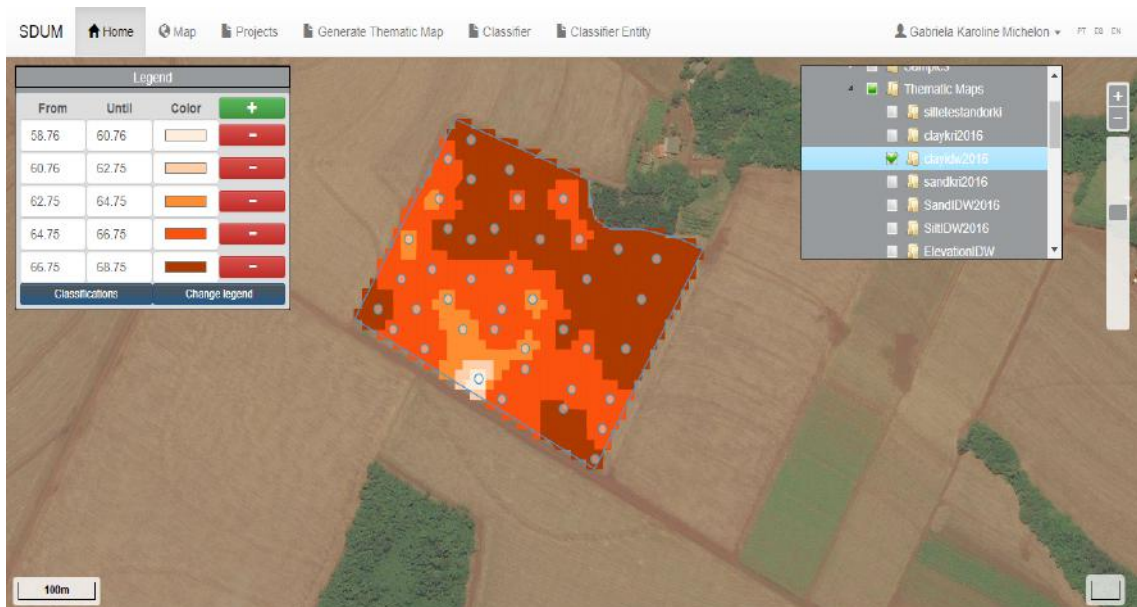

Figure 79 ─ Thematic Map display screen.

Source: Map avaiable through OpenLayers library, Hazzard (2011).

The user can also generate thematic map with classifiers registered by him, just by clicking on the button "Classifications" in the left of the legend box and selecting which classification is best suited for the soil type and attribute of the selected thematic map (Figure 80). If user selects a classification, the next time he generate the same thematic map, it will be displayed with the last classification applied to it when the thematic map was generated (Figure 81).

If data from two nearby areas are selected to be displayed on the map screen, user can view the layers simultaneously on the map screen (Figure 82) and if two thematic maps of nearby areas are selected, they can be simultaneously visualized too (Figure 83).
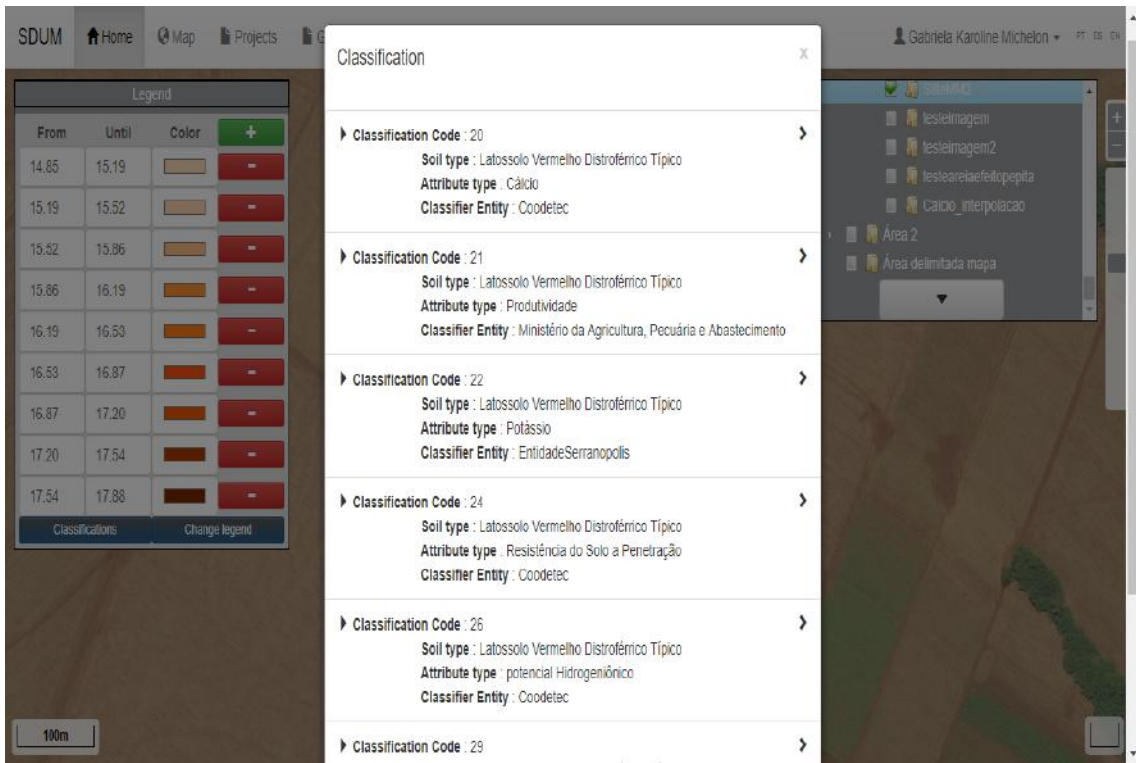
Figure 80 ─ Display screen of Classifications to generate Thematic Map.
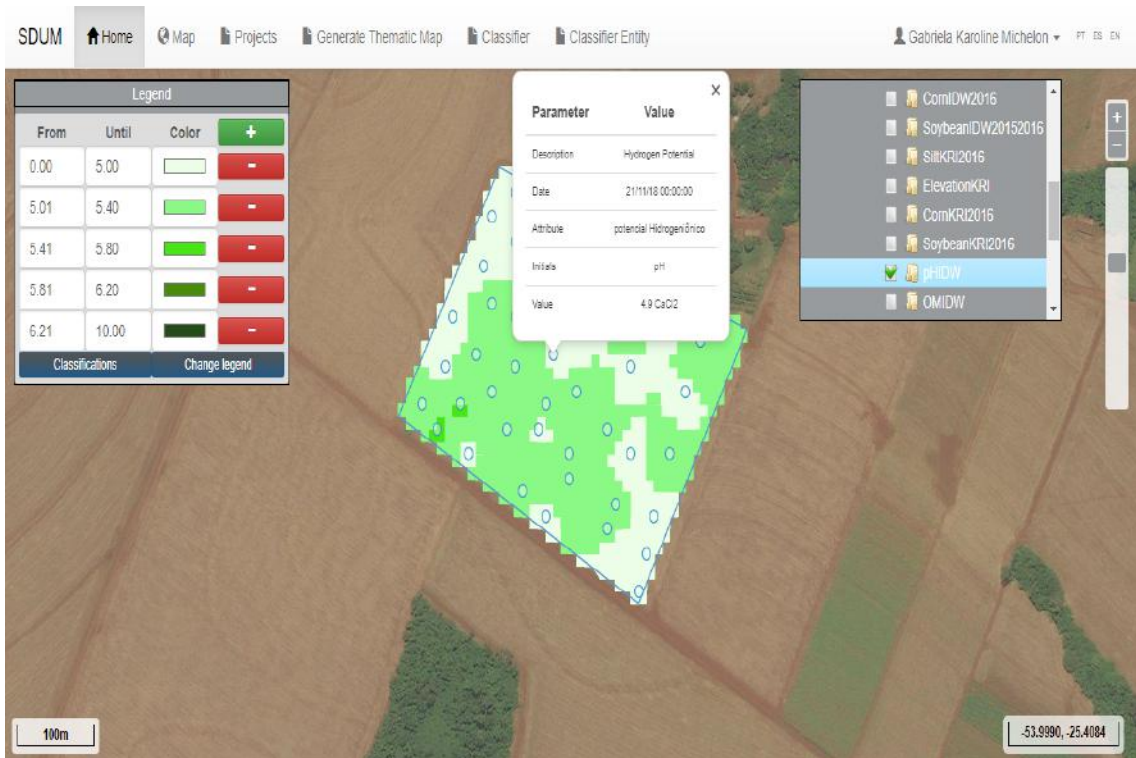
Source: Authorship.

Figure 81 ─ Display of Thematic Map after choosing a Classification.

Source: Authorship.

Figure 82 ─ Display screen of two Areas and their Samples.

Source: Authorship.

Figure 83 ─ Display screen of two Thematic Maps from two Areas.

Source: Authorship.