Sustainable Production and Consumption 34 (2022) 257–270

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Review article

Circular economy in agriculture. An analysis of the state of research based on the life cycle

Juan F. Velasco-Muñoz, Jose A. Aznar-Sánchez *, Belén López-Felices, Isabel M. Román-Sánchez

Department of Economy and Business, Research Centre on Mediterranean Intensive Agrosystems and Agrifood Biotechnology, University of Almería, 04120 Almería, Spain

ARTICLE INFO

Article history:
Received 9 July 2022
Received in revised form 17 September 2022
Accepted 19 September 2022
Available online 22 September 2022

Editor: Prof. K Tsagarakis

Keywords:
Crop production
Bioeconomy
Life cycle analysis
Cradle to farm-gate
Sustainability
Agriculture

ABSTRACT

The circular economy (CE) has emerged as a strategy able to fulfil the double purpose of improving the economic performance of the agricultural activity while minimising the impact generated on the environment by reducing the inflow of resources and waste generation. This has led to an increasingly greater adoption of circular models in agricultural practices. The objective of this study is to analyse the state of research on the application of the circular economy in agriculture throughout each of the stages of its life cycle through a systematic literature review. The results show that this line of research is very new but has been attracting a growing amount of interest in recent years. The most resource-intensive phases are field preparation, fertilizer application, mulching and irrigation, while field preparation, mulching, pruning and training are the most intensive phases of waste generation. The majority of the contributions are made from an environmental perspective, so there is a major opportunity to develop the research addressing the economic and social aspects. There is a need to gain further knowledge about the economic-financial feasibility of the different circular practices considered and the perceptions of the stakeholders.

Contents

* Corresponding author.
E-mail addresses: jfvelasco@ual.es (J.F. Velasco-Muñoz), jaznar@ual.es (J.A. Aznar-Sánchez), blopezfelices@ual.es (B. López-Felices), iroman@ual.es (I.M. Román-Sánchez).

https://doi.org/10.1016/j.spc.2022.09.017

1. Introduction

One of the principal challenges faced by humankind is feeding a constantly growing population (Pandey and Dwivedi, 2020; Circle Economy, 2021). Specifically, it is estimated that we will need to increase food production by 5.1 billion tonnes before 2050 (FAO, 2017). This will generate huge pressure on the agricultural ecosystems, given that they are the principal food providers. Furthermore, this could cause negative impacts on the natural environment as agricultural production consumes large amounts of water and energy (Aznar-Sánchez et al., 2018). More than 90 % of environmental impacts due to land use are related to agriculture (Kusumastuti et al., 2016; Aznar-Sánchez et al., 2019). Moreover, in 2019, agriculture, together with food processing, represented the second largest material footprint with 21.3 billion tonnes and a carbon footprint of 10 billion tonnes of carbon dioxide (CO_2) equivalent, making it the third largest after transport and housing (Circle Economy, 2021).

The circular economy (CE) has emerged as a strategy that can minimise the influx of resources and waste generation, reduce the negative impacts produced by the agricultural ecosystems and improve economic performance (Velasco-Muñoz et al., 2021). The CE can be considered as an alternative to the linear economic system of "take-produce-consume-discard" which currently prevails (Zabaniotou et al., 2015; Suárez-Eiroa et al., 2019; Aznar-Sánchez et al., 2020; Stillitano et al., 2021). The CE can help to guarantee the sustainability of agro-food systems, as it provides solutions that enable integrated and persistent problems to be addressed, such as the transformation of waste into bioproducts (Stillitano et al., 2021). The implementation of CE strategies represents a step forward in the three dimensions of sustainable development in the production and management of food resources (Barros et al., 2020). With respect to the environment, implementing the CE can contribute to combatting climate change, as it is estimated that it is able to reduce emissions by 5.6 billion tonnes of CO_2 equivalent by 2050 (EMF, 2019a). The application of CE strategies in food management in the urban environment could prevent the degradation of 15 million ha of arable land per year and save 450 trillion litres of fresh water (EMF, 2019b).

From an economic and social point of view, the European Union estimates that the implementation of the CE principles in the food chain has the potential to increase the GDP of the Union by an additional 0.1 % by 2030, creating more than 100,000 jobs (European Commission, 2018). Moreover, it is estimated that designing food from circularity would increase farmers' profitability by an average of USD 3100 per hectare (EMF, 2021). There may also be a reduction in health costs from pesticide use, estimated at USD 550 billion, as well as a reduction in air and water pollution (EMF, 2019b). These data show that CE can contribute to all three dimensions of sustainability. For example, a study conducted for potato cultivation establishes that the application of various regenerative farming practices under CE principles can lead to a 55 % decrease in GHG emissions and a 15 % reduction in biodiversity loss, as well as reducing agricultural costs by reducing the need for fertilizers and pesticides and the use of machinery (EMF, 2021).

The CE seeks to carry out a more efficient use of resources by establishing new business models that respect the environment while generating new job opportunities and improving well-being and equity in society (Ghisellini et al., 2016). In this respect, the transition of a linear economic model to a CE model represents a challenge that requires the development and application of new knowledge that will enable the creation of innovative, technological and sustainable processes, products and services (Greco et al., 2019). However, in the case of food production, the scientific progress related to circularity is still in the initial phase. Following de Boer and van Ittersum (2018) "scientific advances related to circularity in food production currently seem to be in their infancy". Measuring the circularity of the food production systems is the first step in the process of moving towards a circular food production system (Velasco-Muñoz et al., 2021). For this, it is necessary to know the level and the possibilities of circularity of each of the phases that make up the complete food production cycle.

The agro-food chain is made up of different phases ranging from input suppliers and farming to the final consumer. This chain includes the suppliers of a wide variety of goods and services that are necessary for the agricultural processes on farms. This chain also includes the companies engaged in processing and marketing foods and the other products obtained (Cucagna and Goldsmith, 2018). The next phase is the distribution to the final consumer. Of all these phases the crop production phase generates the highest amount of pollution on a global level is crop production (Stillitano et al., 2021). It is estimated that GHG from cropland are in the range of 2294–3102 Tg CO_2e yr^{-1} (Carlson et al., 2016). In this stage of the agro-food chain, there is a very high consumption of resources such as water and energy (Muscio and Sisto, 2020). However, this stage of the agro-food chain has received the least attention in the literature in terms of the adoption of circular models (Velasco-Muñoz et al., 2021). Withdrawals for agricultural irrigation account for about 70 % of total water use in agriculture (Velasco-Muñoz et al., 2019), while cropping production consumes about 35 % of the total energy used in the food sector (FAO, 2011). Moreover, it is estimated that 60 % of residual agricultural biomass from agriculture comes from crop production (Sommer et al., 2015). In view of all the above, this study focuses on the agricultural phase of crop production, including all the activities, procedures and nutrient reserves and flows linked to the production of arable crops, including fodder, fruit and vegetables, horticulture and pastures (Van der Wiel et al., 2019).

This study has a multiple objective: i) to identify the different stages of the life cycle of the production of agricultural crops and carry out an adaptation of them based on the CE characteristics; ii) to provide an overview of knowledge dissemination in circular agriculture in terms of number of documents, journals, authors and countries participating in the studies; and iii) to analyse the development experienced in adopting circular models in the different phases identified, the principal contributions made in each of them and the limitations and opportunities existing to promote the adoption of circular models in the agricultural context. To do this, a selection of studies on the CE in agriculture has been made from the reference database. These studies were subsequently analysed in depth. The main novelty of this review compared to previous studies is that it is based on the life cycle stages of agriculture to obtain information on the level of circularity, application opportunities and gaps and limitations of each of them. The results of this study contribute to expanding the knowledge on the implementation of circular models as strategies to guarantee the sustainability of the agricultural activity in the different stages of its life cycle.

2. Materials and methods

In this study, a quantitative and systematic review of the selected sample of articles was carried out. Firstly, the quantitative analysis was performed using the bibliometric method, which allows us to identify, classify and analyse the main components of a specific research area. The search for papers for the selection of the sample was carried out in the two major databases, Scopus and Web of Sciences (WoS). The search was conducted in April 2021 based on the following parameters: TITLE-ABS-KEY ("*circular* *econom*") AND TITLE-ABS-KEY (agricultur* OR farm* OR crop* OR agroecosystem* OR agrosystem* OR cultivation OR "food system"). In order to determine the keywords used as search parameters, previous review works related to the topic of study were analysed, and a selection was made of all the keywords used in the selection of the samples analysed in these studies (e.g. Kristensen and Mosgaard, 2020; Velasco-Muñoz et al., 2021). The initial sample of documents was 10 % higher in WoS, while the match rate exceeded 78 %. A number of restrictions were applied to the initial sample to ensure quality and representativeness. Papers only up to 2020 have been included in order to be able to compare full year periods. The search was limited to documents in English. To avoid duplicates, only original articles and reviews were considered.

Finally, a review of each document was carried out to verify its suitability for the case study. All documents that (i) did not have an EC-based approach, (ii) were not focused on agriculture, and (iii) that could not identify any of the defined stages within the life cycle of crop production were excluded. The final sample consisted of 499 documents, covering a time period from 2007 (the year in which the oldest document in the final sample is published) to 2020. These documents were found in both databases used, so, for operational reasons, only Scopus was used for downloading information. The information was then downloaded and the data were scanned to remove duplicates, detect omissions and errors, and search for incomplete information. The variables analysed were the number of articles per year, subject area, journals, countries and institutions. Secondly, a systematic review was carried out to qualitatively analyse the sample of selected articles. Based on this, the documents were classified according to the stages of the agricultural production life cycle covered in the document. It should be noted that the same document can be classified into different stages. Fig. 1 shows a summary of the methodology applied in this study.

3. Results and discussion

This section presents the results obtained from the analyses carried out. Firstly, the main concepts resulting from the application of the circular economy framework to agriculture are briefly outlined. Next, the general context of the evolution of the main variables related to the scientific production related to research on CEA is shown. Then, the different life cycle stages that make up crop production are detailed and, finally, research on the application of the circular economy in each of these stages will be analysed.

3.1. The circular economy in agriculture

Adapting the CE concept to agriculture requires three principal aspects to be taken into account. First, the efficient use of resources and the optimisation of the processes in a way that reduces the use of resources and prevents wastage (Zabaniotou et al., 2015). Second, environmental, economic and social sustainability in the long term (Burgo-Bencomo et al., 2019). Third, regenerative systems that enable the closure of nutrient loops and minimise leakages (Morseletto, 2020). Taking these three points into account, Velasco-Muñoz et al. (2021) define the CE in the field of agriculture as "the set of activities designed to not only ensure economic, environmental and social sustainability in agriculture through practices that pursue the efficient and effective use of resources in all phases of the value chain, but also guarantee the regeneration of and biodiversity in agro-ecosystems and the surrounding ecosystems".

The CE is based on three principles (EMF, 2015): "design without waste and pollution", "keep products and materials in use", and "regenerate natural systems". The implementation of the first principle within the agricultural context involves the elimination of negative externalities generated by it, such as the pollution and degradation of the soil or water bodies (Aznar-Sánchez et al., 2019). With respect to the second principle, the value of the products, co-products and by-products should be maximised in all the phases of the agro-food supply chain (EMF, 2019a). Finally, the third principle is based on promoting the preservation and improvement of the natural systems through the use of renewable resources (EMF, 2015; Velasco-Muñoz et al., 2021).

In order to implement circular agricultural management models, three phases must be analysed (Burgo-Bencomo et al., 2019): i) production planning, ii) production organization and iii) production application. Production planning is based on the knowledge of the demand for food in the area analysed and the possible surpluses in order to determine the necessary area of the land and the variety of products, to plan the sowing and to estimate the harvest amounts. Production organization includes all of those actions aimed at achieving a correct development of the crop without causing a negative impact on the ecosystems, such as the organization of energy flows or material cycles, and the administration of the workforce. Production application is the stage in which the production systems are used, including the planting, harvest and evaluation of possible damage, the determination of the crop yields, the natural integration with the environment which takes into account aspects such as optimising the use of nutrients considering the needs of the crops or minimising the use of pesticides to avoid impacts on soil biodiversity and, finally, the control and regulation of the process.

However, the implementation of circular models in the agricultural sector involves a series of challenges, such as regulatory limitations, the need to optimise reverse logistics chains, the geographical dispersion of the companies, system boundaries and the leakage of materials, the ignorance and lack of acceptance among consumers, the

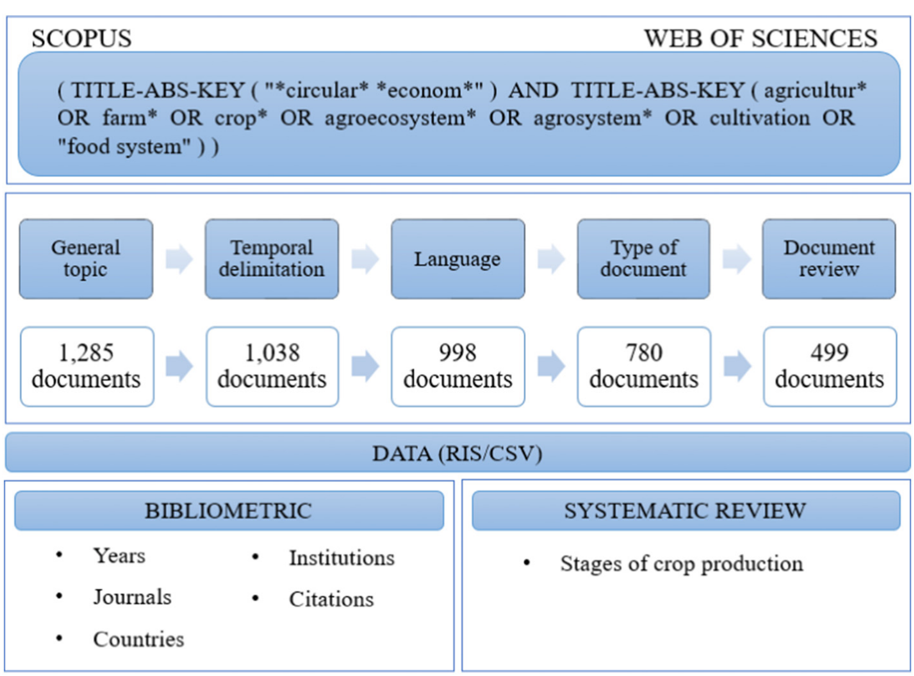

Fig. 1. Summary of the methodology.

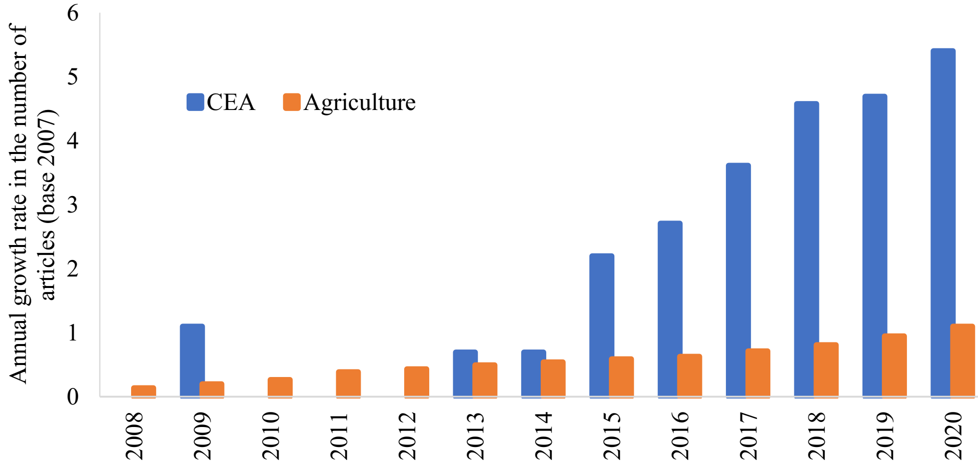

Fig. 2. Comparative trends in circular economy in agriculture (CEA) and agriculture research.

technological limitations and the lack of certainty and incentives with respect to investments (Borrello et al., 2016; Muscio and Sisto, 2020; Velasco-Muñoz et al., 2019). In this context, there are four strategies that can facilitate the development and implementation of circular models in agriculture (Velasco-Muñoz et al., 2021): i) narrowing resource loops, in order to maximise the use of resources; ii) slowing resource loops, so as extend the useful life of the products within the agro-food system; iii) closing resource loops, based on the reuse and recycling of agricultural materials; and iv) regenerating resource flows, which groups together all those actions that promote the conservation and improvement of natural capital.

According to Velasco-Muñoz et al. (2021), the application of CE in agriculture is closely linked to the sustainability of this activity. This is based on the fact that CE aims to generate economic and social prosperity and protect the environment by avoiding pollution, thus facilitating sustainable development (Burgo-Bencomo et al., 2019). In order to achieve sustainability in agriculture, the adoption of circular models aims to i) make agriculture a pillar of the economy, rather than a subsidised sector, ensuring economic sustainability (Bos and Broeze, 2020); (ii) ensuring the conservation of biodiversity and productivity over time in its agro-ecosystems, ensuring environmental sustainability (Jun and Xiang, 2011); and (iii) contributing to providing food security, eradicating poverty and improving health and living conditions, i.e. social sustainability (Burgo-Bencomo et al., 2019; Kristensen et al., 2016).

At the political and legislative level, contributions have been made towards the development of circular models in agriculture. Germany pioneered the integration of the Circular Economy into national laws as early as 1996 with the enactment of the "Closed Substance Cycle and Waste Management Act" (Su et al., 2013). It was followed by Japan's "Basic Law for Establishing a Recycling-based Society" of 2002 (METI, 2004), and the "Law on the Promotion of Circular Economy of the People's Republic of China" of 2009 (Lieder and Rashid, 2016). Supranational bodies have also incorporated circular economy concerns, most notably the 2015 EU Circular Economy Strategy (European Commission, 2015). This Plan was re-launched in 2020, under the umbrella of the European Green Pact, including initiatives throughout the entire life cycle of products, and with the aim of generalising circular economy processes, in order to promote sustainable consumption and to keep the resources used in the EU economy for as long as possible. However, the main impetus at the global level.

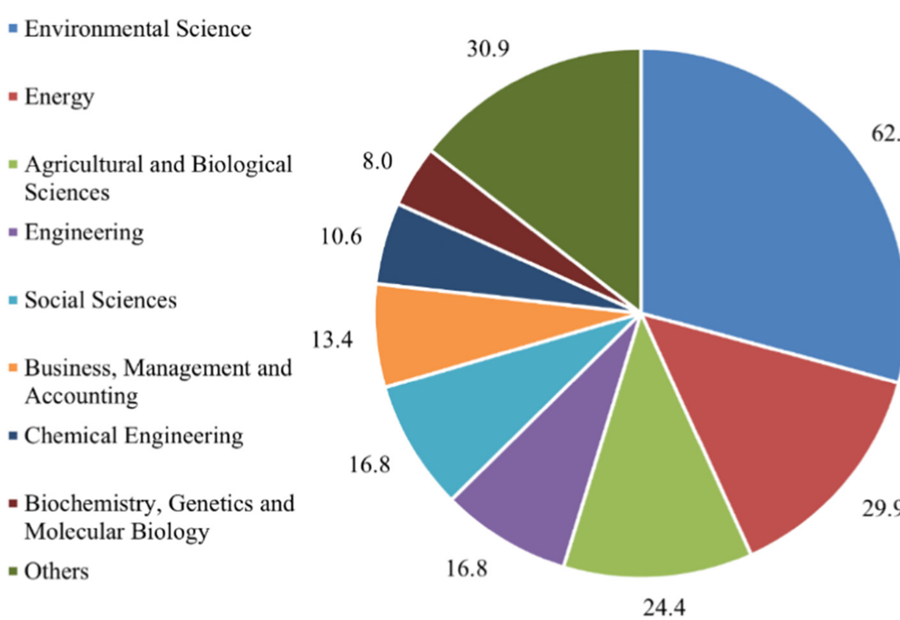

Fig. 3. CEA research by subject area.
Source: Scopus.

3.2. General context of the research on the circular economy in agriculture

In order to contextualise the subject, a summary of the data contained in the principal repositories has been conducted. The overall analysis of the research on the circular economy in agriculture (CEA) shows that it is a new topic with an exponentially growing interest, as the number of documents published increased from 1 in 2007 to 222 in 2020. We should take into account that the most recent theoretical approaches in relation to the CE became more widespread after 2010 as a result of the activity carried out by the Ellen MacArthur Foundation (Velasco-Muñoz et al., 2021). Meanwhile, the average number of authors per document has grown from 2 in 2007 to 5 in 2020. The number of countries participating in the studies on CEA has grown from 1 to 55 in the same period, while the number of journals in which studies on this topic are published has increased from 1 to 100. The average number of citations per document has risen from 0.4 in 2010, the first year that citations were included, to 9.1 in 2020.

In order to contextualise the evolution experienced by this line of research, the annual variation in the number of articles published on CEA has been compared with the number of articles published on Agriculture in general (Fig. 2). The number of articles on Agriculture rose at an average annual rate of 0.5 % between 2007 and 2020, while the number of articles on CEA increased by 1.8 %. This confirms that research on CEA has acquired great interest within the research on agriculture. In turn, Scopus classifies the indexed documents based on the field of knowledge analysed in different subject categories. From this classification, the main thematic categories of CEA research are Environmental Sciences with 62.3 % of the documents in the sample, Energy with 29.9 % and Agricultural and Biological Sciences with 24.4 %. The full set of subject categories in which CEA papers fall and their percentages are shown in Fig. 3.

A total of 71 countries were involved in the research on CEA (Fig. 4). Italy is the country with the highest number of articles on this subject. In this country, particularly noteworthy are the institutions Alma Mater Studiorum Università di Bologna and the Università degli Studi di Foggia as being the most prolific in the area analysed. Spain follows, where the Universidad de Almeria and the Universitat Autònoma de Barcelona are the most relevant institutions in the research on CEA. In China, the most relevant institutions in this research field are the Ministry of Agriculture of the People's Republic of China and the Chinese Academy of Sciences. In the ranking of institutions, Wageningen University of the Netherlands has the highest number of articles published on CEA. Based on the number of affiliated authors in institutions in different countries who share authorship of the papers in the sample, as well as the number of countries, it can be said that there is a wide network of international collaboration between countries and institutions in CEA research.

The analysis of the most used key words allows us to determine the preferences of each country in the specific themes developed in their research on CEA. In the case of Italian production, the terms Sustainable Development, Sustainability, Biomass, Fertilizers, Food Waste, Nonhuman, Recycling, Waste Management, Anaerobic Digestion, Waste, Soil and Food Supply stand out. In the case of Spain, the terms Sustainable Development, Sustainability, Biomass, Fertilizers, Nutrients, Economics, Life Cycle, Nonhuman, Environmental Impact, Life Cycle Assessment, Waste Management and Life Cycle Analysis stand out. In the Chinese research, the most commonly used terms are Sustainable Development, Fertilizers, Agricultural Wastes, Sustainability, Economics, Agricultural Robots, Biomass, Recycling, Anaerobic Digestion, Biogas, Controlled Study, and Greenhouse Gases. As can be seen, there is a common line that is based on the pursuit of sustainable development and sustainability and the study of biomass. However, it is clear how different countries give different degrees of attention to common concepts and focus on different aspects such as soil and food production in the case of Italy, the life cycle approach in the case of Spain, and the use of robotics in agriculture and bioenergy production in the case of China.

3.3. The life cycle in the production phase

The agro-food value chain consists of different steps. In the first step, the suppliers of the goods and services necessary to develop the agricultural activity, including the seed providers, the agro-chemical industry or energy suppliers (Cucagna and Goldsmith, 2018). Next is the production phase, in which farmers use the necessary inputs and practices to obtain their products. After the products are obtained, they move on to the processing stage, in which different procedures are carried out, such as washing, juice extraction, freezing or packaging (Barros et al., 2020). Subsequently, the product obtained undergoes the retailing phases, which includes the supermarket and small retailer chains. The retailers are responsible for taking the product to the last link in the chain, that is, the consumers (Liao et al., 2020). We should take into account that, in many cases, the products do not complete all of the phases of the chain. For example, when producers sell their products directly to the final consumer.

This study focuses on the second phase of the agro-food chain, the production phase of agricultural crops. The life cycle of the production of agricultural crops is characterised as being 'cradle to farm-gate', in which the system boundaries start with the planting or sowing and end with the exit of the products and sub-products to the following stage of the agro-

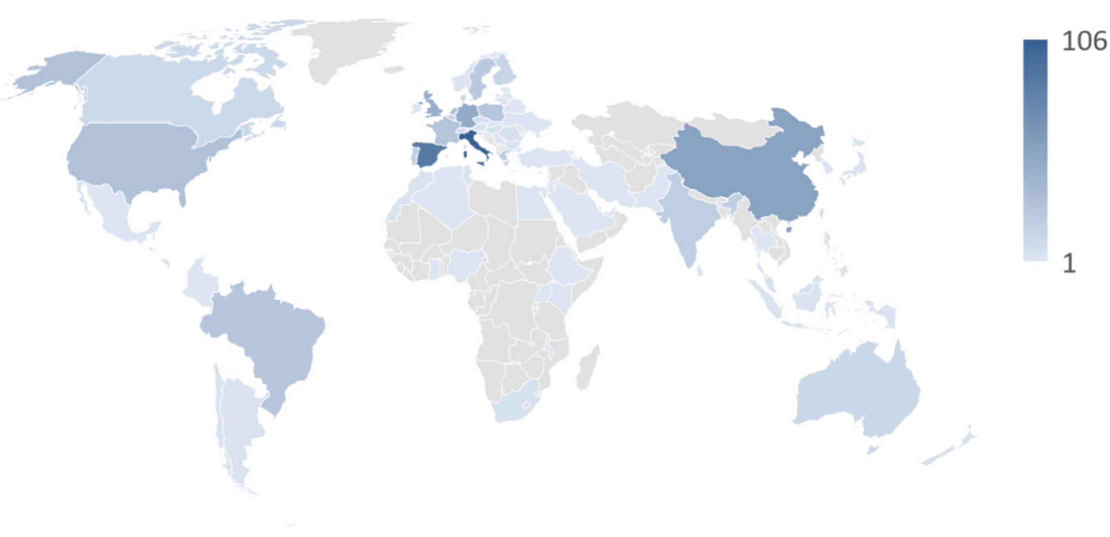

Fig. 4. Distribution of CEA research by country (number of publications).

food chain (Hayashi et al., 2005; Tamburini et al., 2015). The elements of this next phase range from the final consumer, in the case of direct sales, to the incorporation of the product in a transformation process in the different alternatives routes of the value chain (food, pharmaceutical, cosmetics, etc.). The CE has the objective of the efficient and effective use of resources in order to reduce the quantity of inputs necessary in the production processes, and the reuse and recycling of the waste generated (Muscio and Sisto, 2020; Velasco-Muñoz et al., 2021). Therefore, the possibility of applying CE practices in each of the operations undertaken during agricultural production will depend on two factors: i) whether the stage is more or less intensive in the use of resources, and ii) the possibilities of exploiting the waste generated. In order to analyse the adoption of the CE practices in agricultural production, the different stages and the activities carried out in each of them throughout the cultivation process are identified. Subsequently, the life cycle of the production of crops was determined, based on the intensity of the use of resources and the generation of waste and the possibilities to use it. As a result, an adaptation of the agricultural life cycle based on the characteristics of the CE is proposed, as we can observe in Fig. 5. For more detailed information on how nutrient flows occur between the different life cycle stages of crop production, see Papangelou and Mathijs (2021).

The stages of production of agricultural crops range from the sowing to waste management (in green in Fig. 4). In order to develop the different stages, it is necessary to use different inputs which are obtained in the previous phase of the chain and include the suppliers of utilities (water, energy, etc.) and of the different products and materials (seeds, fertilizers, machinery, etc.). Production begins with field preparation, which includes all those activities that are necessary to carry out before the sowing or planting, for the correct development of the crop (Pascual et al., 2018). Once the land has been prepared, the planting stage begins, in which the seeds are planted or, in the case of seedlings grown in nurseries, the plants are inserted into the cultivation area for their development (Villalobos et al., 2016). After the planting stage, different processes are carried out in order to improve the production and quality of the fruits obtained, which can vary depending on the characteristics of the crop and the needs of the plants at each moment. Among them we can find fertilizer application, pest control, mulching, irrigation, pruning and other cultural practices.

Fertilizer application consists in applying materials or substances to the soil in order to increase the yield of crop soils, as well as to increase the quality and quantity of production (Karagöz, 2021). Pest management includes all those actions carried out in order to combat undesirable animal or plant species that appear during the cultivation stage (Sawicka and Egbuna, 2020). Mulching consists in covering the surface of the ground in order to eliminate weeds, reduce the loss of moisture of the soil or increase the efficiency of the fertilizers (Sartore et al., 2018). Irrigation consists in the artificial application of water to the soil to increase the moisture available to the roots in order to favour the plant growth (Asawa, 2008). The pruning process involves the elimination of the undesired branches and leaves, while training operations are carried out to guide the direction of growth and the form of the plants and trees (Ferree and Schupp, 2003; Sharma et al., 2018). Conducting pruning and training operations regularly reduces plagues and diseases and allows the crops to better capture the sunlight (De Pascale and Leonardi, 2011).

The harvesting operations can vary depending on the type of crop, although, in general, they consist in partly or wholly cutting the plant above ground level and separating the useful part from what is considered as waste (Villalobos and Fereres, 2016). Finally, waste management includes the actions necessary to perform during and after the development of the growing process, in order to try and eliminate the waste generated in the different stages (Kapoor et al., 2020). Different outputs are obtained as a result of the production process: i) the products per se, which include foods and different raw materials; ii) by-products that are products obtained secondarily during the production process and which the farmer can market, usually at a lower price than the principal product; and iii) the waste generated during production, which, in many cases, can be used on the farm itself or incorporated into another production process (Berbel and Posadillo, 2018). For example, in the cultivation of olive trees for oil production, the main product obtained consists of the olives collected during the harvesting phase, which will later be used to produce olive oil. Thus, after the fruit is harvested, the trees are pruned resulting in wood and small pruning residues. Wood is a by-product of production that can be used for heating homes or sold as a raw material to produce animal feed, biocomposites or energy (Lo Giudice et al., 2021). Additionally, small pruning residues are waste that can be chopped and shredded for subsequent spreading on the crop (Moreno-García et al., 2018).

3.4. Research on CE in the life cycle in the production phase

This section analyses the research conducted in the field of CEA on each of the phases of the life cycle of agricultural production. To do

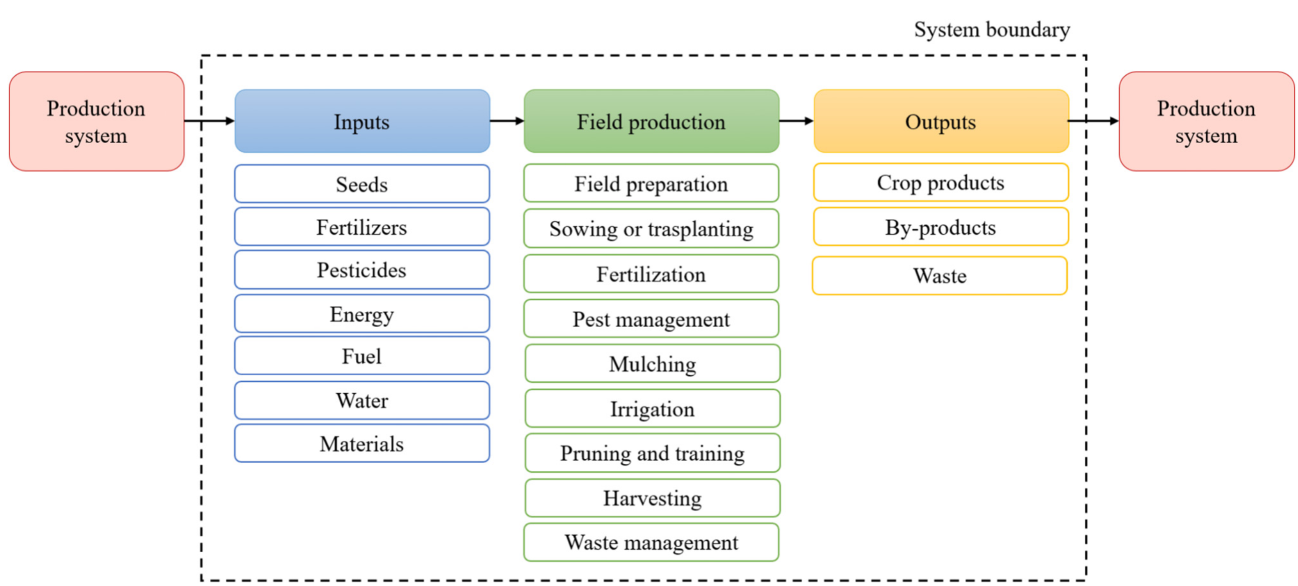

Fig. 5. Circular economy life cycle of crops production.
Adapted from Hayashi et al. (2005) and Tamburini et al. (2015).

this, we refer to the principal inputs that are used in each of the phases, the principal lines of research developed and the problems and gaps identified.

It should be noted that there is a series of inputs that are used in most or all of the phases of the life cycle such as energy, fuel, tools and machinery. No studies have been found that analyse the management of these resources in agriculture from a CE perspective. With respect to energy and fuels for agricultural use, it is conducted that there is a high level of dependency on fossil resources, both to generate electricity and to power machinery. This causes environmental impacts, given that the cultivation practices account for almost 20 % of annual CO_2 emissions on a global level (Circle Economy, 2021). To do this, the use of renewable energy and fuel sources have great potential as a CE strategy which has yet to be implemented and which requires a greater level of knowledge in order to be fully exploited.

In addition, there are also the so-called technical materials used in agriculture, which include all materials of which the inputs to the production process are composed that do not have an organic basis. These materials include the tools and machinery that are usually used continuously over several campaigns. They also include the containers and packaging and other support materials that contain the different materials and products used in the agricultural activities (fertilizers, seeds, phytosanitary products, etc.). CE strategies for these materials should focus on trying to lengthen their useful life as much as possible through reparation, reconditioning and remanufacturing either to reuse them for the same purpose or recover the materials to be reused within the same value chain or between different ones. This would minimise waste generation and the need to incorporate new materials (Sayadi-Gmada et al., 2019; Velasco-Muñoz et al., 2021). However, a lack of research regarding circular alternatives in the generation of this type of resources in the agricultural field has been noted. Some of the possibilities include the adoption of collaborative economy models in the shared use of machinery to maximise their use and to provide access to them by small farmers without resources. Replacing ownership with contractual systems for the temporary use of the machinery is another alternative that requires further study.

3.4.1. Field preparation

The production process begins with field preparation, which includes all of the actions necessary to prepare the farm for cultivation, such as the installation of irrigation systems, the preparation and replacement of greenhouse roofs or the preparation of the growing media for soilless crops. Depending on the action carried out, different inputs will be required. For example, in the case of the greenhouse covers, plastic and wire and different tools are necessary (Aznar-Sánchez et al., 2020). Meanwhile, in the case of soilless crop systems, the growing media in which the roots of the plants develop should be prepared. The non-renewable materials which are most used are peat, pearlite and rock wool (Martin et al., 2019). The priority aspects in this field preparation stage are the preparation of the growing media based on recycled materials and the reuse of the spent growing media.

In addition to the usual inputs for the development of the crops, the soilless systems require the preparation of the growing media in which the roots of the plants develop. A large number of studies focus on the development of alternative materials for the growing media such as almond shells (Kennard et al., 2020), tomato plant stalks (Manríquez-Altamirano et al., 2020), compost and vermicompost (Greco et al., 2019) or waste from the pulp and paper industry (Grimm et al., 2021). The reuse of the growing media for several crop cycles is an action which lengthens the useful life of the materials and resources used and reduces the generation of waste. A line of research related to this aspect is being developed, including the studies by Vandecasteele et al. (2020), in which the spent growing media of the soilless crops is used to cultivate Chrysanthemum in pots or those by Grimm and Wösten (2018) and Zied et al. (2019), that focus on the reuse of spent mushroom substrate in several cycles of mushroom crops.

To improve the circularity of the processes in this stage of cultivation, a greater level of knowledge is required regarding the possibilities of reusing spent growing media, both for different cycles of the same crop and for different varieties. For example, future lines of research could be aimed at improving and extending the life of substrates used in hydroponic crops, such as rock wool or coconut fibre, as well as their subsequent use in other production processes when they are no longer suitable for agricultural use. Thus, it would be necessary to design a complete process for its treatment and conditioning. Therefore, assessments would have to be made from an economic and environmental point of view of these processes, together with comparisons of the different alternatives developed. Moreover, there is a gap in the knowledge on the circular treatment of the permanent and semi-permanent elements of farms, such as greenhouse structures, irrigation systems, ventilation and heating systems, etc. All of these elements provide an opportunity to develop circular models based on the management of technical materials for agriculture. In the management of these materials, it is particularly relevant to develop integrated value chains that include the links not only of a single production process, but also interconnect different processes and sectors. This should be realised through holistic approaches, which implies the simultaneous application of the different circular economy principles in the different life cycle stages of the set of value chains involved and considering all stakeholders (Mangers et al., 2021). The development of such models applied to the management of agricultural materials is a future line of research.

3.4.2. Sowing or transplanting

In this phase, there is a distinction between crops where the seed is sown directly, as in the case of cereals, and others where the plant is previously developed in a nursery, as in the case of vegetables, and later transplanted for its final maturing on the farm (Villalobos et al., 2016). Direct sowing in the field requires the seeds and appropriate machinery when it is performed mechanically. When the seed is grown in a hothouse and is transplanted to the growing area, it is necessary to use materials for transplanting the seedlings. These materials are usually returned to the nurseries after the transplantation has taken place, where they are reused for new crops or are recycled (Aznar-Sánchez et al., 2020). We should take into account that the activity developed in the nursery is similar to that of crop production but with its own characteristic features, such as being carried out under cover and only during the period of time necessary for the seedlings to develop (Pascual et al., 2018). No studies have been found that address the sowing or transplanting activities from a circular perspective. However, this stage is one of the least demanding, in terms of both the quantity and variety of the resources. Therefore, the principal potential from a circular perspective in this phase is related to the replacement of fossil fuels for the machinery, in the case of non-manual sowing, and with the previously mentioned management of technical materials. Furthermore, it is in these centres where a large part of the research on the improvement of varieties is developed and applied. This is one of the main lines of future research to adapt crops to the adverse conditions caused by climate change. Such future research should also include varietal improvement for the development of materials more suitable for circular processes, such as more resistant fibers, biomass with higher calorific value and more biomass per plant. This would also require the development of integrated value chains where supply and demand are coordinated under systemic circular thinking.

3.4.3. Fertilizer application

In order to guarantee the maximum efficiency of the fertilizers, the plants must absorb the maximum fraction possible of nutrients. Therefore it is necessary to correctly choose the fertilizer and the application technique (Delgado et al., 2016). Fertilizers can be classified as organic and inorganic (Karagöz, 2021). Inorganic fertilizers (minerals or chemicals) are those in which the nutrients are obtained through extraction or industrial processes, while organic fertilizers use natural materials of a plant or animal origin (Roba, 2018). Fertilizers are one of the resources most intensively used in agriculture. According to the World Bank, in 2018, approximately 136 kg/ha of fertilizers were consumed, across an area corresponding to 10 % of the world's surface (Karagöz, 2021). In addition, world demand for fertilizers is estimated at over 200 million tonnes (FAO, 2019). Therefore, improving efficiency in the management of this resource is essential. Fertilizers may be applied manually, with machinery and through irrigation systems (fertigation) (Delgado et al., 2016). Research on circularity and fertilizer application has been extensively developed in recent years. The major topics are i) the elaboration of organic fertilizer, ii) the direct application to the soil biomass, iii) the recycling of phosphorous, iv) biostimulants, and v) the farmers' perception on organic fertilizers.

Inorganic fertilizers have been widely used, but their production is costly in terms of materials and energy (Stürmer et al., 2020), while their use generates negative impacts on the adjacent ecosystems (Sharma and Singhvi, 2017). In particular, the continued excessive use of fertilizers has become a major source of soil and water pollution (Khan et al., 2018). In this context, there are several management practices that can minimise these impacts, such as soil analysis to determine soil nutrient requirements and irrigation management (Banerjee et al., 2018). Another alternative is the use of recycled organic fertilizer based on materials such as animal manure, biosolids from human waste, anaerobic digestate, biochar and crop residues (Alobwede et al., 2019). The use of organic fertilizers provides the crops with the macro and micro nutrients necessary for the growth of the plants (Blouin et al., 2019; Czekała et al., 2020). Moreover, the application of organic fertilizer on agricultural land improves soil organic carbon stocks, which is a key attribute of soil quality (Verma et al., 2019). It also maintains soil aeration and soil moisture and promotes the growth of soil microorganisms (Khan et al., 2018). This has led to a recent increase in research related to nutrient recovery processes, as well as waste and materials suitable for use in both recovery processes and fertilizer production. However, organic fertilizers also have certain limitations such as the fact that part of the nutrients are in organic form and their release is not immediate or that the concentration of nutrients depends on the nature and processing of the product (Delgado et al., 2016). This can jeopardise the food security of a growing population, which reaffirms the need to develop management practices that maintain production levels while reducing negative environmental impacts (FAO, 2017).

The recovery and reuse of the biomass derived from post-harvest waste of livestock production or food processing constitutes an alternative to reuse valuable elements for fertilizer application, reducing the use of non-renewable raw materials. There are different methods for exploiting the biomass, such as composting, anaerobic digestion and different methods of thermal processing such as incineration, gasification and pyrolysis (Chojnacka et al., 2020a). The choice of one method or the other depends on the material used, the possibilities for utilization of the material and the purpose of the treatment. The purpose of composting is to obtain material that can be used as a soil amendment, in landscaping, erosion control, mulching and soil remediation. Processes such as incineration are mainly aimed at obtaining energy, in this case by means of controlled combustion that transforms the organic fraction of waste into inert materials and gases and the release of heat. The main differences between the two methods include the possibility of reusing the nutrients in the agricultural production process and the generation of waste, among others. Many studies have addressed aspects related to the application of fertilizers derived from products obtained through these processes such as compost (Cortés et al., 2020; Moretti et al., 2020), digestate (Spyridonidis et al., 2020; Vitti et al., 2021) or biochar (Jindo et al., 2020; Lu et al., 2020; Abbas et al., 2021). Research has also been developed regarding the direct application to the biomass soil of fertilizers derived from different sources, such as algae (Alobwede et al., 2019), pruning residues (Michalopoulos et al., 2020) or straw (Ma et al., 2020).

With respect to the different nutrients, particularly prominent is the management of phosphorous (P) as it is a finite resource essential for plant growth. To this direction, farmers should adopt practices to minimise losses of P to the water due to erosion, incorporate precision agriculture to manage P inputs more efficiently, such as the application of variable rates of P to crops based on integrated geospatial technologies, and integrated agricultural practices that make optimum use of resources of secondary P sources, such as use of organic matter to minimise leaching (Withers et al., 2018; Garske et al., 2020). Furthermore, P fertilizers derived from secondary raw materials can constitute a valuable alternative to extracted phosphate rock and processed P fertilizers (Huygens and Saveyn, 2018; Castro et al., 2020; Herrmann et al., 2020).

The objective of biostimulants is to improve the nutrient absorption mechanisms of the plant and their efficiency, as well as increasing the tolerance to biotic and abiotic stresses. Due to this, the use of biostimulants can reinforce the effectiveness of the fertilizers and reduce the amount applied (Puglia et al., 2021). In this respect, a series of articles exist that analyse the application of different residues and materials as biostimulants for plant growth, such as wool keratin hydrolysate (Gaidau et al., 2019), olive mill waste (Sciubba et al., 2020), fermented alfalfa brown juice (Kisvarga et al., 2020) or microalgae (Kapoore et al., 2021).

When innovations are adopted in agriculture, the opinion of the farmers is definitive. Given the importance of fertilizers, different studies have been conducted on the use of organic fertilizers derived from different sources, such as animals or urban waste (e.g., sewage sludge or organic household residues) (Case et al., 2017). Also notable are studies on the willingness to pay (WTP) for organic fertilizers derived from human excrement (Gwara et al., 2020) or compost (Muhammad et al., 2020), which identify influential factors, such as education, experience or the size of the farm. The barriers to the use of organic fertilizers include legal or political barriers, such as the current Regulation (EC) No. 2003/2003 of the European Parliament and the Council relating to fertilizers, which only regulates the sale of mineral fertilizers in the single market of the EU (Garske et al., 2020; Rahimpour-Golroudbary et al., 2020; Stürmer et al., 2020).

In order to improve the circularity of this stage of agricultural production, greater efforts should be made to maximise the efficiency of the fertilizers and to adjust the dose of application to the real needs of the plants. In this respect, there is extensive research from an agronomic approach, constituting a future line of research. However, this part of literature is not linked to a circular perspective. Therefore, studies should be carried out which integrate both perspectives. The use of organic fertilizers constitutes an opportunity for recovering nutrients within the farm itself, and other sectors. However, there is reticence derived from the composition and properties of the different materials used with respect to the destination crops (Zabaniotou et al., 2015). From an environmental point of view, more information is required regarding the benefits and the disadvantages of the use of the different materials for each crop under different circumstances. For example, returning straw to the soil could generate an increase in methane emissions of more than 20 % (Ma et al., 2020). Furthermore, the studies that address the environmental impacts are usually focused on greenhouse gas emissions, but it is necessary to quantify other aspects related to the pollution of the water or the biodiversity as well. Finally, a future line of research relevant to the fertilization phase is the development and widespread application of globally standardised nutrient circularity indicators (Velasco-Muñoz et al., 2021). This is especially relevant considering the global food trade and the transfer of nutrients from one continent to another.

3.4.4. Pest management

The most common actions carried out in pest management are the adaptation of the growing methods (dates of sowing or crop rotation), the use of chemical products (pesticides, herbicides, insecticides, fungicides, etc.) and biological methods (natural enemies) (Sawicka and

Egbuna, 2020). The intensity in the use of resources in this stage will vary depending on the appearance of plagues during the development of the crop and the technique used to combat them, which is higher when chemical products are used. The research developed on CEA in this stage is principally focused on the production of bioherbicides, and the determining factors are the costs of the process and the choice of economic and technically feasible materials. The options analysed include recycled microalgae (Stefanski et al., 2020), sub-products derived from olive mill waste (Sciubba et al., 2020), organic fraction of municipal solid waste (Ballardo et al., 2017) or biogas slurry (Chang et al., 2011).

The research carried out in this area is very limited. Although the development of bioproducts aimed at controlling the different types of plague has intensified greatly in recent years, there is a lack of research on the development and use of these products from a circular perspective. Although they have a biological basis, the use of these products should be limited to exceptional situations, as there are other alternatives that are much more efficient from a circular point of view. Instead, a reinforced use is required of integrated plague control techniques that include actions such as crop rotation or the implementation of reservoirs to promote biodiversity and biological control through natural enemies (Matthews, 2017). Similarly, in this case, although extensive research has been conducted on the effectiveness of integrated control techniques to fight different types of plagues, this has not been addressed from a circular point of view. This is partly due to the lack of circular economy indicators capable of capturing, on the one hand, the level of circularity of processes under different management practices, as well as the contribution of the adoption of such processes to the final result (Zabaniotou et al., 2015; Velasco-Muñoz et al., 2021). This constitutes another relevant future line of research.

3.4.5. Mulching

The use of mulching has different advantages such as improving the performance and quality of crops, improving water use efficiency by reducing evaporation, decreasing the erosion of the soil and controlling the proliferation of weeds (Sartore et al., 2018). The materials used for mulching can be organic (for example, straw), inorganic (plastic films) or special materials (biodegradable plastic films) (Setti et al., 2020). The research in this stage focuses on the substitution of the inorganic materials with other organic or special materials.

The materials most used for mulching are plastics, constituting the second most important application of plastic in agriculture (Prosperi et al., 2018). This has generated serious environmental problems as its recycling is very complicated, as the film is contaminated by soil, stones and biological waste (Prosperi et al., 2018; Aznar-Sánchez et al., 2020). The use of biodegradable and renewable materials to manufacture mulches can be an interesting alternative for resolving this problem, as at the end of their useful life, these materials degrade into the soil (Sartore et al., 2018). This has led to research on the development of biodegradable plastics based on different materials such as waste from the leather and natural fillers industry (Sartore et al., 2018), citrus pomace biomass (Zannini et al., 2021) or black soldier fly protein bioplastic (Setti et al., 2020). In the case of organic materials, Sayadi-Gmada et al. (2019) consider that the use of a layer of straw can constitute a feasible mulching alternative in vegetable crops, while Bechara et al. (2018) analyse the use of chopped pruning residues in olive cultivation.

In order to improve the circularity of this growing phase, two measures are principally recommended. On the one hand, to always use organic materials from the farm itself for creating mulching. When this is not possible, the recycled organic materials of other crops or sectors should be used. In this way, the use of non-renewable materials is eliminated, resources are recovered and the nutrient cycle is closed. On the other hand, when this alternative is not possible, the use of mulch films produced with organic materials should be prioritised. In this way organic materials from agriculture and other industries can be reused and waste generation can be reduced, based on their biodegradable nature. However, these types of materials are still in the development phase. A greater knowledge of the effectiveness of the materials used, the adaptation to the crops and the economic feasibility of the process for their mass marketing is required, constituting a future line of research. This is particularly relevant, given that, despite the available feasible alternatives, farmers don't use them due to their impact on cost structures (Aznar-Sánchez et al., 2020).

3.4.6. Irrigation

In this stage, the essential elements are the irrigation systems used and the necessary amount of water. There are different types of irrigation systems, principally surface, sprinkler and drip systems (Jägermeyr et al., 2015). The main topics addressed in this phase are the incorporation and technological improvement of irrigation systems and the use of wastewater.

Within the modernisation of the systems used and the use of technologies that improve in the efficiency of the water consumption, particularly noteworthy is the incorporation of micro-irrigation, including drip and sprinkler systems which increases the efficiency in water use by 50 % and 90 % (Aznar-Sánchez et al., 2020; Suresh and Samuel, 2020). Apart from that, the hydroponic crops constitute a promising alternative, given that they enable the recirculation of water and also allow the combination of agriculture with other activities, such as aquiculture (Crappé and Buysens, 2020; Rufí-Salís et al., 2020). Meanwhile, the use of wastewater increases the supply of water necessary for irrigation, while constituting a source of nutrients for plants and enabling traditional irrigation systems to be upgraded to ferti-irrigation (Chojnacka et al., 2020b; Maquet, 2020). The advantages of using this type of water have been proven for the irrigation of different types of crops in a variety of geographical areas (Maestre-Valero et al., 2019; Maquet, 2020; Tallou et al., 2021).

No research has been found, from a circular point of view, on the energy sources necessary for running irrigation systems, which can be fossil fuels or electrical energy, depending on the system used. In addition, irrigation systems are usually used for several campaigns to make the most out of the investment made. However, there is no record of any research on the destination of the obsolete irrigation systems and their possible processing from a circular perspective. Finally, given the vital nature of water for agriculture and the prospect of scarcity shortly, the efforts to improve efficiency in irrigation management must be doubled and the supply of water extended through new alternative sources.

3.4.7. Pruning and training

In order to carry out pruning, it is necessary to use tools such as secateurs, loppers or long reach pruners (Sharma et al., 2018). Pruning operations can also be performed with machinery, particularly in the case of trees. With respect to training operations, the necessary materials vary depending on the type of crop. For example, the training operations in trees usually consist in eliminating branches in order to improve their shape, so the same tools as those used in pruning are needed (Ferree and Schupp, 2003). In the horticultural sector, certain materials are usually used to guide the growth of the plants vertically, such as sticks, raffia, plastic clips, etc. (De Pascale and Leonardi, 2011). From a circular perspective, there are few studies referring to the management of the materials needed to carry out training operations. At the same time, in this phase of cultivation, no biological resources are required, but a large quantity of biomass is produced, which will be dealt with in the waste management phase.

The principal problem identified by the research in this phase of cultivation is the use of plastic materials to guide the growth of the plants, particularly in the growing of plants and vegetables in greenhouses. These materials used are not renewable. Furthermore, there is a problem about what should be done with them after their use and also the biomass materials generated. In the phases after the harvest, the plastic materials, such as clips and raffias are mixed with the plant residues and have to be separated manually in order to be reused (Sayadi-Gmada et al., 2019; Duque-Acevedo et al., 2020; Sayadi-Gmada et al., 2020). Therefore, in order to improve the circularity in this point, the development of systems based on biodegradable materials for training operations is proposed. One of the main reasons for the lack of widespread use of these biodegradable materials is their high cost in relation to plastic alternatives, so it is necessary for these systems to have an affordable final price for the farmer in order to guarantee their use (Duque-Acevedo et al., 2020). Another alternative to explore is the recycling of the plastic materials that are currently used in training operations in other sectors such as the building industry (Awoyera and Adesina, 2020).

The studies identified that address the use of plastic materials in this stage of cultivation are focused on greenhouse farming. However, their results can be extended to any other system with the same problem. The circularity proposals in this stage are concerned with the management of technical resources and energy. Finally, there is an extensive body of literature dedicated to the use of the biomass produced in this phase of cultivation. This body of literature includes two main traditional topics. On the one hand, the use of plant remains for the production of compost and the different related aspects, from the production process to the impact on the different soil characteristics (Moreno-García et al., 2018). And on the other hand, the valorisation of pruning waste for the production of energy through the different possible processes (Tauro et al., 2022).

3.4.8. Harvesting

Harvesting can be performed manually or mechanically (Kusumastuti et al., 2016). Manual harvesting requires the use of tools such as sickles, shears or knifes, and materials in which to deposit the pieces harvested, such as baskets, boxes, mantles or wheelbarrows. In the case of mechanical harvesting, the appropriate machinery for each type of crop is needed. The studies carried out on CEA in this stage of cultivation are scarce and focus on the reuse of the boxes used for depositing the fruit through the implementation of closed circuit models managed by the handling and packaging centres (Sayadi-Gmada et al., 2019; Sayadi-Gmada et al., 2020; Liao et al., 2020).

In order to improve the circularity in this stage, a development of the research on the management of technical materials such as tools, machinery and vehicles and energy and fuel is required, given their intensive use. Moreover, this phase of cultivation is particularly critical with respect to the generation of food waste when the fruit and vegetables and other crops do not comply with the marketing standards or are damaged during harvesting. Therefore, it is particularly relevant to implement measures to eliminate losses and reintroduce all of the materials produced into the value chain, either in the food chain or other sectors such as the pharmaceutical, cosmetic or chemical sectors. There are also other alternatives, such as the transfer of these products to canning or frozen food companies or for the development of black soldier fly larvae for poultry production (Aznar-Sánchez et al., 2020; Dorper et al., 2020).

3.4.9. Waste management

This is one of the most important stages of the life cycle of agricultural production in terms of the CE, given the large amount of waste generated by this activity and the high potential of these resources for their reuse, both on the farm itself and in other productive sectors. Waste can be classified according to its composition as either organic or inorganic. In the case of the agricultural activity, a significant amount of organic waste is usually generated, including damaged fruits, pruning residues or plants at the end cultivation. In this respect, the quantity and distribution of waste in the fields after cultivation will depend on the harvesting method used, and chopping or withdrawal operations may be necessary (Villalobos and Fereres, 2016). Two types of agricultural waste can be distinguished according to its origin. The residues that remain in the fields after the harvesting phase are primary waste and include straw, stalk, stubble, leaves, etc. (Kapoor et al., 2020). Secondary waste is derived from processing and transformation activities of agricultural products, such as rice husk, hulls or corncob (Honorato-Salazar and Sadhukhan, 2020).

With respect to inorganic waste, diverse aspects have been studied, such as the reuse of peat and pearlite substrates used in soilless crops (Vandecasteele et al., 2020), the use of plastics derived from the agricultural activity for the manufacture of other materials (Martínez-Urreaga et al., 2020) and the implementation of collection and reuse programmes of plastic containers of phytosanitary products and fertilizers (Aznar-Sánchez et al., 2020; Blanke, 2020). Documents are also found that analyse the willingness of farmers to recycle agricultural plastics and the necessary machinery (Galati et al., 2020; Pazienza and De Lucia, 2020). According to these authors, younger and more educated farmers, who run smaller businesses, show a greater intention to join plastics recycling programmes, guided by their attitudes, the need to respond to social pressures and the ability to manage recycling programmes. To improve the willingness to recycle plastics, farmers need to be trained and sensitised.

With respect to organic waste, extensive research has been conducted, particularly in terms of its use for different purposes. The energy production is one of the outmost aspects in the literature review (Liu et al., 2018; Palmieri et al., 2020; Torreiro et al., 2020). Different studies propose biorefining processes in which various technologies are used to produce fuels, energy, chemical products, food ingredients, or other biomaterials jointly (Hubenov et al., 2020; Rekleitis et al., 2020; Qin et al., 2021). Other studies have been conducted on the reuse of active compounds in the pharmaceutical (Chiocchio et al., 2020) and cosmetic (Plainfossé et al., 2019) industries. Other agricultural waste of corn, rice, cotton, coffee and coconut crops have the proper characteristics in order to be used in the building sector (Overturf et al., 2020; Ricciardi et al., 2020). Furthermore, much of the organic waste is used for agronomic purposes on the farm itself, either through the direct application of the residues on the soil or the elaboration of organic fertilizer (Michalopoulos et al., 2020; Lu et al., 2020). Finally, some studies analyse the application of organic waste originating from crops for animal feed, which constitutes one of the most common uses (Berbel and Posadillo, 2018; Grimm and Wösten, 2018; Ren et al., 2019).

Regarding CE, it is important to point out that priority should be given to the reuse of the waste in the place where it is generated wherever possible, that is, in the farm itself. This contributes to closing the nutrient cycle, prevents leakages, minimises the exit of materials and narrows the circle and avoids the use of transport. Furthermore, network systems should be developed that connect nearby sectors in order to maximise the exploitation of resources between different links of a value chain. In this way, synergies are generated, material circles are closed and the need for transport and the environmental impact are minimised. Furthermore, consumer perception about products made from circular waste recovery models is not known. Studies have been conducted on the perception of users regarding the use of biomass for bioenergy production, with satisfactory results regarding the consideration of biomass energy, its importance and responsibility, level of awareness, knowledge and ecological approach (Bujdosó et al., 2012; Timonen et al., 2021). A future line of work could replicate these studies in reference to other uses of agricultural biomass.

As mentioned in the field preparation stage, in the waste management stage the need for integrated systems under holistic approaches for the coordination between different processes and production sectors is of particular relevance. In this sense, the application of 4.5 and 5.0 technologies is capable not only of increasing production through the computerisation of all crop-related information in real time and the mechanisation of tasks through robotics, but is also capable of interconnecting users to manage processes and circularise decision-making (Contreras-Medina et al., 2022).

In addition to the positive environmental impact, through the different improvement processes proposed, a series of economic and social benefits are achieved. The transformation of production models towards circularity implies the development of new activities and new business opportunities. In this way, the circularisation of agriculture produces a synergetic effect on the economy as it stimulates the development of new materials and products upstream, but also downstream, as well as in other productive sectors (Aznar-Sánchez et al., 2020). This effect could be seen as a multiplier effect of the circularity of the economy covering all related sectors, from ancillary industries to industries in other sectors such as pharmaceuticals, construction or energy. From a social perspective, the circularity of agricultural activity can have an impact on improving food supply, in a context of severe disruption of production systems due to the consequences of climate change (Velasco-Muñoz et al., 2021). This also has an impact on improving health and life expectancy. In addition, circular progress in agriculture can generate a large number of jobs, especially in rural areas, providing a boost to rural development and population fixation. This also has a positive impact in terms of improved consumption choices of other products, as well as medical and educational services, greater equity in consumption and lifestyles.

Finally, it should be pointed out that although a rigorous procedure has been used in carrying out this work, it is not without its limitations. The first limitation is determined by the dynamics of scientific production in the field of study. The large volume of scientific literature makes it impossible to synthesise it completely in a single work, forcing the selection of a representative sample. The determination of this sample implies the omission of part of the literature, which is a second limitation of this work. Furthermore, this study has focused on a set of variables to be analysed, both from a quantitative and qualitative perspective, omitting part of the information contained in the documents analysed, which is the last limitation of this study. Despite these limitations, the results of this work are sufficiently valid and representative.

4. Conclusion

In agriculture, the CE should start to be seen as an economic model that is respectful of the environment, allowing emerging business and employment opportunities while having a favourable impact on the well-being of society. The research community needs to work to realise this vision by sharing knowledge across countries and regions, and by collaborating with all other stakeholders - governments, producer organisations, consumers, civil society and the private sector. Many studies have been conducted on the management of biological materials, particularly focused on the reuse of primary waste. However, less attention has been paid to the case of the technical materials used in agriculture or the use of energy and fuels. In this sense, it is necessary to highlight that research is often developed in a given context under specific characteristics, making its generalised application difficult. Therefore, it is essential to analyse the practical application of the most promising alternatives in different legal, social and economic contexts. There are many studies on the different aspects of the efficient management and improved techniques in agriculture, always from a technical or agronomic approach. However, this large volume of knowledge has not been integrated in the circular approach, constituting another opportunity to develop further research studies.

The circular alternatives developed to date are still not as effective as those habitually used. For example, this is the case of the recycled organic fertilizer o the biodegradable mulching films. Moreover, the use of certain materials and processes based on circular models such as biomaterials usually have a high cost for the farmer. These factors are decisive for the success of the adoption of circular alternatives in agriculture. Therefore, it is necessary to obtain a greater level of knowledge regarding the cost structure of the farms and the economic-financial feasibility of the different initiatives throughout the different phases of the process. In addition, it is necessary to examine more thoroughly the perceptions of the stakeholders with respect to the different circular model alternatives. Finally, the public entities should be provided with information in order to develop specific action plans with the objective of promoting circularity in agricultural practices.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was partially supported by the Spanish Ministry of Economy and Competitiveness and the European Regional Development Fund by means of the research project ECO2017-82347-P and by the FPU19/04549 Predoctoral Contract to Belén López-Felices.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Abbas, F., Hammad, H.M., Anwar, F., Farooque, A.A., Jawad, R., Bakhat, H.F., Naeem, M.A., Ahmad, S., Qaisrani, S.A., 2021. Transforming a valuable bioresource to biochar, its environmental importance, and potential applications in boosting circular bioeconomy while promoting sustainable agriculture. Sustainability 13 (5), 2599. https://doi.org/10.3390/su13052599.

Alobwede, E., Leake, J.R., Pandhal, J., 2019. Circular economy fertilization: testing micro and macro algal species as soil improvers and nutrient sources for crop production in greenhouse and field conditions. Geoderma 334, 113–123. https://doi.org/10.1016/j.geoderma.2018.07.049.

Asawa, G.L., 2008. Irrigation and Water Resources Engineering. New Age International.

Awoyera, P.O., Adesina, A., 2020. Plastic wastes to construction products: status, limitations and future perspective. Case Stud. Constr. Mater. 12, e00330. https://doi.org/10.1016/J.CSCM.2020.E00330.

Aznar-Sánchez, J.A., Belmonte-Ureña, L.J., Velasco-Muñoz, J.F., Manzano-Agugliaro, F., 2018. Economic analysis of sustainable water use: a review of worldwide research. J. Clean. Prod. 198, 1120–1132. https://doi.org/10.1016/j.jclepro.2018.07.066.

Aznar-Sánchez, J.A., Piquer-Rodríguez, M., Velasco-Muñoz, J.F., Manzano-Agugliaro, F., 2019. Worldwide research trends on sustainable land use in agriculture. Land Use Pol. 87, 104069. https://doi.org/10.1016/j.landusepol.2019.104069.

Aznar-Sánchez, J.A., Velasco-Muñoz, J.F., García-Arca, D., López-Felices, B., 2020. Identification of opportunities for applying the circular economy to intensive agriculture in Almería (South-East Spain). Agronomy-Basel 10, 1499. https://doi.org/10.3390/agronomy10101499.

Ballardo, C., Barrena, R., Artola, A., Sánchez, A., 2017. A novel strategy for producing compost with enhanced biopesticide properties through solid-state fermentation of biowaste and inoculation with bacillus thuringiensis. Waste Manag. 70, 53–58. https://doi.org/10.1016/j.wasman.2017.09.041.

Banerjee, H., Ray, K., Dutta, S.K., 2018. Fertilizer Best Management Practices: Concepts and Recent Advances. Soil Amendments for Sustainability. CRC Press, pp. 33–46 https://doi.org/10.1201/9781351027021-3.

Barros, M.V., Salvador, R., de Francisco, A.C., Piekarski, C.M., 2020. Mapping of research lines on circular economy practices in agriculture: from waste to energy. Renew. Sust. Energ. Rev. 131, 109958. https://doi.org/10.1016/j.rser.2020.109958.

Bechara, E., Papafilippaki, A., Doupis, G., Sofo, A., Koubouris, G., 2018. Nutrient dynamics, soil properties and microbiological aspects in an irrigated olive orchard managed with five different management systems involving soil tillage, cover crops and compost. J. Water Clim. Chang. 9 (4), 736–747. https://doi.org/10.2166/wcc.2018.082.

Berbel, J., Posadillo, A., 2018. Review and analysis of alternatives for the valorisation of agro-industrial olive oil by-products. Sustainability 10, 237. https://doi.org/10.3390/su10010237.

Blanke, M., 2020. (Micro-) plastics in horticulture: GKL workshop on circular economy of plastics in agriculture and horticulture. Erwerbs-Obstbau 62 (4), 489–497.

Blouin, M., Barrere, J., Meyer, N., Lartigue, S., Barot, S., Mathieu, J., 2019. Vermicompost significantly affects plant growth. A meta-analysis. Agron. Sustain. Dev. 39, 34. https://doi.org/10.1007/s13593-019-0579-x.

Borrello, M., Lombardi, A., Pascucci, S., Cembalo, L., 2016. The seven challenges for transitioning into a bio-based circular economy in the Agri-food sector. Recent. Pat. Food. Nutr. Agric. 8 (1), 39–47. https://doi.org/10.2174/2212798408011603041439339.

Bos, H.L., Broeze, J., 2020. Circular bio-based production systems in the context of current biomass and fossil demand. BiofuelsBioprod. Bioref. 14, 187–197. https://doi.org/10.1002/bbb.2080.

Bujdosó, Z., Patkós, C., Kovács, T., Radics, Z., Baros, Z., 2012. The social aspects and public acceptance of biomass giving the example of a hungarian region. Int. J. Renew. Energy Dev. 1 (2), 39–43. https://doi.org/10.14710/ijred.1.2.39-43.

Burgo-Bencomo, O.B., Gaitán-Suazo, V., Yanez-Sarmiento, J., Zambrano-Morales, Á.A., Castellanos-Pallerols, G., Estrada Hernández, J.A., 2019. La Economía circular una

alternativa sostenible Para el desarrollo de la agricultura. Espacios 40 (13), 2. http://www.revistaespacios.com/a19v40n13/a19v40n13p02.pdf.
Carlson, K.M., Gerber, J.S., Mueller, N.D., Herrero, M., MacDonald, G.K., Brauman, K.A., Havlik, P., O'Connell, C.S., Johnson, J.A., Saatchi, S., West, P.C., 2016. Greenhouse gas emissions intensity of global croplands. Nat. Clim. Chang. 7 (1), 63–68. https://doi.org/10.1038/nclimate3158.
Case, S.D.C., Oelofse, M., Hou, Y., Oenema, O., Jensen, L.S., 2017. Farmer perceptions and use of organic waste products as fertilisers–A survey study of potential benefits and barriers. Agric. Syst. 151, 84–95. https://doi.org/10.1016/j.agsy.2016.11.012.
Castro, J.D.S., Calijuri, M.L., Mattiello, E.M., Ribeiro, V.J., Assemany, P.P., 2020. Algal biomass from wastewater: soil phosphorus bioavailability and plants productivity. Sci. Total Environ. 711, 135088. https://doi.org/10.1016/j.scitotenv.2019.135088.
Chang, I.S., Zhao, J., Yin, X., Wu, J., Jia, Z., Wang, L., 2011. Comprehensive utilizations of biogas in Inner Mongolia, China. Renew. Sust. Energ. Rev. 15 (3), 1442–1453. https://doi.org/10.1016/j.rser.2010.11.013.
Chiocchio, I., Prata, C., Mandrone, M., Ricciardiello, F., Marrazzo, P., Tomasi, P., Angeloni, C., Fiorentini, D., Malaguti, M., Poli, F., Hrelia, S., 2020. Leaves and spiny burs of castanea sativa from an experimental chestnut grove: metabolomic analysis and anti-neuroinflammatory activity. Metabolites 10, 408. https://doi.org/10.3390/metabo10100408.
Chojnacka, K., Moustakas, K., Witek-Krowiak, A., 2020a. Bio-based fertilizers: a practical approach towards circular economy. Bioresour. Technol. 295, 122223. https://doi.org/10.1016/j.biortech.2019.122223.
Chojnacka, K., Witek-Krowiak, A., Moustakas, K., Skrzypczak, D., Mikula, K., Loizidou, M., 2020b. A transition from conventional irrigation to fertigation with reclaimed wastewater: prospects and challenges. Renew. Sust. Energ. Rev. 130, 109959. https://doi.org/10.1016/j.rser.2020.109959.
Circle Economy, 2021. The Circularity Gap Report 2021.Available online: https://www.circularity-gap.world/2021#downloads (accessed on 29 April 2021).
Contreras-Medina, D.I., Medina-Cuéllar, S.E., Rodríguez-García, J.M., 2022. Roadmapping 5.0 Technologies in Agriculture: a technological proposal for developing the coffee plant centered on indigenous producers' requirements from Mexico, via knowledge management. Plants 11 (11), 1502. https://doi.org/10.3390/plants11111502.
Cortés, A., Oliveira, L.F.S., Ferrari, V., Taffarel, S.R., Feijoo, G., Moreira, M.T., 2020. Environmental assessment of viticulture waste valorisation through composting as a biofertilisation strategy for cereal and fruit crops. Environ. Pollut. 264, 114794. https://doi.org/10.1016/j.envpol.2020.114794.
Crappé, S., Buysens, S., 2020. How cucumber (Cucumis sativus L.) cultivation can contribute to a sustainable fish production. Acta Hortic. 1294, 61–68. https://doi.org/10.17660/ActaHortic.2020.1294.8.
Cucagna, M.E., Goldsmith, P.D., 2018. Value adding in the agri-food value chain. Int. Food Agribus. Manag. Rev. 21 (3), 293–316. https://doi.org/10.22434/IFAMR2017.0051.
Czekała, W., Lewicki, A., Pochwatka, P., Czekała, A., Wojcieszak, D., Jóźwiakowski, K., Waliszewska, H., 2020. Digestate management in polish farms as an element of the nutrient cycle. J. Clean. Prod. 242, 118454. https://doi.org/10.1016/j.jclepro.2019.118454.
De Boer, I.J., van Ittersum, M.K., 2018. Circularity in agricultural production. Wageningen University & Research.Available online: https://www.wur.nl/en/show/Circularity-in-agricultural-production.htm (accessed on 29 April 2021).
De Pascale, S., Leonardi, C., 2011. Greenhouse crop management: new approaches to an old challenge. In: Kittas, N., Bartzanas, T. (Eds.), International Symposium on Advanced Technologies and Management Towards Sustainable Greenhouse Ecosystems: Greensys 2011. Acta Horticulturae, pp. 343–349.
Delgado, A., Quemada, M., Villalobos, F.J., 2016. Fertilizers. In: Villalobos, F., Fereres, E. (Eds.), Principles of Agronomy for Sustainable Agriculture. Springer, Cham, pp. 321–340 https://doi.org/10.1007/978-3-319-46116-8_16.
Dorper, A., Veldkamp, T., Dicke, M., 2020. Use of black soldier fly and house fly in feed to promote sustainable poultry production. J. Insects Food Feed 7 (5), 761–780. https://doi.org/10.3920/JIFF2020.0064.
Duque-Acevedo, M., Belmonte-Ureña, L.J., Toresano-Sánchez, F., Camacho-Ferre, F., 2020. Biodegradable raffia as a sustainable and cost-effective alternative to improve the management of agricultural waste biomass. Agronomy 10, 1261. https://doi.org/10.3390/agronomy10091261.
Ellen MacArthur Foundation (EMF), 2015. Schools of thought – performance economy. Available online: https://www.ellenmacarthurfoundation.org/circular-economy/concept/schools-of-thought (accessed on 29 April 2021).
Ellen MacArthur Foundation (EMF), 2019. Completing the Picture: How the Circular Economy Tackles Climate Change.Available online: www.ellenmacarthurfoundation.org/publications (accessed on 29 April 2021).
Ellen MacArthur Foundation (EMF), 2019. Cities and Circular Economy for Food.Available online: http://www.ellenmacarthurfoundation.org/publications (accessed on 29 April 2021).
Ellen MacArthur Foundation (EMF), 2021. The big food redesign: Regenerating nature with the circular economy.Available online: https://emf.thirdlight.com/link/TheBigFoodRedsignReport/@/preview/3 (accessed on 9 September 2022).
European Commission, 2015. Closing the Loop - an EU Action Plan for the Circular Economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614.
European Commission, 2018. Impacts of circular economy policies on the labour market. Final Report. Publications Office of the European Union, Luxembourg . https://op.europa.eu/s/pnwH.
Food and Agriculture Organization of the United Nations (FAO), 2011. Energy-Smart Food for People and Climate. Issue Paper.Available online https://www.fao.org/3/i2454e/i2454e.pdf (accessed on 9 September 2022).
Food and Agriculture Organization of the United Nations (FAO), 2017. Strategic work of FAO for Sustainable Food and Agriculture.Available online: http://www.fao.org/3/a-i6488e.pdf (accessed on 29 April 2021).
Food and Agriculture Organization of the United Nations (FAO), 2019. World fertilizer trends and outlook to 2022.Available online: https://www.fao.org/3/ca6746en/ca6746en.pdf (accessed on 9 September 2022).
Ferree, D.C., Schupp, J.R., 2003. Pruning and training physiology. Apples: Botany, Production and Uses, pp. 319–344.
Gaidau, C., Epure, D.G., Enascuta, C.E., Carsote, C., Sendrea, C., Proietti, N., Chen, W., Gu, H., 2019. Wool keratin total solubilisation for recovery and reintegration-an ecological approach. J. Clean. Prod. 236, 117586. https://doi.org/10.1016/j.jclepro.2019.07.061.
Galati, A., Sabatino, L., Prinzivalli, C.S., D'Anna, F., Scalenghe, R., 2020. Strawberry fields forever: that is, how many grams of plastics are used to grow a strawberry? J. Environ. Manag. 276, 111313. https://doi.org/10.1016/j.jenvman.2020.111313.
Garske, B., Stubenrauch, J., Ekardt, F., 2020. Sustainable phosphorus management in european agricultural and environmental law. Rev. Eur. Comp. Int. Environ. 29 (1), 107–117. https://doi.org/10.1111/reel.12318.
Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007.
Greco, C., Agnello, A., La Placa, G., Mammano, M.M., Navickas, K., 2019. Biowaste in a circular bioeconomy in Mediterranean area: a case study of compost and vermicompost as growing substrates alternative to peat. Revista di Studi sulla Sostenibilità 345–362. https://doi.org/10.3280/RISS2019-002-S1022.
Grimm, A., Eilertsen, L., Chen, F., Huang, R., Atterhem, L., Xiong, S., 2021. Cultivation of pleurotus ostreatus mushroom on substrates made of cellulose fibre rejects: product quality and spent substrate fuel properties. Waste Biomass Valoriz. 12, 4331–4340. https://doi.org/10.1007/s12649-020-01311-y.
Grimm, D., Wösten, H.A.B., 2018. Mushroom cultivation in the circular economy. Appl. Microbiol. Biotechnol. 102, 7795–7803. https://doi.org/10.1007/s00253-018-9226-8.
Gwara, S., Wale, E., Odindo, A., Buckley, C., 2020. Why do we know so much and yet so Little? A scoping review of willingness to pay for human excreta derived material in agriculture. Sustainability 12, 6490. https://doi.org/10.3390/su12166490.
Hayashi, K., Gaillard, G., Nemecek, T., 2005. Life cycle assessment of agricultural production systems: current issues and future perspectives. Proc. of the International Seminar on Technology Development for Good Agricultural Practice, Tsukuba, Japan. 25, p. 10 No. 26.
Herrmann, K.R., Ruff, A.J., Schwaneberg, U., 2020. Phytase-based phosphorus recovery process for 20 distinct press cakes. ACS Sustain. Chem. Eng. 8 (9), 3913–3921. https://doi.org/10.1021/acssuschemeng.9b07433.
Honorato-Salazar, J.A., Sadhukhan, J., 2020. Annual biomass variation of agriculture crops and forestry residues, and seasonality of crop residues for energy production in Mexico. Food Bioprod. Process. 119, 1–19. https://doi.org/10.1016/j.fbp.2019.10.005.
Hubenov, V., Carcioch, R.A., Ivanova, J., Vasileva, I., Dimitrov, K., Simeonov, I., Kabaivanova, L., 2020. Biomethane production using ultrasound pre-treated maize stalks with subsequent microalgae cultivation. Biotechnol. Biotechnol. Equip. 34 (1), 800–809. https://doi.org/10.1080/13102818.2020.1806108.
Huygens, D., Saveyn, H.G.M., 2018. Agronomic efficiency of selected phosphorus fertilisers derived from secondary raw materials for European agriculture. A meta-analysis. Agron. Sustain. Dev. 38, 52. https://doi.org/10.1007/s13593-018-0527-1.
Jägermeyr, J., Gerten, D., Heinke, J., Schaphoff, S., Kummu, M., Lucht, W., 2015. Water savings potentials of irrigation systems: global simulation of processes and linkages. Hydrol. Earth Syst. Sci. 19 (7), 3073–3091. https://doi.org/10.5194/hess-19-3073-2015.
Jindo, K., Audette, Y., Higashikawa, F.S., Silva, C.A., Akashi, K., Mastrolonardo, G., Sánchez-Monedero, M.A., Mondini, C., 2020. Role of biochar in promoting circular economy in the agriculture sector. Part 1: a review of the biochar roles in soil N, P and K cycles. Chem. Biol. Technol. Agric. 7 (1), 1–12. https://doi.org/10.1186/s40538-020-00182-8.
Jun, H., Xiang, H., 2011. Development of circular economy is a fundamental way to achieve agriculture sustainable development in China. Energy Procedia 5, 1530–1534. https://doi.org/10.1016/j.egypro.2011.03.262.
Kapoor, R., Ghosh, P., Kumar, M., Sengupta, S., Gupta, A., Kumar, S.S., Vijay, V., Kumar, V., Kumar-Vijay, V., Pant, D., 2020. Valorization of agricultural waste for biogas based circular economy in India: a research outlook. Bioresour. Technol. 304, 123036. https://doi.org/10.1016/j.biortech.2020.123036.
Kapoore, R.V., Wood, E.E., Llewellyn, C.A., 2021. Algae biostimulants: a critical look at microalgal biostimulants for sustainable agricultural practices. Biotechnol. Adv. 49, 107754. https://doi.org/10.1016/j.biotechadv.2021.107754.
Karagöz, I., 2021. Fertilization and fertilizer types. In: Inamuddin, I., Ahamed, M.I., Boddula, R., Altalhi, T.A. (Eds.), Applied Soil Chemistry. Scrivener Publishing LLC, pp. 123–145.
Kennard, N., Stirling, R., Prashar, A., Lopez-Capel, E., 2020. Evaluation of recycled materials as hydroponic growing media. Agronomy-basel 10, 1092. https://doi.org/10.3390/agronomy10081092.
Khan, M.N., Mobin, M., Abbas, Z.K., Alamri, S.A., 2018. Fertilizers and their contaminants in soils, surface and groundwater. Encycl. Anthr. 5, 225–240. https://doi.org/10.1016/B978-0-12-809665-9.09888-8.
Kisvarga, S., Barna, D., Kovács, S., Csatári, G., Tóth, O., I, Fári, M.G., Makleit, P., Veres, S., Alshaal, T., Bákonyi, N., 2020. Fermented alfalfa brown juice significantly stimulates the growth and development of sweet basil (Ocimum basilicum L.) plants. Agronomy-Basel 10, 657. https://doi.org/10.3390/agronomy10050657.
Kristensen, D.K., Kjeldsen, C., Thorsøe, M.H., 2016. Enabling sustainable agro-food futures: exploring fault lines and synergies between the integrated territorial paradigm, rural eco-economy and circular economy. J. Agric. Environ. Ethics 29, 749–765. https://doi.org/10.1007/s10806-016-9632-9.

Kristensen, H.S., Mosgaard, M.A., 2020. A review of micro level indicators for a circular economy–moving away from the three dimensions of sustainability? J. Clean. Prod. 243, 118531. https://doi.org/10.1016/j.jclepro.2019.118531.

Kusumastuti, R.D., Van Donk, D.P., Teunter, R., 2016. Crop-related harvesting and processing planning: a review. Int. J. Prod. Econ. 174, 76–92. https://doi.org/10.1016/j.ijpe.2016.01.010.

Liao, Y., Kaviyani-Charati, M., Hajiaghaei-Keshteli, M., Diabat, A., 2020. Designing a closed-loop supply chain network for citrus fruits crates considering environmental and economic issues. J. Manuf. Syst. 55, 199–220. https://doi.org/10.1016/j.jmsy.2020.02.001.

Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. J. Clean. Prod. 115, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042.

Liu, H., Ou, X., Yuan, J., Yan, X., 2018. Experience of producing natural gas from corn straw in China. Resour. Conserv. Recycl. 135, 216–224. https://doi.org/10.1016/j.resconrec.2017.10.005.

Lo Giudice, V., Faraone, I., Bruno, M.R., Ponticelli, M., Labanca, F., Bisaccia, D., Massarelli, C., Milella, L., Todaro, L., 2021. Olive trees by-products as sources of bioactive and other industrially useful compounds: a systematic review. Molecules 26 (16), 5081. https://doi.org/10.3390/MOLECULES2616508.

Lu, H., Bian, R., Xia, X., Cheng, K., Liu, X., Liu, Y., Wang, P., Li, Z., Zheng, J., Li, L., Joseph, L., Drosos, M., Pan, G., 2020. Legacy of soil health improvement with carbon increase following one time amendment of biochar in a paddy soil–a rice farm trial. Geoderma 376, 114567. https://doi.org/10.1016/j.geoderma.2020.114567.

Ma, Y., Shen, Y., Liu, Y., 2020. State of the art of straw treatment technology: challenges and solutions forward. Bioresour. Technol. 313, 123656. https://doi.org/10.1016/j.biortech.2020.123656.

Maestre-Valero, J.F., Gonzalez-Ortega, M.J., Martinez-Alvarez, V., Gallego-Elvira, B., Conesa-Jodar, F.J., Martin-Gorriz, B., 2019. Revaluing the nutrition potential of reclaimed water for irrigation in southeastern Spain. Agric. Water Manag. 218, 174–181. https://doi.org/10.1016/j.agwat.2019.03.050.

Mangers, J., Minoufekr, M., Plapper, P., Kolla, S., 2021. An innovative strategy allowing a holistic system change towards circular economy within supply-chains. Energies 14 (14), 4375. https://doi.org/10.3390/en14144375.

Manríquez-Altamirano, A., Sierra-Pérez, J., Muñoz, P., Gabarrell, X., 2020. Analysis of urban agriculture solid waste in the frame of circular economy: case study of tomato crop in integrated rooftop greenhouse. Sci. Total Environ. 734, 139375. https://doi.org/10.1016/j.scitotenv.2020.139375.

Maquet, C., 2020. Wastewater reuse: a solution with a future. Field Actions Science Reports. 22 , pp. 64–69. https://bit.ly/2V8XPAq.

Martin, M., Poulikidou, S., Molin, E., 2019. Exploring the environmental performance of urban Symbiosis for vertical hydroponic farming. Sustainability 11, 6724. https://doi.org/10.3390/su11236724.

Martínez-Urreaga, J., Beltrán, F.R., Acosta, J., Aguinaco, T., Fonseca, C., Ochoa, A., Oliet-Paládm J.A., González-Sánchez, C., de la Orden, M.U., 2020. Tube shelters from agricultural plastic waste: an example of circular economy. J. Clean. Prod. 268, 122401. https://doi.org/10.1016/j.jclepro.2020.122401.

Matthews, G., 2017. Integrated Pest management: principles. In: Thomas, B., Murray, B.G., Murphy, D.J. (Eds.), Encyclopedia of Applied Plant Sciences, (Second Edition) vol. 3. Academic Press, pp. 103–107. https://doi.org/10.1016/B978-0-12-394807-6.00060-5.

METI, 2004. Handbook on Resource Recycling Legislation and 3R Initiatives. Japanese Ministry of Economy, Trade and Industry, Tokyo. 2004.

Michalopoulos, G., Kasapi, K.A., Koubouris, G., Psarras, G., Arampatzis, G., Hatzigiannakis, E., Kavvadias, V., Xiloyannis, C., Montanaro, G., Malliaraki, S., Angelaki, A., Manolaraki, C., Giakoumaki, G., Reppas, S., Kourgialas, N., Kokkinos, G., 2020. Adaptation of Mediterranean olive groves to climate change through sustainable cultivation practices. Climate 8, 54. https://doi.org/10.3390/cli8040054.

Moreno-García, M., Repullo-Ruibérriz de Torres, M.A., Carbonell-Bojollo, R.M., Ordóñez-Fernández, R., 2018. Management of pruning residues for soil protection in olive orchards. L. Degrad. Dev. 29 (9), 2975–2984. https://doi.org/10.1002/LDR.3054.

Moretti, B., Bertora, C., Grignani, C., Lerda, C., Celi, L., Sacco, D., 2020. Conversion from mineral fertilisation to MSW compost use: nitrogen fertiliser value in continuous maize and test on crop rotation. Sci. Total Environ. 705, 135308. https://doi.org/10.1016/j.scitotenv.2019.135308.

Morseletto, P., 2020. Restorative and regenerative: exploring the concepts in the circular economy. J. Ind. Ecol. 24 (4), 1–11. https://doi.org/10.1111/jiec.12987.

Muhammad, M.S. Bacha, Shah, S.A.A., 2020. Urban farmers willingness to pay for organic fertilizer in District Mardan, Khyber Pakhtunkhwa, Pakistan. Sarhad J. Agric. 36 (2), 419–426. https://doi.org/10.17582/journal.sja/2020/36.2.419.426.

Muscio, A., Sisto, R., 2020. Are Agri-food systems really switching to a circular economy model? Implications for European research and innovation policy. Sustainability 12, 5554. https://doi.org/10.3390/su12145554.

Overturf, E., Ravasio, N., Zaccheria, F., Tonin, C., Patrucco, A., Bertini, F., Canetti, M., Avramidou, K., Speranza, G., Bavaro, T., Ubiali, D., 2020. Towards a more sustainable circular bioeconomy. Innovative approaches to rice residue valorization: the RiceRes case study. Bioresour. Technol. Reports 11, 100427. https://doi.org/10.1016/j.biteb.2020.100427.

Palmieri, N., Suardi, A., Alfano, V., Pari, L., 2020. Circular economy model: insights from a case study in South Italy. Sustainability 12, 3466. https://doi.org/10.3390/su12083466.

Papangelou, A., Mathijs, E., 2021. Assessing agro-food system circularity using nutrient flows and budgets. J. Environ. Manag. 288, 112383. https://doi.org/10.1016/j.jenvman.2021.112383.

Pandey, S., Dwivedi, N., 2020. Utilisation and management of agriculture and food processing waste. In: Mishra, P., Mishra, R.R., Adetunji, C.O. (Eds.), Innovations in Food Technology. Springer, pp. 269–288 https://doi.org/10.1007/978-981-15-6121-4_19.

Pascual, J.A., Ceglie, F., Tuzel, Y., Koller, M., Koren, A., Hitchings, R., Tittarelli, F., 2018. Organic substrate for transplant production in organic nurseries. A review. Agron. Sustain. Dev. 38 (3), 1–23. https://doi.org/10.1007/s13593-018-0508-4.

Pazienza, P., De Lucia, C., 2020. For a new plastics economy in agriculture: policy reflections on the EU strategy from a local perspective. J. Clean. Prod. 253, 119844. https://doi.org/10.1016/j.jclepro.2019.119844.

Plainfossé, H., Burger, P., Verger-Dubois, G., Azoulay, S., Fernandez, X., 2019. Design methodology for the development of a new cosmetic active based on Prunus domestica L. leaves extract. Cosmetics 6, 8. https://doi.org/10.3390/cosmetics6010008.

Prosperi, M., Sisto, R., Lombardi, M., Zhu, X., 2018. Production of bioplastics for agricultural purposes: a supply chain study. Riv. Stud Sulla Sosten. 1, 119–136. https://doi.org/10.3280/RISS2018-001010.

Puglia, D., Pezzolla, D., Gigliotti, G., Torre, L., Bartucca, M.L., Del Buono, D., 2021. The opportunity of valorizing agricultural waste, through its conversion into biostimulants, biofertilizers, and biopolymers. Sustainability 13 (5), 2710. https://doi.org/10.3390/su13052710.

Qin, S., Shekher-Giri, B., Kumar Patel, A., Sar, T., Liu, H., Chen, H., Juneja, A., Kumar, D., Zhang, Z., Kumar-Awasthi, M., Taherzadeh, M.J., 2021. Resource recovery and biorefinery potential of apple orchard waste in the circular bioeconomy. Bioresour. Technol. 321, 124496. https://doi.org/10.1016/j.biortech.2020.124496.

Rahimpour-Golroudbary, S., El Wali, M., Kraslawski, A., 2020. Rationality of using phosphorus primary and secondary sources in circular economy: game-theory-based analysis. Environ. Sci. Policy 106, 166–176. https://doi.org/10.1016/j.envsci.2020.02.004.

Rekleitis, G., Haralambous, K.-J., Loizidou, M., Aravossis, K., 2020. Utilization of agricultural and livestock waste in anaerobic digestion (A.D): applying the biorefinery concept in a circular economy. Energies 13, 4428. https://doi.org/10.3390/en13174428.

Ren, J., Yu, P., Xu, X., 2019. Straw utilization in China—status and recommendations. Sustainability 11, 1762. https://doi.org/10.3390/su11061762.

Ricciardi, P., Cillari, G., Carnevale-Miino, M., Collivignarelli, M.C., 2020. Valorization of agro-industry residues in the building and environmental sector: a review. Waste Manage. Res. 38 (5), 487–513. https://doi.org/10.1177/0734242X20904426.

Roba, T.B., 2018. Review on: the effect of mixing organic and inorganic fertilizer on productivity and soil fertility. Open Access Library J. 5, e4618. https://doi.org/10.4236/oalib.1104618.

Rufí-Salís, M., Petit-Boix, A., Villalba, G., Sanjuan-Delmás, D., Parada, F., Ercilla-Montserrat, M., Arcas-Pilz, V., Muñoz-Liesa, J., Rieradevall, J., Gabarrell, X., 2020. Recirculating water and nutrients in urban agriculture: an opportunity towards environmental sustainability and water use efficiency? J. Clean. Prod. 261, 121213. https://doi.org/10.1016/j.jclepro.2020.121213.

Sartore, L., Schettini, E., de Palma, L., Brunetti, G., Cocozza, C., Vox, G., 2018. Effect of hydrolyzed protein-based mulching coatings on the soil properties and productivity in a tunnel greenhouse crop system. Sci. Total Environ. 645, 1221–1229. https://doi.org/10.1016/j.scitotenv.2018.07.259.

Sawicka, B., Egbuna, C., 2020. Pests of agricultural crops and control measures. In: Sawicka, B., Egbuna, C. (Eds.), Natural Remedies for Pest, Disease and Weed Control. Academic Press, pp. 1–16 https://doi.org/10.1016/B978-0-12-819304-4.00001-4.

Sayadi-Gmada, S., Rodríguez-Pleguezuelo, C.R., Rojas-Serrano, F., Parra-López, C., Parra-Gómez, S., García-Collado, R., Lorbach-Kelle, M.B., Manrique-Gordillo, T., García-García, M.d.C., 2019. Inorganic waste management in greenhouse agriculture in Almeria (SE Spain): towards a circular system in intensive horticultural production. Sustainability 11, 3782. https://doi.org/10.3390/su11143782.

Sayadi-Gmada, S., Torres-Nieto, J.M., Parra Gómez, S., García-García, M.C., Parra-López, C., 2020. Critical point analysis in solid inorganic waste production in the protected cultivation systems in almeria - approaches to reduce the impact. Acta Hortic. 1268, 205–212. https://doi.org/10.17660/ActaHortic.2020.1268.27.

Sciubba, F., Chronopoulou, L., Pizzichini, D., Lionetti, V., Fontana, C., Aromolo, R., Socciarelli, S., Gambelli, L., Bartolacci, B., Finotti, E., Benedetti, A., Miccheli, A., Neri, U., Palocci, C., Bellincampi, D., 2020. Olive mill wastes: a source of bioactive molecules for plant growth and protection against pathogens. Biology 9, 450. https://doi.org/10.3390/biology9120450.

Setti, L., Francia, E., Pulvirenti, A., De Leo, R., Martinelli, S., Maistrello, L., Macavei, L.I., Montorsi, M., Barbi, S., Ronga, D., 2020. Bioplastic film from black soldier Fly prepupae proteins used as mulch: preliminary results. Agronomy-basel 10, 933. https://doi.org/10.3390/agronomy10070933.

Sommer, S.G., Hamelin, L., Olesen, J.E., Montes, F., Jia, W., Chen, Q., Triolo, J.M., 2015. Agricultural waste biomass. In: Lakovou, E., Bochtis, D., Bochtis, D., Vlachos, D., Aidonis, D. (Eds.), Supply Chain Management for Sustainable Food Networks. John Wiley & Sons, Ltd, pp. 67–106 https://doi.org/10.1002/9781118937495.CH3.

Sharma, N., Singhvi, R., 2017. Effects of chemical fertilizers and pesticides on human health and environment: a review. Int. J. Agric. Environ. Biotechnol. 10 (6), 675–679. https://doi.org/10.5958/2230-732X.2017.00083.3.

Sharma, S., Barman, K., Siddiqui, M.W., Nath, V., 2018. Training and pruning for improved postharvest fruit quality. In: Siddiqui, M.W. (Ed.), Preharvest Modulation of Postharvest Fruit and Vegetable Quality. Academic Press, pp. 257–276.

Spyridonidis, A., Vasiliadou, I.A., Akratos, C.S., Stamatelatou, K., 2020. Performance of a full-scale biogas plant operation in Greece and its impact on the circular economy. Water 12, 3074. https://doi.org/10.3390/w12113074.

Stefanski, F.S., Camargo, A.F., Scapini, T., Bonatto, C., Venturin, B., Weirich, S.N., Ulkovski, C., Carezia, C., Ulrich, A., Michelon, W., Moreira Soares, H., Mathiensen, A., Fingar, G., Mossi, A.J., Treichel, H., 2020. Potential use of biological herbicides in a circular economy context: a sustainable approach. Front. Sustain. Food Syst. 4, 195. https://doi.org/10.3389/fsufs.2020.521102.

Stillitano, T., Spada, E., Iofrida, N., Falcone, G., De Luca, A.I., 2021. Sustainable Agri-food processes and circular economy pathways in a life cycle perspective: state of the

art of applicative research. Sustainability 13 (5), 2472. https://doi.org/10.3390/su13052472.
Stürmer, B., Pfundtner, E., Kirchmeyr, F., Uschnig, S., 2020. Legal requirements for digestate as fertilizer in Austria and the European Union compared to actual technical parameters. J. Environ. Manag. 253, 109756. https://doi.org/10.1016/j.jenvman.2019.109756.
Su, B., Heshmati, A., Geng, Y., Yu, X., 2013. A review of the circular economy in China: moving from rhetoric to implementation. J. Clean. Prod. 42, 215–227. https://doi.org/10.1016/j.jclepro.2012.11.020.
Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G., Soto-Oñate, D., 2019. Operational principles of circular economy for sustainable development: linking theory and practice. J. Clean. Prod. 214, 952–961. https://doi.org/10.1016/j.jclepro.2018.12.271.
Suresh, A., Samuel, M.P., 2020. Micro-irrigation development in India: challenges and strategies. Curr. Sci. 118 (8), 1163.
Tallou, A., Aziz, F., Garcia, A.J., Salcedo, F.P., El Minaoui, F.E., Amir, S., 2021. Bio-fertilizers issued from anaerobic digestion for growing tomatoes under irrigation by treated wastewater: targeting circular economy concept. Int. J. Environ. Sci. Technol. 1–10. https://doi.org/10.1007/s13762-021-03265-7.
Tamburini, E., Pedrini, P., Marchetti, M.G., Fano, E.A., Castaldelli, G., 2015. Life cycle based evaluation of environmental and economic impacts of agricultural productions in the Mediterranean area. Sustainability 7, 2915–2935. https://doi.org/10.3390/su7032915.
Tauro, R., Velázquez-Martí, B., Manrique, S., Ricker, M., Martínez-Bravo, R., Ruiz-García, V.M., Ramos-Vargas, S., Masera, O., Soria-González, J.A., Armendáriz-Arnez, C., 2022. Potential use of pruning residues from avocado trees as energy input in rural communities. Energies 15 (5), 1715. https://doi.org/10.3390/en15051715.
Torreiro, Y., Pérez, L., Piñeiro, G., Pedras, F., Rodríguez-Abalde, A., 2020. The role of energy valuation of agroforestry biomass on the circular economy. Energies 13, 2516. https://doi.org/10.3390/en13102516.
Timonen, K., Reinikainen, A., Kurppa, S., Riipi, I., 2021. Key indicators and social acceptance for bioenergy production potential as part of the green economy transition process in local areas of Lapland. Int. J. Environ. Res. Public Health 18 (2), 527. https://doi.org/10.3390/ijerph18020527.
Van der Wiel, B.Z., Weijma, J., van Middelaar, C.E., Kleinke, M., Buisman, C.J.N., Wichern, F., 2019. Restoring nutrient circularity: a review of nutrient stock and flow analyses of local agro-food-waste systems. Resour. Conserv. Recycl. 3, 100014. https://doi.org/10.1016/j.rcrx.2019.100014.
Vandecasteele, B., Blindeman, L., Amery, F., Pieters, C., Ommeslag, S., Van Loo, K., De Tender, C., Debode, J., 2020. Grow-store-steam-re-peat: reuse of spent growing media for circular cultivation of chrysanthemum. J. Clean. Prod. 276, 124128. https://doi.org/10.1016/j.jclepro.2020.124128.
Velasco-Muñoz, J.F., Aznar-Sánchez, J.A., Batlles-delaFuente, A., Fidelibus, M.D., 2019. Sustainable irrigation in agriculture: an analysis of global research. Water 11, 1758. https://doi.org/10.3390/w11091758.
Velasco-Muñoz, J.F., Mendoza, J.M.F., Aznar-Sánchez, J.A., Gallego-Schmid, A., 2021. Circular economy implementation in the agricultural sector: definition, strategies and indicators. Resour. Conserv. Recycl. 170, 105618. https://doi.org/10.1016/j.resconrec.2021.105618.
Verma, B.C., Pramanik, P., Bhaduri, D., 2019. Organic fertilizers for sustainable soil and environmental management. In: Meena, R. (Ed.), Nutrient Dynamics for Sustainable Crop Production. Springer, Singapore, pp. 289–313 https://doi.org/10.1007/978-981-13-8660-2_10.
Villalobos, F.J., Orgaz, F., Fereres, E., 2016. Sowing and planting. In: Villalobos, F., Fereres, E. (Eds.), Principles of Agronomy for Sustainable Agriculture. Springer, Cham, pp. 217–227 https://doi.org/10.1007/978-3-319-46116-8_16.
Villalobos, F.J., Fereres, E., 2016. Harvest and conservation. In: Villalobos, F., Fereres, E. (Eds.), Principles of Agronomy for Sustainable Agriculture. Springer, Cham, pp. 487–501 https://doi.org/10.1007/978-3-319-46116-8_16.
Vitti, A., Elshafie, H.S., Logozzo, G., Marzario, S., Scopa, A., Camele, I., Nuzzaci, M., 2021. Physico-chemical characterization and biological activities of a digestate and a more stabilized digestate-derived compost from agro-waste. Plants 10 (2), 386. https://doi.org/10.3390/plants10020386.
Withers, P.J.A., Doody, D.G., Sylvester-Bradley, R., 2018. Achieving sustainable phosphorus use in food systems through circularisation. Sustainability 10, 1804. https://doi.org/10.3390/su10061804.
Zabaniotou, A., Rovas, D., Libutti, A., Monteleone, M., 2015. Boosting circular economy and closing the loop in agriculture: case study of a small-scale pyrolysis–biochar based system integrated in an olive farm in symbiosis with an olive mill. Environ. Dev. 14, 22–36. https://doi.org/10.1016/j.envdev.2014.12.002.
Zannini, D., Dal Poggetto, G., Malinconico, M., Santagata, G., Immirzi, B., 2021. Citrus pomace biomass as a source of pectin and lignocellulose fibers: from waste to upgraded biocomposites for mulching applications. Polymers 13 (8), 1280. https://doi.org/10.3390/polym13081280.
Zied, D.C., Pardo-Giménez, A., de Oliveira, G.A., Carrasco, J., Zeraik, M.L., 2019. Study of waste products as supplements in the production and quality of Pleurotus ostreatus var. Florida. Indian J. Microbiol. 59, 328–335. https://doi.org/10.1007/s12088-019-00805-1.