Precision Agric
DOI 10.1007/s11119-012-9267-4

Participative site-specific agriculture analysis for smallholders

Pau Aragó Galindo · Carlos Granell · Paulo Guilherme Molin · Joaquín Huerta Guijarro

Abstract Site-specific agriculture has been adopted in a high-tech context using, for instance, in situ sensors, satellite images for remote sensing analysis, and some other technological devices. However, farmers and smallholders without the economic resources and required knowledge to use and to access the latest technology seem to find an impediment to precision agricultural practices. This article discusses the possibility of adopting precision agriculture (PA) principles for site-specific management but in a low technology context for such farmers. The proposed methodology to support PA combines low technology dependency and a participatory approach by involving smallholders, farmers and experts. The case studies demonstrate how the interplay of low technology and a participative approach may be suitable for smallholders for site-specific agriculture analysis.

Keywords Site-specific · Low technology · GIS · Smallholders · Participatory GIS

Introduction

Site-specific agriculture can be defined as a method for managing soil and crop production in a spatial and precise manner. It takes into account the conditions of various areas that, when combined, define the farming land (Schueller 1992). Site-specific agriculture is sometimes associated with the need for high technological equipment such as sensor-enabled devices, Global Positioning Systems (GPS) and Geographical Information

P. Aragó Galindo (✉) · C. Granell · J. Huerta Guijarro
INIT-Universitat Jaume I, Av. de Vicent Sos Baynat, s/n, 12071 Castelló de la Plana, Spain
e-mail: parago@uji.es

C. Granell
e-mail: canut@uji.es

J. Huerta Guijarro
e-mail: huerta@uji.es

P. G. Molin
"Luiz de Queiroz" College of Agriculture, University of São Paulo, São Paulo, Brazil

Published online: 27 April 2012

Systems (GIS). Technology providers and developers are pushing stakeholders to continuously adopt the latest technologies (Lamb et al. 2008). Nevertheless, precision agriculture (PA) should not be understood only as a high-tech discipline by definition (Molin 1997), but it has its roots in an 'observe-interpret-evaluate-implementation' methodology regardless of the means and tools used (Cook and Bramley 1998). Furthermore, a low technology approach should also be suitable for site-specific analysis provided that the driving principles behind the 'observe–interpret–evaluate–implementation' methodology are supported (Bouma et al. 1999).

PA became an attractive idea for most farmers and agriculture experts in developed countries as a method for optimizing agricultural production (Roberts et al. 2004; Sassenrath et al. 2008; Cook et al. 2003). For instance, site-specific agriculture became attractive for delineating productive zones based on soil quality and production (Mann et al. 2011). Indeed, many smallholders already have the idea of site-specific management in their minds (Cook et al. 2003), even if it is in their subconscious. An example of this is when a limited quantity of fertilizer has to be applied to only a specific location where and when it is needed and not evenly spread across all the farmland (Stoorvogel 2006). Other research has found that farmers know their farm's features and variability (Booltink et al. 2001). Nevertheless, a couple of factors seem to impede the exploitation of PA by smallholders for site-specific analysis in small farms.

First, PA has been based mostly on information technology, high levels of machinery and computational knowledge. This refers to an increase in economic resources as 'input'. For example, the application of high positional accuracy involves implementation costs (Booltink et al. 2001) and training time. This issue affects developing and developed countries alike since, in developed countries, the use of the latest technology in PA is not as widespread as believed (Lamb et al. 2008). Indeed, in Southern Europe the use of site-specific agriculture 'has been delayed because of small farm size' (Fountas et al. 2010) among other reasons. Moreover, in developing countries, a good proportion of the population lack expertise and access to the 'digital world' that surrounds many others; it has been called the digital division between developed and developing countries (ITU 2010). This situation is worse in rural areas which have less access to information technology, as compared to urban areas (James 2008). This gap is filled mostly but not always by 'leading farmers' who are often more highly educated, or take a local/regional 'leadership role' (Lamb et al. 2008) as early adopters of PA technology.

Second, PA is more feasible when the farmland is larger or based on the educational level of the owner (Roberts et al. 2004). Nevertheless, smallholders know their land. They know which areas are best for farming and they can also estimate their crop yield according to their observations. The problem is that this appreciation and knowledge is not recorded and shared. In contrast, experts have both academic and technical know-how. Experts can advise a smallholder based on their know-how and on information provided by smallholders and this is done-through oral communication.

What are the effects of these two factors on site-specific agriculture? Site-specific concepts remain the same, regardless of the farm size and the farmer's educational level. The assumption here is that farmer's knowledge of their land is of critical value compared with technological equipment and the application of sophisticated procedures, which are not needed but are of added value (Aggelopoulou et al. 2009). Computational resources, training, and even education, are scarce in rural environments (Diagne 2009). Even without the potential of being able to use high level technology, small farmers are still able to apply site-specific concepts and ideas by just referring, for instance, to paper maps. This is possible because small farmland owners are more familiar with their own land (Altieri 2004). Since most smallholders are traditional families that have lived on the land for quite some time, they can utilize their 'mental maps' to manage their land (Cook et al. 2003). However, it is important to provide farmers with environmental and agricultural education by using a methodology that will allow them to make appropriate decisions (Ma et al. 2009).

The problem raised here is how to communicate the concepts of PA for site-specific management strategies to smallholders in those cases where it is potentially feasible without having to use high-tech resources. This particular aim was to find out if monitoring, analysis and information exchange of farm production and management, following site-specific agricultural principles, would be feasible with low technology dependency for farmers in participatory contexts.

The paper focused on the use of a site-specific methodology and techniques for smallholders. The proposed methodology used as much of the available concepts of PA for site-specific agricultures as possible without having to use new technologies unknown to the smallholders. In addition, a co-operation among smallholders and experts was promoted to exchange information and advice. The methodology developed might be applied to smallholders in developed and developing countries.

Materials and methods

Study area

The study comprised five different small fields (parcels) located in La Vall d'Uixó, Valencian Community (Spain). Figure 1, shows the location of the parcels. The orange cultivation in the Valencian Community has been traditionally performed on terraces. A terrace has similar characteristics of soil and tree variety. The terraces were originally built to irrigate the trees using border irrigation techniques as well as to avoid erosion problems. A given field or parcel groups various terraces, since the tasks performed in the field are planned on the basis of the natural division into terraces with theoretically homogeneous conditions.

Table 1 shows the details of the fields studied. The field selected as a reference example throughout this paper ('A' in Table 1) is a single field with an area around 2.71 ha (Fig. 2) with only one owner. Farmers A, C, D and E are part-time farmers, while farmer B is a fulltime farmer. All the fields are cultivated with orange trees based on drip irrigation systems. The orange tree variety is mostly *Clemenules.* In the case of farm A, 11 terraces are devoted to *Clemenules*, and only one terrace to *Hernandina*, terrace labeled as m5 (Fig. 2). All the fields were changed from an olive and/or carob tree cultivation to the present orange trees between 1935 and 1990. With this change, a new layer of soil was laid in the area to improve soil conditions for the new cultivation. The change from olive/carob tree cultivation to orange tree cultivation was made by adding soil, to increase the depth and by leveling the field. The terrace may vary depending on the original terrain slope, being more narrow the higher the slope.

Farm A is representative of the Valencian Community's most common orange orchard farm. In the Valencian Community, 3 ha is the average size of an orange farm (MAPA 2003). 78% of farmers are part-time farmers (MAPA 2003).

Methodology

The proposed methodology aimed to collect and exchange spatial data to support site-specific analysis and decision-making based on two aspects: low technology dependency

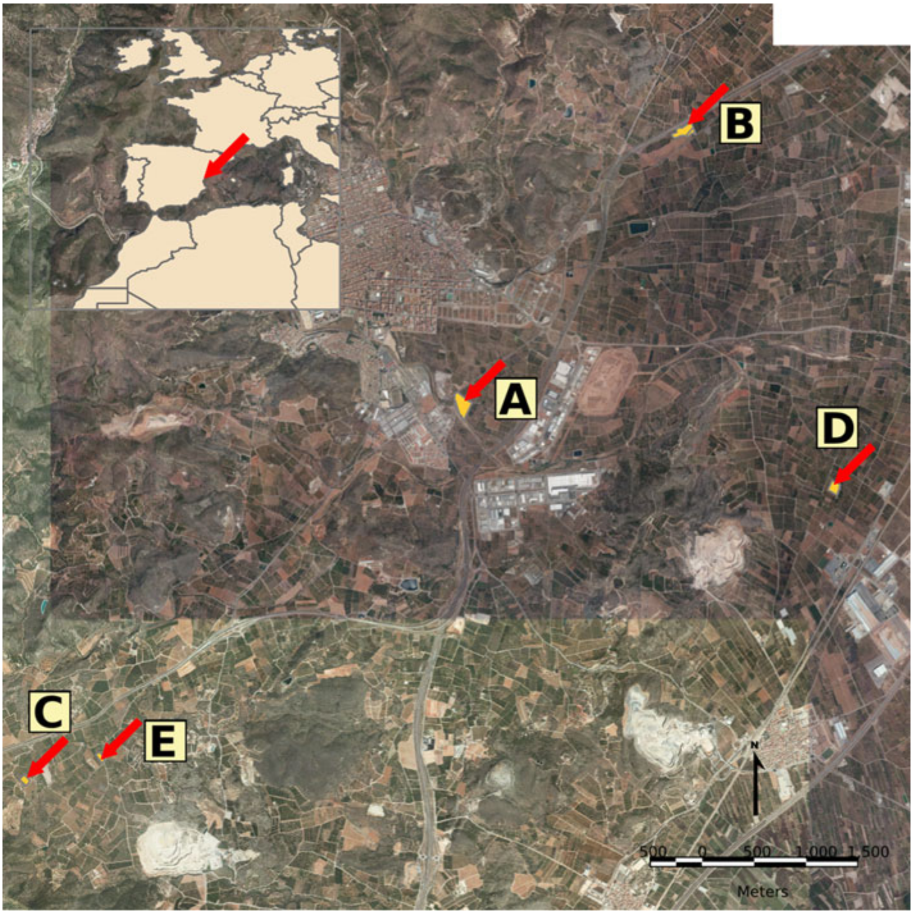

Fig. 1 Location of the farms at La Vall d'Uixó Municipality. The *red arrows* mark the location of the parcels in *orange color* (Color figure online)

Table 1 Description of the farms of the study

Parcel/ farmer id	Parcel area (ha)	Number of terraces	Average terrace area (m^2)	Orange tree	Orange field since	Co-ordinates
A	2.71	12	1 951	Clemenules/ Hernandina	1951–1968	39°48′43.37″N 0°13′21.08″W
B	1.7448	4	4 362	Clemenules	1935–1960	39°50′06.93′’N 0°11′47.26″W
C	0.5409	3	1 803	Clemenules	1983–1990	39°46′50.64″N 0°16′22.22″W
D	0.9917	3	3 306	Clemenules	1958–1962	39°48′13.96″N 0°10′52.06″W
E	0.4495	1	1 498	Clemenules	1970	39°46′57.00″N 0°15′51.56″W

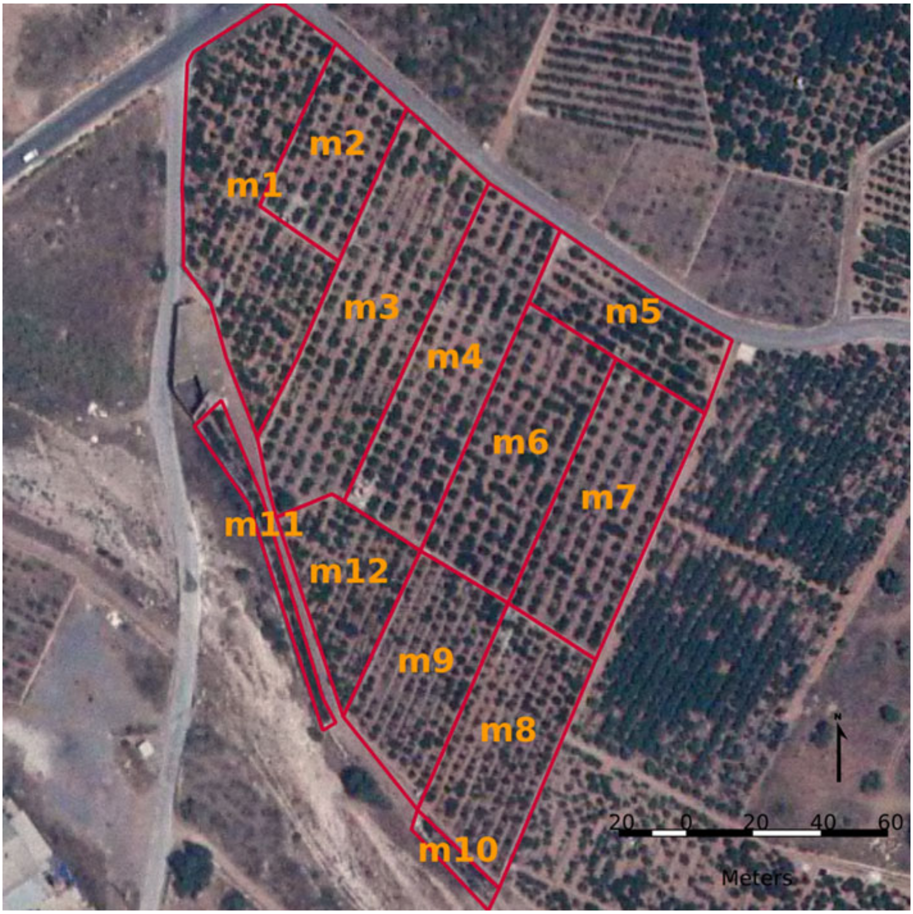

Fig. 2 Aerial image of the field 'A'. Terraces are marked with *red lines* (Color figure online)

for farmers and participatory context. The former refers to minimizing the use of technology to obtain the same or similar results. Many authors have proposed the use of GIS tools and geospatial services to benefit from software open source tools and online spatial data available (e.g. Nash et al. 2009; Paar and Rekittke 2011). In this paper, however, the term low-technology dependency suggests the use of traditional means in those contexts where high-technology tools and devices are limited (lack of resources, knowledge, time, etc.) or when a site-specific analysis can be carried out without the introduction of high level technology.

The latter, the participatory aspect, refers to a bottom-up approach to share information between participating stakeholders. In the geospatial information community, data collection is moving from a top-down approach to a bottom-up approach (Budhathoki et al. 2008). A top-down approach is a traditional way of collecting data by official institutions and experts. A bottom-up approach means that people (e.g., non-experts, citizens) are working as voluntary 'sensors' (Goodchild 2007). People can be like sensors providing spatial information directly from a source. In this scenario, experts can collect spatial information but can also take advantage of an individual's (such as a farmer/smallholder) contribution as a voluntary 'sensor'. The farmer's individual contribution is part of a wider contribution collected by the expert. This way of collecting spatial information has been also called as participatory GIS (PGIS) by Sieber (2006). PGIS facilitates data sharing and knowledge as well as learning interchange between involved participants (e.g. Hall et al. 2010; Bugs et al. 2010).

For this research, the principles of PA for site-specific management (Srinivasan 2006) were applied to five small orange tree farmlands in Spain (Table 1). The farmer collected spatial data using paper maps and notes. This data was shared with an expert, who then uploaded it into a GIS application. The expert could then perform data analysis to provide feedback to the farmer in a personalized way. In this way, farmers can acquire information in a short time frame by observing the environmental resources and production, consequently learning how to improve the management of their land. For example, farmers tend to know which part of the land might be better than another part by simply observing crop progress. These observations are in fact low technology site-specific information that can and should be applied.

Furthermore, two kinds of participants are involved in the following use cases with different technological experience. The first was the expert, who used GIS technologies (high-tech use case) that are not always accessible to smallholders. The second only used paper and pencil (low-tech use case) while still implementing site-specific agriculture behind the principles of PA.

High-tech use case

This section describes the use-case steps followed by the farmer and the expert user to collect needed data and upload it into a GIS tool to perform site-specific analysis (Fig. 3).

The first step was data preparation. It consisted, in this case, of digitizing the field boundaries, terraces and trees (Fig. 4). The most important issue in site-specific farming is location. The location was needed to assign inputs and outputs, in order to perform a posterior analysis that focused on the results per terrace. In other words, site-specific management cannot be performed without spatial data (e.g., data is associated with a concrete location). The map of the field must be drawn for this task. The technology used was gvSIG tool that allowed the expert user (central side Fig. 3) to access remote spatial data sets such as aerial imagery of the study area from the PNOA[1] server and thematic layers provided by the national cadastral agency[2] servers (right side Fig. 3). Hence, the subdivision of the field of study was digitized according to the terrace distribution (Fig. 2). This was also the same division used for the farmer's handmade map. The use of the PNOA image allowed for the digitization of tree position. The expert user provided a paper map of the farm with the terraces division (Fig. 4), cadastral agency data and tree position.

The second step was concerned with data collection and analysis. Data collection was exclusively done by the farmer. In the case of smallholders, it was sometimes difficult to discriminate outputs from each of the terraces within a parcel. Therefore, an effort has been made to measure the crop yield for each terrace (e.g., each subdivision in Fig. 2). The crop yield was harvested manually. Two farmers have measured the crop yield harvested by terrace (parcels A and C), and two farmers have measured the crop yield by parcel (parcels B and D). Farmers B and D did not know which amount of crop yield corresponded to

[1] Spanish national project that manages and offers orthophoto coverage created from aerial photography (http://www.ign.es/PNOA/).

[2] National cadastral agency in Spain (http://www.sedecatastro.gob.es/).

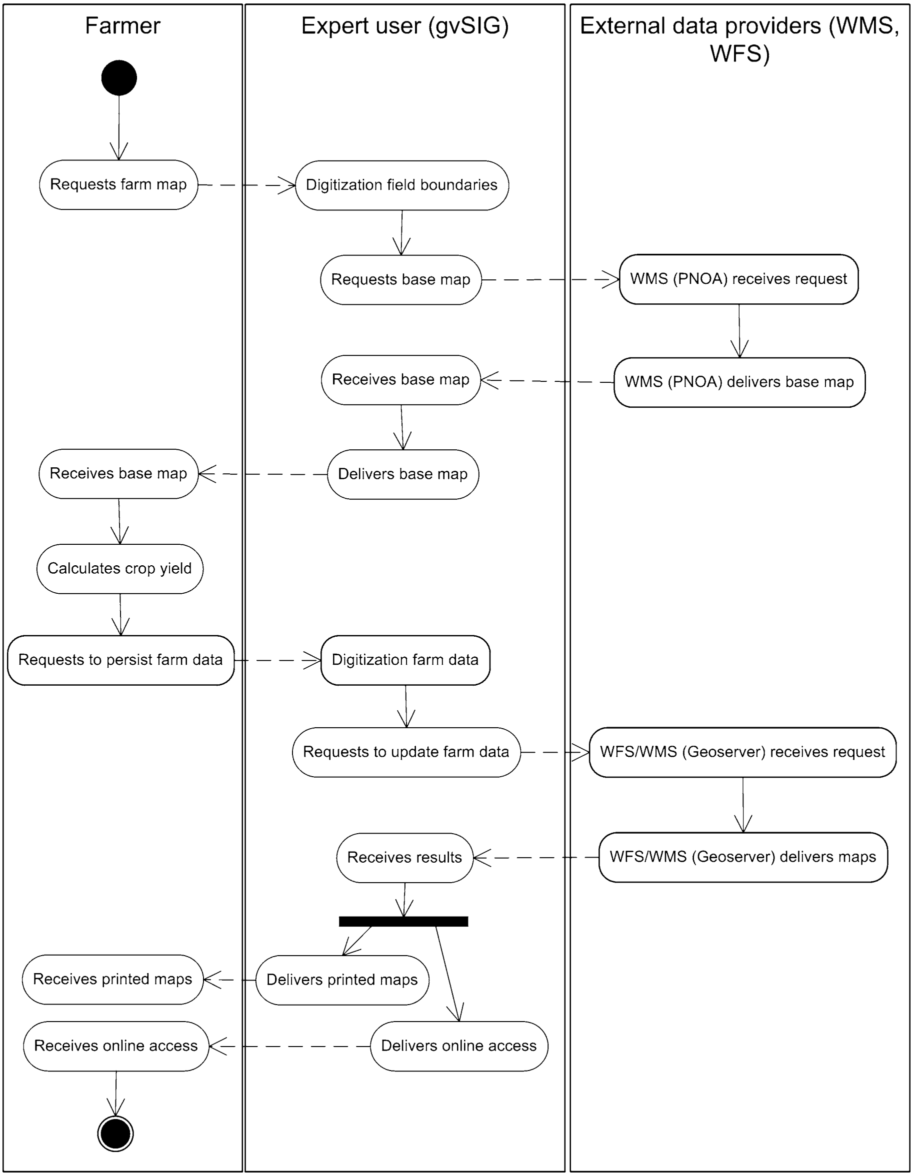

Fig. 3 The *left side* represent the farms, the *center* represents the expert user using a GIS tool [gvSIG—an open source GIS client tool to manage local and remote geospatial data sets (http://www.gvsig.org/web)], the *right side* represents spatial data available from remote services such as Web Map Service (WMS) and Web Feature Service (WFS). The former provides spatial data in image format. The latter provides spatial data in vector format. Nash et al. (2009) provide an extense overview on geospatial services

which terrace. Parcel E had only one terrace within the parcel. On the other hand, the orange data quality was measured by the Orange Packing Co-operative, where the fruit was processed. The co-operative provided feedback to the farmer with a report of the orange yield quality of the farm, not per terrace. The farmer estimated the orange quality per

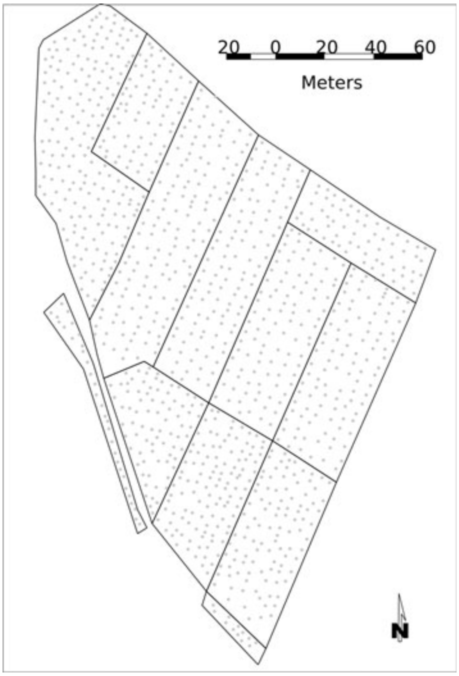

Fig. 4 Field map provided to farmer A by the expert. The map shows the division in terraces of the parcel and the tree location

terrace according to his experience. Hence, parcel orange quality was not considered in this paper because it was only estimated.

The third step consisted of translating collected farm data into a GIS tool, in this case gvSIG. Data was stored in a PostGIS[3] database using gvSIG as a client application. Both tools, gvSIG and PostGIS, are available in several languages and have abundant on-line documentation and tutorials. GvSIG has a mailing list to help users. Data analysis in this case was based only on the computation of some crop yield production parameters, such as harvested oranges in kg/ha, kg/tree and difference between years.

The fourth step referred to information feedback, which was provided to the farmer using printed maps or digital maps through a map viewer application. In this second case, the farmer connected through the map viewer application to on-line map servers (right side Fig. 3). Geoserver[4] was chosen to provide on-line spatial feedback to the farmer. Figure 5 summarizes the spatial information work-flow depicted in Fig. 3. Paper maps produced by the farmer can be available as historical records in Geo-TIFF[5] format.

Low-tech use case

In a non-technology approach, the farmer must use the site-specific management tools and principles (Srinivasan 2006) without the implementation of high levels of GIS technology.

[3] PostGIS is a spatial database extension for the open source PostgreSQL database (http://postgis.refractions.net/).

[4] Geoserver is an open source server to share and manage geospatial data. It is the reference implementation for some relevant OGC standards such as WMS and WFS (http://geoserver.org).

[5] GeoTIFF is a file format for georeferenced raster imagery (http://trac.osgeo.org/geotiff/).

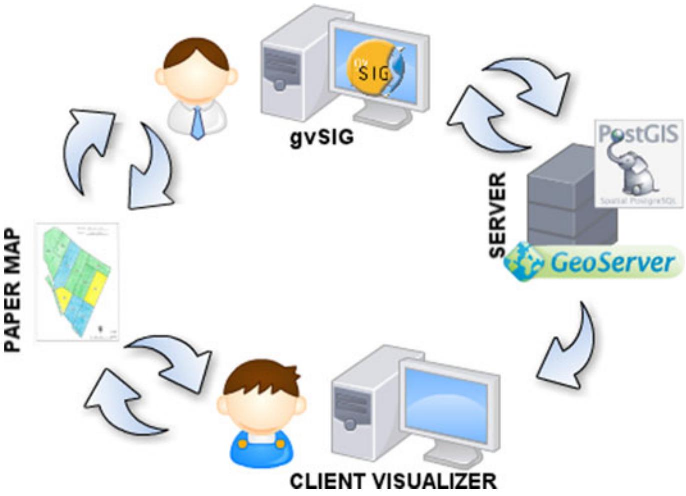

Fig. 5 Spatial information work-flow. The communication between farmer and expert is bidirectional based on digital maps, paper maps or scanned paper maps

The first step was data preparation with regard to field boundaries and terraces. Farmers A, B, C, and D had (prior to the experiment) a sketched map of their land divided into terraces for management purposes. All of the farmers were provided with a set of blank maps initially created with the gvSIG tool. All terraces were measured and labeled according to their area and terrace number. The farmer was also provided with a map (Fig. 4) of the land describing the trees positions.

The second step was data collection and analysis. The orange tree production was provided by the owner of the field as is commented in the previous section. Spatial data was collected using paper maps and paper spreadsheets. There was no difference in the data used by the expert because it is the same data acquired by the farmer. The farmers of parcels A and B showed their fruit yield in the map in kg per 1 000 m^2 to be more easily interpreted by the farmer. The farmers of parcels C, D, and E did not have a production map, so they did not know which crop yield corresponded to which terrace. A colored classification labeling system was created by each farmer (A and B) for the orange production; so that each farmer used his own scale to represent the production in kg per 1 000 m^2. The farmers, according to the crop yield outputs, colored each terrace within the parcel. The result was a map with production information and easy-to-view colored classification. Each production year map was stored as a hard-copy document to be used in the following years as a guide to fill in the information in the same way. The farmers also used the tree location map (Fig. 4) to mark those trees that were receiving special care or were under special control. Tree data was freely recorded by the farmer with just one condition: this recording had to be clear for the expert user. A third map was created by the farmer to limit the areas of the field with different features with regard to tree aspect or soil quality.

The owner will be able to modify the inputs or perform special care according to the analysis of the paper maps and the expert's feedback. For example, terraces with good productivity in previous years would receive less or no input, whereas less productive areas should receive more input or special care. An alternative strategy would be to remove trees from less productive areas.

Results and discussion

According to the steps described in the "Methodology" section, the results for the high-tech and low-tech use cases are described in the following sections.

High-tech use case

The use of GIS tools is an advantage because these tools allow the expert user to implement faster computation processes and advanced analysis using spatial data from remote information sources (e.g. PNOA WMS services). In addition, gvSIG also enables personalization (e.g., changes of colors, legends) and visualization of the analysis results in a more interactive way. Furthermore, the kg/tree ratio was calculated with gvSIG by the expert user. The computations between the field records were simple. The tasks performed with gvSIG support were:

- Calculation of surfaces in m^2, this surface is the same as used for the farmer for his maps.
- Calculation of the production ratio in kg/tree and kg/ha. The ratio allows for direct comparison between terraces and parcels.
- Uploading tree information into the system according to farmer paper maps.
- Uploading spatial data into PostGIS.

Tasks performed with Geoserver:

- Uploading spatial data into Geoserver.
- Uploading paper maps into Geoserver.

Figure 6 shows output maps created with gvSIG. The farmer received the gvSIG output maps from the expert. In addition, the farmer was able to retrieve spatial information from the Geoserver using a light client visualizer (Fig. 5).

Low-tech use case

Farmer A used paper maps to graphically describe the production of the parcel (Fig. 7). Also, he marked trees to delineate areas of the field with similar features. The farmer drew the production to create the map using a quantitative scale, but also performed fast mental calculations to estimate the production maps with regard to the yield. Some reasons motivated him to did this. First the farmer thought it would be better to compare the production between terraces. Second, it would be better to have the production in kg/trees, because there are parcels that have some young, old or sick trees that are not producing oranges. These observations made by the farmer were taken into account by the expert to produce a map with the location of the trees and to compute the kg/tree ratio. Paper maps with tree locations were used by the farmer in successive seasons to record qualitative information about the trees, such as old trees, new plant trees, non-productive trees, and special care (fertilizer addition) trees. The first orange production paper maps motivated the owner of parcel A to draw a map with his own observations about the soil quality. The other farmers, taking into account the experiences of parcel A, were advised to draw a map of soil quality. The different colored sections (e.g., Fig. 7) within the parcel were drawn according to the farmer's knowledge of the soil difference and the visual appearance of the trees.

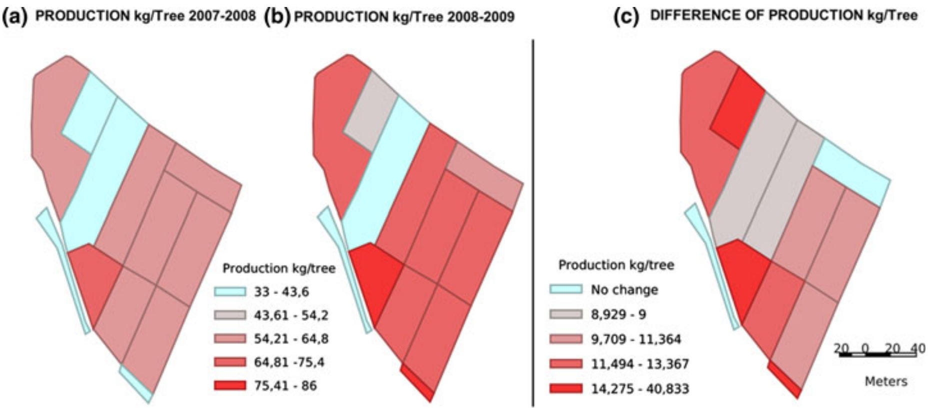

Fig. 6 gvSIG output maps of the crop yield distributed in terraces for parcel A. Seasons 2007–2008 and 2008–2009 (Color figure online)

The time used by the farmers to record the information on maps (i.e., Figs. 7, 8) and spreadsheets was around 4 h for farmer A and 1 h for farmers B, C, D and E, given that all the data were previously collected and distributed per terrace or parcel. Finally, the data collected by the farmers were:

- Production for seasons 2007–2008 to 2010–2011 for farmer A. Production for 2009–2010 and 2010–2011 for farmers B, C, D and E.
- New plant trees (seasons 2007–2011), farmer A.
- Old trees for season 2011, farmer A and B.

Fig. 7 Hand-colored map of soil quality assessment by farmer A (Color figure online)

- Trees with extra special fertilizer (season 2009–2010), farmers A, B, and C.
- Qualitative observation of soil quality and/or tree appearance, for all the farmers and parcels.

Fig. 8 Hand-colored map of the production distribution in the terraces of parcel A. Seasons 2007–2008 to 2010–2011 (Color figure online)

Technology dependency analysis

The farmers like using handmade maps, as they are easy for them to create. The farmers can use these maps to follow the increase or decrease in production. The production maps (Fig. 8) clearly show the terraces that have increased in production, and those that have maintained the same level of production (parcels A and C). Consequently, action plans will be defined according to the results of each parcel. Farmer A suggested an improvement for future maps by adding orange quality by visual assessment, which has a relationship with the final price. Nevertheless, the orange quality (feedback provided by the Orange Packing Co-operative) refers to the total amount of the farm production, as was explained earlier. Farmer A also suggested to predict the yield by using tree flowering (Aggelopoulou et al. 2009) enhanced with visual assessment and then comparing it with the real production. All these new estimations and recordings would be done by the farmer using the handmade maps. Farmers B and C also wanted to continue making handmade maps. Indeed, they asked for more copies of their parcel maps to continue recording the results. Farmers A, B, C and D concluded that it would be interesting to record the resulting maps to have an historical perspective of the evolution of their farms.

In general, the use of GIS tools or handmade maps made no significant difference from the farmers' point of view. The farmers easily performed hand calculations of the ratios and drew them on the maps. Nevertheless, if the farmer provides the amount of production to the expert, he can receive feedback of production result in kg/tree. The difference for the farmer's perspective is the GIS output visualization.

Farmers have stated that they would not attend a basic course of how to use GIS tools for producing the maps, but they would continue with the methodology of using handmade maps. For instance, farmers A and C would record more parameters of the field inputs and outputs, such as the orange quality. Using this data, they would produce some maps, plan their tasks and in some cases show the data and paper maps to a consultant expert. Only farmer E has no interest in following up with paper maps, since his parcel is small and it is not very profitable.

Farmers A and C preferred the maps created with GIS tools, as they can see the differences better with these maps than with handmade ones. They can easily visualize more information in different ways. Farmer A has noticed the evolution of terrace m12 where he has added fertilizer, because the trees had symptoms of a low level of iron (this is an observation of the farmer). The production has increased in this terrace. The expert provided feedback with GIS maps which represented a visual description of the situation.

Participatory GIS analysis

The farmer contributed to the process by providing data from his farmland. The expert user received data from the farmer and uploaded it to the GIS tool, making such data available to other users. Expert users will be able to provide spatial feedback to the farmer with processed information or with other spatial information that will be important for the farmer, such as NDVI (Mann et al. 2011). This methodology provided a dialogue between the farmer and the expert with a never-ending work-flow of information (Fig. 5). All of the farmers have concluded that they are favorably disposed to providing maps to an expert. They were also favorable towards sharing their data if an expert requires it, however, only if they receive feedback and the expert's advice.

This exemplifies a collaborative approach to data collection directly from the source, the farmer. With this data, the expert can complete his/her spatial information with a wider overview of the situation including the farmer's concerns.

Site-specific implications

The success of this methodology depends on a continuous collaboration and information exchange among the different participants. Expert users do not know the field as well as the smallholders. On the other hand, the farmers require some advice regarding advanced agricultural issues. The use of paper maps may help to improve spatial communication among different participants and integrate the collected data with other data sources (Van Wart et al. 2010). The farmer should be able to collect spatial information as easily as possible, by taking advantage of his/her knowledge so as to locate the crop variables on a paper map. As experts require information in GIS formats, paper maps need to be introduced into GIS tools to be processed and analyzed. Hence, the mapping process is the vehicle for exchanging information. The paper map complements the oral information exchange. Indeed, the expert users have an historical record of the field and not just some indications from a farmer based on his memory. On the other hand, as the farmers are getting used to this methodology, they will likely read maps more easily and will be able to understand the feedback of the expert based on maps.

After the experiment, farmers A, B, C and D conferred to identify different problems encountered among their parcels and to assess the next decisions together. Farmers A and B decided to add extra fertilizer to some trees and improved the pruning of a group of trees. Farmer C will provide more organic matter to some parts of his parcel. Farmer D noticed a draining problem in a group of 11 trees. Farmer D will try to improve drainage in that zone. Farmers B and D will measure their crop yield in the future by terrace instead of by parcel. In summary, most farmers (A, B, C and D) have made decisions about the field management based on paper maps and expert feedback to improve site-specific farming. Indeed, such decisions were not applied to the entire parcel but focused on particular parts of the parcel (site-specific). Only farmer E did not change his farm management habits.

The aims of site-specific farming (Srinivasan 2006) are reducing costs, optimization of yield and quality in relation to the productivity capacity of each site, improving the management of the resource base, and protecting the environment. A farmer has to be able to gather information about his field in a way that spatial and temporal variation of the field conditions can be recorded and archived. The collected information should be quantitative in order to perform critical analysis and assessment. Nevertheless, qualitative information may also be recorded as the farmer deems useful for crop management. With the input and output records and expert feedback, the farmer can perform site-specific management of the field, according to predefined objective parameters. Such principles mention the need of spatial and temporal data for site-specific management, but they do not focus only on the technology that makes it possible. Therefore, it is suggested that, in certain scenarios such as those described in this paper, the use of high level technology and equipment is not essential (Cook and Bramley 1998). It is possible for smallholders to take advantage of their field knowledge to locate and represent different variables spatially.

Conclusions

This paper assessed whether site-specific management may be accomplished based on low technology dependency (by farmers) and using a PGIS approach. The following points are the conclusions of this research:

- The implemented methodology is clear and easy to follow by farmers in order for them to collect spatial information by using paper maps.

- The handmade maps provide enough information to allow the farmer to understand his crop situation and farm differences.
- GIS outputs provide extra information to allow the farmer to analyze the current situation.
- Site-specific management can be done in small farms based on farmers mental maps, paper map records, and information exchange with an expert.
- A consultant expert is always needed and can guide the farmer in several tasks such as data collection and decision making.
- The work-flow provides a dynamic dialogue between the farmer and the expert. Both participants can benefit from this collaborative approach.

Although the farmers already had the required knowledge, only after making the maps were they able to realize the problems affecting particular parts of their parcels and most importantly, identify the causes that provoked them. Spatial information is of unquestionable value to farmers to make valid decisions. Simple paper maps may be sufficient to incorporate spatial information into the decision-making processes of smallholders. This exercise has provided the farmers with a new tool to collect data and interpret the results obtained to improve the site-specific management of their fields. The expert users can also benefit from papers maps. For instance, if the methodology is adopted by the farmers of a region, the expert users will get an overview of the past and current situation of a given area that may contain several parcels. The participatory methodology provides the expert users first-hand information about the farmers' concern, they receive feedback and added-value information based on the data provided by the farmer. As the spatial information is centralized in a map server, different experts can have access to the data to analyze it and give feedback to other users or to the farmer.

This paper has proposed a methodology to explore the possibilities of involving smallholders in the process of decision-making together with experts in a participatory approach using paper maps and geospatial technologies. The proposed methodology may provide a significant change in the adoption of site-specific agriculture: the farmer provides more field data to the expert as long as the expert provides spatial information and useful advice to the farmer. Future plans include testing this methodology on a larger scale. The testing will require the participation of farmer communities, associations or co-operatives initiatives.

Acknowledgments We would like to thank the farmers that have participated in this study, providing us with their particular view of their land. The authors wish to thank Dori Apanewicz for proof-reading the manuscript.

References

Aggelopoulou, K. D., Wulfsohn, D., Fountas, S., Gemtos, T. A., Nanos, G. D., & Blackmore, S. (2009). Spatial variation in yield and quality in a small apple orchard. *Precision Agriculture, 11*, 538–556. doi: 10.1007/s11119-009-9146-9.

Altieri, M. A. (2004). Linking ecologists and traditional farmers in the search for sustainable agriculture. *Frontiers in Ecology and the Environment, 2*(1), 35–42. doi:10.1890/1540-9295(2004)002[0035:LEATFI]2.0.CO;2.

Booltink, H., van Alphen, B., Batchelor, W., Paz, J., Stoorvogel, J., & Vargas, R. (2001). Tools for optimizing management of spatially-variable fields. *Agricultural Systems, 70*(2–3), 445–476. doi: 10.1016/S0308-521X(01)00055-5.

Bouma, J., Stoorvogel, J., & Booltink, H. (1999). Pedology, precision agriculture, and the changing paradigm of agricultural research. *Soil Science Society of America Journal, 63*(6), 1763–1768.

Budhathoki, N. R., Bruce, B. C., & Nedovic-Budic, Z. (2008). Reconceptualizing the role of the user of spatial data infrastructure. *GeoJournal, 72*(3–4), 149–160. doi:10.1007/s10708-008-9189-x.

Bugs, G., Granell, C., Fonts, O., Huerta, J., & Painho, M. (2010). An assessment of Public Participation GIS and Web 2.0 technologies in urban planning practice in Canela, Brazil. *Cities: The International Journal of Urban Policy and Planning, 27*(3), 172–181. doi:10.1016/j.cities.2009.11.008.

Cook, S. E., & Bramley, R. G. V. (1998). Precision agriculture—Opportunities, benefits and pitfalls of site-specific crop management in Australia. *Australian Journal of Experimental Agriculture, 38*(7), 753. doi:10.1071/EA97156.

Cook, S. E., O'Brien, R., Corner, R. J., & Oberthür, T. (2003). Is precision agriculture irrelevant to developing countries? In J. V. Stafford & A. Werner (Eds.), *Proceedings of the 4th European conference on precision agriculture* (pp. 115–119). Wageningen: Wageningen Academic Publishers.

Diagne, A. (2009). Technological change in smallholder agriculture: Bridging the adoption gap by understanding its source. In *Agriculture for development in Sub-Saharan Africa*, UC Berkeley, Center of Evaluation for Global Action, Mombasa, Kenya. Accessed 4 February 2012, from http://www.escholarship.org/uc/item/1wf5q4bm.

Fountas, S., Aggelopoulou, K., Bouloulis, C., Nanos, G. D., Wulfsohn, D., Gemtos, T. A., et al. (2010). Site-specific management in an olive plantation. *Precision Agriculture, 12*(2), 179–195. doi:10.1007/s11119-010-9167-4.

Goodchild, M. F. (2007). Citizens as voluntary sensors: Spatial data infrastructure in the world of web 2.0. *International Journal of Spatial Data Infrastructure Research, 2*, 24–32.

Hall, G. B., Chipeniuk, R., Feick, R. D., Leahy, M. G., & Deparday, V. (2010). Community-based production of geographic information using open source software and web 2.0. *International Journal of Geographical Information Science, 24*, 761–781. doi:10.1080/13658810903213288.

ITU. (2010). Measuring the information society 2010. Technical report, International Telecommunication Union. Accessed 4 February 2012, from http://www.itu.int/ITU-D/ict/publications/idi/2010/index.html.

James, J. (2008). The digital divide across all citizens of the world: A new concept. *Social Indicators Research, 89*(2), 275–282. doi:10.1007/s11205-007-9156-9.

Lamb, D. W., Frazier, P., & Adams, P. (2008). Improving pathways to adoption: Putting the right p's in precision agriculture. *Computers and Electronics in Agriculture, 61*(1), 4–9. doi:10.1016/j.compag.2007.04.009.

Ma, Y., Chen, L., Zhao, X., Zheng, H., & Lü, Y. (2009). What motivates farmers to participate in sustainable agriculture? Evidence and policy implications. *International Journal of Sustainable Development & World Ecology, 16*(6), 374. doi:10.1080/13504500903319047.

Mann, K., Schumann, A., & Obreza, T. (2011). Delineating productivity zones in a citrus grove using citrus production, tree growth and temporally stable soil data. *Precision Agriculture, 12*, 457–472. doi:10.1007/s11119-010-9189-y.

MAPA. (2003). *Libro blanco de la agricultura y el desarrollo rural* [Agriculture and rural development white book]. Madrid: Ministerio de Agricultura Pesca y Aalimentación (MAPA), Centro de Publicaciones. Accessed 8 February 2012, from http://www.libroblancoagricultura.com/publicacion/publicacion.asp.

Molin, J. (1997). Agricultura de precisao, parte 1: o que e o estado da arte em sensoriamento [Precision agriculture part 1: Remote sensing state of the art]. *Engenharia Agricola (Brazil), 17*(2), 97–107. Accessed 9 December 2012, from http://br.monografias.com/trabalhos901/agricultura-precisao-sensoriamento/agricultura-precisao-sensoriamento.pdf.

Nash, E., Korduan, P., & Bill, R. (2009). Applications of open geospatial web services in precision agriculture: A review. *Precision Agriculture, 10*, 546–560.

Paar, P., & Rekittke, J. (2011). Low-cost mapping and publishing methods for landscape architectural analysis and design in slum-upgrading projects. *Future Internet, 3*(4), 228–247.

Roberts, R. K., English, B. C., Larson, J. A., Cochran, R. L., Goodman, W. R., Marra, M. C., et al. (2004). Adoption of site-specific information and variable-rate technologies in cotton precision farming. *Journal of Agricultural and Applied Economics, 36*(1), 148.

Sassenrath, G., Heilman, P., Luschei, E., Bennett, G., Fitzgerald, G., Klesius, P., et al. (2008). Technology, complexity and change in agricultural production systems. *Renewable Agriculture and Food Systems, 23*(Special Issue 04), 285–295. doi:10.1017/S174217050700213X.

Schueller, J. K. (1992). A review and integrating analysis of spatially-variable control of crop production. *Fertilizer Research, 33*(1), 1–34. doi:10.1007/BF01058007.

Sieber, R. (2006). Public participation geographic information systems: A literature review and framework. *Annals of the Association of American Geographers, 96*(3), 491–507. doi:10.1111/j.1467-8306.2006.00702.x.

Srinivasan, A. (2006). *Handbook of precision agriculture: principles and applications*. Binghamton NY: Food Products Press.

Stoorvogel, J. (2006). Precision farming and smallholders. Accessed 9 December 2012, from http://ictupdate.cta.int/en/Regulars/Q-A/Q-A-Precision-farming-and-smallholders.

Van Wart, S., Tsai, K. J., & Parikh, T. (2010). Local ground: A paper-based toolkit for documenting local geo-spatial knowledge. In A. Dearden (Ed.) *Proceedings of the first ACM symposium on computing for development*. London: ACM Press. doi:10.1145/1926180.1926194.