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Precision techniques for improving the management of the olive groves of southern Spain

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Abstract

Precision agriculture has progressed in integrating different techniques, but nowadays the environmental and economic benefits of implementing the concept remain unproven. This is the first study that analyzes the agronomic and economic impact of the application of precision agriculture to a specific crop. This paper presents a study applied to olive orchards at a high level of detail. The research is conducted in order to establish a methodology for integrating Geographic Information Systems (GIS) and Global Positioning System (GPS) to implement precision agriculture in a specific olive grove in southern Spain. In this study the variability of five consecutive harvests, the homogeneous areas within the farm and the composition of the crop nutrients are all analysed. Different georeferenced management areas, analysis of cost of tillage, fertilization, herbicide treatments, pruning and harvesting are integrated into a GIS. In this study it has been possible to select a zone in the exploitation knowing immediately, for example, if the leaf N content was less than 1.5% in any campaign. The results show that detailed analyses in collecting the harvest and in the use of agrochemicals help to produce reductions in their use, with the consequent savings to olive growers and, in general, environmental benefits for the whole of society.

Additional key words: GIS; GPS; olive farming; precision agriculture.

Resumen

Técnicas de precisión para mejorar el manejo de los olivares en el sur de España

La agricultura de precisión ha avanzado en la integración de diferentes técnicas, pero en la actualidad los beneficios ambientales y económicos de aplicación no se han probado. Este es el primer trabajo que analiza el impacto agronómico y económico de la aplicación de la agricultura de precisión a un cultivo específico. Este trabajo presenta un estudio aplicado a un olivar con un alto nivel de detalle. La investigación se lleva a cabo con el fin de establecer una metodología para la integración de Sistemas de Información Geográfica (SIG) y Sistema de Posicionamiento Global (GPS) para implementar la agricultura de precisión en un sitio específico del olivar en el sur de España. En este trabajo se han analizado la variabilidad de las cinco cosechas consecutivas, las áreas homogéneas dentro de la finca y la composición de los nutrientes de los cultivos, y se han integrado en un SIG las áreas georreferenciadas de manejo diferencial y el análisis de costo de la labranza, fertilización, tratamientos herbicidas, la poda y cosecha. Como resultado ha sido posible seleccionar una zona en la explotación y conocer inmediatamente, por ejemplo, si el contenido de N de la hoja era inferior a 1,5% en cualquier campaña. Los análisis de detalle en la recolección y en el uso de agroquímicos ayudan a producir reducciones en el uso de los mismos, con el consiguiente ahorro a los productores aceite de oliva y, en general, los beneficios ambientales para el conjunto de la sociedad.

Palabras clave adicionales: agricultura del olivar; agricultura de precisión; GPS; SIG.

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Abbreviations used: DEM (digital elevation model); GIS (geographic information system); GPS (global positioning system).

Introduction

Precision Agriculture is a relatively new concept in farming in which spatial and temporal variability within a field are analysed in order to improve benefits (Stafford, 2000). This concept is based on new technologies of positioning and representation such as GPS (Global Positioning System) and GIS (Geographic Information System). These tools allow us to map a study area and extract and plot information with high variances within the field instead of estimating an average value for the entire field (Neményi *et al.*, 2003). In practice this can be summed up as "doing the right thing" at "the right place" and at "the right time", using sensors, computers and other electronic equipment in order to render this process automatic (Lowenberg-DeBoer, 2001). Thus, according to Blackmore (2002), precision agriculture is the management of farm variability in order to improve economic benefits and reduce environmental impact.

The increase of farm size, mechanization and specialization of farm practices mean that a farm is not homogeneous across its surface or over time, so there is a variability that should be studied (Zhang *et al.,* 2002):

— Yield variability: Maps representing variations in the distribution of crops of previous years can be generated. In order to study both spatial and temporal variability the integration of yield maps of a UK cereal farm obtained in successive years using a GIS must be highlighted (Swindell, 1997), as well as a PhD thesis based on the realization of yield maps during successive years in England (Blackmore, 2003). Other research also works with maps of yield variability of tree crops: vineyards, orchards and citrus groves (Bramley & Hamilton, 2004; Zaman & Schumann, 2005; Tisseyre & McBratney, 2008; Arnó *et al.*, 2009; Aggelopoulou *et al.*, 2010).

— Field variability: Spatial and temporal variability of a field must be analyzed to improve benefits (Stafford, 2000).

— Variability of soil fertility: This depends on the availability of nutrients: nitrogen (N), phosphorus (P), potassium (K), etc., and also important are the soil´s physical and chemical properties.

— Management variability: Most studies are related to the distribution of fertilizers and plant protection products using variable rate technologies (VRT) applied to tree crops (Ehsani *et al.*, 2009).

It is necessary to take into account all the information collected in order to make good agricultural management decisions. This is linked to a new concept of positioning and representation technologies such as GPS and GIS which are emerging in precision agriculture.

Over the last 15 years of development, precision agriculture has progressed in integrating different techniques, but the environmental and economic benefits of implementing the concept remain unproven (Stafford, 2000). The reasons for adopting this technology come from: a) the growing concern over the excessive use of agrochemicals; b) increasingly stricter legislation on the environment; and c) the economic benefits of reducing inputs and improving the efficiency of farm management.

Regarding the economic benefits for farmers, Lambert & Lowenberg-DeBoer (2000) conducted a literature review of 108 studies related to precision agriculture, which found that 69% of the studies showed some economic benefits. A general rule is that higher profitability is achieved with high-value crops.

The research for the development and implementation of Precision Agriculture began with cereal crops. Nowadays, precision agriculture for traditional crops such as maize, wheat, rice, cotton, soybeans, and other row crops is being widely used (Casanova *et al.*, 1998; Panda, 2003; Magri, 2005; Baez-Gonzalez *et al.*, 2005; Lobell *et al.*, 2005). There are also some studies on implementing precision agriculture in perennial crops. Some theoretical work on the potential advantages of its use (Emmott *et al.*, 1997) has been applied , specifically to citrus in Florida (Whitney *et al.*, 1998; Schueller *et al.*, 1999), in a banana plantation in Costa Rica (Stoorvogel & Orlich, 2000), and in vineyards in Australia (Bramley *et al.*, 2005; Cook *et al.,* 2006), in France (Tisseyre *et al.*, 2005; Goutouly *et al.*, 2006), in Chile (Ortega *et al.*, 2003) and in Spain (Arnó *et al.*, 2005).

The cultivation of olive trees (*Olea europaea* L.) is distributed mainly throughout the Mediterranean area, which contains 95% of the global olive grove surface, amounting at present to 8.8 million hectares (Vilar *et al.*, 2005). Southern Spain, especially Andalusia, contains the greatest concentration of Spanish olive cultivation (75%) (IEA, 2004) and supports the population of many rural Mediterranean areas (Loumou & Giourga, 2003), so optimal use of land in olive groves is an obvious necessity (Berzal *et al.*, 2004). Despite the importance of this crop in precision agriculture olive farms have not yet been well developed. In this sense we can highlight the early work related to this issue of Alcalá Jiménez *et al.* (1998a,b), and more recently by Perez-Ruiz *et al.* (2010) and Ramos *et al.* (2007, 2008), which are some initiatives for the implementation of precision farming of olive trees.

The goal of our research was to study the implementation of Precision Agriculture, through the use of GPS and GIS, in an olive farm sited in southern Spain. Different georeferenced management areas within the farm are delineated using GPS, and analysis of costs of tillage, fertilization, herbicide treatments, pruning and harvesting are integrated into a GIS to analyse the economic impact.

Material and methods

Description of the farm

It is first necessary to note that this methodology has worked on a farm in full production. Is not, therefore, an experimental farm. This determines certain aspects of research such as the lack of uniformity in the collection during the different campaigns. But the results can be described as real and applicable to any farm operated by olive farmers without knowledge of scientific analysis.

The farm was chosen for being representative of most of the olive groves in the South of Spain. An unirrigated olive orchard located in Martos (37°39’20’’ N and 4°3’15’’ W), province of Jaen, Andalusia (Spain) was chosen. This farm consists of two plots separated by a dirt road. The cadastral references of these plots are (county / municipality / polygon / plot): 23 / 60 / 43 / 7 and 207. The total area of operation is 31.7 ha. This property has 2,633 mature olive trees, three trunks, and is planted on a framework of 11 m. The average plantation density is 83 trees ha^{-1} (Fig. 1).

Technical and economical characteristics of the farm

In order to determine the profitability of the farm, cultivation practises were monitored: tillage, fertilizer, herbicide treatments, pruning, harvesting and processing. All this information was considered for five consecutive campaigns, evaluating all the costs. As an example the average annual direct costs can be seen in Table 1.

Indirect costs (maintenance, management, etc.) accounted for € 83 ha^{-1}. Income from the cultivation of olive trees is linked to oil production. This includes

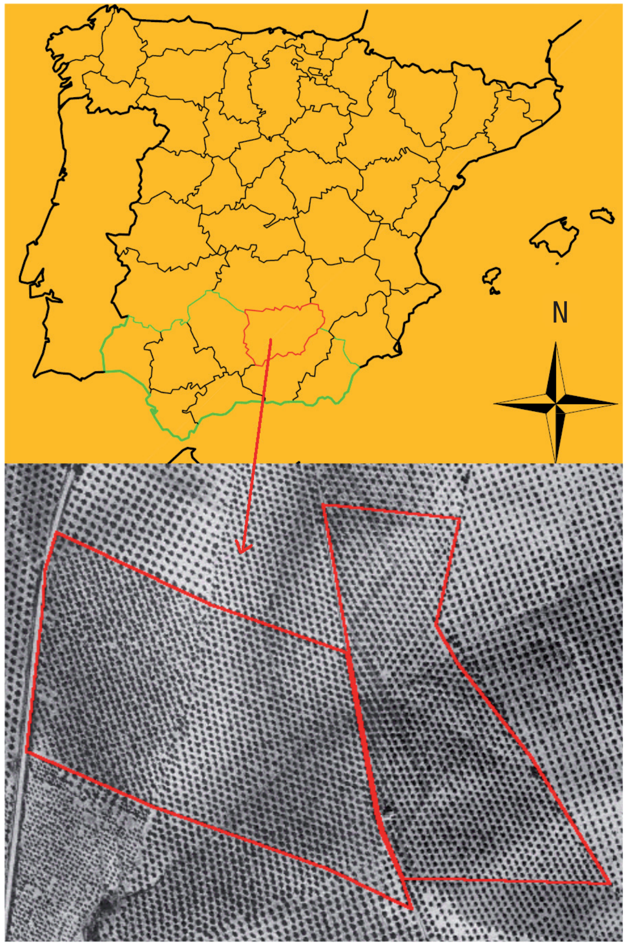

Figure 1. Location map of Andalucía and Jaen (above). Aerial picture of the farm (below). Extracted from the SIG Oleícola (MAGRAMA, 2011).

Table 1. Direct costs of farming practices

Farming practices	Total cost (€)	Cost per hectare (€ ha^{-1})	Relative cost (%)
Soil management	6,162.96	194.62	18.2
Pruning and cleaning	5,747.17	181.49	16.9
Phytosanitary treatments	1,366.50	43.15	4.0
Fertilization	2,161.43	68.26	6.4
Harvest, transportation and cleaning	18,508.89	584.50	54.5
Total	33,946.95	1,072.02	100.0

Table 2. Net margin of the farm

€ ha^{-1}	Campaign	
	4	5
Total income	2,475.76	3,875.96
Total costs	1,155.02	1,416.15
Net margin	1,320.74	2,459.81

Table 3. Olives and oil harvest

Campaign	Olives (kg)	Fat yield (%)	Oil (kg)
1	132,198	19.89	26,294
2	150,787	24.09	36,332
3	51,046	28.10	14,346
4	118,721	24.55	29,144
5	179,527	27.02	48,504

income earned from the sale of olive oil and revenues from European Union aid to olive oil.

The net margin is determined by the difference between the total income and the total cost of cultivation (direct and indirect). As an example, Table 2 shows the difference between income and costs of the farm in campaigns 4 and 5, expressed in current prices.

In Table 3, a summary of the harvest of the five campaigns is presented. It includes data on the kilograms of olive fruits harvested, the oil obtained in the mill performance and fat yield from the two plots of the property. Data were obtained from the olive harvest, oil and fat yield (the latter relates the olive harvest and oil). Thus, the values of oil production per unit area (m^2) were obtained from multiplying the kilograms of olive by fat yield (in per unit) of the year concerned.

Data capture

Agricultural databases need several years to be reliable, due to climate variability. So in order to have accurate information of potential harvests data are needed from several campaigns. Data were taken from the harvest of five campaigns from 1999 to 2004. In the same way, collecting fertility data on the same areas for several years allows us to determine the gradient of fertility of the farm (Lowenberg-DeBoer, 1996).

In 2001 and 2002 foliar analyses were also performed (N, P, K and B were analysed) and a digital elevation model (DEM) of the farm studied was performed. See methods below. To georeference the data two GPS relative positioning with System 1200 Leica dual- frequency receivers were used to obtain the planimetric and altimetric coordinates (Fig. 2). One was a reference station and was considered as a fixed point. The other receiver was moved through the interior of the farm in order to take coordinates of each point.

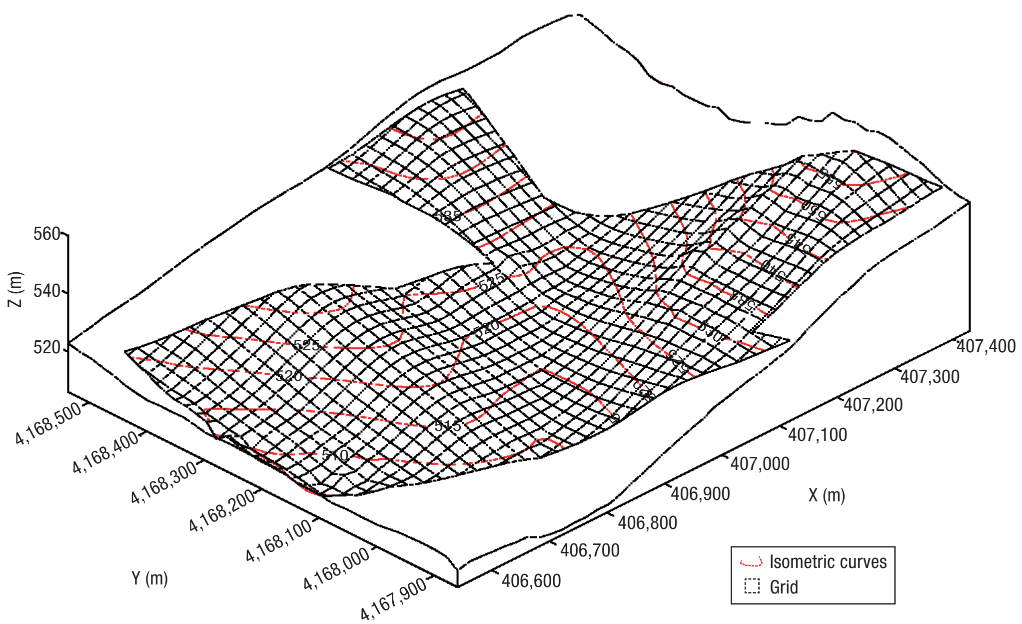

Figure 2. Three-dimensional model of exploitation.

Harvest data capture

In crops such as wheat, corn soybeans or grapevines there are yield monitoring sensors that can be installed in the combine harvester to record the yield with the position given by the GPS receiver. In fruit crops, such as olive trees, the fruit is harvested from the tree using multidirectional trunk vibrators. In this case the main problem is to monitor the yield, because sensor technology is much more difficult to develop.

The harvest collection did not follow a previously established route, harvesting the same number of trees, in the same direction and taking the same references in successive crop years. If this had been the case, it would have been easy to define some rectangles oriented in just one direction (for example North-South). This design would have been feasible at an experimental farm, with a regular plantation and staff assigned to the project. But such a theoretical outcome would hardly give rise to extrapolation and subsequent implementation by farmers. This was the reason there was no interference with the normal handling of the harvest.

The olives collected were weighed in a cropping area of 20-30 trees. This accumulated weight was recorded along with the GPS three-dimensional coordinates of the centre of the cropped area. In this way a yield map of accumulated olive weight was produced in each cropping area. This method is similar to that used for citrus (Whitney *et al.*, 1998; Schueller *et al.*, 1999). Thus, considering that the daily harvest data were more easily managed than the data for individual points, the farm was divided into polygons. The surface of each polygon was known, as well as the number of olive trees and the accumulated harvest. Each one was composed of several squares of 20 m × 20 m (full or in part).

Sampling for foliar analysis

The sampling was conducted during the first fortnight of July in 2001 and 2002 campaigns. Data were collected after flowering and after fruit set in the third and fourth campaign. For both dates the same olive trees were sampled. In order to georeference, the GPS receiver was located in the centre of the quadrilateral formed by the four nearest olive trees. Forty-two sampling points were taken including four olive trees at each point (Fig. 3).

Each leaf sample was comprised of four subsamples of 25 healthy, fully expanded, mature leaves collected from the middle portion of non-bearing current-season shoots, about 1.5 m above the soil surface, at the four cardinal points from every olive tree, as recommended by Fernández-Escobar (1997). These four subsamples were mixed in paper bags to provide a bulked sample

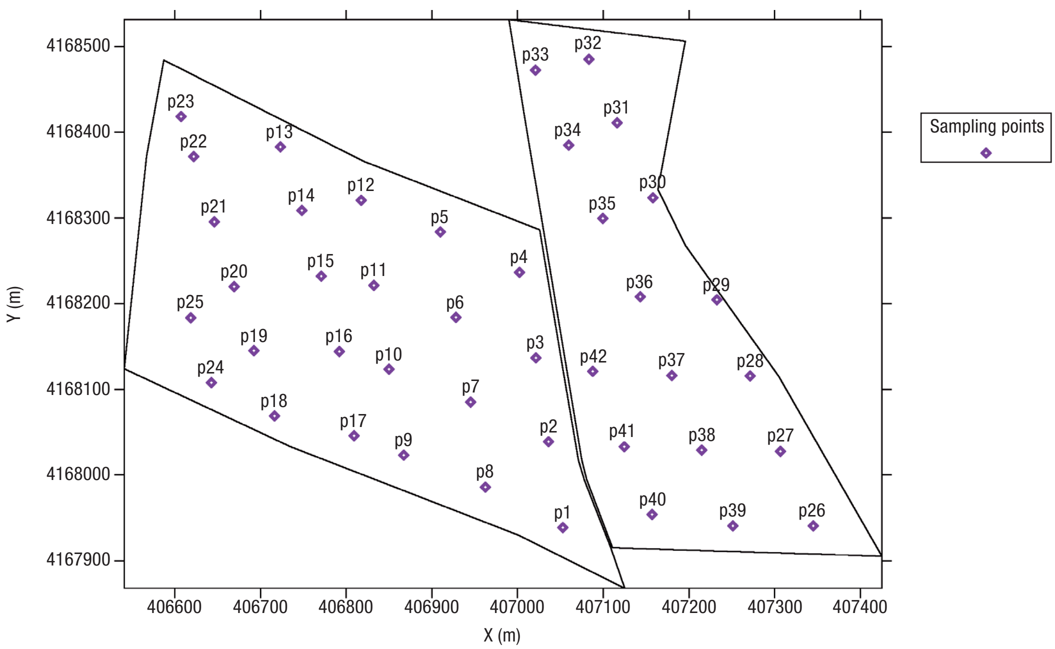

Figure 3. Location of forty-two sampling points for foliar analysis in the farm.

with 100 leaves to ensure that it was representative of the surrounding area.

After sampling, leaves were carried inmediately to the "Instituto de Agricultura Sostenible" of Córdoba, with which a partnership agreement had been reached. They were kept in a refrigerator and sent to the company Fertiberia (Jaén, Andalusia, Spain), which was responsible for conducting the analysis. There the content of N (%), P (%), K (%) and B (mg kg^{-1}) was determined. N was analysed by Kjeldahl digestion, and P and K by dry ashing and subsequent dissolution in hot HCl (Jones *et al.*, 1991). Leaf B was analyzed according to Barbier & Chabannes (1953). This last micronutrient was decided to be analyzed because its deficiency causes serious injury. Foliar analysis is a reliable method for detecting possible deficiency, according to Fernandez Escobar *et al.* (2002).

For data analysis the software Surfer (Golden, 1999) was used. Assuming that the nutrient content of each tree would be similar to the closest olive trees analyzed, the kriging interpolation method was used to estimate the value in points which did not have foliar analysis. The weight of each sampling point was based on the distance between the points. The resolution of the grid used was 20 m × 20 m. The variogram model used was linear. Although a specific study recommends the spherical one (López Granados *et al.*, 2004) results did not differ in the level of this study. Leaf data analyses were integrated into a GIS as with the harvest data analysis. The software GIS MapInfo (MapInfo Cor., 2007) was used.

Digital elevation model

In order to georeference the farm 563 points in both the X and Y axes, as in the bench mark Z, were measured. Given that our aim was to ascertain the economic viability of applying these techniques, and that the data came from groups of 4 olives, in the case of leaf sampling, or larger groups in the case of data harvesting, it was estimated that the minimum unit of study should include four trees. Therefore, the farm was divided into a grid measuring 20 m on each side taking the cell centroid as the mean value of each square. This method is similar to that used by Auernhammer *et al.* (1994) to obtain maps of cereal crops. Special care was taken in setting the perimeter of the farm, the road that separates the two parcels and a gully caused by runoff water. Point 406500;4167800 was chosen as the origin of our coordinates.

The data obtained after processing were introduced in the software Surfer. This software can store interpolated data in a grid-like format, whose size can be defined by the user.

Results and discussion

Digital elevation model (DEM)

Fig. 2 shows the DEM of the exploitation under study. Both data elevation and slope were integrated into a GIS to study the possible relationship between these variables and yield maps and maps of distribution of nutrients, in order to characterize qualitatively homogeneous zones of operation from a technical and economical standpoint.

Yield maps

The minimum harvest value was studied for each unit. In a given campaign each unit of the grid belongs to a specified production area, whose values are expressed in kilograms of olives per square meter.

The yield maps obtained for each year show the differences between the years of good harvest and years of poor harvest, Fig. 4. As this is non-irrigated land, the yield difference for individual trees in alternate years is more marked than with irrigated land.

For yield maps the same intervals of production were chosen (CAP, 2003). To sum up, intervals ≤500, 500-1,500, 1,500-3,000, 3,000-5,000 and >5,000 kg ha^{-1} were used. In Fig. 4 the same intervals of olive fruits in kg m^{-2} are shown, that is to say ≤0.05, 0.05-0.15, 0.15-0.30, 0.30-0.50 and 0.50-1.00 kg m^{-2}. Yield maps of the five campaigns studied were generated as shown in Fig. 4.

The harvest was distributed in a very irregular way, meaning that in the southeast zone of the farm there was no harvest in the first campaign, these grids were left blank.

Maps of nutrient content

This method is based on the assumption that the nutrient content of each tree will be similar to the olive trees close to it in order to estimate the value of nutrients when no leaves were taken to be analysed. The

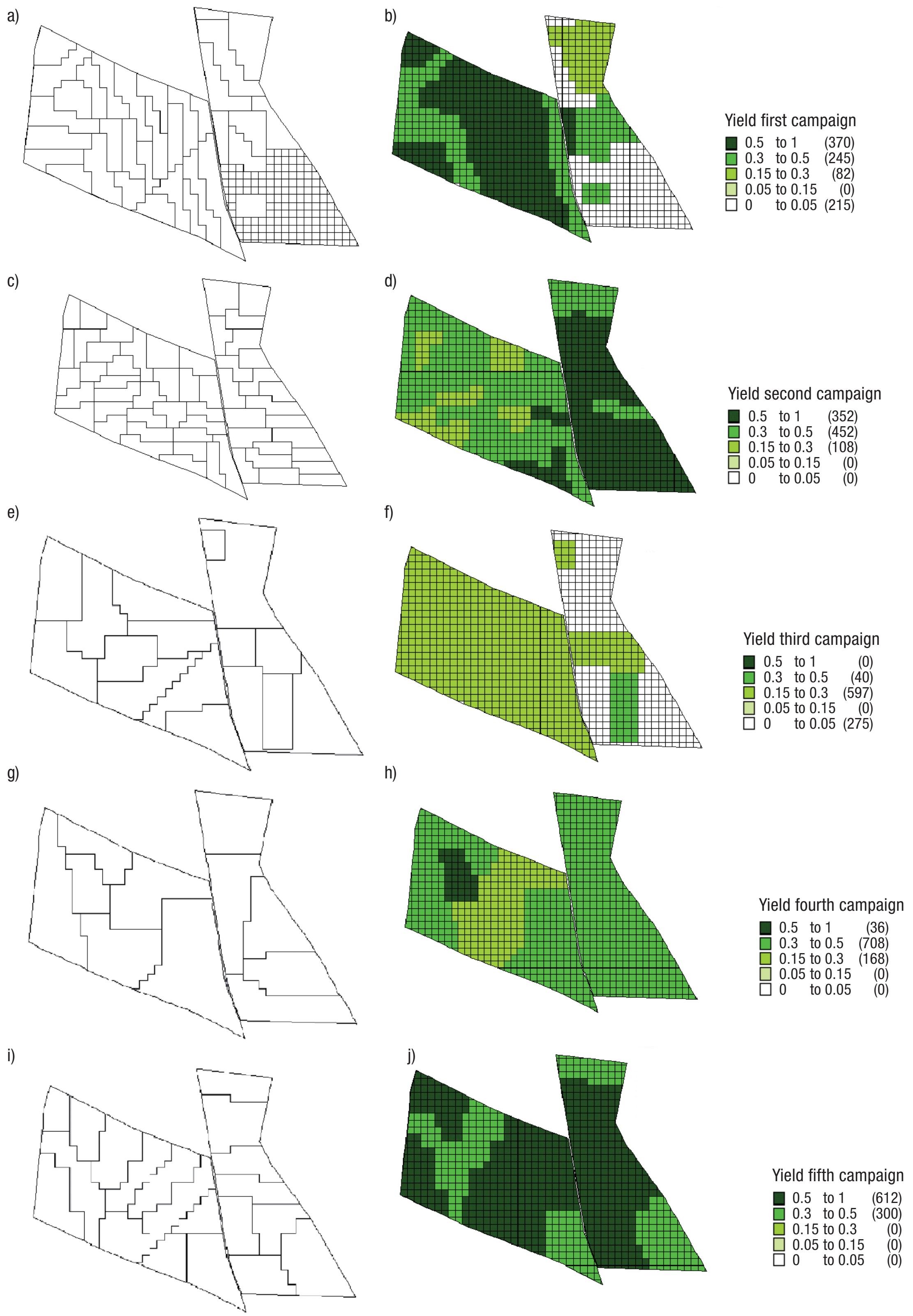

Figure 4. Yield (kg m^{-2}) polygons of first (a), second (c), third (e), fourth (g) and fifth (i) campaigns. Yield (kg m^{-2}) map of first (b), second (d), third (f), fourth (h) and fifth (j) campaigns. The number in parentheses is the number of selected cells.

method of interpolation called kriging was used in weighting each sample point according to the distance between two points.

The software "Surfer" was used to obtain maps of the spatial distribution of four nutrients (N, P, K and B) for two years. As an example, Fig. 5 shows the distribution of N and K from both samples.

Once these data are integrated into the GIS, through the software MapInfo, a thematic map is generated for each element analysed. Thus in Fig. 6, in which red areas represent nutrient deficiencies, yellow areas show that the content of the element is below the optimum, and green units of study identify where values are adequate.

Integration of results at the level of exploitation

A vectorial grid system was used to define minimum units of analysis. These units were cells of 20 × 20 m^2 (inside the farm), or were left incomplete to adapt to the edge of the plots. Each minimum unit is defined by the X and Y coordinates of its centroid, a code that unites in a single variable coordinates X and Y, an identifier (a whole number) and the plot to which it belongs (plot 7 or 207). Thus it is possible to distinguish several pieces of cell from a single one even though they are separated by a line serving as the edge of the plots.

From all the farm data collected the following was analysed: altitude and slope values extracted from the DEM, the orthophoto of olive orchards (Fig. 1), the position of each olive tree, yield maps of the five campaigns representing the production in every unit area and, because the gross yield of each campaign was known, it was possible to determine oil production per unit area. Additionally, from the maps of nutrient content ASCII files were generated and data concentrations of elements analyzed from foliar samples were exported to separate tables created with the software MapInfo.

All this information was integrated into a table called "Results" in which, for each unit minimum of analysis, were incorporated values of altitude and slope; number

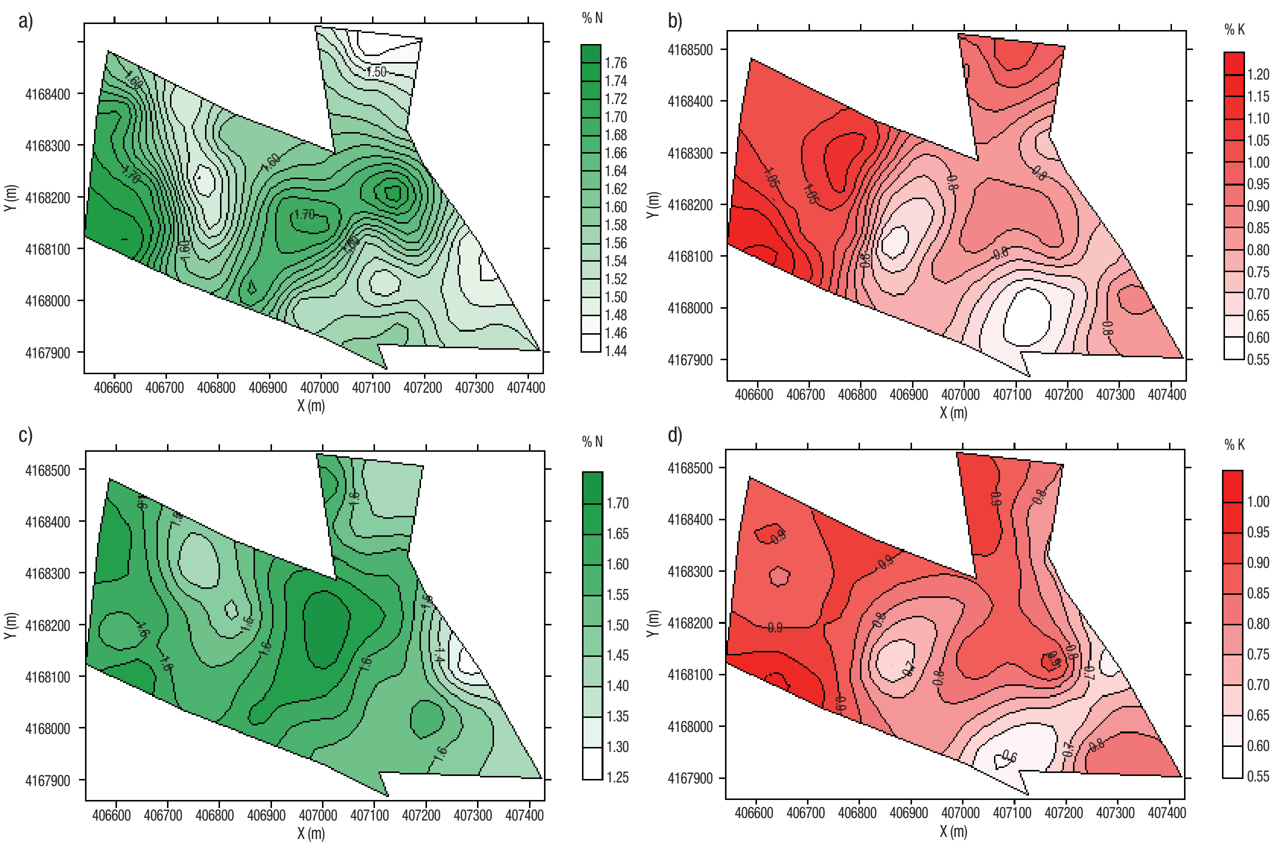

Figure 5. Nitrogen (%) distribution in first (a) and second sampling (c). Potassium (%) distribution in first (b) and second sampling (d).

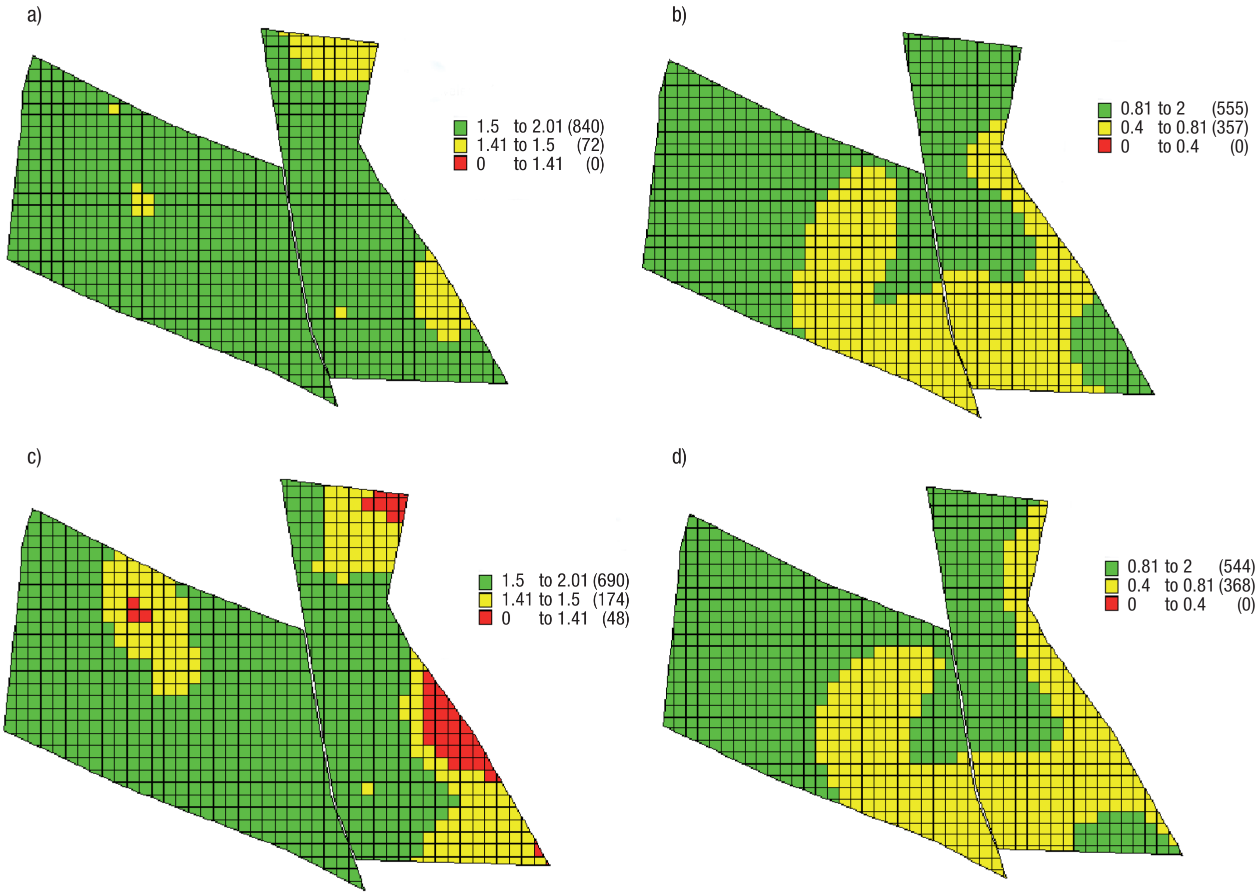

Figure 6. Critical level of nitrogen in the first (a) and second (c) sampling. Critical level of potassium in the first (b) and second (d) sampling. The number in parentheses is the number of selected cells.

of olive trees; 5 olive fruit production data, one per campaign; 5 olive oil production data, one per campaign; and 8 data concerning content of nutrients (two analyses of each N, P, K and B).

Use of information and decision making

For decision-making in managing the farm it is of great interest to know the cumulative harvest in the five campaigns. This is recommended by Swindell in a study of a farm of arable crops in the UK (Swindell, 1997). Fig. 7 shows the map representing in each cell the accumulated value of the crop. In this case the standard deviation has been chosen to represent the different intervals. This figure shows the areas of highest production and profitability of the farm.

Thanks to the integration of all the data into a single table it is possible to obtain, through simple queries, results that integrate the different variables with economic importance. Fig. 7 shows the cells of the farm in which the N content was below the threshold that is considered appropriate (Beutel *et al.,* 1983).

Fig. 8 represents the area selected as a single object. This gives us the possibility of using raster data with the advantages of vectorial entities. In this case, it is possible to know immediately the area of the selected object and all information about it stored in the database, and so analyse, for example, how this area where the leaf N content was less than 1.5% in any campaign, measured 7.86 ha, accounting for 24.8% of the area of exploitation.

Additional queries can be made with regard to other features (production, slope, etc.) that are important to highlight. For example it is possible to value the relationship between the areas with lower crop yields and areas with N deficiencies in the leaves. So Fig. 9 shows the area with an average yield lower than 1.59 kg m^{-2};

in other words, the one which belongs to the last interval of Fig. 6. In total, this was an area of 4.56 ha.

Fig. 9 incorporates data from previous figures. This figure shows that 80.9% of the land (3.69 ha in dark blue) presents a lower cumulative yield, moreover with N deficiencies in the leaves.

As for the economic benefit and reducing the environmental impact, it must be considered that the annual application of N fertilizers to the olive trees does not appear to be necessary in order to obtain good production and growth while the N content in the leaves remain above the threshold considered appropriate (Marín & Fernández-Escobar, 1997). In addition, it has been recently stated that an excessive fertilization in annual N (N content of the leaf is greater than or equal to 1.5%) not only adversely affects the quality of groundwater and the economy of the farmer, but also affects negatively the quality of olive oil due to a decline in the content of polyphenols (Fernández-Escobar *et al.*, 2002). According to the authors cited, widespread application of N fertilizers on the farm would not be necessary every year, only in those areas where the foliar analysis showed N content in the leaf below 1.5%.

This is the first study of Precision Agriculture applied to olive orchards at such a high level of detail. This study has been carried out in a sector of great strategic interest for Spain and the countries of the Mediterranean basin, for its great contribution to employment generation and wealth.

Thanks to Precision Agriculture, and as has been found in the results obtained in this work, there can be a saving in the application of fertilizers, with the resulting economic benefit to growers and environmental improvement for the whole of society.

Through the GPS system it is possible to obtain the geographic coordinates of the data in order to locate them on the farm. The following were georreferenced: elevation values (DEM), micronutrients, and the accumulated weight of the olives collected in each crop. Then all the information was integrated into a GIS, that was shown to be a very useful tool in this investigation, allowing us to analyze and check large amounts of information and support decision making. This is essential in this study since the mechanization of this crop is not well advanced. No sensors for the harvest of olives exist, as is the case with grain harvesters. The tools implemented in this work, together with the high level of detail of the data captured, spatial unit minimum of 20 m^2, provide the farmer with the possibility to analyse individually the different sectors and thus to develop specific treatment for each one.

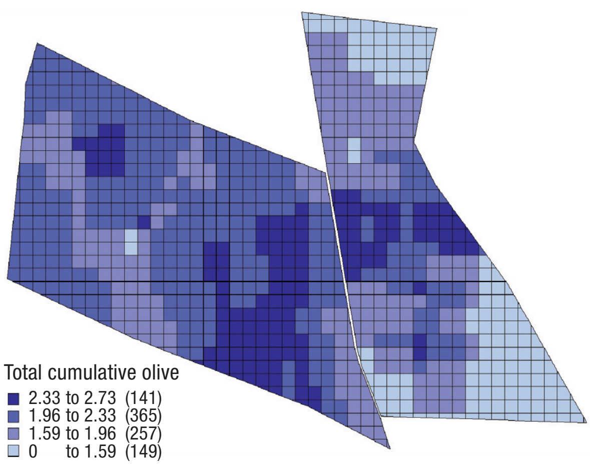

Figure 7. Cumulative total olive harvest (kg m^{-2}). The number in parentheses is the number of selected cells.

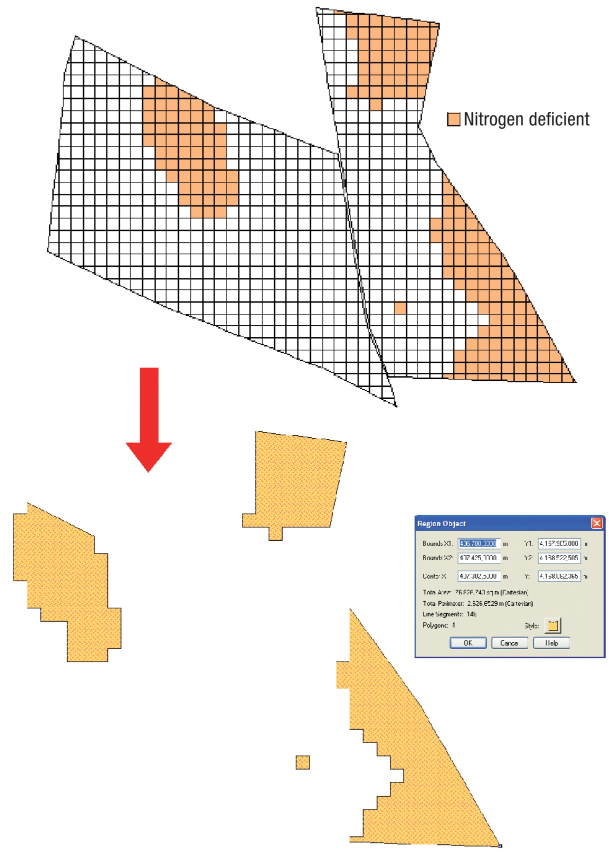

Figure 8. Area of farm nitrogen deficiency.

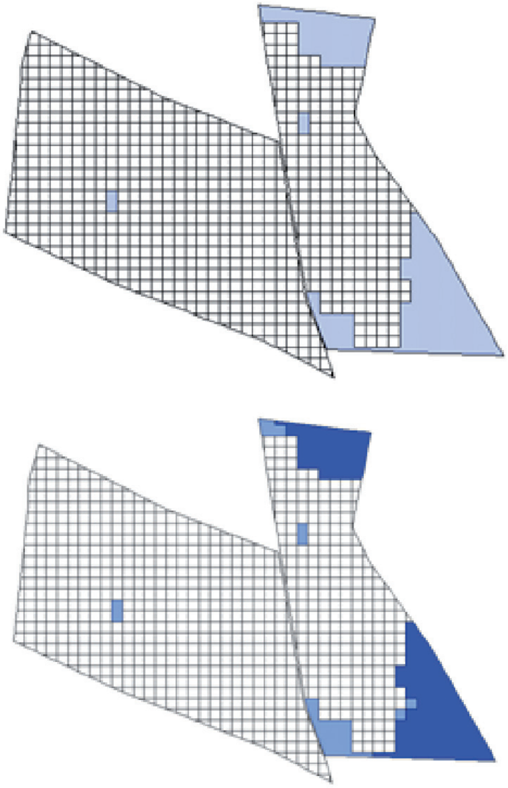

Figure 9. Lower accumulated crop yield (above) and nitrogen deficiency (below).

More investigation is needed to evaluate the profitability of using Precision Agriculture in other olive farms, even smaller ones if they are part of associations (cooperatives), communities of irrigators, etc. As shown in this study, the practice of Precision Agriculture requires a high level of detail in the variables analyzed. Therefore, along with the use of GPS and GIS for georeferencing and decision making, it is necessary to have an adequate mechanization and automation of agriculture. Only the integration of these technologies ensures economic and environmental benefits.

Acknowledgments

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