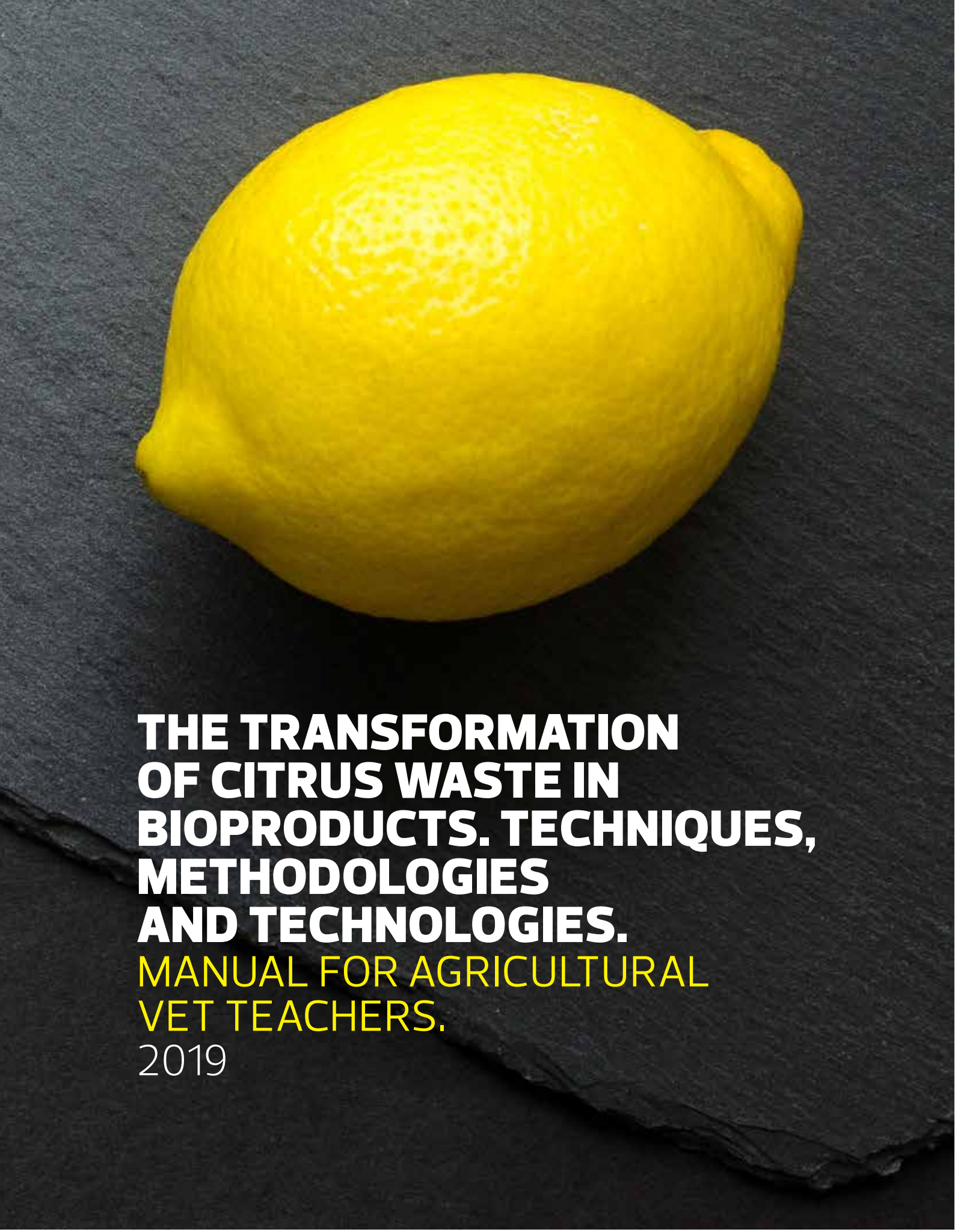

THE TRANSFORMATION OF CITRUS WASTE IN BIOPRODUCTS. TECHNIQUES, METHODOLOGIES AND TECHNOLOGIES.

MANUAL FOR AGRICULTURAL VET TEACHERS.

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The transformation of citrus waste in bioproducts.

Techniques, methodologies and technologies.

Manual for agricultural VET teachers

CitriVET Project Consortium

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The transformation of citrus waste in bioproducts. Techniques, methodologies and technologies

Manual for agricultural VET teachers

MODULE 1

INTRODUCTION TO THE CITRUS WASTE VALORISATION

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1.1. TRADITIONAL CONSUMPTION AND NEW DEMANDS FOR HIGH QUALITY CITRUS PRODUCTS

The term citrus is used to denote a wide range of fruit species, among which the most important are sweet orange, mandarin, lemon and grapefruit. In addition to being used as fruit trees, some citrus species are also used as ornamental plants in public spaces, in private gardens and as indoor plants. This group of species are originated from Asia and the Malay Archipelago (Vavilov, 1926), but they found in the Mediterranean a second homeland, where their production has been going on for centuries and where the quality of the fruits reaches very high levels, even higher than in their areas of origin. Mediterranean Basin became an important citrus production zone, especially mandarins, and much of this fruit is exported as fresh fruit. Some Mediterranean countries are important citrus producers and exporters. Spain is the most important exporter of fresh citrus fruits in the world. This country exports more than one and a half million tons of oranges each year, nearly the same amount of tangerines and about six hundred thousand tons of lemons (FAO, 2019). Italy is the most important producer of blood oranges.

Some of today's citrus fruits originated in the Mediterranean through natural mutations or hybridizations. This is the case of clementines, very popular for their ease of consumption and the almost absence of seeds.

Citrus fruits have been part of the Mediterranean diet for many years, being consumed as fresh fruit, but also used to make various dishes and desserts (Duarte *et al*., 2016). However, in the last decades, citrus consumption has evolved considerably, following what happens with almost all kinds of food. Consumers and society demand from farmers the supply of food with guarantees of quality and with a low environmental impact. However, the prices paid to the farmers are many times a small part of the value paid by consumer in the supermarket. Packaging, marketing and transporter structures retain most of this value. These conditions bring the farmer to rationalize the resources application. In this context, the fact that production residues can be regarded as a resource potentially provides an economic advantage for farmer and has also a positive effect on society's image of citrus production.

1.2. BUSINESS MODELS IN THE CITRUS SECTOR OF THE MEDITERRANEAN COUNTRIES

In Mediterranean countries citrus trees were cultivated together with other fruit trees, in a polyculture system on familiar farms. Almost all those farms included also livestock. In these complex systems the waste of a sector was a resource to other(s). Damaged fruits were used to feed swine or other livestock species. The chickens grazing in the field took advantage of all the uncollected fruits and still controlled the weeds and some pests in the garden. Wood resulting from pruning was used as fuel in the farm itself or at the home of farmers or rural workers.

In the last decades this type of farm has been disappearing. In their place appeared specialized farms. Those engaged in citrus production usually have no other productions. Those farms achieve

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greater productive efficiency as a result of a greater dominance of production technology. It is easier to master the production technology from a single crop than to do so for a broad set of crops of different groups. However, these specialized farms acquire all the production factors and sell almost all production, since self-consumption has almost no expression. On these farms everything the orchard produces but is not accepted on the market is a waste and represents an additional production cost due to waste management. There are no other farm activities that can absorb/use this waste. The conversion of the farms to the monoculture leads to a reduction in the environmental sustainability of the farms themselves and of the territories in which they are located (Jacques & Jacques, 2012; Fernandes et al., 2016).

The shift from polyculture to specialized production has been accompanied by a shift from the closer marketing model to a larger scale marketing model that focuses on distant national markets and export. Marketing is now done through fruit packing plants owned by private companies, POs or Groupings that centralize production for larger markets.

1.3. AGRICULTURAL PRODUCTION MODES AND QUALITY CERTIFICATION

In recent years different farms have taken different strategies in terms of production mode. Integrated production is the minimum in terms of production sustainability that all farms had to adopt. Some have gone further and have been converting to organic farming. Some companies continue to have a strategy of intensifying production and there are even some experiences towards the establishment of super intensive orchards. The most sustainable modes of production are certified by independent certifying organizations.

1.3.1. INTEGRATED PRODUCTION

Integrated Plant Protection (IPP) has been adopted by most citrus growers for several decades. This consists of a balanced approach to managing crop production systems for the effective, economical and environmentally sound suppression of pests and diseases. IPP is not a stand-alone concept but should be integrated into the production system since many other components of tree fruit production can impact the prevalence of weeds and plant pests and diseases. The successful application of most IPP components is very dependent on the proper management of other production practices. For this reason, integrated production turned out to be the production system adopted by almost all farmers.

Integrated production is regulated in each of the countries of the European Union and in some cases, regulations may be specific to each region.

In the case of Portugal, integrated production standards are applied throughout the national territory and, as regards pruning, stipulate that pruning is advisable to be carried out after harvesting as often as is appropriate to avoid problems of alternate bearing, improve fruit quality, improve tree aeration and lighting (Fig. 1), facilitate harvesting and increase the effectiveness of

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pesticide treatments (Cavaco & Calouro, 2005). About the destination to be given to pruning waste establishes that the burning of pruning residues in the parcels is prohibited. In orchards in good sanitary conditions it is advisable to incorporate pruning residues into the soil after it has been fragmented and shredded on site. In cases of doubt about sanitary conditions of the pruning waste, composting is recommended whenever possible (Cavaco & Calouro, 2005).

Figure 1 – Good fruit production inside the canopy on a 'Washington Navel' orange tree, pruned to improve tree aeration and lighting.

In the case of Spain, integrated production standards for citrus fruit have been established for the different autonomous communities in which the citriculture is of major economic importance.
For the Comunitat Valenciana the standards for integrated production in citrus were approved by the Regional Government [Conselleria de Agricultura, Medio Ambiente, Cambio Climático y Desarrollo Rural (CAMACCDR)]. In this region, burning of pruning waste is not completely prohibited It is only said that the burning of pruning waste is prohibited under uncontrolled conditions and when there is a risk of fire spread. In these norms it is recommended to incorporate the pruning waste by means of cutting and crushing it in situ, except in the case that they show symptoms of attack by pests or diseases (*Alternaria* and other fungi). In this case, pruning waste will be removed from the field and burned immediately (CAMACCDR, 2017).

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The integrated production standards of the Community of Murcia recommend the "destruction of pruning waste outside the crop plot, preferably by fire (Fig. 2). In case of crushing within the plot itself, make sure that the size of the remaining chips is smaller than 10-15 cm" (CAA-CARM, 2007).

Figure 2 - Burning pruning waste inside a citrus orchard.

The Andalusian Integrated Production Standards recommend "incorporating pruning waste into the field by cutting and crushing in situ, except in plantations affected by diseases in which pruning waste may contain the disease inoculum" (CAPDR-JA, 2015).

In Italy, Sicily and Calabria's integrated production technical standards refer to citrus pruning as an important cultural operation, but do not determine the destination of pruning waste (ARASPM-RS, 2017; DARASFR, 2018). Thus, the adoption of integrated production does not guarantee that pruning waste will be recovered in all Mediterranean countries.

1.3.2. SUPER INTENSIVE ORCHARDS

The super intensive production technology that has been developed for olive and other fruit crops is being adapted to citrus trees. But so far, this technology is limited to a few trials. This production technology is based on annual pruning with the elimination of all branches that go outside the boundaries of a hedge and topping (Fig. 3). Thus, the amount of pruning waste to be produced by this form of citrus training system will be very high. This makes the valorisation of pruning waste very important if this technology will be adopted on a large scale.

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Figure 3 - Mechanical pruning of an experimental super intensive citrus orchard.

1.3.3. ORGANIC FARMING

Organic farming, also known as “agricultura ecologica” (Spain), “agricoltura biologica” (Italy) or “agricultura biológica” (Portugal), is an environmentally friendly mode of production whose importance has increased in recent decades. Organic growers are prohibited from using most synthetic pesticides and fertilizers and must take measures to protect water and soil quality. The Organic Farming logo is a guarantee that the food we are buying was produced in ways that minimize harm to our health and the environment. The organic logo can only be used on products that have been certified as organic by an authorised control agency or body. This means that they have fulfilled strict conditions on how they must be produced, processed, transported and stored. The logo can only be used on products when they contain at least 95% of organic ingredients and additionally respect further strict conditions for the remaining 5%. So, it is a high-quality fruit production for local markets and for export.

European Regulation (EU) No 848 (2018) did not lay down specific rules on pruning or pruning waste in organic farming. However, this mode of production is based on the use of local resources and the minimization of waste generation, integrating in the spirit of the circular economy. Pruning citrus grown in organic farming is important for pest and disease control. In this production mode it makes no sense to burn pruning waste. The most recommended is its incorporation in the soil, to increase its organic matter content. One of the principles of organic farming regulation is to improve or

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maintain soil fertility, so any operation that allows organic matter to be returned to the soil is advisable, such as shredding pruning waste and incorporating it into the soil.

1.3.4. GEOGRAPHICAL INDICATIONS

Citrus fruits produced in some regions of the Mediterranean Basin have a high quality, recognized by consumers and markets. The European Union has been recognizing the quality of these products and establishing protected names that are used to value products that go through a certification process which ensures their authenticity. At this moment there are at least 5 protected geographical indications (PGI) for citrus fruits: *Citrinos do Algarve* (Portugal), *Cítricos Valencianos / Cítrics Valencians* (Spain), *Arancia Rossa di Sicilia* (Italy), *Arancia del Gargano* (Italy), and *Citron de Menton* (France). There is also a protected designations of origin (PDO): *Arancia di Ribera* (Italy). Even when the fruit certified under these denominations does not receive the deserved price appreciation, the certification seal facilitates the marketing of the fruits.

Each geographical indication has a specification setting out the rules to be respected for fruit production. Some of the geographical indications include norms regarding the level of sustainability of production.

1.4. RELEVANT ACTORS IN THE PRODUCTION AND MARKETING OF CITRUS

Citrus production is increasingly concentrated in a small number of farmers. This process is most evident in some regions such as Andalusia in Spain or Alentejo in Portugal. These larger farmers play an important role in the dissemination of new citrus production strategies. In regions such as Valencia, Spain, or the Algarve, Portugal, rural property is more divided and citrus farms are smaller. In these regions, producer organizations, which concentrate and market the production of dozens (or hundreds) of farmers, are the most relevant actors in the production and marketing of citrus.

Changing farming practices obviously must go through changing the mindset of farmers and changing the factors that contribute to their decisions. Farmers' associations and producer organizations play a relevant role in disseminating information leading to the modernization of farms or the adoption of new production strategies. Awareness-raising campaigns on the need to make agriculture more sustainable include, in the case of citrus, recommendations for a more sustainable treatment of pruning waste. However, given farmers' short margins of profit, cultural practices change in mass only when legislation / regulation requires it or when new practices are economically viable (by changing prices or by consumer demands).

Producers organizations, cooperatives, private packinghouses and juice industries often place new demands and disseminate information that contributes to changes in agriculture. Often the certifications required by commercial chains through packinghouses and juice industries are stricter than official regulations. In this case, farmers, in order to be able to sell their produce, are obliged

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to change the way they produce. For this it is also important that the certifying entities do their work well, advising and demanding compliance with the established rules.

1.5. CONCEPT OF CIRCULAR ECONOMY AND ITS APPLICATION TO CITRICULTURE

The concept of circular economy began to be developed by Kenneth Ewart Boulding in 1966, although he did not use the term "circular economy". This author created the concept of "spaceman economy" or closed economy, as an economy model that should replace the "cowboy economy" or open economy (Boulding, 1966). He called the “open economy the "cowboy economy," the cowboy being symbolic of the illimitable plains and associated with reckless, exploitative, romantic, and violent behaviour, which is characteristic of open societies” (Boulding, 1966). The closed economy was considered by Boulding as the economy of the future which he called the "spaceman" economy, “in which the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy” (Boulding, 1966).

The term "circular economy" appears to be first used by Pearce & Turner (1990) as an economic model based on the principle that 'everything is an input to everything else'. Indeed, the concept is very similar to Boulding's "closed economy" concept. In recent decades, a growing body of literature has emerged that has influenced our current understanding and interpretation of the term "circular economy" (Lieder & Rashid, 2016; Rizos *et al*., 2017).

To understand the concept of circular economics, it is necessary to draw on the knowledge and concepts of industrial ecology that involves a holistic perspective in dealing with human economic activity and sustainability. This discipline introduces the notion that the natural ecosystem and the man-made industrial (or agricultural) system operate similarly, and both are characterized by flows of materials, energy and information (Erkman, 1997; Ehrenfeld, 2007).

Currently, there are several possible definitions for the term "circular economy". Several authors have provided resource-oriented definitions, emphasizing the need to create closed-loop material flows and reduce the consumption of virgin resources, while also mitigating the detrimental environmental impacts of their extraction. Sauvé *et al*. (2016), defined the circular economy as the “production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste (including pollution)’’. For these authors, the circular economy implies above all the reduction of resource consumption, pollution and waste at each stage of the product life cycle. Keeping resources in use for as long as possible and extracting the maximum value from products and materials, using them for as long as possible and then recovering and reusing them are also important aspects of circular economy (Mitchell, 2015). Other authors stress that the transition to

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a circular economy requires facing the challenge of establishing a sustainable supply of energy, as well as decisive action in several other areas, such as agriculture, water, soil and biodiversity (Heck, 2006). Circular economy can also be defined as "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models'' (Ellen MacArthur Foundation, 2013)

Applying the circular economy principles to citriculture requires a reduction in pesticide application, an increase in the life of the orchard, the reuse of all residues resulting from the production and processing of fruits, the use of residues from other crops or other agricultural activities (for example, livestock) (Raimondo *et al*., 2018). The adoption of this new approach may lead to an increase in fruit quality, namely an increase in vitamin C content in the juice (Duarte *et al*., 2010). From a circular economy perspective, branches and leaves removed from trees during citrus pruning should not be considered as waste, but as a by-product with some use.

1.6. ENVIRONMENTAL PROBLEMS ASSOCIATED WITH THE PRODUCTION AND MARKETING OF CITRUS FRUITS.

In citrus orchards the waste produced in bigger quantity are the pruning waste (branches and leaves removed) and the fruits damaged by pests, diseases or physiological disorders.

Traditionally, pruning residues were eliminated from the orchard and burned. In recent years, farmers have started grinding the pruning wood between the tree lines (Hondebrink *et al*., 2017). This leads to the enrichment of the soil in organic matter, creating a dead blanket on the ground (Fig. 4). This enrichment in organic matter improves soil structure, increases water infiltration, decreasing rainwater runoff (Hondebrink *et al*., 2017). The crushing of the pruning wood is done simultaneously with the destruction of the weeds (Duarte & Martins, 2005), which also, end up enriching the surface layer of the soil in organic matter.

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Figure 4 - Crunched pruned branches between tree lines.

Compared with the burning of the pruned branches, crushing it is economically more viable and environmentally more sustainable. However, it is not yet clear what effect the existence of citrus wood chips can have on the surrounding trees. This dead wood provides the development of fungi, which can pass into the trees themselves. In cases of serious diseases, removing pruned branches from the orchard is a necessary measure.

Removing pruned branches out of the orchard and using them as a resource elsewhere may be the most sustainable solution.

As regards the marketing of citrus fruits, their packaging and transport to distant markets has a significant environmental impact.

1.7. VALORISATION OF CITRUS BY-PRODUCTS

For valorisation of citrus waste, we need to consider it as a by-product that should be of some use. The richness of citrus tree branches and leaves in essential oils and energy makes it easier to find use for these materials.

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The leaves of citrus fruits are rich in essential oils, widely used in the cosmetics industry, among other uses. On the other hand, the thicker branches can be used as renewable fuel. Thus, the use of the leaves of pruned branches for the manufacture of essential oils seems to be a good solution for the residue and increases the availability of essential oils on the market, which have potential for wide use, including the replacement of products from chemical industry. Unmarketable fruits can be used for extraction of essential oils or composting.

1.8. CITRUS BY-PRODUCTS AS A SOURCE OF ENERGY

Agricultural resources are important sources of energy, indispensable for further technological development, especially in rural communities (Bentsen & Felby, 2012; Berthet *et al*., 2016). In this regards, in the last decade, an energy strategy to mitigate climate change was discussed by the European social media emphasizing the achievement of definite environmental goals of energy strategy and advancement (Banja *et al*., e2017) of agriculture-based bioenergy and biofuels (Lyytimäki, 2018; Isoaho & Karhunmaa, 2019).

However, the use of biofuels also has drawbacks and, from a negative perspective, the use of agricultural areas for energy crop cultivation may decrease future availability of arable land for food production, which may result in food deficiency (Srirangan *et al*., 2012). Installing a biomass plant in regions producing biomass from forest or agricultural activities is a more sustainable solution. (Bonazi *et al*., 2018).

Considering these trade-offs, the development of new technologies for the valorisation of pruning wood as a resource and the dissemination of this technology among trainees in vocational schools are an important contribution to circular agriculture and circular economy as well as to minimise the effect of citrus production on climate changes.

In rural areas, the establishment of self-sufficient agro-energy districts is a viable alternative as long as local resources are properly harnessed (Colantoni *et al*., 2016a, 2016b; Zambon *et al*., 2016; Al-Hamamre, 2017; Carlini *et al*., 2017; Moulogianni & Bournaris, 2017). In these areas, the implementation of these new technologies can contribute to significant increases in the welfare of the population (Walter, 2003).

The use of waste as a source of energy is one of the elements of agricultural innovation that must be considered as a co-evolutionary process where technological, socioeconomic and institutional changes are combined (Leeuwis & Aarts, 2011; Klerkx *et al*., 2012). In some cases, the pruned thicker branches are separated and used in ovens (Fig. 5).

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Figure 5 - After pruning, the pruned thick branches were separated for later burning in bread ovens.

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