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Precision Agriculture in a sweet cherry orchard

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I hereby declare that the work submitted is mine and that where I have made use of another's work, I have attributed the source(s) according to the Regulations set in the Student's Handbook.

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Abstract

This dissertation was written as part of the MSc in Sustainable Agriculture and Business at the International Hellenic University.

This research is related to the application of precision agriculture methods in a sweet cherry orchard at the region of Pella, and more specific Achladochori village at the foothills of mount Paiko. The main purpose was to map the spatial variability of 2018 yield and correlate it with the cherry fruit quality parameters of weight, size and sugar content (BRIX). Soil texture and EC were mapped too. Data analysis brought out a significant spatial variability despite the small size of the orchard.

First of all, I want to thank my supervisor As. Prof. Mr. Spyros Fountas for his confidence. In addition, Mrs Nicoleta Dara because without her important help and support this dissertation would be very difficult to complete and finally, my parents for their patience and assistance.

Keywords: Precision Agriculture; cherry orchard; spatial variability; yield mapping

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Preface

Cherry orchards occupy a small share of the cultivating area in Greece, approximately 14,000 out of almost 3 million cultivated hectares, but this area is enough to place Greece at the 10 biggest producers and exporters worldwide. Therefore, the adoption of PA practices in agricultural production is necessary in order to maintain the competitive advantages and reap more benefits, such as managerial improvements, higher yields, lower costs, minimization of environmental impacts and quality improvements. However, the implementation of these methods in Greek agricultural sector are still at the embryonic stage. Specifically, the application of Precision Agriculture methods in Greece has started in 2001 in cotton cultivation (Markinos et al., 2003) and during the last decades has expanded to other crops, such as apple orchards (Rappos et. al, 2005, Aggelopoulou et. al, 2007, Tanos et. al, 2007), olive orchards (Fountas et.al 2011, Chatzipapadopoulos and Protonarios, 2017) and pear orchards (Vatsanidou et.al, 2014).

The main objective of this study is the investigation of the spatial variability of a cherry orchard, according to the principal methods of precision agriculture. The cherry orchard that was selected included three different planted varieties; 'Early Bigi' as the main variety and "Bigarreau Burlat' and 'Lapins' as pollinators. Delineation of management zones, as well as yield and quality measurements were exploited, allowing the monitoring of significant parameters for the growth of the cultivation. Furthermore, Soil Electrical Conductivity (EC) measurements together with soil sampling were conducted, by using a GPS for the geo-reference of all the measurements. The analysis of the collected data for the map creation was applied to ArcGIS (ESRI) software and a statistical analysis was performed to determine data correlations using IBM SPSS® Statistics V25.

Contents

1 Precision Agriculture

1.1 Need for production and sustainability

The adoption of accurate cultivating techniques and practices was always a wish and a challenge for farmers. Before the mechanization of agriculture farmers met their farms needs as they were crossing through them the whole cultivating period (Fountas and Gemtos, 2015).

Every interference during the season between farmers, plants, soil and the living organisms/pests taking action in the field was happening either by following a pattern/rule or because something concerning emerged. This, still happens especially in orchards, because the modernization of agriculture has not reached, and may never reach at the point which farmers' presence in their fields will be unnecessary. However, new technologies such as software systems, IoT sensors, UAV or farm robotics have evidenced their essential role for the upgrade of agriculture area, through the improvement of the cultivations' management efficiency and competitiveness.

Modern agriculture seems to start in 1901 when Dan Albone completed the first light-weight petrol powered general purpose agricultural vehicle, the "Ivel Agricultural Motor". The first commercially successful attempt took place nine years earlier, back in 1892, where John Froelich built the first successful gas tractor with forward and reverse gears near the end of the British Agricultural Revolution (also known as "Second Agricultural Revolution (SAR)", mid-17th – late-19th centuries). During SAR there is a phenomenal increase of production at the agricultural sector caused by the augmentation of labor force and land productivity and this period is cited as an essential cause for the Industrial Revolution (Marc Overton, 1996).

The introduction and implementation of mechanization in agriculture brought the enlargement of land parcels which affected in turn the direct impact between farmer and field. Although farmers know that their land is disparate, until now they have managed every field as uniform with very slight differences in the cultivated interventions. The input levels are the same for each part of their field without taking into account the differences between them. This increases the misapplication of products and reduces crop and farm efficiency.

A typical example is fertilization before and after harvesting fruit trees. Despite the variability of the trees' nutritional needs across the field, the amount and type of fertilizers applied in every area remains the same. Similar are the treatments amongst pruning, the apical farmer-plant interference in an orchard, and other inputs such as irrigation, herbicides, insecticides and fungicides.

Agricultural inputs are categorized in two types, the consumable and the capital inputs. Seeds and planting material (SPA), manures and fertilizers, plant protection products (PPP), gas, lubricants and electricity are considered as consumable inputs. Tractors, agricultural machineries, agricultural implements and tools on the other hand are identified as capital inputs.

Food and Agriculture Organization (FAO) estimates that agriculture in 2050 will need to produce almost 50% more food, feed and biofuel than it did in 2012. This specific estimation is due to the increase of population on Earth. Despite that the population growth is slowing down, predictions by the United Nations (UN) indicate that the world's population would reach 9.73 billion in 2050. An interesting fact is that in Sub-Saharan Africa and South Asia the need for agricultural outputs will be more than double by 2050 compared to 2012 levels, while in the rest of the world the expected increase shall be about one-third above.

Agricultural production has met major challenges in the past and achieved them. Between 1961 and 2011, a similar time frame to 2012-2050, a much bigger increase in production was accomplished. During that period, global agricultural output was more than tripled (Alexandratos and Bruinsma, 2012) with irrigation, agro-chemicals and the increased use of land playing a major role. That pace is difficult to be maintained due to a range of factors like underinvestment in agriculture, gaps in technology, climate change and pressure on natural resources. Moreover, past development brought negative effects on agriculture's natural resources and that frame includes land degradation, salinization of irrigated areas, over-extraction of groundwater, the build-up of pest resistance and the erosion of biodiversity (FAO, 2017).

It is obvious that humans are now dominating Earth (Schueller, 2016), and that in order for the future generations to maintain or improve their standards of living sustainable practices of production and human activities shall be followed. According to FAO, *the key to a sustainable agricultural growth is the more efficient use of land, labor and agricultural inputs through technological progress, social innovation and new business models*. Cultivating practices and techniques shall differ due to the particular local conditions and needs worldwide, but the necessary sustainability could be achieved or improved through the applications of precision agriculture.

1.2 Precision Agriculture-Development and definitions

The development of new technologies has allowed us to measure the spatial and temporal variability of several parameters from yield and soil and gave us the opportunity to develop Precision Agriculture (PA) systems (Fountas and Gemtos, 2015). Spatial variability refers to physical changes in the field and temporal variability to physical time-based changes. PA can be defined as the management of spatial and temporal variability of the fields using Information, Computers and Technology (ICT) (Gemtos et al., 2013) in order to upgrade the fields' efficiency, reduce any negative impact that improper use of inputs brings to the environment and maximize their effectiveness, but we will return later on the definition subject.

There are many definitions existing to describe what PA is besides the one mentioned earlier on the text. The United States House of Representatives gave the first actual definition of PA as *"an integrated information - and production-based farming system that is designed to increase long-term, site specific and whole farm production efficiencies, productivity, and profitability while minimizing unintended impacts on wildlife and the environment"* (H.R. 725, 1997).

In a recent study of 2016, EU characterizes PA as *"a modern farming management concept using digital techniques to monitor and optimize agricultural production processes"*. PA contains methods which *"promise to increase the quantity and quality of agricultural output while using less input"* aiming *"to save costs, reduce environmental impact and produce more and better food"*. EU has established the last few years strict legislations regarding agrochemical residues on food and environment subsidizing farmers through CAP pillars for their good environmental practices. Firms operating on food networks in central and northern countries of EU function are very intensely and strictly concerning agrochemical residues on commodities they trade. In Greece however, there are no real time on-field inspections.

CEMA, the European association representing the agricultural machinery industry in Europe, defines PA as *"the management of variations in the field accurately to grow more food using fewer resources and reducing production costs"*. That is a simple explanation but even simpler is the one from Leonard (2015) who describe PA as a method to manage variabilities in space and time.

Gebbers and Adamchuk (2010) outline that PA is an *"information-based management of agricultural production systems"* that emerged *"as a way to apply the right treatment in the right place at the right time".* This is going to be achieved by the application of progressive and developed technologies which could improve crop production combined with the reduction of any possible environmental pollution. From that point of view PA is not only science but art too (Khosla and Shaver, 2001).

Fountas et al. (2016) define PA as *"the management of spatial and temporal variability in fields using ICT"*. Farmers could benefit from this farming system and reduce both costs and environmental impact by using precise and optimized inputs. Moreover, PA *"can be utilized in a traceability system that could record the activities at a site-specific level"* (Fountas et al., 2011). On the other hand, Stone and Raun (2016) identify PA as the site-specific crop management (SSCM) and not SSCM as a part of PA.

Recent approaches relate PA to climate change resilience such as Climate Smart Agriculture (CSA). CSA aims to increase food security and incomes as well as adapt and build resilience to climate change in a sustainable way while trying to connect innovations such as conservation agriculture, agroecology, agroforestry and the development of crop varieties more tolerant to drought, waterlogging, salinity, diseases or pests (FAO, 2013a).

Given these points, PA could be considered as an integrated information holistic management system of spatial and temporal variabilities using ICT. Focuses on the optimized use of inputs for the growth of production's quantity and quality including food security, while reducing financial costs and environmental impacts; enhancing a sustainable agricultural growth.

1.3 Expected benefits

In agriculture as well as to every business, better decision making and planning is likely to bring a wide range of benefits (EU, 2014) analyzed by economic, environmental or social perspectives. Being a farmer is not as simple as it sounds because agriculture depends on a lot of parameters that affect production and its quality features. Factors such as propagating material and soil, applied consumable or capital inputs for the cultivating techniques and practices and climate, the big imponderable, affect the whole-farm management. Interactions amongst the above bring the final result in production's quantity and quality, costs, income and environmental impact (Fountas and Gemtos, 2015).

Although there are no models that can relate accurately all these factors combined despite the technological progress and scientific agricultural research, PA can provide a significant facilitation to farmers. Creation of long-term databases relating field productivity and weather conditions, can lead to projections about crop reactions; therefore, to management adjustments (Fountas and Gemtos, 2015). GPS technology can be used in order to detect and record the machinery tasks and traffic and estimate of execution times for each of them, therefore the labor force needed.

PA technologies facilitate the precise tracking of farm production and assist the optimization of production's quantity and quality through a site-specific management plan. The modification of distribution and timing of inputs like fertilizers and other agrochemicals based on the field's spatial and temporal variability (Zhang et al., 2002) along with the knowledge of inputs' costs, may improve profit potential and reduce some risks as Oriade and Popp (2000) have already illustrated. But this can take place only in a whole-farm approach and after considering all cropping activities and resource limitations. In the economic crisis environment where gross margin and profitability are getting tighter for the farmers, the operational cost reduction without a production decline below a breakeven line, or no production decrease at all, is valuable.

An important challenge for PA applications is the minimization of environmental impact and risk. Controlled traffic farming and variable dosage technologies can play a key role here. However, in order to evaluate the environmental benefits by PA technologies use, there must be a comparison with the environmental damage under conventional and precision farming technologies (Ancev et al., 2005). This is something difficult because the damages or benefits from each other *"have not been systematically and quantitatively measured"* (Zhang et al., 2002). There are researches that reveal positive results though, such as the improved efficiency of nitrogen (N) use and minimization of its leaching by Wong et al. (2005), who used PA techniques and the APSIM model (Agricultural Production Systems sIMulator) concluding that N management can be improved under PA management.

Social and working conditions could also be affected by PA. Advanced and modern technologies need educated personnel to operate; workforce which stays informed concerning every turn of their field of work. This can increase knowledge standards of society through the tuition of people who intend to work as farmers or for farmers. The environment stability PA intends to establish could ameliorate social and working conditions. New machinery provides safety to users, assisting them to work safer and in some occasions lesser compared to the preceding years.

Moreover, operational cost reductions under normal sequence of normal seasons, lead to bigger profits for farmers most of the times or salary increases for the labor force. Finally, technology progress comes through technology use which brings the required knowledge for amendments and development. Borrowing an example from physics, CERN is not just the Large Hadron Collider and ATLAS experiment. The transfer of its technologies and expertise to society provide solutions in many fields such as cultural heritage, industry, aerospace applications, medical and biomedical technologies etc.

1.4 The Greek case

While in countries such as the USA, the UK, Denmark and Sweden implementation of PA started at the beginning of 1990s, Greece got aboard a decade later, in 2001. This however is not just another Greek paradox but a general phenomenon in many southern Europe countries as a result of some prevailing socioeconomic and agricultural conditions.

According to Gemtos et al. (2003) five factors affected the implementation of PA in Greece. Initially, farmers could not disengage from obsolete cultivating practices and detach from governmental and EU subsidies, descended into non-profitable cultivating techniques and training systems or select subsidized crops; factors that appear until now. Rural population in Greece is getting older as years pass, and the educational level has taken an upturn only the last few years. In addition, agricultural land is constituted by many and small fields and does not belong to farmers exclusively (a notable part of potential agrarian territories belongs to citizens of other professions), increasing the cultivating costs. Finally, in Greece and other southern European countries fruits and vegetables are cultivated in big scale. For these crops did not exist well-developed technologies for PA applications.

In my opinion, pathogenic factors such as bad economic conditions and poor intertemporal political decisions, still holds back the development and implementation of PA techniques, in Greece. Within EU's CAP agreements for the confined cultivation of some crops in some countries, Greece nearly stopped the cultivation of tobacco and the cultivation of sugar beet has shrunk excessively. For that purpose, farmers who cultivated these crops have been subsidized with large amounts of money. It is a strong fact that only a small part of these subsidies reinvested in agriculture for development and modernization.

Moreover, due to the economic crisis, its progress and the results brought through legislation, PA technologies are relatively expensive for individual farmers. PA implementation could be delivered through well-organized agricultural cooperatives. Finally, Greek governments have no agricultural policy regardless their political view and position. Their concern is how to maximize farmers' cash inflow using subsidies and follow CAP without any effort to upgrade agricultural production (Fountas and Gemtos, 2015).

However, many scientific PA projects have been implemented in the past and many others continue or start nowadays.

1.5 Representative implementations of PA in Greece

There is a significant research in progress at universities and institutes all over the country, but there are no references for implementations by farmers until now (Fountas and Gemtos, 2015), which is the big challenge for PA.

1.5.1 Implementations on cotton and grain

The first PA implementation took place in 2001 during cotton harvesting, where the main target was to map cotton yield. During the next five years of the research, increased yield variability emerged even in small parcels. Soil sampling and analysis gave the necessary information about soil texture and chemistry, while sensor VERIS 3000 was used for the electrical conductivity (EC) measurements in order to evaluate the variability of yield's quality.

Hydrosense program (2010) was another PA implementation on cotton and its main target was to display the efficiency of new technologies for the conservation of irrigation water, N fertilizing and plant protection products through PA. The results showed 18% irrigation water saving, percentage that increases up to 70% for herbicides, ending to 50% conservation of N fertilizers with only 8% decrease of efficiency compared to conventional fertilizing techniques (Evangelou and Tsantilas, 2011).

Chloros (2010) and Fytilis (2011) installed a yield mapping and seed moisture sensor on a Claas Dominator 106 harvester for the yield mapping of maize and winter grains. The variability of yield and moisture across the field proved that there is a need for site-specific management zones in order to manage increase productivity and reduce the level of inputs.

1.5.2 Implementations on apple orchards

Implementations in apple orchards started in 2005 with yield mapping. The estimation of orchard's productivity made by weighing the yield, showing substantial alterations between different plots of the field. Apples' quality characteristics measured and mapped, presenting variability between plots and that except fruit size the other quality standards are not increased in plots with high productivity. Soil analyses and EC measurements were included, and the research concluded with a proposal for variable N fertilization (Aggelopoulou, 2008).

Aggellopoulou et al. (2011) continued the specific study by researching the flower spatial variability, trying to estimate that way the upcoming season yield. Few years later, Liakos (2013) added measurements of normalized difference vegetation index (NDVI) using CIRCLE device. NDVI measurements proved that variations of vegetation index connect with yield and he confirmed the connection between flower number and yield studied by Aggelopoulou. Based on his results, Liakos (2013) also applied diverse N fertilization succeeding in increasing farmer's profit by 21% while decreasing N fertilization 32.4% in 2011 and in 2012 farmer's profit increased 9% while the amount of N fertilization showed a decrease of 56.6%. These are the results by applying PA methods, compared to conventional agricultural practices applied by the farmer in different plots of the same field.

1.5.3 Implementations on olive trees and vineyards

Significant PA implementations have taken place in olive trees and vineyards which are two of the most cultivated agricultural species in Greece, extending in wide areas.

Fountas et al. (2011) applied yield mapping using GPS after weighing the yield of every plot in a commercial olive tree orchard of 9.1 hectares for olive oil production. Soil sampling and analyses aided the creation of P, K and pH maps based on which lime for pH corrections and fertilizers were applied at a variable rate manually. *Maps of penetration resistance and organic matter were used to compare two different weed control strategies, namely rotary cultivation and the use of post emergence herbicides under no-tillage. After three seasons of herbicide use, the non-tilled part of the field had a significantly larger organic matter content and smaller penetration resistance compared to the part of the field under soil cultivation for weed control.*

The first decade of 2000 marked the start of studying yield and quality standards variabilities of vineyards. Tagarakis (2014) added in the studies soil samples analysis, measurements of NDVI and plants' normal features such as water potential. Combined with soil moisture measurements and soil mapping he succeeded to reduce the use of irrigating water almost 20%. Moreover, in the same research was attempted to estimate with a laser scanner the number of branches that would be cut off during pruning. The scanning procedure took place before and after pruning. That method was successfully applied for the estimation of olive trees diameter.

Furthermore, Lowrence (2014) developed a system to measure sap flow in grapevines and transfer the collected data to a web server for storage. He used Arduino-based technology for monitoring the water status of plants, with wireless sensor networks. The aim of his research was to increase the ability of small-scale farmers to measure more accurately their plants' water use by developing a low-cost
monitoring system from easily obtainable materials. The developed system can be used at irrigation systems for the orchard water management (Fountas and Gemtos, 2015).

1.5.4 Other implementations

Implementations in pear orchards comprised by yield mapping, noticing considerable variability in quantity and quality of fruits. Based on application maps N fertilization applied saving 56% and 50% of N fertilizer in two years (Vatsanidou et al., 2014).

Implementations in peach orchards included automatic yield mapping system using RFID labels and GPS concluding to high yield variability. Moreover, a monitoring system of workers' movements was used attempting to eliminate unnecessary steps. This system proved that workers' productivity could be increased by streamlining their movements (Ampatzidis, 2010).

Fountas et al. (2015) applied yield, quality standards and EC mapping in a watermelon field. They installed a system for measuring soil moisture in the field and by following differentiated irrigation saved 10% of water and increased 10% the marketable amount of watermelons comparing to conventional practices.

1.6 PA technologies

PA uses modern technologies to gather information about spatial and temporal variations within a field utilizing that information for the management of inputs and practices (Grisso et al., 2009) in all the production stages (Fountas and Gemtos, 2015). Such technologies are:

1. Global positioning and geographic information systems (GPS and GIS)
2. Yield mapping
3. Soil properties mapping
4. Soil EC mapping
5. Remote sensing (RS)
6. Variable rate applications (VRA)

1.6.1 Global Positioning System (GPS)

1.6.1.1 Introduction

GPS is used for the specification of absolute and relative positioning coordinates by processing data form or to satellites (Pantelis et al., 2004); providing that way positioning, navigation, and timing (PNT) services to users. It is a U.S.-owned utility developed, maintained and operated at 2/3 by U.S. Air Force.

1.6.1.2 Operational parts of GPS

GPS consists of three segments:

1. The space segment.
2. The control segment.
3. The user segment.

The space segment consists of a constellation of 24 satellites transmitting radio signals to users (Figure 1.1). They fly in medium Earth orbit (MEO) at an altitude of approximately 20,200 km and each one circles the Earth every twelve hours. The satellites are arranged into six equally-spaced orbital planes surrounding the Earth and each plane contains four satellites. This 24-slot arrangement ensures that at least four satellites send signals at any point of Earth for 24 hours every day.

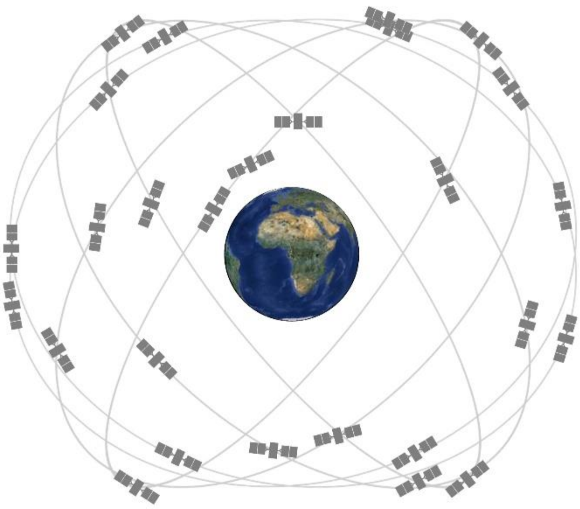


Figure 1.1. The 24-slot satellite constellation (Source: https://www.gps.gov)

The control segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current Operational Control Segment (OCS) includes a master control station, an alternate master control station, 11 command and control antennas, and 16 monitoring sites (Figure 1.2). Monitor stations track GPS satellites as they pass overhead,

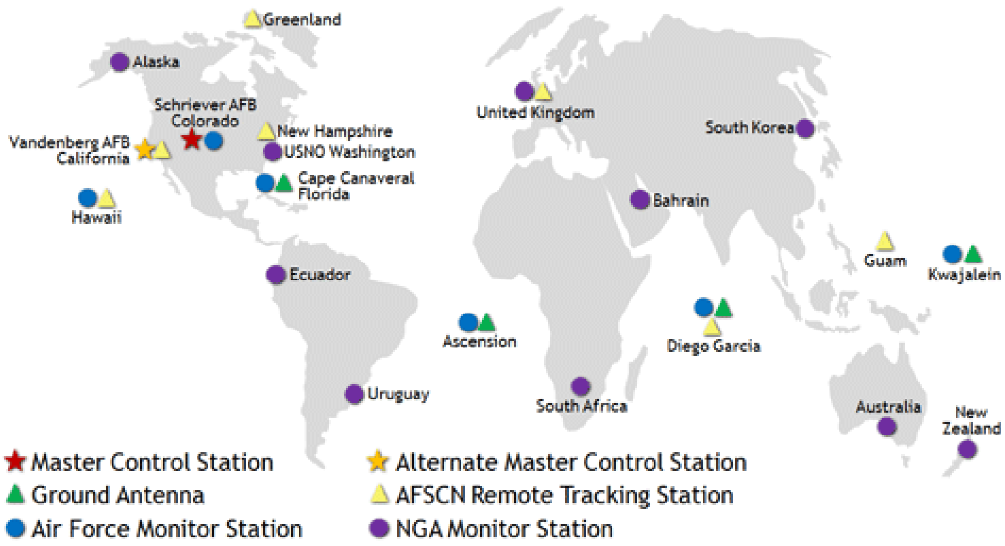


Figure 1.2. GPS control segment map (Source: https://www.gps.gov)

collect navigation signals, range/carrier measurements, and atmospheric data, feed observations to the master control station, utilize sophisticated GPS receivers and provide global coverage via 16 sites. Master control station:

1. provides command and control of the GPS constellation,
2. uses global monitor station data to compute the precise locations of the satellites,
3. generates navigation messages for upload to the satellites,

4. monitors satellite broadcasts and system integrity to ensure constellation health and accuracy and
5. performs satellite maintenance and anomaly resolution, including repositioning satellites to maintain optimal constellation.

Finally, it is backed up by a fully operational alternate master control station and uses two separate systems to control operational and non-operational satellites; the Architecture Evolution Plan (AEP) and the Launch/early orbit, Anomaly resolution, and Disposal Operations system (LADO). Ground antennas send commands, navigation data uploads and processor program loads to the satellites, collect telemetry and communicate via S-band and perform S-band ranging to provide anomaly resolution and early orbit support. S- band is a microwave band covering frequencies between 2 and 4 GHz. Ground antennas consist of 4 dedicated GPS ground antennas plus 7 Air Force Satellite Control Network (AFSCN) remote tracking stations.

The user segment consists of/involves users, citizens and army, using GPS for navigation and positioning purposes of people or vehicles (Fountas and Gemtos 2015). It consists on L-band radio receiver/processors and antennas which receive GPS signals, determine pseudoranges (and other observables) and solve the navigation equations in order to obtain their coordinates and provide a very accurate time. L-band range in the radio spectrum from 1 to 2 GHz. GPS is free and open to users and there is no need of operating license.

1.6.1.3 GPS in PA

The development and implementation of PA has been made possible by combining GPS and GIS. These technologies enable the coupling of real-time data collection with accurate position information, leading to the efficient manipulation and analysis of large amounts of geospatial data. GPS-based applications in PA are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications and yield mapping. GPS allows farmers to work during harsh field conditions with low visibility such as rain, dust, fog, and darkness.

GPS equipment manufacturers have developed several tools to help farmers and agribusinesses become more productive and efficient in their precision farming activities. Today, many farmers use GPS-derived products to enhance operations in their farming businesses. Location information is collected by GPS receivers for mapping field boundaries, roads, irrigation systems, and problem areas in crops such as weeds or disease. The accuracy of GPS allows farmers to create farm maps with the precise expanse of field areas, road locations and distances between points of interest. GPS allows farmers to accurately navigate to specific locations in the field, year after year, to collect soil samples or monitor crop conditions.

Crop advisors use rugged data collection devices with GPS for accurate positioning and mapping of pest, insect, and weed infestations in the field. Pest problem areas in crops can be detected and mapped for future management decisions and input recommendations. The same field data can also be used by aircraft sprayers, enabling accurate swathing of fields without use of human “flaggers” to guide them. Crop dusters equipped with GPS are able to fly in accurate paths over the field, applying chemicals only where needed, minimizing chemical drift, reducing the amount of chemicals needed, thereby benefiting the environment. GPS also allows pilots to provide farmers with accurate maps.

Farmers and agriculture service providers can expect even further improvements as GPS continues to improve.

1.6.1.4 Enhancements to GPS

GPS accuracy ranges between and 10 meters and that is the reason for the creation of new systems such as Differential GPS (D-GPS) and Real-Time Kinematic GPS (RTK-GPS) that improve accuracy even to 1 centimeter.

D-GPS is an enhancement to GPS technology providing improved location accuracy. It uses a fixed ground-based network of reference stations to broadcast the position difference indicated between GPS satellite system and the know fixed positions. These stations transmit the difference between measured satellite pseudoranges and actual pseudoranges and correct their pseudoranges by the same amount. The corrected signal is disseminated locally over ground-based transmitters of shorter range and its accuracy ranges between 0.3 m and 1 m. Similar systems such as EGNOS (Europe), WAAS (USA), SDMC (Russia) and Starfire (JohnDeere) for implementation in agriculture use satellites instead of ground-based stations for signal corrections (Figure 1.3).

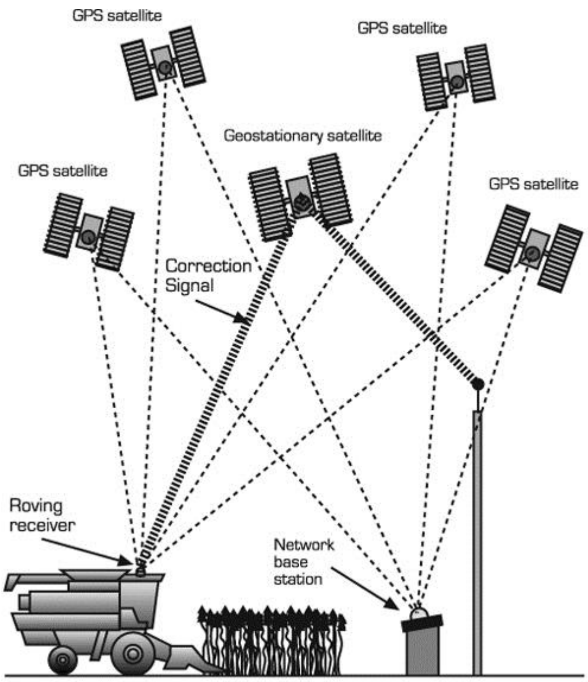


Figure 1.3. Differential GPS Systems (Source: https://pubs.ext.vt.edu/442/442-503.html#L6)

RTK-GPS is a positioning technique that allows users to acquire real-time positioning accuracy at the level of centimeters (Elhattab, 2016). RTK technique provides high positioning performance due to the proximity of a base station. Such technique is based on the use of carrier measurements and the transmission of signal corrections from the base station to a rover station. Base station's location is known, and the main errors neutralize. The RTK technique can be used for distances up to 10-20 km, accuracy of a few centimeters in the rover position and it is widely used in surveying applications. Main limitations of RTK are the limited range in connection with the base location, the need of a communication channel for real time applications, the time needed to fix the signal errors (some seconds to some minutes) which depends on the processing algorithm and the distance between the base and the rover and the incompatibility with urban applications because the rover has to track the GPS signals continuously to avoid re-initialization of the processing.

1.6.1.5 Other Global Navigation Satellite Systems (GNSS)

The term of GNSS refers to systems which use constellations of satellites to provide positioning and timing signals from space to receivers on Earth, for the determination of their location. The performance of a GNSS is assessed by criteria such as accuracy, integrity, continuity and availability. Besides USA's NAVSTAR GPS other GNSS exist and will be discusses briefly further down.

Galileo is Europe's GNSS and the only GNSS option under civil control worldwide. It is a joint initiative of the European Commission (EC), the European GNSS Agency (GSA) and the European Space Agency (ESA). There are now 26 Galileo satellites orbiting the Earth, and the supporting ground station infrastructure is working well so, Galileo is now ready to be used. However, the system will reach its Full Operational Capability (FOC) of 30 satellites in 2020. The complete system constellation will comprise satellites spread evenly around three orbital planes inclined at an angle of 56 degrees to the equator. Each satellite will take about 14 hours to orbit the Earth and one satellite in each plane will be a spare, in case any operational satellite fails. From most locations, six to eight satellites will always be visible, allowing positions and timing to be determined very accurately to within a few centimeters. Once fully operational, Galileo will offer four services; the open (OS), the high accuracy (HAS), the public regulated (PRS) and the search and rescue service (SAR).

BeiDou (BDS) is a GNSS constructed and operated by China under a three-phase strategy. Phase one comprised the construction of BDS-1 which aimed to provide services to the whole country by the end of 2000. Phase two, the construction of BDS-2, targeted the provision of services to the Asia-Pacific region by the end of 2012. Phase three was planned to complete the construction of BDS-3 around 2020, to provide services worldwide using an orbital constellation of 35 satellites (Figure 1.4). 5 BeiDou-G satellites regulated in the

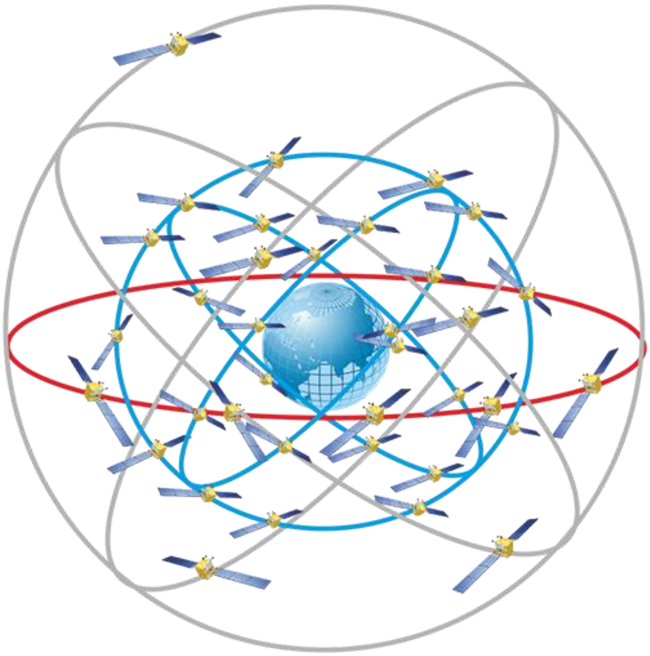


Figure 1.4. BeiDou Orbital Constellation (Source: https://www.glonass-iac.ru/en/guide/beidou.php)

geostationary orbit (GEO) (58.75° E, 80° E, 110.5° E, 140° E and 160° E), 27 BeiDou-M satellites arranged in medium Earth orbit (MEO) (in three planes with the nominal altitude of 21,528 km and nominal period of 12 hours 53 min inclined at 55° relative to the equator) and 3 BeiDou-I satellites organized in inclined geosynchronous orbits (IGSO) with the altitude of 35,786 kilometers and an inclination of 55° to the equatorial plane. The sub-satellite tracks for those satellites coincide while the longitude of the intersection point is at 118°E.

On December 27, 2018, the State Council Information Office announced that the BDS-3 Primary System was completed to provide global services with 10 meters horizontal and 10 meters vertical (95% confidence level) positioning accuracy (5 meters horizontal and vertical accuracy in Asia-Pacific region), 0.2 meters per second (95% confidence level) velocity accuracy, 20 nanoseconds (95% confidence level) timing accuracy and more than 95% system service availability.

The Indian Regional Navigation Satellite System (IRNSS) or NavIC (NAVigation with Indian Constellation) is an independent regional navigation satellite system being developed by India. It will provide a Standard Positioning Service (SPS) for all users and a Restricted Service (RS), which is an encrypted service only for authorized users. The expected position accuracy is better than 20 meters in the primary service area, an area which includes India and the region extending up to 1500 km from its boundary. The space segment consists of an eight-satellite constellation. Three satellites (IRNSS 1C, 1E, 1I) are in the GEO and the other five (IRNSS 1A, 1B, 1D, 1F, 1G) are in IGSO in two different planes. The SPS is transmitted on L5 (1,164.45 – 1,188.45 MHz) and S (2483.5-2500 MHz) bands. An extended service area lies between the primary service area and the area enclosed by the rectangle from latitude 30^{o} S to 50^{o} N and longitude 30^{o} E to 130^{o} E.

Quasi-Zenith Satellite System (QZSS) is a regional navigation satellite system commissioned by the Japanese Government as a National Space Development Program and

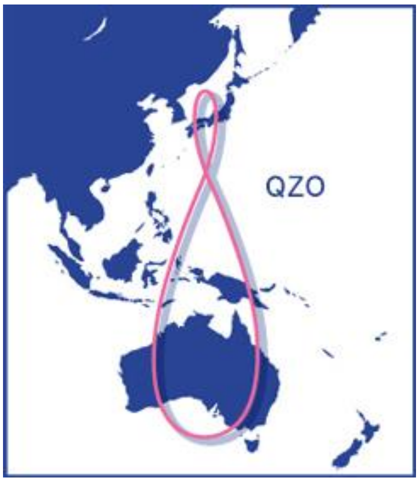


Figure 1.5: The Quasi-Zenith Satellite Orbit (Source: http://qzss.go.jp/en/)

its services started officially on November 1, 2018. This system is compatible with GPS satellites and can be utilized with them in an integrated fashion. Moreover, it can be used in the Asia-Oceania regions with longitudes close to Japan. QZSS is currently a four-satellite constellation and will become a seven-satellite constellation in the future. Three satellites are in a quasi-zenith satellite orbit (QZO) (Figure 1.5) and one in the GEO. GZSS applications include PA amongst others and it has messaging and position-related services. Messaging service provides users in the field with disaster management and rescue. The positioning-related services are four and include the Satellite Positioning Service which provides the same as GPS satellites despite urban and mountain areas, the Sub-Meter Level Augmentation Service providing accurate positioning around 2-3 meters, the Centimeter Level Augmentation Service (CLAS) supporting highly accurate positioning around 10 centimeters and the Position Technology Verification Services which provide an application demonstration for new positioning technology.

Globalnaya navigatsionnaya sputnikovaya sistema or "Global Navigation Satellite System" (GLONASS) in English, is a radio-based satellite navigation system operated by the Russian government's Russian Space Forces. It is considered as an alternative and complementary at the same time to GPS, BeiDou and Galileo. Its orbital constellation consists of 24 satellites equally distributed in three orbital planes inclined at 64.8° to the equator. The GLONASS satellites are placed in roughly circular orbits with the nominal orbit altitude 19,100 km and an orbital period of 11 hours, 15 minutes, 44 seconds. Currently, GLONASS run on third generation satellites GLONASS-K which is a substantial improvement of the previous generation GLONASS-M. It is the first unpressurised GLONASS satellite with a reduced mass

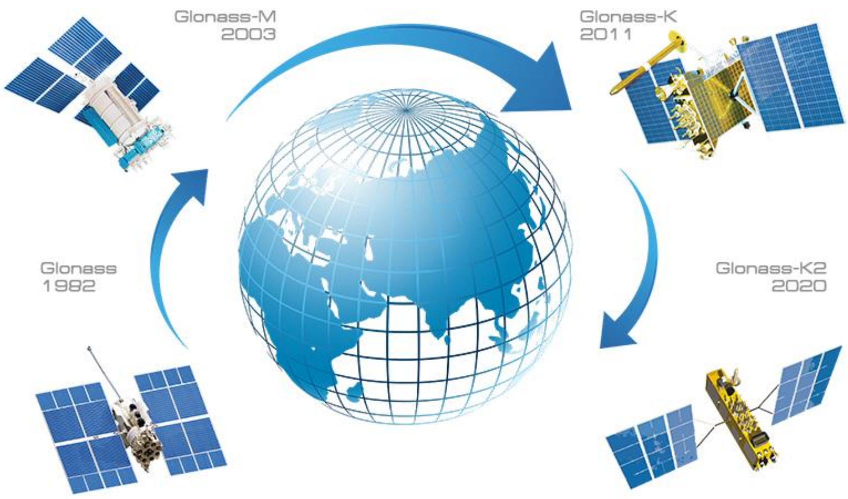


Figure 1.6. GLONASS satellites generetaions (Source: https://www.glonass-iac.ru/en/)

(750 kg instead of 1,450 kg of GLONASS-M) and an operational lifetime of 10 years (GLONASS-M lasted for 7 years). It will transmit more navigation signals to improve the system's accuracy, including the new CDMA signals in L3 and L5 bands. System's development does not stop and research for the GLONASS-K2 satellite construction is in progress (Figure 1.6).

1.6.2 Geographic Information Systems (GIS)

1.6.2.1 Introduction

GIS is a very useful technological tool for working with geographic information (Huisman and de By, 2009) and answering to geographical questions. The use of computers for the description and creation of digital representations of the Earth's surface to take managing decision, is denoted by the GIS term (Longley et al, 2005). Nowadays, GIS has evolved from a mapping feature to a spatial science technology due to two things; the increasing demand on spatial information and the rapid growth of computer technologies (Bohner et al, 2005).

1.6.2.2 GIS functioning

The wide amount of collected data needs to be organized, analyzed and processed, therefore a software is required. The final results are exported as digital maps of the examined area. Moreover, additional analytical tools such as statistics, simulations and models can be applied through the GIS to extract more information from the data and support decisions, and that is the real power of GIS (Westervelt and Reetz, 2000).

A GIS software consists of the following parts:

1. A spatial data input system which admit/identify and register the data.
2. A data storage and database organization system.
3. A data output system containing analysis' outcomes such as tables, maps, shapes that either ascend on the computer screen or being recorded at the computer memory.
4. A data analysis system which contains all the necessary tools that assist users to delete possible errors from data, determine parameters and surfaces, change scale map and make geostatistic data analysis.
5. A user interface system with menus and commands for the user-program interaction. (Fountas and Gemtos, 2015)

Data are stored in a GIS in two main formats, vector and raster (Figure 1.7). Vector representation of data defines objects as points, connected points (lines) or areas enclosed

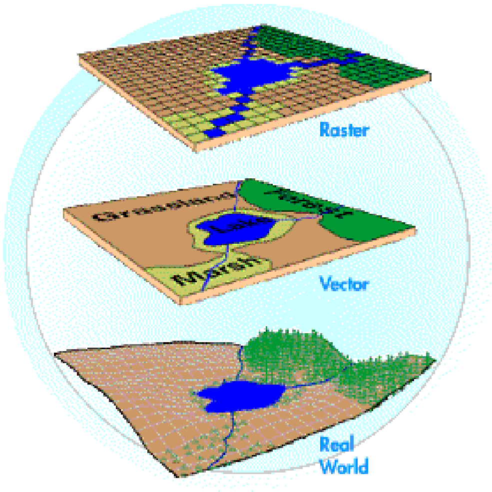


Figure 1.7. Raster and Vector representation (Source: https://www.rst2.org/ties/GENTOOLS/gis_wrk.html)

by lines (polygons). Raster representation demands the entire cell to be identified with the same representation. Precision depends upon the relative size of the grid cells. In vector format, points are stored as individual (x,y) coordinates, lines as a set of mathematically connected points and areas are stored as a mathematically connected set of points defining the boundary. In raster format, points are stored as individual column-row matrix cells, lines as connected cells and areas as a set of contiguous cells defining the interior (Figure 1.8) (Westervelt and Reetz, 2000).

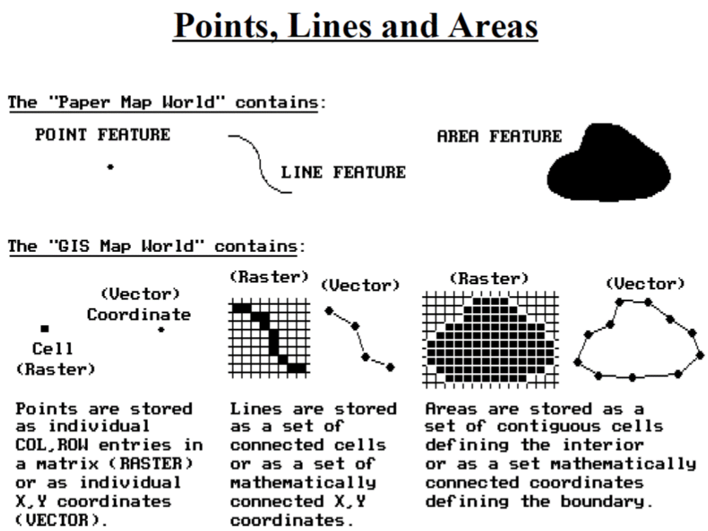


Figure 1.8. Points, lines and areas in vector and raster representation (Berry, 1997)

1.6.2.3 GIS and coordinate systems

The necessity of a coordinate system is obvious since the imported data in the GIS software are linked to their geolocation, supporting their depiction on a map. A local system can be adopted and the user will define its (x,y)=(0,0) location. In that case, all the other locations of the examined area will be identified as depended upon the zero-point. Such a system is very useful if the examined area is for example an orchard where the tree location is permanent/fixed. The main disadvantage of a local coordinate system is that data from other sources need to be converted manually to match the system's format. Furthermore, interpolations by Earth's curvature may appear when a research runs on a large land parcel.

Two other worldwide coordinate systems are more suitable and recommended as alternatives to local system implementations. The longitude-latitude system determines one angle from the equator and one from the prime meridian based in Greenwich, resulting in coordinates measured in degrees, minutes and seconds. The Universal Transverse Mercator system (UTM) uses a two-dimensional Cartesian coordinate system to give locations on the surface of the Earth. It is a horizontal position representation meaning that it is used to identify locations independently of altitude and the coordinates corresponds to meters north and east. UTM divides the Earth into 60 zones, each 6° of longitude in width, and each zone uses a transverse Mercator projection that can map a region of large north-south extent with low distortion.

The most popular utilization in cartography, geodesy and satellite navigation is the World Geodetic System which comprises a standard coordinate system for the Earth, a standard spheroidal reference surface for raw altitude data (called datum or reference ellipsoid), and a gravitational equipotential surface (geoid) that defines the nominal sea level. Its latest version is WGS 84. The coordinate origin of WGS 84 is the Earth's center of mass with a possible error less than 2 centimeters, the meridian of zero longitude is the IERS Reference Meridian (IRM), the datum surface is a spheroid with equatorial radius a=6,378,137 meters at the equator and flattening f=1/298.257223563 and finally, WGS 84 uses the Earth Gravitational Model 1996 (EGM96) geoid, lately as revised in 2004.

1.6.2.4 GIS in PA

GIS are evolving into very important tools for PA implementations because they can capture, prepare, manage, store and preserve, process, analyze and present data space related but time alterable. Through these procedures GIS technologies can play a crucial role in agriculture, helping farmers manage and develop their land in a more efficient way ending up to an increased quantity and quality of production, while reducing the expenses. That happens because PA systems are taking into account various information/data coming from field measurements.

Fundamental part of such functioning and development is the decision-making based on geography. The significant thing about GIS on data imaging is their substantial potential to combine disparate data in a mutual database. These data then are referred as layers representing many different variables (Fountas and Gemtos, 2015).

The biggest GIS advantage over single mapping is that interactions between maps and collected data take place in GIS after user command and all the collected data can be viewed on a map after being processed. That way, modern and specialized GIS software may offer to users/farmers the possibility to predict yield, harvest accordingly to quality standards or control the quality of production according to protocols and certifications like AGRO, GLOBALGAP etc. in order to increase their income. In addition, such software can assist the use of inputs in a more efficient way for sustainability and reduction of production cost. Moreover, larger amount of data can be managed easily and quickly (Floras, 2004). The big disadvantage of GIS is that they are technologically-dependent and that without computers their utilization is very difficult.

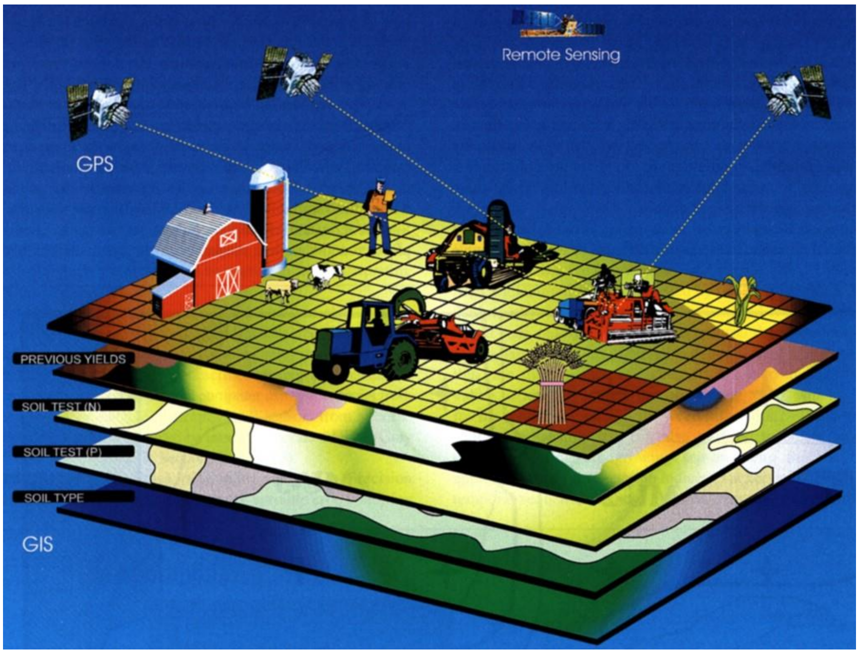


Figure 1.9. Integration of GIS, GPS and remote sensing (Brisco et al, 1998)

Maps present the variability of one or several examined figures. The creation of precise thematic maps is very important because side by side with the knowledge upon a fields background, they may affect long-term cultivation managing decisions.

The first step for a map creation is the insertion of field boundaries. This can happen either by scanning an aerial photo or by mapping using GPS. After that, data are imported and smoothed or interpolated. Users can import data from many examined parameters as data layers and they will appear in different images, because every map represents individual measurable values. The selection of scheme colors and legends comes after and finally every map is ready for printing or demonstration (Figure 1.9).

1.6.3 Yield mapping

Yield mapping is the first step for a farmer to detect if a PA system implementation is essential or not. If there is no significant yield spatial variability and its amount is adequate, there is no need for investing in PA technologies. On the contrary, if spatial variability is substantial the cultivated techniques and management methods are not efficiently applied without modification in the entire field. In that case, implementation of PA can improve and increase yield (Fountas and Gemtos, 2015).

Yield mapping means to monitor crop yield in various but definite locations of the field. This is the start of investigating which factors affect, if they do, crop yield and combined with other data such as soil properties or weather, PA implementation can begin.

Most advanced yield mapping systems have been developed in machine-harvested crops. The combined utilization of sensors in specific parts of the machinery, GPS, computers and GIS software gives the eventual result of yield illustration on maps. Sensors measure data such as crop yield, seed moisture, machinery velocity and header elevation but the whole system needs calibration because yield sensors do not measure directly crop yield but volume, impact force, plate displacement, radiation absorption and moisture. GPS provides the machinery position while a computer on the cropping machine captures, saves and displays the compiled from sensors data. With a PCMCIA card (Personal Computer Memory Card International Association) the gathered data are transferred to a personal computer and using a GIS software the crop yield maps are created.

All attempts for yield mapping in orchards and non-machine harvested crops have a common denominator; the manual crop yield weighing on scales during harvest. However, every research has used different methods for dividing the examined field into zones (cells) and weighing crop yield.

Schuller et al. (1999) considered harvest as an important and busy period so their priority was to eliminate any interference between yield measurement/mapping and harvest. They implemented yield mapping (Figures 1.10 and 1.11) in hand-harvested citrus by recording the location of containers full of fruits as they were picked up by a goat truck. The Crop Harvest Tracking System (CHTS) was used to map the location of each container and the goat truck operators were handling the yield measurement equipment.

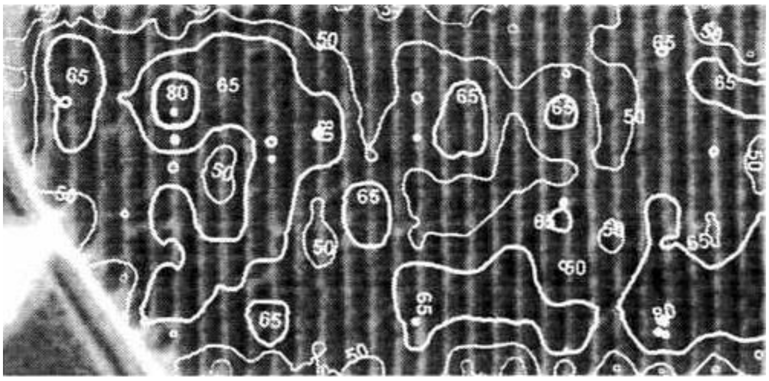


Figure 1.10: Surface intepolation yield map (in t/ha) of a 3.5-ha block overlaid on georefereced aerial photograph (source: Schueller et al., 1999)

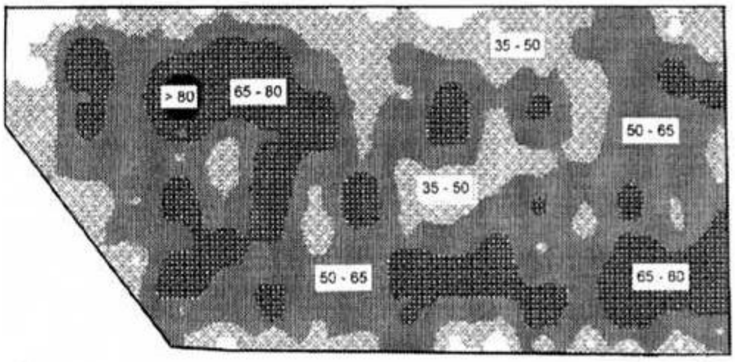


Figure 1.11: An interpolated surface map (in t/ha) showing spatial variation in field (Source: Whitney et al., 1999)

Greece is a country with a large variety of hand-harvested crops and many research efforts take place. Some significant examples are cited further down. Aggelopoulou et al. (2010, 2011) implemented yield mapping in apple orchards of free palmette training system using a commercial scale for weighing, and GPS for mapping the location of containers that were grouped per 10 or every specific tree number because of the training system. Tagarakis et al. (2011) used the same method for yield mapping in vineyards. In peach orchards, a crucial tree crop for Greece, Ampatzidis et al. (2009) developed a system based on Radio Frequency Identification (RFID) and GPS technologies. They installed on the trailer platform a scale with RFID reader and GPS for weighing and recording the location of every container. In 2007 and 2008, Fountas et al. (2011) implemented yield mapping in an olive tree plantation (Figure 1.12). Instead of containers olives were placed in bags which are flexible containers.

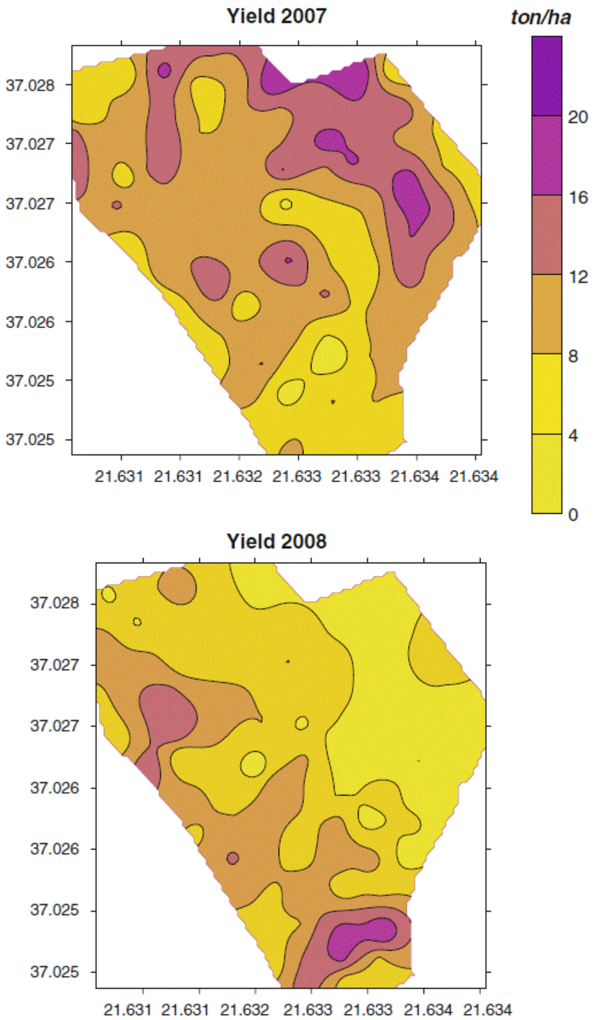


Figure 1.12. Yield maps of 2007 and 2008 (Source: Fountas et al., 2011)

After determining their weigh, bags were positioned using a GPS and every bag was related to the nearby trees.

Similar methods are developed and applied worldwide for yield mapping in orchards and vegetables. Moreover, estimation of production has been brought forward, but more extensive research is being conducted on the estimation of quality characteristics of fruits and vegetables. This necessity arises by the demand for harvesting and trading according to high quality standards, something that could benefit both producers (higher income) and consumers (better commodities).

1.6.4 Soil properties and EC mapping

1.6.4.1 Soil sampling

Soil sampling is a keystone for the estimation of soil properties and EC. Frequent or periodic soil sampling and analysis is a guidance for a fertilizing plan (Fountas and Gemtos, 2015), an irrigation system installment, even for the selection of cultivars or the plant species itself. For example, kiwi fruit trees shall not be planted and cultivated in all types of soil.

For years the basic soil sample that represents a field has been a composite sample (Franzen and Mulla, 2016) compiled by soil that is extracted from multiple areas of the field. The first known soil sampling approach goes back in 1929 and the book “Test your soils for acidity” by Linsley and Bauer (Figure 1.13). It is a proposed sampling strategy for a 12.5-hectare square field.

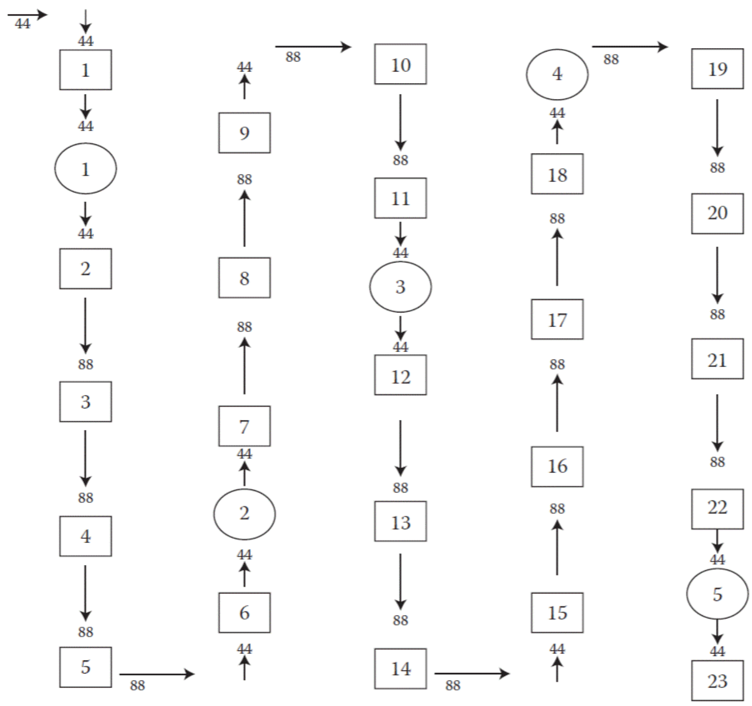


Figure 1.13. Sampling strategy by Linsley and Bauer (1929). Rectangles are for 0–15 cm surface cores and circles denote locations for a deeper, 0–30 cm core. The 44 and 88 designations are the steps between sampling points (Source: Franzen and Mulla, 2016)

The lack of location instruments within a filed such as GPS affected all initial soil sampling recommendations. Samples were collected neither in a random manner over the field nor from unusual areas, and the whole philosophy was based on unbiased sampling with equal distances between sampling locations; the most widely researched and suggested approach until the 1990s.

Starting approximately at the early 1990s, grid sampling was introduced and implemented. In grid sampling a field is divided in square or rectangle grid cells and soil samples are extracted using steps similar as the ones presented in Figure 1.14. After the samples extraction they are georeferenced and analyzed, and particular soil theme maps are created. Soil type sampling is another method. Sampling takes place in field parts with similar soil type and that demands prepared soil maps, so the random samples of each soil type get mixes.

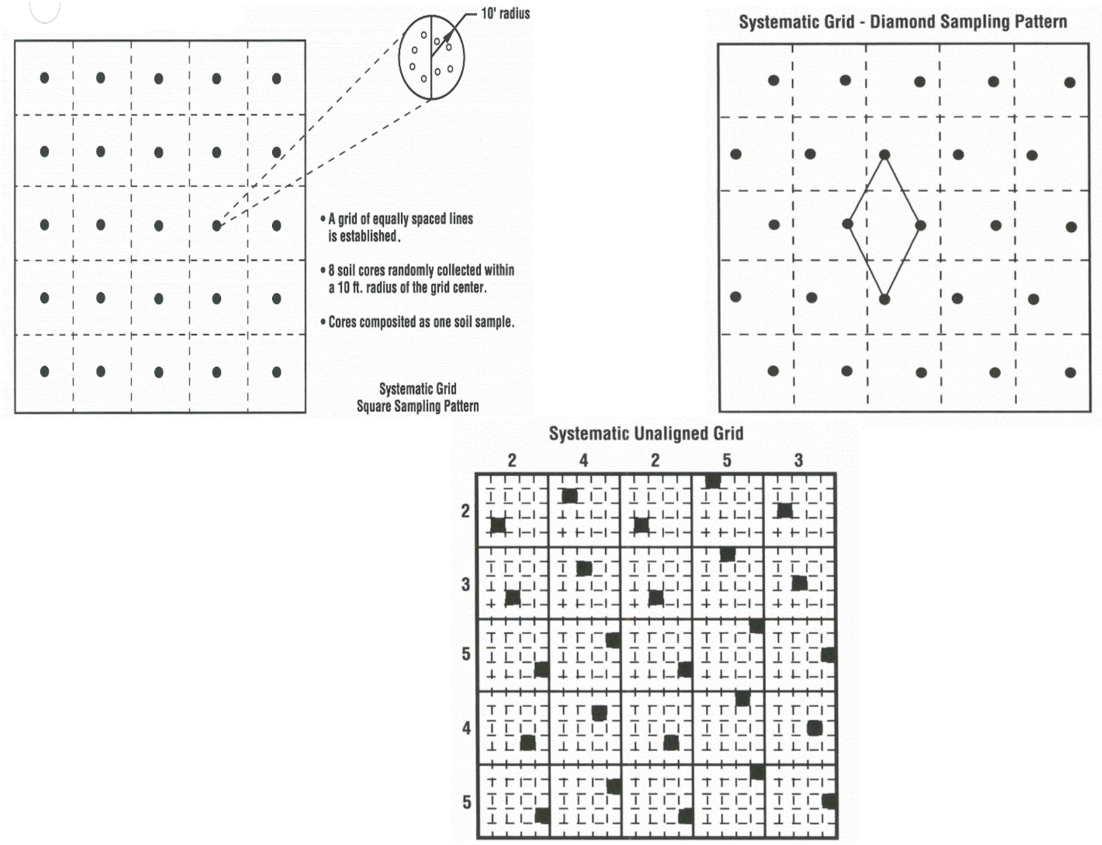


Figure 1.14. Grid sampling patterns (Source: Wollenhaupt and Wolkowski, 1994)

It is a fact that soil analysis in a PA system comes rather expensive for a farmer, at least in Greek reality. For instance, the yield of a cherry orchard reaches 0.5 tones per 0.1 hectare approximately, and its average income is 1.5 euros per kilogram (More details in Chapter 2). A Greek farmer gains a turnover of 825 euros per 0.1 hectare from which the expenses are extracted and paid. If we assume that a field is divided at 0.1-hectare grid cells, for every soil sample analysis there is a cost of 35 to 50 euros, which is added to the per hectare expenses. The range of a grid cell is chosen after taking in account that in Greece every field is a small land parcel.

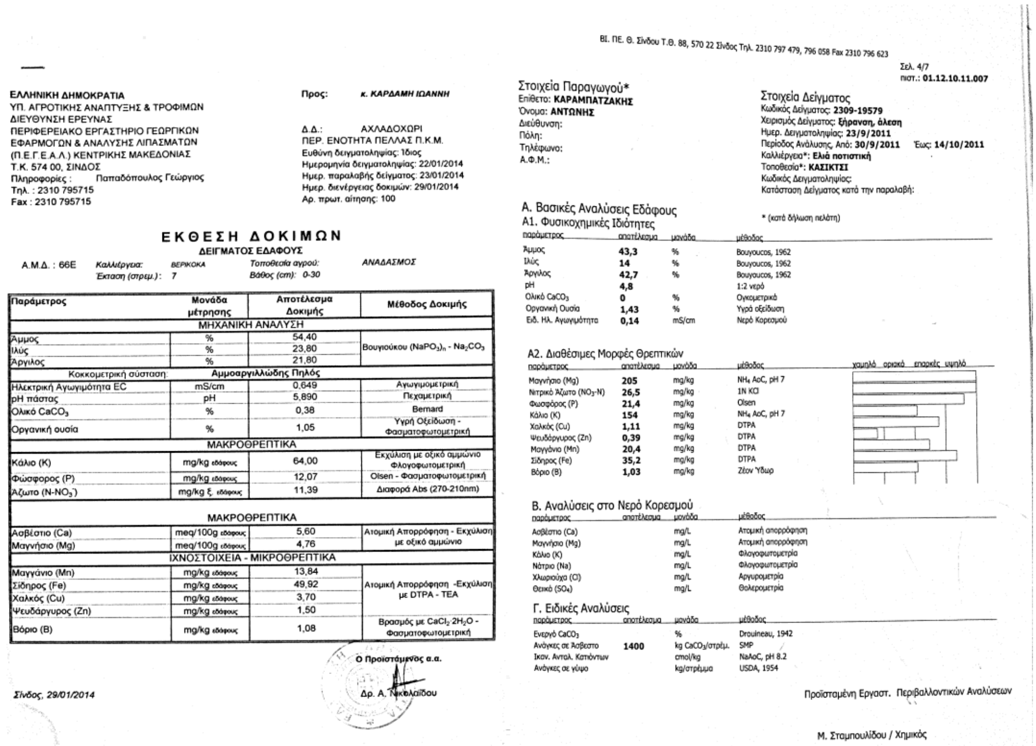
Therefore, soil sampling in Greece is composed by five or six cores extracted from the whole field in a random sampling manner, including unusual parts of it. PA sampling methods could be implemented under conditions which include well organized agricultural cooperatives, governmental initiatives and collaboration of public agricultural institutes.

1.6.4.2 Soil properties

Knowledge of soil properties is a precondition for the estimation of soil variability and thus, a key component for proper agronomic decision making (Lukas et al., 2009) on input implementation and cultivation techniques and methods. In agriculture we care about the complete soil compositions, that is the physical and chemical properties of the soil, its fertility and its profile, formation and classification.

There is an example of a soil analysis below (Figure 1.15), where the measured parameters are texture, EC (see 1.7.4.3), total calcium carbonate ($CaCO_3$), pH, organic matter, potassium (K), phosphorus (P), nitrate nitrogen (NO_3-N), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B). N, P and K are considered as primary elements, Ca and Mg as secondary elements and Mn, Fe, Cu Zn and B as micronutrients.

Texture refers to the relative proportions of particles of various sizes such as sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) in the soil. Is a factor that controls nutrient availability, water holding capacity, soil porosity, air-water circulation and soil reaction and density. It is also a determinant for crop selection, irrigation practices, fertilizer application and soil management (Chakraborty and Mistri, 2015).



ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΥΠ. ΑΓΡΟΤΙΚΗΣ ΑΝΑΠΤΥΞΗΣ & ΤΡΟΦΙΜΩΝ
ΔΙΕΥΘΥΝΣΗ ΕΡΕΥΝΑΣ
ΠΕΡΙΦΕΡΕΙΑΚΟ ΕΡΓΑΣΤΗΡΙΟ ΓΕΩΡΓΙΚΩΝ
ΕΦΑΡΜΟΓΩΝ & ΑΝΑΛΥΣΗΣ ΛΙΠΑΣΜΑΤΩΝ
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Προς: *κ. ΚΑΡΔΑΜΗ ΙΩΑΝΝΗ*

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ΠΕΡ. ΕΝΟΤΗΤΑ ΠΕΛΛΑΣ Π.Κ.Μ.
Ευθύνη δειγματοληψίας: Ιδιος
Ημερομηνία δειγματοληψίας: 22/01/2014
Ημερ. παραλαβής δείγματος: 23/01/2014
Ημερ. διενέργειας δοκιμών: 29/01/2014
Αρ. πρωτ. αίτησης: 100

ΕΚΘΕΣΗ ΔΟΚΙΜΩΝ
ΔΕΙΓΜΑΤΟΣ ΕΔΑΦΟΥΣ

Α.Μ.Δ. : 66Ε *Καλλιέργεια:* *ΒΕΡΙΚΟΚΑ* *Τοποθεσία αγρού:* *ΑΝΑΔΑΣΜΟΣ*
Έκταση (στρεμ.): 7 *Βάθος (cm):* 0-30

Παράμετρος	Μονάδα μέτρησης	Αποτέλεσμα Δοκιμής	Μέθοδος Δοκιμής
ΜΗΧΑΝΙΚΗ ΑΝΑΛΥΣΗ			
Άμμος	%	54,40	Βουγιούκου $(NaPO_3)_n$ - Na_2CO_3
Ιλύς	%	23,80	
Άργιλος	%	21,80	
Κοκκομετρική σύσταση:	Αμμοαργιλλώδης Πηλός		
Ηλεκτρική Αγωγιμότητα EC	mS/cm	0,649	Αγωγιμομετρική
pH πάστας	pH	5,890	Πεχαμετρική
Ολικό $CaCO_3$	%	0,38	Bernard
Οργανική ουσία	%	1,05	Υγρή Οξείδωση - Φασματοφωτομετρική
ΜΑΚΡΟΘΡΕΠΤΙΚΑ			
Κάλιο (K)	mg/kg εδάφους	64,00	Εκχύλιση με οξικό αμμώνιο Φλογοφωτομετρική
Φώσφορος (P)	mg/kg εδάφους	12,07	Olsen - Φασματοφωτομετρική
Άζωτο ($N-NO_3^-$)	mg/kg ξ. εδάφους	11,39	Διαφορά Abs (270-210nm)
ΜΑΚΡΟΘΡΕΠΤΙΚΑ			
Ασβέστιο (Ca)	meq/100g εδάφους	5,60	Ατομική Απορρόφηση - Εκχύλιση με οξικό αμμώνιο
Μαγνήσιο (Mg)	meq/100g εδάφους	4,76	
ΙΧΝΟΣΤΟΙΧΕΙΑ - ΜΙΚΡΟΘΡΕΠΤΙΚΑ			
Μαγγάνιο (Mn)	mg/kg εδάφους	13,84	Ατομική Απορρόφηση -Εκχύλιση με DTPA - TEA
Σίδηρος (Fe)	mg/kg εδάφους	49,92	
Χαλκός (Cu)	mg/kg εδάφους	3,70	
Ψευδάργυρος (Zn)	mg/kg εδάφους	1,50	
Βόριο (B)	mg/kg εδάφους	1,08	Βρασμός με $CaCl_2 \cdot 2H_2O$ - Φασματοφωτομετρική

Σίνδος, 29/01/2014

Ο Προϊστάμενος α.α.
Δρ. Α. Νικολαΐδου

ΒΙ. ΠΕ. Θ. Σίνδου Τ.Θ. 88, 570 22 Σίνδος Τηλ. 2310 797 479, 796 058 Fax 2310 796 623

Σελ. 4/7
πιστ.: **01.12.10.11.007**

Στοιχεία Παραγωγού*
Επίθετο: **ΚΑΡΑΜΠΑΤΖΑΚΗΣ**
Όνομα: **ΑΝΤΩΝΗΣ**
Διεύθυνση:
Πόλη:
Τηλέφωνο:
Α.Φ.Μ.:

Στοιχεία Δείγματος
Κωδικός Δείγματος: **2309-19579**
Χειρισμός Δείγματος: **Ξήρανση, άλεση**
Ημερ. Δειγματοληψίας: **23/9/2011**
Περίοδος Ανάλυσης, Από: **30/9/2011** Έως: **14/10/2011**
Καλλιέργεια*: **Ελιά ποτιστική**
Τοποθεσία*: **ΚΑΣΙΚΤΣΙ**
Κωδικός Δειγματοληψίας:
Κατάσταση Δείγματος κατά την παραλαβή:

* (κατά δήλωση πελάτη)

Α. Βασικές Αναλύσεις Εδάφους
Α1. Φυσικοχημικές Ιδιότητες

παράμετρος	αποτέλεσμα	μονάδα	μέθοδος
Άμμος	**43,3**	%	Bouyoucos, 1962
Ιλύς	**14**	%	Bouyoucos, 1962
Άργιλος	**42,7**	%	Bouyoucos, 1962
pH	**4,8**		1:2 νερό
Ολικό $CaCO_3$	**0**	%	Ογκομετρικά
Οργανική Ουσία	**1,43**	%	Υγρά οξείδωση
Ειδ. Ηλ. Αγωγιμότητα	**0,14**	mS/cm	Νερό Κορεσμού

Α2. Διαθέσιμες Μορφές Θρεπτικών

παράμετρος	αποτέλεσμα	μονάδα	μέθοδος
Μαγνήσιο (Mg)	**205**	mg/kg	NH_4 AoC, pH 7
Νιτρικό Άζωτο (NO_3-N)	**26,5**	mg/kg	1N KCl
Φωσφόρος (P)	**21,4**	mg/kg	Olsen
Κάλιο (K)	**154**	mg/kg	NH_4 AoC, pH 7
Χαλκός (Cu)	**1,11**	mg/kg	DTPA
Ψευδάργυρος (Zn)	**0,39**	mg/kg	DTPA
Μαγγάνιο (Mn)	**20,4**	mg/kg	DTPA
Σίδηρος (Fe)	**35,2**	mg/kg	DTPA
Βόριο (B)	**1,03**	mg/kg	Ζέον Ύδωρ

χαμηλό οριακό επαρκές υψηλό

Β. Αναλύσεις στο Νερό Κορεσμού

παράμετρος	αποτέλεσμα	μονάδα	μέθοδος
Ασβέστιο (Ca)		mg/L	Ατομική απορρόφηση
Μαγνήσιο (Mg)		mg/L	Ατομική απορρόφηση
Κάλιο (K)		mg/L	Φλογοφωτομετρία
Νάτριο (Na)		mg/L	Φλογοφωτομετρία
Χλωριούχα (Cl)		mg/L	Αργυρομετρία
Θειικό (SO_4)		mg/L	Θολερομετρία

Γ. Ειδικές Αναλύσεις

παράμετρος	αποτέλεσμα	μονάδα	μέθοδος
Ενεργό $CaCO_3$		%	Drouineau, 1942
Ανάγκες σε Άσβεστο	**1400**	kg $CaCO_3$/στρέμ.	SMP
Ικαν. Ανταλ. Κατιόντων		cmol/kg	NaAoC, pH 8.2
Ανάγκες σε γύψο		kg/στρέμμα	USDA, 1954

Προϊσταμένη Εργαστ. Περιβαλλοντικών Αναλύσεων

Μ. Σταμπουλίδου / Χημικός

Figure 1.15. Soil analysis by two laboratories in Thessaloniki

Nitrogen (N) is a critical agricultural input for crop production. Most of the cropping systems are naturally deficient in N, making N inputs necessary to produce the crop yields needed. Leguminous plants and soil microorganisms contribute significant amounts of N used by crops, but N needs are higher than those provided by natural means. The increasing use of reactive N (nitrogen compounds that support growth directly or indirectly) in agriculture increased the amount of N lost to the environment as ammonia (NH_3), ammonium (NH_4), nitrogen oxides (NO_x), nitrous oxide (N_2O), and nitrate (NO_3); all reactive forms of N. This has undesirable impacts on water, terrestrial and atmospheric resources leading to disruptions in ecosystem function and affect directly species composition, diversity, and dynamics. Most N losses are outcome of soil erosion, runoff, ammonia volatilization, leaching, denitrification and nitrification (Ribaudo et al., 2011). Soil sampling for N analysis takes place just before N fertilization (Fountas and Gemtos, 2015).

Phosphorus (P) is essential to all known life forms because it is a key element in many physiological and biochemical processes. In plants is one of the primary structural components of membranes that surround cells, is involved in the synthesis of proteins and vitamins, occurs in important enzymes and is a fundamental to photosynthesis. Because its compounds are not very soluble, the amount of plant available P in the soil solution tends to be far less than the plants require. A P deficiency affects plant growth and development, crop yield, the quality of the fruit, the formation of seeds and can delay the ripening of crops (Johnston and Steen, 2000). P losses can appear only after soil erosion and its implementation time is not required to be fixed (Fountas and Gemtos, 2015).

K^+ is the most abundant inorganic cation in plant cells, is vital for plant growth and along with N and P strongly determines crop yield (Dreyer, 2014). The availability of K depends on the soil type and is affected by its physico-chemical properties. Water-soluble, exchangeable, non-exchangeable and structural forms are the four groups that K can be classified depending its availability to plants. High accumulation of K by crops during optimal growing conditions may enable the plant to better survive a sudden environmental stress. Plant species differ in their K requirement and in their ability to take up K as they differ in root structure (density, depth, hair length) (Zorb et al., 2014). Only a potential of 1-10% of soil K is available to plants (Mitsios, 2004) and soil analysis aims to measure its amount in order to determine the applicable quantity (Fountas and Gemtos, 2015).

Soil pH is another factor that determines crop's establishment and characteristics in a field and refers to the degree of acidity or alkalinity of the soil. The scale ranges from 1 to 14 with pH 7.0 being the neutral point. Most crops will grow under a wide range of soil pH between 4.0 and 8.0 but the most important effect of soil pH is in relation to the availability of plant nutrients. The lower the pH is the less available nutrients are.

As for the secondary elements, Ca stimulates growth of roots, stem and leaves and enhances the plant's resistance to diseases. Mg is essential for chlorophyll production and assists the production of sugars and starch. Although micronutrients are required in small amounts in most crops, in cheery trees often occur deficiencies of Mn, Zn and B so a soil analysis must include them. Other deficiencies in cherry trees contain Ca (very important), Mg and K.

1.6.4.3 Soil EC

EC is the ability of a material to transmit an electrical current, expressed in units of milliSiemens per meter (mS/m). Soil EC correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics.

Soil EC interacts with soil particle size and texture. It varies depending on the amount of moisture held by soil particles. Sands, silts and clays have low, medium and high conductivity respectively. Electricity is conducted more easily as the total soil porosity increases. Soils with high clay content, when other soil parameters remain constant, has more total pore space than sandier soils. Water holding capacity typically has the single greatest effect on crop yield amongst the other factors that correlate with EC. This is likely the most valuable use of EC measurements. As water holding capacity rises, EC increments too. Excess of dissolved salts in the soil affects EC and an increase of their concentration increases EC. Organic matter grasps ions so it escalates soil EC. CEC is related to percent of clay and organic matter. As the percentage of clay and organic matter increase, CEC also increases and thus soil EC rises. Finally, as temperature decreases to the freezing point of water soil EC decreases slightly. Below freezing point soil pores become increasingly insulated from each other and overall soil EC declines rapidly.

Soil EC measurements assist a precision agriculture system to divide a field in site-specific zones. This happens because the value of soil EC does not significantly change during time, unless a farmer applies big amounts of organic matter or soil ameliorants, irrigation water with big amount of salts, deep tillage and soil carrying (grinding for example).

There are two methods existing for soil EC mapping, via electromagnetic (EM) induction or via contact. The EM induction method measures any effect soil has on a magnetic field. This effect is related with soil EC. It is a difficult method to apply, requires frequent calibration, is susceptible to interferences with metallic objects and the measurements can reach at a certain depth. Contact method measures the voltage difference between two electrodes inserted in the ground. It is an easy, fast and low-cost method (Fountas and Gemtos, 2015).

1.6.5 Management Zones

The formation of management zones (MZ) aiming to VRA of inputs in a field is fundamental for a PA system. MZs are field areas differentiated from the rest of the field to receive individual management attention. Particularly, MZs are homogeneous regions displaying similar behavior, chosen after processing and analyzing spatial and temporal data of the field (Fountas et al., 2018).

The main objective of a MZ delineation is the maximization of yield, quality and productivity benefits; enhancing land sustainability. Such improvements are consequences of the site-specific, or spatial, implementations of various inputs according to the very particular crop needs.

The establishment of MZs is attached to the answers of two questions. Based on what aspects the delineation will take place and which is the preferable extent of the MZs? The primary for a PA system is the precise application of inputs in spatial variable proportions, so the stretch of MZs must be advantageous and practical for the precise site-specific VRA of inputs. Size and number of MZs is affected by the size of the field, the machinery employed and the type of cultivation. For example, experiments conducted at Illinois (Franzen and Peck, 1995), Wisconsin (Wollenhaupt et al., 1994), and Nebraska (Gotway et al., 1996) indicated that to detect soil P, K, and soil pH patterns adequately for the composition of a valid variable rate fertilization or lime application, a 0.4-hectare grid was necessary at the examined fields.

The setup of MZs depend upon various field attributes which can be soil-based (i.e. texture, EC), plant-based (i.e. yield, vegetation indices) or a combination of them. Soil-based measurements create more temporally stable MZs, but they do not explain sometimes the spatial variability of yield or quality (Fountas et al., 2018). Vegetation indices are used for outlining MZs with NDVI evolving to a useful tool. MZs may also be created in connection with a specific input application, and so irrigation, nutrient or MZs for pesticide and herbicide VRA can be designed.

There are frequently used methods rather than standard rules on delineating MZs. The empirical methods combine the farmers' experience that is formed over the timeless cultivation of the same field, and feature maps or aerial images inspecting the field for areas with similar attributes. Geostatistical methods can analyze and combine different spatial-dependent values. By interpolating the disparate sampling points are produced surface MZ maps.

Clustering methods group data in different combinations of many variables (Fountas et al., 2018). Data within the same cluster have a high degree of similarity and are very dissimilar to the data in different clusters (Tiwari and Misra, 2011). The most important non-hierarchical clustering method to delineate MZs is Fuzzy k-means. Tagarakis et al. (2013) and Kitchen et al. (2015) used the degree of agreement method. This method compares different parameters to assist MZ delineation. More precisely, outcomes from existing MZs (i.e. yield, quality and soil parameters) are matched and used to create the best-suited final MZ.

1.6.6 Remote Sensing

1.6.6.1 Introduction

RS is the ability of obtaining and interpreting information for a region or an object from a distance. The various properties are measured using sensors that are not in physical contact with the object itself and the electromagnetic radiation (EMR) (Figure 1.16) is used

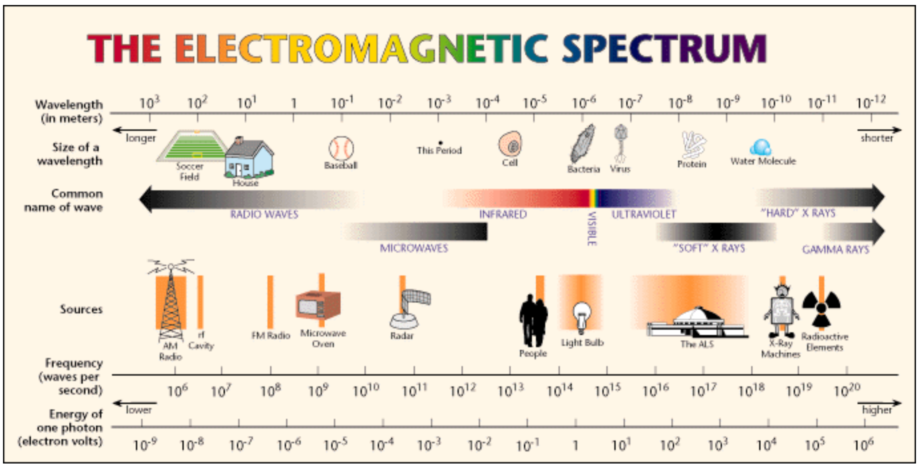

Figure 1.16. The Electromagnetic Spectrum
(Source: https://marine.rutgers.edu/cool/education/class/josh/em_spec.html)

by majority of RS applications to acquire the specific information. The EMR represents a very efficient high-speed communications link between the sensor and the remote phenomenon. Sensors detect the various changes in the amount and properties of the EMR and the electromagnetic energy measurements are turned into information for the user using visual and digital image processing techniques (Jensen, 2014).

1.6.6.2 Advantages and Limitations

RS though has advantages and limitations. Passive RS (the sensor just transcripts the electromagnetic energy reflected or emitted by the examined object) is non-disturbing for the examined object or area. RS can be programmed to collect data consistently replacing in some extent the in-situ sampling, because it is not always economically possible or practical to sample large geographic areas due to the extensive and expensive laboratory analysis, interpolation and the labor required (Karaska et al., 2004). Moreover, using RS it is possible to study places that are inaccessible to human exploration and acquire knowledge on them (Liaghat and Balasundram, 2010).

Compared to other applications such as GIS it is a science independent by the data gathered from others and as a science can contribute with fundamental information to other scientific surveys. Location, elevation, depth, biomass, temperature, moisture content, color and chlorophyll spectral behavior (Fountas and Gemtos, 2015) are some of the biophysical information provided and that is why RS is critical for the modeling of natural and cultural processes (Jensen 2014).

On the contrary, when active RS systems that emit their own EMR (e.g. RADAR, SONAR, LIDAR) are used, there is not enough knowledge on how intrusive they can be and in what extent they affect the examined object. Furthermore, RS technology will provide some spatiotemporal and spectral information but not all the necessary information for the research conducted. A combination with other schemes may be mandatory and sometimes such technology may evolve to something doubtful for its efficiency and economic return by the extracted information.

A major factor affecting the RS efficiency is the human factor, who may not use the RS technology in a proper way. Select a suitable RS system, adjust its resolution, arrange which data will be gathered and when, calibrate the system, pick the suitable carriers for the sensors, determine the data processing procedure. In short, specify all the parameters. If for example the sensors become uncalibrated the gathered data will be uncalibrated too. Finally, data quality depends on environmental conditions like dust, light or cloudiness.

1.6.6.3 Remote Sensing in Precision Agriculture

RS technology is a key component of PA because it has a vary range of applications. Identification of problematic soils, crop health analysis and identification of pests and disease infestation are some of the RS implementation outcomes.

Vegetation biophysical characteristics are crucial for agriculture and RS can provide information about these parameters using vegetation indexes. According to http://www.indexdatabase.de/ the are 519 indexes until today. The biophysical properties of vegetation allow the absorption, reflection and transmission of EMR in different wavelengths of the EM spectrum. The vegetation indexes can:

1. Facilitate the sorting of areas with or without vegetation.
2. Allow the distinction between the different types of vegetation.
3. Distinct the differences on healthy vegetation.
4. Trace and map the existence and distribution of affections and infections in plants.
5. Detect the maturation of plants for the harvest procedure.

Vegetation indexes are separated in two categories, the ones who measure the radiometric distance from the soil (distance-based) and those who result from ratios of spectral channels (Darra, 2019)

The most significant indexes for agricultural applications are presented at the Appendix.

1.6.7 Variable Rate Application

The delineation to MZs is followed by the VRA of inputs in a SSCM program. VRA is the input application according the MZ needs and there are two basic technological methods to support it; map-based and sensor-based. Aims to maximize profit, make input application more efficient and establish environmental safety and sustainability.

Map-based VRA is prearranged and the application rate is adjusted according to a prescription map, which is a data file containing specific information about input rates to be applied in every MZ. Map-based methods use maps of measured attributes and are adjusted either on one or on a combination of them. These systems after determining the machinery location within the field using GNSS relate its position to the desired application rate by processing the prescription map (Grisso et al., 2011). The amount of installment is either the input volume or the input weight per unit of area (Fountas and Gemtos, 2015).

Sensor-based VRA operates using real-time sensor data and there is no mapping, data collection or positioning involved. Sensors located on the machinery collect data concerning soil properties or crop characteristics “on the go”. Measurements of the desired feature guide the machinery control system to do the right calculations for inputs needed, and the appropriate amount of inputs in implemented. Sensor-based VRA has an extra option available; to gather and record georeferenced data (a positioning system is required here) so they can be used for future SSCM applications, creation of prescription maps or to provide an input implementation archive for the farmers.

SSCM systems can be developed to take advantage of the beneficial options of both map-based and sensor-bases VRA methods, because each on has benefits and limitations.

2 Sweet cherry cultivation in Greece

2.1 Evolution of cherry cultivation

Cherry trees thrive across the temperate zone of the Earth and can be considered as well-adjusted plants in the Mediterranean ecosystems; an inference obtained after considering the available historical data.

Though the origin of cherry trees is unknown, Hendrick et al. (1915) made the case that ancient Greeks were the first to domesticate them, not for their fruits but for their hardwood and gum resin which was used for pharmaceutical purposes. Theofrastos (ancient Greek philosopher, 371-287 B.C.) was the first to describe cherries as red or vermilion shaded fruits with similar shape to persimmon at the size of a bean. He also noted that cherry trees thrive at the same places as linden trees (Tilia) do.

Approximately fifty years before the Roman period, Lucius Licinius Lucullus is said to have brought cherry trees into Europe from Pontus in 72 B.C., as a gift to Rome after winning in battle the local king Mithridates (Rhind, 1841 and Herbermann, 1913). Many ancient Greek philosophers mentioned that cherries originate from the region of Pontus named Kerasous (Giresun of Turkey nowadays), region from which the fruit took its Greek name “kerasi”.

Commercial cultivation of cherry trees started in Greece during the Interwar era (1923-1940 for Greece) at mountainous regions, because wild cherry trees were found to thrive in forests. The first plantations were extensive with very large trees (Chatzicharissis and Kazantzis, 2014) growing as central leader trees with rapid growth and strong apical dominance (Long et al., 2015). The trees were either planted as seedlings or transplanted as wild forest cherry trees, grafted on the spot and left to grow without any cultivation interference apart from harvesting (Chatzicharissis and Kazantzis, 2014). These traditional training systems created complex canopies, took years to fully develop and lacked a systematic plan to renew fruiting wood (Long et al., 2015).

Due to the rising cost of production, an increasingly limited skilled labor pool and escalating competition on the world market, modern training systems developed to offer growers results such as precocity or early fruiting for high early yields and a more rapid return on investment, production on well-exposed wood of moderate vigor to provide high-quality fruit, a systematic process to renew fruiting wood, repeated canopy units for simplicity in training and pruning (Long et al., 2015).

The modernization effort started during 60's and continues until now, moving at a slow pace in cherries compared to other fruit trees. This happens because the economic life of a cherry tree can last up to 50 years, holding back the replacement of old plantations. This effort is expected to continue as long as problems that need confrontation appear, new knowledge is being brought forth and added, new varieties and rootstocks are created, more efficient and inexpensive cultivation methods and techniques develop, markets' and consumers' demands change and the competitiveness for the commercial transaction of cherry products at the international markets rise (Chatzicharissis and Kazantzis, 2014).

2.2 Farming and financial data and prospects

Examining the available data of Hellenic Statistics Authority (HSA), Incofruit Hellas (IH) and FAO from 2010 through 2017, the growing importance of sweet cherry production for the local producers, exporters and the country can be understood.

The data results extracted from the total cropping areas lead to the conclusion that the general agricultural sector is retreating year after year. HSA data reveal that the cultivation of almost 417,000 ha came to an end between 2010 and 2016 (Table 2.1). On the other hand, the subsection of tree crops after a decrease of more than 4,000 ha between 2010 and 2015 increased again in 2016 above the 2010 level, at 1,022,515 ha. Fruit tree cultivations followed the same path, declining by 11,600 ha between 2010 and 2015 and rising rapidly up to 89,528 ha in 2010, extend bigger than in any other of the examined years (Table 2.1). The big difference in fruit trees between 2015 and 2016 may be caused by many unregistered new orchards which entered their productive life period in 2016 and then got registered at O.S.D.E. (Integrated Administration and Control System).

Cherry cultivation gained 4,427 ha during the period 2010-2016, starting from 10,460 ha in 2010 ending up to 14,887 in 2016 (Table 2.1). The extent of 14,200 ha seems that has been established as a threshold after bringing in the equation the estimates of IH for 2017 (14,271 ha). Moreover, cherry plantations were representing in 2016 the 16.63% of fruit trees (12.07% in 2010), the 1.45% of tree crops (1.02% in 2010) and the 0.45% of the total cropping areas (0.28% in 2010).

The increase of cherry trees cultivation brought a rapid boost of cherry production which almost doubled its quantities. The 44,900 tons of 2010 turned into 83,194 tons in 2016 (HSA data) with an estimation of 85,000 tons for 2017 by IH (Table 2.2). The harvested quantities depend on the weather conditions mostly between March and June, so they may vary from year to year. Cherry is a very delicate fruit affected by weather conditions, picking methods and postharvest handling.

Table 2.1: Cultivated areas in Greece based on HSA data

	2010	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***
Total crop areas	3,670,930	3,566,298	3,559,990	3,516,083	3,334,105	3,282,517	3,254,079
Tree crops	1,020,550	1,022,447	1,023,391	1,012,763	1,015,482	1,016,409	1,022,515
Fruit trees	86,660	80,972	81,066	77,686	74,016	74,967	89,528
Cherry trees	10,460	10,610	10,860	11,061	13,448	14,206	14,887

Note: The metric system unit of area used is the hectare.

Table 2.2: Total cherry production based on HSA and IH data

	2010	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***
Total production	44,900	49,413	47,300	46,572	67,030	75,191	83,194	85,000

Note: The quantities are measured in tons.

According to data recorded by FAO, since 2014 Greece has been established between the top ten sweet cherry producers worldwide (Table 2.3). Countries that precede are Turkey (TR), USA and Islamic Republic of Iran (IR); the three major producers. Chile (CL), Uzbekistan (UZ), Italy (IT), Spain (ES), Greece (GR), Romania (RO), Ukraine (UA) and Syrian Arab Republic (SY) compete for the rankings between 4 and 10. Between the European countries (EU and non-EU) Greece in placed at the top 4 producers.

The observed annual fluctuations of produced quantities for all countries, variations that affect global production, are due to the existing climate conditions during the flowering and the fruit maturation season. Rainfalls during these periods result to reduction or even the total destruction of sweet cherry production. The Department of Deciduous Fruit Trees in Naousa (Pomology Institute) has recorded that every five years there is a total destruction of sweet cherry production and another one with a significant quantity decrease due to rainfalls (Chatzicharissis and Kazantzis, 2014).

Table 2.3: Top 12 cherry producing countries based on FAO data.

	2010	***R***	***2011***	***R***	***2012***	***R***	***2013***	***R***	***2014***	***R***	***2015***	***R***	***2016***	***R***
Tr	417,905	1	438,550	1	470,887	1	494,325	1	445,556	1	535,600	1	599,650	1
USA	284,148	2	303,377	2	384,647	2	301,276	2	329,852	2	306,991	2	288,480	2
IR	228,093	3	244,927	3	253,496	3	279,430	3	133,987	3	136,000	3	220,393	3
IT	115,476	4	112,775	4	104,766	4	131,175	4	110,766	5	111,119	4	94,888	6
ES	85,192	5	101,945	5	96,946	5	97,200	5	118,220	4	94,145	6	94,138	7
UZ	75,000	6	56,481	11	62,000	11	70,000	10	80,000	8	90,000	7	95,267	5
UA	73,000	7	72,800	9	72,600	7	81,200	6	67,330	11	76,640	9	63,320	11
RO	70,290	8	81,842	7	70,542	10	80,477	8	82,808	7	75,503	10	73,834	8
RU	66,500	9	76,000	8	72,000	8	78,000	9	77,000	9	41,600	15	46,089	13
CL	60,356	10	85,793	6	71,523	9	81,023	7	84,919	6	103,416	5	123,224	4
SY	58,084	11	62,195	10	82,341	6	62,373	11	54,211	12	61,860	11	69,153	10
GR	***44,910***	***12***	***49,413***	***12***	***47,319***	***12***	***48,134***	***12***	***70,042***	***10***	***87,240***	***8***	***71,858***	***9***

Note: The quantities are measured in tons. In 2015 Russian Federation (RU) was replaced by Bulgaria and in 2016 by Poland. (R=Rank)

The average per hectare yield in Greece range between 4 and 6,5 tons, not much lower than in the other EU cherry producing countries. In modern and intensive cultivation systems this number can reach 15 tons per hectare during the maximum productivity years of the trees.

During the last decade the average per income per kilo for the producers is arranged around the price of 1.5 euros, price much bigger than the other fruit trees. Moreover, the cultivating cost is lower amongst other crops, adding an exception during the fruit harvesting period when wage expenses for the workers form the 60% to 70% of the total production cost. Still, the average per hectare revenue for the farmers is the biggest amongst fruit trees.

Beyond the big disadvantage mentioned earlier, the delayed entrance of sweet cherry trees at their fully productive period is another aggravating factor. Depending on the variety and chosen rootstock, the entrance at this life period can happen between the fifth and tenth year. A combination of the appropriate rootstock and training system can solve such problems (Chatzicharissis and Kazantzis, 2014) alongside with the implementation of precision agriculture techniques.

2.3 Rain-induced cracking

The major limitation for cherry production is rain-induced cracking, because it may result in complete crop failure. Cracking occurs during or after rainfall (Knoche and Winkler, 2017) shortly before and during harvest period. The cracking stretch depends mainly on the rainfall intensity with sunlight as a collateral factor. According to Looney (1985), if the canopy contains above about 25% of cracked fruits, the harvest becomes uneconomic due to the high labor cost related with the elimination of cracked fruits both in the orchard (picking) and the packhouse (grading). The exact mechanism of cherry cracking is unknown (Knoche and Winkler, 2017).

Rainfalls not only cause cracking but lead to decreased storage quality too. Despite the fruit's macroscopically intact surface wetness causes the formation of microscopic cracks or microcracks in the cuticle. These cracks bypass the barrier function and may result into increased incidence of fruit rot (Borve et al., 2000), increased water uptake during rainfall (Knoche and Peschel, 2006), increased pre- and postharvest transpiration (Knoche et al., 2002; Beyer et al., 2005), loss of firmness and impaired appearance (shrivelled and dull). Any or several of the above bring a reduced market appeal and price.

Fruit cracking may be evaluated by crack size, crack position or the mode of failure. There are few studies that have attempted to relate the different categories of cracks and the position of them with their potential causes (Measham et al., 2009, 2010, 2014) or their genetic background (Quero-Garcia et al., 2014).

When the evaluation relies on crack size, two subcategories exist: the microscopic cracks (microcracks) and the macroscopic cracks (macrocracks).

Microcracks (Figure 2.1) are cracks in the skin, limited to the cuticle and do not extend to the underlying epidermal and hypodermal cell layer. Normally they cannot be detected by visual inspection with naked eyes. They can be quantified by counting the number of total cracks, measuring their total length or classifying the large and small cracks per fruit. Another quantification method might be borrowed from Grimm et al. (2012) who determined the area of the infiltration zone around a crack in apples. Outwardly, microcracking has no immediate consequence to the crop's market value. However, the frequency of fungal infections increases along with transpiration and the fruits shrivel faster. The postharvest treatment of cherries in the packhouse leads to increased rate of water uptake when microcracking exists.

Macrocracks (Figure 2.1) are cracks in the skin that traverse the cuticle and extend into the epidermal and hypodermal cell layers, possibly into the flesh and occasionally down to the pit. They are visible to the naked eye (Knoche and Winkler, 2017). It is believed that macrocracks have their origin to microcracks (Glenn and Poovaiah, 1989) but the experimental evidence is lacking for that hypothesis. Regarding the marketing chain, fruits with small macrocracks around the stylar scar or in the stem cavity are accepted if there is no fungal decay. Fruits with larger macrocracks on the cheek and/or suture are mostly rejected, unless they are harvested for industrial processing.

According to Christensen (1996), there are three common cracking positions: at the stylar scar (apical cracks or nose cracks), in the stem cavity or around the rim of the stem cavity (ring cracks) and on the cheek or suture side of the fruit (Figure 2.1). The first visible disfigurement is the macrocracks around the stylar scar and in the stem cavity. At the same

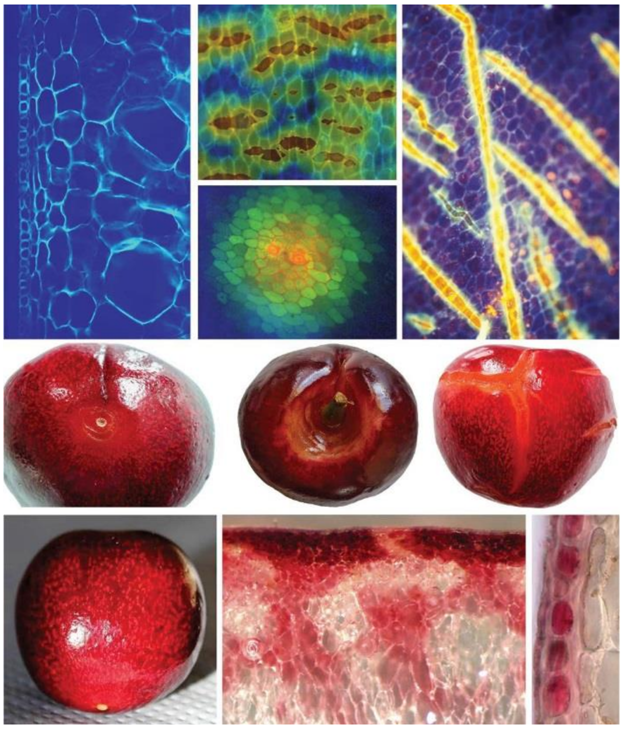

Figure 2.1: (A) Micrograph of cross-section of the skin of a mature fruit after staining with calcofluor white. The skin comprises cuticle, epidermis and several hypodermal cell layers. (B, C) Microcracks in the cuticle after infiltration by acridine orange solution. (D) Stomata after infiltration by acridine orange solution. (E–G) Macroscopic cracks by position: in the stylar scar region (E), in the stem cavity region (F) and in the cheek region (G). (H–J) Strain spots on the surface of mature fruit: overview (H), cross-section through fruit skin and underlying flesh (I), and cross-section through the epidermis (with anthocyanin) and first layer of hypodermis (without anthocyanin) (J). Source: Knoche and Winkler, 2017)

positions can be detected the most severe and primal microcracking (Peschel and Knoche, 2005). Frequently, cracks on the cheek are extensions of pre-existing apical or ring cracks.

Measham et al. (2010) related the type of rain induced cracking with the different modes of water entry into the fruit, concluding that there is a connection between irrigated root-zone soil and dry or wet canopy concerning the development of side cracks and cuticular cracks.

A successful method form cracking prevention is the use of rain shelters. Microcracking is also remarkably reduced because the surface of fruits stays dry (Knoche and Peschel, 2006). According to Cline et al. (1995b) it is possible a small percentage of fruit (<5%) to crack, probably due to water uptake via the vascular system (Measham et al., 2010), the lack of transpiration or the water vapor uptake from a vapor-saturated atmosphere (Beyer et al., 2005). Farmers using rain shelters have reported increased cases of monilinia, something that requires further research.

Another preventing method is the spraying applications of calcium salts. The mechanism of calcium in reducing cracking has been related with effects on the mechanical properties of the cell walls (improved cross-linking of cell wall constituents) and reduced water uptake (osmotic effect caused by the decrease in osmotic potential of the Ca solution) (Knoche and Winkler, 2017). In addition to Ca, lately Si is being used in foliar spay applications with adequate observed effect on cracking but no recorded data; another issue requiring further research.

2.4 Temperature as a climatic limiting factor

Several stages of cherry tree growth, including dormancy, flowering and fruit development and quality, are subject to strict temperature control and at risk from temperature extremes. Temperature-based constraints have a high impact on production and it is essential to have a better understanding of them, especially in the context of global warming, to anticipate future production changes, research needs and breeding strategies (Wenden et al., 2017).

Cherry trees thrive mainly in temperate climates which do not experience very high temperatures during summer and very low during winter. As long as the vegetation cycle lasts, the optimal temperatures range between 15^{o}C and 30^{o}C. Temperatures below 0^{o}C that emerge at the beginning of that period, early in the spring, can damage the flowers or the fruit set (stage called also "in the shuck" or "Husk fall"). Temperatures higher than 30°C during the same period afflict the trees, constrain their vegetation and hasten the fruit maturation before it acquires its organoleptic properties.

During winter and dormancy period, ligneous parts of the trees can cope with temperatures between -20°C and -30°C, depending on the variety and the rootstock, and the buds withstand temperatures between -10°C and -15°C depending on the variety and their stage of dormancy (Chatzicharissis and Kazantzis, 2014). Most cherry varieties need 400-1400 chilling hours (below 7.2°C) (Wenden et al., 2017). According to Chatzicharissis and Kazantzis (2014) chilling hours range between 800 and 1500 and Alburquerque et al. (2008) have recorded that variety Cristobalina required only 176 hours below 7.2°C.

Dormancy as a tree strategy to survive freezing winter temperatures, is affected by temperature fluctuations. The significance of that period and the chilling hours is that if the chilling requirements of a cherry tree are not fulfilled, many undesirable symptoms will appear such as delayed, reduced and uneven bud burst and uneven flowering. Chilling requirements have a strong effect on flowering dates (Alburquerque et al. 2008, Castede et al., 2014). In many popular and commercial varieties chilling hours are essential for their productivity. Low rate of bud burst, or sporadic bud burst, anatomical abnormalities in flower buds (absence of pistils, atrophied ovules, immature pollen) lead to low productivity (Oukabli and Mahhou, 2007) and irregular fruit growth (Xu et al., 2014). Poor fruit set has been linked with inadequate ovule and embryo sac development by Wang et al. (2004).

Freezing temperatures in autumn, spring and flowering period are also associated with loss of cherry crops. Different climatic situations such as radiative, advective and evaporative cooling can cause freezing damage, which depends on the intensity, rate of temperature decrease and duration of the freezing event (Rodrigo, 2000). The actual damage is caused mainly by intracellular rather than extracellular ice formation. Flower buds may be damaged by freezing temperatures from autumn to after flowering and during early fruit development in spring. In autumn, damage often occurs when a warm period is followed by a rapid drop to freezing temperatures (Wenden et al., 2017). During flowering, bud hardiness is very

limited and even shallow freezing (–2°C) may cause damage to some buds but an almost 100% damage in fully open flowers at -2.5°C has been recorded (Szabo et al., 1996). Proebsting and Mills (1978) and Ballard et al. (1982) have shown in their studies on low-temperature resistance to frost the temperatures that can damage 10%-90% of buds depending the development stage.

Damage to a small percentage of buds does not lower marketable yield due to increased compensation growth by non-damaged fruit. In sweet cherry, this percentage can be lower than 20-30% of flower buds. The exact impact on yield depends on the cultivar, cultivation conditions, marketable fruit quality and potential for compensation growth (Wenden et al., 2017). Genetic control of spring bud hardiness may be expressed through differences in flowering time, variation in flower bud stage, the density of flower buds, critical temperatures for damage and the ability to supercool (Rodrigo, 2000).

As years pass, cherry production moves from cool mountainous regions to warmer ones for earlier harvest and the overtake of higher market prices. Production stability in these areas is limited by poor fruit set, the occurrence of double fruit (Figure 2.2), malformed flowers containing pistil-like appendages in lieu of anthers (Figure 2.3) and fruit with deep sutures, because the carpel margins do not fuse at the base and remain open. Among these problems, poor fruit set and double fruits are the most serious issues that are in position to affect orchard profitability. High summer temperatures during flower bud differentiation are believed to cause double pistil formation, resulting in double fruit the following year (Micke et al., 1983).

Figure 2.2: Uneven (A) and even (B) double fruits

Figure 2.3: Abnormal flower caused by high temperatures.

According to Faust (1989), the period from initial flower formation to the final reproductive development ranges between 86 and 112 days, with cultivars and climate as variables that play a crucial role. Floral commencement of sweet cherries starts in July and temperatures above 30oC are crucial for the formation of double pistils.

In areas with hot summers the risk of producing double fruit, therefore the reduction of marketable fruit, is elevated. That can limit the planting of sweet cherries. However, because cultivar susceptibility for double-fruit formation has a strong genetic influence, the combination of cultivar-behavior knowledge and temperature databases could diminish such problem.

2.5 Environmental limiting factors

To achieve an economically profitable cherry production along with quality, optimized nutrient and water management strategies shall be implemented in cherry orchards.

Except oxygen (O), hydrogen (H) and carbon (C), plants uptake the rest of 13 necessary nutrients [nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mg), molybdenum (Mo), zinc (Zn)] from the soil in the form of ions, cations or anions depending the elements properties. The uptake of C occurs from the air in the form of carbon dioxide (CO_2), during photosynthesis the degradation of water into H and O gives the necessary H and O derives from the air and the procedure of assimilation (Chatzicharissis and Kazantzis, 2014).

In order to reach soil fertility and calibrate annual nutrient requirements for perennial cherry orchards, other abiotic soil factors that influence cherry production must be examined first.

2.5.1 Soil organic matter, salinity, texture and pH

Organic matter mainly consists of lower amount of nutrients in comparison to inorganic fertilizers, but yet, has been recognized as a beneficial factor in enhancing soil quality. Organic amendments seem to release plenty of plant nutrients upon decomposition, in contrast to chemical fertilizers that supply a specific number of them. Cherry trees have been grown successfully in soils with OM contents ranging from <1% to 10%. Although the association between improved orchard performance and increased soil OM is not always direct, it is a good management strategy to enhance the OM content of soils that are below 2% (Neilsen et al., 2017).

There is no information available regarding salt tolerance among cherry rootstocks and a little detailed information is available regarding the salt tolerance of cherry trees. In other *Prunus spp.* such as peach and plum reduced vegetative growth probably occurs at a relatively low salinity threshold of 1.5–1.7 dSm^{-1} (Maas, 1987). Sensitivity to specific ion toxicities, including Cl, sodium (Na) and B, may be associated to an extend with the excess salinity intolerance.

Soil texture knowledge is important due to the management differences implemented amongst different soil textural groups (Figure 2.4). Soil particle size affects critical soil properties including water-holding capacity, bulk density and porosity, soil

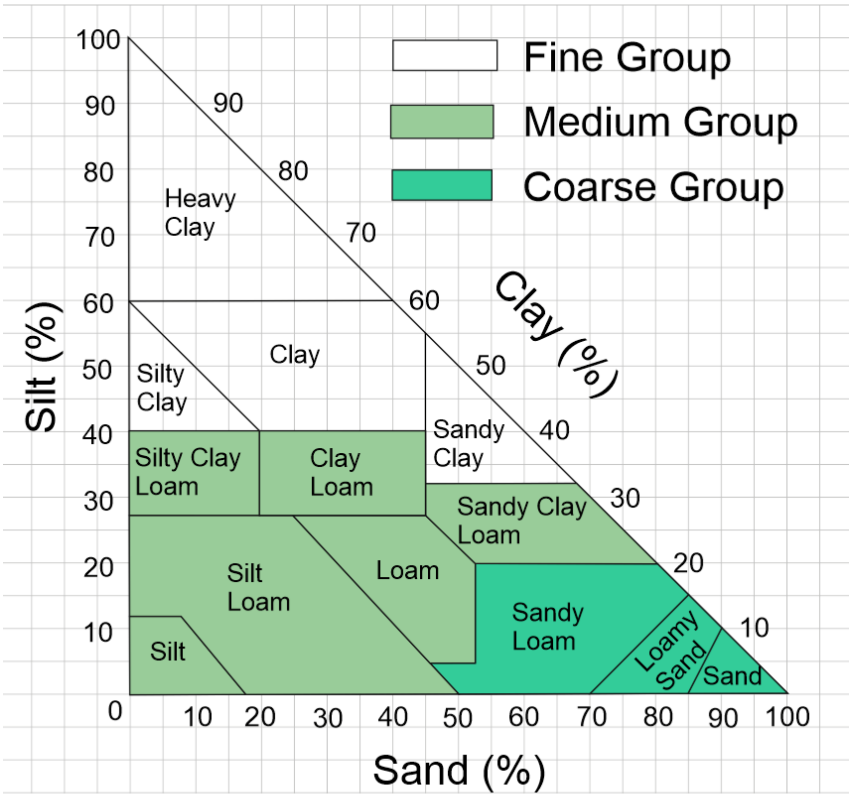

Figure 2.4: Soil texture triangle representing the relative percentages of sand, silt and clay in each soil textural class

amelioration and root growth. In heavy clayey, clayey, sandy and silty clayey soils fine-textured particles predominate. Soils consisting of silty clay loam, clay loam, sandy clay loam, loam, silt loam or silt form a medium-textured soil group and a coarse-textured group is formed by sandy loam, loamy sand or sand. Coarse-textured soils retain less plant-available water, drain rapidly and thus are more prone to drought, particularly if they are shallow and stony. Fine-textured soils retain more water but are susceptible to aeration problems at high water contents.

Most plant nutrients are mainly available to cherry trees from slightly acid to neutral pH levels ranging between 6.0 and 7.0 (Figure 2.5); the generally recommended soil pH for an optimum growth of cherry (Neilsen et al., 2017). In such soil pH, cherry trees may develop

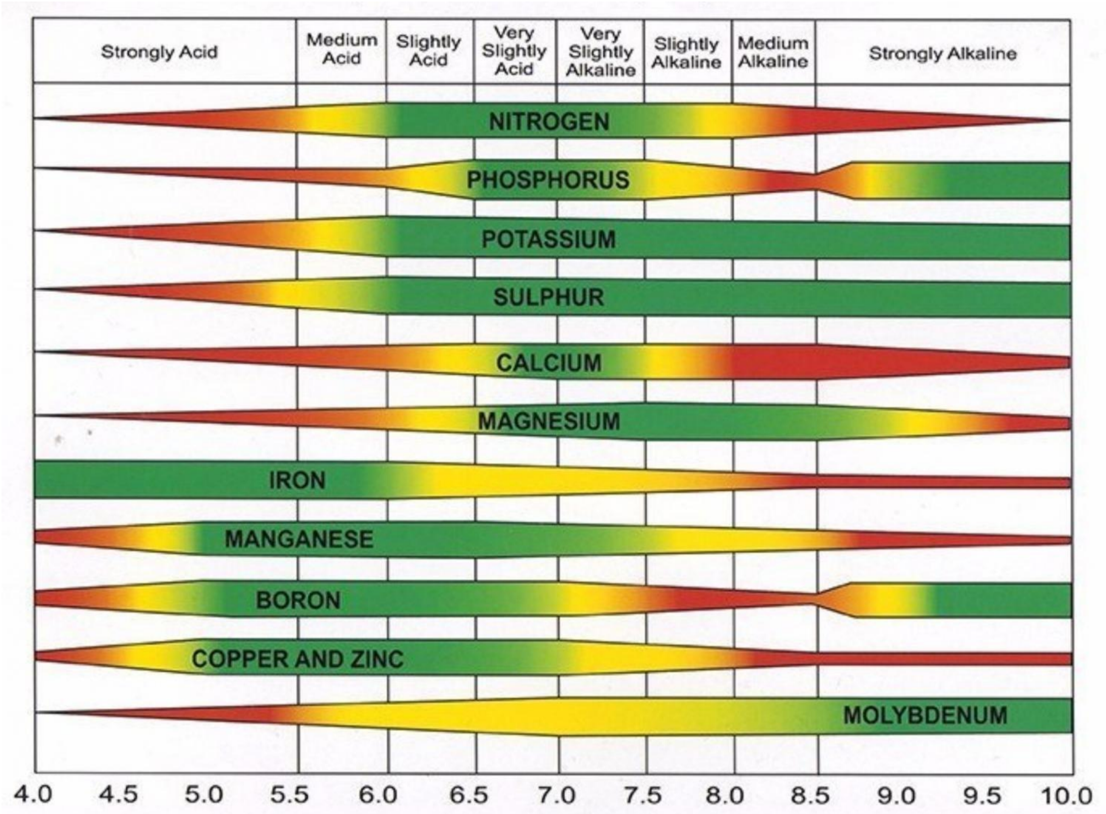

Figure 2.5: How soil pH affects availability of plant nutrients (Source: http://www.agrobest.com.au)

micronutrient deficiencies of Mn, Zn and Fe, which are much more likely when the soil pH exceeds 7.0, a threshold for toxic accumulations of Na and Cl^-. On the other hand, it is most likely that soil with high acidity levels will inhibit cherry growth, especially in loamy soils because of the acidification associated with leaching of soil bases. In acid soils large quantities of plant-available aluminum (Al) and Mn can be released and in soil pH lower than 5.5, accumulation of Al in soil and leaves may result in death for sweet cherry seedlings (Melakeberhan et al., 1995) along with inhibition of initial root and top growth (Neilsen et al., 1990). The consequences of low soil pH may be observed more readily when replanting previous cherry orchard sites that have experienced management-induced soil pH decline (Neilsen et al., 2017).

2.5.2 Soil fertility – Seasonal nutrient limitations

Nutritional needs can be defined by soil and leaf analysis. Soil analysis before orchard planting can define soil's chemical and mechanical properties, possible problems caused by chemical toxicities, soil acidity, alkalinity or salinity but also can determine rootstock selection and a fertilization program. Soil analysis is also able to determine the total soil nutrient content but not the available quantities for tree intake. There are no adequate methods to specify nutrient availability and their estimation takes place indirectly through leaf analysis.

Leaf analysis define leaf nutrient content. The correlation between soil and leaf nutrient content outlines the available nutrient amount in the soil. If leaf nutrient content is lower than soil, there is a problem pending that needs to be examined and fixed. In Table 2.4 are presented the levels of sufficiency, lack and excess of nutrients in cherry leaves.

Table 2.4: Nutrient concentration levels in cherry leaves

	%					*ppm*				
	N	***K***	***P***	***Ca***	***Mg***	***Mn***	***Fe***	***Cu***	***B***	***Zn***
Low	1.7	1.0	0.08	0.20	0.18	20	40	1	30	10
Normal	2.3	1.2	0.12	1.00	0.24	25	50	4	35	18
Increased	2.6	3.0	0.30	2.5	1.00	200	400	50	80	100
Excessive	4.0	4.0	0.70	3.00	2.00	450	500	100	100	200

Source: Chatzicharissis and Kazantzis, 2014

Amongst others, a factor affecting the exploitation of nutrients is the interactions between nutrients themselves. Many minerals, after dissolving in water and taking the ionic form (plants absorb minerals in ionic form), interact either synergistic or antagonistic. In the first case the excess of a nutrient facilitates the intake of another whereas in the second case it prevents the nutrient uptake (Figure 2.6). Of course, irrigation, soil structure and fertility, rootstocks or varieties etc. "cooperate" with ionic interactions for the facilitation or inhibition of nutrient uptake.

Nutrients shall get together in a balance in order to achieve the best results when it comes to fertilizing. Their impacts on tree nourishment are not independent but codependent, the optimal amount of each one is not standard but depends on the quantity of the others and is related to them with a proportional correlation (i.e Zn-P, K-N). Nutrient levels do not remain constant but alter under the effect of factors relevant to the soil or the

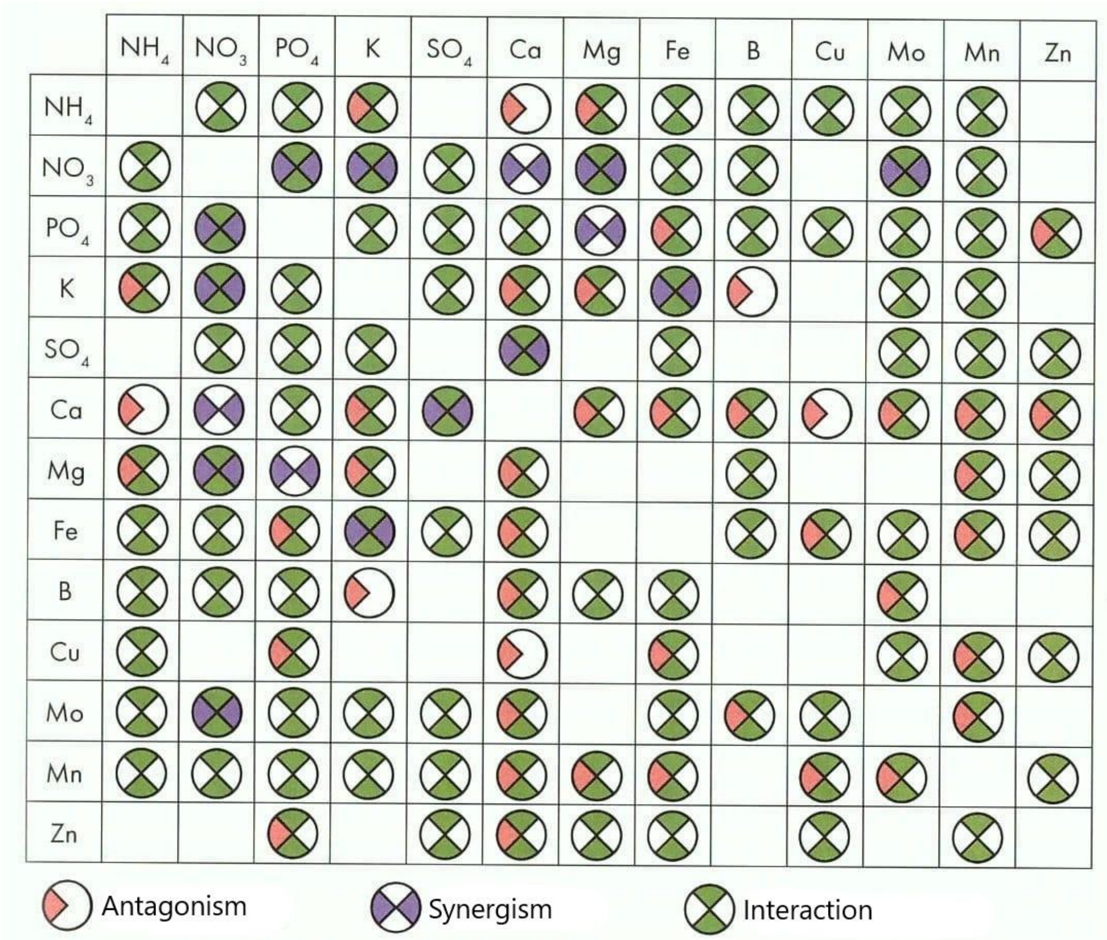

Figure 2.6: Interactions between nutrient ions (Source: Chatzicharissis and Kazantzis, 2014)

trees. For example, changes in soil pH affects the uptake of some nutrients, winter pruning increases N levels in plant tissues and summer pruning increases Ca in leaves but decreases N, K and P. Such knowledge is very important for the fertilization management (Chatzicharissis and Kazantzis, 2014). Beverly (1991) has provided with some rates between nutrients for cherries (Table 2.5) using Diagnosis and Recommendation Integrated System (DRIS) method.

Table 2.5: Nutrient rates according to Beverly (1991)

Nutrient ratio	***Average***	***Significant Difference (SD)***
N/K	1.24	0.372
N/Zn	0.187	0.059
P/Ca	0.170	0.044
P/K	0.200	0.043
P/B	0.006	0.001

P/Cu	0.048	0.016
P/Zn	0.031	0.009
Ca/Mn	0.040	0.009
Ca/Zn	0.189	0.058
Mg/K	0.365	0.122
Mg/P	1.82	0.425
Mg/Ca	0.295	0.063
Mg/Mn	0.011	0.002
Mg/Zn	0.055	0.018
Mn/N	26.79	6.99
Mn/K	31.80	7.68
Mn/B	0.906	0.175
Mn/Zn	4.77	1.24
Fe/K	65.82	34.80
Fe/Ca	50.70	13.90
Fe/P	320.50	126.00
Fe/Zn	9.52	3.82
Fe/Mn	1.99	0.658
Cu/K	4.64	1.85
Cu/Ca	3.73	1.17
Cu/Zn	0.672	0.208
Cu/Mn	0.146	0.046
B/K	35.24	6.13
B/Cu	8.59	3.36
Zn/K	7.08	2.31
Zn/B	0.20	0.057

Apart from nutrient concentration in leaves, some studies have attempted to estimate the macronutrients extracted annually by cherry cultivation. Roversi and Monteforte (2006), after weighing dry matter from winter and summer pruning, fruit and leaves in six cherry cultivars, three for fresh consumption and three for processing, concluded that there is great variability in annual mineral extraction for each of the tested N, P, K, Ca and Mg (Table 2.6). The quantity of each mineral nutrient required annually to produce 1 ton of fresh cherries appear to be highest for N (6.37 kg), followed by Ca (5.37 kg), K (5.34 kg), P (1.14 kg) and Mg

(0.92 kg). Thus, minimum and maximum per hectare nutrient uptakes seem to depend more on the yield of the different cultivars.

Table 2.6 Estimated gross annual nutrient requirements (kg ha^{-1} year^{-1})

Mineral element	*Minimum*	*Average*	*Maximun*
N	38.56	47.20	64.60
P	6.20	8.37	10.77
K	16.47	28.22	47.09
Ca	25.76	40.77	55.03
Mg	5.08	6.76	8.79

In addition to soil and leaf nutrient requirements, Table 2.7 contains the typical values for nutrients in fresh weight of cherry fruits. Unfortunately, deficiencies and potential toxicities have not yet been established (NE).

Table 2.7: Nutrient concentration ranges for cherry fruits (fresh weight basis) (mg/100g)

Nutrient	*Deficiency*	*Normal Range*	*Potential toxicity*
N	NE	110-190	NE
P	NE	15-25	NE
K	NE	120-220	NE
Ca	NE	7-14	NE
Mg	NE	7-12	NE
B	NE	0.2-0.5	NE

2.5.2.1 Nitrogen

Nitrogen is the key element for the control of vegetation and fruit bearing. Greek soils are generally poor in N due to their low OM content (Stylianidis et al., 2002) and since cherry trees have a relatively high demand of N, it is the nutrient most likely to be inadequate in cherry orchards (Nielsen et al., 2017). N deficiency is characterized by reduced shoot length and small, pale-green leaves (Figure 2.7) that may abscise prematurely in autumn. Sometimes such inadequacy might be caused by competition for N with sod and weed species. Either

Figure 2.7: N deficiency in terminal leaves (Source: Pastopoulos and Kazantzis, 2018)

way, low N availability contributes to lower yields and smaller fruits. Low N deficiency drive cherry trees to the formation of many reproductive buds, plentiful flowering and amount of fruits.

Excess of N has the positive effect of significant vegetation, but the disadvantage is fairly important because fruits become “watery” of low quality and organoleptic properties. Moreover, fruits become more susceptible during transportation and conservation conditions; N excess can depress the defensive mechanisms of cherry trees and make leaves and fruits vulnerable to diseases and other enemies like pests. However, excess of N is not toxic for cherry trees (Chatzicharissis and Kazantzis, 2014).

The timing of N application is influenced by the growth pattern of cherry (Neilsen et al., 2017). Uptake of soil-applied N very early in the growing season is minimal due to cool soils and lack of significant evapotranspirational movement of soil water and dissolved nutrients into the plant until leaf emergence and expansion. Therefore, flowering and fruit set therefore depend largely on remobilization of N from storage reserves for about 3 weeks after bud break (Grassi et al., 2002, 2003). The short fruit development period creates opportunities for postharvest N implementations. Neilsen et al. (2004) and Azarenko et al. (2008) have suggested that there is inefficient N uptake when these applications are made to the soil. Improved availability for N remobilization the following spring can be achieved late in the summer with postharvest urea spray applications in the 2–5% (w/v) concentration range, due to its effectiveness at increasing N stored in flowering spurs, shoot tips and buds

(Ouzounis and Lang, 2011; Thielemann et al., 2014), but not for trees with high N status at the season end (Wojcik and Morgas, 2015).

2.5.2.2 Phosphorus

Absolute cherry P requirements are low relative to other major plant nutrients (Tables 2.4, 2.6, 2.7) and the identification of P deficiency in cherries under field conditions is quite difficult. It is believed that such deficiency is included in the causes of fruit cracking (Stylianidis et al., 20002) and premature harvest, effects not well-established yet (Chatzicharissis and Kazantzis, 2014).

P deficiency is a limitation factor for tree respiration, hardens its tissues and impedes water losses by them. Generally, there are no visual indications for P deficiency although they resemble the N deficiency symptoms with slight differences. Sometimes they can be confused because under low P concentrations trees cannot sufficiently manage N. On the other hand, high N fertilization decreases P concentration in the leaves.

Moreover, P deficiency is responsible for the development of an impotent root system. Toxicity effects are not so likely regardless P concentration, but this nutrient interacts negatively with others (N, Cu, Mn, and mostly Fe and Zn), binds them and that way other deficiencies might be caused.

Nevertheless, first-year canopy and root growth can be increased at high soil P in acid soil, implying a role for P in improved cherry establishment (Neilsen et al., 1990). Studies have indicated increased vigor and yield in some varieties after long-term P fertilization on low-P, acid soils of pH 4.4 (Ystaas and Froynes, 1995a). Others have revealed increased growth and yield due to annual fertilization of 20 g of P as ammonium polyphosphate at bloom the first years of a cherry tree's life, but delayed fruit harvest the following years (Neilsen et al., 2010, 2014). There have been no documented beneficial foliar P applications.

2.5.2.3 Potassium, Magnesium and Calcium

These three soil nutrients, often referred as base cations, are considered to have intermediate mobility in soils due to potential interaction with clay minerals and soil OM (Neilsen et al, 2017).

Potassium is a basic nutrient for cherry trees contributing to a better fruit quality (size, shape, color, organoleptic properties), moisture adjustment and stress resistance. About 25%

of agricultural soils in Greece have a poor exchangeable K (<100 ppm) content (Stylianidis et el., 2002), mainly sandy soils (Chatzicharissis and Kazantzis, 2014). Total cherry requirements for K are second to those of N and very close to those of Ca (Tables 2.4, 2.6) and generally represent the highest mineral concentration in fruit (Table 2.7).

Low deficiency of K affects shoot thickness making them thinner, and as such deficiency increases affects shoot length too, dehydrating them to death. This may affect tree branches, even the whole tree. Cherry fruits become smaller with sour flavor and mild color, yield increments during the first deficiency stages but finally declines (Chatzicharissis and Kazantzis, 2014). K deficiency has also been associated with chlorosis, leaf curl, and marginal leaf scorch and necrosis, especially apparent on basal leaves of new-year extension growth (Figure 2.8). Years of high yield may also depress annual leaf K concentration due to the high concentration of K in cherry fruit.

Figure 2.8: K deficiency in cherry tree leaves (Source: Chatzicharissis and Kazantzis, 2014)

Ca requirements in cherry orchards are high, often approaching those of N and K (Tables 2.4, 2.6) and deficiencies often appear in low pH soils. Fruits intake Ca through the xylem but not through the leaves and its concentration inside them is similar to Mg. Deficient concentrations of Ca in fruits have long been associated with major quality disorders including surface pitting (Figure 2.9), decreased fruit firmness and cracking prevention. Ca sprayings have been reported to reduce cracking in sweet cherry fruit and increase firmness. The

Figure 2.9: Surface pitting as a result of deficient Ca concentration

preferred method of augmenting fruit Ca concentration has been via multiple dilute Ca salt sprays applied during the growing season. Soil Ca applications generally are not effective at increasing cherry Ca concentration but have been applied to increase soil pH (Neilsen et al., 2017).

Ca toxicities have not yet been reported but excessive amount of it in soils cause problems due to fixation of nutrients such as Fe, Zn, Cu, Mn, Mg and B., leading to deficiencies which can even eliminate the tree's life. Ca affects indirectly some nutrient uptake due to soil pH increment, compared with their previous confined availability (Chatzicharissis and Kazantzis, 2014).

Cherry requirements for Mg are lower than those for K and Ca (Tables 2.4, 2.6, 2.7). Most soils in Greece are sufficient to total and exchangeable Mg (Chatzicharissis and Kazantzis, 2014), a fact documented from relative research work carried out in Northern Greece where it was found that only a percentage of 8% out of 3790 surface soil samples were insufficiently supplied with Mg and constitute of concentrations lower that 25 ppm of exchangeable Mg (Stylianidis et al., 2002). High soil Mg concentration increases soil pH binding other nutrients due to competitiveness.

Deficiencies of Mg may occur under high concentrations of NH_4^+, K^+, Ca^{++} ions in soil solution. Field symptoms of Mg deficiency on cherry include the commonly known bronzing (Figure 2.10), an interveinal leaf chlorosis progressing to necrosis on basal leaves of new extension growth (Neilsen et al., 2017). Intense Mg deficiency does not affect leaf size but can be associated with early leaf senescence and abscission. (Mulder, 1950). It can be treated with both fertilization and spraying applications. In soil applications levels of K, N and pH shall be considered. K binds Mg, low and high N concentrations limit and favor Mg uptake respectively, soil pH defines the type of applied Mg. Soil Mg amelioration may take one or two years to complete but will last for a significant period. It is very toxic if absorbed by plant cells as the only ion of a nutrient solution (Chatzicharissis and Kazantzis, 2014).

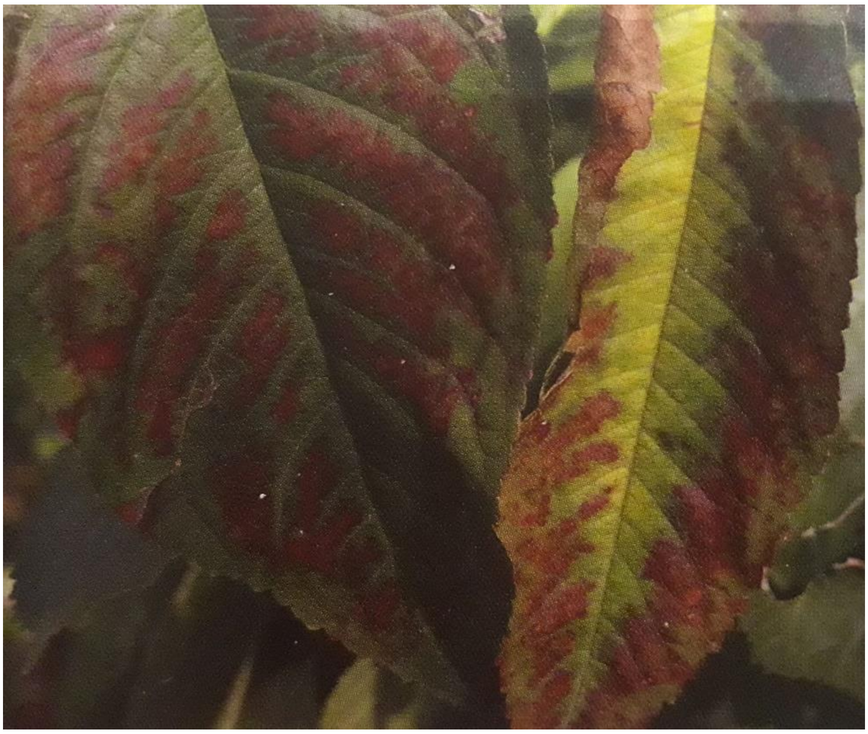

Figure 2.10: Mg deficiency in cherry leaves (Source: Chatzicharissis and Kazantzis, 2014)

2.5.2.4 Boron, Zinc, Manganese, Iron and Copper

Micronutrient requirements are low in cherry orchards, usually less than 1 kg ha^{-1}, but still, deficiencies of micronutrients have been identified for cherries with an exception of Cu.

B is the only non-mineral micronutrient. Its deficiency emerges in acidic, sandy, low-Ca and low-OM soils, or if it has been leached from the soil (Chatzicharissis and Kazantzis, 2014). B deficiency is the most widespread micronutrient deficiency around the world causing large losses in crop production and quality, since it affects vegetative and reproductive growth of plants. Soil OM can be an important potential source of plant-available B. Soil B availability increases at high soil pH, however, cherry growth in such high-pH soils is frequently inhibited by excessive salinity and Na or Cl toxicity (Neilsen et al., 2017).

In sweet cherries B deficiency causes reduced terminal growth, bud death, defoliation of shoot terminals after growth started, leaves with irregular margins and failure of blossoms to develop (Woodbridge, 1955) with insufficient formation of petals (Figure 2.11B) or no petals at all (Figure 2.11A). Some researchers associate pitting and cracking with B deficiency

Figure 2.11: Influence of B deficiency on the formation of flowers (A) and petals (B) (Stylianidis et al., 2002)

(most researchers link them with Ca deficiency), but mostly cherry fruits remain small in size, develop a white-yellowish color with bright red hue and finally fall down from the tree. B restoration in cheery trees may take two or three years with fertilizing and foliar spraying applications (Chatzicharissis and Kazantzis, 2014). The narrow range between B deficiency and toxicity for most plants suggests that B applications to sweet cherry should be moderate once adequate B levels are achieved (Neilsen et al., 2017).

Zn deficiency is one of the most widespread micronutrient deficiencies worldwide causing large losses in crop production and quality. It is the first highlighted nutrient deficiency triggering the research on micronutrient importance. Soil pH and Zn solubility interact with inverse relations; high-pH soils have limited Zn solubility (Broadley et al., 2007). Zn soil availability is also affected by soil OM, its adsorption from clayey surfaces, the environmental conditions and the interactions with other nutrient ions. Divalent cations Mg^{2+}, Ca^{2+}, Ba^{2+}, Sr^{2+} and Cu^{2+} in various concentrations block the Zn^{2+} root uptake (Chatzicharissis and Kazantzis, 2014).

A cluster of leaves with shortened internodes is being developed. Some leaves are normal sized and colored while others are quite small (little leaf) with interveinal chlorosis. Affected branches are stunted with undeveloped blind buds. Mild Zn deficiency symptoms

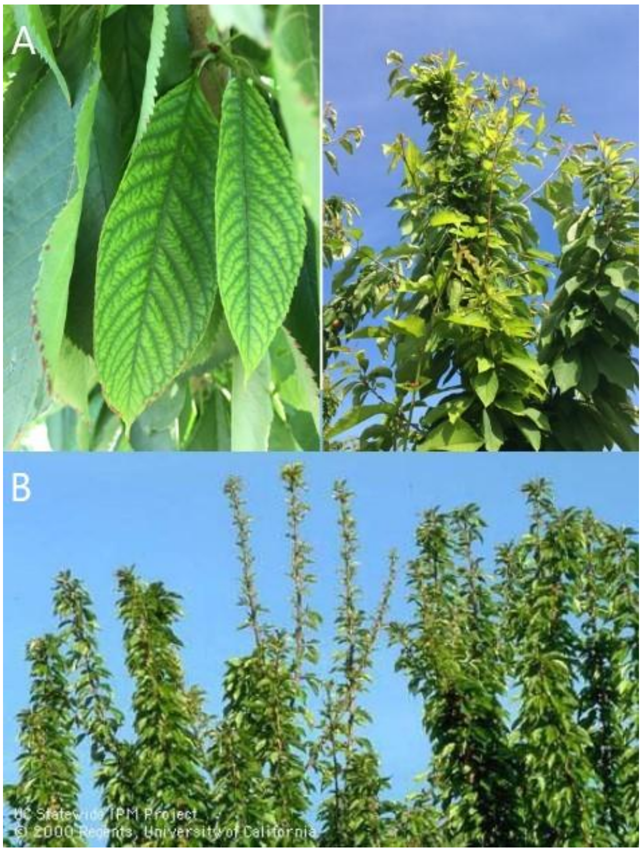

Figure 2.12: Cherry leaves with symptoms of Zn deficiency (Source: treefruit.wsu.edu (A), fruitandnuteducation.ucdavis.edu (B))

are restricted to terminal leaves, which are elongated with a green-yellowish color (Neilsen et al., 2017) (Figure 2.12). Fruits are long shaped, prematurely colored and fallen off the trees. Zn deficiency is also very difficult to cope with since it takes two or three years to eliminate the symptoms from the trees. Commonly, soil or foliar applications of $ZnSO_4$ or organic compounds of it are used as treatments. Lately, mycorrhizas have being tasted giving good results not only for Zn uptake but for P, Cu and Mn too (Chatzicharissis and Kazantzis, 2014).

Mn is a micronutrient with similar to Mg involvement at the biochemical functions of the trees. Normal concentrations at the dry weight of leaves vary between 20-200 ppm (Table 2.4) whilst its concentration in soil solution depends on soil pH and redox potential. Mn deficiencies are very rare in Greek orchards and occur in soil pH>7 (Chatzicharissis and Kazantzis, 2014). Mn deficiency in sweet cherry is characterized by interveinal leaf chlorosis (Figure 2.13) especially on recently matured, basal leaves of new growth. Leaves can become completely chlorotic and Mn deficiency can be mistaken for lime-induced Fe (Figure 2.14) or Zn deficiency under severe deficiency conditions (Neilsen et al., 2014). Yield and fruit quality are reduced also.

Figure 2.13: Zn deficiency in cherry leaves (Source: https://www.yara.co.nz)

Mn deficiency can be corrected by early season manganese sulfate sprays at petal fall at first and several weeks later if required. Winter spraying and soil Mn application efficacy is still controversial. Mn toxicity effects have not yet been recorded in Greek cherry orchards.

Despite that after oxygen, silicon and aluminum Fe is the forth element in abundance on Earth, consisting the 5% of the Earth's crust (Stylianidis et al., 2002), its availability and tree uptake depends on many factors such as Fe oxidation state, the amount of P, soil OM and nitrate N, soil humidity and temperature, the interactions with other nutrients and the chosen rootstock (Chatzicharissis and Kazantzis, 2014).

Inadequate Fe inhibits the normal development of chlorophyll and is initially apparent as interveinal chlorosis on young (shoot tip) leaves, resulting in prominent green veins. Symptoms can progress from younger to older leaves, with chlorosis eventually extending to complete yellowing of leaves (Figure 2.14) that can be susceptible to leaf scorch late in the growing season. Leaf and fruit size can be severely decreased (Neilsen et al., 2017).

Figure 2.14: Fe deficiency in cherry leaves (Source: www.humofert.gr)

Fe deficiency is very common at alkaline soils and soils with pH>7. It is also affected by high contents of calcium carbonate, high concentrations of CO_3^- and Ca^{++}, imbalance between Mn, Zn and Cu ions and excess of P. Such attributes mainly appear when there is an excess of HCO_3 in the soil. Under poor soil aeration and drainage conditions Fe deficiency deteriorates.

Overcoming Fe deficiency has frequently been problematic, so, a combination of cultivating methods shall be followed. First comes the selection of a proper rootstock. *Prunus mahaleb*, *Prunus myrobalana* and some hybrids of Maxma are Fe-inadequacy resilient. A second concern is the proper soil aeration and drainage. The decrease of soil pH in alkaline soils, the application of acidifying fertilizers and the implementation of organic (Fe-EDTA and FE-EDDHA) and inorganic ($FeSO_4$) forms of Fe can be moderately effective. Foliar spraying applications have been proved effective too (Chatzicharissis and Kazantzis, 2014). Finally, the use of graminaceous cover crops, fertilized with $FeSO_4$ or the application of Fe-enriched organic amendments, have been proposed as agronomic methods to improve Fe nutrition (Tagliavini et al., 2000).

Cu is a very interesting micronutrient with no recorded deficiencies. Spraying the trees with Cu during winter enriches the soil. Possible deficiencies may appear at heavy clayey and salty soils or due to high soil pH, high rates of N, P and OM and low reserve of Cu in the soil, Toxicities have not yet been reported but high Cu concentration foliar spraying applications may cause burn marks on the leaves and high Cu concentrations in the soil solution may impede root and shoot growth.

2.5.3 Seasonal water limitations

Interactions amongst environmental conditions, management practices and genetics have an impact on water requirements of cherries but yet, there has been relatively little research on that matter (Neilsen et al., 2017).

When cherries are watered to 100% evapotranspiration (ET) replacement in high vapor pressure deficit (VPD) environments, they may require an amount of irrigation water ranging from 550 mm up to 1000 mm (Hanson and Proebsting, 1996; Marsal et al., 2010; Neilsen et al., 2017). A range of factors affect cherry tree responses to water inputs at the same aforementioned environmental conditions denoting irrigation methods, crop load and rootstocks as the three major. Midday stem water and predawn leaf water potential are the two determinants that define when destructive stress appears; approximately -1.5MPa for the first and -0.5MPa for the second (Proebsting et al., 1981; Schmitt et al., 1989; Marsal et al., 2009, 2010; Oyarzun et al., 2010; Livellara et al., 2011; Measham et al., 2014; Neilsen et al., 2016).

In addition to plant water potential measurements, in-plant sensors and remote sensing thermal and leaf reflectance imagery could be applied to diagnose water stress and potentially to schedule irrigation. Moreover, ET-based methods using vegetation indices could be implemented for irrigation scheduling. Unfortunately, there are relatively very few, or no, studies for cherries.

Irrigation is the most common process to mitigate water stress. Soil moisture sensing is an increasingly widespread method measuring either soil moisture content or soil moisture potential. Multiple sensors can be used to schedule irrigation. For example, Juhasz et al. (2013) used a combination of automatic weather station data to calculate the reference crop ET (ET_0) and an automated soil moisture monitoring to schedule supplemental irrigation based on maintenance of soil moisture between predefined trigger levels.

Empirical soil management practices by farmers, suggest that tilling the soil using a combination of rotary tiller at first followed by spring tines cultivator with crumbler roller some days after rainfall or adequate irrigating, retains soil moisture for a long time, in some cases even for a month. Such a management needs further scientific research in order to result in reliable conclusions concerning water management, trees and crop before and after harvest.

Finally, the impact of excess water on fruit quality is the primal concern, because due to rain on fruit and/or excess water in the soil fruit cracking is caused on sweet cherries affecting cherry production. Empirical observations during the years highlight that adequate irrigation before rainfall mitigates fruit cracking, but the precise implementation of a such preventing method needs further research. This shall be tested in a combination with the chosen rootstock which a factor controlling plant water uptake, transport and stress.

Seasonal water requirements management is evolving to an important matter due to the growing concerns about available and reliable water supplies. Cherries are harvested several months before leaf senescence and fall. That gives us an opportunity to reduce water inputs postharvest without affecting current season fruit quality (Neilsen et al., 2017) and enhance the in-plant biochemical processes as trees prepare themselves for next year's crop.

2.6 Diseases and pests

2.6.1 Pests

There are six major arthropod pests concerning cherry cultivation in Greece: *Myzus Cerasi, Rhagoletis Cerasi, Droshophila Suzukii* (Matsumura), *Caliroa Cerasi L.* and both *Tetranychus urticae* and *Panonychus Ulmi*, and require annual control.

There are other pests but not included in major ones, because they need to be controlled after monitoring and examining the economic injury level if they appear, like *Cotinis nitida, Cossus Cossus, Capnodis tenebrionis, Scolytus rugulosus, Tropinota Hirta* and *Otiorrhynchus spp*.

2.7 Rootstocks and varieties

2.7.1 Rootstocks

Rootstocks for sweet and sour cherries are chosen considering their graft compatibility with cherry varieties, the soil fertility and desired training system, their resistance to diseases and pathogens and their environmental adaptability. Based on that, major species of rootstocks include *Prunus avium* L., *Prunus cerasus* L., *Prunus canescens* Bois, *Prunus fruticosa* Pall. and *Prunus mahaleb* L., as well as their hybrids (Hrotko and Rozpara, 2017).

Perry (1987) listed the rootstock breeding objectives which include size reduction, increased scion precocity and cropping, wide range of compatibility, uniformity in performance, cold hardiness, adaptation to a wide range of soils, and disease and pest tolerance. The main target of most cherry rootstock breeding programs is the dwarfing rootstock because growers tend to prefer more intensive orchards which allow planting densities of up to 1000-5000 trees/ha (Sansavini and Lugli, 2014; Musacchi et al., 2015). However, based on the climate change and the variable soil fertility in the various cherry growing regions, it would be more prudent to try to adapt the vigour control on soil and climate (Hrotko and Rozpara, 2017).

In Greece, nearly all orchards planted before 30 years or earlier, consist of varieties grafted on *P. anium* L. (Mazzard). Exception was the region of Komotini where mostly the local varieties were grafted on *P. mahaleb* L. (Mahaleb). The utilization of the first vegetative propagated rootstock, "Colt", started before 30 years by the agronomist and nursery owner Mr Tsesmeliadis (Chatzicharisis and Kazantzis, 2014). During the last 20 years Greek cherry orchards adapted the use of rootstocks like CAB, Maxma and Gisela which are moderate-vigorous and dwarfing compared to Mazzard (Figure 2.15).

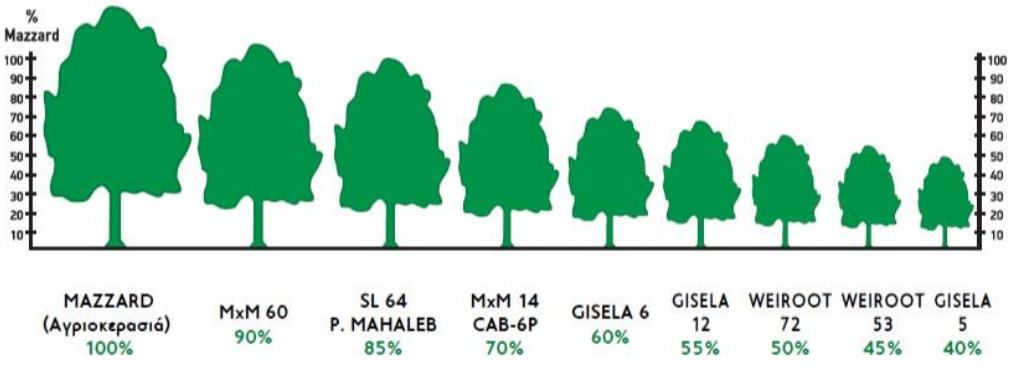

Figure 2.15: Vigour comparison of different cherry rootstocks (Source: Chatzicharissis and Kazantzis, 2014)

'Colt' is a *P. avium* x *P. pseudocerasus* hybrid introduced to nurseries in the 1970s as a semi-dwarfing rootstock (Long and Kaiser, 2010), however, at many sites produces vigorous trees similar in size to those grafted on Mazzard or 'F 12/1' (Rozpara, 2013). It is sensitive to droughty soils (Long and Kaiser, 2010) but low resistant to frost (Grzyb, 2012). 'Colt' roots exceptionally easu and has a beneficial influence on the health and vigour of sweet cherry trees, as well as on the quality of the fruit (Hrotko and Rozpara, 2017). It is resistant to cherry stem pitting and Phytophthora root rot, bacterial canker and gopher damage but is susceptible to crown gall (Agrobacterium tumefaciens) (Long and Kaiser, 2010). Moreover, ‘Colt’ performs well in replant situations where cherries follow cherries on non-fumigated sites (Long, 1995), but trees and soil shall not be infected by crown gall (Chatzicharissis and Kazantzis, 2014).

‘Gisela 6’ is a semi-dwarf and easy to manage rootstock, hybrid of *P. cerasus x P. canescens*. Trees grafted on this rootstock are relatively vigorous and very precocious, bearing fruits 2-3 years earlier than on standard rootstocks (Hrotko and Rozpara, 2017), but need to be properly pruned from an early age in order to maintain fruit size and quality. Premium fruit quality is possible with varieties of moderate to low productivity but more difficult with very productive ones (Long and Kaiser, 2010). ‘Gisela 6’ is well suited for a wide range of soil types, from light to heavy; however, by personal experience heavy soils inhibit the proper functioning of the trees and also good drainage is essential. The ‘GiSela 6’ rootstock is tolerant to Prune dwarf virus (PDV) and *Prunus* necrotic ringspot virus (PNRSV).

‘CAB-6P’ rootstock is a *P. cerasus* clone, very popular amongst farmers due to its adaptability in heavy soils and drought conditions. It is reported to give 20–30% reduction in scion vigour compared to ‘Mazzard’ rootstocks (Thomidis and Sotiropoulos, 2003) amongst with high and relatively precocious productivity (Sarropoulou, 2008). Most of *Phytophthora spp.* tested were not found to be pathogenic on ‘CAB-6P’ (Thomidis and Sotiropoulos, 2003). It is susceptible to *Armillaria mellea* fungi and *Meloidogyne spp.* and *Pratylenchus vulnus* nematodes, but moderately susceptible to *Agrobacterium tumefaciens* fungi and *Pratylenchus penetrans* and *Coccomyces hiemalis* nematodes (Sarropoulou, 2008).

‘MaxMa 14’ is a *P. mahaleb* x *P. avium* hybrid and it is considered as a semi-standard rootstock, because trees grafted on it grow about 30-40% less vigorously than on ‘Mazzard’ (Hrotko and Rozpara, 2017). It is a precocious, semi-dwarfing and resistance to iron-induced chlorosis caused by calcareous soils rootstock, but it shall not be recommended for super-high-density orchards because sometimes it can produce trees larger than ‘Mazzard’ (Long and Kaiser, 2010); growth vigour depends on soil fertility. This rootstock is resilient to *Phytophthora spp.* infection and tolerant to bacterial canker (Chatzicharissis and Kazantzis, 2014), more than ‘Mazzard’. It is sensitive to soil water shortage and requires irrigation during periods of drought. Trees grafted on ‘MaxMa 14’ usually yield well, do not need support, normally are healthy and resistant to lime-induced chlorosis (Hrotko and Rozpara, 2014).

2.7.2 Varieties

Greece has entered the last few years in the stage of renewal of the traditional cherry orchards, either retaining the old and local varieties like 'Tragana Edessis' in new rootstocks less vigorous than 'Mazzard' or planting new and more commercial worldwide varieties.

The International Union for the Protection of New Varieties of Plants (UPOV) and International Bank for Plant Genetic Resources (IBPGR) have listed the 30 and 60 key features for variety evaluation. Researchers and geneticists are concerned for the most of them. Farmers are interested in those features related with cultivating techniques, productivity, and commercial-economic value (Chatzicharissis and Kazantzis, 2014).

Cultivating varieties in Greece can be distinct into three major categories; the classic ones extending in a wide range of areas, many new rapidly expanding varieties which produce large fruits and in some cases are self-compatible and some local varieties of little commercial interest but well established in the local unique microclimate. The first category constitutes of varieties such as 'Bigarreau Burlat', 'Larian', 'Lapins', 'B.S. Hardy Giant', 'Ferrovia', 'Van', 'Germersdorfer', 'Tragana Edessis' and 'Bakirtzeika'. The second category is formed by varieties such as 'Sweet Early', 'Early BiGi', 'Early Lory', 'Early Star', 'Giorgia', 'Giant Red', 'Canada Giant', 'Grace Star', 'Blaze Star', 'Kordia', 'Regina', 'Samba', 'Black Star', 'Skeena', 'Sabrina', 'Satin', 'Sweetheart'. Varieties such as 'Kifisias', 'Kokkina Anastasias', 'Tragano Komotinis', 'Mavro Proimo Achaias', 'Mavro Tripoleos', 'Proimo Kolyndrou', 'Gervasiou', 'Fraoula Volou', 'Karamela Tripoleos', 'Petrokeraso Achaias' and 'Moschato Evvoias' are localy cultivated in small areas (Kazantzis and Marnasidis, 2013).

For the sake of brevity, only a detailed description of the examined in the research varieties will follow, i.e. 'Early BiGi', 'Bigarreau Burlat' and 'Lapins'.

'Early BiGi' is a variety inadequately examined yet about its adaptability in Greek soils and climate. It is a French variety selected by Pierre Argot and is also known by the name 'Bigisol'. Is a self-sterile variety requiring pollination, belongs to XVIII incompatibility group (S_1S_9 genotype) and flowers generally during the last days of March (early flowering variety). Proper pollinators are 'B. Burlat' (S_3S_9 genotype, XVI group) and 'Lapins' (S_1S_4 genotype, SC group). 'Early BiGi' is a very early variety maturing 4-5 days before B. Burlat, its productivity is average to high. Fruits are large and very thick with an approximate diameter of 28-29 mm, their skin color is red-dark red, pulp color is pink-red, but they are susceptible to cracking and

Monilinia spp. The tree is very vigorous with an open growth habit, very easy to train, but requires different management depending the rootstock.

'B. Burat' was for many years the most important early variety in Greece. The last decade is being replaced by other very early varieties like 'Early BiGi' or 'Early Lory' but yet, its cultivated and economic importance cannot be overlooked. This variety was selected by Leonard Burlat back in 1915 in France but has an unknown parentage. It is a self-sterile variety requiring pollination, belongs to XVI incompatibility group (S_3S_9 genotype) and flowers during the last days of March. In older orchards 'Van' (S_1S_3, II) and 'B.S. Hardy Giant' (S_1S_2, I) were used as pollinators. Observations in modern plantations indicate that 'Lapins', 'Early BiGi' or 'Larian' (S_4S_6, XVII) may be suitable pollinators too. 'B. Burlat' is considered as the reference maturation point for all the other varieties, giving very good and standard yield every year which may reach 150 kg per tree. Trees have a semi-upright growth habit, are very vigorous, susceptible to mild winters and *Monilinia laxa* but resistant to *Stigmina carpophila* and *Gnomonia erythrostoma*. Fruits are red, oblate, medium sized, have medium to low firmness but are susceptible to cracking and give many double fruits.

'Lapins' is a variety of both commercial and genetic interest due to its fruit characteristics, large and stable annual yield and self-compatibility. It is a hybrib of 'Van' and 'Stella' (self-fertile, S_3S_4 genotype) cultivars, developed in 1965 by the agronomist Karlis O. Lapins in Summerland, British Columbia at the Summerland Research Station. 'Lapins' is an excellent pollinator for other cherry varieties giving very upright and vigorous trees of an early blooming time. International literature reports that its ripening time is around 25-28 days after 'Burlat', but in Greece this time period is very shorter, at 12 days after 'Burlat'. Fruits are roundish to heart-shaped, medium to large, firm at a purple red color. Due to large annual yields 'Lapins' trees require mindful training in order to reach the medium to large fruit size. It is a moderately susceptible to cracking and *Monilinia laxa* variety, has low-chilling requirements and already mentioned, is regularly productive.

3 Materials and methods

3.1 Experimental cherry orchard description

The experiment took place in 2018 at a 0.43 ha sweet cherry orchard with coordinates 40°49'11.5"N and 22°19'14.9"E (Figure 3.1), located in the region of Giannitsa, Pella, at the foothills of mountain Paiko (Figure 3.2). The orchard which was set up during January of 2012, is composed of the varieties 'Early BiGi' as the main variety, 'B. Burlat' and 'Lapins' as pollinators.

Figure 3.1: Orchard coordinates (photos taken by Google Earth)

It is consisted of 208 trees that were planted during the year of 2012 on a 4 x 5 m grid; 104 of them are 'Early Bigi', 52 are 'Bigarreau Burlat' and 52 are 'Lapins'. All trees were ordered to be grafted on 'MxM 14' rootstock. The orchard has 8 rows and every row consists of 26 cherry trees. The odd rows consist of the main variety 'Early Bigi', and the pollinators

Figure 3.2: Orchard location with mountain Paiko as a reference point

'Lapins' and 'Bigarreau Burlat' are planted as pairs from the same variety succeeding one another on the even rows to achieve maximum pollination of 'Early Bigi' flowers.

Due to a mice infestation, a percentage of 17.64% (36 trees) were dried. A total of 32 out of 104 (31 'Lapins' and 1 'Bigarreau Burlat') pollinator trees have been drought; due to the fact that most of them were not grafted on the selected rootstock of 'MxM 14' for reasons of poor nursery management decisions.

The orchard was divided into 32 grid cells (Figure 3.3) for optimal data management and high accuracy of the results. Every row consists of four grid cells and every grid cell is

Figure 3.3: Division of the orchard in 32 grid cells

composed of 6 or 7 trees spreading to an area of 0.012 ha (24 x 5 m) and 0.014 ha (28 x 5 m) respectively; the 1st and 3rd grid cells contain 6 trees while the 2nd and 4th grid cells contain 7 trees. Due to the aforementioned pest problem, no pollinator grid cell is at its full capacity and 3 of them lack of any 'Lapins' trees (Figure 3.4).

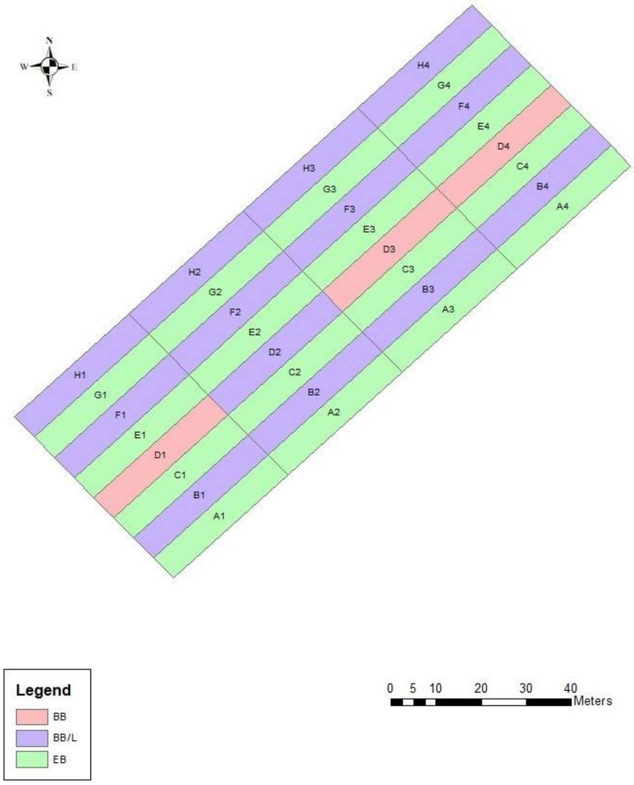

Figure 3.4: The variety map of the orchard ('BB'='Bigarreau Burlat', 'L'='Lapins', 'EB'='Early Bigi')

The division in 32 grid cells assisted the estimation of harvested cherry volume, its correlation with the fruit quality characteristics of sugar content (BRIX), weight and size, along with soil texture and EC.

3.2 Quantity and quality measurements

Cherry harvest was completed in three phases for 'Early Bigi' and two for 'Bigarreau Burlat and 'Lapins', interrupted by heavy rainfalls. 'Early Bigi' was harvested between 4 and 10 of May 2018, 'Bigarreau Burlat' on 12 and 15 of May and 'Lapins' on 27 and 30 of the same month.

Plastic cases were used for the yield estimation. Their commercial capacity is at 6 kg, but the real cherry load accommodated in is between 6.5 kg and 6.8 kg. A professional scale with maximum weighing capacity of 150 kg and a GPS were also used. Workers put the harvested cherries of each grid cell into buckets and after sorting them on a workbench into categories ‘A’ (high-price, commercial), ‘B’ (low-price, commercial) and cracked (non-commercial) the plastic cases were filled. The yield of every grid cell was determined using the scale and at the measuring point its coordinates were recorded using the GPS. To ensure the accuracy of measurements and yield mapping, an empty plastic case was weighed and its heft, multiplied with the total number of cases in each grid cell, was subtracted from the final result for the net cherry yield estimation.

The fruit quality standards estimation was processed using a small precision balance, a caliper and a refractometer. In each one of the harvesting stages that took place, three random cherries of each category were picked for every grid cell. Their weight was estimated using the small precision balance, their size using the caliper and the refractometer was employed for the BRIX estimation. The grid cell recorded coordinates from the yield estimation phase were used at the quality standard measurements. That on-field evaluation was intercepting the harvest procedure so it took place on a workbench at indoors.

3.3 Soil sampling

Soil sampling took place some months after harvesting, during February of 2019. The principal objective of such a procedure was to map soil texture and EC of the examined farm.

The soil samples were collected from a depth of 0-30 cm in foam cups using a digging and a garden shovel (Figure 3.5). They were left to dry in room temperature for 5 days (Figure 3.6). After that, they were sent (Figure 3.7) to the loboratories of the Agricultural University of Athens for further analysis.

Figure 3.5: Shovels used (right) and foam cups (left)

Figure 3.6: Drying process of soil samples

Figure 3.7: Soil sample packing for laboratory analysis

3.4 Statistical analysis and map creation

In order to estimate whether there is a linear correlation or not between soil texture, soil EC, yield and quality standards, statistical analysis was implemented including descriptive statistics and Pearson correlation coefficient. IBM SPSS® Statistics V25 was the software for the data processing. Pearson correlation coefficient r has a value between +1 and −1, where 1 is total positive linear correlation, 0 is no linear correlation, and −1 is total negative linear correlation (Table 3.1).

Table 3.1: Pearson correlation coefficient

±0.0≤r<±0.1	No correlation
±0.1≤r<±0.4	Low correlation
±0.4≤r<±0.7	Medium correlation
±0.7≤r≤±1	High correlation

Applying the analysis of the collected data to ArcGIS (ESRI) software, soil texture, soil EC, yield and variety maps were created.

4 Results

4.1 Yield mapping

Figure 4.1 presents the fluctuation of yield per grid cell, as it was weighed in May 2018. Apparently, even grid cells consisting of the same variety and do not lack of any trees, vary on their productivity.

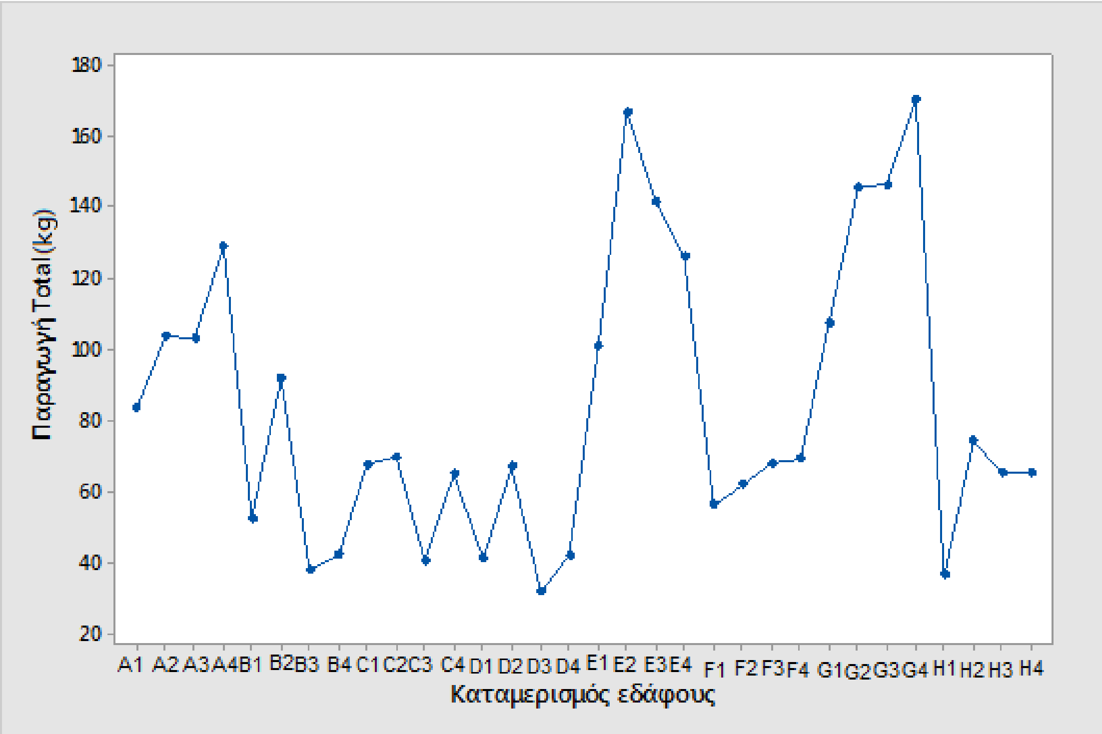

Figure 4.1: Cherry weight per grid cell

As displayed on the yield map (Figure 4.2), there is a noticeable spatial variability of 2018 yield. In grid cells B3 and D3 the lowest harvested values at 37.18 kg and 31.77 kg, respectively, are recorded. The two highest weight measurements are recorded in grid cells E2 and G4 with 166.69 kg and 170.04 kg of harvested cherries respectively. Descriptive statistics indicate that the minimum harvested quantity in a grid cell was 31.77 kg and the maximum was 170.04 kg, but the average per cell yield was 68.53 kg (Table 4.1). The total field output of the examined cropping season ranged between 44.44 kg/ha and 84.73 kg/ha and it seems that the northern parts of the field tend to be more productive.

Table 4.1: Descriptive statistics for yield

	N	Mean	SE Mean	SD	Min	Mid	Max	Skewness	Kurtosis
Yield (kg)	32	*83.44*	7.07	*39.98*	31.86	68.53	170.04	0.75	-0.48

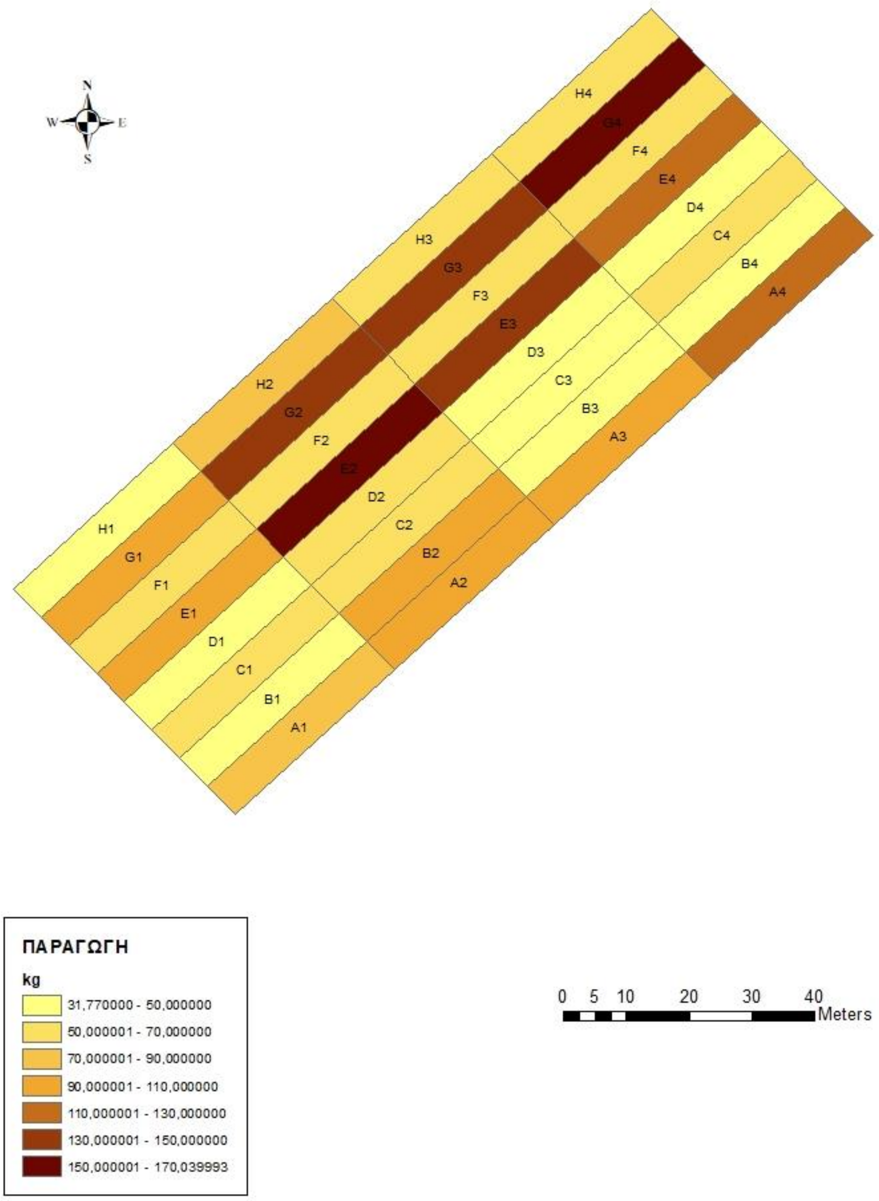

Figure 4.2: Yield map containing all three varieties

Such a spatial variability may be caused by a number of factors, mainly based on the poor orchard management and the unified cultivating practices applied. Soil properties may differ in particular sites of the orchard affecting apart from other factors, yield. Soil fertilization, watering systems and tree training are key parts for a substantial yield, and if not applied according the orchard needs in a site-specific way, they may alter the harvesting quantities.

However, a cherry orchard cultivated with self-incompatible varieties is composed by at least two varieties in order to achieve better pollination; requiring more research. The examined orchard is being planted with three varieties, which shall be studied individually.

'Early Bigi' yield ranges between 40.6 kg in C3 grid cell (4 trees) and 170.04 kg in G4 grid cell (7 trees). In C3 the average tree output is 10.13 kg and the corresponding per tree yield in G4 is 24.9 kg. The total average production per tree for the main variety is 17.67 kg. Examining the quality characteristics of 'Early Bigi', trees of C3 grid cell produced the thickest cherries (30.15 mm) and trees of G3 grid cells produced the thinnest cherries in the orchard (27.65 mm). In average, the fruit size of 'Early Bigi' harvested cherries is 29.17 mm. The average fruit weight is 10.6 gr, C3 produced the heaviest cherries (11.52 gr) and G3 the lightest (9.54 gr). The average sugar content is at 12.14; 11.13 in G2 (min) and 12.63 in C4 (max).

'Early Bigi' presents strong correlations between fruit size and weight but BRIX seems to stay unaffected by variety productivity. BRIX of 'Early Bigi' cherries are slightly related with fruit size and weight, but tree productivity and fruit size and weight are highly moderate related (Table 4.2).

Table 4.2: 'Early Bigi' quantity and quality correlations

	Yield	**Fruit size**	**Fruit weight**	**BRIX**
Yield	1.000	*-0.626*	*-0.588*	-0.168
Fruit size	-0.626	1.000	*0.968*	0.241
Fruit weight	-0.588	0.968	1.000	0.314
BRIX	-0.168	0.241	0.314	1.000

Figures 4.3 and 4.4 present the spatial variability of 'Bigarreau Burlat' and 'Lapins' yield respectively. All pollinator grid cells lack of at least one tree, and in D1, D3 and D4 there is a complete absence of 'Lapins'.

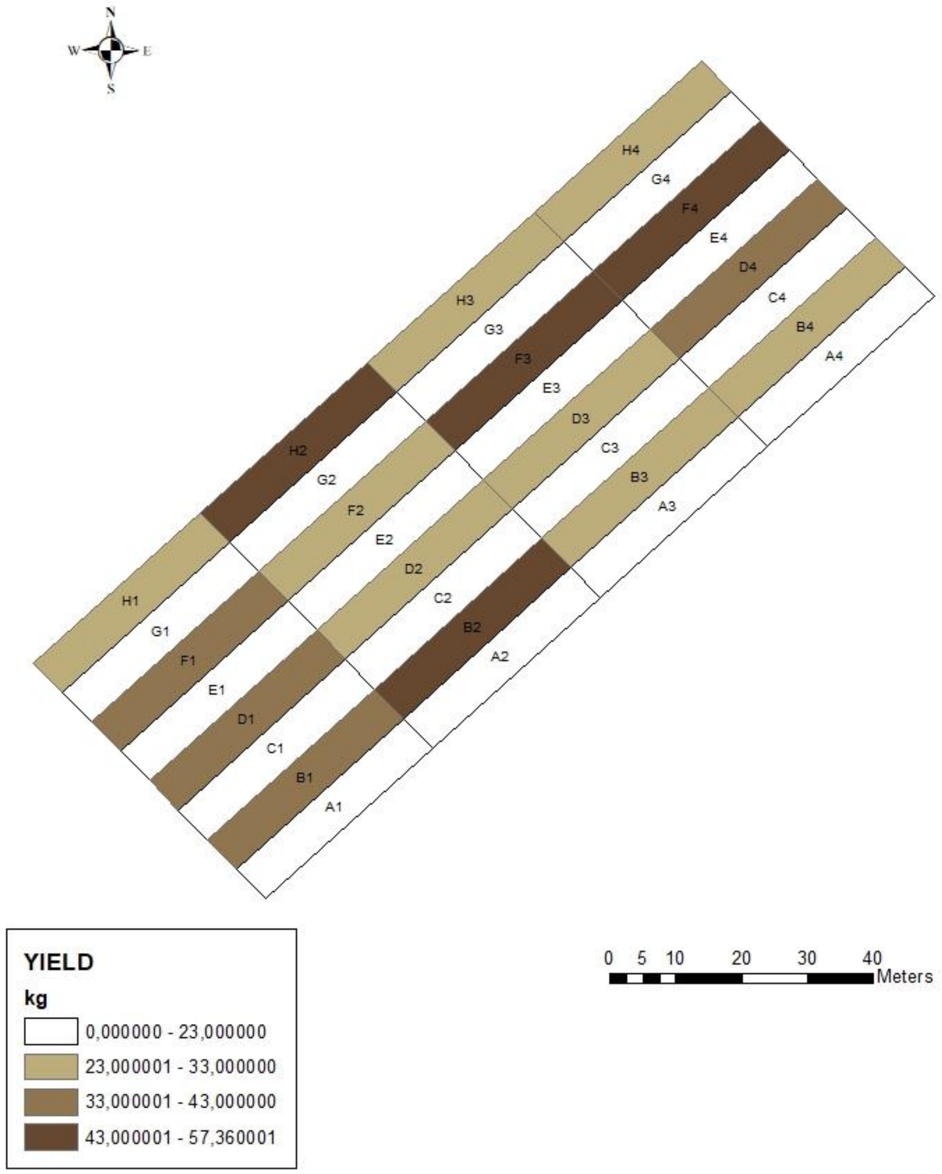

Figure 4.3: 'Biggarreau Burlat' yield map

'Bigarreau Burlat' yield ranges between 23.74 kg in B3 grid cell (3 trees) and 57.36 kg in B2 grid cell (4 trees). In B3 the average tree output is 7.91 kg and the corresponding per tree yield in B2 is 14.34 kg. However, the biggest yield per tree is found in B1 grid cell (2 trees) and it is 18.22 kg. The total average production per tree for the main variety is 11.65 kg. Examining the quality characteristics of 'Bigarreau Burlat', trees of D4 grid cell produced the thickest cherries (29.6 mm) and trees of H1 grid cells produced the thinnest cherries in the orchard (26.61 mm). In average, the fruit size of 'Bigarreau Burlat' harvested cherries is 28.23 mm. The average fruit weight is 10.03 gr, D4 produced the heaviest cherries (10.81 gr) and H1 the lightest (9 gr). The average sugar content is at 12.43; a minimum of 11.03 in D3 (min) and a maximum of 13.6 in H3.

‘Bigarreau Burlat’ shows strong correlation between fruit size and weight. Fruit weight seems to stay unaffected by the trees’ productivity, but there are there are very low correlations between productivity fruit size and BRIX and moderate correlations amongst BRIX, fruit size and weight (Table 4.3).

Table 4.3. ‘Bigarreau Burlat’ quantity and quality correlations

	Yield	**Fruit size**	**Fruit weight**	**BRIX**
Yield	1.000	*-0.179*	*-0.023*	0.281
Fruit size	-0.179	1.000	0.928	-0.410
Fruit weight	-0.023	0.928	1.000	-0.369
BRIX	0.281	*-0.410*	-0.369	1.000

‘Lapins’ yield ranges between 11.15 kg in H1 grid cell (1 tree) and 34.9 kg in D2 grid cell (2 trees); empty grid cells are not included in any calculations. In H1 the average tree output is 11.15 kg derived by the only one ‘Lapins’ tree of the grid cell, and the corresponding per tree yield in D2 is 17.45 kg. The total average production per tree for the main variety is 14.74 kg. Examining the quality characteristics of ‘Lapins’, trees of B3 grid cell produced the thickest cherries (27.82 mm) and trees of D2 grid cells produced the thinnest cherries in the orchard (24.66 mm). In average, the fruit size of ‘Lapins’ harvested cherries is 26.98 mm. The average fruit weight is 9.93 gr, H4 produced the heaviest cherries (11.06 gr) and D2 the lightest (7.9 gr). The average sugar content is at 14.68; 13.73 in B1 which is the minimum BRIX and 15.97 in B3, the maximum BRIX.

‘Lapins’ display strong correlations amongst productivity, fruit size, weight and BRIX (Table 4.4).

Table 4.4. ‘Lapins’ quantity and quality correlations

	Yield	**Fruit size**	**Fruit weight**	**BRIX**
Yield	1.000	*0.770*	*0.770*	0.762
Fruit size	0.770	1.000	0.993	0.997
Fruit weight	0.770	0.993	1.000	0.985
BRIX	*0.762*	*0.997*	*0.985*	1.000

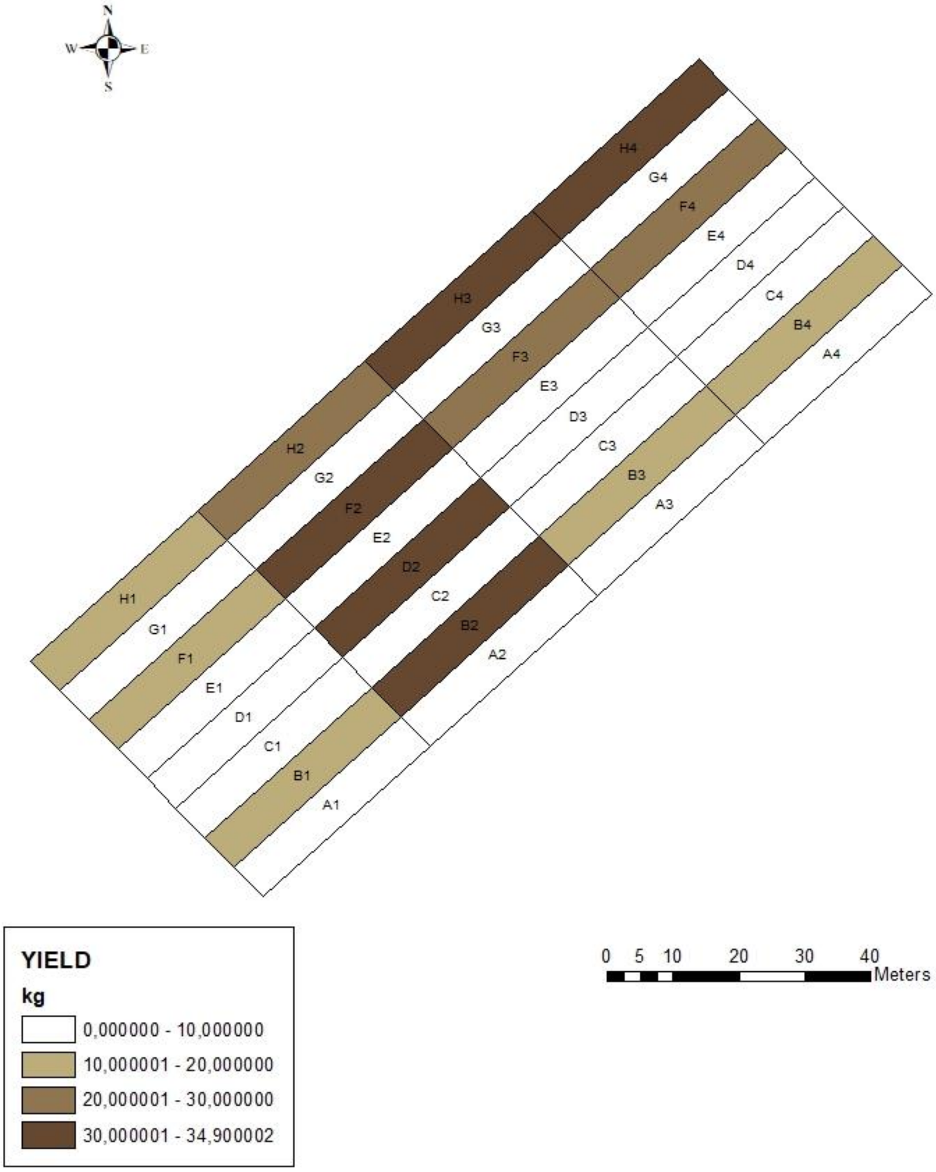

Figure 4.4: 'Lapins' yield map

4.2 Soil texture and EC

Soil EC mapping (Figure 4.5) revealed a slight variability of EC in the orchard as in 56% of it, EC varies between 2 and 15 dS/m. The biggest EC rates are recorded at the south -east part of the orchard, something that can be induced by the small inclination that the orchards of this area have for better water drainage. Moreover, the A and H groups of grid cells are flanked by other orchards being watered by the old method of flood and are always more humid. The first tree of every grid cell from A1 to H1 is planted in a distance of 6 m from the artificial drainage waterways that every orchard in the area has.

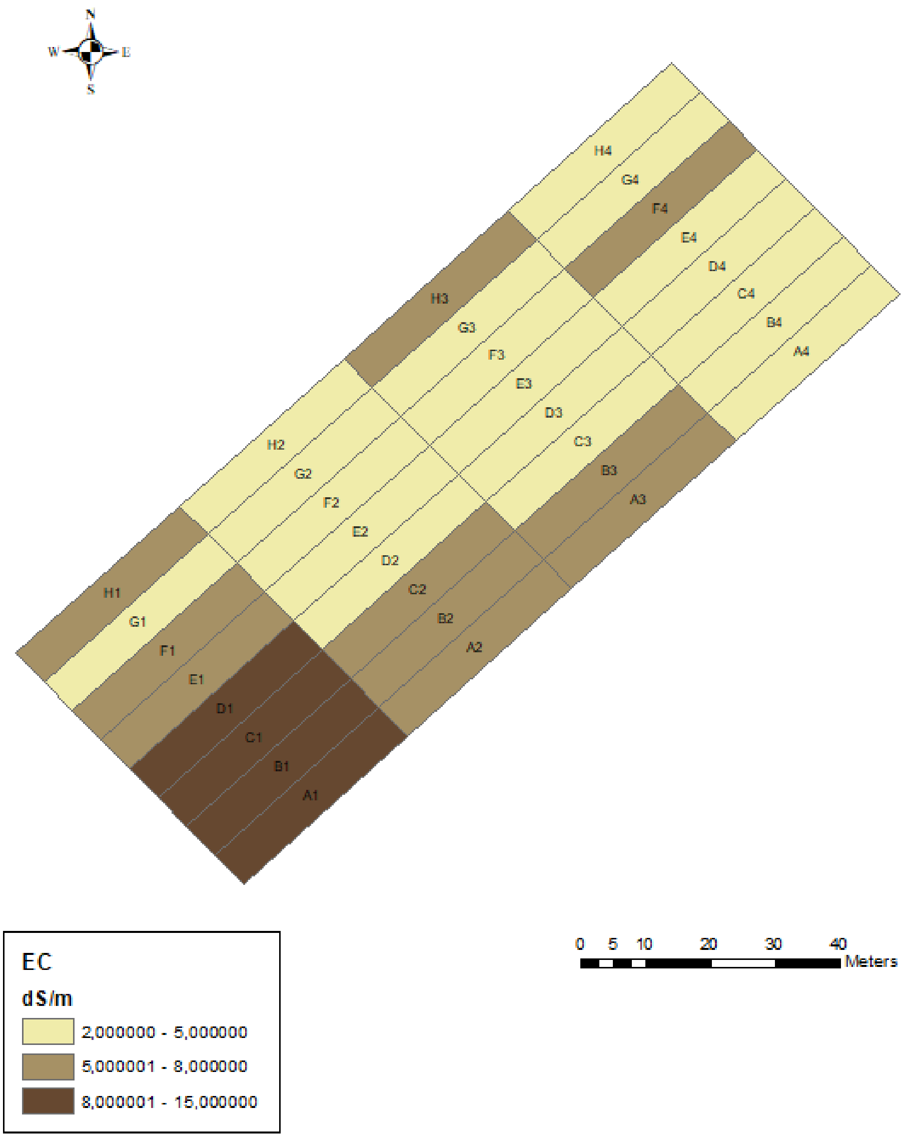

Figure 4.5: Soil EC mapping

Sand, silt and clay demonstrate different spatial variability (Figures 4.6-4.8). Pearson method has shown moderate and strong negative correlation between sand, silt and clay and no correlation between silt and clay. There is a relatively low correlation between EC, sand, silt and clay. (Table 4.5).

Clay percentage ranges between 28.5% and 32% and spreads almost equally in more than 65% of the orchard. The north-east and south-east parts of the orchard differ with a percentage of clay lower than 28.5% and only one grid cell demonstrated higher amount of clay (Figure 4.6).

Table 4.5. Correlations between soil EC and texture

	EC	Sand	Silt	Clay	Silt and Clay
EC	1.000	0.354	-0.341	-0.128	-0.354
Sand	0.354	1.000	-0.805	-0.579	-1.000
Silt	-0.341	-0.805	1.000	-0.017	0.805
Clay	-0.128	-0.579	-0.017	1.000	0.579
Silt and Clay	-0.354	-1.000	0.805	0.579	1.000

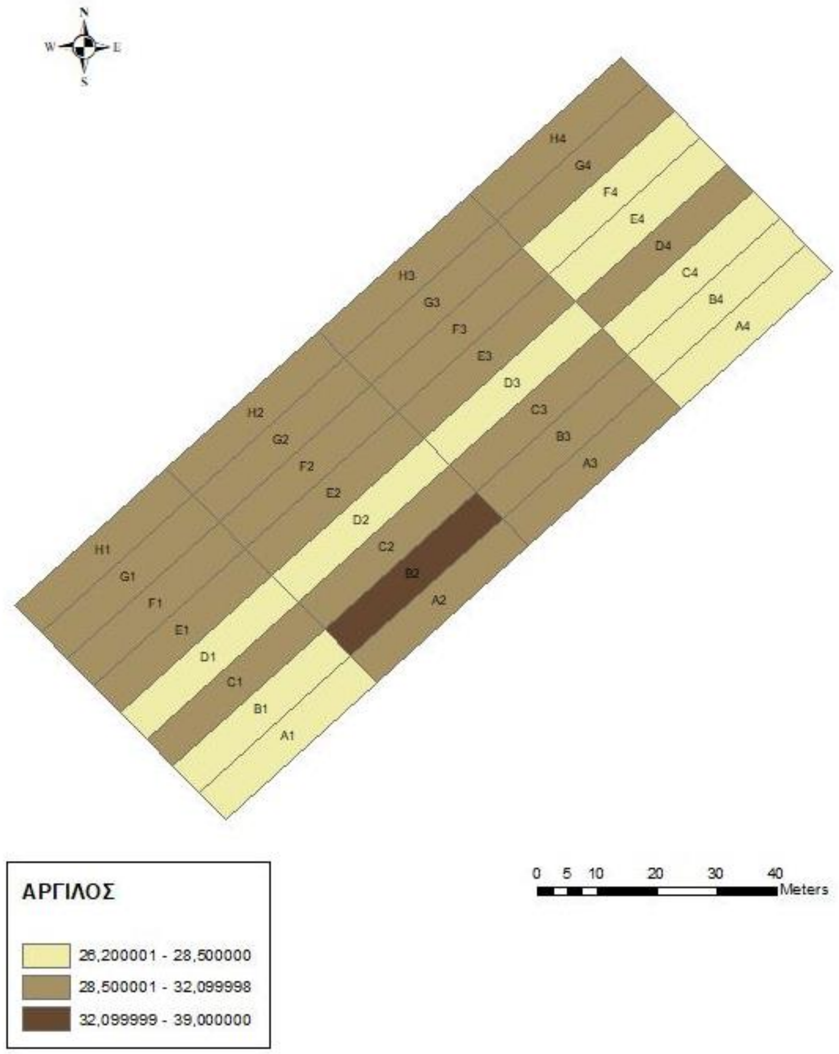

Figure 4.6: Soil texture in % of Clay

The central and north/north-east parts of the orchard display the bigger amount of silt percentages. Combined in the orchard, middle and high percentages of silt have been recorded, in percentage coverage of 75%. Only the south-west area has smaller concentrations of silt and some grid cells dispersed at the central and east parts of the orchard (Figure 4.7).

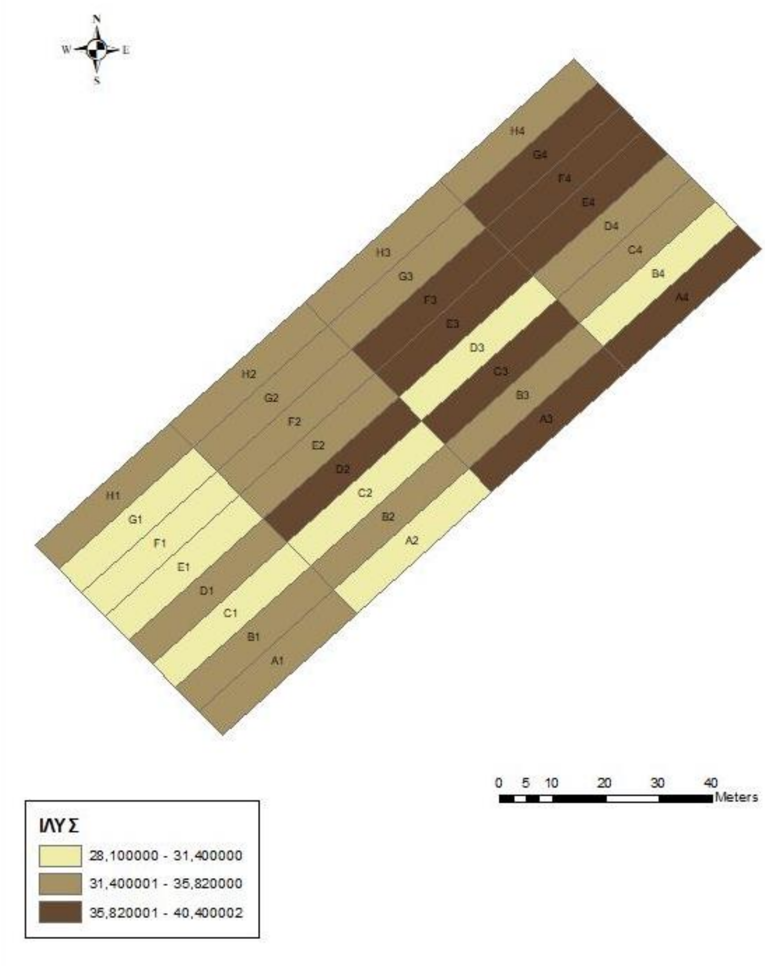

Figure 4.7: Soil texture in % of Silt

Most parts of the orchard have middle and high content of sand and only 18% of it has lower sand content, especially the grid cells directly after the middle of the orchard (A3-H3) (Figure 4.8).

Yield variability is not affected by soil texture or EC, as the Pearson method showed low negative correlation between yield EC and sand, low positive correlation with silt and no correlation with clay (Table 4.6).

Table 4.6. Correlations between yield, soil EC and soil texture

	EC	Sand	Silt	Clay	Silt and Clay
Yield	-0.155	-0.257	0.248	0.092	0.257

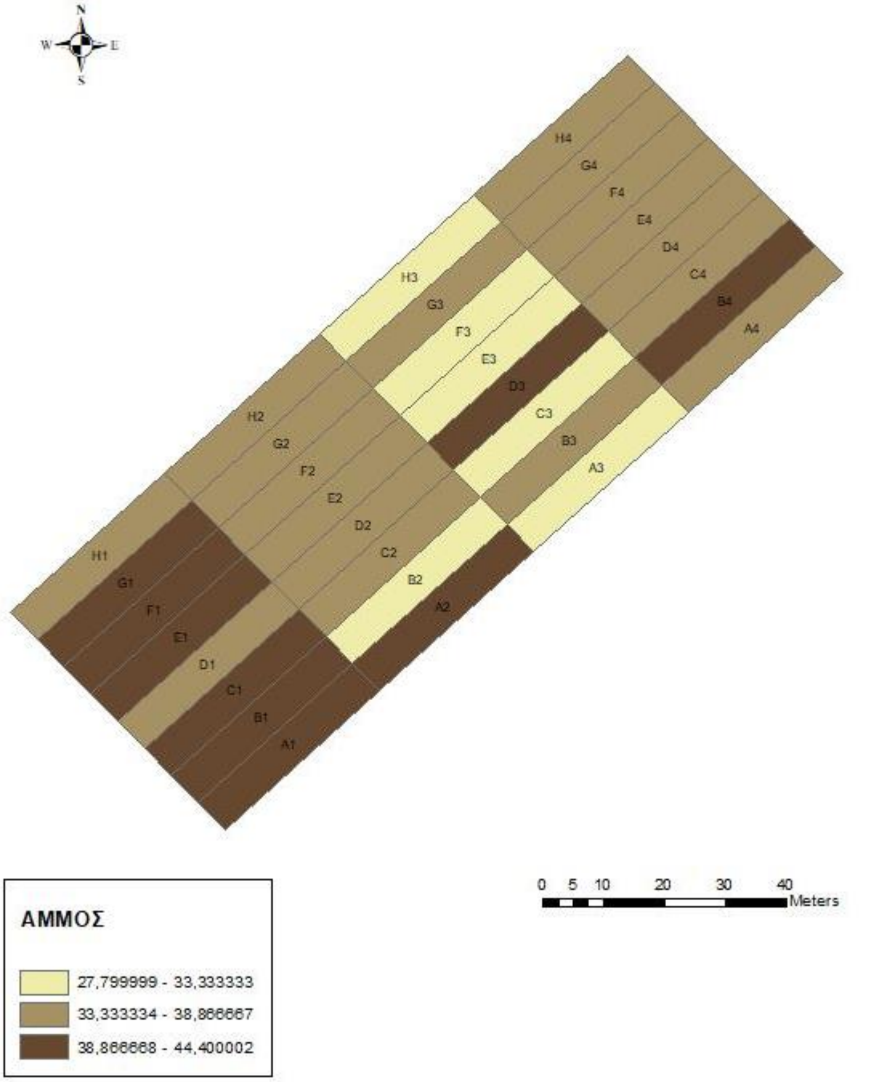

Figure 4.8: Soil texture in % of Sand

5 Conclusions and Discussion

5.1 Conclusions

Spatial variability of soil texture, EC and yield indicates that even small fields like the examined one can be separated to management zones. Variable rate application of inputs and regional differentiated cultivation practices may lead to a better, more sustainable and efficient farm management.

Soil texture and EC have a very small interference with cherry yield but yield and quality characteristics act upon each other for all three studied varieties.

For 'Early Bigi', fruit weight and size are altered depending on the cherry production volume per tree. On the other hand, in 'Bigarreau Burlat' fruit size and weight are not affected by the yield rather than each other in a positive correlation. 'Lapins' variety seems to have the biggest interdependence between quantity and quality, and quality characteristics themselves.

The results indicate that apart from spatial management zones, in cases that orchards are planted in a pattern like the studied one, every variety shall be managed particularly.

5.2 Future research proposals

The subject of this inquiry was to examine and record the existence, or not, of spatial variabilities in soil properties and yield in a sweet cherry orchard. Therefore, research was conducted with the implementation of methods related with precision agriculture, and could be broadened by including other factors which could affect yield. The employment of soil and foliar data is essential, because macro and micro-nutrients are key parts for the robustness and productivity of cherry trees. Combined soil and leaf analysis can lead to conclusions for the sufficiency of nutrients in the soil and their intake by cherry trees. Organic matter and soil humidity may affect cherry yield.

The recording and exploitation of meteorological data is a part of the analysis of the yield spatial variability. Weather conditions are fundamental for the productivity and overall functioning of cherry trees. The following harvesting period of May 2019, the examined varieties did not flourish together due to disorders upon their chilling and heat requirements.

The delineation in management zones and the long-term variable rate application of inputs based on the other collected data could explain and retrieve spatial variabilities in yield and soil.

Utilization of vegetation indexes and satellite data may assist the overall orchard management.

Rain-induced cracking is the most serious yield limitation for cherries (Knoche and Winkler, 2017) and if the canopy contains above 25% of cracked fruit the harvest becomes uneconomic (Looney 1985). The creation of an on-field fruit cracking detecting device could become an additional assistance. That would provide sufficient information whether the yield should be harvested or not and a useful estimation of the required harvest labor.

6 References

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6.2 Greek

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6.3 Internet

BeiDou Navigation Satellite System http://en.beidou.gov.cn/

CEMA aisbl - European Agricultural Machinery Industry Association: http://old.cema-agri.org/page/precision-farming-0

CC Orchards: http://ccorchards.com/wp-content/uploads/2018/01/Stages-of-Cherry-Development.pdf

ESA: https://gssc.esa.int/

ESA: https://gssc.esa.int/navipedia/index.php/Category:GLONASS

ESA: https://gssc.esa.int/navipedia/index.php/QZSS

GSA: https://www.gsa.europa.eu/

IAC: https://www.glonass-iac.ru/en/guide/beidou.php

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ISRO: https://www.isro.gov.in/irnss-programme

Quasi-Zenith Satellite (QZSS): http://qzss.go.jp/en/

US Congress (1997) https://www.congress.gov/bill/105th-congress/house-bill/725

Appendix

NDVI (Normalized Difference Vegetation Index):

Applied for measurements such as lead area indicator (LAI), biomass, chlorophyll concentrations, yield, fractional vegetation cover and rainfall.

$$\boldsymbol{NDVI = {}^{NIR - RED}\!/_{NIR + RED}}$$

NDSI (Normal Difference Soil Index):

Applied for soil features measurements.

$$\boldsymbol{NDSI = {}^{SWIR - NIR}\!/_{SWIR + NIR}}$$

NDWI (Normal Difference Water Index):

Applied for water features measurements.

$$\boldsymbol{NDWI = {}^{RED - SWIR}\!/_{RED + SWIR}}$$

NVMI (Normalized Vegetation Moisture Index):

$$\boldsymbol{NVMI = {}^{NIR - SWIR}\!/_{NIR + SWIR}}$$

SAVI (Soil-Adjusted Vegetation Index):

$$\boldsymbol{SAVI = \frac{NIR - RED}{NIR + RED + L} * (1 + L)}$$

SR or RVI (Simple Ratio or Ratio Vegetation Index):

$$\boldsymbol{RVI = {}^{NIR}\!/_{RED}}$$

GNDVI (Green Normalized Difference Vegetation Index):

$$\boldsymbol{GNDVI = {}^{NIR - GREEN}\!/_{NIR + GREEN}}$$

CVI (Chlorophyll Vegetation Index):

$$\boldsymbol{CVI = \frac{NIR}{GREEN} * \frac{RED}{GREEN}}$$

NBRI (Normalized Burn Ratio Index):

$$\boldsymbol{NBRI = {}^{NIR - MIR}\!/_{NIR + MIR}}$$

NIR= Near infrared wavelength

RED= Red wavelength

SWIR= Microwaves

L= Variable with values between 0 (total vegetation cover) and 1 (no vegetation cover)

GREEN= Green wavelength

MIR= Middle infrared wavelength