UAS Application in Agriculture:
A Review of Technologies Possible to Apply in Portugal

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Muito obrigado por tudo!
Vielen Dank für Alles!

"For what it's worth, it's never too late,
or in my case too early, to be whoever you want to be...
I hope you live a life you're proud of, and if you're not,
I hope you have the courage to start over again."
F. Scott Fitzegarld

Acknowledgments

The conclusion of this dissertation marks the end of a cycle. The last years have been full of experiences and special moments, but this would not be possible without the support of extraordinary people that I had the bless to have by my side.

At first, I would like to express a word of immense gratitude to my supervisor, dear Professor Jorge Silva who was always there when I needed him and gave me his encouragement, knowledge, and patience. He made all the work on this dissertation possible.

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Resumo

A população mundial tem vindo a crescer de forma muito significativa ao longo dos últimos anos. Consequentemente, também as necessidades e a procura de matérias-primas e bens têm aumentado. Neste contexto, a produção, de forma sustentável e nas quantidades necessárias, de bens alimentares é fonte de preocupação e estudo. Paralelamente tem-se verificado uma evolução bastante grande nos Veículos Aéreos Não Tripulados (UAV), quer ao nível do equipamento em si, quer ao dos cenários operacionais nos quais têm vindo a ser empregues.

Portugal apresenta-se como um país em que as atividades agropecuárias têm uma predominância muito grande no uso do solo disponível e na economia. No entanto, a falta de estudos e da implementação de novas tecnologias continuam a ser fatores limitativo ao aumento de produtividade, do aproveitamento sustentável dos recursos disponíveis e do valor que a agricultura agrega à balança comercial nacional.

O objetivo principal desta dissertação foi mostrar que é possível aplicar diversos novos métodos e técnicas, e mais especificamente UAV, ao cenário agrícola português. Para tal foi efetuada uma extensa pesquisa e selecionado um conjunto de estudos considerados relevantes e com potencial de serem adaptados e implementados em Portugal, englobando diversas culturas e atividades a elas associadas.

Com este propósito e depois de os estudos escolhidos terem sido expostos e cuidadosamente analisados foi possível perceber que a aplicação de UAS na agricultura portuguesa seria uma grande mais-valia na medida em que poderia conduzir à poupança de diversos milhões de euros tanto no aumento de produtividade, assim como na redução dos custos em químicos e testes de campo que se estão a tornar obsoletos. Poderá também contribuir para a poupança de recursos naturais, nomeadamente de água.

Palavras-chave

Agricultura de Precisão (PA); Veículos Aéreos Não Tripulados (UAV); Sistemas Aéreos Não Tripulados (UAS)

Resumo Alargado

Motivação

A população a nível mundial está a aumentar! Dados apontam que em aproximadamente 40 anos, a população mundial irá passar de 7,8 mil milhões de pessoas para mais de 10 mil milhões [1] (Figure 1). Enquanto isto acontece uma série de outros problemas como as alterações climáticas, a urbanização e a superexploração agrícola devem contribuir para perdas consideráveis de terras aráveis, o que causará sérios problemas ao equilíbrio produção-consumo [2].

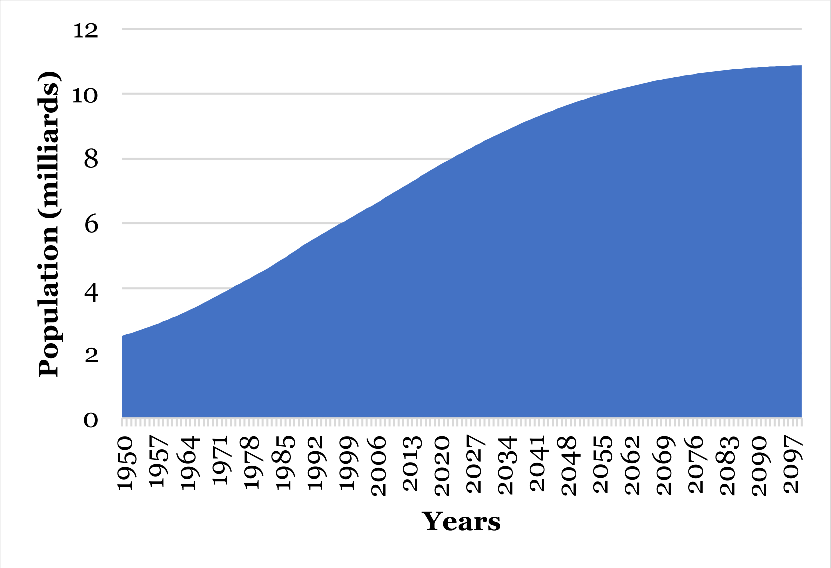

Figure 1 – Evolução Populacional – Fonte: elaboração própria com base em [1]

Face a este cenário, alguma coisa tem de ser feita para prevenir esta possível crise generalizada de recursos em geral e em particular alimentares.

Paralelamente a este aumento populacional, assiste-se a consideráveis progressos tecnológicos que nos podem trazer benefícios, como é o caso dos UAV, que são cada vez mais populares e que podem ser usados ao serviço das explorações agrícolas. Em particular, durante a última década tem-se verificado um aumento exponencial no fabrico, uso e popularidade dos UAS. A contribuir para isto há um fator muito importante: versatilidade! Um UAV pode ser empregado numa grande variedade de áreas e de muitas formas, tendo muitos formatos e tamanhos diferentes. Alguns dos exemplos mais comuns são:

- Apoio ofensivo/defensivo em zonas de guerra;

- Vigilância e controlo de multidões;
- Acesso a áreas difíceis e/ou perigosas para seres humanos;
- Entrega de mercadorias;
- Suporte agrícola;
- Etc.

Tendo em conta os atuais problemas ao nível da produção de alimentos e com o evidentes aumentos da população, verifica-se que o uso de UAS para propósitos agrícolas tem crescido significativamente nos últimos anos. No entanto, em Portugal o uso deste tipo de sistemas ainda está por implementar de forma efetiva e a agricultura ainda está aquém da produtividade e eficiência desejáveis [3].

Face ao exposto coloca-se a questão: O que é que poderia ser feito para corrigir este problema e tornar a agricultura portuguesa numa indústria competitiva com a ajuda de UAS?

Objeto e Objetivos

Com base na questão colocada no fim da Motivação, considerou-se o objeto de estudo desta dissertação o uso de UAS na agricultura e a sua possível aplicação em Portugal.

Quanto aos objetivos principais foram considerados os seguintes:

1. Perceber a situação atual do setor agrícola português, o uso de veículos aéreos neste (independentemente da tipologia) e por último perceber como os UAS em geral funcionam;
2. Perceber de que forma os *drones* poderiam ser usados em Portugal para melhorar a produtividade, mas também a rentabilidade da agricultura em diversos aspetos distintos.

Metodologia

O desenvolvimento desta dissertação começou com uma extensiva revisão bibliográfica. O principal objetivo nesta fase foi reunir o máximo de informação possível sobre agricultura e UAS. Quando se trata de agricultura, o foco foi como a terra é usada nos dias de hoje, as principais culturas e quanta influência esta tem na economia portuguesa tanto em termos monetários, bem como no emprego e no desenvolvimento em geral. Por outro lado, foi necessário adquirir mais conhecimento sobre os diferentes tipos e classificações dos UAV, os seus elementos e a legislação aplicada às suas operações. Ao longo do trabalho estes aspetos serão apresentados de forma mais extensiva.

Depois desta análise, o caso de estudo será montado. Este contemplará uma série de diferentes estudos feitos em países que parecem ser de grande interesse pelo autor desta dissertação. Está prevista a realização de uma análise dos equipamentos usados, metodologia, taxa de sucesso e semelhanças com Portugal. Os resultados serão então analisados e possíveis formas de implementação das soluções propostas por estes estudos em Portugal serão estudadas. No fim uma explicação sobre as possíveis implementações será providenciada (Figure 2).

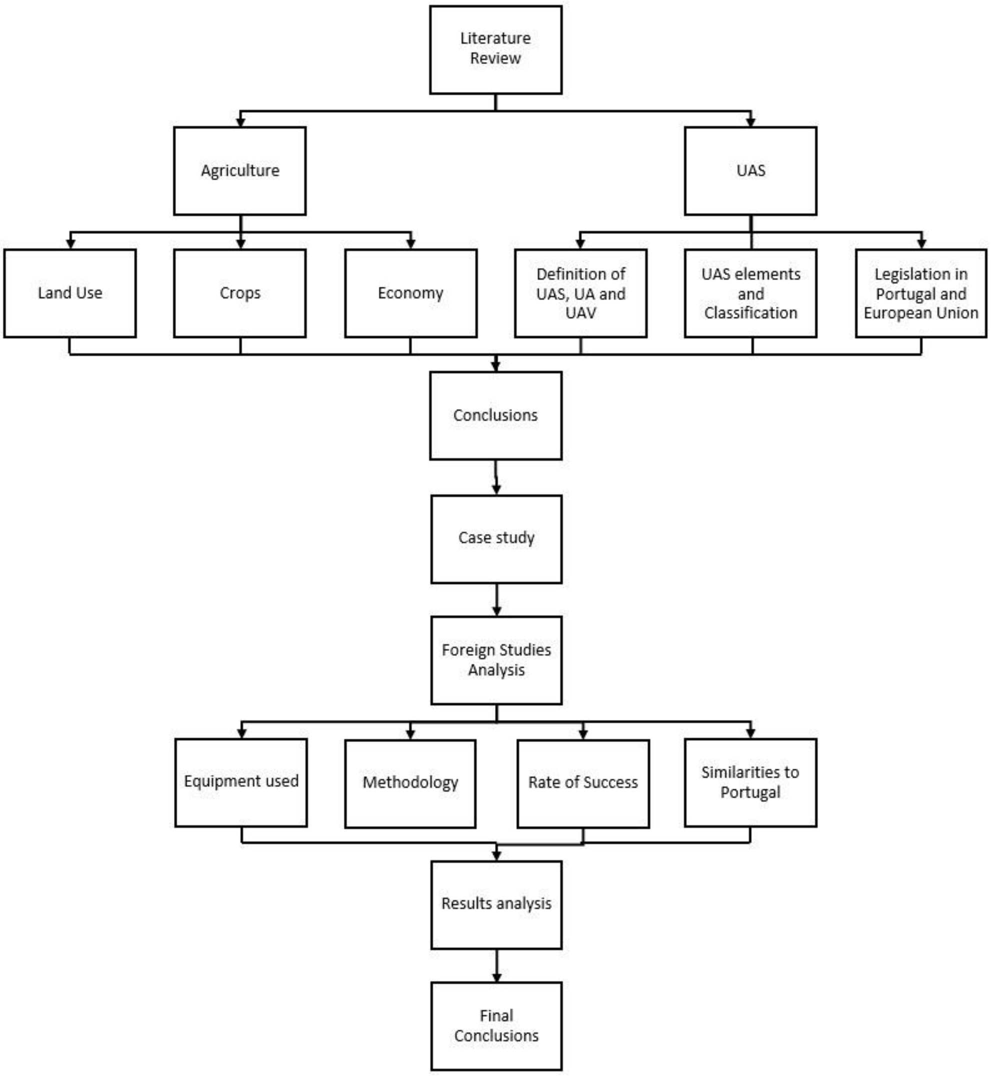

Figure 2 – Fluxograma da Metodologia – Fonte: elaboração própria

Análise e Resultados

Através da realização deste estudo foi possível obter diversos resultados e conclusões importantes que permitiram obter uma resposta à questão inicial e aos dois objetivos iniciais propostos.

Em primeiro lugar, foi possível perceber que a agricultura é uma atividade comum e tradicionalmente presente em todo o território nacional, com uma diversidade bastante grande de produtos que vão desde os produtos frescos, passando pela vinha, azeitona e cereais. Sem surpresa a atividade pecuária está também muito presente. Apesar disso a situação não é ideal e os métodos utilizados são, em geral, ainda algo antiquados. Como tal um aumento na produção e produtividade seria muito bem-vindo. A elevada idade média dos agricultores (64 anos) é também um fator preocupante que poderá causar alguma resistência quando se trata da implementação de novas tecnologias neste setor. No entanto, com o aumento substancial da presença de sociedades empresariais na agricultura poderá aqui haver uma luz ao fundo do túnel. São geralmente este tipo de empreendimentos que, com o objetivo de aumentar as receitas e reduzir despesas, possuem a vontade e a capacidade de investir em novas tecnologias e tirar o melhor partido das mesmas.

No que se refere aos UAS foi possível perceber como estes operam e de que forma todos os seus diversos componentes trabalham de forma harmoniosa em conjunto para executar missões complexas. Naturalmente apesar de serem equipamentos altamente versáteis e eficazes também apresentam desvantagens, dependendo muito do teatro de operações apresentado. Apesar da legislação ter evoluído de forma muito eficaz e rápida nos últimos anos concluiu-se que esta é ainda algo limitativa, nomeadamente em Portugal onde a utilização em grandes propriedades agrícolas e de forma massiva é limitada por legislação que o autor considera obsoleta, antiquada e dissuasora de investimentos significativos que visam a aplicação desta tecnologia.

Passando ao segundo objetivo, foi feito primeiro uma prospeção daquilo que eventualmente se encontra a ser feito na agricultura portuguesa, ou que tenha sido feito num passado recente, com o recurso a aeronaves tripuladas ou UAV. Para tal foram realizadas pesquisas em bases de dados online, contactadas empresas nacionais neste ramo e estabelecido contacto com pessoas que eventualmente pudessem dar algum tipo de informação relativamente a este cenário. Infelizmente, isto produziu resultados escassos e desanimadores tendo-se concluído que na grande maior parte das culturas não há nenhuma, ou quase nenhuma, aplicação deste tipo de tipo tecnologia, tendo até uma das empresas contactadas terminado recentemente as suas atividades no ramo da agricultura. Há, no entanto, alguns pequenos sinais encorajadores de empresas pequenas e recentemente fundadas que procuram dinamizar este tipo de atividade.

Posteriormente, foi efetuada uma pesquisa profunda a nível internacional daquilo que recentemente se tem feito ao nível do uso de UAS na agricultura. Esta pesquisa teve em conta as culturas presentes em Portugal e as características do terreno. Para uma maior facilidade de análise dos diversos estudos optou-se por dividir a pesquisa de acordo com as culturas mais importantes: cereais, árvores de fruto, oliveiras, batatas e tomate, e vinha. Foi também reservado um capítulo para um aspeto bastante importante quando se trabalha com grandes quantidades de dados: a gestão adequada dos mesmos. Os temas abordados variam bastante, mas há alguns aspetos gerais que se mantêm para todas, ou quase todas, as culturas: gestão do uso de pesticidas, gestão dos recursos hídricos disponíveis, monitorização em tempo real do cultivo e a deteção atempada de infestantes. Tendo em conta as pesquisas realizadas e depois de se procurar perceber de que modo estas se poderiam aplicar no cenário português concluiu-se que há bastante espaço para que tal aconteça, desde que haja vontade e recursos disponibilizados para um investimento adequando. Trata-se de um potencial aumento de receitas (aumento da quantidade produzida) e diminuição de despesas (menos fertilizantes e pesticidas) na ordem de vários milhares, e até eventualmente milhões, de euros. Foi também possível perceber que uma melhor gestão dos sistemas de rega, mais adequada à real necessidade das plantas poderia significar uma grande poupança de água, um bem essencial à atividade agrícola.

Abstract

The world population has been significantly growing over the last years. Consequently, also the needs and search of raw materials and goods has been increasing. In this context, the production, in a sustainable way and in the needed quantities, of food is a source of concern and study. At the same time a big evolution in the Unmanned Aerial Vehicles (UAV) has been verified, both in terms at the level of the equipment, and the operational scenarios where they have been used.

Portugal presents itself as a country where the agriculture and livestock activities have a very big predominance in the use of the available soil and the economy. However, the lack of studies and implementation of new technologies keeps on being a limiting factor to the increase of productivity, sustainable use of the available resources and of the value that agriculture adds to the national trade balance.

The main objective of this dissertation was to show that it is possible to apply several new methods and techniques, more specifically UAVs, to the Portuguese agricultural scenario. For this extensive research was carried out and a set of studies with the potential to be adapted and implement in Portugal were selected, encompassing different cultures and activities associated with them.

After the chosen studies had been exposed and carefully analysed it was possible to perceive that the application of UAS' in Portuguese agriculture would be a great added value insofar as it could lead to savings of several million euros both in increasing productivity, as well as in reducing costs with chemicals and field tests that are becoming obsolete. The saving of limited natural resources, namely water is also a very important factor.

Keywords

Precision Agriculture (PA), Unmanned Aerial Vehicle (UAV); Unmanned Aerial Systems (UAS)

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List of Acronyms

ACL	Autonomous Control Level
ALE	Alentejo
ALG	Algarve
ALO	Avión Ligero de Observación
ANAC	Autoridade Nacional da Aviação Civil
BMS	Battery Management System
BRLOS	Beyond Radio Line-of-Sight
CC	Canopy Cover
CH	Canopy Height
CN	Cabeça Normal
CPB	Colorado Potato Beetle
CRB	Complete Randomized Block
CSWI	Crop Water Stress Index
CV	Canopy Volume
DGAV	Direção Geral de Alimentação e Veterinária
DGPS	Differential Global Positioning Systems
ESC	Electronic Speed Controller
EU	European Union
ExG	Excess Green vegetation index
ET	evapotranspiration
FAO	Food and Agriculture Organization
FOV	Field of View
fps	Frames per second
FPV	First Person View
GAV	Gross Added Value
Gb	Gigabyte
GCP	Ground Control Points
GCS	Ground Control Station
GDP	Gross Domestic Product
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GNDVI	Green Normalized Difference Vegetation Index
GRP	Gabinete de Relações Públicas
GRRI	Green-Red Ratio Index
GRVI	Green-Red Vegetation Index
GSM	Global System for Mobile Communication
HLB	Huanglongbing
HTP	High-Throughput Phenotyping
ICADS	International Center for Agro-Informatics and Sustainable Development
ICAO	International Civil Aviation Organization
ICE	Internal Combustion Engine
INTA	Instituto Nacional de Técnica Aeroespacial
IoT	Internet of Things
ISR	Intelligence Gathering, Surveillance and Reconnaissance
IVV	Instituto da Vinha e do Vinho

L&R	Launch & Recovery
LAI	Leaf Area Index
LMEM	Linear Mixed Effect Model
LOS	Line of Sight
LST	Land Surface Temperature
MAGRAMA	Ministry of Agriculture and Fisheries, Food and Environment
MGRVI	Modified GRVI
MSAVI	Modified SAVI
MTOW	Maximum Take-Off Weight
NDRE	Normalised Difference Red-Edge
NDVI	Normalized Difference Vegetation Index
NGBDI	Normalized Green-Blue Difference Index
NGRDI	Normalized Green-Red Difference Index
NIR	Near-Infrared
OSAVI	Optimized SAVI
PCR	Polymerase Chain Reaction
RGB	Red, Green and Blue
RGBVI	Red-Green Blue Vegetation Index
RLOS	Radio Line-of-Sight
RMSE	Root Mean Squared Error
RO	Ribatejo e Oeste/ Romania
RPA	Remotely Piloted Aircraft
RW	Reclaimed Water
SAP	Systemanalyse Programmentwicklung
SAU	Superfície Agrícola Utilizada
SAVI	Soil Adjusted Vegetation Index
SD	Standard Deviation
SIFT	Scale Invariant Feature Transform
SSWM	Site-Specific Weed Management
STOL	Short Take-Off and Landing
SVM	Support Vector Machine
TIR	Thermal Infrared
TW	Transfer Water
TYLCV	Tomato Yellow Leaf Curl Virus
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UBI	Universidade da Beira Interior
USA	United States of America
USAF	United States Air Force
UTA	Unidade de Trabalho Ano
VDVI	Visible-band Difference Vegetation Index
VIs	Vegetation Indices
VTOL	Vertical Take-Off and Landing
WDI	Water Deficit Indicator
WS	Water Stress
WSP	Water Sensitive Papers
WW	Well-Watered

Chapter 1 – Introduction

1.1 Motivation

World population is increasing! Data appoints that in approximately 40 years, the planet's population is expected to grow from 7,8 milliards to over 10 milliards [1] (Figure 3). While this happens, a serious of other problems, such as climate change, urbanization, and agricultural overexploitation, are set to contribute to considerable arable land losses, which will cause serious problems to the production-consumption balance [2].

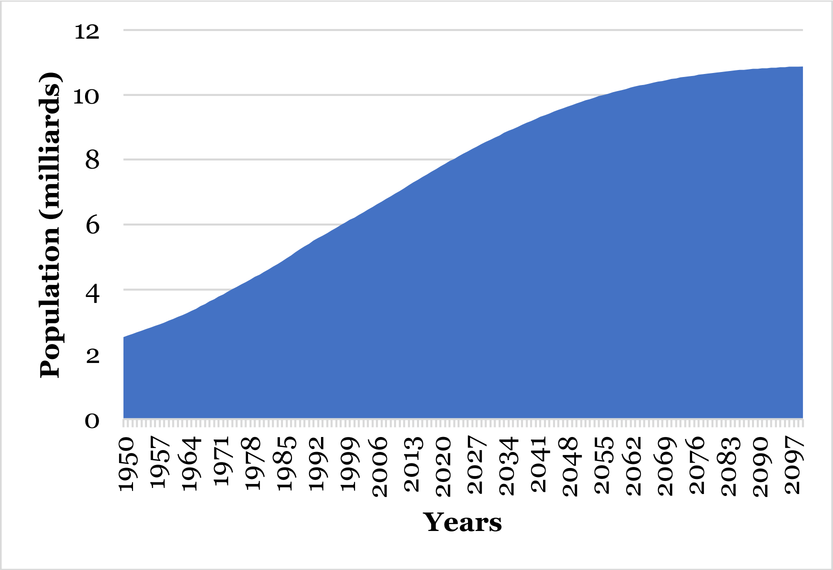

Figure 3 – Population Evolution – Source: own elaboration based on [1]

Something needs to be done to prevent a possible generalized resource and food crisis!

At the same time, in the last years, the use of Unmanned Aircraft Systems (UAS), has become more and more popular. Particularly during the last decade an exponential growth in their manufacturing, usage and popularity has been experienced. Contributing to that is a very important factor: versatility! UAV can be employed in a great variety of areas and in many ways and sizes. Some of the most common examples are:

- Offensive/defensive support in a warzone;
- Crowd vigilance and control;
- Access to difficult and/or dangerous areas for a human being;
- Package delivery;
- Agricultural support;

- Etc.

Considering the food problems described and with the population keeping on growing path the use of UAS for agricultural purposes has significantly increased in the last years. However, in Portugal the use of this type of systems is yet to be implemented in an effective way and agriculture is quite unproductive [3].

This leads to the question: What could possibly be done to correct this issue and turn the Portuguese agriculture into a competitive industry with the help of UAS? This works aims to answer this question in the best way possible and with the resources available.

1.2 Object and objectives

The object of this dissertation is the use of UAS in the agriculture and its possible use in Portugal.

The objective (first one) of this work is firstly to understand the current situation of the Portuguese agriculture sector, the use of any form of air vehicle in it and how UAS in general work.

After this, the goal (second objective) is to understand if and how the use of drones could be possibly used in Portugal to improve the productivity but also the profitability of farming in some different ways.

1.3 Methodology

The development of this dissertation began with an extensive literature review. The main goal during this phase was to gather as much information as possible about agriculture and UAS. When it comes to agriculture, the focus was on how the land is used nowadays, the main crops cultivated and how much influence it has on the Portuguese economy, both in terms of money but also on the employment and development. On the other hand, it was necessary to acquire more knowledge about the different types and classifications of UAV's, their elements and the legislation applied to their operations. Further in this work these aspects will be more extensively presented.

After this the case study will be put together. This will consist of a series of different studies made in foreign countries that seemed to be of great interest by the author. An analysis on the equipment used, methodology, rate of success and similarities to Portugal is set to be performed. The results will then be analysed and possible ways of implementing any of the solutions proposed by these studies in the Portuguese scenario will be studied. At the end detailed explanations about the possible implementations will be provided (Figure 4).

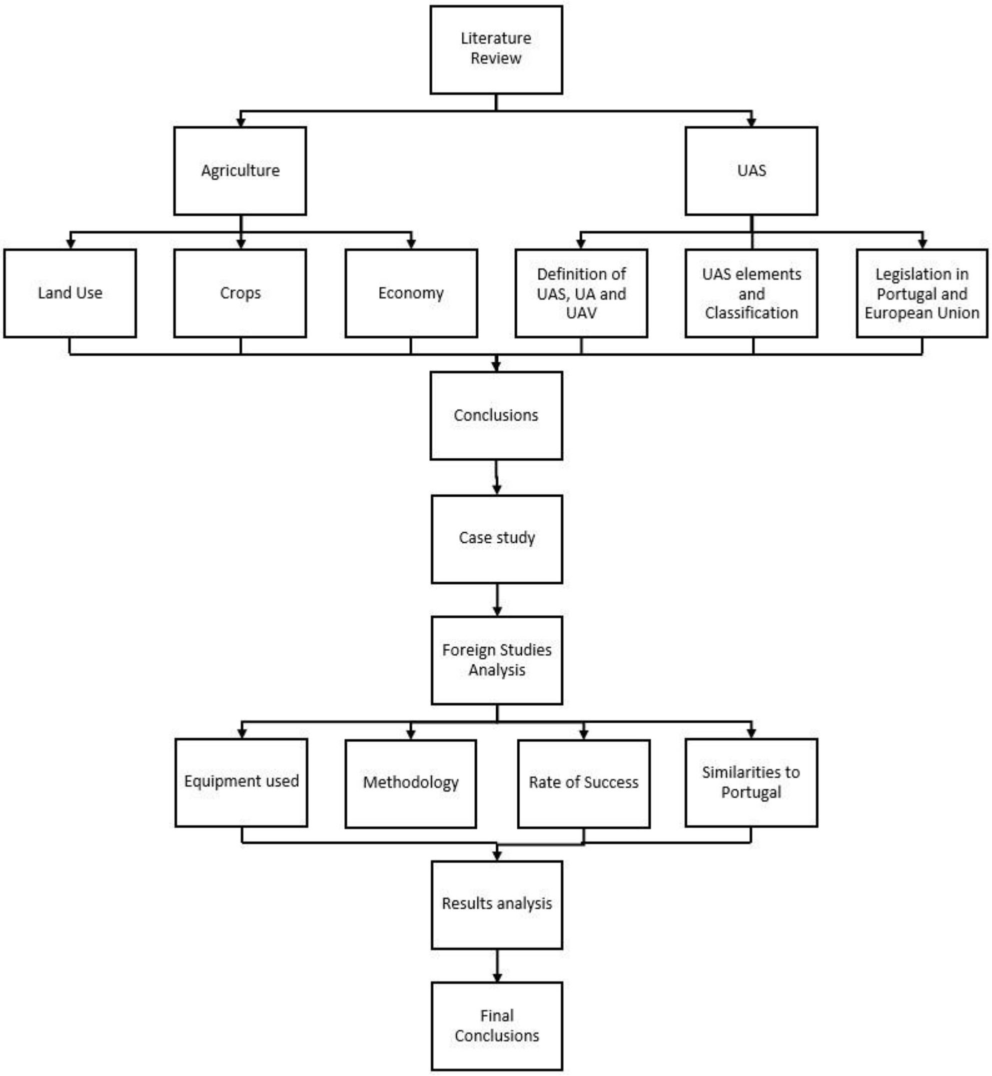

Figure 4 – Methodology Flowchart – Source: own elaboration

1.4 Dissertation Structure

This dissertation starts with the introduction where the object and objectives are exposed as well as the methodology and the full structure.

Chapter 2 is dedicated to the literature review of the agricultural situation in Portugal, where the main aspects of it will be described.

Chapter 3 focuses on the literature review of UAS: how they are classified, composed and the legislation applied to their operations.

Chapter 4 will present the selected studies made about the successful use of UAS in agricultural situations in foreign countries.

Chapter 5 aims to present a parallel of these studies to Portuguese scenarios and their viability.

Chapter 6 is the conclusion, where all the results obtained will be exposed, as well as some concluding remarks and propositions for future works.

Chapter 2 – Relevant Agriculture Information

2.1 Introduction

To be able to talk about the impact UAS have and could have it is important first to know some general information about agriculture. Given the complexity and coverage of this theme in this chapter will only be presented the data that was considered most relevant. An overview of the current situation in Portugal will also be made. The case of the Portuguese archipelagos, Azores and Madeira, will be neglected because the size of their territories did not seem interesting enough for the study that will be conducted.

2.2 Precision Agriculture

Precision Agriculture: one of the most important concepts for this dissertation.

When it comes to farming, the use of technology in agriculture can be characterized as Precision Agriculture (PA), as defined by Bongiovanni and Lowenberg-DeBoer (2004): “the use of information technology in all agricultural production practices, whether to adapt the use of inputs to achieve the desired results in specific areas, or to monitor the results achieved in agricultural plantations” [4][1]. Basically, any use of technology to detect problems, avoid diseases, increase production, etc. can be considered as Precision Agriculture. It allows the farmer to get better results using the resources available. It enables savings that can be as much as thousands or even millions of Euros, as will be shown later in this document.

2.3 Phytopharmaceuticals/Pesticides and Fertilizers

To increase production a series of chemicals are used in agriculture. These are divided into two different categories which depends on their main use:

- Phytopharmaceuticals, also known as pesticides, used to kill weeds and insect infestations and to cure/prevent diseases;
- Fertilizers, used to give the plants essential components for their growing.

2.3.1 Phytopharmaceuticals/Pesticides

With the food increase demand there is usually also an increase in the number of pesticides used [4]. Phytopharmaceuticals, mostly know as pesticides, are products used for pest

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[1] [4], pp. 210

control and creation of a nearly ideal environment for the crop growth. There are mainly 2 different ways of applying pesticides in a crop field:

- Terrestrial: in this case the product is sprayed using ground vehicles and paths within the field are needed and since this application is done very closely to the plant the risk of drift is greatly reduced. But this is a relatively slow process which reduces the area that can be sprayed;
- Aerial: in this case the product is sprayed using aircraft systems, which can be manned or unmanned. This is a very fast process that does not need any paths withing the crop. But the risk of drift is increased because of the larger distance between the plants and the applying system.

As said, there is always a risk of drift when spraying the cultures. As shown in Figure 5, the drift of pesticides occurs mainly in aerial applications and happens because of the dynamic environments that are experienced in the real world, for example change of wind speed and direction. This represents a huge problem and can result in "extensive damage, such as overlapping pesticides, non-sprayed regions and contamination of rivers, forests and inhabited areas" [4][2].

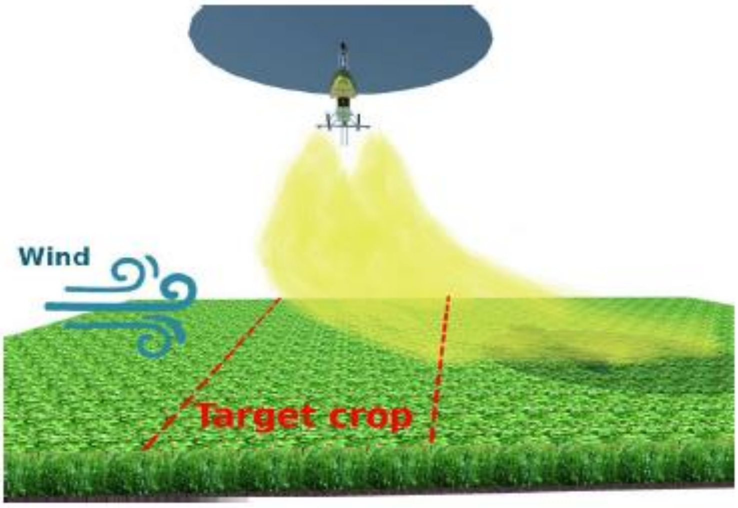

Figure 5 – Drift of Airsprayed Substances in dynamic environments – Source: [4]

2.3.2 Fertilizers

On the other hand, there are other substances used in agriculture: the fertilizers. These are used to supply the plant with nutrients and can be natural or synthetic. They are used since ancient times in the form of human or animal dejects, rotten plants, among others. More

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[2] [4], pp. 212

recently, during the industrialization era, other procedures to get more powerful, cheap and easy to transport fertilizers have been developed.

In Portugal according to [5], in 2017 were sold around 8 thousand tons of pesticides. According to their type, approximately 51,2% were fungicides, 23,2% herbicides, 11,6% insecticides and 14% others. The most common active substance was sulphur, present in 20,7% of the products sold.

2.3.3 Limitations

In both cases, pesticides and fertilizers, ecological problems always appear since they can be very harmful to the environment. The industrial produced chemicals are very powerful and if not correctly employed the amount of damage done can last for decades. For example, it is speculated that the use "Agent Orange" by the United States military during the Vietnam War is still affects local population almost 50 years after. So, a lot of precautions need to be taken and the area of use must be well defined and the operators well protected [6].

Because of the huge number of substances that can be used as pesticides the European Union currently has established an online data base, accessible to everyone, about pesticides. On this data base it is possible to get detailed information about every aspect of the pesticide used in the EU. It also contains vital information about the active substances: state of approval, category, countries in which the approval is valid, toxicological information, reports about the substance, among other details. In the case the substance is not approved it cannot be used in any country.

2.4 Land use

Currently the land is used in many ways, more specifically in Portugal and the EU. In this subchapter will be exposed the way it is distributed, what type of economic identities are involved in its exploration, the most usual crops and how the economy in general benefits from agriculture.

When analysing the agriculture in Portugal some definitions need to be considered [3]:

- Agricultural producer: the juridical and economical responsible of the exploration. This is the physical or juridical person in whose name or on account of the exploration produces, it gets the benefits and supports eventual loses. It is the producer who takes all the important decisions with economical and financial impact, such as the production system that will be used, the investments, the loans, etc.

- Legal nature of the producer: the legal personality of the legal and economical responsible of the exploration. This can take some different forms:
    - Singular person: when the producer is a physical person, independently if he has record of the economic activity in the tax authority ;
    - Society: when it is a moral entity, constituted according the commercial and civil codes in a joint stock company, limited liability company, general partnership, limited partnership, sole proprietorship or other;
    - Wasteland: fields owned and managed by local communities which, in this case, and according to the Portuguese law have the right to use them;
    - Other forms: includes the Portuguese State and public persons, when the exploration is submitted to central or local administration, directly or through an organism (e.g., agrarian station, agricultural school, public institutions, public companies, forest administrations, barracks, prisons, etc), as well as private entities, such as cooperatives, associations, foundations, Private Social Solidarity Institutions, seminaries, convents, monasteries, private schools, among others.

2.4.1 Land Type, Distribution and Main Crops

The land is distributed differently according to the different parts of the country and the size of the farms vary in size and ownership. Two other concepts that are very important to understand before going more deeply into the data are the Utilized Agricultural Area, in Portuguese Superfície Agrícola Utilizada (SAU) and the Cabeça Normal (CN), which is a unit of measurement used in livestock production where a conversion table is used, and an adult bovine specimen equals to 1 CN. Furthermore, the Portuguese acronym will be used on this dissertation.

The Agricultural Area, as defined by the Food and Agriculture Organization (FAO) includes arable land, permanent crops and permanent pastures. It is usually expressed as a percentage of the total land area but can also be expressed in hectare (ha):

- Arable land: “land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for arable land are not meant to indicate the amount of land that is potentially cultivable” [7][3];

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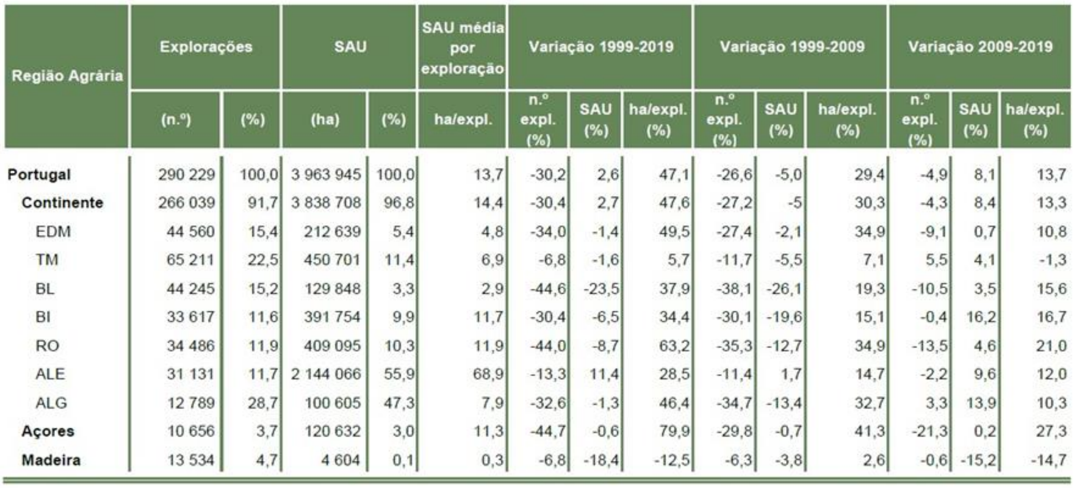
[3] [7], pp. 1

- Permanent crops: “land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber” [7][4];
- Permanent pastures: “land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land)” [7][5].

As it is possible to see in Table 1, the SAU in 2019 was approximately 3,964 million hectares, which represents around 43% of the Portuguese territory, representing an increase of about 2,6% in the last 20 years. This number is higher than the EU28 (SAU represents 39%). But even though the SAU has increased the number of explorations has suffered a diminution of about 30,2% while the number of ha/exploration has increased 47,1%. This means that there are fewer owners but the farms have gone bigger. Currently the average SAU per exploration is approximately 13,7ha. Something that is interesting to notice as well is that 55,9% of the SAU is located in the ALE (Alentejo) region.

Table 1 - SAU distribution along the Portuguese territory - Source: [3]



Região Agrária	Explorações		SAU		SAU média por exploração	Variação 1999-2019			Variação 1999-2009			Variação 2009-2019		
	(n.º)	(%)	(ha)	(%)	ha/expl.	n.º expl. (%)	SAU (%)	ha/expl. (%)	n.º expl. (%)	SAU (%)	ha/expl. (%)	n.º expl. (%)	SAU (%)	ha/expl. (%)
Portugal	290 229	100,0	3 963 945	100,0	13,7	-30,2	2,6	47,1	-26,6	-5,0	29,4	-4,9	8,1	13,7
Continente	266 039	91,7	3 838 708	96,8	14,4	-30,4	2,7	47,6	-27,2	-5	30,3	-4,3	8,4	13,3
EDM	44 560	15,4	212 639	5,4	4,8	-34,0	-1,4	49,5	-27,4	-2,1	34,9	-9,1	0,7	10,8
TM	65 211	22,5	450 701	11,4	6,9	-6,8	-1,6	5,7	-11,7	-5,5	7,1	5,5	4,1	-1,3
BL	44 245	15,2	129 848	3,3	2,9	-44,6	-23,5	37,9	-38,1	-26,1	19,3	-10,5	3,5	15,6
BI	33 617	11,6	391 754	9,9	11,7	-30,4	-6,5	34,4	-30,1	-19,6	15,1	-0,4	16,2	16,7
RO	34 486	11,9	409 095	10,3	11,9	-44,0	-8,7	63,2	-35,3	-12,7	34,9	-13,5	4,6	21,0
ALE	31 131	11,7	2 144 066	55,9	68,9	-13,3	11,4	28,5	-11,4	1,7	14,7	-2,2	9,6	12,0
ALG	12 789	28,7	100 605	47,3	7,9	-32,6	-1,3	46,4	-34,7	-13,4	32,7	3,3	13,9	10,3
Açores	10 656	3,7	120 632	3,0	11,3	-44,7	-0,6	79,9	-29,8	-0,7	41,3	-21,3	0,2	27,3
Madeira	13 534	4,7	4 604	0,1	0,3	-6,8	-18,4	-12,5	-6,3	-3,8	2,6	-0,6	-15,2	-14,7

Figure 6 and Figure 7 represent the distribution of farms and their size along the territory. By analysing them it is possible to see that in the Northern region there are more explorations, but their average size is smaller than the ones in the South. There, the average size is far bigger, but the number of farms is greatly reduced. One important factor that influences this is the demography of the Portuguese territory. Many people live in the North of the country while in the South the demographic pressure is greatly reduced, and the territory is also extremely good for big scale farming. This happens because the Alentejo is

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[4] [7], pp. 1
[5] [7], pp. 1

mainly constituted by plains, where the usage of industrial machines is more interesting and economically viable.

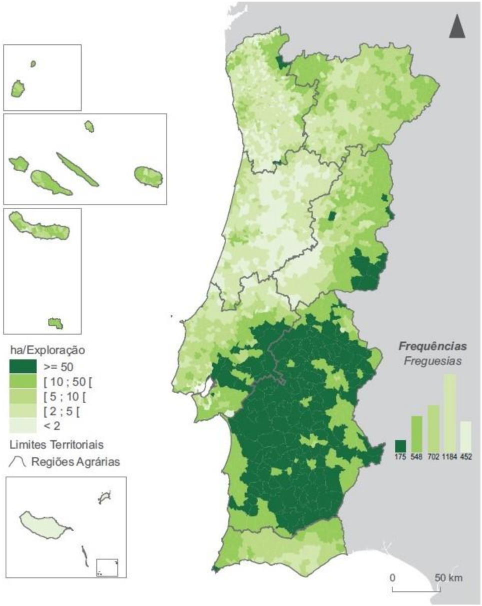


Figure 6 - Average Dimension of farms - Source [3]

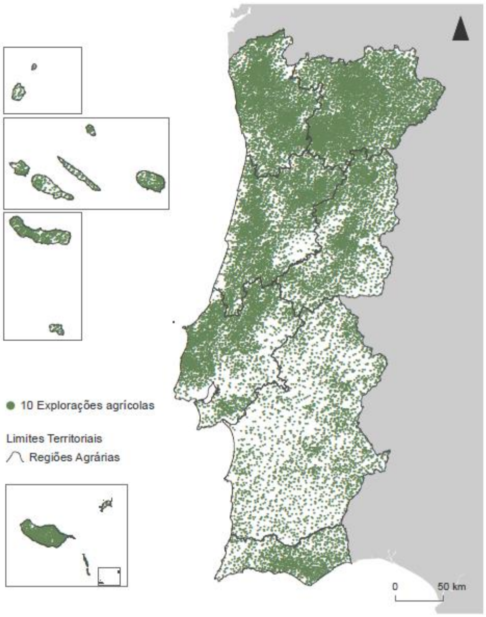


Figure 7- Agricultural Explorations - Source: [3]

When it comes to the type of cultures that occupy more space in Portugal their areas and percentage of total land use can be seen in Figure 8.

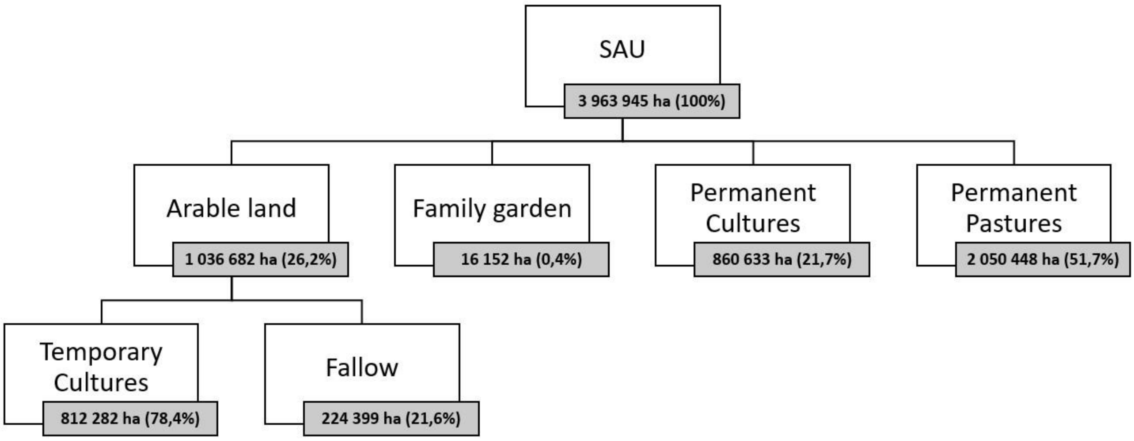


Figure 8 - Most common type of cultures in Portugal - Source: own elaboration based on [3] and [5]

By subdividing these main categories into subcategories, the most relevant when it comes to temporary cultures are:

- Cereals for grain: 234 599 ha (8,8%);
- Temporary "prados" and silage cultures: 484 180 ha (59,6%).

And when it comes to permanent cultures the most relevant subcategories are:

- Nuts: 228 707 ha (26,6%);
- Olives: 377 234 ha (43,8%), with around 98,9 % of them for oil production;
- Vineyard: 173 254 ha (20,1%), with around 98,7% for vine production.

Even if these are the type of crops that, aside from pastures, cover the most part of the land available it does not mean that they are the ones with the most goods produced. For example, the cultivation of tomato for industrial purposes only represents a total area of 14 470 ha, but it is one of the crops with the most quantity produced with around 1 226 828 tones. Also, fruit trees like apple and pear, respectively with areas of 14 577 ha and 12 504 ha, and productions of 263 961 t and 161 353 t, are quite relevant.

In general, the amount of agriculture goods the country produces do not fully fulfills the need of its population (85%) [8]. However, the scenario presents itself as bad when it comes to cereals, essential for a serious of industries (animal rations, bakery, beer, etc.). Only 18,6% of the needed cereals are currently produced [5]. Currently there is a production of around 63 799 ha (2 419 780 ton) of silage maize and 54 638 ha (801 290 ton) of silage oats for example. These values need a substantial increase to satisfy the country's needs.

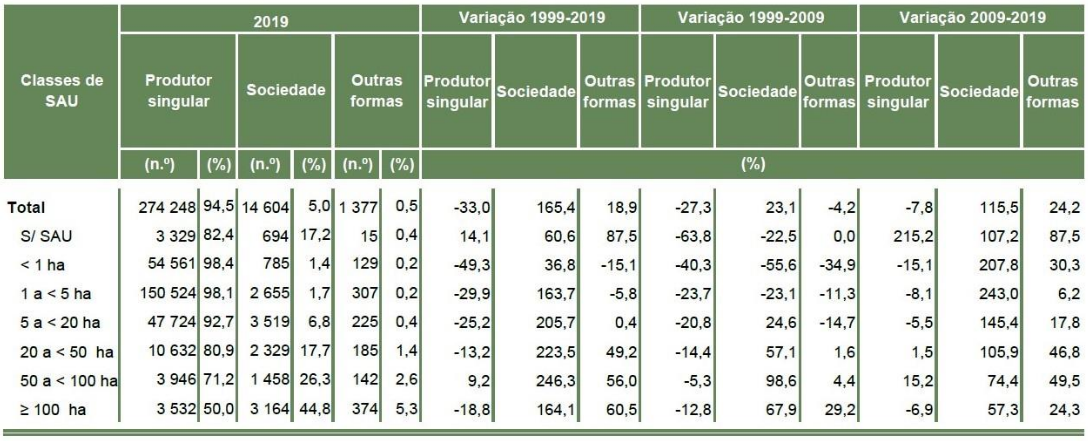
2.4.2 Economy

In Table 2 is represented the legal nature of the producer, considering different classes of SAU. By analysing it, it shows up that:

- 94,5% of the explorations are still in control of single persons;
- 5,0% is in the hands of corporations;
- 0,5% are managed in other ways.

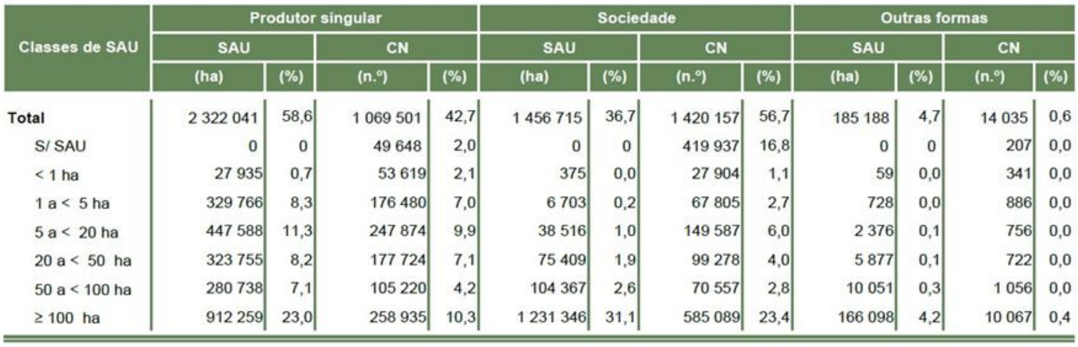
5,0% might appear not to be a lot but compared to 2009 this represents an increase of 115,5% and they are also almost the main responsible for the big farms (>100 ha) with about 44,8%. The average size of the farms controlled by societies is around 99,7 ha [5]. And, even if they might only represent 5,0% of the number of explorations, they control around 36,7% of the total SAU and 56,7 % of the animal creation (Table 3).

Table 2 - SAU and CN according to the legal nature of the producer - Source: [3]



Classes de SAU	2019						Variação 1999-2019			Variação 1999-2009			Variação 2009-2019		
	Produtor singular		Sociedade		Outras formas		Produtor singular	Sociedade	Outras formas	Produtor singular	Sociedade	Outras formas	Produtor singular	Sociedade	Outras formas
	(n.º)	(%)	(n.º)	(%)	(n.º)	(%)	(%)								
Total	274 248	94,5	14 604	5,0	1 377	0,5	-33,0	165,4	18,9	-27,3	23,1	-4,2	-7,8	115,5	24,2
S/ SAU	3 329	82,4	694	17,2	15	0,4	14,1	60,6	87,5	-63,8	-22,5	0,0	215,2	107,2	87,5
< 1 ha	54 561	98,4	785	1,4	129	0,2	-49,3	36,8	-15,1	-40,3	-55,6	-34,9	-15,1	207,8	30,3
1 a < 5 ha	150 524	98,1	2 655	1,7	307	0,2	-29,9	163,7	-5,8	-23,7	-23,1	-11,3	-8,1	243,0	6,2
5 a < 20 ha	47 724	92,7	3 519	6,8	225	0,4	-25,2	205,7	0,4	-20,8	24,6	-14,7	-5,5	145,4	17,8
20 a < 50 ha	10 632	80,9	2 329	17,7	185	1,4	-13,2	223,5	49,2	-14,4	57,1	1,6	1,5	105,9	46,8
50 a < 100 ha	3 946	71,2	1 458	26,3	142	2,6	9,2	246,3	56,0	-5,3	98,6	4,4	15,2	74,4	49,5
≥ 100 ha	3 532	50,0	3 164	44,8	374	5,3	-18,8	164,1	60,5	-12,8	67,9	29,2	-6,9	57,3	24,3

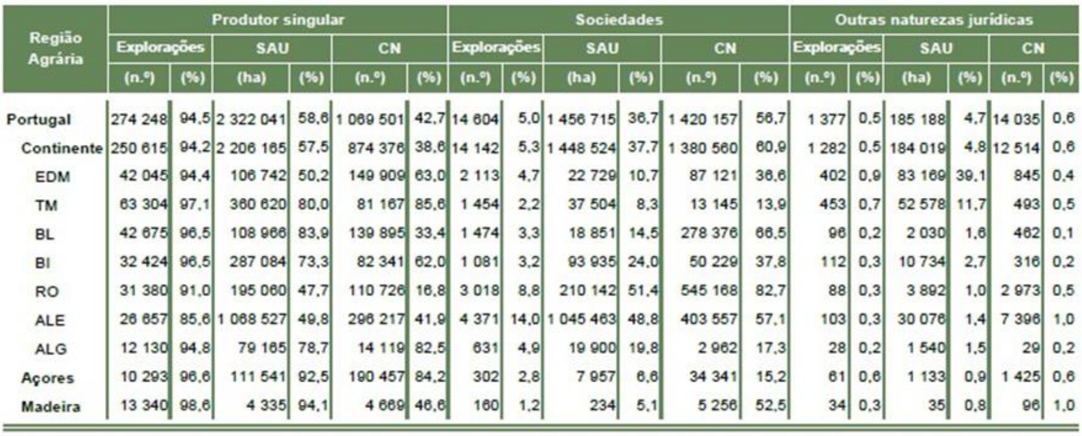
Table 3 - Legal Nature of the producer, by SAU class - Source: [3]



Classes de SAU	Produtor singular				Sociedade				Outras formas			
	SAU		CN		SAU		CN		SAU		CN	
	(ha)	(%)	(n.º)	(%)	(ha)	(%)	(n.º)	(%)	(ha)	(%)	(n.º)	(%)
Total	2 322 041	58,6	1 069 501	42,7	1 456 715	36,7	1 420 157	56,7	185 188	4,7	14 035	0,6
S/ SAU	0	0	49 648	2,0	0	0	419 937	16,8	0	0	207	0,0
< 1 ha	27 935	0,7	53 619	2,1	375	0,0	27 904	1,1	59	0,0	341	0,0
1 a < 5 ha	329 766	8,3	176 480	7,0	6 703	0,2	67 805	2,7	728	0,0	886	0,0
5 a < 20 ha	447 588	11,3	247 874	9,9	38 516	1,0	149 587	6,0	2 376	0,1	756	0,0
20 a < 50 ha	323 755	8,2	177 724	7,1	75 409	1,9	99 278	4,0	5 877	0,1	722	0,0
50 a < 100 ha	280 738	7,1	105 220	4,2	104 367	2,6	70 557	2,8	10 051	0,3	1 056	0,0
≥ 100 ha	912 259	23,0	258 935	10,3	1 231 346	31,1	585 089	23,4	166 098	4,2	10 067	0,4

Also, important to note that, as shown in Table 4, it is in the Ribatejo e Oeste region (RO) and ALE region where the companies have more influence with 51,4% and 48,8% of the total SAU, respectively controlled by them.

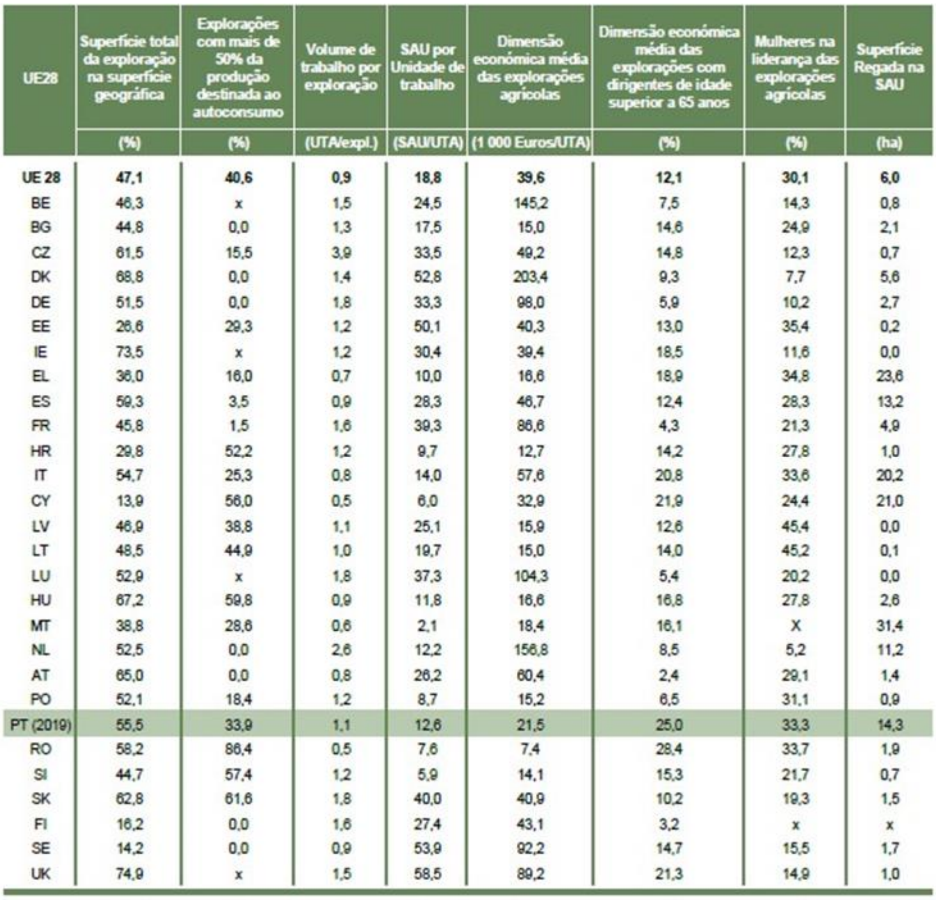
Table 4 - Number of explorations, SAU and CN, according to the legal nature of the producer and the region - Source: [3]



Região Agrária	Produtor singular						Sociedades						Outras naturezas jurídicas					
	Explorações		SAU		CN		Explorações		SAU		CN		Explorações		SAU		CN	
	(n.º)	(%)	(ha)	(%)	(n.º)	(%)	(n.º)	(%)	(ha)	(%)	(n.º)	(%)	(n.º)	(%)	(ha)	(%)	(n.º)	(%)
Portugal	274 248	94,5	2 322 041	58,6	1 069 501	42,7	14 604	5,0	1 456 715	36,7	1 420 157	56,7	1 377	0,5	185 188	4,7	14 035	0,6
Continente	250 615	94,2	2 206 165	57,5	874 376	38,6	14 142	5,3	1 448 524	37,7	1 380 560	60,9	1 282	0,5	184 019	4,8	12 514	0,6
EDM	42 045	94,4	106 742	50,2	149 909	63,0	2 113	4,7	22 729	10,7	87 121	36,6	402	0,9	83 169	39,1	845	0,4
TM	63 304	97,1	360 620	80,0	81 167	85,6	1 454	2,2	37 504	8,3	13 145	13,9	453	0,7	52 578	11,7	493	0,5
BL	42 675	96,5	108 966	83,9	139 895	33,4	1 474	3,3	18 851	14,5	278 376	66,5	96	0,2	2 030	1,6	462	0,1
BI	32 424	96,5	287 084	73,3	82 341	62,0	1 081	3,2	93 935	24,0	50 229	37,8	112	0,3	10 734	2,7	316	0,2
RO	31 380	91,0	195 060	47,7	110 726	16,8	3 018	8,8	210 142	51,4	545 168	82,7	88	0,3	3 892	1,0	2 973	0,5
ALE	26 657	85,6	1 068 527	49,8	296 217	41,9	4 371	14,0	1 045 463	48,8	403 557	57,1	103	0,3	30 076	1,4	7 396	1,0
ALG	12 130	94,8	79 165	78,7	14 119	82,5	631	4,9	19 900	19,8	2 962	17,3	28	0,2	1 540	1,5	29	0,2
Açores	10 293	96,6	111 541	92,5	190 457	84,2	302	2,8	7 957	6,6	34 341	15,2	61	0,6	1 133	0,9	1 425	0,6
Madeira	13 340	98,6	4 335	94,1	4 669	46,6	160	1,2	234	5,1	5 256	52,5	34	0,3	35	0,8	96	1,0

When talking about the productivity and comparing it to the European scenario the Portuguese one is quite low compared to the EU28. The average money every worker generates in the EU28 is approximately 39,6 thousand euros which is 1,8 times more than in Portugal (21,5 thousand euros). So, an increase in this is required. Important to notice that *Unidade de Trabalho Ano* (UTA) measure unit that equals to the work done by 1 worker employed in a full-time regime for one year, so 1 UTA = 240 work days x 8 hours/day (Table 5).

Table 5 - Some important structural indicator of EU28 - Source: [3]



UE28	Superfície total da exploração na superfície geográfica	Explorações com mais de 50% da produção destinada ao autoconsumo	Volume de trabalho por exploração	SAU por Unidade de trabalho	Dimensão económica média das explorações agrícolas	Dimensão económica média das explorações com dirigentes de idade superior a 65 anos	Mulheres na liderança das explorações agrícolas	Superfície Regada na SAU
	(%)	(%)	(UTA/expl.)	(SAU/UTA)	(1 000 Euros/UTA)	(%)	(%)	(ha)
UE 28	**47,1**	**40,6**	**0,9**	**18,8**	**39,6**	**12,1**	**30,1**	**6,0**
BE	46,3	x	1,5	24,5	145,2	7,5	14,3	0,8
BG	44,8	0,0	1,3	17,5	15,0	14,6	24,9	2,1
CZ	61,5	15,5	3,9	33,5	49,2	14,8	12,3	0,7
DK	68,8	0,0	1,4	52,8	203,4	9,3	7,7	5,6
DE	51,5	0,0	1,8	33,3	98,0	5,9	10,2	2,7
EE	26,6	29,3	1,2	50,1	40,3	13,0	35,4	0,2
IE	73,5	x	1,2	30,4	39,4	18,5	11,6	0,0
EL	36,0	16,0	0,7	10,0	16,6	18,9	34,8	23,6
ES	59,3	3,5	0,9	28,3	46,7	12,4	28,3	13,2
FR	45,8	1,5	1,6	39,3	86,6	4,3	21,3	4,9
HR	29,8	52,2	1,2	9,7	12,7	14,2	27,8	1,0
IT	54,7	25,3	0,8	14,0	57,6	20,8	33,6	20,2
CY	13,9	56,0	0,5	6,0	32,9	21,9	24,4	21,0
LV	46,9	38,8	1,1	25,1	15,9	12,6	45,4	0,0
LT	48,5	44,9	1,0	19,7	15,0	14,0	45,2	0,1
LU	52,9	x	1,8	37,3	104,3	5,4	20,2	0,0
HU	67,2	59,8	0,9	11,8	16,6	16,8	27,8	2,6
MT	38,8	28,6	0,6	2,1	18,4	16,1	X	31,4
NL	52,5	0,0	2,6	12,2	156,8	8,5	5,2	11,2
AT	65,0	0,0	0,8	26,2	60,4	2,4	29,1	1,4
PO	52,1	18,4	1,2	8,7	15,2	6,5	31,1	0,9
PT (2019)	55,5	33,9	1,1	12,6	21,5	25,0	33,3	14,3
RO	58,2	86,4	0,5	7,6	7,4	28,4	33,7	1,9
SI	44,7	57,4	1,2	5,9	14,1	15,3	21,7	0,7
SK	62,8	61,6	1,8	40,0	40,9	10,2	19,3	1,5
FI	16,2	0,0	1,6	27,4	43,1	3,2	x	x
SE	14,2	0,0	0,9	53,9	92,2	14,7	15,5	1,7
UK	74,9	x	1,5	58,5	89,2	21,3	14,9	1,0

In 2019 there were approximately 4,913 million employed people in the country, with 2,701 million of them employed in the sector of agriculture, cattle raising, hunting, forestry and fishing. Another important fact is that only 13,1% of the Portuguese producers make agriculture their primary job (17,0% in the UE28) and around 2/3 of the farmers dedicate less than 50% of their labour time to it [3]. Also, their average age is 64,3 years, the highest of the UE28, where the average is 58,0 years (Figure 9).

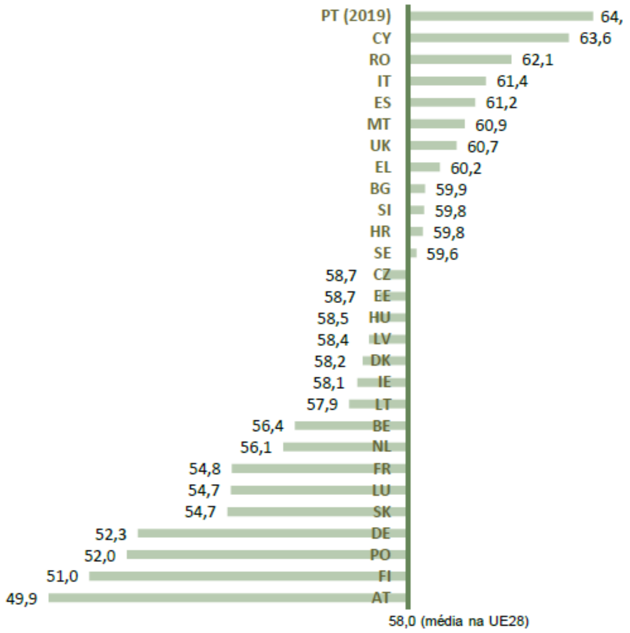


Figure 9 - Average age of a farmer in the EU28 - Source: [3]

When it comes to the money generated by agriculture provisional data appoint that the agricultural activities represent a total of 2,4% of the Portuguese Gross Domestic Product (GDP). And the Gross Added Value (GVA) by agriculture is located at approximately 3 008,20 million euros. The intermediary consumption represents around 4 825,30 million euros, and total production was 7 833,50 million euros. In the last 40 years the GAV has suffered from a relative stagnation (Figure 10). Even though, when it comes to food goods the difference between the exportations and importations is still negative (-3 981,30 €).

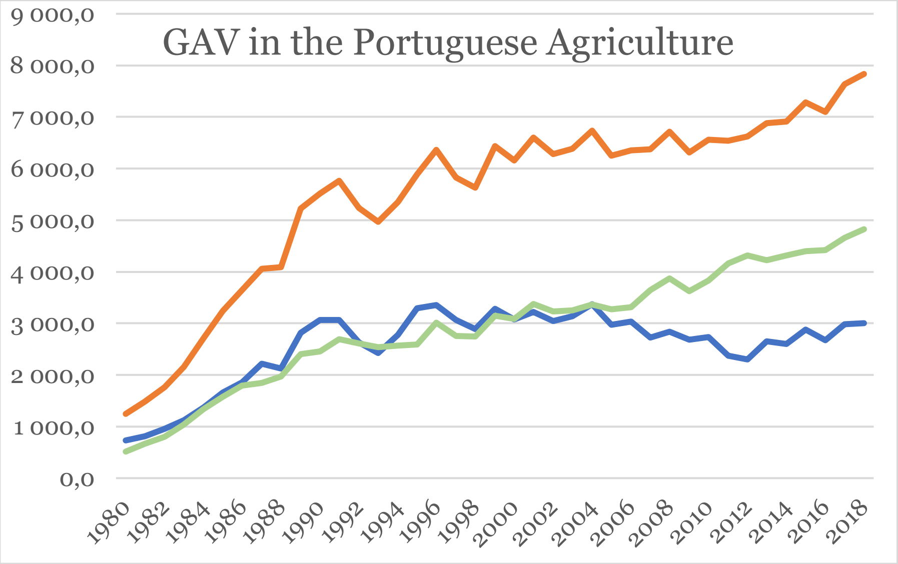


Figure 10 – Evolution of the Portuguese GAV in milliards of €, (orange) production of the agricultural sector, (green) intermediate consumption, (blue) GAV – Source: [9]

3.3 Conclusion

The information gathered in this chapter provided a valuable insight of the current situation of the agriculture in Portugal. They will be of great help further in this dissertation when analysing the study cases.

As shown, Portugal is a country with a strong agricultural tradition and a very diverse range of products. However, the situation is not ideal and a substantial increase in production and productivity would be more than welcome. The average age of the farmers is also a problematic factor and possibly leads to some resistance when it comes to implementing new technologies in the process. It is possible to see that the interest of societies to profit from agriculture in Portugal has hugely increased in the last years. Usually, they are the ones that with the willingness and capability to invest in new technology and take the best out of them.

Chapter 3 – UAS

3.1 Introduction

Over the last two decades it is possible to see that the discussion about UAS and the development and implementation of this technology has seen a great increase. However, this type of technology is nothing new to the aeronautical/aerospace sector. In fact, it has been used since many years with different types of applications and complexity. Indeed, the first UAV was built in 1916, only 13 years after the first ever successful flight by the Wright brothers [10].

During these early years of aviation, the development of this kind of technologies was still in a very embryonic phase as all there were also big revolutions occurring. The first jet planes appeared, innovative materials started to be introduced, a greater study on aerodynamics was in development, among so many others [11].

Later in the decade of 1950-1960 some new developments appeared, and the USAF started to see some real potential in this kind of equipment. First as moving targets for realistic combat trainings and later as surveillance aircrafts [12]. This turned out to be a catalyser for what would soon follow. In the 1970's developers of some countries such as Israel and the United States revolutionized the concept of the UAV. They started to use smaller, slower, and cheaper aircraft while giving them small video camaras that allowed the operator to receive photos of the ground under the aircraft in real time [13]. A new era for the UAS was born!

Further in the late 90's and early 2000's it is possible to see the appearance of big, versatile, and extremely well-equipped aircrafts mainly for military purposes. The most know examples are the General Atomics MQ-1 "Predator", its "son" the General Atomics MQ-9 "Reaper" and the Northrop Grumman RQ-4 "Global Hawk". Three high altitude surveillance aircrafts, with the first also being used as "surgical killers".

With all the possibilities opened by these developments it is not surprising that sooner or later it would begin to be thought as an incredible possibility for the commercial and Civil market. And when it comes to the use of UAS in agriculture FAO states that "Applications of UAVs [unmanned aerial vehicles] are only limited by our imagination" [14][6].

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[6] [14], pp. 6

3.2 Definition of UA, UAV and UAS

According to the International Civil Aviation Organization (ICAO), the term UA is defined as "An Aircraft which is intended to operate with no pilot on board" [15][7].

On the other hand, the same identity (ICAO) defines UAV in [16][8] as "An unmanned aerial vehicle is a pilotless aircraft, in the sense of Article 8 of the Convention on International Civil Aviation, which is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place (ground, another aircraft, space) or programmed and fully autonomous". The most usual term for them is "Drones".

The terms UAV and UAS are quite similar, however, ICAO defines UAS as "An aircraft and its associated elements which are operated with no pilot on board" [15][9]. So, basically the UAV is the aircraft, while the UAS is the whole systems which comprises the aircraft, the command-and-control equipment, the communication data link, the human element and the payload.

In [17] it is shown in a very clear way some of the different ways an UAV can be classified based on many different characteristics: MTOW and Ground Impact Risk, Operational Altitude and Mid-air Collision Risk, Autonomy, Ownership and can also have different military classifications.

According to [18] there are mainly three types of UAS: fixed wing, VTOL (which could also be STOL), and hybrid platforms. Their main characteristics are the following ones:

- Fixed wing: it is the more conventional, similar to a manned aircraft. Easy to build with "high capability and durability" [18]. These are very popular because of "their ease of deployment" [18]. They "are often capable of long flight durations that can maximize their time in the air and their range" [18][10] which makes them very attractive for military missions where they are used for ISR and weapons delivery. However, it brings up some logistical problems because they usually need a runway or a catapult to be launched, and a net or capture cable to be recovered. These problems disappear when it is a micro-UAV;
- VTOL/STOL: Usually these consist of multirotor aircraft similar in design to helicopters or tiltrotors. These UAVs are easy to fly because they usually have an autopilot installed and their endurance is usually "approximately 25 minutes, with

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[7] [15], pp. (x)
[8] [16], pp. B-6
[9] [15], pp. (x)
[10] [18], pp. 59

some claiming to fly for as much as 90 minutes" [18][11]. Because of their hovering capabilities they can be used in proximity monitoring and are also very easy to deploy creating less problems in the L&R process;

- Hybrid platforms: this is a new concept emerging in the last years in the industry. It consists of an aircraft that tries to combine the advantages of the fixed wing and the VTOL/STOL platforms. It aims to make the aircraft able to do VTOL operations and to fly to the target area using a fixed wing configuration. Further studies are actually being conducted to make this a viable concept.

3.3 UAS elements

As stated previously there are many different elements that are part of the UAS, the UAV being only a small piece of it. In these subchapters will be shown what elements they are, how do they integrate with each other and a light overview of their production process. In Figure 11 it is possible to see how an UAS splits into its different elements.

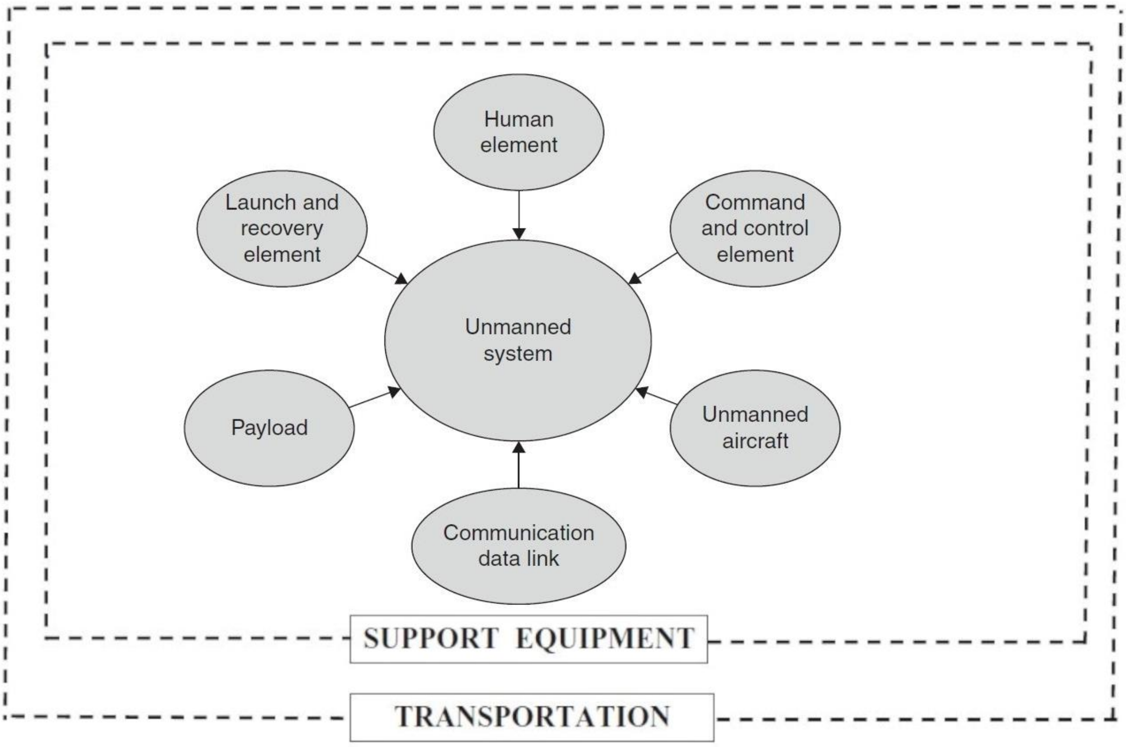

Figure 11 - Elements of an UAS – Source: Own elaboration based on [18] and [19]

3.3.1 Command and Control Element

This element is one of the most important ones because it defines how the UAV will behave when airborne. There are several different levels of autonomy in the control of an UAS,

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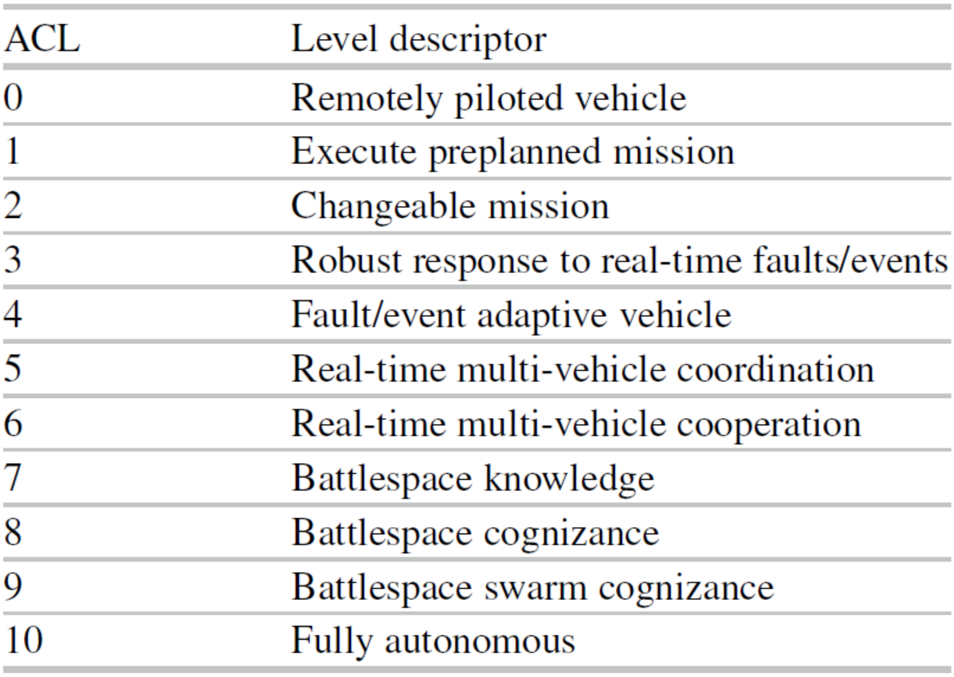
[11] [18], pp. 59

going from manually controlled to fully autonomous systems. In normal flight conditions in fully autonomous mode the UAS does not need any human intervention. On the other hand, in the case of manually controlled the aircraft is operated completely via remote control by a pilot.

When completely autonomous an autopilot installed in the UAV is completely responsible for every phase of the flight, from the take-off to the landing. In this case the aircraft is guided along a previously designated path. In this case the aircraft can operate on itself, however adjustments can be made if necessary or if an emergency situation appears.

Autopilot:

In the last years the development of the technology of autopilots has seen a great advance. They are getting smaller, lighter, more accurate, more efficient and cheaper, really cheaper. They can now be integrated in small radio controlled UASs and are able to control every single phase of the flight if needed. In Figure 12 it is possible to see an example of how the UAS can be classified based on their level of autonomy.



ACL	Level descriptor
0	Remotely piloted vehicle
1	Execute preplanned mission
2	Changeable mission
3	Robust response to real-time faults/events
4	Fault/event adaptive vehicle
5	Real-time multi-vehicle coordination
6	Real-time multi-vehicle cooperation
7	Battlespace knowledge
8	Battlespace cognizance
9	Battlespace swarm cognizance
10	Fully autonomous

Figure 12 - Autonomous Control Levels- Source: [17]

In the case of the mission proposed for this study a complete level of autonomy would not be optimal, but the ACL 2 would be ideal during the process. Many of the autopilots that are used nowadays have the standard procedure to return and land to the starting point if the connection between the aircraft and the ground station is lost. This means that in a possibly problematic situation the risk of losing the equipment, which sometimes means the loss of dozens or even hundreds of thousands of euros, can be avoided.

Ground Station:

"It is commonly accepted that the ground station is one of three main segments of a UAS, being the other two the UAV itself and the communication link" [20][12]. Here occurs all the man-machine interference and it is responsible for the control of the aircraft during its operation. The size and complexity from such a station can go from a person with a radio-controller flying in LOS to a "self- contained facility with multiple workstations" [18][13].

Usually, the GCS is divided into two different stations: a pilot station and a sensor station. In the pilot station is where the operator controls the aircraft and its main systems. While in the sensor station usually another operator controls the other systems of the UAV, such as flight control, radio communication, camaras or other payloads that the aircraft might have onboard. In some cases, when one operator is capable of dealing with both things, the two separate stations can be combined into a single one. The missions itself can be planned in the GCS but might also be planned in another locations, for instance in a remote military base, and then uploaded to the GCS.

Figure 13 - FPV with video goggles - Source: [21]

There are two ways for the operator to manually control de UAV: through Line of Sight (LOS) or First-Person View (FPV). In the first case it is essential that the pilot can observe the aircraft during the whole flight. In the second case a video transmission from an onboard

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[12] [20], pp. 2
[13] [18], pp. 61

camera to a display on the ground, usually a screen or video goggles, is required (Figure 13) [21].

There are mainly two types of FVP video links, the analogic and the digital, with advantages and disadvantages in both cases. The analogic video does not require any type of imaging processing, and, thanks to it, the image viewed by the operator has almost no delay in the image received. However, this makes it susceptible to the presence of noise when the link begins to fall due to range limitations, when there are obstacles and when there is radio interference [21].

There are some ways to overcome these problems. When the main problem are interferences caused by other sources of radio this could be easily corrected by selecting a different band of operations, as far away as possible from the interfering frequency. Another way to solve interferences is by using a high gain directional antenna. “Antennas with a narrow beam and high directional gain increase the received strength of the video signal transmitted from the UAV. These types of antennas can also be equipped with a UAV tracking system that automatically directs the antenna at the moving platform” [22].

In the last years, a lot of progress has been made in the FPV systems allowing them to become digital and transmitting video to the operator in High Definition (HD). Nevertheless, this comes with some disadvantages. The digital systems, when compared to the analogic ones, are usually more expensive and bulkier. As commonly known an increase in the weight of the UAV is undesirable and it can also bring problems when the system is transported by ground personnel. On top the transmission range is smaller withing the most commercial offers.

3.3.2 Communication Data Link

As stated before, the communication data link is one of the most important elements in the whole UAS. This element, in tune with the GCS, is the key element for an efficient change of information between the aircraft and the operators on the ground (Figure 14). Therefore, it is vital to be correctly established so that the mission is accomplished with the highest rate of success possible.

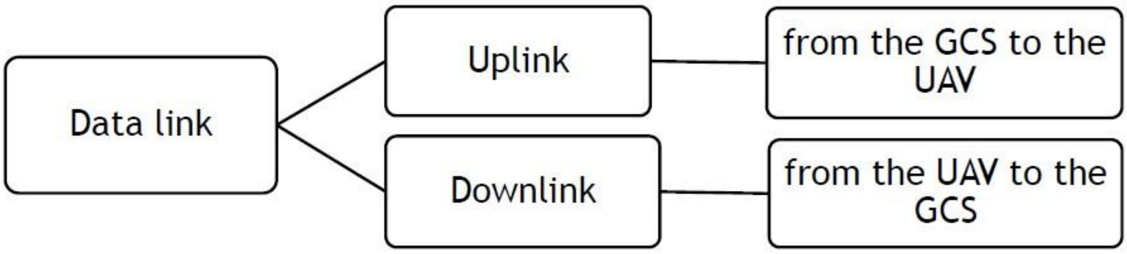

Figure 14 - Data link schematic - Source: [22]

The data transmission between the UAV and the GCS can be made (is usually made) per radio frequency but a laser beam or even optical fibres can be used [19]. The most relevant one for this study is the radio transmission, so it will be the one explained with more detail.

The radio link can be established in two distinct ways: Radio Line-of-Sight (RLOS) or Beyond Radio Line-of-Sight (BRLOS) [23].

In the case of the RLOS operation "the transmitter(s) and receiver(s) are within mutual radio link coverage and thus able to communicate directly or through a ground network providing that the remote transmitter has RLOS to the RPA and transmissions are completed in a comparable timeframe" [23][14].

On the other side in the case of the BRLOS operation "the transmitters and receivers are not in RLOS. BRLOS thus includes all satellite systems and possibly any system where an RPS communicates with one or more ground stations via a terrestrial network which cannot complete transmissions in a timeframe comparable to that of an RLOS system" [23][15]**.** This means that the transmission delay is greater in BRLOS operations than in RLOS operations.

3.3.3 Payload

The payload of the UAV can vary a lot according to the type of mission it is destined to do, and it should help to accomplish that mission.

The recent and fast advances in technology have made the payload one of the components that is expected to chance with a great frequency. According to [19] the payload can be divided into two main categories:

- "Nondispensable Payloads": these remain with the aircraft, such as cameras, sensors, extra fuel tanks…;

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[14] [23], pp. 2-2
[15] [23], pp. 2-2

- “Dispensable Payloads”: these are either dropped during or after their use, such as crop-spray fluid (pesticides, fungicides or possibly fertilisers and anti-frost measures), fire suppressant material, post, vaccines, missiles and other type of armament…

In the last years, several different payloads have been used in UAVs. When applied in crop-spraying one of the most important things is that the UAV can carry as much as fluid possible and at the same time being cheap to operate and easy to refuel and reload. Also, it should be well equipped to spray the fluid in the most efficient way possible to save money and to not pollute unnecessarily. On the other side when analysing the damages caused by plagues and/or natural disasters, that often affect this sector of activity, it is vital that the aircraft is equipped with sensors and cameras able to inspect and evaluate the extension of the damages caused to the crop.

When there are sensors onboard, these can be divided into two separate categories:

- Active sensors, which have their own source of light/laser;
- Passive sensors, which do not have their own source of light/laser.

“Active sensors used by small-scale UAVs are mainly miniature laser devices for detection and ranging. Other common terms include: LIDAR (light detection and ranging), LADAR (laser detection and ranging), laser radar, and laser range finder. They use a laser beam to determine the distance to an object or designate a target. Despite its enhanced precision, active sensors, compared with the passive counterparts, are less commonly used in either military or civil applications, mainly because they are relatively heavy, energy consuming, and vulnerable to atmospheric condition changes. However, research on guidance and navigation based on active sensors have been actively conducted over the past decades, driven by the researchers’ enthusiasm on pushing the autonomy of small-scale UAVs to a higher level” [24][16].

On the other side, the “passive sensors primarily refer to various kinds of imagers or cameras, which further consist of the following three types: 1) electro-optical cameras, 2) low-light-level (LLL) cameras, and 3) thermal imagers” [24][17].

In this case the following ones are the most common, and in the view of the author of this dissertation the most adequate for agricultural use [18], [22], [24]:

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[16] [24], pp. 82

[17] [24], pp. 82

- Electro-Optical (EO) cameras, usually known as daylight or visible light camera. This type of cameras uses electronic tools to work in the properties of the image and operate in the perceptible light spectrum and is used primarily during the day. Almost all the Mini UAVs are equipped with a camera of this kind;
- Low-Light-Level (LLL) cameras, which in terms of operation are very similar to the standard optical cameras but present a significant difference, this being the amplifier gain of the light sensor;
- Through the optical fibre, this gain is accumulated in the lens, allowing this type of camera to operate with only one-tenth of the light needed for the operation of standard cameras. Due to this type of characteristic, this sensor stands at a higher price level than the ones that are currently used.

To overcome the problem caused by the situation where the camara is fixed in the UAV a range of solutions exist being the main the application of a system called gimbal or turret. This allows the camera to have a predetermined range of mobility and so it improves the operator's Field of View (FOV).

3.3.4 Launch and Recovery Element (LER)

The LRE is one of the most complex and labour-intensive aspects of the UAS operations. Often large UAS systems have very elaborate LER procedures that include a large team, GPUs, fuel trucks, among others. In the case of the smaller ones the procedures are usually simpler and demand less work force.

The equipment need for this operation can be divided in the following categories [19]:

- Launch Equipment: this is the equipment need to get the UAV airborne when they are not VTOL and there is no airstrip available. It usually takes the form of a ramp on which the aircraft is accelerated on a trolley with the aid of compressed air for example, this is similar in its principle to the systems used in aircraft carriers;
- Recovery Equipment: consists of the equipment needed also in the case of a non-VTOL aircraft. It usually consists of a parachute and an auxiliar airbag system to absorb the impact energy. A large net can also be used. Some other ingenious systems are also being developed;
- Retrieval equipment: only used in the case when the UAV is too big to be man-portable and is used to transport it back to its launcher.

3.3.5 Human Element

The human element is a crucial element to the whole operation of the equipment. Even if all devices are in perfect conditions, human failure could still compromise the whole operation. The autopilot can help in many situations, but if the operator gives the wrong commands to the machine or does any other type of mistake it becomes a huge problem. Usually, this element is composed of a pilot, a sensor, and a supporting ground crew. However, depending on the complexity of the UAS, as stated before, some of these positions can be merged. Another important factor is the fact that the technological capabilities and automation of the systems is always improving, this leads to less and less need of human interaction [18].

3.3.6 Support Equipment and Transportation

These are two areas that are often underestimated. However, they play an important part on the "logistical footprint" and on the final operational costs. The support equipment "ranges from operating and maintenance manuals, through tools and spares to special test equipment and power supplies [19][18]. In the case of the transportation element, it depends on the size of the aircraft. Bigger aircrafts need bigger crews and more vehicles to be transported from one place to another, and this includes also all the systems required for their operation. On the other side, smaller UAVs can be easily carried by a single person [19].

3.4 Legislation in Portugal

In the following subchapter will be exposed the most important regulations regarding the ownership, assembly, and operation of UAS. For this dissertation, the focus will be on the commercial use of UAS since this is the most relevant for the subject in study. It is important to know how the use of drones for use in an agricultural exploration is covered by the law. For more detailed information all the regulations are in public archive for consult. Another thing important to note is, as the study is focused on the applications of UAS in Portugal, this subchapter will mainly cover European and Portuguese legislation issues.

3.4.1 Operation Categories

According to [25] the operation of the UAS is divided into three different categories: open, specific and certified. Since Portugal adopts the European laws regarding the operation of UAV's this subchapter applied not only for the European case in general but also to local operations. So, the categories defined here are common.

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[18] [19], pp.14

3.4.1.1 Open

According to [25][19] the operations of UAS shall be classified as open only when the following requirements are met:

a) "The UAS belongs to one of the classes set out in Delegated Regulation (EU) 2019/945 or is privately built or meets the conditions defined in Article 20;
b) the unmanned aircraft has a maximum take-off mass of less than 25 kg;
c) the remote pilot ensures that the unmanned aircraft is kept at a safe distance from people and that it is not flown over assemblies of people;
d) the remote pilot keeps the unmanned aircraft in VLOS at all times except when flying in follow-me mode or when using an unmanned aircraft observer as specified in Part A of the Annex;
e) during flight, the unmanned aircraft is maintained within 120 metres from the closest point of the surface of the earth, except when overflying an obstacle, as specified in Part A of the Annex;
f) during flight, the unmanned aircraft does not carry dangerous goods and does not drop any material".

The operations in this category are further divided with more detail into subcategories as stated in [25].

Regarding the operation itself, according to [26][20] "UAS operations in the 'open' category shall not be subject to any prior operational authorisation, nor to an operational declaration by the UAS operator before the operation takes place".

3.4.1.2 Specific

According to [25][21] the following points define the operations of UAS classified as specific:

1. "Where one of the requirements laid down in Article 4 or in Part A of the Annex is not met, a UAS operator shall be required to obtain an operational authorisation pursuant to Article 12 from the competent authority in the Member State where it is registered.
2. When applying to a competent authority for an operational authorisation pursuant Article 12, the operator shall perform a risk assessment in accordance with Article 11 and submit it together with the application, including adequate mitigating measures.

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[19] [25], pp. 152/49
[20] [26], pp. 23
[21] [25], pp. 152/49

3. In accordance with point UAS.SPEC.040 laid down in Part B of the Annex, the competent authority shall issue an operational authorisation, if it considers that the operational risks are adequately mitigated in accordance with Article 12.
4. The competent authority shall specify whether the operational authorisation concerns:

a) the approval of a single operation or a number of operations specified in time or location(s) or both. The operational authorisation shall include the associated precise list of mitigating measures;
b) the approval of an LUC, in accordance with part C of the Annex.

5. Where the UAS operator submits a declaration to the competent authority of the Member State of registration in accordance with point UAS.SPEC.020 laid down in Part B of the Annex for an operation complying with a standard scenario as defined in Appendix 1 to that Annex, the UAS operator shall not be required to obtain an operational authorisation in accordance with paragraphs 1 to 4 of this Article and the procedure laid down in paragraph 5 of Article 12 shall apply.
6. An operational authorisation or a declaration shall not be required for:

a) UAS operators holding an LUC with appropriate privileges in accordance with point UAS.LUC.060 of the Annex;
b) operations conducted in the framework of model aircraft clubs and associations that have received an authorisation in accordance with Article 16”.

Regarding the operation itself, according to [26][22] “UAS operations in the ‘specific’ category shall require an operational authorisation issued by the competent authority pursuant to Article 12 or an authorisation received in accordance with Article 16, or, under circumstances defined in Article 5(5), a declaration to be made by a UAS operator”.

3.4.1.3 Certified

To define the certified operation category, it is important to read Article 6 of Regulation (EU) 2019/947 together with Article 40 of Regulation (EU) 2019/945. The conjunction of these two articles results in [26][23]:

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[22] [26], pp. 23
[23] [26], pp. 26

a) “The transport of people is always in the ‘certified’ category. Indeed, the UAS must be certified in accordance with Article 40 and the transport of people is one of the UAS operations identified in Article 6 as being in the ‘certified’ category;
b) flying over assemblies of people with a UAS that has a characteristic dimension of less than 3 m may be in the ‘specific’ category unless the risk assessment concludes that it is in the ‘certified’ category; and
c) the transport of dangerous goods is in the ‘certified’ category if the payload is not in a crash-protected container, such that there is a high risk for third parties in the case of an accident”.

Under any circumstances the operations of an UAS are considered certified when they fall into the following requirements [26][24]:

- “Are conducted over assemblies of people with a UA that has characteristic dimensions of 3 m or more; or
- involve the transport of people; or
- involve the carriage of dangerous goods that may result in a high risk for third parties in the event of an accident”.

Under this category fall any drones that are used for air spraying operations, since they always substances that, if not adequately manipulated, are potentially very harmful to living beings and the environment in general.

Regarding to the operation itself, according to [26][25] “UAS operations in the ‘certified’ category shall require the certification of the UAS pursuant to Delegated Regulation (EU) 2019/945 and the certification of the operator and, where applicable, the licensing of the remote pilot”.

3.4.2 Air Spraying operations

Air spraying operations are a very specific and unique case of UAS use in agriculture. Because it has the problem of dropping substances potentially harmful and influence a very large area it needs to be very well regulated and controlled to protect people and the environment.

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[24] [26], pp. 24
[25] [26], pp. 23

3.4.2.1 European Union

According to European Regulations [27][26] “Dropping or spraying from an aircraft in flight shall only be conducted in accordance with:

a) Union legislation or, where applicable, national legislation for aircraft operations regulated by Member States; and
b) as indicated by any relevant information, advice and/or clearance from the appropriate air traffic services unit”.

3.4.2.2 Portugal

In Portugal currently, according to [28], the use of aerial applications of phytopharmaceuticals is expressively forbidden, that includes the use of UAS as clarified by the Direção Geral de Alimentação e Veterinária (DGAV), [29]**.** However, according to the same source it is possible to get an authorization for the use of the aerial application when it is proven that there is no other better way to do the required work and safety of humans and environment is assured.

3.5 Conclusion

During this chapter it was possible to get more profound knowledge about how the UAS operate and how their different components work harmoniously together to allow the execution of complex missions. Each of the elements presented is essential for the smooth operation and so presents abilities but also limitations when applied to any scenario. It was also very important to understand what legislation is applied in general and more specifically to the agricultural use of this type of air vehicles.

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[26] [27], pp. 281/13

Chapter 4 – Case Study

4.1 Introduction

After an explanation about the Agricultural Situation in Portugal and about the main working principals of UAS, now will be done a presentation of diverse studies that could possibly be adapted and used in Portugal. Due to the lack of works and reduced use of UAVs for agricultural purposes in Portugal, the studies are mainly from other countries, such as Italy, Spain, and France. Even though they were made in different countries, crops and operative scenarios, their main objective is similar: to improve the efficiency of the resources available.

This chapter is mainly divided into groups of crops according the most relevant in Portugal: cereals, fresh products, olives, orchards and vineyards. Also, a section is reserved for PA in general that might be transversal to different crops and activities. Like shown before the Portuguese SAU represents a total area of approximately 3,96 million ha (~43% of the total territory) with about 1,91 million ha (~48,3% of the total SAU) used in agriculture. Being the area so big it is of general interest that the best technologies and solutions are applied.

It is important to consider that, given the great number of studies and place where the UAS have been applied for agricultural purposes, not all of them could be presented in this dissertation. So, a criterion was needed, being the following aspects the most important to select the studies. The order of importance is usually the one in which they are presented, but may sometimes slightly change, if considered that a particular study is considered extremely relevant:

1. Year of publication, more recent is generally more relevant;
2. Type of crop, the more similar to the Portuguese ones the better;
3. References, documents with citations considered reliable were preferred over other;
4. Publication, studies published in recognized journals are usually more important/relevant;
5. Diversity, documents who give a more embracing view of the whole study were preferred over others who focus too much on a single aspect of the study in question;
6. Language, English and Portuguese documents were preferred.

4.2 Cereals

Being used for a wide range of applications cereals are one of the most vital products cultivated by humans. They are used in bread and beer fabrication and are the main ingredient of most animal food, being the foundation of another essential industry: animal growing for meat, milk, eggs, fur, among others.

With a total area of around 235 thousand ha of cereal cultivation for grain and 554 thousand ha for silage, this culture corresponds to about 20% of all the cultivated area in Portugal. Since the country has a significant animal production industry it is very important that a constant flow of this good is maintained. Currently the most produced cereals are [30]:

- For grain:
    - Maize: 77 019 ha, 755 126 t;
    - Oat: 36 581 ha, 49 810 t;
    - Rice: 28 833, 161 496 t;
    - Wheat: 28 531 ha, 74 473 t;
    - Barley: 21 939 ha, 69 233 t;
    - Rye: 14 592 ha, 16 228 t;
    - Triticale: 15 642 ha, 24 924 t.
- For silage:
    - Maize: 71 935 ha, 3 072 259 t;
    - Oat: 84 856 ha, 1 513 774 t.

The farming of this type of culture is transversal to the whole country and their sustained development is vital for the economy. Unfortunately, when it comes to the use of modern technologies, more specifically UAS, to improve its farming there is a considerable lack of studies made in Portugal. It almost seems that it is completely neglected.

However, in foreign countries there are many studies which aim to answer a series of problems and to improve the results obtained from cereal farming.

4.2.1 Biomass Estimation

Farming has many variables to consider, but when it comes to the harvest and transportation of the goods there are some important operational costs that need to be considered: fuel, personal and equipment insurance, electricity, equipment wear, among others. Sometimes the equipment needs to be rented which increases the costs even further. To adjust the best way possible the resources available while keeping the expenses to the absolute essential a good estimation of the total harvested goods that will need transportation is important.

In 2013 a group of researchers from the Institute of Geography, Research Centre Hanninghof and the International Center for Agro-Informatics and Sustainable

Development (ICADS), developed a study whose main purpose was to understand the influence in biomass monitoring in barley of the combination of plant heigh and vegetation indexes. Their main objective was not to directly reduce the costs, but they ended up developing a quite cost effective and useful way to assess the biomass of a barley field.

The work was conducted at the Campus Klein-Altendorf agricultural research station located 40km south of Cologne, Germany. It was comprised of:

- 36 3 x 7 m plots (0,076 ha):
    - 3 x 5 m for plant height and reflectance measurements;
    - 3 x 2 m for destructive sampling.
- 18 summer barley cultivars (*Hordeum vulgare*), 10 of them were new cultivars;
- 2 levels of nitrogen fertilizing:
    - 40 kgN/ha;
    - 80 kgN/ha.
- 300 plants/m^2;
- 0,104 m row spacing;
- Ground Control Points (GCP) for the UAV evenly distributed.

The whole distribution can be seen with more detail on Figure 15.

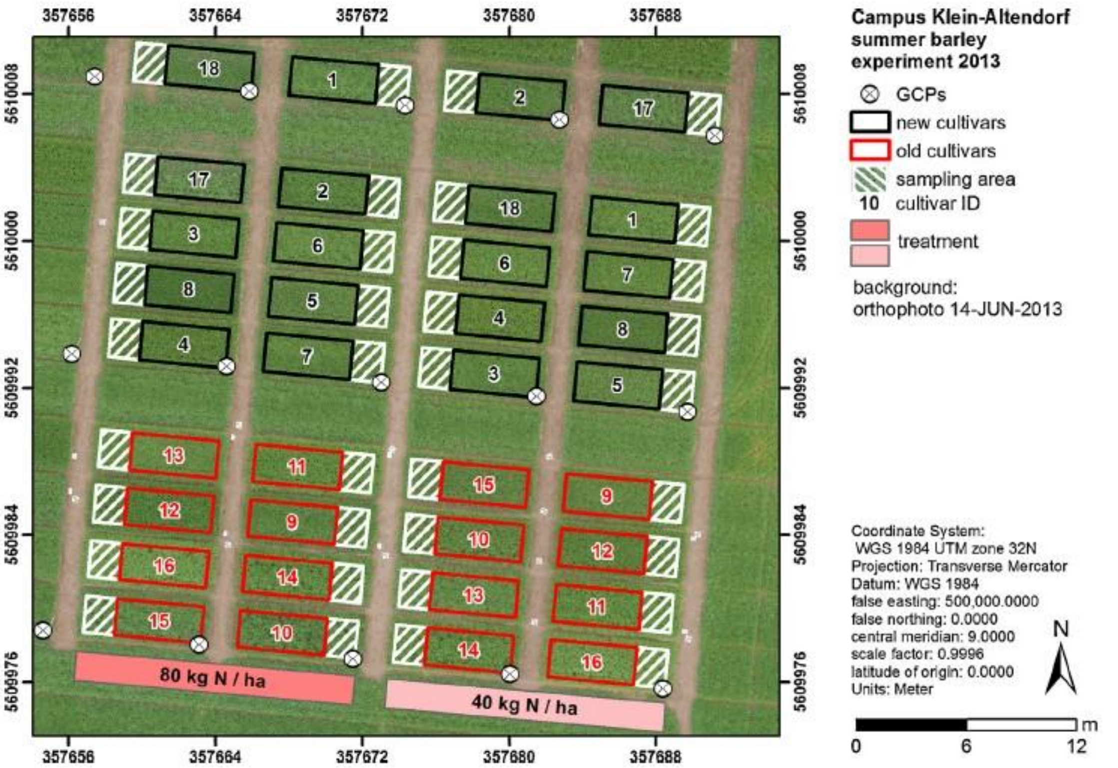


Figure 15 – Test Site Germany – Source: [31]

To study the biomass a series of destructive samples were taken frequently between April and July and evaluated, all the values were extrapolated to kg/m^2 for further analysis and comparison with the estimations provided using the UAS.

Following are the details of the UAS and payload used for the data collection of this study:

- Multi-rotor MK-Oktokopter by HiSystems GmBH;
- RGB (Red, Green and Blue) sensor;
- 16 Megapixel Panasonic Lumix GX1 digital camera (20 mm fixed lens), attached to the UAV with a gimbal.

6 different flights were made between May and July (2/month), and they were conducted at a fixed altitude of 50 m above ground level with a capture rate of 2 frames/second. A ASD FieldSpec3 field spectroradiometer was used to measure the barley canopy reflectance and later use for the calculation of the Vegetation Indices (VIs). The vegetation indices analysed in this work are divided between near infrared vegetation indices:

- Normalized Difference Vegetation Index (NDVI);
- Soil Adjusted Vegetation Index (SAVI);
- Modified SAVI (MSAVI);
- Optimized SAVI (OSAVI).

And visible band VIs:

- Green-Red Vegetation Index (GRVI);
- Modified GRVI (MGRVI);
- Red-Green Blue Vegetation Index (RGBVI).

A model considering these indices and the measurements made by the UAS was developed to estimate the biomass of the barley and compare it to the data obtained from the destructive samples. When comparing the data obtained from the spectroradiometer with the one collected by the UAV investigators observed that while the ground equipment only produced point data the flying platform can capture the infield variability faster and with a denser spatial coverage. So, they concluded that using only an 800 € sensor the plant height can be measured effectively, and the biomass can be estimated with almost the same quality as with the far more expensive and localized spectroradiometer. They also noted that the combination of vegetation indices and plant heigh did not reveal to significantly improve the model performance.

4.2.2 Real-time Monitoring

Later in 2017 a group of scientists in Japan made a study aimed at monitoring the real-time growth status map within-field spatial variations of a wheat yield using high resolution images taken by and UAS. The wheat farmland was in Memuro, Hokkaido and it consisted of a planted area of about 3,2 ha (Figure 16). The wheat was planted in September 2014 and harvested in July 2015 [32].

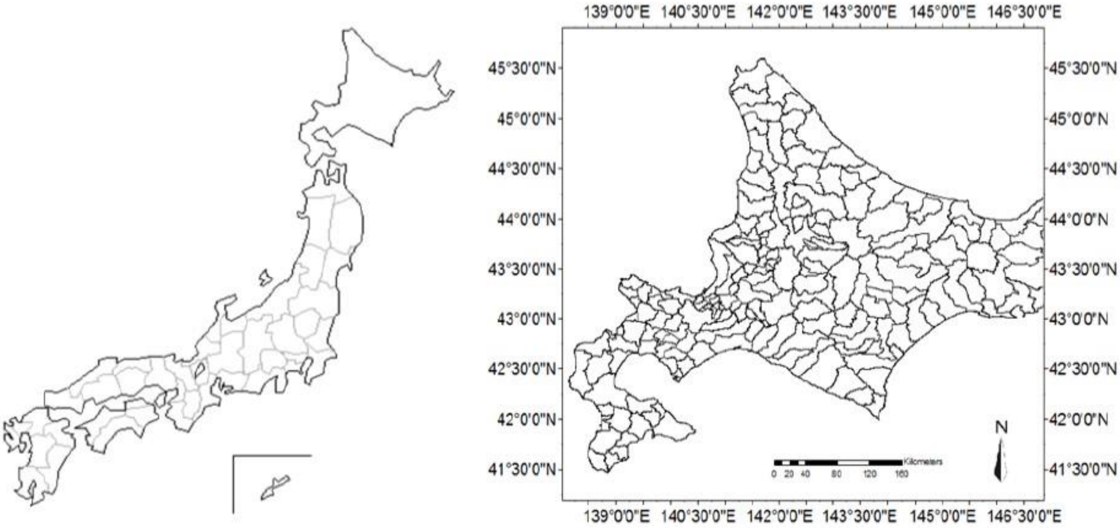


Figure 16 – Test Site Japan – Source: [32]

The UAV and payload used for the data acquisition were:

- Small quadrotor (ENROUTE CO., LTD., Fujimino, Japan), (Figure 17);
- Commercial digital camera: SONY ILYCE-600.

Figure 17 – UAS used in the study – Source: [32]

9 wheat samples of the field were collected on 24 July and 8 flights were conducted on 2, 10, 19, and 25 June 2015, and on 2, 10, 16, and 24 July 2015 (at 11h00, local time) at a fixed

altitude of 100 m above ground level and its flights were made completely autonomously according to a beforehand defined flying path. The data was then object of post-processing procedures:

- Orthomosaic images generation;
- Orthomosaic image geo-referencing;
- Radiometric normalization.

This was necessary to transform the raw images in usable data and generate maps of:

- Visible-band Difference Vegetation Index (VDVI);
- Normalized Green-Red Difference Index (NGRDI);
- Normalized Green-Blue Difference Index (NGBDI);
- Green-Red Ratio Index (GRRI);
- Excess Green vegetation index (ExG).

The indexes cited above provide substantial visual and easy to read information about the field and its composition. With this investigation the researchers understood that the UAV allowed to determine the day on which the wheat reached its peak condition and when it began to yellow. The orhtomosaic images could be used to generate maps with the specific local lodging conditions of the ripe wheat to allow perfect adjustment of the operation speed of the harvesting equipment. Also, an estimation of the grain weight per square meter was possible to be made with a minor error.

4.2.3 Water Stress Estimation

Being water one of the most important factors for healthy plants, and therefore a good yield, it is essential to use it wisely. If a plant gets too much, it can rotten, but if it does not get enough, it will not grow and eventually die. To answer this question in the cereal farming a group of Danish and Spanish researchers developed in 2014 a study about the water stress suffered during an entire growing season of barley. For this they aimed to understand if a Water Deficit Indicator (WDI) produced with UAS imagery could provide accurate crop water stress maps, and also if the WDI would be applicable when the land surface was in part composed of bare soil and when the crops were senescing [33].

The work was conducted on two fields, with a combined area of approximately 32 ha, located in western Denmark (Figure 18). The irrigation procedures were the same as usual to other years with no special adjustments made for the study. The barley was sown on 14 March and later harvested on 22 August.

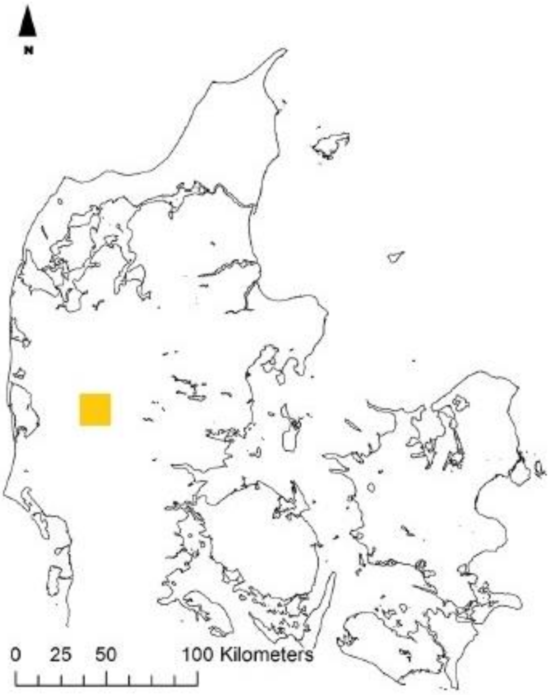


Figure 18 – Test site Denmark – Source: [33]

The UAV and payload used for this were:

- Fixed wing UAV (Figure 19);
- Optris PI 450 thermal camera;
- DMC-LX5 RGB camera.

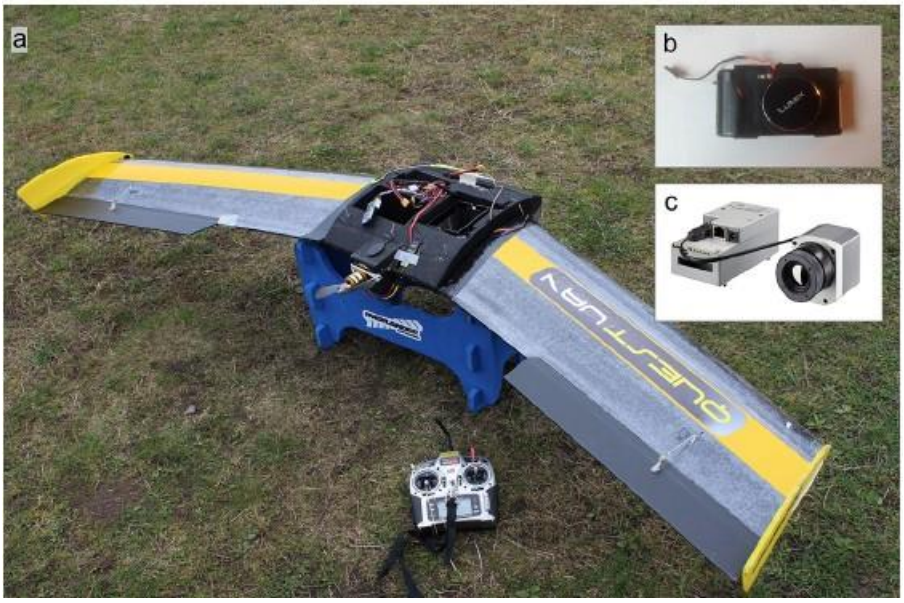


Figure 19 – UAS and imagery equipment used – Source: [33]

The flights for data collection were made at a fixed altitude of 90 m on three different dates: 22 April, 18 June and 2 July. They took approximately 20 min each one. The purpose of the use of an UAS in this study was to collect composite Land Surface Temperature (LST) images and colour images. The LST images were used to compute maps of surface-air temperature differences, while the colour images were used to produce the NGRDI, which constitutes the indicator of surface greenness. This information was also used to improve further the WDI. NGRDI, temperature and WDI were validated using a series of ground equipment and techniques to ensure their veracity.

With this work it was possible to understand that the WDI maps represent an accurate solution to determine the absolute water stress within a barley field. This index allowed to understand the areas of ripe and prematurely ripe crops which no longer needed irrigation and given its robustness represents a great alternative to the more commonly used Crop Water Stress Index (CSWI). Also, by only using the surface-air temperature differences maps it would be possible to estimate the areas where the crops will become prematurely ripe without sufficient irrigation. With a simple, lightweight, and cheap UAV, an uncooled and uncalibrated thermal camera, and a general consumer available camera it was possible to produce all this information. This is much cheaper than relying on expensive multispectral technology.

4.2.4 Pesticide Reduction and Seeding Failure Estimation

As shown before maize, whether is it's for grain or silage, is a quite important cereal. Its combined production in Portugal is around 3,07 million t, more than 60% of the total grain production! With such a representative number it is important to optimize as much as possible its farming.

Weeds and its control are a big issue that any farmer faces. They inhibit the normal growing process of the crops and are estimated to potentially cause yield losses of up to 34 % globally [34]. The herbicides to prevent them are expensive and dangerous, big, and heavy equipment is needed, and it consumes a lot of time and resources in general. And a lot of the chemicals are usually not used to their full potential, they are just dropped on the field following a uniform blanket application. This is bad for farmer, who is losing money, time, and resources, and for the environment.

The possible use of UAS to determine the exact location of the weed patches and therefore allow for patch spraying, instead of uniform blanket application was studied during the 2014 and 2015 growing seasons. If the spatial distribution of the weeds is known this could lead to the development of Site-Specific Seed Management (SSWM) systems allowing for a more efficient use of the chemicals [34].

All the important information about the fields, located in Vetralla, Italy can be found in Figure 20.

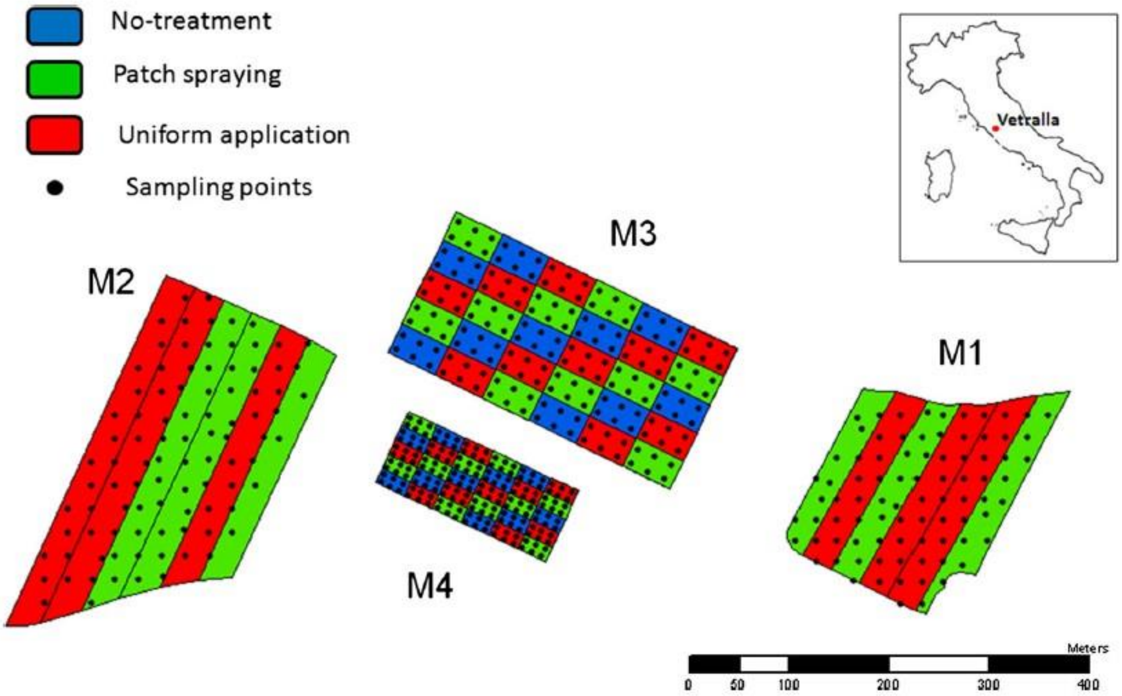


Figure 20 – Experimental layout employed in the two years of the experiment. M1 and M2 in 2014, M3 and M4 in 2015. – Source: [34]

In 2014, the fields were divided into six 24 m wide strips extending to the whole length of the field, with three randomly assigned strips for each treatment. Then the following strategies were applied:

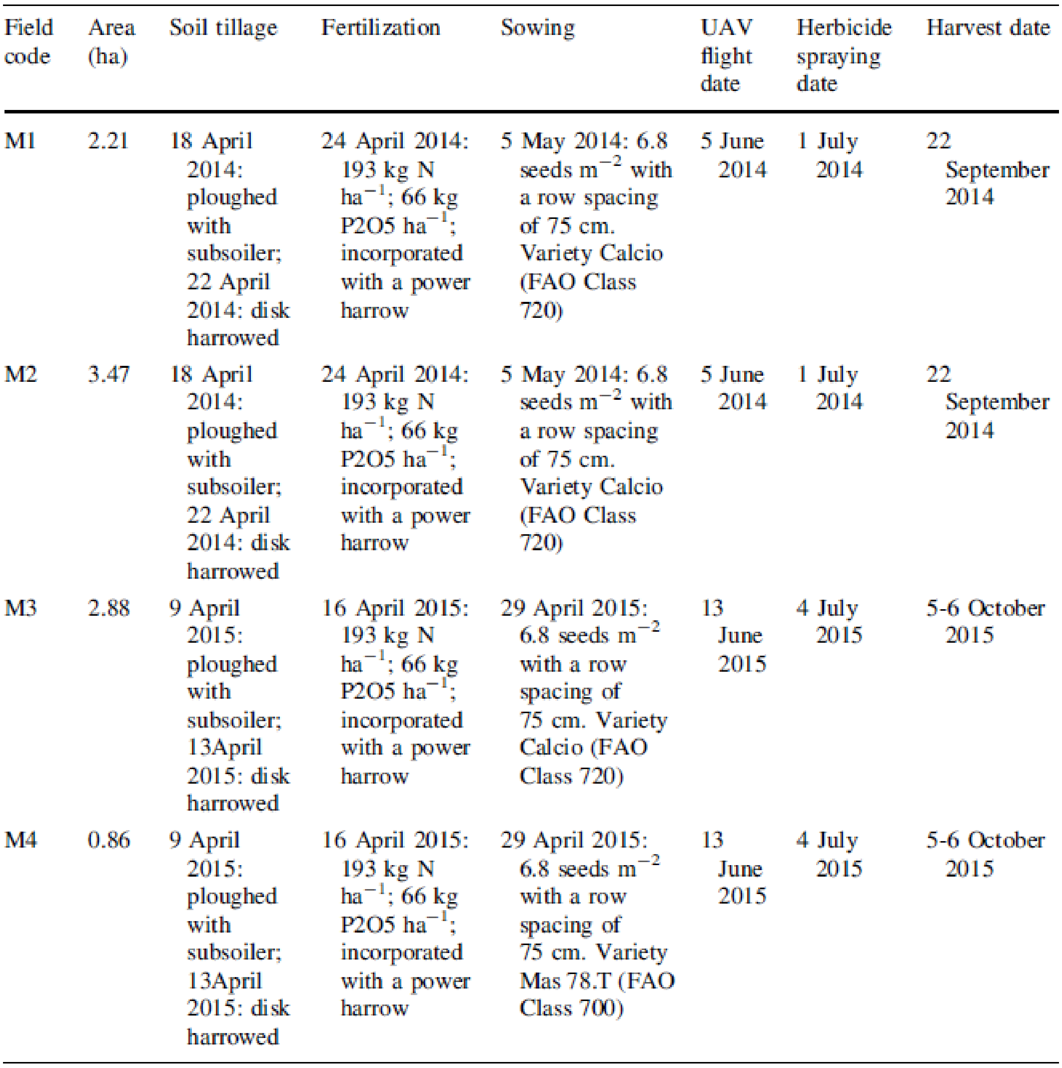
i. Uniform blanket distribution;
ii. Patch spraying according to the prescription map.

In 2015, to allow the application of an improved methodology for the spatial modelling of the results, a different experimental design was employed. In this year each of the fields was divided into 30 plots, with groups of 10 according to their treatment application:

i. Untreated control;
ii. Uniform blanket application;
iii. Patch spraying according to the prescription map.

The above-described procedure can be visualized on Table 6.

Table 6 – Details of the agronomic management of the maize fields in which the experiments were carried out. – Source: [34]



Field code	Area (ha)	Soil tillage	Fertilization	Sowing	UAV flight date	Herbicide spraying date	Harvest date
M1	2.21	18 April 2014: ploughed with subsoiler; 22 April 2014: disk harrowed	24 April 2014: 193 kg N ha^{-1}; 66 kg P2O5 ha^{-1}; incorporated with a power harrow	5 May 2014: 6.8 seeds m^{-2} with a row spacing of 75 cm. Variety Calcio (FAO Class 720)	5 June 2014	1 July 2014	22 September 2014
M2	3.47	18 April 2014: ploughed with subsoiler; 22 April 2014: disk harrowed	24 April 2014: 193 kg N ha^{-1}; 66 kg P2O5 ha^{-1}; incorporated with a power harrow	5 May 2014: 6.8 seeds m^{-2} with a row spacing of 75 cm. Variety Calcio (FAO Class 720)	5 June 2014	1 July 2014	22 September 2014
M3	2.88	9 April 2015: ploughed with subsoiler; 13April 2015: disk harrowed	16 April 2015: 193 kg N ha^{-1}; 66 kg P2O5 ha^{-1}; incorporated with a power harrow	29 April 2015: 6.8 seeds m^{-2} with a row spacing of 75 cm. Variety Calcio (FAO Class 720)	13 June 2015	4 July 2015	5-6 October 2015
M4	0.86	9 April 2015: ploughed with subsoiler; 13April 2015: disk harrowed	16 April 2015: 193 kg N ha^{-1}; 66 kg P2O5 ha^{-1}; incorporated with a power harrow	29 April 2015: 6.8 seeds m^{-2} with a row spacing of 75 cm. Variety Mas 78.T (FAO Class 700)	13 June 2015	4 July 2015	5-6 October 2015

After describing the area now will be presented details about the equipment used and the flights.

In 2014:

- Fixed wing eBee Ag UAV (senseFly SA, Cheseaux-Lausanne, Switzerland);
- Canon s110, 4 channel camera;
- Acquired 4 weeks after planting:
    - main weed, *Cyperus rotundus L.*, at the end of the leaf development stage, with a height of about 100–150 mm and nine or more true leave;
    - Other weeds observed residually.

- 150 m flight altitude.

In 2015:

- Multicopter VTOL SF6 UAV system (Skyrobotic, Narni, Italy);
- Agrosensor (AIRINOV, Paris, France) multispectral camera;
- Acquired approximately 9 weeks after planting:
    - main weed, *Cyperus rotundus L.*
- 35 m flight altitude.

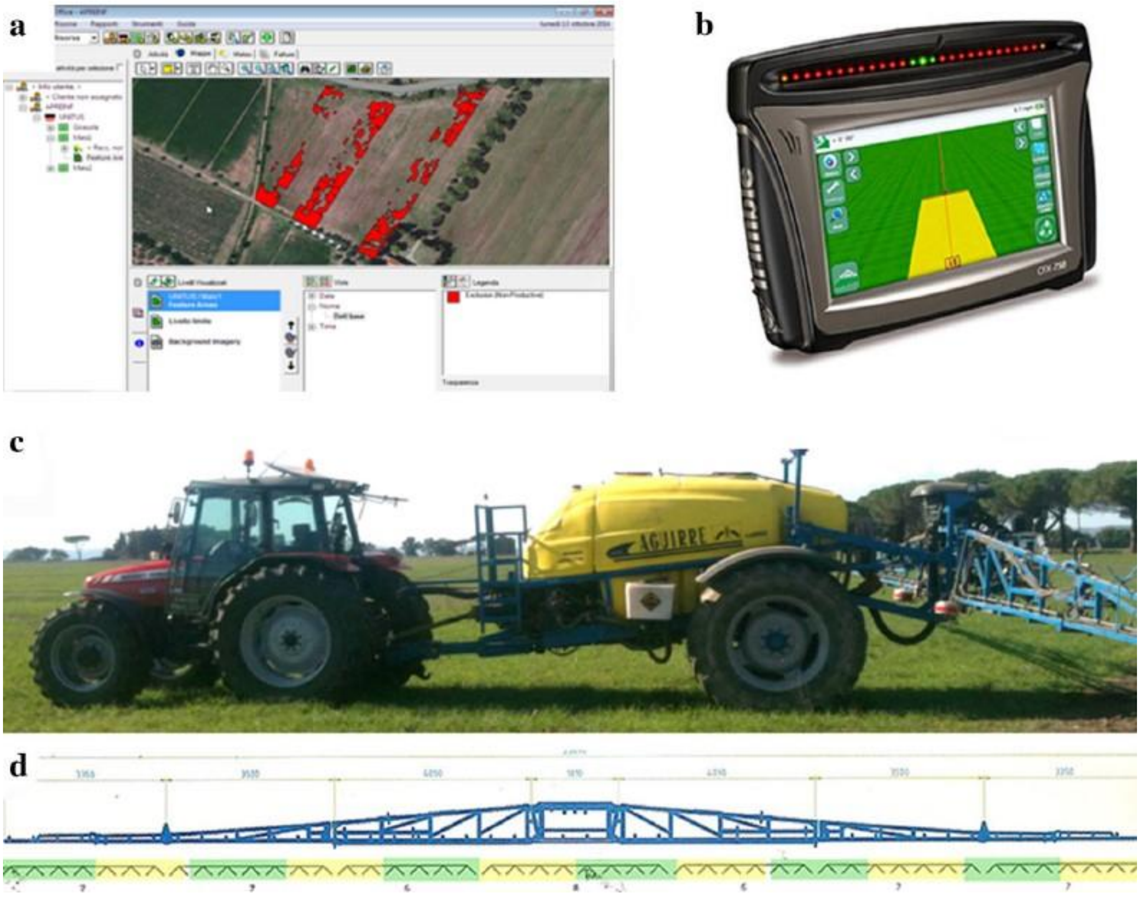


Figure 21 – Ground equipment used: (a) application map, (b) on-board monitor with uploaded prescription map, (c) tractor and sprayer, (d) sprayer with 12 independent nozzles. – Source: [34]

The UAS in this study was used only to map the weed patches, for the spraying a ground system composed of a tractor with an on-board monitor, a boom sprayer and an input control system was used (Figure 21). After the harvest of the crops the biomass was estimated and comparisons between the 2 distinct years and methods were done. It was concluded that the prescription maps had an overall classification accuracy of approximately 61 % with all the areas without weeds correctly identified by the UAS.

However only 57 % of the area to be sprayed was identified, which means that about 43 % of the area affected by weeds was not treated. But this does not represent a big issue since most of this area has a very low weed ground cover. Even given some flaws the prescription maps were considered satisfactory when compared to ground data and the investigators concluded that the use of this type of procedure increases the biomass production, leads to an herbicide save between 14 and 39,2 % and allows a saving from 16 to 45 €/ha.

The study published in 2020 and made by an investigation group of Portuguese and Spanish people is quite interesting: the area in which it was developed, county of Estremadura, is located along the Portuguese border (Figure 22). The objective was to understand the influence of UAVs and NDVI techniques as PA tools in small Mediterranean farms [35].

Figure 22 – Test site – Source: [35]

During this study 3 properties were involved:

- Plot A: irrigated parcel of 19,8 hectares dedicated to the production of corn;
- Plot B: irrigated parcel of 17,4 hectares dedicated to the production of corn;
- Plot C: irrigated parcel of 28,8 hectares dedicated to olive production.

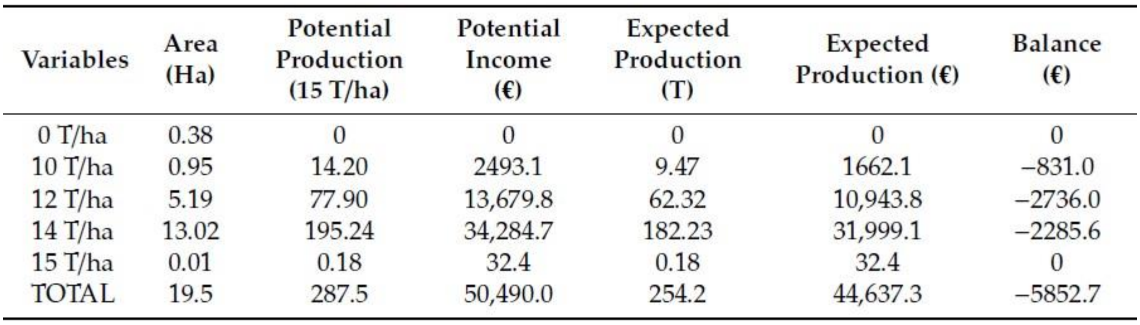
In this subchapter only the components of the study reflecting over plot A and B will be exposed, plot C will be further discussed in the "Olives" subchapter.

For plot A the objective was used for seeding failure and production estimation and plot B for potential reduction in the use of agrochemicals. The UAS for all the data collection was the same and consisted of:

- ModelDJI Phantom 3 professional multirotor, VTOL capable;
- RGB camera (visible spectrum);
- NIR (Near-Infrared) sensor (MAPIR Survey 2).

In Plot A NDVI was used to estimate the production and assess seeding failures. It was observed that approximately 0,3 ha were left without plants (1,5% of the field). Considering the price/t of corn of 175,6€, published by MAGRAMA (Ministry of Agriculture and Fisheries, Food and Environment) for the 2016/2017 Table 7 was produced.

Table 7 – Analysis of the corn productivity – Source: [35]

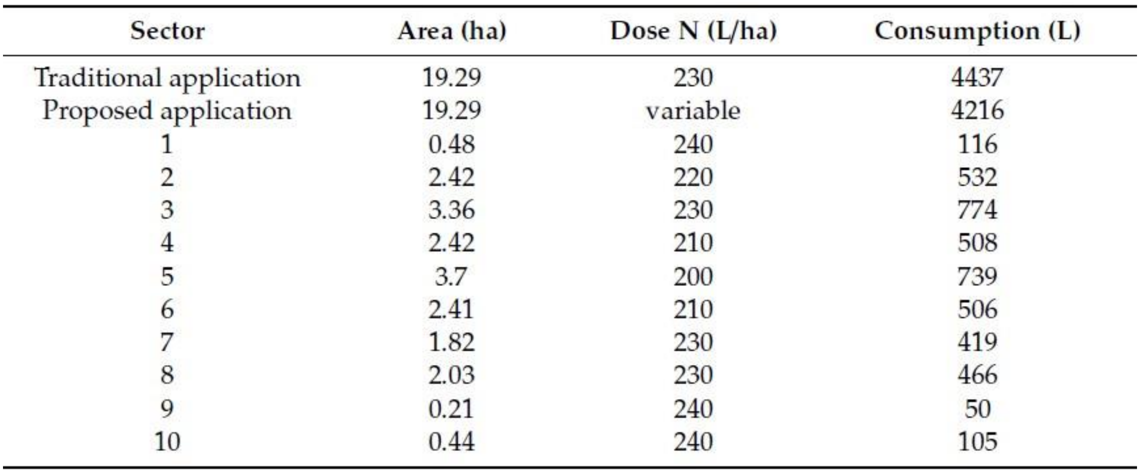


Variables	Area (Ha)	Potential Production (15 T/ha)	Potential Income (€)	Expected Production (T)	Expected Production (€)	Balance (€)
0 T/ha	0.38	0	0	0	0	0
10 T/ha	0.95	14.20	2493.1	9.47	1662.1	−831.0
12 T/ha	5.19	77.90	13,679.8	62.32	10,943.8	−2736.0
14 T/ha	13.02	195.24	34,284.7	182.23	31,999.1	−2285.6
15 T/ha	0.01	0.18	32.4	0.18	32.4	0
TOTAL	19.5	287.5	50,490.0	254.2	44,637.3	−5852.7

The cost per flight of the UAS was estimated to be 500 € and so it is possible to understand that this property the loss caused by this 0,3-ha seeding failure is estimated to be approximately 5 300 €. Making more calculations it is also possible to see that a 1,5 % seeding failure caused a 11,6 % loss.

As for Plot B NDVI was used to elaborate a fertilizing prescription plan based on NDVI, however this faced the limitation presented by the irrigation system divided into 10 sectors. Because of this an average NDVI was used for each parcel. Based on the data collected by the UAS Table 8 was elaborated and a reduction of 5 % in the chemicals used achieved while maintaining the productivity.

Table 8 – Fertilizer use reduction plan – Source: [35]



Sector	Area (ha)	Dose N (L/ha)	Consumption (L)
Traditional application	19.29	230	4437
Proposed application	19.29	variable	4216
1	0.48	240	116
2	2.42	220	532
3	3.36	230	774
4	2.42	210	508
5	3.7	200	739
6	2.41	210	506
7	1.82	230	419
8	2.03	230	466
9	0.21	240	50
10	0.44	240	105

4.3 Data management

The studies presented in the other subchapters focus over one specific culture but there are several works and technologies developed, or being developed, that are of interest for a lot of different plants. During the research one in specific appeared to the author of this dissertation as very interesting and seemed to be very important for every use in any situation where large amounts of data are dealt with. So, it was decided to include it as well.

During this dissertation it was shown how UAS represent a huge advance in agriculture and that they can do many different tasks and solve a lot of inconveniences while operation under almost any condition. But there is a problem that is rarely referred and that seems to be an important limitation to their use: the amount of data they generate and the impossibility of their use in real time. This causes delays and it is no longer enough for the farmers to just get simple aerial images of their farmland. Frequently the delay is so great that when they understand that there is a problem with the crops it is already too late to remedy the situation [36].

Given the fact that the price of the UAS itself has decreased, with the possibility to buy one for as little as a few hundred dollars the main focus of development has become the equipment that the vehicle carries. The real-time use of the data captured is vital. With this in mind SAP (*Systemanalyse Programmentwicklung*), a German software company based in Walldorf, Germany and with more than 101,000 employees worldwide, launched SAP Leonardo in 2016. This platform is based on the concept of Internet of Things (IoT) and aims to integrate technologies altogether running them in the cloud. It recognizes that there are some points that might be common to many different farmers, but each one has his one specific needs. This may allow the combination of different type of data obtained from: UAS, Geographic Information Systems (GIS), in-field IoT, farm machinery, as well as agriculture commodity prices, fertilizer commodity prices and information obtained from other agro-economic sources.

The huge amount of data that can be generated per growing season can be up to 50 thousand Gb (Gigabyte), considering 10 to 20 operations. Using a fully integrated cloud system SAP proposes to solve this problem providing the farmers with enough analytical capability to use all this information in a faster and more efficient way. Also given the fact that big farming extensions are often located in remote regions with difficulties to access the internet the author proposed a series of measures that could be taken to mitigate this problem:

- Local solar charged battery powered wi-fi stations;
- Smart duty load manging systems;
- Local pre-processing of the data;
- Local wi-fi networks connected to the main network;
- Local temporary data storage when no connection is temporarily available.

This system was already tested on a cattle farming and on a banana plantation with approximately 810 ha and the results are very promising.

4.4 Fruit Trees

Also important in the Portuguese Agriculture are the products derived from trees such as apples, citrus fruits, pears, subtropical fruits, and various nuts. Olives and vineyards could also fall in this category but because of their specificity it was decided to dedicate a subchapter to each one of them.

In Portugal the most important products in this category are [30]:

- Nuts: 106 733 ha, 82 521 t:
    - Chestnuts: 51 694 ha, 43 841 t;
    - Almonds: 49 345 ha, 32 299 t;
    - Walnuts: 5 371 ha, 6 158 t.
- Main Fresh Products: 44 484 ha, 685 892 t:
    - Apple: 14 311 ha, 370 708 t;
    - Pear: 11 325 ha, 198 465 t;
    - Peach: 3 780 ha, 44 767 t;
    - Cherry: 6 387 ha, 22 000 t;

    - Plum: 1 834 ha, 20 795 t.
- Citrus fruits: 21 368 ha, 412 057 t;
    - Oranges: 17 129 ha, 346 510 t;
    - Tangerines: 2 485 ha, 40 697 t;
    - Lemons: 1 620 ha, 23 187 t.

Currently there are only a limited number of studies on the use of UAS in chestnuts plantations, these were made mainly by the same group of scientists from the northern region of Portugal. They reflect over a series of aspects using mainly the UAS as a platform to obtain high resolution images and multispectral data, used to generate VIs and obtain detailed information about the orchards, machine learning techniques are also used to some extent. The results obtained from these studies are very promising. Unfortunately, regarding the other nut species there are no major studies conducted in the national territory. When it comes fresh products trees, there are no studies except for one made about the use of an UAS to collect high-resolution images about a peach plantation. The same happens when it comes to citrus fruits, only one study about the crop yield estimation of a citrus orchard.

4.4.1 UAS Fertilizing Feasibility

On trees the application of pesticides or fertilizers is a bit more complicated and presents greater coverage challenges given its dense foliar canopies [37]. To evaluate the feasibility of recent UAS technologies for this purpose a group of investigators conducted a study in the USA (United States of America) about it.

The aircraft and its payload used in this study consisted of:

- DJI Matrice 600 electric hexacopter (DJI Inc., Shenzhen, China);
- Customized commercial spray system by Leading Edge Aerial Technologies, Inc. (Leading Edge Associates, Asheville, NC, USA):
    - 1,2 m fixed boom;
    - 13,2 l tank.

The product applications were made by a licensed pilot in coordination with a ground crew responsible for the pesticide mixing and loading. The UAS operated autonomously during take-off, landing, ferrying and turn time (non-spraying operations).

The application trials were carried out during the 2018 and 2019 growing seasons at research almond orchard in Arbuckle, California, USA. The 2018 season was just used as a proof of concept but in the 2019 season the application was made at the hull-splitting stage. By this time the tree canopy density is the greatest, crop load is maximum, and a good spray coverage is extremely important. In overall a total area of 0,34 ha was sprayed which consisted of 120 trees sprayed. The control area for result comparison between aerial and ground application was a 0,8-ha treatment area. The two aerial applications made in 2019 were conducted on 10 and 14 July.

For the UAS application two different spray rates were used, 46,8 l/ha and 93,6 l/ha and the flight altitude between 1,83 m and 2,43 above the tree's canopy at a speed of about 4,82 km/h. The ground applicator was a standard commercial one used for this type of purposes capable of spraying the recommended rate of 935,4 l/ha at a speed of approximately 3,2 km/h.

To understand whether the UAS spraying was effective or not compared to the ground methods it was important to take measures of the spray penetration. For this matter Water Sensitive Papers (WSP) and glass fibre filter papers were employed. They were placed on the trees before application and retrieved and analysed using software after the operation of the aircraft. Also, nut samples were randomly picked for deposition analysis and the RPA was examined (Figure 23).

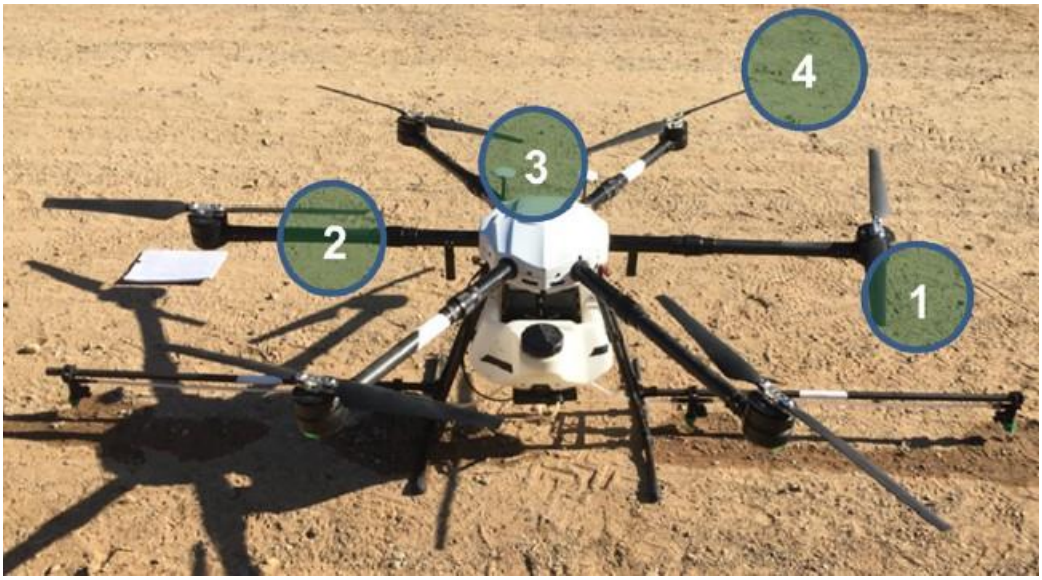


Figure 23 – Locations of the pesticide depositions found on the UAV: (1) spray boom, (2) arms, (3) central hub, (4) rotor blades – Source: [37]

After a careful analysis the scientist involved in this project could understand that the UAS and the ground application methods had comparable overall pesticide residue levels but different coverage and residue patterns depending on the canopy elevations. The higher spray application rate of 93,5 l/ha provided a higher coverage percentage, which indicates that the spray volume label recommendations continue to be vital. It was observed that the spray detected over the drone was minimal opening the possibility to do clean operations. However, the authors of the study considered that, in this type of situation, the UAS might not be able yet to take care of the spraying all by itself, the best choice would most probably be a cooperation between ground and aerial spraying.

4.4.2 Frost Prevention

During the colder seasons frost becomes a common and terrible problem for the orchards. To face the frost problems there are active and passive methods. Active measures consist usually of sprinklers, wind machines, and heaters, while passive methods are commonly site and plant selection, cold air drainage, soil and plant covers.

But to use efficiently any of those methods it is important to know the temperature of the trees composing the orchard. Usually, the temperature monitoring is made using specifically designed thermometers which are placed inside instrumental shelters. This represents, however, some problems and limitations:

- Number of thermometers limits the spatial temperature measurement precision;
- Workers are required to check the temperature;
- Plant tissue temperature might be different from the air temperature;
- Usual ignorance of the spatial plant growth stage variation in the orchard.

To face these problems and try to come up with a better solution two scientist from the Department of Agricultural and Biological Engineering of The Pennsylvania State University, USA studied during the 2020 growing season the possibility of applying an UAS with thermal and RGB cameras to create a heating requirement assessment methodology [38]. The UAS for this study was a DJI Matrice 600 electric hexacopter (DJI Inc., Shenzhen, China) which could carry a DJI Zenmuse XT2 thermal camera (DJI Inc., Shenzhen, China) or a DJI Zenmuse Z30 RGB camera (DJI Inc., Shenzhen, China). This equipment is unfortunately not waterproof, and its lower operating temperature is only -10 ºC. But for this study that did not matter since the main purpose was only to demonstrate the feasibility of the method proposed. The thermal data was collected on 2 June 2020, and the RGB images on 19, 23 and 28 April, 2020, on 2, 7, 13, 16 and 21 May, 2020, and on 24 September, 2020. Thermal images were meant for demonstration and RGB images for model training. The demonstration field was located Russell E. Larson Agricultural Research Center Pennsylvania Furnace and consisted of an orchard with approximately 0.038 ha divided into 4 rows containing 16 apple trees each (Figure 24).

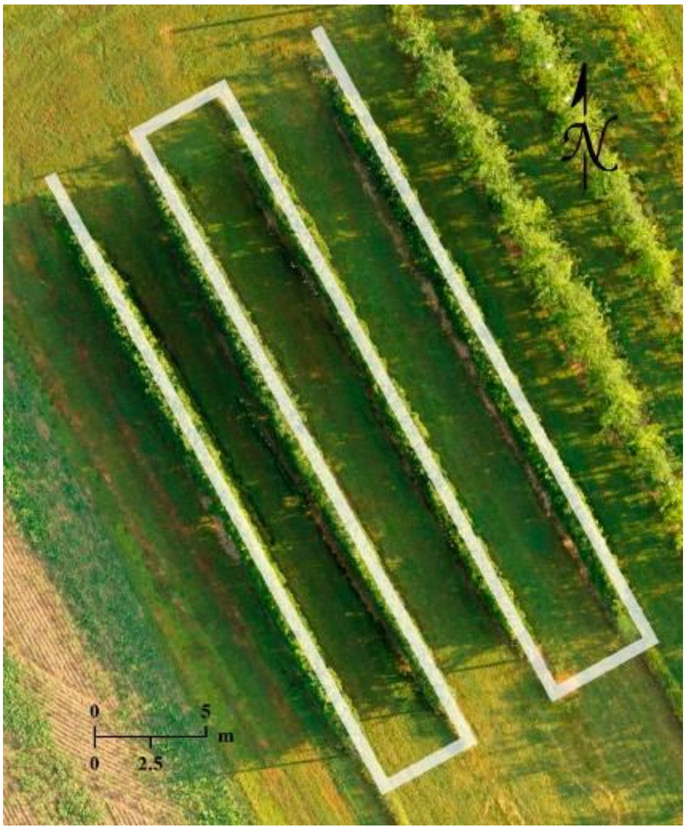


Figure 24 – Test site and flight plan of the UAS used over the orchard – Source: [38]

The data collected by the sensors was later used in a series of methods developed by the researching team and resulted in maps used to validate the study (Figure 25, Figure 26 and Figure 27).

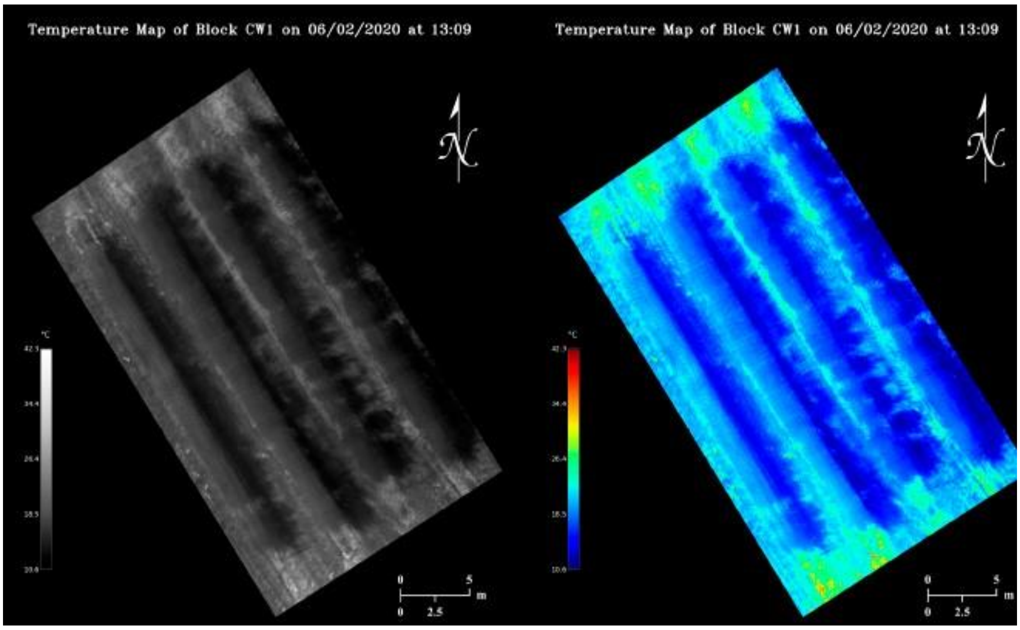


Figure 25 – Difference between the use of gray-scale and false-colour temperature maps – Source: [38]

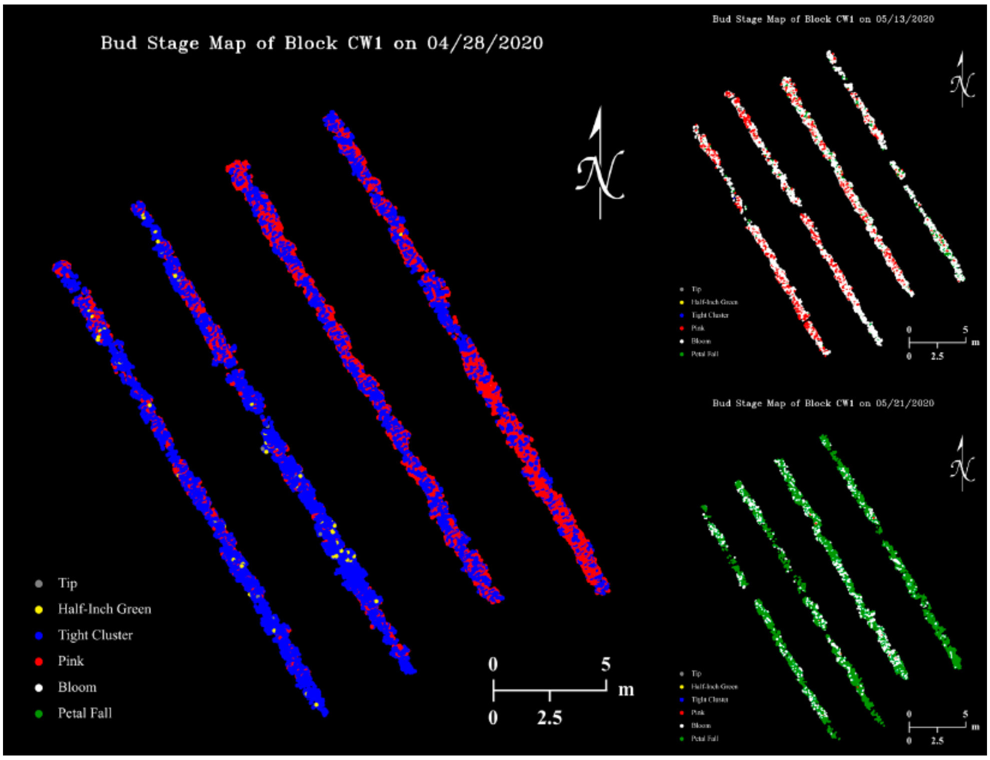


Figure 26 – Growth stage of the apple orchard on three different dates: 28/04/2020 (left), 13/05/2020 (top right), and 21/05/2020 (bottom left) – Source: [38]

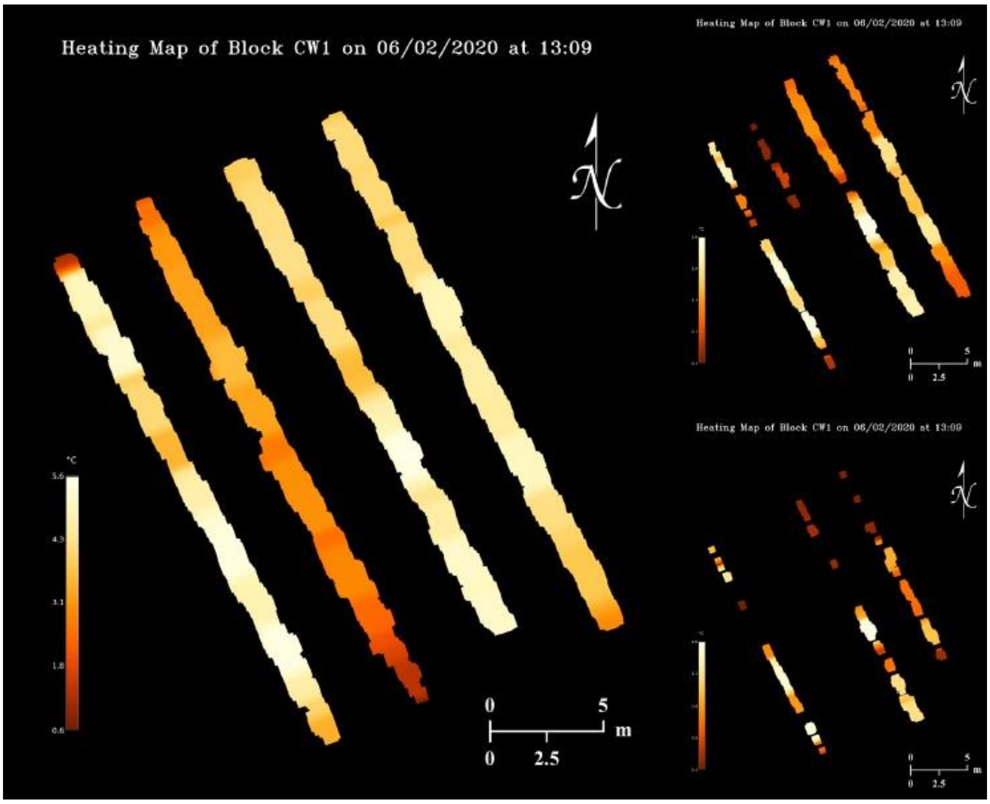


Figure 27 – Heating requirements maps of the orchard using three different levels of artificial critical temperatures – Source: [38]

The work was considered a success and it showed that the proposed methodology is feasible. The thermal image stitching algorithm that was able to produce georeferenced temperature maps with high resolutions considered good enough for individual flower bud mapping. The time to generate those maps can be reduced by sacrificing thermal mosaic resolution. Even considering the difficulty of the RGB datasets the apple flower bud growth stage classifier has achieves satisfactory performances. It was mainly concluded that the uniform heating treatments currently used might be wasteful.

4.4.3 Water Stress Estimation and Management

Regarding also issues on apple orchards further studies were made concerning the water stress suffered by these trees. As already referred before water is vital for any culture and a good management of this resource is essential. A group of French researchers used in 2013 an UAV to acquire images and further treated them to assess the water stress suffered by an apple orchard [39].

The equipment and payload used was (Figure 28):

- Eight-motored multicopter UAV (MikroKopter®);
- Thermal infrared camera (Thermoteknix Miricle® 307 K, 640 x 480);
- 2 compact digital cameras (Sigma® DP1x, 2640 x 1760 pixels):
    - 1 RGB;
    - 1 modified to acquire in the NIR spectral band.

Figure 28 – UAV used for the study – Source: [39]

For thermal validation were installed on the ground 51hermos-radiometers and meteorological sensors. The data acquisitions were done on under fully sun conditions at noon on 4 and 19 July, 1 August and 6 September 2013. On 1 August, five UAV flight took place on 08:00, 10:00, 12:00, 14:00 and 16:00 (local time) this was meant to study the yield intraday variation of temperature. The UAS flew at 40 m and lasted between 4 and 6 minutes. The field area was composed of 520 trees arranged in 10 rows on 5 x 2 m grid, consisting of a total area of 0,64 ha, located near Montpellier, France. Half of the trees (260) were Well-Watered (WW) while the other half submitted to a progressive summer Water Stress (WS).

After the images were captured, they passed through post-processing method so that they could be used to generate information about the orchard (Figure 29). An example of a thermal image extracted from the thermal data collected by the UAV can be seen on Figure 30.

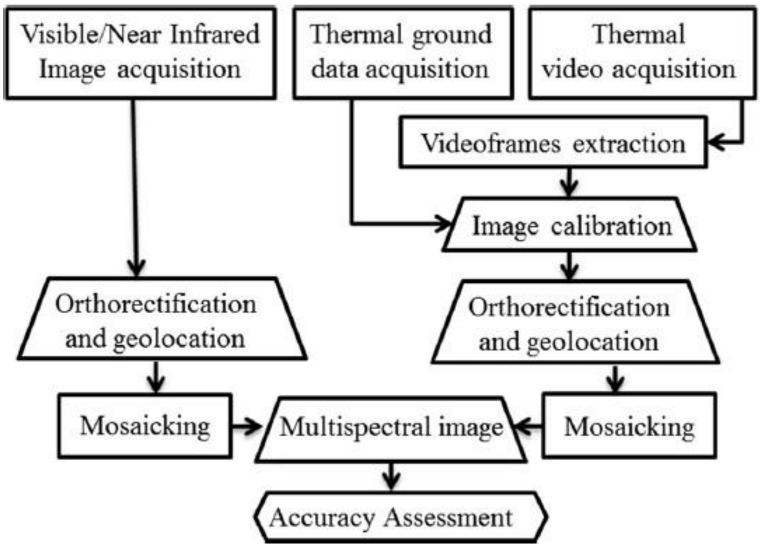


Figure 29 – Flowchart of the data collection and post-processing method – Source: [39]

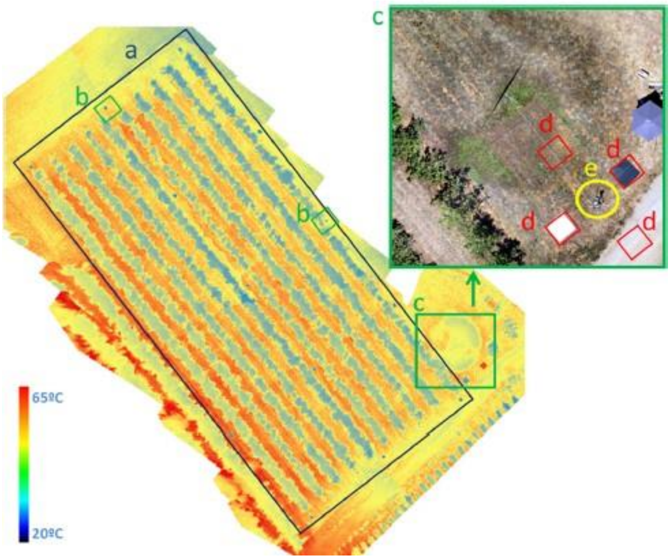


Figure 30 – Thermal image of the plot collected on 13 May obtained from the merge of 30 images. (a) total orchard area, (b) GCPs (15 in total), (c) Ground base station (RGB image), (d) Ground calibration targets, € Meteorological station – Source: [39]

Having collected all the necessary flight data, the people involved proceeded to assess whether the images collected were usable or not and accurate. A thermal validation was also necessary. It was observed that the WS trees initially got a small reduce in their temperature when compared to the WW trees. But as time goes on the WS ones tend to present a higher canopy temperature (Figure 31). At the same time also the soil water potential was measured at a depth of 30 and 60 cm, which allows to understand that even though the leaf temperature of the WS and WW trees on September 6th is similar the WS are under severe water stress.

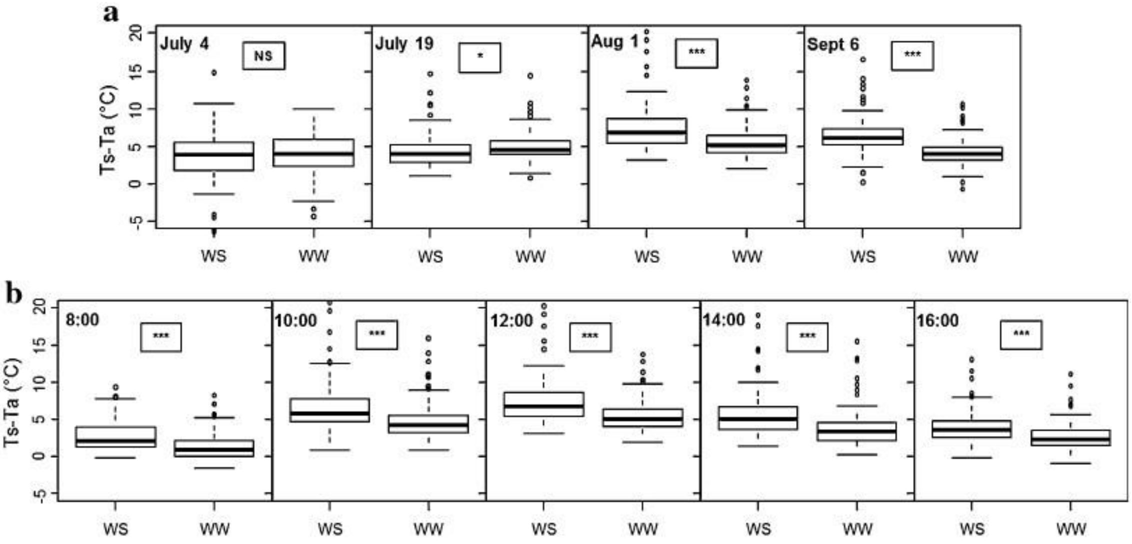


Figure 31 – Canopy minus air temperature distribution (Ts – Ta) for WS and WW apple trees: (a) evolution on four days, (b) daily evolution on 1 August – Source: [39]

This study was considered a success. It developed an effective method for the radiometric calibration of thermal infrared images, which could be critical when using uncooled TIR (Thermal Infrared) cameras. Also, it was possible to assess the tree canopy surface of an entire orchard while maintaining a great spatial resolution allowing for individual tree water stress level evaluation.

Still concerning water management quite interesting was the study developed in 2015 by a group of Spanish people. They focused on the evaluation of the effects caused not only by deficit irrigation but also from the use of saline Reclaimed Waters (RW) and Transfer Water (TW) during a eight year period (prolonged exposure), on two distinct fields: one with grapefruit and the other one with mandarin. The cultivars were part of a 1 ha experimental plot located near Campotéjar, Spain [40].

In this case they used a fixed wing UAV (eBee from SenseFly) equipped with a Canon IXUS 125 HS digital compact camera to collect 110 images over each of the fields in a predefined autopilot flight plan. They were taken on July 7th at an approximate altitude of 100 m (above ground level). From these images the NDVI was extracted (Figure 32). On the same day were conducted physiological and structural measurements at plant scale using a portable photosynthesis system (LI-6400 Li-Cor, Lincoln, Nebraska, USA) for leaf-scale gas-exchange parameters and water potential, an area meter (LI-3100 Leaf AreaMeter, Li-Cor, Lincoln, Nebraska, USA) for leaf area, and a spectrometer (ICP-ICAP6500 DUO Thermo, Cambridge, UK) and a Chromatograph Metrohm (Switzerland) for the detection of phytotoxic elements (sodium, boron and chloride anion).

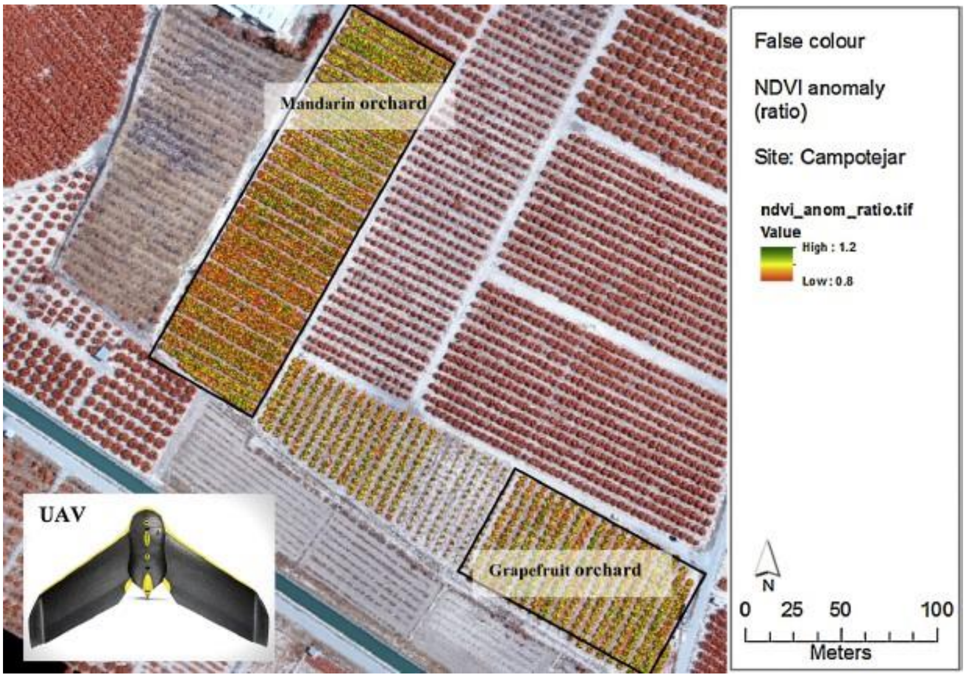


Figure 32 – Obtained NDVI images and UAV used in the study (bottom left) – Source: [40]

After treating the images obtained from the cameras mounted on the UAS, analysing them, and comparing them to the collected ground information the investigators considered that the use of an UAV for the purpose of assessing physiological and structural properties of citrus orchards under water and saline stress is completely feasible.

4.4.4 Disease Control

Not only the combat, but also the prevention of diseases in any type of culture is important. When it comes to the citrus trees one of the most common diseases is the Huanglongbing (HLB), more commonly known as citrus greening disease or *enverdecimento dos citrinos* in Portugal. Recently, given the detection of the first spots affected by this problem, a special authorization has been released by DGAV to combat one of the insects responsible for its transmission, *Trioza erytreae* [41]. The study developed in 2011 in the USA seems here a quite interesting approach for an earlier and faster detection of the affected areas.

Their main objective was to understand if an UAV equipped with a multi-band imaging sensor would have the same capabilities of a conventional aircraft usually used for taking images of the orchards. The area selected for this objective was 0,35 ha plot inside a citrus orchard managed by the University of Florida, in Lake Alfred, USA.

For the UAS the equipment consisted mainly of an hexacopter (HiSystems GmbH, Moormerland, Germany), (Figure 33) and a six narrow-band multispectral camera (miniMCA6, Tetracam, Inc., CA, USA). The flight took place at an altitude of 100 m (above ground level) on two dates, 14 February and 8 March 2012 [42].

Figure 33 – UAV used for the study – Source: [42]

On the other side a single-engine fixed-wing aircraft equipped with AISA EAGLE VNIR Hyperspectral Imaging Sensor (Specim Ltd., Oulu, Finland) was used. It flew over the designated study area on 14 December 2011, at an approximate altitude of 590 m (above ground level).

Using the images obtained from both aircrafts seven Vegetation Indices were calculated:

- NDVI;
- Green Normalized Difference Vegetation Index (GNDVI);
- SAVI;
- NIR;
- R/NIR;
- Green (G)/R;
- And NIR/R.

After analysing the different images and indices obtained from the two aerial platforms the researchers estimated an UAS classification accuracy of the infected areas of 67 – 85 % and lower false negatives of 7 – 32 %, for the conventional aircraft these values ranged from 61 – 74 % and 28 – 45 %, respectively.

4.5 Olives

Portugal is a country known for its good food and healthy traditional diet. One of the products that comes to it is the Portuguese olive oil. With an area of 377 234 ha (98,9 % for olive oil production) [3] corresponding to a production of approximately 153, 8 milliards litres [43] the country places itself among the top 10 olive oil producers in the world [44]. Unfortunately, there are only a reduced number of studies developed in the Portugal about this tree, as happens with the fruit trees this works focus mainly on the use of an UAS for imagery purposes and obtaining different data from the olive trees.

4.5.1 Old UAS Conversion

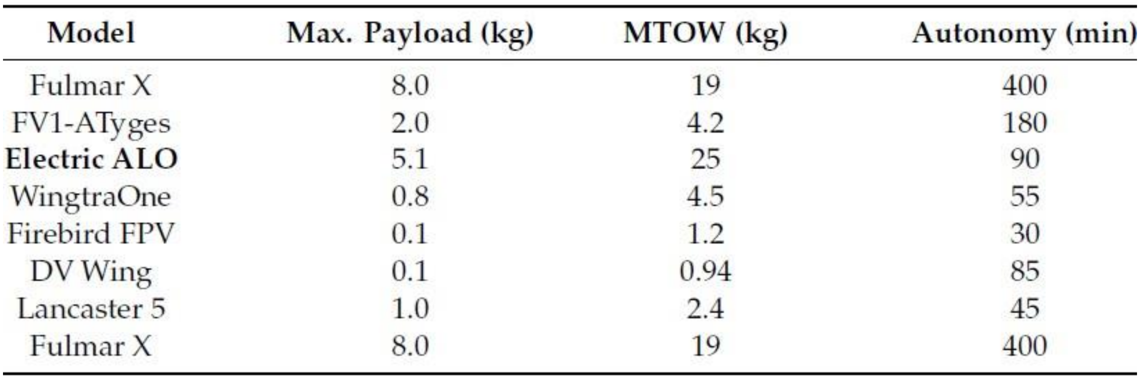
As for works made abroad the selection is quite wide. Very interesting was the project published in 2020 and made in Huelva, Spain. The aim in this case was to convert an old fixed-wing UAS propelled with an internal combustion to electric propulsion. The RPA used in this case was obsolete and declassified and used to be employed as aerial target for military applications and in reconnaissance and surveillance missions at low cost. The objective was to convert it to be used as a data collection platform for olive trees and other large area cultivations [45].

The RPA used in this study was selected from the Avión Ligero de Observación (ALO) program, developed by Instituto Nacional de Técnica Aeroespacial (INTA) in Spain, equipped with a series of sensors that allowed the capture and emission in real time of observations made from the ground. The whole system can be set up in less than 30 min and is easy to transport in a small military truck (Figure 34).

Figure 34 – Complete ALO systems: GCS, launcher and UAV – Source: [45]

The propulsion system was two-cylinder two-stroke engine providing approximately 6,8 hp, fuel tanks were located in the wings. To achieve a 100 % electrical capability all the components related to the Internal Combustion Engine (ICE) needed to be removed. This included the engine, the harnesses, the wing fuel tanks and the fuel supply system. They were then replaced by an electric engine, an Electronic Speed Controller (ESC), a battery and Battery Management System (BMS), a new propeller and a telemetry module. All the new components needed to be fitted inside the aircraft and tuned to work smoothly with each other and with the already existing ones. Weight balance also needed to be adjusted because the new parts had different masses.

After extensive testing and tunning of the redesigned platform the researcher achieved a significant noise reduction and a range increase of about 50 % compared to the ICE aircraft but the payload suffered a reduction. The resulting UAV has similar capabilities, and sometimes even superior, to the drones constructed from the start to be electrically powered (Figure 35). The project developed shows that such an approach is perfectly feasible.



Model	Max. Payload (kg)	MTOW (kg)	Autonomy (min)
Fulmar X	8.0	19	400
FV1-ATyges	2.0	4.2	180
Electric ALO	5.1	25	90
WingtraOne	0.8	4.5	55
Firebird FPV	0.1	1.2	30
DV Wing	0.1	0.94	85
Lancaster 5	1.0	2.4	45
Fulmar X	8.0	19	400

Figure 35 – Comparison between the Electric ALO (converted UAS) and other commercial fixed-wing UAVs – Source: [45]

4.5.2 Irrigation Estimation and Management

The next study considered of relevance also comes from Spain. Published in 2019 and developed by three people it focuses on the development of simple photogrammetric method used to identify areas with a heterogeneous irrigation in olive groves and vineyards [46]. Since this subchapter focuses on olive trees only the relevant parts will be exposed. The work was conducted on a property near Barcelona, Spain on different olive plots with a total area of 1,71 ha (Figure 36). For the imagery a Phantom 4 Pro (DJI Inc., Shenzhen, China) was used equipped with a Parrot Sequoia 4.0 multispectral camera.

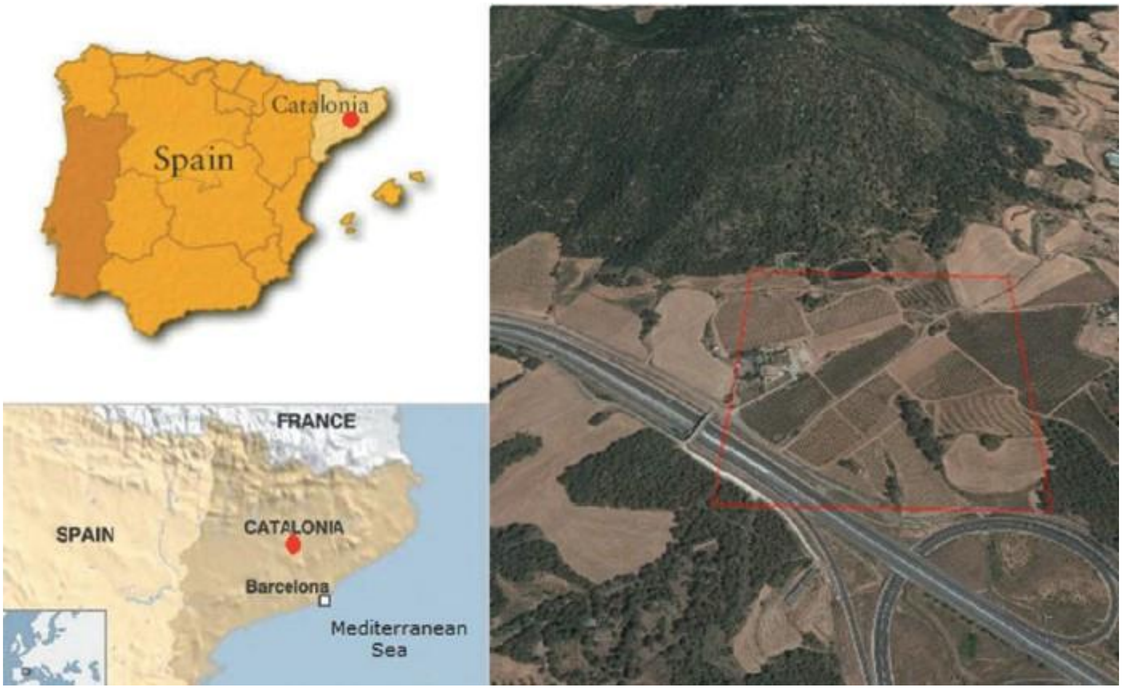


Figure 36 – Location of the study site including an aerial view of the fields – Source: [46]

With the images obtained from the UAS four vegetation indices were calculated: NDVI, GNDVI, SAVI and NDRE (Normalised Difference Red-Edge). These indices were then used to create vigour maps and understand the health of the crop. The use of several indices, easily and quickly acquirable with the UAS, shows of great value since it allowed the combination of them allowed the observation of a series of irrigation irregularities. For example, it let to discover why a specific area of the field had significant vigour problems. Once again, the UAS is a quite unique and fast solution.

Now moving closer to the Portuguese border there is a study of interest developed in the region of Estremadura in Spain. This study was already exposed in the "Cereals" subchapter but now "Plot C", consisting of an irrigated parcel of 28,8 hectares dedicated to olive production, and here will be more exposed [35].

In this area the main objective was to understand whether the existing irrigation plan was adequate or not, for this NDVI maps were used. With the data collected it was possible for the researchers to create an irrigation efficiency map (Figure 37).

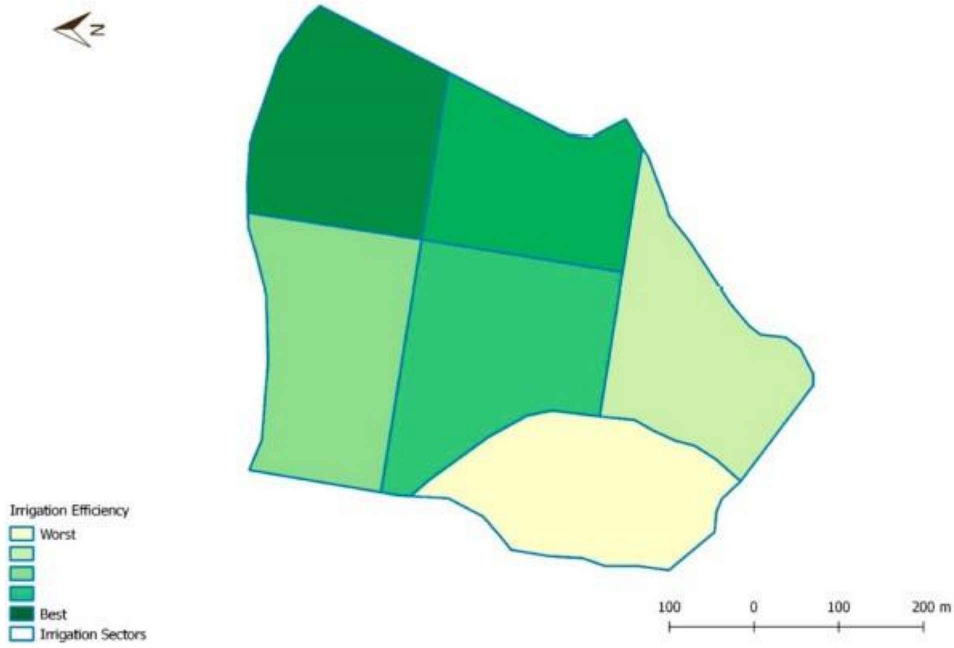


Figure 37 – Irrigation efficiency map developed according to NDVI information – Source: [35]

As in the other plots the cost of the UAS operation was around 500 € but the benefits clearly cover this. The estimated gains of production were estimated at up to 1,7 t/ha, considering the average price of 400 €/t this means that a gain of 680 €/ha is made. In total it represents 19 584 € in the whole field. For a small field this is quite a huge increase in profitability.

4.6 Potato and Tomato

Two products that have a large impact on the Portuguese agriculture and economy are potatoes and tomatoes. Potatoes represent an area of 17 989 ha with a production of 424 294 t [30]. According to [44] Portugal is the 15th largest tomato producer in the world and the 6th in Europe, with a total production of approximately 1,53 million t in 2019 over an area of 15,8 thousand ha, with the vast majority (~94 %) destined to industry [30]. Both cultures represent a small percentage in terms of area in the Portuguese agriculture but their total production and production per area (t/ha) is significative, 23,6 t/ha (potato) and 97,6 t/ha (tomato) [30]. For this reason, it was decided to dedicate a subchapter to them.

At the time this dissertation is being written, there are, unfortunately, no major studies or works available using UAS for tomato and potato farming in Portugal. However, this situation is completely different in foreign countries where a series of studies have been developed throughout the last years. Following will be presented some studies for each culture concerning different aspects where an UAV could represent an improvement.

4.6.1 TYLCV Detection

When it comes to tomato production one of the main diseases in warm and temperate regions is the Tomato Yellow Leaf Curl Virus (TYLCV), this disease is caused by a combination of at least six different virus species. It is so dangerous that it can cause the destruction of an entire crop. Traditionally, to detect its presence on the field a series of samples are collected and analysed by technicians. But this is expensive and time consuming with a significative delay between detection and treatment. Whit the objective of mitigating this problem during the 2018 growing season a group of 3 scientist from Texas studied the possibility of using an UAS based algorithm for early detection of TYLCV [47].

A small study area containing several tomato hybrids with different levels of TYLCV resistance was analysed (Figure 38). Polymerase Chain Reaction (PCR) was used to confirm the infection by the disease and validate the UAS collected data. The flights took place on a weekly basis from 11 April to 10 July 2018 at an altitude of approximately 30 m and used the following equipment:

- Matrice 100 quadcopter;
- DJI Phantom 4 Pro camera;
- SlantRange 3P multispectral sensor.

Figure 38 – Location of the study field in the USA – Source: [47]

To create the algorithm a whole lot of attributes were extracted from the UAS image data: canopy height, canopy cover, canopy volume, and vegetation indexes including NDVI, SAVI, and ExG. Later, machine learning techniques based on artificial neural networks were applied to create the detection algorithm.

Comparing the data obtained from ground validation to the UAV obtained one during the period from 11 April to 10 May the accuracy reached a level of 90% which indicates that the use of airborne systems is feasibly and accurate for early detection of TYLCV. Also, the UAS presents a cheaper and faster way to detect the disease without the use of expensive and time-consuming laboratory tests.

4.6.2 Yield Estimation

Tomato is a fruit with a great number of different varieties, for this reason it is extremely important to select the right one considering their genetics, the environment and the management conditions. In 2016 investigators from the USA and South Korea studied the possibility of using High-Throughput Phenotyping (HTP) from multitemporal UAS images to estimate the yield obtained from a tomato plantation [48].

The field used in this study was located the Texas A&M AgriLife Research and Extension Center in Weslaco, Texas, USA (Figure 39) and 9 different tomato varieties were planted.

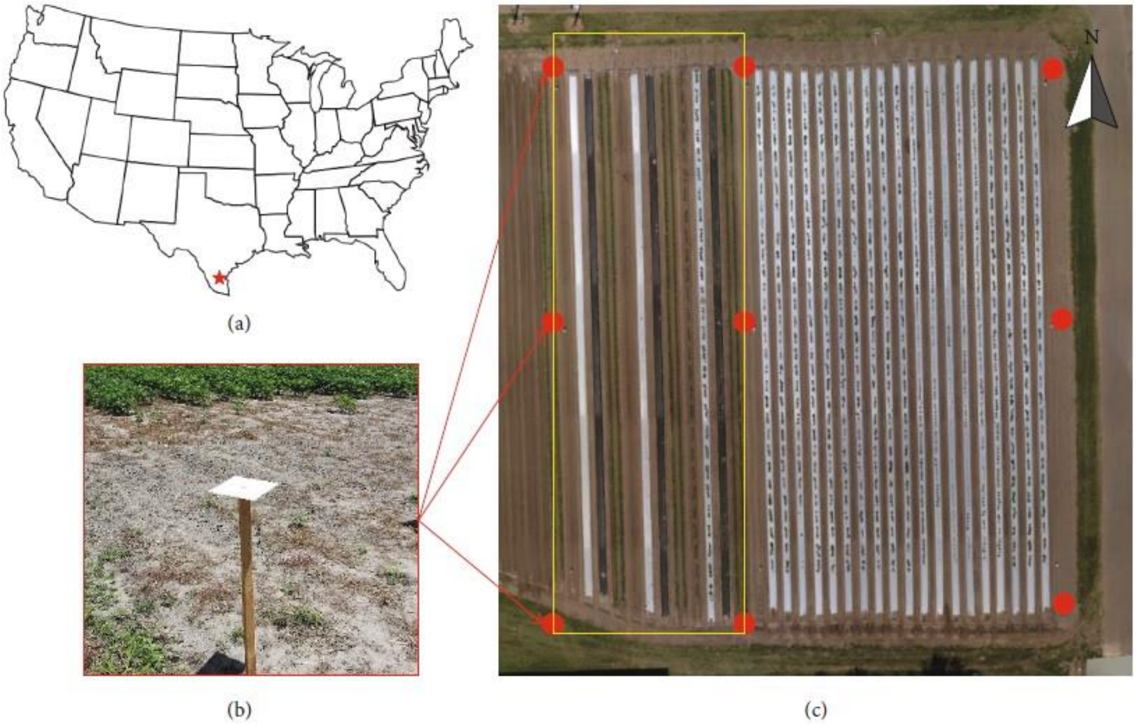


Figure 39 – (a) approximate location of the study field in the USA, (b) ground photo of a GCP, (c) aerial image of the field covered by UAS, the yellow area indicates the selected field for the experiment – Source: [48]

In this case to collect the information four different UAS were assembled, three for RGB data collection and another one for multispectral imagery.

For RGB (Figure 40):

- Iris quadcopter (3DR, Berkeley, USA) + Canon S110 digital camera (Canon, Tokyo, Japan);
- Phantom 2 Vision (DJI, Shenzhen, China) + FC200 camera (DJI, Shenzhen, China);
- Phantom 4 (DJI, Shenzhen, China) + FC330 camera (DJI, Shenzhen, China).

Figure 40 – Example of an UAS used for RGB data collection – Source: [48]

For multispectral imagery (Figure 41):

- X8 octocopter (3DR, Berkeley, USA);
- ADC Snap multispectral camera (Tetracam, Chatsworth, UAS).

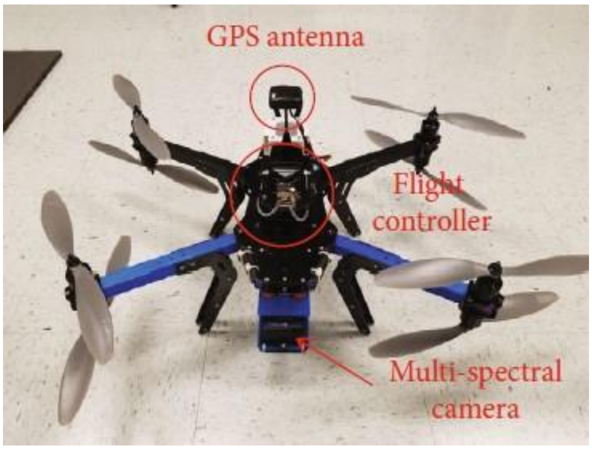


Figure 41 – UAS used for multispectral data collection – Source: [48]

There were conducted 18 flights for RGB data collection between March and June 2016 using the different equipment available, the flying altitude varied between 20 and 40 m. Fort multispectral data imagery 8 flights were made during the same period at an altitude varying between 40 and 50 m. The information collected was then used to mathematically determine canopy cover, canopy, volume, and vegetation indices (ExG and NDVI), also crop growth and growth rate were calculated. It was observed that in high-performance varieties the estimator created based on UAS imagery has some flaws but on lower-performing ones there was a perfect match between the UAS estimated and the real yields. The data collected by UAS was estimated to generate an increase of about 53 % in the tomato yield.

4.6.3 Crop Monitoring

Also in Texas, between 2016 and 2018, a study was conducted to determine the viability of an UAS-based crop monitoring system for tomato fields management. This work focused on 3 different tomato varieties analysing different factors, such as planting dates, plant density, use of plastic mulch and fertilization rate.

In this case the fields used are part of Texas A&M AgriLife Research and Extension Center in Weslaco, TX, USA. With the objective of evaluating the effect of planting dates and mulch covers in 2016 plantation was made on 3 different dates (1st-28/02/2016; 2nd-15/03/2016 and 3rd-31/03/2016) in a Complete Randomized Block (CRB) design with three replicates using white plastic mulch, black plastic mulch, and bare soil. In 2017 the field was planted on 20/02/2017 on white plastic mulch utilizing CRB design with three replicates, the main objective that year was to evaluate the effect of different fertilization rates, so nitrogen fertilization was performed according to 3 different rates 135 kg/ha, 168 kg/ha and 202 kg/ha. Finally in 2018 the objective was solely to study the effect of different plantation dates, so the field was planted on 3 different dates (1st-05/03/2018; 2nd-20/03/2018; 3rd-03/04/2018), [49]. Directly from the field were collected the total yield data and the weather data for each season.

A DJI Phantom 4 Pro UAV (DJI, Shenzhen, China) carrying a 20 Mega Pixel RGB camera was used weekly during the 3 growing seasons, a DJI Matrice 100 (DJI, Shenzhen, China) carrying a multispectral a SlantRange 3P multispectral sensor (SlantRange, San Diego, USA) was also used. The UAV equipped for RGB imagery was flown at an altitude of 20 m at 3 m/s and the one used for multispectral imagery was flown at an altitude of 30 m at 3 m/s. As usual the data was then post-processed to be usable. To understand the influence of the different factors mentioned above, Canopy Cover (CC), Canopy Volume (CV), ExG and Canopy Height (CH).

This study led to a better understanding of how different methodologies, treatments and weather conditions influence the yield obtained from a tomato field. The UAS presents itself in this situation, unquestionably, to be a capable solution of assessing the plant response to different actions and help select the most adequate management practises. This saves the farmer not only money but also a lot of time.

Given the fact that the tomato varieties from the aforementioned study are very specific, the author of this dissertation considered to be of low value the presentation of the observations made by the researchers.

4.6.4 CPB detection

Colorado Potato Beetle (CPB), *Leptinotarsa decemlineata*, is one of the most important and destructive insect pests affecting potato plantations and its larvae and adults are so voracious leaf eater that they can easily and quickly destroy completely a whole field. They also possess the ability to rapidly become resistant to insecticides which lead to unsustainable crop failure cycles and spreading of resistant populations [50]. Considering that the quicker the CPB is detected the better and more effectively it can be contained, two American researchers aimed to understand the effectiveness of an UAS for early detection of damage caused by this pest. This study was conducted during the 2014 growing season and one of the main problems that was faced early on, was that the fact that emergence of insects or its immigration from other fields is essentially random. This rises challenges to the development of prediction algorithms.

The study was conducted at Oregon State University's Hermiston Agricultural Research and Extension Center located in Hermiston, Oregon with the plantations consisting of 16 plots with a size of 9.2 m × 2.6 m (three rows wide). To conduct the study CPB was artificially added to the plots and no insecticide applications were made. To prevent migration of CPB from surrounding areas an insecticide was applied to the region surrounding the study area. Irrigation and fungicide and herbicide application was carried following the usual commercial practices. The CPB were applied on June 9th, 2014, in different densities to each plot: low (1,5 CPB/plant), medium (4,5 CPB/plant) and high (7,5 CPB/plant), (Figure 42).

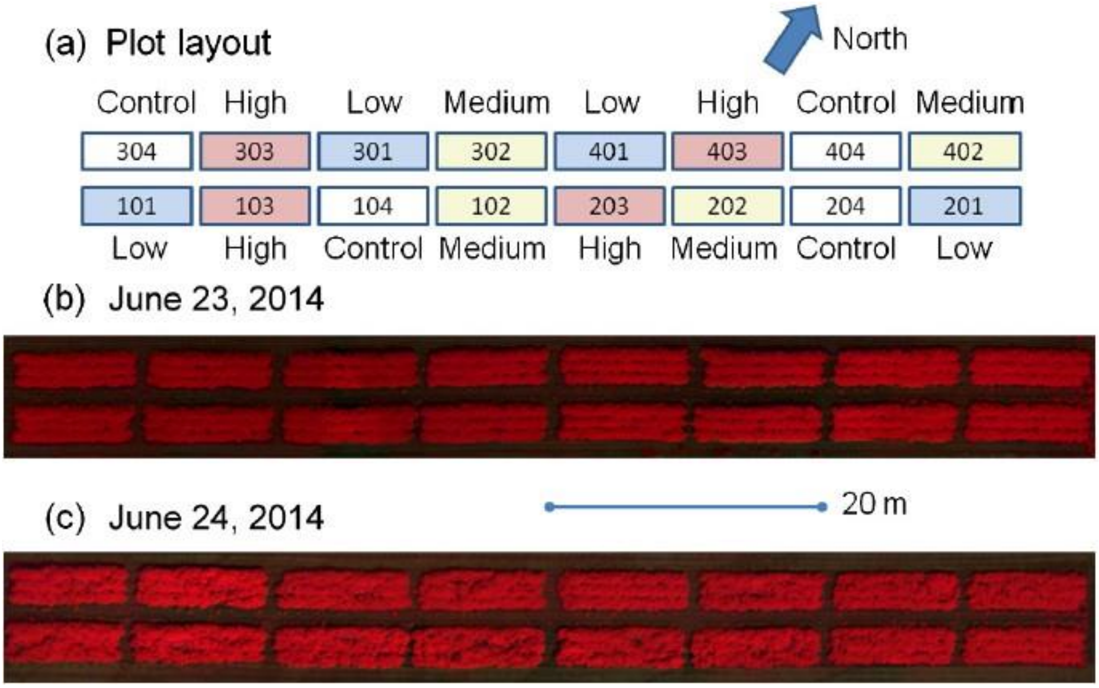


Figure 42 – (a) Plot layout considering the density of CPB applied per plant, (b) Color-infrared orthomosaic image taken on 23 June 2014, (c) Color-infrared orthomosaic image taken on 24 June 2014 – Source: [50]

The flights were made using a S800 hexacopter (DJI Inc., Shenzhen, China) carrying a six-channel Mini Multi Camera Array (mini-MCA, Tetracam, Inc., Chatworth, California) and took place from June 10th to June 24th between 15:00 and 16:00 hours (local time). On 23 June no plant damage was observed but on 24 visual plant damage was evident and since the researcher's main objective was to compare images taken before and after the detection of CPB they considered only the data obtained on these days. The images were then processed, and a series of indices were obtained but only NDVI was used, the plots were then visually ranked according to the density of insect presence.

For supervised classification of early CPB damage three different methods were used: plant height, pixel-based NDVI thresholds and object-based image analysis. It was observed that all of these methods found damage when it first appeared visually, object-based image analysis was the most accurate one.

4.6.5 Satellite vs UAS

Nowadays in some situations satellite imagery is essential to create site-specific irrigation management procedures, it estimates accurately the evapotranspiration (ET). However, the limited resolution and time between observation (several days) is a barrier that restricts the potential capabilities of this method. To surpass this issue a group of investigators tried to understand if this could be done with an UAS endowed with high-resolution imagery capabilities. On this study three crops were analysed, spearmint, potato, and alfalfa, but since for this subchapter of the dissertation focuses on potatoes only the data referent to it will be considered [51].

The study was conducted on a potato field in Washington, USA (45º59'43,52" N, 119º33'57,57" W) with an area of about 4,68 ha. The equipment used for the flight data collection consisted mainly of an ATI AgBOT™ quadcopter (Aerial Technology International, Wilsonville, OR, USA) equipped with a RedEdge 3 multispectral camera (MicaSense, Inc., Seattle, WA, USA) and a Tau 2 640 infrared imaging sensor (FLIR Systems, Wilsonville, OR, USA). For radiometric calibration a calibrated reflectance panel (CRP), (Micasense Inc., Seattle, WA, USA), was used before and after each flight. The UAV was flown at an altitude of 100 m (above ground level). The satellite system used for comparing data obtained from the UAS was the Landsat 7/8 which has an approximate gap between field overpasses of approximately of 16 days, the UAS' flight dates were established to match these ones. The potato data was acquired on July 7th and July 27th, 2018, 72 and 48 days before harvesting respectively.

To process the information obtained from the aircraft three variants of the Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC) energy balance were adopted, UAS-METRIC-1, -2, and -3 (UASM-1, -2, and -3). Figure 43 represents the general flow chart for the models. These three variants were then compared to the standard LM approach.

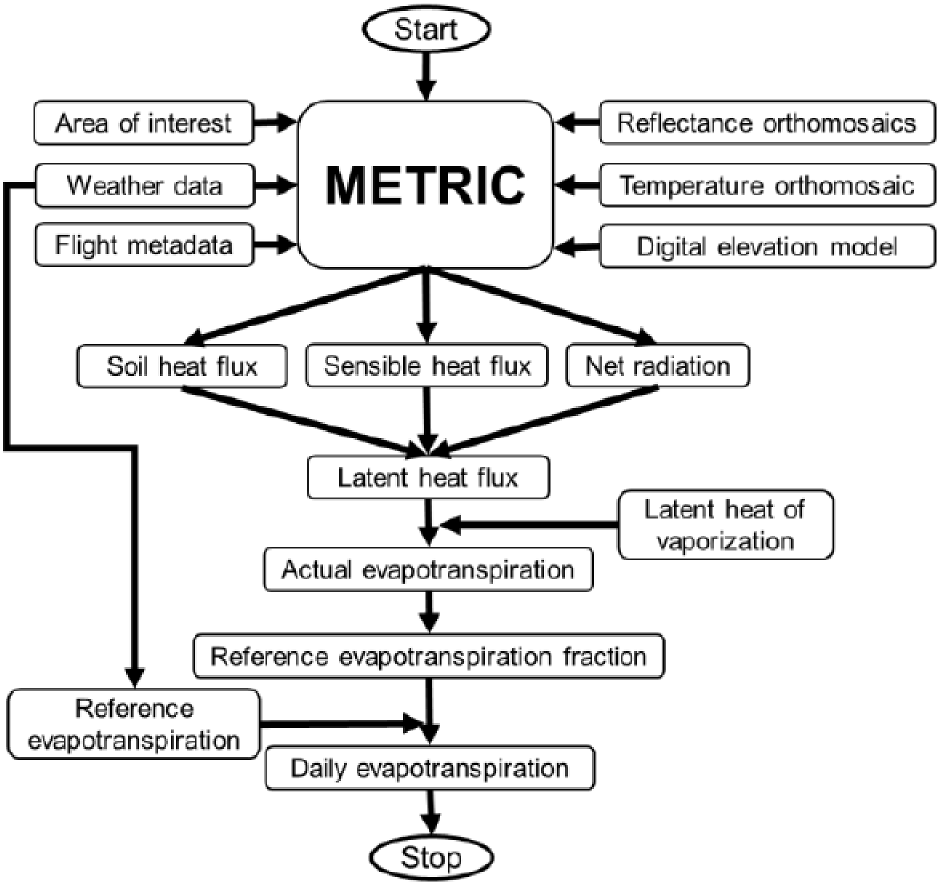


Figure 43 – Flow chart for processing UAS-based imagery data with Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) energy balance model – Source: [51]

After analysing the results obtained the researchers observed that the spatial ET variation potential obtained from the UAS derived maps (6,7–24,3 %) is greater than the one from Landsat satellite derived maps (2,1–11,2 %). The different UASM models performed in a very similar way to the standard LM model with UASM-2 showing the highest similarity. Once again, the adaptability of the UAS and its ease of employment showed to be a huge advantage. The high time between overpasses from the satellite (~16 days) and its susceptibility to cloud cover give the UAS a considerable advantage over it.

4.7 Vineyards

Vineyard cultivation is one of the most representative agricultural products that Portugal has and it has been produced over centuries in all regions of the country. The Douro regions red wine, the Alentejo red wine and the Port wine are just a few examples of the great beverages produced. Currently about 4,4 % (173 254 ha) of the whole farming area in Portugal is dedicated to vineyards with 98,9 % (170 970 ha) of this area destined for wine production [30]. Unfortunately, once again the lack of work done using UAS is astonishing and almost non-existent. In foreign countries there are some studies that seem very promising for application in the Portuguese territory.

4.7.1 Grape Phylloxera

Grape phylloxera is a small insect primarily living under the ground that feeds on the roots damaging the grapevine's root system and consequently blocking the absorption of water and nutrients by the plant. Fortunately, nowadays even being spreader a bit around the world's this is relatively controlled, but at the end of the 19th century a massive epidemic affected a lot of countries in the world.

To study the possible use of hyperspectral and spatial data obtained by an UAV to improve the plant pest surveillance research was made in 2016 in Australia. During this study were analysed two phylloxera-infested vineyard containing multiple grapevine varieties [52].

Site one:

- 8,5 ha;
- 104 rows;
- 160-266 grapevines/row.

Site two:

- 3,16 ha;
- 80 rows;
- 59-63 grapevines/row.

The UAS and its payload used in this study were (Figure 44):

- S800 EVO Hexacopter (DJI Ltd., Shenzhen, China);
- Canon 5DsR (Canon Inc., Tokyo, Japan) high resolution camera;
- MicaSense RedEdge (MicaSense Inc., Simi Valley, CA, USA) multispectral camera;
- Headwall Nano-Hyperspec (Headwall Photonics Inc., Bolton, MA, USA) hyperspectral sensor.

Figure 44 – UAS in action over the vineyard – Source: [52]

In Figure 45 it is possible to understand better the workflow of this study. The UAS in this study was used to collect RGB, multispectral, and hyperspectral data. Later this information was combined with ground-collected data to develop a predictive detection method for pests. Ground methods were also used to confirm the presence of grape phylloxera in the ground and its abundance. The UAS data were acquired in two different periods according to the grapevine phenological cycle: post-flowering (14–15 December 2016) and veraison (14–15 February 2017). The veraison corresponds to the change of colour of the grape berries, in other words when the grapes start to mature [53]. Even though this study was conducted for detection of phylloxera the method could be used without major changes in other types of cultures, such as fruit trees.

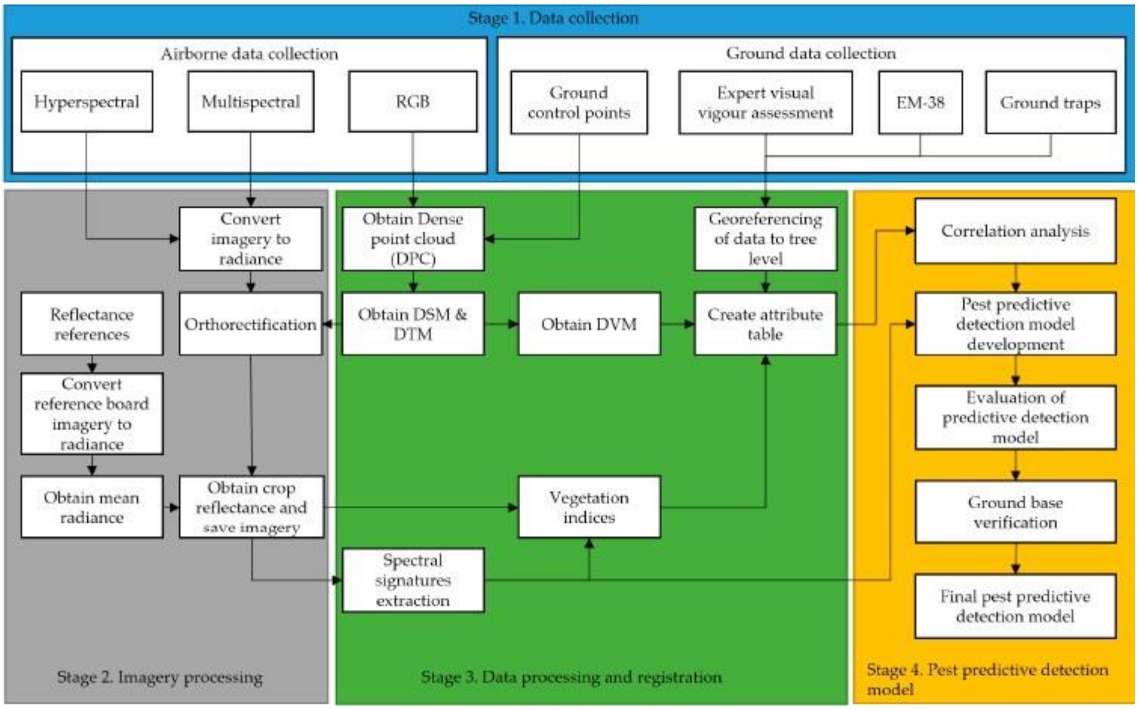


Figure 45 – Workflow of the presented study – Source: [52]

A comparison between the digital vigour model and an expert visual assessment was performed showing that the method developed appears to be a correct approach for the generation of vigour assessments in vineyards. They concluded that the development of a specific phylloxera index is important to assess the extent and severity of the plant pest, which could aid in vineyard management decisions, and it can help in the early detection of the infection since the current ground methods are very slow. With the UAS it is even possible to detect the infection before it is apparent to visual inspection.

4.7.2 Fertilizer Spraying

And when it comes to the use of UAS for spraying a quite interesting study was presented in 2015 by Durham K. Giles and Ryan C. Billing from the Department of Biological & Agricultural Engineering, University of California. They evaluated the performance of an UAV for crop spraying compared to a standard ground system. The aircraft used in this study was a petrol-powered helicopter (RMAX, Yamaha Motor Co. USA, Cypress, CA USA), which was originally developed for race field spraying in Asia (Figure 46). This equipment weighed about 100 kg and was powered by a 13,6-kW engine and had a length of 3,6 m and a rotor diameter of 3,1 m. It also included two cameras with time-stamped records and a radio link control, and since its operation was by direct operator manipulation flights were limited to a 400 m line-of-sight range [54].

Figure 46 – Helicopter UAV used for the study – Source: [54]

The field in which the flights took place was located in located at the University of California Oakville Field Station in Napa County, CA USA and consisted of an 0,61-ha vineyard area with 42 rows, each 61 m long with a row spacing of 2.4 m. All spraying flights were made the same way they would be performed in a commercial operation so that the spray application rate (l/ha) and the work rate (ha/h) would be as most as realistic as possible.

Two different UAV spray systems configurations were tested one consisting of two flat fan nozzles operating at 300 kPa and the other one consisting of three flat fan nozzles also operating at 300 kPa. This means that the UAS is capable of spraying 47l/ha. The spray depositions of this configurations were then compared to the ones of a standard ground sprayer, which consist of an equipment that applies 935 l/ha at a ground speed of 3,5 km/h with hollow-cone nozzles operating at 750 kPa.

The investigators used a series of metallic spray tracers to quantify the spray deposition and verified that the deposition in the grape canopy was similar between the UAS and the ground system showing that an UAV is in fact a viable solution. They also concluded that the deposition rates of the UAS were like the ones of achieved by manned aircrafts operating in similar conditions. Because of these two similarities this type of system can be used to take advantage of the high work rates of the aerial spraying while as well enjoying the ease of deployment of the ground-based spraying systems.

4.7.3 Water Status Estimation

Going back again to the water problem, in 2015 in the Shangri-La region, located in the Chinese Yunnan province, a group of investigators tried to perform a vineyard water status estimation by using multispectral imagery provided by an UAS and machine learning algorithms. Their main objective was to use these technologies to create effective irrigation schedules which could lead to enormous water saves [55].

The field used for this work had 4,7 ha and the vineyard was planted in a 1,2 x 1,5 m grid (plant x row), (Figure 47). The plantation is irrigated by furrow irrigation system. The UAS used in this experiment was composed of a Phantom 3 professional UAV (DJI Co. Ltd, Shenzhen, China) equipped with SEQUOIA multispectral sensors (Parrot Co. Ltd, Paris, France). The flights were made at 13:00 local time on three different dates at veraison during the 2016 growing season: 7 October, 22 October and 4 November . This equipment was used to collect the reflectance data of the whole experimental vineyard.

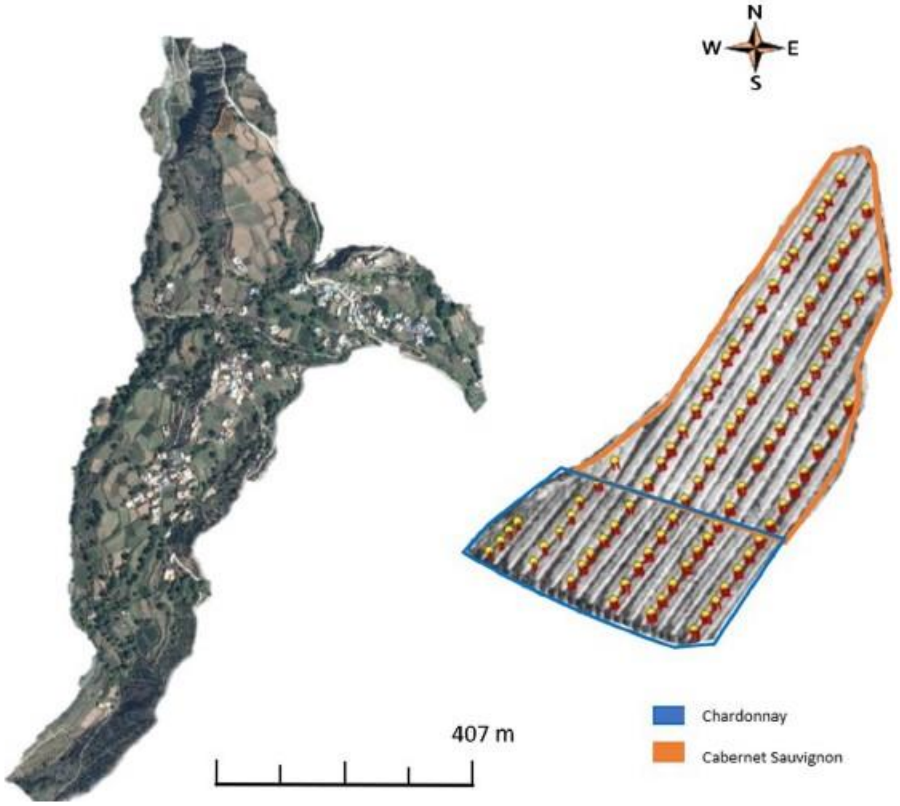


Figure 47 – Map of the area and distribution according to the vine variety – Source: [55]

The data collected from the UAV was then post-processed, used to calculate VIs which were then used to assess the water stress status of the vineyard. The ground data to be compared with the UAS data was obtained using two Scholander pressure bombs (PSM 600 D. Albany, OR, USA) that were used during a period of two hours (12:00 – 14:00 local time) on 90 vines distributed according to a grid inside the measurement plot.

With the information available two Models were constructed: Model 1 and Model 2. Model 1 is a machine learning modelling method, implemented using the Matlab Neural Network Toolbox™ 10 (Mathworks Inc., Matick, MA, USA), used to process the multispectral and physiological data obtained from the UAS. Model 2 has the main purpose of classify the water status levels based on the Vis measured, it was assembled to train a pattern recognition neural network model.

At the end of this experiment, it was concluded that the UAS provide high-resolution images to monitor the vineyard's water status, which is considerably faster and embracing than the usual ground method. The machine learning methods, once properly trained, are a powerful tool to mining data from the multi-dimensional maps and given the high correlations that were found between the actual water status and the estimated one they are very accurate. The use of more precise data (pixel by pixel data) can even allow to detect localized irrigation problems and provide for a better and more detailed irrigation plan. The UAV's used for this type of work represent undoubtedly an efficient, fast and cheap alternative to the currently existing ground systems.

4.7.4 Cost Efficiency

When it comes to do a cost-effective job while getting promising information from the field Italian scientist from the Italian National Research Council showed quite well how to make it. They managed to build a whole capable system with less than 4 000 €. Their main objective was to develop a flexible UAS based tool capable for precision agriculture uses [56].

The equipment used in this study was:

- Six-rotor UAV ("VIPtero"):
    - Modified Mikrokopter Hexa-II (HiSystems GmbH, Moomerland, Germany) – open-source project;
    - 1 kg of effective payload.
- EagleTree telemetry kit;
- Custom-made First-Person View flight system (Eagle Tree Systems LLC, Bellevue, WA, USA);
- "Black Box":
    - Autonomous power supply;
    - GPS;
    - Global System for Mobile Communication (GSM);
- Tetracam ADC-lite camera (Tetracam, Inc., Gainesville, FL, USA);
- Total weight < 7 kg.

To validate the results from the flight was used a FieldSpec Pro spectroradiometer (ASD Inc., Boulder, CO, USA).

The area in study was a vineyard located in Monteboro, Empoli, Italy with approximately 0,5 h. The flight was made on 27 May 2011, at 13:05 local time and took about 7,5 min at an altitude of 150 m. On this flight 63 multispectral images were taken, these were then analysed and processed according to Figure 48.

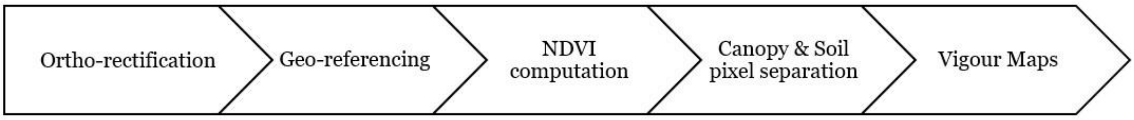


Figure 48 – Image processing of the collected flight data – Source: Own elaboration based on [56]

The resulting maps obtained from this procedure can be seen in Figure 49.

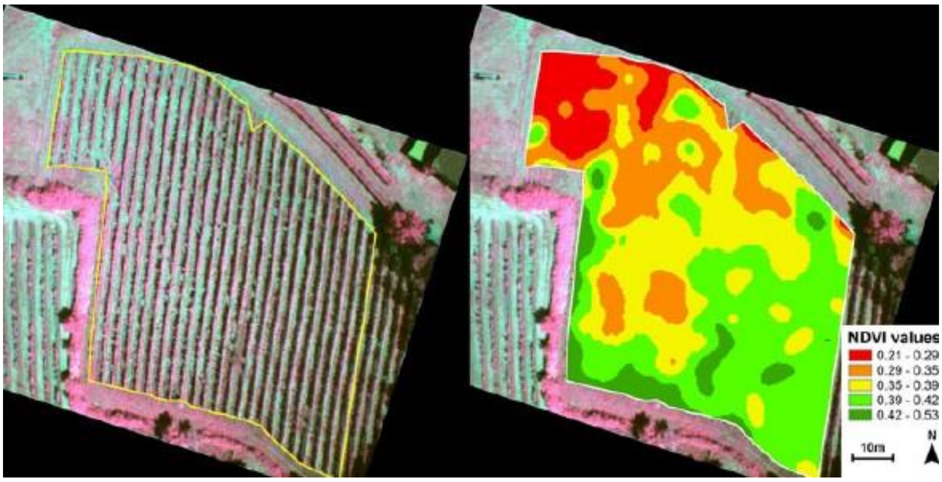


Figure 49 – (left) multi-spectral images obtained from the vineyard, (right) NDVI based vigour map – Source: [56]

The researchers concluded that the UAS used in this study showed good performance while not using complex and expensive technologies. Thanks to its low weight and since it flies in LOS it is not subject to major airspace limitations and does not require scheduled flight plans making it a very flexible platform. However mechanical vibrations still cause some interferences in the image acquisition limiting the quality and number of usable images.

4.8 Conclusion

The main objective of this chapter was to show the current situation of the use of UAS in the Portuguese agriculture and the possible studies made abroad that show potential to be applied in Portugal. Unfortunately, there is still a huge gap in the Portuguese agriculture when it comes to the use of this type of equipment. But when the search is extended to the other countries the number of studies developed in the last years around the application of UAS in agriculture is astonishing.

During this chapter 24 studies and cases were shown where UAV-based technologies were successfully employed in different farming scenarios. There are many more out there and as this dissertation is being written many more platforms are being developed, tested, tuned and applied to increase the profitability, productivity, efficiency and sustainability of agriculture.

Several attempts were made to establish contact with some Portuguese companies working with conventional aircrafts or UAS in the agriculture sector. However only a little few answered and gave any relevant information, showing that this business area is still in an underdeveloped phase when it comes to the application of UAVs in agriculture. The only enterprise answering that used conventional aircraft even discontinued this component of their activities last year.

Chapter 5 – Data analysis

5.1 Introduction

Chapter 5 follows on from chapter 4, where the different studies were exposed. Now a reflection on how they could be applied in the Portuguese agriculture and what advantages they might present will be made. The subchapters of this chapter will be named the same as from chapter 4 to indicate which culture is being talked about. General remarks about all the work done will be made later in Chapter 6.

Unfortunately, there is no major comparison between what is done in foreign countries: as shown in the previous chapter there is a huge lack of use of UAS within the Portuguese agriculture making it difficult to compare what is done in foreign countries with what is done inside Portugal, when there is nothing done or being done.

5.2 Cereals

Whit approximately 380 thousand ha of cereals planted in Portugal the potential of using UAS is huge. Therefore 5 studies were exposed covering 4 different and important topics: Biomass Estimation, Real Time Monitoring, Water Stress Estimation and Pesticide Reduction and Seed Failure Estimation.

The first work presented showed that with only an 800 € sensor, cheap when compared to complex ground equipment, it was possible to effectively estimate the biomass of a small barley field. The uniformity of the data obtained by using an UAS platform was also an important point. This means that this method represents a far more simple, cheaper, and faster way compared to expensive and complex ground-based measurement methods. In Portugal the use of this method could mean savings of thousands or eventually even millions of euros in complex and obsolete ground equipment without the need to instal ground checkpoint affecting the culture. Simple overpasses from UAS are suitable to do all this work. The increasing simplicity of drones also makes them attractive. Specific training and knowledge are needed for both type of equipment, but drones are becoming more and more simple each day. The software used in both cases is also similar. Estimating correctly the biomass is transversal to other areas allowing savings on fertilizers, allowing for the early detection of diseases, pests, irrigation problems and other possible anomalies. So, the saving potential in every aspect is huge!

Connected to the same topic there is the real time monitoring possibility of the plants enabling a constant knowledge of health and growing status of the plants on the field which can as well lead to an estimation on the perfect date for harvest therefore increasing the obtained yield. It also gives uniform information about the whole field without the need to instal other ground sensors along the field resulting in the removal need when it is time to harvest. So, no expensive ground equipment is needed, all the area available can be used for cultivation since there is no need to reserve space for sensors and cables. Since the drone can provide all the data without needing any plant sample the use of destructive testing is also eliminated. With such a large area and quantity of cereal cultivated in Portugal the use of UAS' could be of vital importance to increase the speed the information is collected, treated, and effectively used. The ease in operating this type of aircrafts is also encouraging when it comes to the use by farmer of a more advanced age.

Now when it comes to the 3rd topic water stress estimation it is of common knowledge that the availability of water for human consumption, including agriculture, is on a spiral decay so it is vital to save as much as possible and to use it effective and wisely. Portugal has been suffering from this problem for years and a 2-minute research in the web is enough to unearth dozens of news about this issue. The study presented by the author could be easily applied in the national territory. It eliminates the need for multispectral imaging by only using cheaper thermal and RGB cameras equipped on a simple UAV. The savings of water could reach the order of millions of litres.

On the last subject studied for cereal farming two different studies were presented reflecting over the overuse of pesticides and the seeding failure problem. In the first study it was shown that the UAS is perfectly capable of detecting the most important weed patch areas, therefore allowing the correct elaboration of pesticide distribution maps. With a shown potential save of 14 to 39,2 % in chemicals and savings ranging from 16 to 45 €. Using these values together with the Portuguese area information it is possible to estimate a potential save between 1,15 and 3,24 million € only in silage maize cultivation. Even when spread between the different farmers this value is still huge and could make an important difference. The environmental savings are also very important, less chemicals thrown onto the ground means less soil and water pollution.

Diving into the second study it is more focused on small scale farmers for whom "every penny counts", and any savings or improvements are more than welcome. However, the results can as well be used on big scale cultivations with simple adjustments to cost per flight of the UAS. The study was made so close to the Portuguese borders with very similar conditions that it can be easily adapted. Using the 1,5 % seeding failure observation and the total area of corn produced in Portugal (~380 thousand ha) it is possible to roughly estimate that approximately 5,7 thousand ha are not effectively being used for production. To give it a clearer vision: this is about 1,4 times the area of Porto region that is being wasted. This problem could be easily being detected with an UAV and corrected by reseeding of the more critical areas decreasing this issue.

5.3 Data Management

The data management is perhaps one of the most adaptable works presented. Since the platform is so versatile and flexible it would only be necessary to acquire the SAP system. Besides the inputs coming from the UAS each farmer can chose exactly what type of data he considers to necessary to introduce and obtain the information he wants. This system would be particularly useful in the most remote or mountainous areas with poor internet connections. Using such a system would be particularly useful for industrial scale farmers which own large fields where the amount of information generated is far higher compared to small scale agriculture. For the small producer this might not be of great relevance since a simple computer with adequate software would perfectly satisfy their needs and manage all the data collected.

5.4 Fruit Trees

With a smaller area occupied than the cereals come the fruit trees (~173 thousand ha). They cover a quite varied range of products with many different fruits: the nuts, main fresh products, and citrus fruits.

The first study that was presented reflected over a problem that is common to any tree goods producer around the globe: the challenges presented by their dense canopies and the problems that this represents for the use of UAS in tree fertilizing operations. This was the main reason why this was one of the selected works that the author found interesting to include. This study different from others presented in this dissertation does not directly presents a procedure or estimations that could be translated to the Portuguese agriculture. Rather it serves as an incentive for UAS usage for fertilizing trees. The study authors effectively showed that when correctly tuned and operated an UAV has equivalent spraying capabilities to a conventional ground equipment while presenting itself as cheaper and quicker, less noise and air polluting, and quite more versatile.

The frost prevention technique shown has high potential to be used in Portugal. Even though there are generally no problems related to intense snowfall the cold is still an issue to be faced mainly during the winter and in the more mountainous regions of the country. The study presented once again simplified data acquisition opening the possibility for better elaboration of active measure use plans. This can lead to loss reduction in tree yield caused by cold temperatures and frost.

Once again it was decided to include studies covering the water problem. In the orchards the cases studied exposed are slightly different from each other, but both show great potential to be applied in Portugal. The first one developed a calibration method for uncooled TIR cameras, which are cheaper than and simpler that cooled ones. It is of common knowledge that the Portuguese territory suffers with high temperatures mainly during the Summer and its interference in imagery becomes a problem. So, any efficient and cheap method to combat this issue is more than welcome. Form the study can as well be taken that UAS are extremely efficient in quickly collecting data about the water stress of the trees therefore allowing the specific needs along the orchard. Having this information in hand farmers could use in a more efficient way the scarce water they have. Giving this scarcity another possibility is the use of reclaimed waters. These can be used for irrigation without any major problem and keep the use of drinking water for irrigation purposes to a minimal. It is quite important however to keep the irrigated plants with such liquid under tight control to study their reaction and adapt the treatments made. For this an UAS showed to be an excellent solution and can avoid the need for sample collecting from the trees which causes them damage. Also the coverage of the UAV enables it to analyse quickly and cheaply a great area without the need for expensive laboratory tests.

And at least in any plant diseases play a major role when it comes to problems. As said before the HLB is currently becoming a massive problem and threats the citrus production in Portugal. Since the insects responsible for its spreading develop quickly a premature detection can save the orchard. For this reason, the study presented is very interesting and important to be further studied and applied in Portugal. A 67 – 85 % classification accuracy of the infected areas with only a simple pass from a small UAS is extremely promising and if the UAS could be used several times over the field it tends certainly to increase the accuracy of the data. This speed and accuracy cannot be matched by any ground equipment available. A whole production of more than 412 t needs to be saved and effective measures and direct actions are needed.

5.5 Olives

During the research of the use of UAS in the cultivation of olives one article that popped up and showed great potential not only to be applied in the Portuguese Agriculture but also in other sectors was the conversion made to an old combustion engine powered RPA. In general, this could be applied always everywhere where this type of older unmanned aircraft is used. However, there are costs, work hours involved and the requirement of specialized personal which might not be worth it. Because of this the author would recommend the elaboration of a previous analysis of the expected benefits versus the conversion costs for every specific situation.

Irrigation problems for this culture, like others, could be detected and corrected using a cheap UAS equipped with a multispectral camera which can be easily used to calculate vegetation indices showing irrigation irregularities. If in Portugal this issue would be detected earlier the yield and quality of the olives and subsequently of the olive oil could possibly be increased making it an ever better and more attractive product for exportation. High quality products usually have more demand and higher sell prices than the more standard ones.

5.6 Potato and Tomato

The research for studies covering the use of UAS for potato and tomato farming produced quite interesting results. The studies found were very specific and show great applicability in the Portuguese scenario, specially the one covering CPB detection.

The TYLCV is a problem any tomato producer is certainly familiar; it brings destruction and losses to their farms. If it could be managed, they would for sure be very happy and spare a lot of stress and more importantly money and resources that could be better relocated. By using an UAS for early and fast detection the Portuguese farmers could bypass expensive and lengthy ground processes which involve laboratories and sample collection. They would simply lunch their cheap aircraft over the suspected area, make a few flights, pass the data obtained through a specific software and have easily readable graphics and images showing the extent of the infection and damage caused. All this possibly within a single day depending on the extent of the cultivation and the time of flight. Taking the information obtained it would be very easy for them to quickly put in movement containment procedures.

The yield estimation study presented for this plant is a little bit different than the ones from for other plants. It would be quite interesting for the farmers to know which specific tomato variety has the better yield and disease and pest resistance according to the conditions of their own fields. For this it would of course be necessary to work more but this kind of breeding programs would be cheaper and have faster result analysis by using an UAV. Faster results means that the varieties with better results can be sooner introduced in the farm. Even if this takes one or two years yield the benefits in the long term are obvious: less need of chemicals, more efficient irrigation, and better yield. It has the potential to save thousands and thousands of euros while helping the environment. It is also very important for any farmer to understand how different treatments affect their plants.

When it comes to a pest affecting the potatoes plants CPB is the big deal. Even with their big differences it might be considered the equivalent of TYLCV for potatoes: highly destructive, quickly spreading and a total disaster for any farmer. As any major pest the sooner it is detected the better. For this in Portugal the author suggests the use of an UAS for early detection as was exemplified in the study presented in Chapter 4. It was shown that damage appeared overnight so no ground equipment would be quick and accurate enough to show how much of the field was affected and how severe the damage already was. Similar to TYLCV with the use of an UAV any farmer, from small scale to industrial scale, would simply need to perform an overflight, process and analyse the data, starting the treatment as soon as possible and protect most of the potential yield, which means protecting their profits.

5.7 Vineyard

At last, comes the wine industry. One of the most important ones for the Portuguese industry great effort was put into choosing studies as much as relevant as possible. The first one covered the phylloxera problem which in the past was responsible for great destruction of Portuguese vineyards. As any pest it is always important to detect any disease focus so an UAS would, once more, be an incredible solution for any farmer in Portugal involved in wine production. When compared to ground methods they are faster, cheaper, and extremely more versatile covering a huge area providing accurate and uniform information about the field. Using an UAV for early detection of phylloxera might prevent the loss of several ha of vineyards and avoid thousands of euros in losses. Sometimes this kind of issues is exactly what it takes for a farmer to quit the activity for good. With such a vast territory Portugal needs to keep its farmers motivated.

The use of UAS fertilization methods can as well be used in vineyards. The study presented showed that also in vineyards they have similar work capabilities to the ground equipment currently used. The use of an unmanned aircraft could be quite interesting to apply to the Douro region where vineyards are planted in slopes, and it is easier for an UAS to operate compared to ground sprayers.

A good irrigation is critical for vineyards to reach its full potential and produce high quality grapes which later defines the quality of the wine. This means that if the plants are put under water stress the farmer will later face the consequences and might even have severe losses due to poor sales and eventually drought of the vineyard. For this reason, a full and quick assessment made regularly by an UAV is one of the best solutions available. It gives the grower the possibility to adjust irrigation plans accordingly to the needs of each region of its field, helping the plant to grow as healthy as possible. At the same time, he can even use the data captured to study eventual ruptures in the water supply system.

To capture data with an UAS there is no need for big costs. A simple platform with an estimated cost of less than 4 000 € was assembled in 2011 by Italian investigators. This comprised everything from the aircraft to the payload and all the systems. They managed to capture accurate NDVI maps from a vineyard. It happened almost eleven years ago! With the technology development in UAS the price is most certainly even lower nowadays. Other interesting fact is that this platform was developed over an open-source project which means that any farmer can use and adapt it without the need for major commercial licenses by the company. It is incredible!

5.8 Conclusion

Through the explanations presented in this chapter it is clear that the possible applications of UAS in the Portuguese agriculture are in fact enormous. Millions of euros in possible savings and profits are not currently being taken advantage of just because there is not enough investment in this type of technology. The UAS present themselves relatively cheap and easy to operate machines with a great potential be used in every aspect of the agriculture and in almost any type of conditions.

Chapter 6 – Conclusion

6.1 Introduction

This chapter presents the final results of the study developed in the last chapters and tries to understand if the initial objectives were accomplished. A synthesis of all the work done will be presented as well as some final considerations, and finally the author will try to introduce some future research that could be further done on the subject in study.

6.2 Dissertation synthesis

To begin this dissertation the object and objectives were set, where it was agreed to study the use of UAS in agriculture and the feasibility of its application in Portugal. So, this was considered the object of study. Food production is vital for human survival and any new technology that could help it should be more profoundly studied and further developed. Also, the Portuguese agriculture seems a bit late in the use of UAS for the purpose of creating a better and more sustainable agriculture. Because of this the two main objectives for this work were firstly to understand the current situation of the Portuguese agriculture sector, the use of any form of air vehicle in it and how UAS in general work, and after this assessment was made to understand if and how the use of drones could be possibly used in Portugal to improve the productivity but also the profitability of farming in any way possible.

The importance of the agriculture for the Portuguese economy and therefore the need of long-term sustainability became very clear in Chapter 2 where a literature review on its current situation was made. Agriculture is common to the whole territory and a great variety of products are currently being farmed, ranging from fresh products, passing through olives, grapes for wine production and cereals, cattle raising is also very important. However, the situation is not ideal and the methods are still, in general quite old. Currently farming activities are responsible for about 2,4 % (7 833,50 million €) of the Portuguese GDP but the food balance is still negative (-3 981,30 million €). So, an increase in the quantities produced and in productivity would be more than welcome. The high average age of the farmers (64 years) is also a concerning factor, which could possibly lead to some resistance when it comes to implementing new technologies in this sector. The substantial increase in the presence of corporations in agriculture could here lead to some important development, it is usually this type of owners that, seeking for an increase in profits and decrease of expenses, that have the will and capability to invest in new technologies and get the best out of them.

In Chapter 3 a literature review on the current state of the UAV technologies was made. It was possible to understand that they have become very common and quite easy to build and operate over the last years. When all its components work smoothly together, they become very versatile and can execute complex missions which otherwise would be extremely dangerous or even impossible to accomplish. Like any other technologies UAS also have limitations and disadvantages, depending a lot on the mission scenario and the components installed. In the last years there has been quick and effective evolution in the UAS regulations, however they are still somehow limitative, more specifically in Portugal where the use of UAVs on big agricultural properties and in a massive way is still limited by legislations that the author of this work considers obsolete, antiquate and investment deterrent of significative investments in this type of technology.

The study case in itself (chapters 4 and 5) consisted firstly a prospection of what currently is being made in the Portuguese agriculture, or has been made in the recent past, using UAVs. For this, extensive research was made in online data bases, national companies in this sector where and related people where contacted. Unfortunately, this has produced scarce and discouraging results. It was concluded that for the majority of cultures there are none, or almost no application of UAS, with one of the contacted having even shut down its activity in the agricultural sector. There are, however, some little encouraging signs coming from some small and recent companies which are trying to dynamize a bit this activity.

Posteriorly, a profound research on international level was performed focusing on recently developed technologies and methodologies using UAS in agriculture. For this search the species farmed in Portugal and characteristics of the terrain were taken into account. For an easier analysis and exposure of the different studies found it was decided the research according to the most important cultures: cereals, fruit trees, olives, potato and tomato and vineyards. A subchapter was also reserved for an aspect considered very important when it comes to managing huge amounts of information: the proper data management. The themes explored vary quite a lot, but there are some that are common to almost every culture: pesticide management, management of the water resources available, real-time monitoring of the farm and the early detection of parasites.

Taking into account the studies/works found and after trying to understand how they could possibly be applied in the Portuguese scenario it was noticed that there is in fact a lot of room for it to happen, as long as there is the willing and the need resources for and adequate investment are made available. In the horizon lays a concrete potential increase in profits (higher quantity produced) and decrease in expenses (less chemicals) in the order of several thousands, eventually even millions, of euros. It was also possible to understand that a better management of the irrigation systems could lead to huge savings of water, so vital for farming activities.

6.3 Final Considerations

Both main objectives previously established at the beginning of this work were fulfilled since it was possible to perceive the main cultures currently being farmed, how agriculture impacts on the global Portuguese economy and if there are any aircrafts being used. Also, very important was to understand the main components of an UAS and what makes them so versatile and adaptable to many different operational scenarios. Thanks to this it was easier to make an effective and concise research on relevant methods and technologies developed in foreign countries. Unfortunately, there are not many studies developed in Portugal which at some point discouraged a bit the author of this dissertation, but it also worked as an incentive to try to show that UAVs could represent a significative added value to the Portuguese agriculture.

6.4 Future Work

During the development of this dissertation, it became clear that more specific and accurate data could be obtained if similar methods to the ones of the studies presented would be used in Portugal. To prove the real feasibility of the methods and technologies presented it would be interesting to actually implement them in some farms. This would allow to gather real data and prove the theoretical estimations made in this dissertation. It would also allow to better take into consideration the Portuguese real land conditions.

As shown before, alongside agriculture cattle raising is also a very important activity in Portugal. So, since this dissertation focused mainly on the agriculture a study covering the use of UAS in that type of activity would also be very interesting and helpful.

6.5 Conclusion

This dissertation tried to show how the UAS could possibly be used in the Portuguese agriculture and the benefits that can be taken from it. The author hopes that the different works, technologies and methodologies hereby presented could possibly serve as a starting point and incentive to those who have the power and resources to actually make a difference in the way food is currently produced.

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