Precision Agriculture Applications in Horticultural Crops in Greece and Worldwide

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Abstract. Precision agriculture is the management of spatial and temporal variability of the fields using ICT. The application in horticultural crops was developed in the last ten years. Data are collected from different sources (yield and quality, soil properties, remote sensing), stored to GIS data bases, analysed using geostatistical methods to develop management zones and decision support systems are used to assist farmers to the management. Variable rate application systems were developed to apply inputs according to the real requirements of the plants in the management zones. Although variability is a well established fact, farmers' adoption is rather slower than expected because the system is complicated and in many cases profitability is not well demonstrated. Additionally, environmental benefits cannot take direct monetary values for the farmer. PA has a wider application impact like precise movement and management of farm machinery, development of efficient mechanization and fleet management as well development of farm management information systems.

Key works: Precision agriculture, horticultural crops, decision support systems, adoption, and profitability.

1. Introduction

Precision agriculture (PA) can be defined as the management of spatial and temporal (within the growing period and between the years) variability of the fields using Information and Communications Technologies (ICT). PA was in some way applied in the past. The small farm manager was able to observe all variation within the fields and take appropriate decisions for each part. Mechanisation and increase of farm size reduced this knowledge. The larger the field, the lower the knowledge of the variability. The average rule was used to manage the fields. When the first yield monitors were developed it was proved that yield and soil properties varied highly within a field. This fact marked the development of precision agriculture.PA is aiming at increasing farmers' knowledge of his field and return better management based on this new knowledge. PA has a rather short history. Its application started about 20 years ago when GPS and new sensor technologies were made available (Heraud and Lange 2009). The initial applications were mainly for arable crops. The applications in horticultural crops were rather delayed and started by the end of the 1990's and the last decade. PA is a cyclic system of data collection, use for the crop management, evaluation of the decisions and the cycle continues for the subsequent years (Figure 1). Each year data are stored in a data base (library) and is used as historical data for the future decisions.
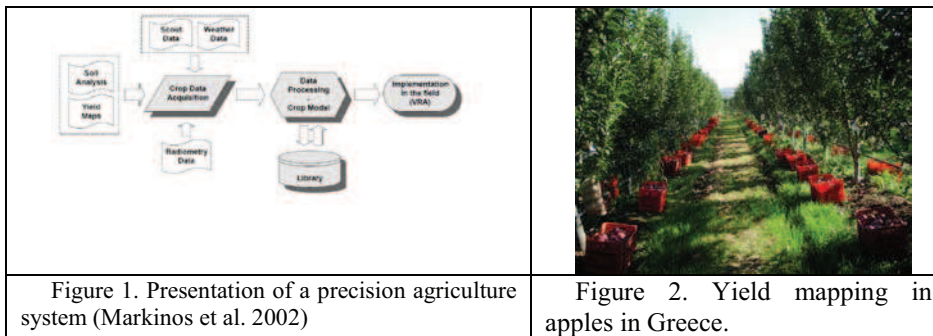
The objectives of this paper is to give an account of the progress made the last few years in application of precision agriculture in horticultural crops as a mean to enhance its use by the Greek agronomists and farmers.

2. Data Collection

Many types of data can be collected during the growing season. All have to be geo-referenced using GPS technology and introduced to a GIS data base.

2.1 Yield mapping

Yield mapping can be carried out easily in mechanized crops. In vines sensors were developed relatively early for the mechanical harvesting of grapes for wine making. They were applied in 1999 vintage in Australia and in the USA (Arno 2009). They used either loading cells that weighed the crop passing on a conveying belt or an array of sonic beam mounted over the grape discharge chute to estimate the volume, and the tonnage, of fruit harvested (Bramley and Hamilton 2004). The results in Australia showed 8-10 fold difference of yield between parts of the same parcel (Bramley 2001a). Temporal variability is an important factor in the development of stable management zones. Research in arable crops (cereals Blackmore et al.2003 and in cotton Fountas et al. 2004) showed that the trends after the third year are cancelling out and we can only define areas of stable high and low yielding and unstable yielding. Tree crops seem to have more stable yields as Bramley and Hamilton (2004) and Bramley et al. (2003) found in vineyards after five years data.

Figure 1. Presentation of a precision agriculture system (Markinos et al. 2002)	Figure 2. Yield mapping in apples in Greece.

In handpicked fruits yield mapping is more difficult. In Florida's citrus plantations, Shueller et al.(1999) used a system to weigh the palette bins where the oranges were collected. The bins were removed by a hydraulic lift which used loading cells to weigh them and a GPS to record the position. It was assumed that each bin represented the yield of the surrounding trees. Yield variability was observed in a 3.6 ha orchard. In Greece Aggelopoulou et al.(2010a) mapped the yield in apple orchards. The apples were handpicked and placed in 20 kg bins along the rows of the palmette shaped trees (Figure 2). Each bin was weighed and geo-referenced. The bins corresponding to 5 or 10 trees were grouped to represent their yield. A similar approach was used by Tagarakis et al. (2010) for yield mapping of vines. Yield spatial variability was evident in all applications even in orchards of 1 ha. Fountas et al. (2011) measured the yield variation in olive trees orchard. Olives, in conventional orchards, were picked by hitting the fruit branches by sticks. Olives were falling on plastic sheets underneath each tree. The olives were placed in bags and left in groups for loading to a platform. Each bag was weighed and geo-referenced using a GPS. Each group of bags was considered to present the yield of the surrounding trees and was the basis for the yield map. Spatial variability was also present. Ampatzidis et al.(2009) have mapped the yield of peaches. They used RFID or bar code tags on the

bins. A weighing machine was combined with a tag reader and a GPS to record the weight and the place of each bin. The data collected was used to produce yield maps of the orchard. Konoatski et al. (2009) have mapped the yield of a 1.6 ha pear orchard. They measure the yield of each tree (harvested in three passes).

Qiao et al. (2005) developed a mobile automatic grading robot. It was moved from plant to plant. Workers picked the peppers and placed them on the machine for grading. The machine located the plant, weighed the fruits of each plant and analysed the quality. Yield and quality maps showed spatial variability even in the very small plot of the experiment. Akdemir et al. (2005) have measured the yield variability in dry onions in Turkey. They have divided the field in 10X10 m grid and they had collected onions from each grid by hand and weighed them. They found a yield variation from 10 to 50 t/ha
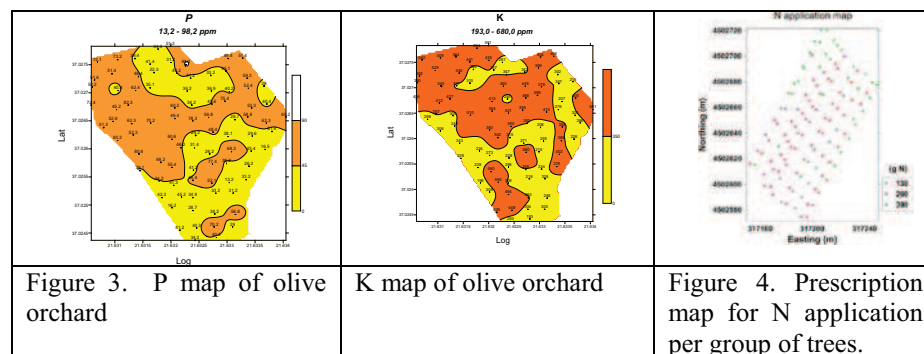
2.2 Quality mapping

Quantity and quality are the two components of the field production. Quality is very important and its variability was the object of relevant research. Several laboratories are working to develop sensors to measure quality of products. In high value crops quality offer premium prices and increased income to the farmer.

Extensive work on the grapes' quality was carried out. Grape samples were taken and analysed to assess its variability. Using remote sensing they found high correlation between the vegetation indices maps near veraison (beginning of maturity) and the grape quality maps. Based on that, they separated the production of the two zones which produced different quality of wines. The dense vegetation part gave lower quality with lighter colour (Bramley et al. 2003). But it was not always true that low yielding parts produced high quality (Bramley and Hamilton 2004). Bramley (2005) has studied the quality variability in commercial fields. Quality variation was there but was much lower than yield's. The zones formed by the quality parameters were not always similar to the yield zones. He concluded that it is difficult to define zones of certain quality characteristics as the wine industry is requiring. Cost of samples collection and analysis is high and only on the go sensors could offer the opportunity to separate qualities of grapes. Best et al. (2005) measured an index m^2leaf/kg-fruit in vines. They found that quality of grape (Brix, colour) were lower when the index was larger (higher vigour of the plants). Sethuramasamyraja et al. (2010) used a hand held NIR spectrometer to analyse anthocyanin variability in two vineyards for two years in CA, USA. The vines were divided into two management zones based on threshold values suggested by the vineries. A harvester with two stores was developed and used. Different quality grapes from the two zones were directed to the appropriate store. The two quality lots produced different quality wine and proved the usefulness of the method. Aggelopoulou et al. (2010a) have analysed the spatial variability of quality of apples. They measured several parameters of the quality like colour, sugars, malic acid, pH and flesh firmness and found negative correlation between yield and quality. The variability existed even in small size orchards.

2.3 Soil properties analysis

Soil is the substrate where crops are grown. It affects several parameters of crop growth, the final yield and its quality. Most of the cropping activities are also affecting soil through tillage, compaction fertilization etc. Soils were analysed for

their properties. Grid sampling of different size was used. A parcel size of 0.4 ha was considered reasonable for commercial applications. Samples taken from the parcel were mixed, homogenised and then analysed for their properties. Soil maps were produced for each property and could be used to define fertilization. Fountas et al.(2011) using a grid sampling and analysis of an olive orchard defined the soil maps (Figure 3) and the amount of P and K fertilization for each tree.

Figure 3. P map of olive orchard	K map of olive orchard	Figure 4. Prescription map for N application per group of trees.

Aggelopoulou et al. (2010) have analysed soils in a dense grid. They found that correlations between soil nutrients and yield was not consistent. They suggested taking into account apples' yield and the nutrients removed to produce prescription maps for fertilizers application. Best el al. (2005) found also low correlation between soil properties and yield parameters but better between yield and ECa maps.

Soil sampling and analysis is labour intensive and costly activity. For research purposes this can be justified but not in most commercial applications. A second possibility is to define management zones with another measurement like yield and direct the soil sampling to the zones. This highly reduces the samples and the cost. A third possibility is to develop sensors that can measure soil properties on the go. This is a fast and usually low cost method. Several methods were developed or are under development. The soil sensors were based on electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical measurements (Adumchuk et al.2004). Electrical resistivity and electromagnetic induction (EM) measure soil apparent electrical conductivity (ECa). This property is directly connected to soil properties like texture, water content, organic matter, salinity, ions in the soil and temperature. If we exclude saline soils and take measurements near field capacity then measurements are correlated to soil texture. Many researchers have reported correlation of yield and ECa (Kitchen et al. 2005). Soil texture is a basic factor of soil variability and influences several soil and crop parameters. Heavier or lighter soils react differently to weather; require different water, fertiliser and herbicides applications. The GPS readings when they are relatively accurate can offer at the same time elevation maps.

Aerial and satellite images obtained using remote sensing help in analyzing the variability of soil (Adumchuk et al. 2004). Soil colour without vegetation offers an indication of its texture and soil organic matter. Early laboratory studies showed correlation of soil OM with both visible and near infrared (NIR) reflectance.

Mechanical sensors have been used to assess soil compaction using instrumented tines (Andrale et al. 2002) or automatic penetrometers. They gave good results but they have to pass through the soil to assess compaction. Electromechanical sensors have been developed. One with commercial application can map pH. Soil samples were taken on the go and electrodes can measure pH.

2.4 Remote sensing

Remote sensing is the group of techniques than can collect field data without being in contact to plants, soil etc. An electromagnetic wave when falling on an object it can pass through, reflected or absorbed. Measuring these effects we can have useful information. It is a useful technology for PA as it can give data for parameters of the field relatively easily. In general we see the reflected sun light that is formed by the ultraviolet wave lengths, the visible light (Red, Green and Blue) and the infrared. The green plants are absorbing the red and blue wave lengths and reflect the green and the infrared. Measuring the reflected wavelengths with a multispectral cameras we can measure the vigour of the plants or any problem like disease, nutrient deficiency or water logging etc. We can correlate soil colour to the organic matter, moisture etc. Light reflectance (sun or some artificial light source) has been used in PA in the form of vegetation indices. The most used of them is the Normalised Vegetation Index (NDVI). Several other indices can be calculated and used offering good agreement with certain characteristics of the crop. NDVI has been correlated to crop yield and quality. The measurements of plant reflectance can be carried out by satellites, airplanes or ground instruments.

In several PA studies crop reflectance was used as an early measurement of the crop growth and for prediction of yield and product quality. Bramley et al. (2003) have used NDVI of vines at vaireson as an indication of grapes quality and used it to separate the product into high and low wine quality producing lots. The idea was successful and gave a good results and a profit to the farmer (see later). Best et al. (2005) in Chile, found good agreement between NDVI and yield and quality of a vineyard (correlation coefficient $r^2 > 0.7$) and between LAI and NDVI ($r^2 > 0.75$). Hall et al. (2010) studied the correlations between spectral images and the properties of the grapes and yield. They estimated canopy area and canopy density, which were consistently significantly correlated to fruit anthocyanin and phenolic content, berry size and yield. But total soluble solids correlations were not stable.

Any object when have a temperature above absolute zero emits electromagnetic radiation. This is used in thermal cameras that can detect differences in temperature in plants. Thermal cameras have been used in precision agriculture to assess water status of crops and regulate irrigation (Agam et al. 2009).

3. Data analysis and management zones delineation

All data collected have to be analysed and interpreted. Simple exploratory (descriptive) statics can give a first idea on the values, their spread, the range and the distribution. Geostatistics, are used for spatial interpolation. Final construction of the thematic maps for successive years are made using spatial variability structure of the sampled data (variogram) and an interpolation method (kriging). Semi-variograms are used to assess the spatial variability of the measured values. Maps covering the whole field can be produced and indicate the variability of the properties. There are

several methods of data analysis although that there is not a clear method to compare the produced maps. We are still based on optical impression for the comparison of the maps. Correlations between parts of the field with different parameters can be carried out to assess their relationships. Kitchen et al. (2005) tried to delineate productivity management zones based on ECa, elevation and yield using MZA. They used a pixel agreement between zones to compare the zones based on different parameters. Taylor et al. (2007) have presented a protocol for data analysis and management zones delineation using available free software to help farmers in the better use of the data collected through precision agriculture technologies.

Soft computing techniques have been employed to define correlation between the properties measured and permit a forecast of the results. Neural networks, fuzzy logic, fuzzy cognitive maps has been used recently to analyse data and explain yield variation. (Papageorgiou et al. 2010).

The analysis of the data aims at defining parts of the field called management zones with common characteristics which can be managed in a common way. Management zones delineation should form homogeneous parts of the field where inputs or other practices can be applied in the same way. The management zones should be large enough to permit VRA of inputs but small enough to be homogeneous. Management zone delineation can be done using fuzzy cluster analysis.

4. Variable Rate Application (VRA)

VRA technology is the major target for PA. All information gathered should result in a better management of the formed zones. VR means that the appropriate rates of inputs will be applied leading either to reduced inputs, costs and environmental effects or improved yields and quality. Two methods are used to apply VR. The first called map based, is based on historical data (previous or present year). Process control technologies allow information drawn from the GIS (prescription maps) to adjust fertilizer application, seeding rates, and pesticide selection and application rate, thus providing for the proper management of the inputs. The second, named sensor based, uses sensors that can adjust the applications rates on the go. The sensors detect some characteristics of the crop or soil and adjust the application equipment. VRA can be applied to all inputs. Both systems have advantages and disadvantages. The on the go sensors are more acceptable by the farmers. Probably using a mixture of both will offer most advantages in the future.

Variable fertilizer applications in vineyard could help minimizing variability in vine growth as well as fruit quality (Sethuramasamyraja et al. 2010). Devenport et al. (2002) applied VR fertiliser in a vineyard for four years. They have analysed the nutrient content of the soil and concluded that N and K applications benefited the field as they reduced variation but not the P application where the CV remained high.

Based on management zone delineation and historical data prescription maps can be produced defining the specific requirements of each zone. The prescription map is imported to the controller of the application machine and changes the adjustment (the amount of the input applied per unit of area as prescribed) as the machine moves through the field. Obviously a lot of data have to be collected and properly analysed to make effective the application. In tree crops where temporal variability is lower this application is more feasible than in arable crops.

Prescription maps can be produced based on several characteristics of the field or the crop. In the case of the orchard of Fig. 3 (Fountas et al.2011) the farmer applied the fertilizer by hand in each tree. He was able to use the map with the two zones and apply one or two portions of fertilizer in the defined trees. In apples Aggelopoulou et al. (2010b) have used the soil analysis data and the nutrients removal from the soil by the crop to prepare prescription maps for fertilizer application (Fig 4). Prescription maps can be based on characteristics measured during the growing season. Aggelopoulou at al. (2011) found high correlation between estimated variability of flowers and yield distribution. This can be used to manage the inputs of the crop as low yielding parts requirements are different that high yielding.

Several on the go sensors have been presented and used. The most known is the sensor that detects light reflectance from the crop. Using NDVI the sensor detects the vigour of the crop. Usually crops with sufficient nitrogen are greener than plants with lower nitrogen. This characteristic was used to adjust N rates in crops like cereals. In tree crops several characteristics can be used to directly adjust inputs. Tree canopy volume, density and height can be measured electronically (Giles et al. 1988). In citrus orchards of Florida, tree canopy measured by ultrasonic or laser sensors was correlated to yield. This property was used to adjust the variable chemical application. (Giles et al. 1988, Turbo et al. 2002). Pulse width modulation nozzles that use fast reaction solenoids to open or close the flow several times per second can be used to vary discharge. One other idea changes the active ingredient solution by introducing it at different rates in the distribution tubes of the sprayer (after the pump). (Ess and Morgan 2003). Gil et al. (2007) tested a variable rate application sprayer in vines. The sprayer had three nozzles groups in each part of the row. Ultrasonic sensors were sensing the canopy width and adjusted the sprayer achieving 58.8% savings.

Variable rate irrigation is of great importance due to the shortage of water reserves and the importance of irrigated crops in many parts of the word. Applications in central pivot systems using prescription maps based on soil properties, crop conditions and the real conditions of the field proved that considerable saving in water and energy can be achieved (Perry et al. 2002). In a feasibility study of fields in Greece and Turkey based on soil variability savings of up to 7% (range 2.5-7.2) of water and energy can be achieved (Gemtos et al. 2010). Perry and Milton (2007) estimated 12% water savings while Hedley et al. (2009) at 7%.

In orchards, irrigation systems have to be designed from the beginning to achieve variable rate irrigation. Knowing the soil variability it is possible to develop more than one networks applying different water depths or frequency of application. The zones separation criteria are soil texture and soil elevation. Wireless systems of sensors were developed to measure soil water content during the growing season. The sensors can give information to the farmer or directly to the controllers of automatic irrigation systems that can define proper application levels.

Several direct sensing systems have been used for weed control. Some herbicides are sensitive to soil organic matter. Soil organic matter detection was used to automatically adjust the herbicide application rate. Increased efficiency was reported (lit). A second line of action is the detection of green plants and use herbicides only where the weeds are. The system is to be used between the rows of vegetables or other crops. More than 30% herbicide savings were reported. In the same line weed

recognition systems can be used and drops of herbicides are applied only on the weeds. These systems work also on the crop row. High herbicide savings are reported (Bak and Jacobsen 2003). A third line of action is the use of mechanical weed control by avoiding crop plants. The system defines the crop plants position. There are two ways. One to detect the seed placement in the field using a RTK-GPS and then produce maps with plants' position. The second is to use a camera in front of the machine to detect crop plants and direct a tool only to the weeds. Several tools were developed. The most successful commercially is a horizontal disk system that has one sector removed (Figure 5). The machine vision system or the plant map or both detect the crop plants and adjust the discs rotation in such way to avoid damaging them (Dedoussis et al. 2007)

5. Decision Support Systems for the Farmer

A decision support system (DSS) is a computer-based system that supports business decisions. In agriculture it refers to the decision taken by the farmer for the management of the farm. Precision Agriculture is directly connected to decision making by the farmer. PA (Viticulture) can be basically described as an example of the conversion of data into decisions (McBratney and Whelan, 2001). It is quite true that research is not successful in that respect at the moment. The lack of functional tools for decision-taking, explains to certain extend the difficulty faced so far for a rapid and widespread adoption of PA. This is a fact recognized by researchers in the field. Arno et al. (2009) pointed that the development of Decision-Support Systems (DSS) in PV undoubtedly remains a pending assignment. Kitchen et al. (2005) pointed that more precise crop models working in PA can help in the development of successful DSS.

| Figure 5. Curved disc with one sector removed | Figure 5. Selective weed control machine prototype | Figure On the row weed control withtines |

6. Profitability and Adoption of Precision Farming

The adoption of a new technology by the farmers is a difficult procedure. The evolution of agriculture in many parts of the world resulted in aged farmers and usually of lower education level. This makes changes and adoption of new technologies even more difficult. Different surveys indicate a lower use of computers and internet by farmers. Kuter et al. (2011) defined farmers' adoption of PA as the combined utilization of several site-specific technologies using GPS such as auto guidance and VRT of inputs and/or yield mapping on farm. The farmers to adopt a new system have to recognize, research, and implement these technologies and

management practices at an on-farm production level (Kosh and Khosla 2003). Kuter et al. (2011) pointed that farmers will adopt PA when they are sure that offers economic benefit, advantages over traditional methods and it is less complicated. Additionally farmers like to observe an application and see the benefits before adopting any innovative technology. Research showed that large farms and young farmers adopt more PA. Ehsani et al. (2010) have reported that the farmers expect from the new technologies to be proven and robust, cost effective and when new equipment will be employed to be reliable and well backed up for service and repair. Early and accurate yield predictions are important.

Adoption is wider in the USA. In 2003, 32% of Ohio farmers had used one PA component and this percentage increased from previous studies. Larger farms showed larger application rates (Batte et al. 2003). In Europe adoption is rather low. It is wider in the North than in the South. Wider to arable than in horticultural crops. A lot of small farms in Europe make adoption difficult. It is suggested that cooperative use of equipment or through contractors can help to that direction.

The economic returns of PA have been studied. It is clear that PA application requires some new equipment (yield sensors, installation of equipment, ECa sensors, VRA equipment, computers etc) that has to be depreciated. Additional costs for training are also required. Variable costs are the every year data analysis and interpretation. All these costs should be covered by the benefits from the application. In many cases improved yields and reduced costs are the benefits and can be directly estimated. Reduction of chemicals, water or energy use, which apart from the direct reduction of costs have additional benefits to the environment is difficult to be translated in monetary units. In high value crops quality improvement can be of great interest. Bramley et al. (2003) in a separate harvest of the two parts of a vineyard the high quality grapes gave wine of high price ($30/bottle) while the low quality low price wine ($19/bottle). They comment that if the grapes were harvested all in bulk they would produce low quality wine. The profit based on the gross price of wine was around $30,000/ha. An estimation of the application cost was at $11/t of harvested fruit which is negligible compared to the profit.

7. ICT in Agriculture

Precision agriculture is not only site specific management. Most of the technologies used in precision agriculture can be used in several applications improving farm management. The use of GPS technology can offer guidance systems to the tractors that help them to follow desired paths in the field. This can lead to more accurate tree planting or controlled traffic in vegetable fields. The addition of GPS and other sensors to the tractor (using the ISO BUS standardisation) can offer a full record of the farm machinery movement as well as fuel and energy consumption. Recording of farm machinery activities (with inputs form the farmer) can lead to Farm Management Information System that can cover administration requirements for certification of production systems (like integrated crop production management systems) or EU cross compliance (Future Farm 2011). Keeping records on inputs and yields we form the first step of a traceability system so required by the consumers.

Knowing the machinery movements we can estimate better use or better itineraries that can improve efficiency. This can save time and fuel but also reduce soil compaction. The development of autonomous vehicles can led to improved

mechanization systems with fleets of small sized tractors working 24 hours a day and doing accurately all farming activities (Blackmore et al. 2007).

8. Conclusions

From the presented data, it can be concluded that:

- Yield, quality and soil spatial variability is present in most of the fields, even in small size. Therefore precision agriculture can benefit the farmers.
- Data analysis still requires better methods especially in correlating thematic maps. Decision support systems have to be developed to enhance PA adoption.
- VR technology has developed methods for site specific applications that can not only reduce costs but have additional beneficial effects to the environment.
- PA has a wider impact in farm management through more efficient machinery management.

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