Precision Agriculture: crop management for improved productivity and reduced environmental impact or improved sustainability

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ABSTRACT

In this chapter a general outline of precision agriculture as applied to crops is given. A general plan of its application is given describing the methods to collect data to prove and analyse variability of the fields and the crops. An account is given for the data analysis and the methods to use the data in the site specific management of the crops. Several applications are presented indicating the potential of precision agriculture to lead to optimisation of resources use like fertilisers and chemicals, water and energy leading to reduced inputs and minimizing adverse effects to the environment. In several applications the economic benefits to the farmers are proved. Precision agriculture can address the main components of agriculture sustainability. For an economic perspective precision agriculture can improve income to the farmers, for a social perspective it can improve conditions to the farmers and the farming communities bringing the farmers to the cutting edge technological era, while for the environment reducing inputs and resource use and reducing the adverse effects to the environment.

Key words: precision agriculture, sustainability, farm management, resources use

1. INTRODUCTION

Precision Agriculture (PA) can be defined as the management of spatial and temporal variability in the fields using Information and Communications Technologies (ICT). Bramley (2001) defined PA as the term that incorporates technologies that permit the improved management of agricultural production through the recognition that land productivity and input-output relations can vary even in small distances in the field. Precision agriculture is the art and science of utilizing advanced technologies for enhancing crop production while minimizing potential environmental pollution (Khosla and Shaver (2001)). Precision agriculture is also referred to as site specific management. Precision agriculture is a management system of the farms that aims to improve productivity and resources use either through increased yields or reduced inputs and adverse environmental effects. Precision agriculture can assist crop producers, because it permits precise and optimized inputs use leading to reduced costs and environmental impact, while it could be utilized in a traceability system that could record the activities at site-specific level (Fountas et al, 2011a).

Precision agriculture is not a new idea. Few decades ago the farms were small and the farmer had to walk all over his fields several times every year. The farmer was able to observe all variation within the fields and take appropriate management decisions for each part. This farmer was able to add more seeds in parts where emergence was low or add more fertilizer where growth was lower or the plants were yellow. This knowledge depended on his memory combined with direct observation. One problem was that in most cases his decisions were influenced more by the recent years' results that were kept in his memory but which were more influenced by weather or other factors not present in the following years. This connection and knowledge of the fields were reduced with farm mechanisation and the increase of the farm size. The larger the field and the farm, the lower the farmer knowledge of his field variability. Gradually the average rule was used to manage the fields. Average soil properties and yields were used. The underlined assumption was that the field was homogeneous and the same management in all parts was justified. When the first yield monitors were developed and yield maps were created, it was proved that yield and soil properties varied highly within even small fields. This fact marked the development of precision agriculture.

The present paper aims at giving an account on the application of precision agriculture in the last 25 years, on the methods used, the results obtained, the adoption of the technology and the effects to crop management, to the environment and the sustainability of agricultural systems.

2. HOW PRECISION AGRICULTURE IS APPLIED

2.1 Introduction

Precision agriculture is a cyclic system of data collection and analysis, use of the results for the crop management, evaluation of the decisions and the cycle continues for the subsequent years. Figure 1 presents this cycle. The first task before applying a PA management is to establish soil and crop variability. A homogeneous soil planted with a homogeneous genetic material has very limited benefits from applying PA. Therefore, data collection is the first stage of the system, followed by data analysis and the application of the system. Each year data are stored in a database (library) and used as historical data for the future decisions. The system can be divided in data collection, data analysis, managerial decisions and applications and evaluation.

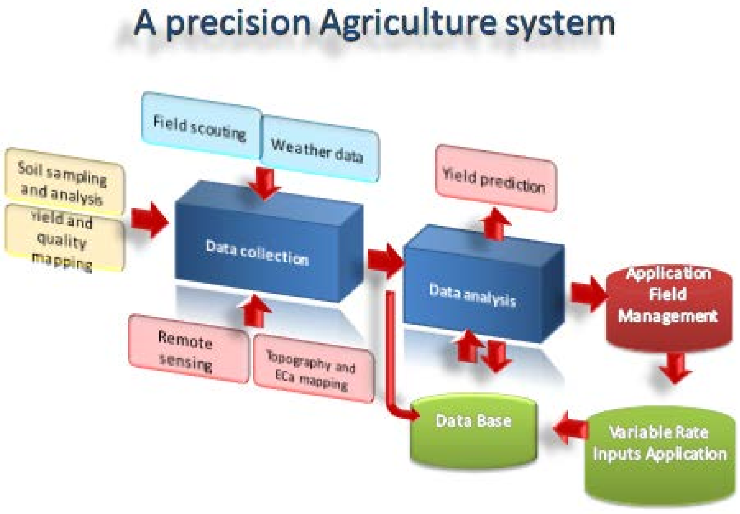


Figure 1. A generalized precision agriculture system (adapted from Tagarakis 2014a)

Precision agriculture aims to increase farmer knowledge of his field and return to a better management based on this new knowledge. PA has a rather short history. Its application started about 25 years ago when GPS and new sensor technologies were made available. GPS (Global Positioning System), as a military application was available earlier but the civilian use was allowed by the end of 1980’s. Its accuracy improved when selective availability was removed in 2000 (Heraud and Lange, 2009). The initial applications were mainly for arable crops. Harvesting was mechanised and sensors were placed on the machines to map yield variability. In early 1990’s the first applications started in cereals using impact or γ ray grain flow sensors (Godwin et al., 2003), while applications in high value crops (fruits and vegetables) delayed and started by the end of the 1990’s.

2.2 DATA COLLECTION

Many types of data can be collected during the growing season. Yield spatial distribution data, soil data (physical and chemical properties, topography), remote sensing data, data collected by crop scouting (crop growth, diseases, pests, weeds that at the moment they cannot detected by sensors), as well as weather data can be collected for every field at site-specific level to assist farm manager in the crop management. All data have to be geo-referenced using GPS technology and introduced to a GIS (Geografin Information Systems) data base. GPS technology has different levels of accuracy. Simple GPS offer few meters accuracy, DGPS sub meter accuracy while RTK-GPS (Real Time Kinematic – GPS) 1-2 cm accuracy (Heraud and Lange 2009). For most applications DGPS (Differential GPS) accuracy seems to be sufficient as RTK systems are too expensive for farm use. Recently, RTK GPS central systems were installed and can be accessed by farmers at low cost. This will enhance high accuracy GPS use.

2.2.1 Yield mapping

Yield mapping can be carried out easily in mechanized crops with sensing and recording systems added to the machines. The system consists of the sensor that measures the crop flow in the harvesting machine, sensors that can measure some quality properties of the crop, a GPS receiver and a CPU (Central Processsing Unit) that receives the collected data and store them for future use. They measure yield on the go every adjustable time intervals which gives yield every few square meters. Some on the go data analysis can be performed and seen by the farmer during the work of the machine on a monitor. Initial applications were in combine harvesters using γ ray sensors (Godwin et al.2003). Later sensors based on seed impact to a plate (AgLeader Technology 2014 http://www.agleader.com/) and volumetric applications were developed and used. Several sensors were developed for machine harvested crops as for cotton using light sensors (Tomasson et al. 1999), processing tomatoes using loading cells under the conveying chains of the machines (Pelletier et al. 1999), hay producing crops (Wild and Auernhammer 1999, Kromer et al., 1999) and peanuts (Vellidis et al. 2001).

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 (Arnó 2009). They used either loading cells that weighed the crop passing on a conveying belt or an array of sonic beam sensors mounted over the grape discharge chute to estimate the volume, and hence tonnage, of fruit harvested (Bramley and Hamilton 2004). In Florida citrus plantations, Schueller et al. (1999) used a system to weigh the palette bins where the oranges were collected. Each worker had a picking bag where they placed the fruits. When the bags were filled they emptied them to the nearby field containers (tubs or pallet bins) placed between the trees (Whitney et al. 1999). The bins were removed by a hydraulic lift which used loading cells to weigh them and a GPS receiver recorded the position. It was assumed that each bin represented the yield of the surrounding trees. A reasonable assumption since each worker would empty the bag into the nearest bin. Yield was estimated by the dividing weight by the area covered by each bin. Position and yield resulted in yield maps. Yield variability was observed in a 3,6 ha orchard.

In Greece, Aggelopoulou et al. (2011a) mapped the yield in apple orchards. The apples were handpicked and placed in about 20 kg capacity bins along the rows of the palmette formed trees. (Figure 2). Each bin was weighed and geo-referenced using a GPS receiver. The bins corresponding to groups of 5 or 10 trees were grouped to represent their yield. The collection of the yield of each tree was not possible due to the palmette formation where branches of adjacent trees were mixed. The system facilitated the workers who have to pick the fruits continuously and the yield mapping did not interfere with their work. A similar approach was used by Tagarakis et al. (2014a) for yield mapping of hand picked vines. Yield spatial variability was evident in all applications even in orchards or vineyards of 1 ha.

Figure 2. Data collection for yield mapping in an apple orchard in Greece.

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 where they were filled, for loading later 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 tags on the bins. A weighing machine was combined with an RFID 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. Konopatski 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 of the workers) and found also variability of the yeld. Qiao et al. (2005) developed a mobile automatic grading robot. It was moved to a plant, a worker 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.

From the abovementioned work it has been noted that yield spatial variability is a fact even in the small fields with arable or fruit and vegetables. The variability in most cases is high enough to justify the investment in precision agriculture technology.

2.1.2. Quality mapping

In most crops the quantity is one component of the production of a field. The quality of the product is a second component. In most cases quality is important. Especially in fruits and vegetables high quality secure a premium price. But in other crops like durum wheat for pasta making high protein content also receives premium price. Sensors for cereal moisture content were developed from the early stages of yield mapping. Systems using grain permittivity were developed and used successfully. Light spectrum sensors were developed for some of the grain or seed properties and are in commercial use like the protein content of cereal seeds or the oil content of oily seeds (Zeltex ACUHARVEST http://www.zeltex.com/accuharvest.html). Several laboratories are working to develop sensors to measure quality of products (i.e. NIRS Forage and Feed Testing Consortium http://www.uwex.edu/ces/forage/NIRS/home-page.htm, NIRS/XRF laboratoryUniversity of

Padova). Attempts were made to analyse product quality by manual sampling and analysis were carried out in cotton proving the variability of the quality (Gemtos et al. 2005). According to Kondo and Ting (1998), for fruit crops, quality commonly includes outer parameters (size, colour, shape, surface texture and mass), inner parameters (sweetness, acidity or inner diseases) and freshness. Given the high cost of hand picking of most table horticultural crops in many cases lower yields with better quality can be more profitable for the farmer.

Extensive work on the grapes' quality was carried out by researchers. Grape samples were taken and analysed to assess the variability of the quality to produce high quality wine. Using remote sensing they found high correlation between the vegetation indices (like NDVI) maps near veraison (beginning of maturity) and the grape quality maps. Based on that they separate the production of the two zones of the field which produced different quality of wines. The dense vegetation part gave lower quality with lighter colour (Bramley et al. 2003).They found also that the dense vegetation part produced more (about double) than the lower. But it was not always true that low yielding parts produced high quality (Bramley and Hamilton 2004). Bramley (2005) has presented the results of grape quality analysis in two commercial vineyards. The variability of the parameters of the quality was there although that this variation was much lower than yield's variation. The zones formed by the quality parameters were not always similar to the yield zones. It seems that the factors affecting quality are more complex than the factors affecting yield. The spatial variability of the quality characteristics was relatively low. He concluded that it is difficult to define zones of certain quality characteristics as the wine industry is requiring. Additionally the 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 factors (Brix, colour factors) 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 (gondolas) was developed and used. Based on management zones boundaries the different quality grapes were directed to the appropriate store. The two quality lots were used separately to produce wine. Experts' panels testing the wines verified the different quality and proved the usefulness of the method. Aggelopoulou et al. (2010) have analysed the spatial variability of yield, soil and quality of apples. They measured several parameters of the quality like colour, sugars, malic acid, pH and flesh firmness. The variability existed even in small size orchards. The fruit quality (sugar content and flesh firmness) was negatively correlated with the yield.

2.1.3 Soil sampling and 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 physical and chemical properties from the beginning of precision agriculture. Initially grid sampling was used. The idea was to mark the field by normal lines at a certain distance between them and produce small parcels from where samples were taken. The size of the parcels differs depending on the purpose of the study. In research projects smaller parcels were used (less than 0.1 ha) but for commercial applications parcels of 0.4 ha are the usual size. Samples were taken from the parcel (from different parts of the parcel) were mixed, homogenised and then analysed for their properties like texture, nutrient elements content, CEC, pH, organic matter etc. Soil maps were produced for each property and could be used to define fertilization. Fountas et al. (2011b) 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.

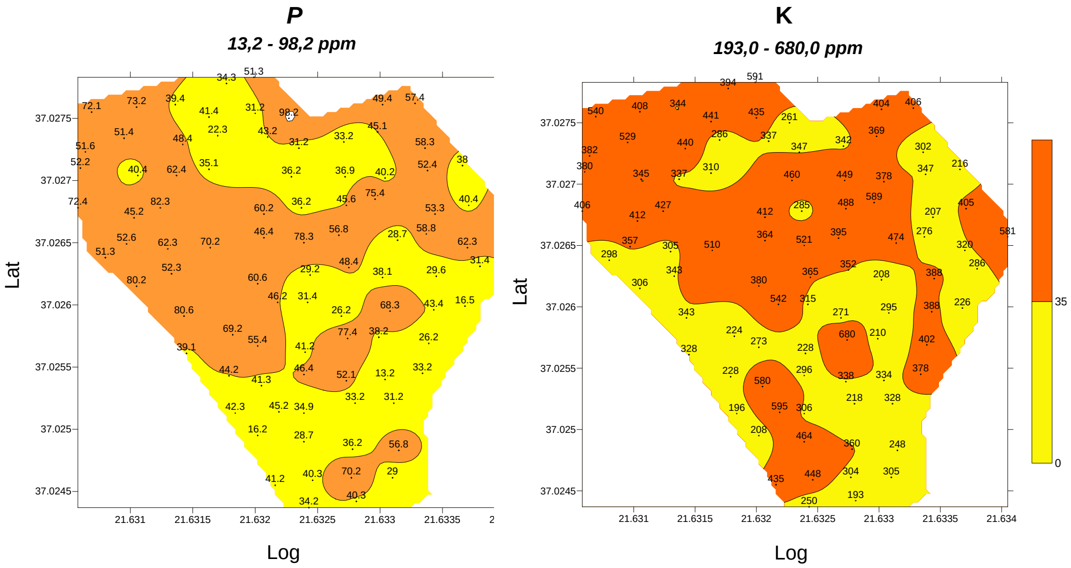


Figure 3. P and K maps of an olive trees orchard (Fountas et al, 2011b)

Aggelopoulou et al. (2011a) have also analysed soils in dense grid. They found that correlations between soil nutrients and yield were not consistent. They suggested taking into account the apples yield and the nutrients removed to produce prescription maps for fertilizers application. Best el al. (2005) found also low correlation coefficients between soil properties by sampling even with 10 samples per ha and yield parameters. They suggested that better correlation exists of yield parameters to ECa (Apparent Electrical Conductivity) maps. Soil sampling and analysis is a labour intensive and costly activity. For research purposes this can be justified but in most commercial applications it is not acceptable. A second possibility is to define management zones with another measurement like yield mapping or apparent electrical conductivity mapping and direct the soil sampling to the zones. This highly reduces the number of samples and the cost and offers a good picture of the field for crop management. Tagarakis (2014a) has applied directed sampling in a vineyard based on ECa, elevation maps and the delineation of management zones by the farmer. Nine samples were sufficient to characterise the soil.

A third possibility is to develop sensors that can measure soil properties on the go. This is a fast and low cost method. Several methods to assess soil parameters were developed or are under development. The soil sensors were based on properties like electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical measurements (Adumchuk et al. 2004). Electrical resistivity and electromagnetic induction (EM) was used to assess the soil apparent electrical conductivity (ECa). The ECa measures conductance through not only the soil solution, but also through the solid soil particles and via exchangeable cations that exist at the solid–liquid interface of clay minerals (Corwin and Lesch, 2003). 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 from the measurements and take measurements near filed capacity most measured conductivity variability is due to soil texture. Electric resistivity instruments use flat, vertical disks to apply a voltage and measure the soil resistance by measuring the current in other similar disks (Figure 3). The distance between the disks defines the depth of the measurement. In Electromagnetic induction sensors (Figure 4) coils are used to induce and measure the electricity. An EM transmitter coil located at one end of the instrument induces circular eddy-current loops in the soil. The magnitude of these loops is directly proportional to the EC of the soil in the vicinity of that loop. A second coil measures the produced current which is the result of soil properties (e.g., clay content, water content, organic matter, ions). Instrument orientation and distance from the soil define the depth of measurements.

Figure 4. Electrical resistivity instrument (VERIS)

Figure 5. Electromagnetic induction (EM38) instrument.

The two instruments were used in many applications in precision agriculture combined with GPS. They provide a fast and relatively cheap way to produce maps which are presenting the variability of the field and they are correlated to yield. Many researchers have reported this connection (Kitchen et al. 2005). Soil texture is a basic factor of soil variability and influences several soil and crop parameters. At the beginning of the application of PA can permit a directed soil sampling and analysis. In many cases it is directly connected to yield and product quality. Heavier or lighter soils react differently to weather conditions, while require different water, fertiliser and herbicides applications. The GPS readings when they are relatively accurate can offer at the same time elevation maps. Elevation maps can help in farm management of fields with inclination. ECa was also correlated to the water holding capacity of the soil and was used for variable rate irrigation (Hedley and Yule 2009).

Adumchuck et al. (2004) name them “bare soil images”. 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 (Andrade et al. 2002)   or automatic penetrometers. They gave good results but they have to pass through the soil to assess the compaction. Acoustic sensors during soil braking by a tine were also tested.
Electromechanical sensors have been developed. One with commercial application can map pH. A tool is lowered into the soil when the instrument moved in the field and extracted a sample before returning to its initial position above the soil. The sample is analysed by either an ion-selective electrode (glass or polymer membrane), or an ion-selective field effect transistor (ISFET) (Adamchuk et al. 2004). The electrodes can measure pH, K^+, NO_3^- but the time needed for measuring ions is long and not suitable for on the go measurements. The only commercial application is for the pH measurements. It is combined with an electromagretic resistance (ECa) instrument and measures both.

Sensors are under development that can assess some soil properties like organic matter and nutrient content using the properties of light when reflected or passing through the soil. Proximal soil sensors were developed that can provide high resolution data on spatial variation in soil properties (Stenberg et al., 2010), which enables the management of land at field and sub-field scale. Sensors based on visible and infrared radiation analysis were developed and placed on mobile platforms. The sensors were placed at the back of a sub-soiler shank and measured the reflected light from the soil. A fibre type, vis-NIR spectrophotometer with a measurement range of 305-2200 nm was used. They claim good correlation between measured reflected wave lengths and soil properties like soil texture, soil organic matter, soil water content, pH, Phosphorus but low correlation to potassium (Shaddad, 2014)

Figure 6. The on-line visible and near infrared (vis-NIR) soil sensor (Mouazen, 2006)

2.1.4 Remote sensing

Remote sensing is defined as the group of techniques than can collect field data without being in contact to the object (plant, 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 for the plants. It is a useful technology for PA as it can give data for parameters of the field relatively easily. Whatever we see in the field is remote sensing. In general, we see the reflected sun light. Sun light is an electromagnetic wave that is formed by a spectrum of wave lengths. The sunlight is formed by the ultraviolet wave lengths, the visible light 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 miltispectral camera we can measure the vigour of the plants that makes them greener. We can also see green plants that can have a problem like a disease, a nutrient deficiency or water logging etc. We can see the soil and correlate the colour to the soil organic matter, moisture etc. Light reflectance (sun or some artificial) has been used in PA in the form of vegetation indices. The most used of them is the Normalised Vegetation Index (NDVI). NDVI is an expression of the vigour of the plants and has been correlated to crop yield and quality. Several other indices can be calculated and used offering good agreement with certain characteristics of the crop.

The measurements of plant reflectance can be carried out by satellites, airplanes or ground instruments. Satellites can give images of large areas, at relatively low cost but they cannot work when clouds are covering the earth. Airplanes or helicopters do not have the clouds problem but they are more expensive. Ground sensors are working well but require more labour. Ground sensors are usually using an artificial light that makes measurements independent of sun light and can be carried out even during the night. In several PA studies crop reflectance was used as an early measurement of the crop growth, crop vigour which reflects the nitrogen availability and the health status of the plants and for prediction of yield and product quality. In the most used application NDVI was used to regulate nitrogen application. The hypothesis is that greener plants (higher NDVI) have more available nitrogen and require less application through fertilisation compared to less green plants (lower NDVI). Sensors developed by YARA use artificial light, measure NDVI on the go and adjust N applications for crops like cereal, rapeseed or potatoes. Several applications in the same line in different crops offer N fertiliser savings, improved yields and product quality (Lan et al., 2008).

Bramley et al. (2003) have used the 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 plots. The idea was successful and gave good results and profit to the farmer. For vines, high vegetation at the end of the growing season indicate a high yield which in most cases but not all is followed by low quality. Best et al. (2005) in Chile they found good agreement between NDVI and yield and quality characteristics of a vineyard (correlation coefficient $r^2>0.7$). They found also high correlation between LAI and NDVI ($r^2>0.75$). Hall et al. (2010) have studied the correlations between spectral images and the properties of the grapes and yield. They have estimated canopy area and canopy density and the total soluble solids, yield and berry size and anthocyanins. Canopy area and density 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 (Alchanatis et al, 2010). Another property of plants or product is the electromagnetic wave absorption when pass through it. Every object has a characteristic absorption of parts of wavelength and this can be used to find its quality characteristics. Sensors for assessing the protein or oil content of seeds are already in commercial use as presented earlier. Chlorophyll fluorescence can depict the photosynthesis state in green leaves. Fluorescence sensors measure the absorption of specific wavelengths followed by the dissipation of the absorbed energy by light emission at longer wavelengths (Corpa et al., 2003). Fluorescence sensing technology can be used to detect plant nitrogen status. It also give information about the chlorophyll status, (Tremblay et al., 2012). A commercial fluorescence-based optical sensor, (FORCE-A, Orsay, France), was successfully used for monitoring grapes anthocyanin but also new sensors can assess chlorophyll status of the plants for fertiliser applications.

2.1.5 Field scouting

Field scouting is a part of each management system that cannot be avoided at least at the moment. The farmer has to go to the filed to verify the indications offered by the different instrument used. In many cases measurements of emergence rates, growth of the plants measured by their height or the canopy of the trees or trunk size of the trees are useful information to apply PA. Some of them can be measured by instruments but still some of them have to be measured by human labour. Farmers, even in large farms have a good knowledge of their farm. In many cases, at the beginning of the application of PA it is useful to ask the farmed to draw a map of their field with the characteristics of each part. In many cases the farmer opinion does not differ much from the management zones defined through sensors data.

2.2 DATA ANALYSIS AND MANAGEMENT ZONES DELINEATION

All data collected have to be analysed and interpreted if a meaning can be drawn from them. The data are really too many and appropriate methods exist or have to be developed for the analysis. Simple exploratory (descriptive) statics can give a first idea on the values, their spread, the range and the distribution. Geostatistics, based on what is called, «the theory of regionalised variables», is basically a probabilistic method of spatial interpolation. Final construction of the map corresponding to parcel level is made possible, based on estimation of the error at non-sampled points, using the spatial variability structure of the sampled data (variogram) and an interpolation method (kriging). This type of information, which can be obtained for different properties and for successive years, opens new and interesting possibilities in agronomic crop analysis and management (Arnó, 2009). Given the spatial dependence of the values interpolation between the sapling points can be made using geostatics methods like kriging. 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 maps using MZA. They used a pixel agreement between zones to compare the zones based on different parameters. Tagarakis (2013) has used the same approach to compare maps a precision agriculture in vineyards project. Taylor et al. (2007) have presented a protocol for data analysis and management zones delineation using available free software. This protocol could 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 (Papageorgiou et al. 2011). Neural networks, fuzzy logic, fuzzy cognitive maps have been used recently to analyse data and explain yield variation. Aggelopoulou et al. (2010) delineated management zones in apples based on yield, soil and quality data using a multivariate approach. Data fusion from different sensors was proposed as a method to analyse data and provide useful correlations for management zone delineation or for on the go variation of inputs.

The analysis of the data aims at defining to parts of the field with common characteristics that can be managed separately. These parts are the management zones. The term management zone implies a part of the field with similar characteristics that 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 (Variable Rate Application) of inputs but small enough to be homogeneous.

2.3 VARIABLE RATE APPLICATION (VRA) TECHNOLOGY

VRA technology is the major target for precision agriculture. All information gathered should result in a better management of the formed zones. VR means that the appropriate rates of inputs will be applied at the appropriate time and precisely, leading either to reduced inputs, costs and adverse 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 control processes such as fertilizer application, seeding rates, and herbicide 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 like fertiliser application, spraying for pests, water application but also for practices like pruning or even separate harvesting of the zones (Auernhammer, 2001). Both systems have advantages and disadvantages. The on the go sensors are more acceptable by the farmers as it is simple to use and facilitates their work. Probably using a mixture of both will offer most advantages in the future.

Variable fertiliser applications in vineyard management and other practices like, foliar nutrient programs and drip irrigation could help to minimize variability in vine growth as well as fruit quality (Sethuramasamyraja et al. 2010). Davenport et al. (2002) applied VR fertiliser in a vineyard for four years. They have analysed the nutrient content of the soil. They concluded that N and K applications benefited the field as they reduced CV of the nutrients content 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. Several machines were produced to adjust according to prescription maps the seeding, fertilizer, manure, water rate, or have areas where a pesticide can be applied or not. 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 Figure 3 (Fountas et al. 2011b) 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. (2011a) have used the soil analysis data and the nutrients removal from the soil by the crop to prepare prescription maps for fertilizer application (Figure 7). Prescription maps can be based on characteristics measured during the growing season. Aggelopoulou at al. (2011b) found high correlation between flowers and yield distribution. This can be used to manage the inputs of the crop as low yielding parts requirements are different than high yielding early in the season (in spring).

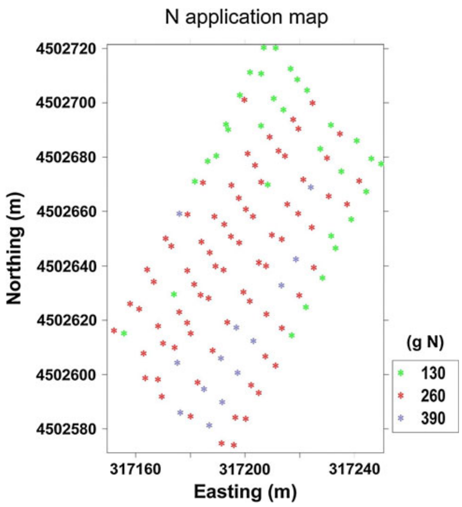


Figure 7. Prescription map for N application per group of trees (Aggelopoulou et al.2011a)

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 supply are greener than plants with lower nitrogen. This characteristic was used to adjust N rates in the field in crops like cereals. The most known sensor YARA (http://www.yara.co.uk/crop-nutrition/Tools-and-Services/n-sensor/) is used in many applications of N fertiliser. Other manufacturers have produced similar sensors (i.e.TOPCON CRPSPEC http://ag.topconpositioning.com/ag-products/x20-application-kits/cropspec). New proximity sensors claim the ability to detect other nutrient or soil properties than can be used for VR fertiliser applications like the sensor in Figure 6.

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 (Zaman et al., 2005; 2006). In spraying sensors detecting missing trees can stop spraying. This automates the spraying stopping at the headlands and facilitates operator’s work. Other sensors detect the trees density and height (using laser scanners, ultrasoninc or photoelectric sensors) (Giles et al. 1988; Tumbo et al.. 2002) and adjust the spraying direction of nozzles to reduce out of target spaying. New nozzles were developed to change the output. These are pulse width modulation nozzles that use fast reaction solenoids to open or close the flow several times per second varying the 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 nozzles in three groups of five in each part of the row. Ultrasonic sensors were sensing the canopy width and adjusted the sprayer. 58.8% saving was achieved with same coverage of the canopy by the two sprayers (conventional and experimental) with the VR sprayer having better depositions inside the canopy.

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. Variable rate irrigation attracted the interest of researchers. Applications in central pivot systems based on prescription maps proved that considerable savings in water and energy can be achieved. Prescription maps can be based on soil properties, crop conditions and the real conditions of the field. In parts of the field without plants water applications is st6opped. In feasibility study of fields in Greece and Turkey based on soil variability savings of up to 7% of water and energy can be achieved (Gemtos et al. 2010). Based on soil texture map (Figure 8), three management zones were delineated using the FUZME software (Figure 9) in a cotton field for variable rate irrigation.

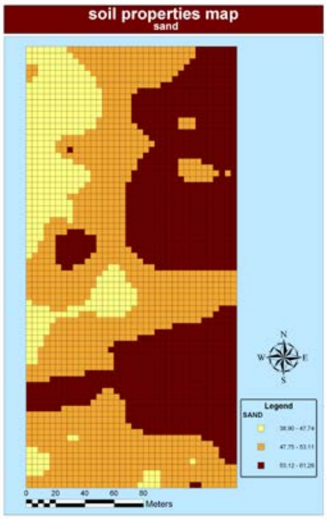
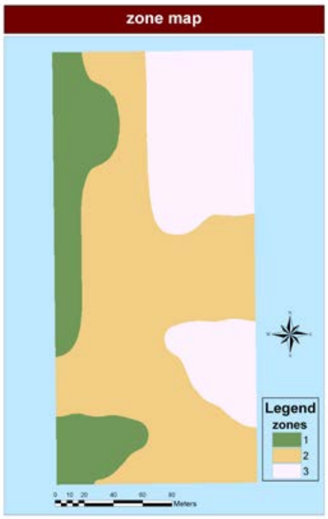
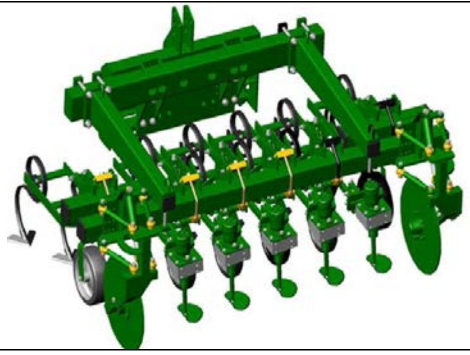
	

Figure 8. Soil clay content map	Figure 9. Management zones and prescription map for irrigation.

Using the FAO model CROPWAT model for cotton water application a range of water savings between 2.5 and 7.2 % were achieved. 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 can be soil texture and soil elevation (Tagarakis 2014a).

In the last years wireless systems of sensors were developed to measure soil water content during the growing season. The sensors are installed in the management zones and can give information to the farmer so that he decides the irrigation 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 (Grisso et al., 2011). A second line of action is the detection of green plants and use herbicides only when the weeds are. The system is to be used between the rows of vegetables or other crops. A sensor detects the green colour of the plants from the soil and applies the herbicide (like round up) only when green plants are detected. 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. A third line of action is the use of mechanical weed control by avoiding the crop plants. The system detects the useful plants. There are two ways. One to detect the seed placement in the field using a RTK-GPS and then produce maps with the plant places. The second is to use a camera in front of the machine to detect weeds and 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 (Figures 10, 11). 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 (Dedousis and Godwin, 2008)

	
Figure 10 . Curved disc with one sector removed	Figure 11. Selective weed control machine prototype.

2.4 AUTO GUIDANCE SYSTEMS AND OTHER APPLICATIONS

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. Especially RTK GPS offer high accuracy. This can help to avoid double passing or missing strips in the field when chemicals are applied leading to savings in material and reduction of the effects to the environment. This can lead to more accurate tree planting or controlled traffic in fields reducing the compaction problem of the soils. 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 (Sorensen et al, 2010). Keeping records on inputs and yields we form the first step of a traceability system so required by the consumers. PA can assist in the development of Certified Integrated Crop Production systems. Setting targets to reduce fertiliser inputs can be achieved by redistributing the fertilisers within the field without reducing yields. 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; Blackmore et al. 2009).

3. 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. It is quite true that in that respect research is not successful 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. Arnó 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. Many efforts have been made to capture the decision making process for farmers using precision agriculture starting from data collection in the field, capturing external data and processing it to derive useful decisions (Fountas et al., 2006).

4. PROFITABILITY AND ADOPTION OF PRECISION FARMING

The adoption of a new technology by the farmers is a difficult procedure. Farmers are generally of the more conservative parts of the society. 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. Even in many places infrastructure for commutations is inferior in rural areas. Kutter et al. (2011) defined farmers' adoption of PA as the combined utilization of several site-specific technologies using Global Positioning Systems (GPS) such as auto guidance and variable rate applications (VRT) of inputs and/or yield mapping on farm. This definition does not imply that these practices have to be carried out by farm staff but can be offered by a third party as well.

The farmers to adopt a new system have to recognize, research, and implement these technologies and management practices at an on-farm production level (Koch and Khosla 2003). Kutter et al. (2011) pointed that farmers will adopt PA when they are convinced that they will have an economic benefit, offers advantages over traditional methods and it is less complicated. This is not clear. Additionally farmers usually like to observe an application and see the benefits before adopting any innovative technology. Research showed that large farms adopt more PA. The same applies to young farmers. Ehsani et al. (2010) reported the results of a meeting with stakeholders in Florida. They presented a summary of the requirements of the farmers from new technologies in agriculture. They expect 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. They are expecting to find sensors for disease recognition and early warning and help them to follow regulations. Early and accurate yield predictions are important. For autonomous vehicles they require reliability and safety, to have the possibility for manual driving when a problem appears. Moreover, Lawson et al. (2011) carried out a wide survey across four nations in Europe recording their attitudes towards precision agriculture and information systems and they recorded the basic incentives that farmers had, using the advanced systems.

Adoption is wider in the USA. In 2003, 32% of Ohio farmers had used one PA component and this percentage increased for previous studies. Larger farms showed larger application rates (Batte et al. 2003). In 2013 survey (Ericson et al. 2013) the answers by dealers in the USA indicate the best sellers are GPS based guidance systems (85% used), about 40% used satellite/aerial imagery but only 13% soil sensors (ECa or pH).GPS enabled srpyers boom with sections control was used by 53%. VR single nutrient application was offered by 70% of the responders. Only 15% responded that they did not offer PA appications. These results gave an indication of the interest for PA applications. In a Florida survey for farmers, 17,5% used sensor based VRA, 16.1% soil variability mapping and GPS boundary mapping. Zarko Tajada et al.. (2014) claim that similar figures are indicative for EU as well. Although dealership interst indicate a farmer interest the real figures for Pa appications are rather smaller. Survey for Englan for the application of PA (Department of Environment, Food and Rural Afairs (2013) gave an increase of PA used between 2009 and 2012 for GPS receivers from 14% to 22% of the farms, for soil mapping from 14% to 20%, for variable rate application from 13% to 16% and for yield mapping from 7% to 11%. 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. Even though, PA has been adopted in large farms in Northern Europe, USA and Latin America, the application of PA in the areas in the world where small farms occurs is still a big challenge and has to be explored both for its economic and environmental benefits.

Most of research is pointing that PA will be adopted by the farmers if it offers economic advantages over conventional and is simple and easy to be applied. The economic returns of PA have been studied. It is clear that PA requires some new equipment (yield sensors, installation of equipment, ECa sensors, VRA equipment, computers, etc.) that has to be depreciated. Depreciation time has to be short as is the case in most electronic devices. Additional costs for training to produce maps and interpret the results 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 benefit and can be directly estimated. In many cases like the reduction of chemicals, water or energy use which apart from the direct reduction of costs have additional benefits to the environment that 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 field 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.

5. PRECISION AGRICULTURE AND SUSTAINABILIY

Sustainability is a term used for production systems friendly to the environment. The UN Brutland committee defined the term as the development able to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). The American Society of Agronomy defined sustainable agriculture as the one that, over the long term, enhances environmental quality and the resource base in which agriculture depends; provides for basic human food and fibre needs; is economically viable; and enhances the quality of life for farmers and the society as whole” (American Society of Agronomy, 1989). Sustainability is described as the intersection of economy, society and ecology. The definitions indicate that sustainable agriculture has to be: a) productive to cover the increasing human population with high quality food (food security and safety) and raw material even lately energy; b) to secure profit to the farmers and maintain their welfare but at the same time has to make an optimum use of resources and save them for the next generation; and c) to reduce the adverse effects of agriculture to the environment. Resources like soil, water, energy, biodiversity have to be used for the present production but maintained for the next generations.

PA as analysed in this paper is a farm management system that works at subfield level and provides the inputs required for optimum production in quantity and quality. Conventional management uses the mean values of production or soil properties, accepts that all are homogeneous in the field and applies the inputs accordingly. Applying fertilisers homogeneously in a field with variable properties (soil, crop) means that in low yielding parts of the field more than required inputs are applied wasting resources (energy, phosphates) but also polluting the environment. Applying pesticides in all the field wastes pesticides in areas without pests and pollutes. The same applies for other practices like tillage or water application. PA establishes variability of soil, crops and production and through the variable rate technology applies the input according to the real needs of each part of the field resulting in reduced inputs of chemicals, water, reduced energy consumption for tillage and other operations.

Bongiovanni and LowenbergDeBoer (2004) have reviewed the sustainability effects of precision agriculture. Several literature references indicate fertiliser inputs reduction and the effects to the environment. VR fertiliser applications have attracted the interest of the scientific community. N is the input with the higher energy input to the system but causes also pollution. In rain fed crops N fertilisers account for 34% of the energy inputs (about the same as tillage 39%) and 29% in irrigated crops (with irrigation to account for 48% in sunflower) (Gemtos et al. 2013). Several studies indicate fertiliser saving with increased or unaffected yields and improved profit to the farmers and the environment. Lan et al. (2008) studied variable rate fertiliser (N, P, K) on maize crop. Yield analysis showed that VRF increased yield by 11% and 33% for the two years of the experiment while they decrease the amount of applied fertilizer 32% and 29% respectively. Morari et al. (2013) have applied variable rate N application in a Durum Wheat field in Veneto area, Italy. They applied N based on NDVI sensors and achieved improved grain quality and reduced N inputs. Vatsanidou et al. (2014) have applied nitrogen with variable rate based on the replacement of the removed nutrients by the previous year crop. They achieved a 43% reduction in the applied rate without affecting the year’s yield. In a study in apples in Greece Liakos (2013) has applied homogeneous and variable rate (based on the nutrients removed by yield) fertilisation in alternate rows of the orchard for two years. He found considerable reduction of the N inputs with small decrease of the yield but the profit of the farmer increased. He found also an improved quality of the apples.

Several examples of inputs saving were given in the presentation of the technologies of PA. Tagarakis (2014a) in a 1 ha vineyard has split the drip irrigation network in two based on soil texture and elevation and achieve up to 20% water saving. It is quite clear the PA can offer considerable help in developing a sustainable agriculture assisting farmers in their decision making during the growing of their crops. New sensors able to detect any irregular reaction of the crops or the soil will enhance increased productivity, resources use, profitability and reduced affects to the environment.

6. CONCLUSIONS

Precision Agriculture (PA) is a crop management system that adapts inputs to the requirements of each part of the field. It assesses at the beginning the variability of the field and the crop using several technologies and sensors and then applies inputs to meet the crop requirements. Variable rate inputs application is the technology that offers the opportunity to adjust inputs to requirements leading to reduced inputs and/or increased yields, improved resources use and reduced adverse effects to the environment. Additionally PA offers improved profitability and productivity of the farms. These are the components that lead to improved sustainabilty of agriculture. The adoption is however still not as anticipated especially in many regions in Europe especially in the cases where small farms exist and their benefits should be explored.

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