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Yield map generation of perennial crops for fresh consumption

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Abstract
Yield mapping technologies can help to increase the quantity and quality of agricultural production. Current systems only focus on the quantification of the harvest, but the quality has equal or greater importance in some perennial crops and impacts directly on the financial profitability. Therefore, a system was developed to quantify and relate the quality obtained in the classification line with the plants of the orchard and for decision-making. The system is comprised of hardware, which obtains the location of the harvester bag during harvesting and unloading at the unloading site, and software that processes the collected data. The cloud of real-time data contributed from the different collectors (bins) allows the construction of yield maps, considering the multi-stage harvesting system. Further, the system enables the creation of a detailed map of the plants and fruits harvested. As the harvest focuses on quality, it takes place in stages, depending on the ripening of the fruits. In addition to the yield maps, the system allows identification of the efficiency of each worker undertaking the harvest by the number of performed discharges and by the time spent. The system was developed in partnership with the Federal Technological University of Paraná and Embrapa Uva & Vinho and was tested in apple orchards in southern Brazil. Although the system was evaluated with only data from apple cultivation, monitoring the quality and quantifying other orchard fruits can positively impact the fruit sector.

Keywords Apple · AgDataBox · Perennial · Yield maps · Manual harvest

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Introduction

Perennial crops are a highly commercialized product, especially for fresh consumption (McClure et al., 2014). Brazil has annually exported more than 300 kt of fruits from cultures such as mango, apple, grape and orange (Kist, 2018). Ampatzidis et al. (2016) state that perennial crops need special attention regarding planting, management, fertilization and pruning. In addition to that, perennial crops, which require more technical work, need specific management during harvesting, with an emphasis on productivity because production costs are high. Unlike in grain production, and some perennial fruits focusing on industrial destination (juice, pulp, etc.), the production of fresh fruit brings the difficulty of using mechanized resources, and most of the cultivation phases are done manually, considering the characteristics of each culture (Gallardo et al., 2019; Roy et al., 2019).

Difficulties in adopting precision agriculture (PA) techniques have occurred, especially, for obtaining data on the spatial variability of yields and quality of fresh fruit crops (Lee & Ehsani, 2015). To obtain data is challenging mainly when numerous workers are involved simultaneously during harvest periods and there are no adapted or standardized methods or techniques for this purpose. In addition, depending on the crop, the harvest takes place in stages, according to the ripening of the fruits (Gongal et al., 2016). Furthermore, in the case of some fruit trees oriented towards fresh consumption, the conduction system adopted may also hinder data collection, if the lateral branches overlap fruits. Such a situation occurs in Brazilian orchards, where the plants form a continuous wall in the row. This makes it difficult to individually identify which plant resulted in the respective production that contributes to the harvest bin. Thus, the best option is to monitor the zone of such data in the row of plants.

Monitoring by zone makes a large difference between perennial crops destined for large industrialization, where the quality can be adjusted during processing, such as orange or grape for juice. Monitoring by zone also impacts those whose production value is closely linked to maintaining the quality of the individual fruit, such as crops for fresh consumption, whose only stage of industrialization are classification and packaging. In the first case, decision-making in precision agriculture is based only on maximizing the volume produced (Molin & Mascarin, 2007; Schueller et al., 1999). In the second case, even with smaller production, the final quality of the product will have greater weight in the results and in the remuneration of the area (Zude-Sasse et al., 2016). Thus, yield maps for crops for different purposes must be designed according to the desired results and not only based on the yield.

The contribution of this work is the implementation of a system that allows the collection and storage of georeferenced data on the movement of each harvesting area by means of hardware. In addition to this, the system enables the identification of the plants to which each harvest worker had access to fill his/her harvest bag and the composition of the fruit contribution zone for filling the field storage box. The field storage box is also related to the time of work for harvesting in fruit orchards with a focus on product quality. The software system is able to manage the georeferenced data, by importing and analyzing the collected data through productivity maps. The productivity maps are generated by ordinary kriging (Kri) or inverse distance weighting (IDW), which after this can receive the quality data from the classifier. The system was validated by testing it in two experimental areas cultivated with apple trees, which are located in southern Brazil.

Materials and methods

Management of perennial crops for fresh consumption

The harvesting procedure is carried out annually and manually for most of the perennial crops intended for fresh consumption. Manual harvesting is due to the care necessary to maintain the quality of the fruits and, mainly, due to unevenness of the plants in the different parts of the orchard, which makes it difficult to use mechanized systems (Kang & Chen, 2020). It is important to remember that, unlike orchards of industrial crops, in orchards intended for fresh consumption, not all the fruits of a tree will be at the same point of maturity simultaneously. Harvest in industrial crops is done at the medium maturity point and for all the fruits. For fresh consumption, several harvest passages must be made on different days, removing, at a time, only the fruits at the ideal point of maturation (Stajnko et al., 2004; Stefas et al., 2019). Normally, orchards of certain crops, such as apple trees, can include hundreds or thousands of trees per hectare, with on average 200 to 300 fruits each. Besides that, the harvest is usually carried out by more than one worker, simultaneously.

All these factors generate complexity in the creation of productivity maps of these cultures, even if possible random variables are disregarded in the process. For instance, the occurrence of adverse weather conditions between one harvest season and the next leading to fruit fall or injuries to the fruits, makes it impossible to sell for fresh consumption. Such scenarios would mask the area's yield, either in quantity or quality, and affect the profitability of the orchard.

Collecting harvest yield data field

A hardware device was built (Fig. 1a) in order to provide a systematic way of collecting data for fruit harvesting. The hardware device works similarly to a vehicle tracker, attached to the harvest bag of the worker who carries out this service (Fig. 1b). The device allows storage of the geographic location data of the worker at each configurable time-lapse, (3 s in the results presented in Fig. 2). The record sequence is interrupted by a beep when the harvested volume is unloaded into the storage container (Fig. 1c and d), interpreting what occurred when the bag was emptied.

(a) (b) (c) (d)

Fig. 1 **a** Device developed to collect harvest data; **b** worker with the device installed in the harvesting bag; **c** Storage box for fruit harvested in the field (harvesting bins); **d** worker carrying out the unloading of the harvested produce in the harvest bin

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EQUIPMENT_ID|BOX_ID|DATE      | TIME    |LONGITUDE |LATITUDE
0004        |00000 |17/01/2020|10:40:23|-50.881943|-28.515100
0004        |00000 |17/01/2020|10:40:28|-50.881874|-28.515156
0004        |00000 |17/01/2020|10:40:31|-50.881874|-28.515156
0004        |00000 |17/01/2020|10:40:34|-50.881874|-28.515156
0004        |00001 |17/01/2020|10:40:36|-50.881874|-28.515156
0004        |00000 |17/01/2020|10:40:39|-50.881874|-28.515156
0004        |00000 |17/01/2020|10:40:42|-50.881889|-28.515165
0004        |00000 |17/01/2020|10:40:45|-50.881889|-28.515186
0004        |00000 |17/01/2020|10:40:48|-50.881889|-28.515186
0004        |00002 |17/01/2020|10:40:50|-50.881748|-28.515207
```

Fig. 2 File in text format, containing the harvest data collection

The identification of the storage container is carried out automatically by means of *Radio Frequency Identification* (RFID) technology, the moment the worker approaches the discharge site (harvesting bins) with the device attached to their harvesting bag. The storage boxes (Bins) are placed in the field in strategic places during the harvest and, as the collection devices have their own identification, the system indicates which device deposited fruit in a given storage box.

Thus, the collection bag has the active part of the system while the Bin is the holder of the passive part, being equipped only with a TAG tape with its identification (Ampatzidis et al., 2009). This operational design was chosen to allow recharging the batteries of the tracking equipment in the harvest bags at the end of the working day. The bin, depending on the crop being harvested, leaves the field directly to a refrigerated and sealed storage chamber for days to months (often under controlled atmosphere), preventing the battery from recharging. In addition, at the time of classification, the Bin is immersed in water to remove the fruit without causing injury to the product. If the bin were instrumented (as a carrier for the register or a built-in load cell for weight registration), it would need insulation against cold water, and dirt, which could make the system excessively expensive and more fragile.

In Fig. 2, the lines highlighted in green colors represent the geographical position of the worker at the time of fruit collected from the trees. The yellow colors represent the geographic position of the storage box (bin) when the bag is emptied. The data structure stored in the collection device is:

EQUIPMENT_ID: corresponds to an identifier number of the collector, that is, of the worker, who has an individual identification;

BOX_ID: identifier of the storage box, in which the fruits are stored;

TIME: current date and time generated by the global navigation satellite system (GNSS) receiver at the time of fruit collection;

X (longitude) and Y (latitude): represent the geographical co-ordinates obtained by the GNSS receiver.

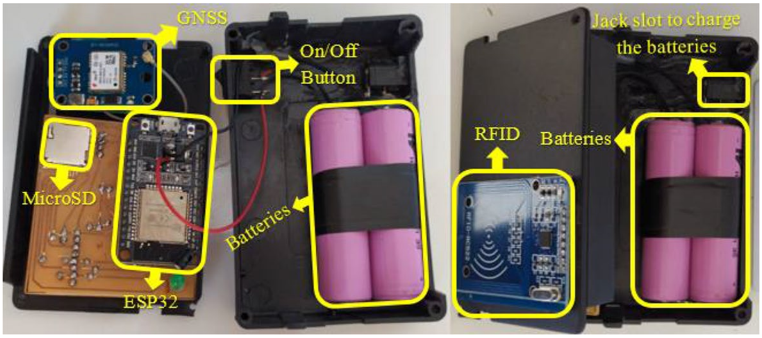

Fig. 3 Internal view of the electronic tracking device developed

Data collection device

The tracking device (Fig. 3) was developed using embedded software implemented in the *Integrated Development Environment* (IDE) (Arduino, 2020). Its architecture is composed of a box (rack) 30 × 104 × 68 mm, an RFID reader, a GNSS signal receiver, a micro SD card, an ESP32 microcontroller, a *Printed Circuit Board* (PCI) and two Li-ion (Lithium Ion) batteries of 3.7 V in series, with approximate support of 18 h of duration for the device in operation.

Definition of yield

The operation of the data collection device follows a pre-configured periodic determination of data recording (every 1 s, 2 s or 3 s), with a line being recorded in the data file every time, indicating the geographic position of the device at that time. This continues until the bag is completely full and then the worker moves to the download box to empty it. When it gets close to the harvesting bin, the system identifies the presence of the TAG, which indicates that the bag's contents were unloaded in the storage box (Bin). Then, the worker returns to harvest again, returning to the planting row, repeating the process cyclically.

Following this sequential procedure, the location data of the places where the harvest was carried out and in which box each bag was unloaded is obtained. The weight of each bag is slightly variable even though it is completely full, and thus, an average value for defining productivity is estimated, which can be calculated in two different ways.

Method 1: yield achieved with reference to storage boxes

In this method, there is a sequence of points of location of the places where the fruits were harvested because each bag takes a certain time to be filled. The centroid of these points is calculated, indicating that a bag was collected at this location. Once this procedure is done for all bags unloaded in a given bin, the centroid calculation is performed again, now considering the locations where all bags unloaded in the bin were collected.

In this way, such a centroid serves as a reference from where the bin load was obtained, relating to it the estimated weight of the number of harvest bags multiplied by the average

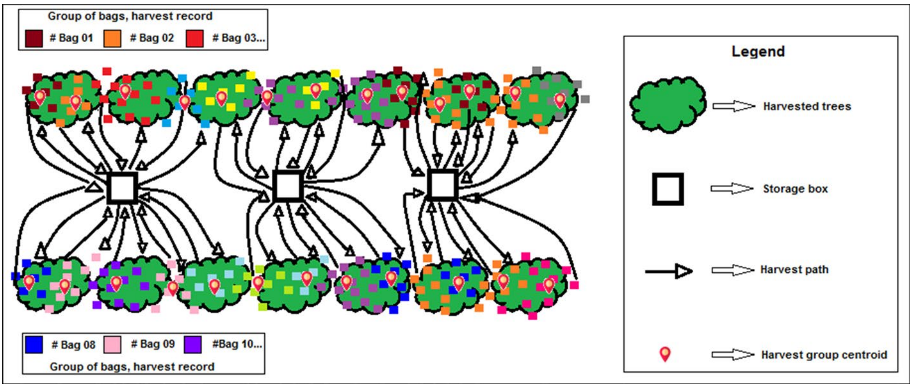

Fig. 4 Scheme for estimating orchard yield using method #1

weight of each bag, or even by the total weight obtained when weighing the bin. Figure 4 shows how the sequence of steps is carried out.

Method 2: yield obtained with reference to a sampling grid that represents the trees in the orchard

Aiming to simulate the trees in an orchard, this method seeks to create an initial sample grid and relate each point that represents the moment of harvest to a point in the sample grid closest to its location. Therefore, the number of bags harvested in each location (sampling point) is theoretically obtained, estimating productivity, multiplying the number of bags by their average weight. Figure 5 shows how the sequence of steps in the field is carried out.

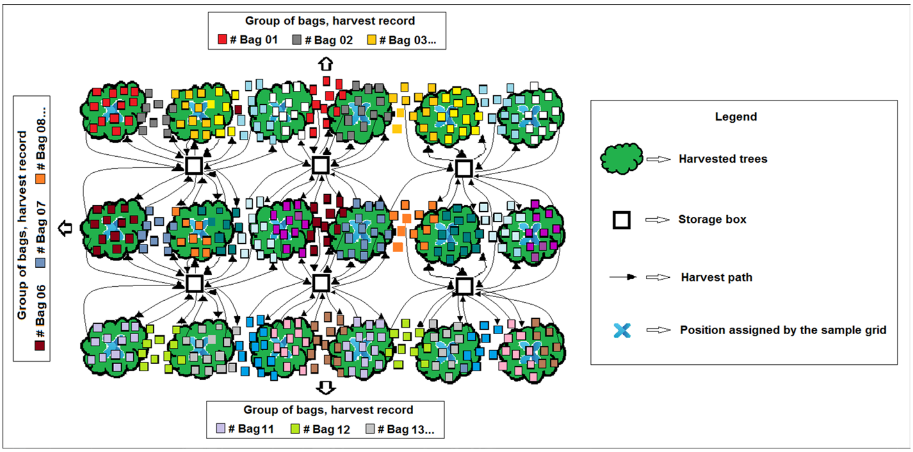

Fig. 5 Scheme for estimating yield considering method #2

During each harvesting pass, there is no established time for a bag to be filled by the worker. Furthermore, the number of fruits arranged in the trees can result in different amounts of points (and plants) for each bag harvested depending on the location condition and the agility of the worker. Thus, in order to give better visibility regarding the perception of the quality of the fruits of one or another tree, which may be very close, a procedure was carried out. The procedure aims to attribute the weight proportionality of each georeferenced point, in relation to the weight of the bag. That is, the proportion of weight participation at a given point is calculated by Eq. 1.

$$P_{Pij} = \frac{P_b}{N_j} \quad (1)$$

where, P_{Pij} is the equivalent proportion of a point i generated by the harvested bag j; P_b—is the weight of the bag; N_j—Number of georeferenced points at time j.

Greater precision is achieved with this definition of weights per georeferenced point, regarding the weight contribution that each period (represented by the sample point) effectively represents for harvest. This also allows distributing quality results of the fruit harvested by the area, using of the quality reports issued by the packing house. Besides that, the definition of weights allows the generation of quality maps without the need for on-site samples.

Software development

As a standard for software development, the Model-View-Controller (MVC) was used, opting for the use of free tools, with the IDE Spring Tools 4 for Eclipse (STS4) (Eclipse, 2020; Sommerville, 2011; Spring, 2020). The front end 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. To view the maps, the OpenLayers library was used (AdminLTE, 2020; OpenLayers, 2020). Java technology was the programming language adopted, through the JEE platform (Andrade, 2015; Deitel, 2016). The PostgreSQL database manager, the Postgis spatial extension and the Hibernate, and Hibernate Spatial data persistence frameworks were also employed (Hibernate, 2020; Hibernate Spatial, 2020; Momjian, 2001).

It was decided to use the *Application Programming Interface* (API) of the AgDataBox web platform (Agricultural Data Box; Bazzi et al., 2019) because of the complexity of working with data interpolation procedures. The AgDataBox can carry out geostatistical analysis and create thematic maps using ordinary kriging (Kri) or inverse distance weighting (IDW).

Software for importing, analyzing and creating a thematic map

Web software was developed for importing and interpreting the data collected in a field. It allowed the import of data through a file in text format (.txt), generated by the collection device. After importing the data, the software enabled data validation, which is read sequentially and stored in a database created for this purpose. Files generated by different workers can be imported and grouped in order to create yield maps with data obtained by

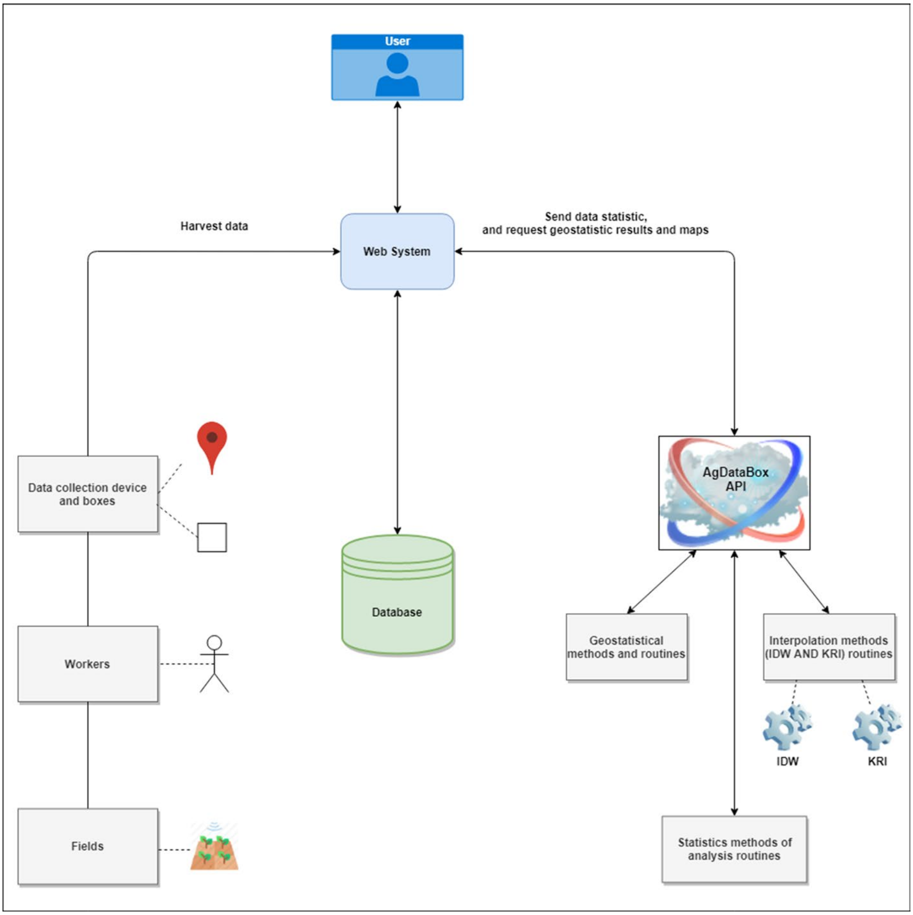

Fig. 6 Flowchart of operation of the developed web software. The web system integrate AgDataBox API functions with the harvest steps and keep a database

different workers in one harvest operation, as well as data collected in different operations, carried out in the harvest window.

The software allowed the stored data to be visualized punctually on the map, as well as the creation of thematic maps of productivity, which are generated through the application ADB-Map (Dall'Agnol et al., 2020) of the platform AgDataBox (Bazzi et al., 2019; Borges et al., 2020; Dall'Agnol et al., 2020; Michelon et al., 2019). In addition, the software allows performing geostatistical analysis automatically and creating productivity maps by inverse distance weighting (IDW) or kriging (Kri) (Fig. 6). The automatic setting of the best model fit for the semivariogram to be used in Kri was done by computational routines developed by Betzek et al. (2019) and implemented in the ADB-API.

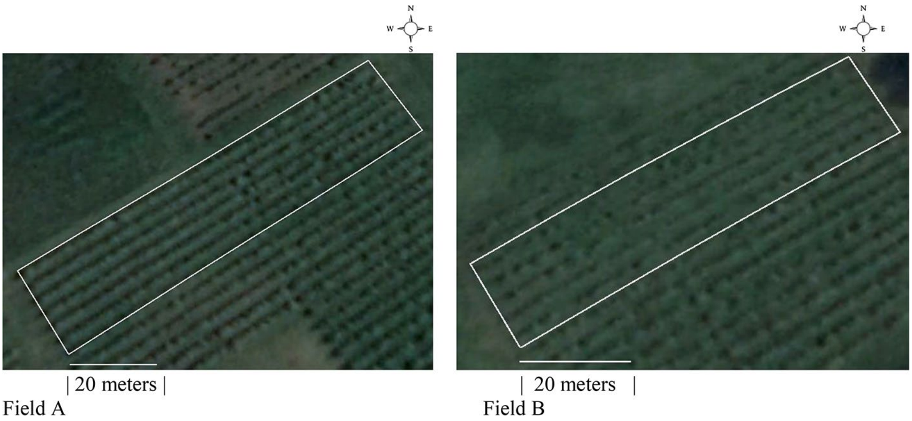

Fig. 7 EFCT fields used in the experiment

Experimental areas and harvest data

Two experimental areas were used (Fig. 7), which are located in the municipality of Vacaria, in the southern region of Brazil. These areas belong to the Experimental Research Station for Temperate Climate Fruits (EFCT) of Embrapa Grape and Wine (EMBRAPA UVA E VINHO, 2020), (50° 53′ 00.0″ W, 28° 30′ 53.3″ S). Field A (0.26 ha) was cultivated with the Maxi Gala variety and field B (0.17 ha) with Fuji Suprema.

Results and discussion

Importing data obtained in the field by using the harvest tracking device

After the harvest, the tracking devices were collected and the files, whose data were stored on MicroSD cards in the field units, were imported by the mapping system developed (Table 1).

Once the software was started, the area was registered and after the harvest was finished, it was possible to carry out the import and storage of datasets in the software database. Figure 8 shows the geographic layout of the data obtained in the system developed after importing the harvest data from the tested fields. Each colored dot represents a position obtained by the device at times when the harvest was being carried out. The different colors represent the different harvesting bins. It is important to note that, in many cases, the same plant contributes to more than one of the bins since several people are passing

Table 1 Datasets obtained from tracking devices during the harvesting of plots (A) and (B) in EFCT apple orchards, between 16 and 17 January 2020

Field	Year	Number of records
A	2020	4624
B	2020	3285

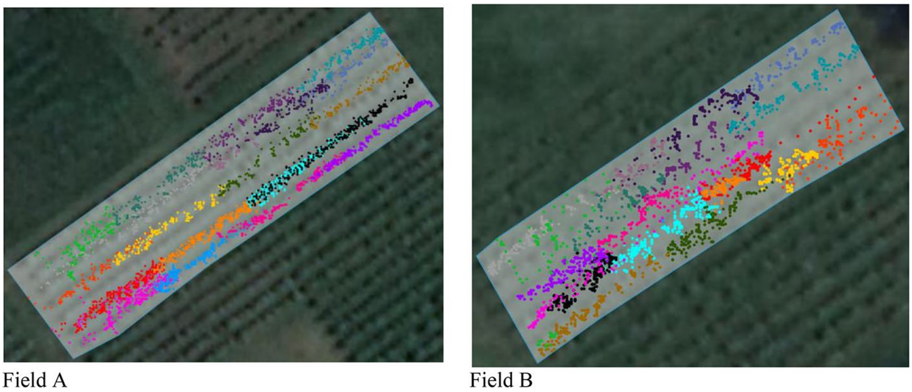

Fig. 8 Arrangement of the harvest data obtained by the device and presented in the developed software. Each color represents the location of points to harvest one bag

Table 2 Productivity estimate considering the proportion of bags collected, using estimation methods #1 and #2

Field-method	No. points	Proportion of unloaded bags				CV
		Mínimum	Mean	Median	Maximum	
Field A—Method #1	20	3	7.6	6.5	17	50.9
Field A—Method #2	112	0.04	1.33	0.92	6.4	100.4
Field B—Method #1	20	3	5.45	4.5	22	45.5
Field B—Method #2	70	0.034	1.52	0.99	13.8	125.3

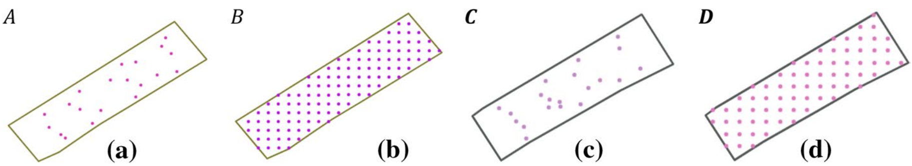

Fig. 9 Geographic arrangement of the sample points considering the productivity estimates considered by methods #1 and #2: **A** Field A—Method #1; **B** Field A—Method #2; **C** Field B—Method #1; **D** Field B—Method #2

through the line and executing the harvest simultaneously. Configured in this way, the system allows the generation of fruit contribution zones for each bin.

After importing the datasets related to the productivity, estimates were generated (Table 2) using methods #1 and #2. Method #1 is based on productivity and estimates productivity considering the geographic location of the bins (a sample corresponds to a bin). Thus, it was presented with a reduced number of sample points (20 for each plot) in relation to method #2 (112 for field A and 70 for field B). Then, when method #1 was used to estimate productivity, the number of sample elements was a limiting factor for making the experimental semivariogram for Kriging interpolation (Journel & Huijbregts, 1978). Clark

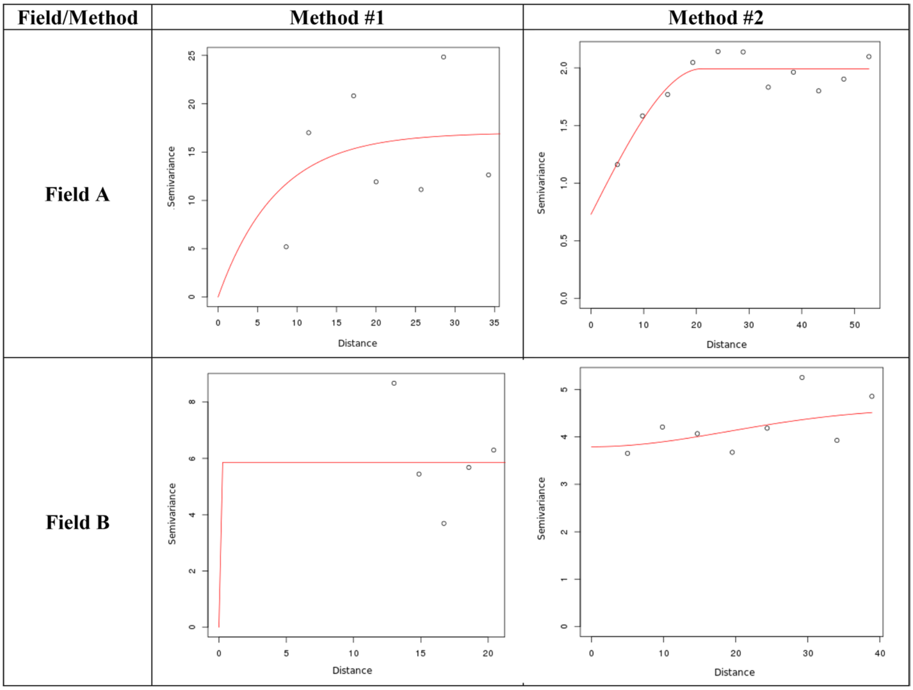

Fig. 10 Experimental semivariograms considering the yield estimates used by methods #1 and #2 in both fields

(1979) recommended at least 30–50 data points for using kriging. Nevertheless, some authors have suggested that the minimum number of data needed is as much as 100 (e.g., Webster & Oliver, 1993), especially for data that exhibit a large amount of short-range variability. The geographic layout of the sample points can be seen in Fig. 9.

After creating the semivariograms with the estimated yield datasets (Fig. 10), it was possible to identify a strong spatial dependence only for the dataset generated by method #2, in field A. For the other cases, kriging interpolation proved to be non-feasible considering the low number of sample points (method #1 in both areas) and low spatial dependence on the dataset generated by method #2, in field B. These sets were then subjected to interpolation by inverse distance weighting (IDW). For interpolation, the average weight of 14 kg of apple was used, for a completely full harvest bag.

The maps generated by the system can be seen in Fig. 11, possibly allowing future generation of management zones from harvest maps.

Conclusion

Software was presented able to import, store, do geostatistical analysis and data interpolation for the creation of yield maps in perennial crops. The yield maps were generated from the dataset obtained from harvesting apple trees by an electronic tracking device.

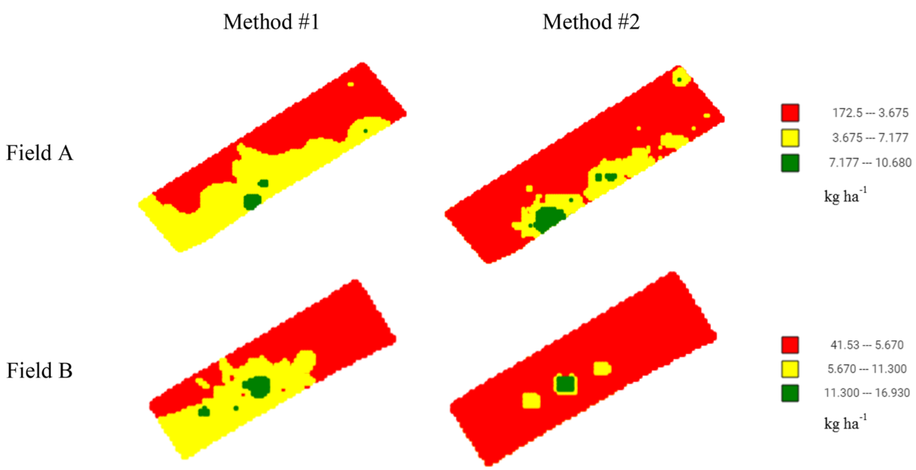

Fig. 11 Yield maps generated from the productivity (kg ha^{-1}) estimate obtained by methods #1 and #2, using the interpolators Kri (Field A, method #2) and IDW (for the other datasets)

The prototype of the tracking hardware developed, coupled to the harvest bag, met the objectives for which it was designed, and the geolocation of the points obtained at the time of harvest was consistent with what occurred in the field.

The software interface proved to be easy to use, in addition to automating processes in relation to obtaining productivity data from perennial crops (apple orchards).

Even though the methods for estimating crop productivity varied according to the number of points generated by the grid, both were able to generate yield maps for the crop (apple tree). Depending on the restricted number of sample points, method #1 was shown to be more restricted than method #2 in terms of the generation of maps by kriging.

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