YIELD MAPPING IN FRUIT FARMING

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ABSTRACT
Due to the importance of increasing the quantity and quality of world agricultural production, the use of technologies to assist in production processes is essential. Despite this, a timid adoption by precision agriculture (PA) technologies is verified by the Brazilian fruit producers, even though it is one of the segments that had been stood out in recent years in the country's economy. In the PA context, yield maps are rich sources of information, especially by species harvested through machines, where the measurement of volumes harvested at georeferenced points is easier, allowing the generation of yield maps. In orchards intended for fresh fruit market, it is more difficult to generate yield data/maps, since it is linked to the volume harvested manually and, more importantly, to the quality of the fruit. One factor that makes it difficult to measure yield is that the harvest is done at different times because to maintain their quality, the fruits of an area are only when they reach the stipulated maturity point. To construct a system that permits of contemplating the complexity of the manual fruit harvesting processes, this paper aims to present a system that allows the yield mapping of hand-harvested orchards. The system is comprised of hardware components (intended to obtain the location of the harvester as well as the unloading record of their harvesting device at the unloading site) and software that allows processing the data obtained by the hardware device and create a mapped environment from which fruits were harvested, allowing the construction of yield maps. In addition to the yield maps, the system allows identifying the yield level of each worker performing the harvest by the number of discharges performed and the time spent. The system has been developed in partnership between the Federal Technological University of Paraná and Embrapa Grape & Wine and has been tested in apple orchards in southern Brazil. The system is expected to positively impact the sector by enabling monitoring of the quality and quantity of fruit from the orchards and providing more appropriate management aiming at the stability of the field production. Although tested only in apple cultivation, the system is promising for other segments of fruit growing, such as the production of pears, orange, fig, among others.

INTRODUCTION

Perennial plantations have become a highly commercialized product, especially for fresh consumption (MCCLURE et al., 2014). In Brazil, more than 300 thousand tons of fruit from crops such as mango, apple, grape and orange have been exported annually (KIST et al., 2018), out of a total of about 45 million tons produced by the country (IBGE, 2018). The remarkable economic importance of these crops in Brazil represents, according to the Food and Agriculture Organization (FAO, 2018), a cultivation of about seven million hectares.Ampatzidis et al. (2016) says that perennial crops need exclusive attention regarding planting, management, fertilization, pruning, in addition to specific management during the harvest, as it requires more technical work, with an emphasis on productivity and quality, due to the high costs of production. Unlike what occurs in grain production, the production of fresh fruit brings the difficulty of using mechanized resources, and most of the stages of cultivation take place manually, considering the characteristics of each culture. In this sense, difficulties in the adoption of precision farming techniques have occurred for this type of crop, especially due to the difficulty in obtaining data on the spatial variability of productivity and fruit quality, as it involves countless simultaneous workers during harvest periods and there is no adapted / standardized methods / techniques for this purpose. Depending on the crop, there is a prospect of harvesting in stages, according to the ripeness of the fruits.In this context, the aim of this paper is to present a hardware solution that enables the collection and storage of georeferenced data collection in fruit orchards as well as a software solution that enables the import of data collected and the analysis thereof by of productivity maps generated by ordinary kriging (KRI) or mathematical interpolators such as the inverse of the distance raised to a power (IDW). In order to validate the proposed system and methodology, productivity maps were built in two experimental areas located in southern Brazil, cultivated with apple trees.

MATERIAL AND METHODS

Management of perennial crops for fresh consumption

The countless stages of work planned in orchards include soil preparation, planting of seedlings, pruning, biological and chemical management, pest control and finally, fruit harvesting (Freire, 1994). With a focus on the elaboration of productivity maps, the present work aims to explain about the harvesting procedures, in order to provide an understanding of how it is carried out in most orchards in Brazil. In this sense, we seek to present how each step was detailed for the construction of the proposed system, based on data collection and generation of productivity maps.

The harvesting procedure for most perennial crops intended for fresh consumption is carried out annually, manually due to the delicacy necessary to maintain the quality of the harvested fruit and, mainly, due to the unevenness of the plants in the different plots of the orchard, which make it difficult mechanization. Still, it is important to remember that at a certain moment in which the harvest is being sought, not all the fruits of a tree will be at the same point of maturity, therefore requiring that several harvest passes be made on different days, withdrawing , at a time, only the fruits at the ideal ripening point. Also, as an average orchard can contemplate hundreds to thousands of trees with a few hundred fruits each, normally the harvest is carried out simultaneously by more than one worker. In this way, the complexity in the elaboration of thematic maps of productivity of these cultures is verified, considering the innumerable variables foreseen in the process.

Field productivity data collection

As a way of providing a systematic way of collecting data for fruit harvesting, it was decided to build a hardware device (Figure 1a), which works similarly to a vehicle tracker, attached to the harvesting bag of the worker who performs the harvest (Figure 1b). This device allows the storage of the geographic location data of the worker every three seconds (configurable) (Figure 2), and when unloading the harvested volume in a certain period of time with the storage container (Figure 1c and 1d) , the registration sequence is interrupted by a sound signal indicating the emptying of the bag. The identification of the storage container is carried out automatically by means of RFID (Radio-Frequency IDentification) technology, when the worker approaches the discharge site with the device attached to his collection bag.

a) b) c) d)

Figure 1. a) device developed to collect harvest data; b) worker with the device installed in the collection bag; c) Storage box for fruits harvested in the field; d) worker carrying out the unloading of the harvested produce next to the storage box.

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 1 EQUIPMENT ID|BOX ID|DATE      | TIME   |LONGITUDE |LATITUDE
 2 0004        |00000 |17/01/2020|10:40:23|-50.881943|-28.515100
 3 0004        |00000 |17/01/2020|10:40:28|-50.881874|-28.515156
 4 0004        |00000 |17/01/2020|10:40:31|-50.881874|-28.515156
 5 0004        |00000 |17/01/2020|10:40:34|-50.881874|-28.515156
 6 0004        |00001 |17/01/2020|10:40:36|-50.881874|-28.515156
 7 0004        |00000 |17/01/2020|10:40:39|-50.881874|-28.515156
 8 0004        |00000 |17/01/2020|10:40:42|-50.881889|-28.515165
 9 0004        |00000 |17/01/2020|10:40:45|-50.881889|-28.515186
10 0004        |00000 |17/01/2020|10:40:48|-50.881889|-28.515186
11 0004        |00002 |17/01/2020|10:40:50|-50.881748|-28.515207
```

Figure 2. File in text format, containing the harvest collection data. The highlighted lines represent the moment of unloading the bag in the unloading box.

Figure 2 shows the structure of the data stored in the collection device, being:

a) EQUIPMENT_ID: corresponds to an identifier number of the collector, that is, each worker has an identification;

b) BOX_ID: identifier of the storage box in which the fruits are dumped;

c) DATE / TIME: current date and time generated by the GPS receiver at the time of fruit collection;

d) X (Longitude) and Y (Latitude): represents the geographical coordinates obtained by the GPS receiver.

It is important to remember that the storage box, which is placed in the field in strategic points before the beginning of the harvest, as well as the collection devices have their own identification, allowing to indicate which device has unloaded fruits in a given storage box.

Data collection device

The tracking device was developed using an embedded software implemented in the IDE, type Arduino. Its architecture consists of a box (stand) measuring 30x104x68mm, a Radio-Frequency Identification (RFID) reader, a GPS signal receiver, a micro SD card, an ESP32 microcontroller, a Printed Circuit Board (PCI) and two batteries of Lion-Ion (Lithium Ion) 3.7 V in series, with approximately 18 hours of support for the device in operation. In Figure 3, the device developed with the indication of the components used is shown.

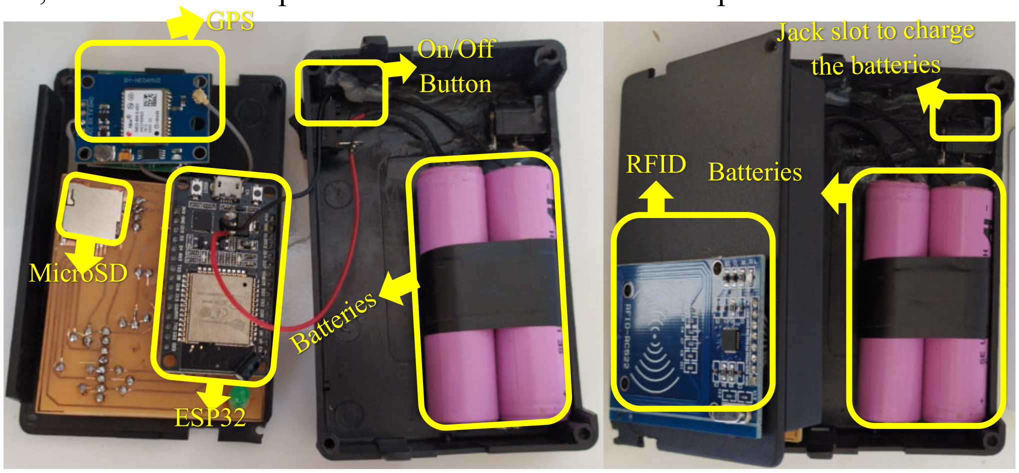


Figure 3: Electronic tracking device viewed internally, with the arrangement of the components used.

Estimated productivity

The operation of the data collection device follows a periodic determination of data recording (1s, 2s or 3s), and each time a line is recorded in the data file, indicating the geographic position of the device at that time. In this way, this procedure is continued until the bag is completely full and then the worker goes to the unloading box to empty it. Upon reaching the box, the system identifies the presence of the TAG, which indicates that the contents of the bag have been unloaded in the storage box. A record in the data file is inserted indicating the bag and box number. Then, the worker starts to harvest again, returning to the planting line, repeating the process again cyclically. Then, the location data of the places where the harvest was carried out and in which box each bag was unloaded, sequentially. The weight of each bag is slightly variable as long as it is completely full, and this way, an average value for defining productivity is estimated, which can be calculated in two different ways:

***Method 1: Productivity obtained with reference to storage boxes* -** In this method, as each bag takes a certain period to be filled and, therefore, there is a sequence of points of location of the places where the fruits were harvested, the calculation of the centroid of these points is performed, indicating that in this location a bag was harvested. Performing this procedure for all bags unloaded in a given box, the centroid calculation of all bags is performed. In this way, this centroid serves as a reference from where the box's load was obtained, relating to it the estimated weight of the number of bags multiplied by the average weight of each bag, or even by the total weight obtained when weighing the box. Figure 4 shows the way in which the sequence of steps is performed.

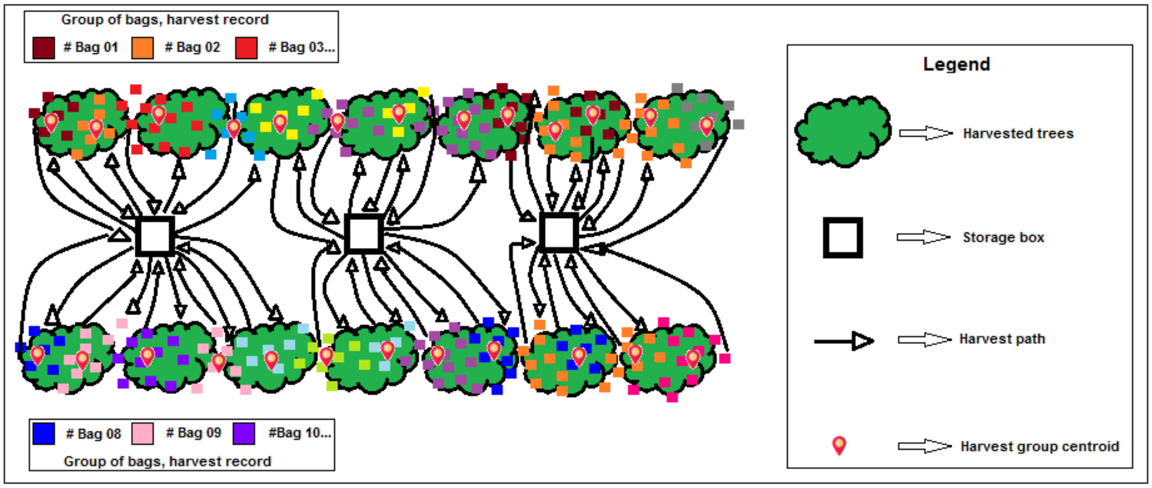


Figure 4: Scheme for estimating productivity considering method #1

***Method 2: Productivity obtained with reference to a sample grid that represents the trees in the orchard* -** Aiming to simulate the trees in an orchard, this method seeks to create an initial sampling grid and relate each point that represents the moment of harvest to a point in the sampling grid closest to its location. In this way, we theoretically have the number of bags collected in each location, thus estimating productivity by multiplying the number of bags with the stipulated average weight. Figure 5 shows the way in which the sequence of steps in the field is performed.

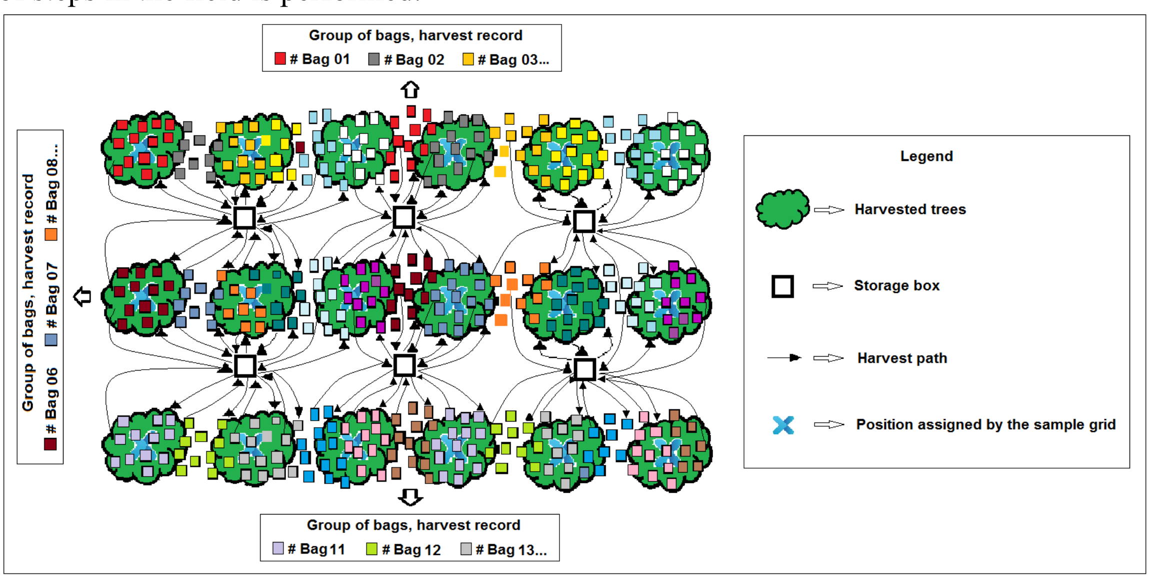


Figure 5: Scheme for estimating productivity considering method #2

Software development technologies

As a software development model, the MVC (Model-View-Controller) standard was used, opting for the use of free tools, with the IDE (Integrated Development Environment) Spring Tools 4 for Eclipse (STS4) (ECLIPSE, 2019). The frontend frameworks AdminLTE and Bootstrap, together with the languages HTML, CSS, JQuery and JavaScript were also used in the production of the system's web pages. For the visualization of the maps, the OpenLayers library was used (OpenLayers, 2019). Java technology was the programming language adopted, through the JEE platform (Andrade, 2015). The PostgreSQL database manager, the Postgis spatial extension and the Hibernate and Hibernate Spatial data persistence frameworks were also employed. (Hibernate, 2019; Hibernate Spatial, 2019; Momjian, 2001)

In view of the complexity of working with data interpolation procedures, we opted to use the AgDataBox API (Application Programming Interface) (Bazzi et al. 2019), for geostatistical analysis and generation of thematic maps using ordinary kriging (KRI) and inverse of the distance raised to a power (IDW).

Software for importing, analyzing and generating thematic maps

A web software was developed to perform the import and interpretation of the data collected in the field, and it allows the import of the data through the file in text format (.txt), generated by the collection device. After importing, the software allows you to validate the data, which is read sequentially and stores them in a database created for this purpose. Files generated by different workers can be imported and grouped in order to generate productivity maps with data obtained by different workers in one harvest operation, as well as with data collected in different operations, performed in the harvest window.

The software allows the stored data to be displayed in a punctual way on the map, as well as allowing the generation of thematic productivity maps, which are generated through the AgDataBox-API platform (Bazzi, et al. 2019) which allows, in addition to the generation of the productivity maps using the KRI and IDW methods, perform the geostatisticalanalysis automatically (Figure 6).

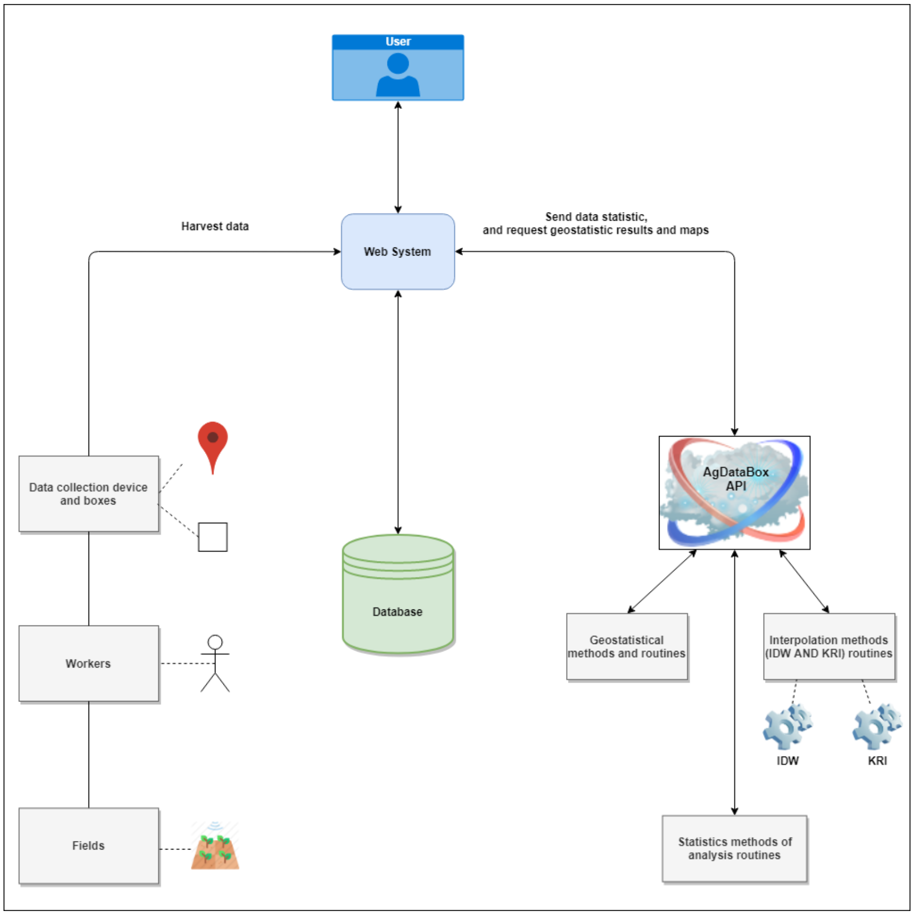
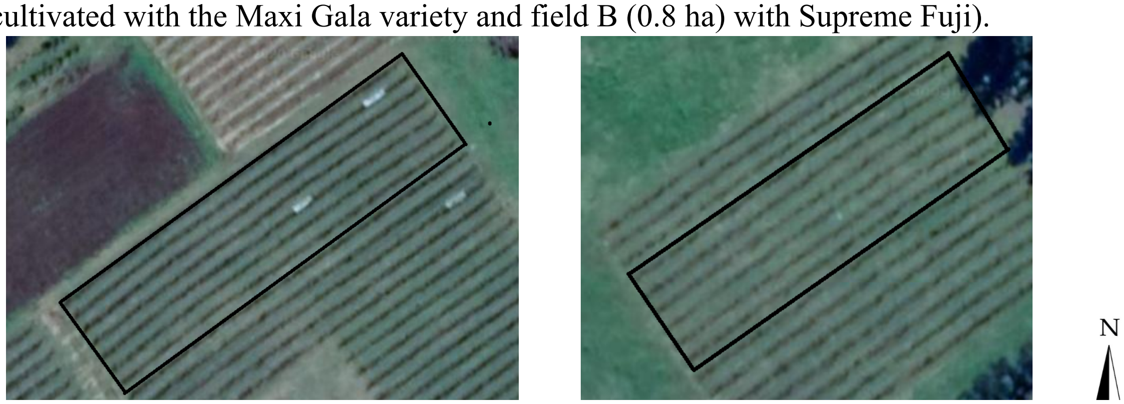


Figure 6: Flowchart of operation of the developed Web software.

Fields and Data

In order to test the proposed methodologies, as well as the developed system, harvests were carried out using the tracking device in two experimental areas located in the municipality of Vacaria, in the southern region of Brazil (Figure 7), next to the Experimental Fruticulture Station of Temperate Climate (EFCT) of Embrapa Uva e Vinho, with coordinates of Longitude 50º53'00.0 ”West and Latitude 28º30'53.3” South. Field A (with 0.8 ha) is cultivated with the Maxi Gala variety and field B (0.8 ha) with Supreme Fuji).



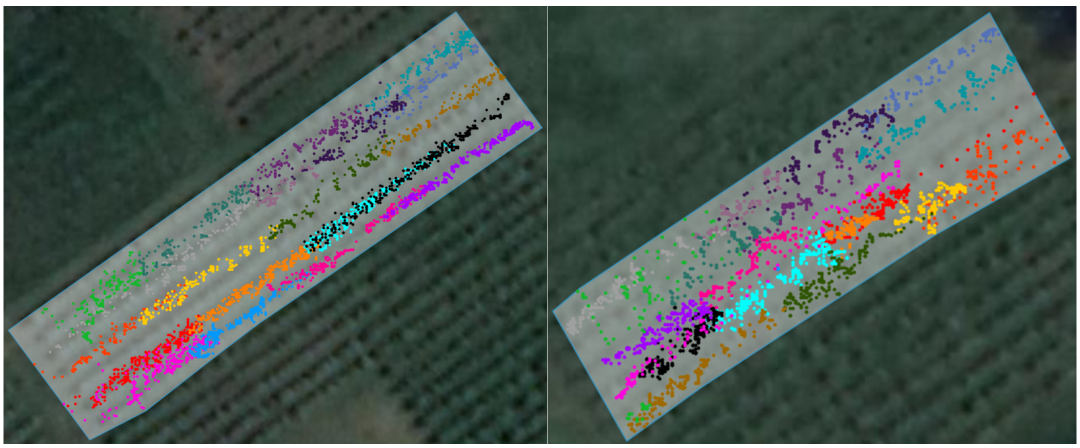
Field A Field B

Figure 7: Fields of EFCT used in the experiment

RESULTS AND DISCUSSION

Importing data from tracker device

After the harvest, the data collection devices are collected and the files with the data are obtained from the MicroSD card. After starting the software, after entering the login and password data and registering the area and harvesting, it is possible to import the data and the data is stored in the application database. Figure 8 shows the geographic arrangement of the data obtained when harvesting the plots presented in the developed system. Each red dot represents a position obtained by the device at times when the harvest was being performed.



Field A Field B

Figure 8: Arrangement of harvest data obtained by the device and presented in the developed software

After the data is imported, the software interprets and estimates the productivity by generating sample grids from each storage box (method 1) or representing the harvested trees (method 2), so that generation is possible of productivity maps.

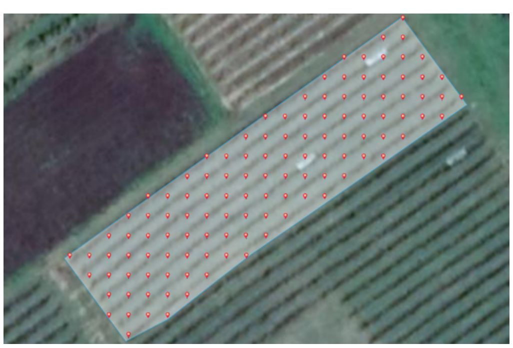


Figure 9 a) Sample grid generated to represent the trees harvested in the plot, to estimate productivity (method 2)

ID	Quantity of Bags	Geometry	Delete
21	1.2470046082949302	POINT (-50.881405 -28.5151)	Delete
22	1.0736308857249506	POINT (-50.88135390202089 -28.51509995539273)	Delete
23	2.467104388010794	POINT (-50.88130280404189 -28.515099910766242)	Delete
24	2.5404955928377904	POINT (-50.881251706063004 -28.5150986612054)	Delete
25	2.0929448929448955	POINT (-50.881200608084235 -28.515099821455628)	Delete
26	0.1721966205837173	POINT (-50.88145609797924 -28.51510004458805)	Delete
27	0.3238095238095239	POINT (-50.88150719595859 -28.51510008915689)	Delete

Figure 9 b) Data in text format so that you can eliminate points without interest and check the approximate number of bags removed at that point.

From this stage, it is possible to perform the geostatistical analysis, in which the best model adjusted to the semivariogram is automatically suggested (routine performed on the AgDataBox-API platform), allowing, however, that for each adjusted model it is possible to generate the respective thematic map (Figure 10).

All Records of Geostatistical Analyzes Performed (ISI)

Show 10 entries   Search:

ID	Model	Method	ICE	Contribution	Range	Kappa Value	Average Error	Standard Deviation	ISI	Show
10	**SPHERICAL**	**WLS**	**0.999968257157279**	**1.16091832892326**	**42.8492656920316**	**0.5**	**-0.0138497669721394**	**1.16879681459385**	**0.692650936941781**	Show Map
5	SPHERICAL	OLS	0.999825022211669	1.40602531755788	23.0726815264785	0.5	-0.0138486907163352	1.16939224069621	0.693107726468098	Generate Map
12	GAUSSIAN	OLS	0.999893919854106	1.16091832892326	23.0726815264785	0.5	-0.0145055475460089	1.15229578376897	0.710459924010952	Generate Map
11	GAUSSIAN	WLS	0.999971311994164	1.65113230619249	13.184389443702	0.5	-0.0146035577124685	1.15252386915173	0.715425561545828	Generate Map
3	MATERN	OLS	0.999841650769318	1.16091832892326	52.7375577748081	2.0	-0.0180094106027742	1.14713841157474	0.876598247660139	Generate Map
8	MATERN	WLS	0.999948312509597	1.40602531755788	42.8492656920316	2.0	-0.0185507944708736	1.14750524499209	0.903263508222106	Generate Map
2	MATERN	OLS	0.999738860153379	2.14134628346172	52.7375577748081	1.5	-0.0187351641588269	1.14939703539155	0.913855357537302	Generate Map
4	EXPONENTIAL	OLS	0.999994834987488	2.14134628346172	32.9609736092551	0.5	-0.0191227112372169	1.15706890904112	0.939279565267924	Generate Map
9	EXPONENTIAL	WLS	0.999997265608597	1.16091832892326	32.9609736092551	0.5	-0.0191725813987801	1.15713177709605	0.941760729514199	Generate Map
7	MATERN	WLS	0.999979940349295	1.89623929482711	23.0726815264785	1.5	-0.0193637209071503	1.15005290848185	0.945010881392178	Generate Map

Showing 1 to 10 of 12 entries   Previous 1 2 Next

Figure 10 List of models fitted to the semivariogram

The models adjusted to the semivariogram are selected from cross-validation statistics, being calculated by ISI (Betzek, et al. 2019). In Figure 11, it is possible to verify the models adjusted to the semivariogram (left) and the best model selected using ISI statistics (right).

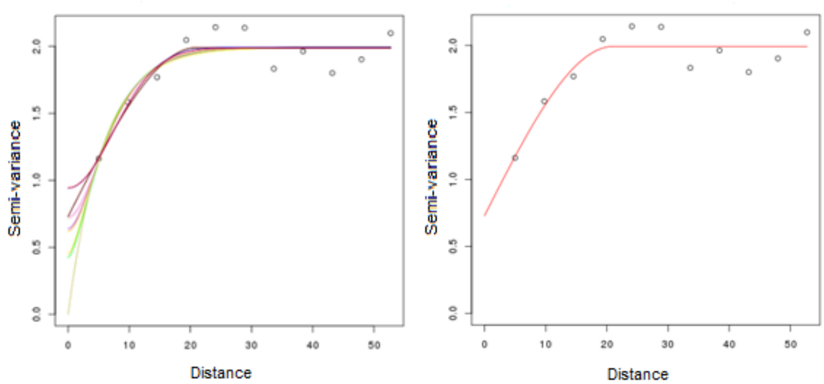
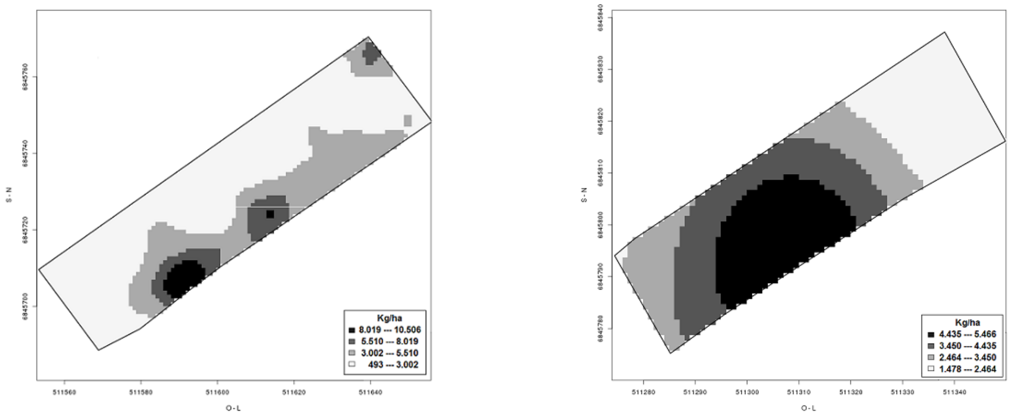


Figure 11: Graphical representation of the semivariogram generated with field A productivity data with the adjusted models (left) and with the best selected model (right).
From geostatistical analysis, productivity maps can be generated, as shown in figure 12.



Field A Field B

Figure 12: Map of productivity in areas A and B generated by Krigagem

CONCLUSION

The prototype of tracking hardware developed met the objectives for which it was designed, and obtaining coordinates was consistent with the activities developed in the field.

The methods for estimating crop yields proved to be adequate, with method 1 requiring a larger number of collection points to have a more adequate geostatistical model, due to the restricted number of sampling points.

The developed software met the expected expectations, considering that it allowed the generation of productivity maps generated from the data obtained by the hardware device in the harvest of the apple trees.

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