Science of the Total Environment 876 (2023) 162666

Contents lists available at ScienceDirect

Science of the Total Environment

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

Nitrogen management in farming systems under the use of agricultural wastes and circular economy

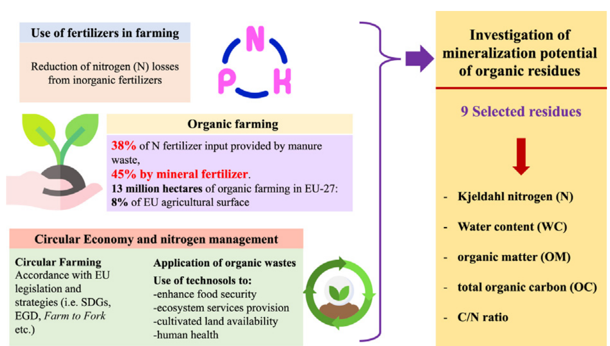
Teresa Rodríguez-Espinosa [a], Iliana Papamichael [b], Irene Voukkali [b], Ana Pérez Gimeno [a], María Belén Almendro Candel [a], Jose Navarro-Pedreño [a,*], Antonis A. Zorpas [b,*], Ignacio Gómez Lucas [a]

[a] University Miguel Hernández of Elche, Department of Agrochemistry and Environment, Avd. de la Universidad s/n, 03202 Elche (Alicante), Spain
[b] Laboratory of Chemical Engineering and Engineering Sustainability, Faculty of Pure and Applied Sciences, Open University of Cyprus, Giannou Kranidioti 89, 2231, Latsia, Nicosia, Cyprus

HIGHLIGHTS

- Nitrogen nutrition provided by organic wastes to agricultural systems
- Review of current state of knowledge of utilization of organic waste in farming
- Circular economy integration into farming and nutrition management systems
- Research about mineralization potential of nine organic residues

GRAPHICAL ABSTRACT



ARTICLE INFO

Guest editor: Prakash Kumar Sarangi

Keywords:
Circular farming
Organic waste
Organic farming
Nitrogen management
Nutrient management

ABSTRACT

Population growth leads to an increase in the demand for energy, water, and food as cities grow and urbanize. However, the Earth's limited resources are unable to meet these rising demands. Modern farming practices increase productivity, but waste resources and consume too much energy. Agricultural activities occupy 50 % of all habitable land. After a rise of 80 % in 2021, fertilizer prices have increased by nearly 30 % in 2022, representing a significant cost for farmers. Sustainable and organic farming has the potential to reduce the use of inorganic fertilizers and increase the utilization of organic residues as a nitrogen (N) source for plant nutrition. Agricultural management typically prioritizes nutrient cycling and supply for crop growth, whereas the mineralization of added biomass regulates crop nutrient supply and CO_2 emissions. To reduce overconsumption of natural resources and environmental damage, the current economic model of "take-make-use-dispose" must be replaced by "prevention-reuse-remake-recycle". The circular economy model is promising for preserving natural resources and providing sustainable, restorative, and regenerative farming. Technosols and organic wastes can improve food security, ecosystem services, the availability of arable land, and human health. This study intends to investigate the nitrogen nutrition provided by organic wastes to agricultural systems, reviewing the current state of knowledge and demonstrating how common organic wastes can be utilized to promote sustainable farming management. Nine waste residues were selected to promote sustainability in farming based on circular economy and zero waste criteria. Using standard methods, their water content, organic matter, total organic carbon, Kjeldahl nitrogen, and ammonium levels were determined, along with their potential to improve soil fertility via N supply and technosol formulation. 10 % to 15 % of organic waste was mineralized and

* Corresponding authors.
E-mail addresses: maria.rodrigueze@umh.es (T. Rodríguez-Espinosa), iliana.papamichael@gmail.com (I. Papamichael), irene.voukkali1@ouc.ac.cy voukkei@yahoo.gr (I. Voukkali), aperez@umh.es (A.P. Gimeno), mb.almendro@umh.es (M.B.A. Candel), jonavar@umh.es (J. Navarro-Pedreño), antonis.zorpas@ouc.ac.cy antoniszorpas@yahoo.com (A.A. Zorpas), ignacio.gomez@umh.es (I.G. Lucas).

http://dx.doi.org/10.1016/j.scitotenv.2023.162666
Received 28 December 2022; Received in revised form 23 January 2023; Accepted 2 March 2023
Available online 8 March 2023

analysed during a six-month cultivation cycle. Through the results, the combination of organic and inorganic fertilization to increase crop yield is recommended, as is the search for realistic and practical methods of dealing with massive amounts of organic residues within the context of a circular economy.

1. Introduction

Due to the increasing global population, the demand for energy, water and food is growing as the cities become more developed and urbanized. However, the Earth's resources are scarce and have a limited capacity to meet these rising needs (Aznar-Sánchez et al., 2020). The current economic model of "take-make-use-dispose" must be replaced by "prevention-reuse-remake-recycle" (Papamichael et al., 2022). The implementation of modern farming practices rapidly improves productivity, however with a high cost in terms of resources overconsumption and unsustainable energy use. This is evident as half of the habitable land is now used for agriculture (Kristinn et al., 2021).

To develop more sustainable future, environmental threats such as pollution, climate change, and biodiversity must be addressed. Specifically, it is estimated that by 2050, the need for food production will increase by 5.1 billion tonnes (FAO, 2017; Willett et al., 2019). Given that agricultural ecosystems are the primary food providers, this will put tremendous stress on them. Every year, approximately 90 billion tons of primary resources are extracted and used worldwide, while 10 % of them are being recycled. Furthermore, farming accounts for about 70 % of global freshwater withdrawals and for approximately 31 % of GHGs emissions, making farming a significant contributor to climate change (Aznar-Sánchez et al., 2020; Ferrari Machado et al., 2021). Besides that, according to Circle Economy data in 2019, agriculture, along with the food sector, had the second largest material footprint with 21.3 billion tons and a carbon footprint of 10 billion tons of CO_2 equivalent (eq.), ranking third after transportation and housing (Circle Economy, 2019; Velasco-Muñoz et al., 2022). Agricultural intensification has also been driven by increased use of chemical fertilizers, which has eroded the quality of farming land. Mainly due to accumulation and losses of nitrogen, phosphorus and metals (Golia et al., 2009), that pollute water bodies, reduce soil functions and soil biodiversity (De Vries et al., 2022). Chemical fertilizers use increased from about 12 million tons in 1961 to more than 110 million tons by 2018. By now, the use of nitrogen and phosphorus, exceeds planetary boundaries by a factor of two (Steffen et al., 2015; Springmann et al., 2018; CEAT, 2021) illustrating the huge challenge of improving sustainability in the farming sector, taking into account that most imminent nitrate and ammonia pollution.

1.1. The use of fertilizers in farming

Fertilizers are a major expense for farmers. Traditionally, fertilizers have been responsible for approximately 35 % of maize and wheat production costs, and nearly 15–20 % of rice production costs. Worldwide fertilizer rates are influenced by the balance of both supply and demand, which is supported by production costs. Prices are also affected by agricultural seasonality and the timing of fertilizer purchases throughout the year (Baffes and Koh, 2021; Mangisoni, 2021). Fertilizers price variation through the year is closely related to the cropping cycle, with high prices just before harvest and much lower prices just after harvest especially in remote areas, due to increased transportation costs during the rainy season (Cedrez et al., 2020). Since the beginning of 2022, fertilizers prices have increased by almost 30 %, following the 80 % increase of 2021. Prices are rising as a result many factors, including but not limited to: (i) increased resources costs, (ii) supply interruption caused by sanctions from Russian taking into consideration that the country is the leading exporter of fertilizers, and (iii) the trade restrictions taking place in China which postponed exports of fertilizers to ensure domestic availability (Nyondo et al., 2021; USDA, 2022). According to the World Bank (2020), the global fertilizer market in 2021 amounted to more than 193 billion US dollars, signifying a 12 % increase over 2020. The fertilizer market is expected to exceed 240 billion US dollars by 2030 (Fig. 1).

Specifically, according to Research Dive Analysis Report (2022) the global fertilizer market is expected to garner a revenue of $252 billion between 2022 and 2030, rising from $195 billion in 2021, at a health compound annual rate of growth (CAGR) of 3.6 %. Regarding the type of fertilizer, in 2021, the global inorganic fertilizer market had leading market share and is estimated to produce revenue of $230 billion by 2030, increasing from $172 billion in 2021. The dry fertilizer sub-segment is foreseen to dominate the market and generate a revenue of $202 billion by 2030, growing from $152 billion in 2021 with a CAGR of 3.3 %. Based on application the agriculture sub-segment is anticipated to have a leading market share and produce a revenue of $110 billion by 2030, rising from $83 billion in 2021. Finally, the analysis shows that the market for fertilizer in Asia- Pacific is the most dominant and fastest growing. The Asia–Pacific fertilizer market accounted $99 billion in 2021 and is estimated to grow with CAGR of 3.8 %.

According to FAO (2019) maize, wheat, and rice account for more than half of all harvested land on Earth. Specifically, maize is the most produced

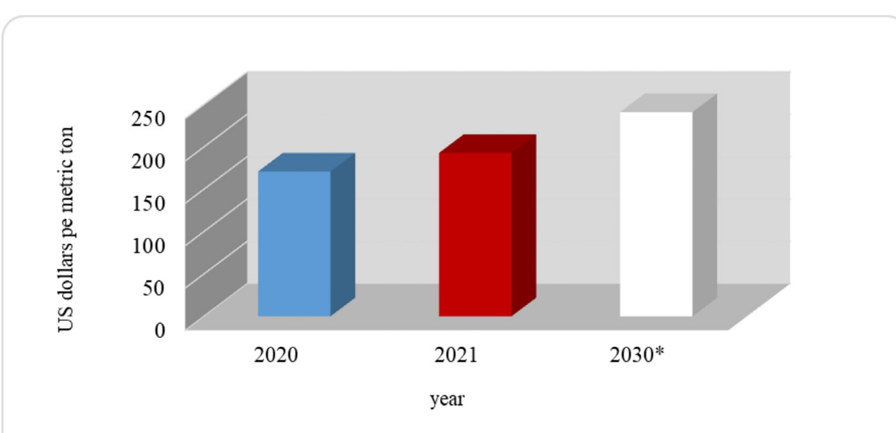


Fig. 1. Global inorganic fertilizer market size in 2020 and 2021, with a forecast for 2030 (Statista, 2022).

crop globally with an average yield of 1.1 billion tons/yr, followed by wheat and rice, amounting to 765 and 755, million tons, respectively. A billion tons of their production is used for human consumption products, 750 million tons end up as animal feed while the remaining amount is processed for industrial use or wasted. Specifically for wheat alone, 65 % of its production is used for human consumption, 17 % from animal feed and 12 % for biofuels production or other uses. Furthermore, rice is the crop with the biggest contribution to food staple (Shiferaw et al., 2011; FAO, 2019; Ritchie et al., 2022). IFA (2022) indicating that cereal crops accounted for 59 % of global fertilizer N consumption in 2018. Maize receives the most N fertilizers, accounting for 20 % of total global use, followed by wheat 18 % and rice 16 %. Due to the fact that soybeans remove N from the atmosphere, its contribution to global N consumption is minimal, less than 2 %. Furthermore, oil crops make a minor contribution to global N fertilizer consumption approximately up to 7 %. The remaining amount is shared between fibre crops such as cotton, sugar, roots and tubers (10 %), fruits and vegetables (12 %), grassland and other crops (10 %) (Fig. 2).

Fig. 3 shows the worldwide trend for the four main fertilizer consuming crops (maize, wheat, soybean, and rise) for 2010, 2014 and 2018. In 2014 57.3 Mt. N applied to cereals accounting 55.9 % of world fertilizer N consumption. Wheat was the main crop receiving N fertilizers, accounting 18.2 % of global use, followed by maize with 17.8 % and rice with 15.2 %. Overall, crop shares of total fertilizer consumption in 2018 remained similar to those reported in 2014, with cereals accounting for 59 % of global N consumption. However, in 2018 the main crop receiving the highest amount of N fertilizers was maize accounting for 20 % of total global use. The change in the main crops share of global N fertilizer consumption reveals the changes in the world's crop area over the last decade. In 2018, global maize area increased by about 30 million ha (18 %) over 2010, while soybean area increased by nearly 22 million ha (21 %). Conversely, rice area increased by only 5 million ha (3 %), while total wheat area remained relatively unchanged (IFA, 2022). This is mostly due to the fact that maize and soybean growing as globally used, traded feed and energy commodities. Rice, on the other hand, is cultivated and consumed primarily for human consumption, with only about 10 % traded and used for energy production.

1.2. Reducing nitrogen losses from fertilizer use

Reducing nitrogen (N) losses from inorganic fertilizers in soils is one of the major goals in agriculture (Navarro-Pedreño et al., 1996a) while diminishing the use of inorganic fertilizers and promoting the addition of organic residues as a source of N for plant nutrition would be a desirable objective for sustainable agriculture. The Farm to Fork Strategy of the European Union (EU) urges Member States to reduce nutrient losses by at least 50 % and the use of fertilizers by 20 %, as well as to achieve 25 % of agricultural land use for organic farming by 2030 (EC, 2020). To bring about the change, Farm to Fork Strategy proposes the use of organic waste as renewable fertilizers. This practice can become widespread sooner rather than later as common agricultural policy strategic plans (CAP) can significantly contribute to the mitigation of adverse environmental burdens due to the use of inorganic fertilizers like soil toxicity (EU Regulation 2021/2115).

Although crop yield has increased worldwide from 1,100,750 tons per hectare in 2019 to 1,114,524 tons per hectare in 2021 (FAOSTAT, 2021, 2023), it is estimated that by 2050, crop yields will decrease by 6 to 13 % (Brunelle et al., 2015). Moreover, efficient use of N in EU agriculture is low (60 %), so agroecological practices that reduce N releases are vital (De Vries et al., 2022; Brunelle et al., 2015; Mosier et al., 2001). Excess nutrients applied to soil can lead to undesirable impacts, including economic loss due to an increased resources consumption, a crop yield reduction, unbalancing the nitrogen cycle that is associated with ecosystem eutrophication and acidification, soil degradation, N leaching, and Greenhouse gasses (GHGs) emissions (N_2O) contributing to climate change (Galloway et al., 2008; Golia et al., 2009; Herrero et al., 2010; Zhang et al., 2013; Sainju et al., 2017; Sainju et al., 2019; Anas et al., 2020; De Vries et al., 2022; Naz et al., 2022). Nitrogen plays a crucial role in agricultural crops and constitutes a key nutrient to sustain crop yields due to its involvement in biomass production (Sainju et al., 2019; Anas et al., 2020). Therefore, N fertilizers are increasingly utilized in farming to enhance crop quality and yield. In fact, some authors consider inorganic fertilizer application rate higher than necessary (Zipori et al., 2020). However, each season crop uptakes only 40–50 % of N available by organic or inorganic sources (Mosier

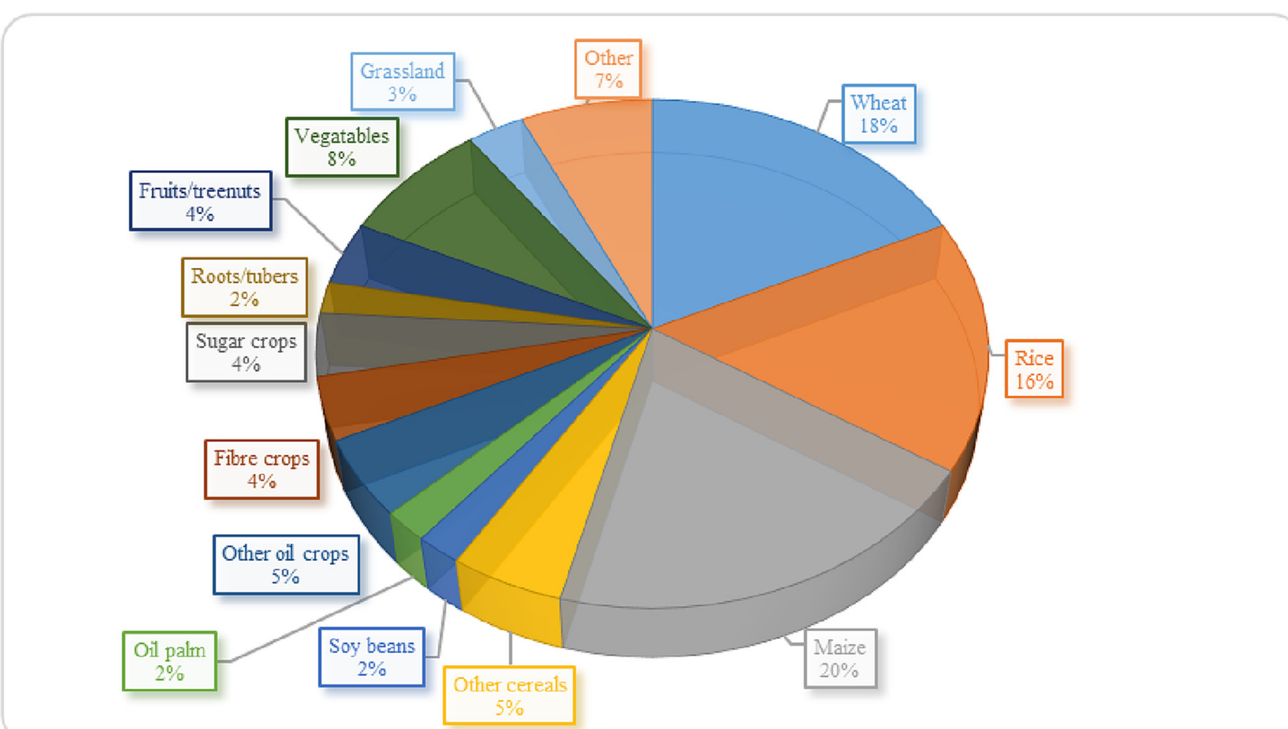


Fig. 2. Global N fertilizer (%) use by different types of crops (IFA, 2022).

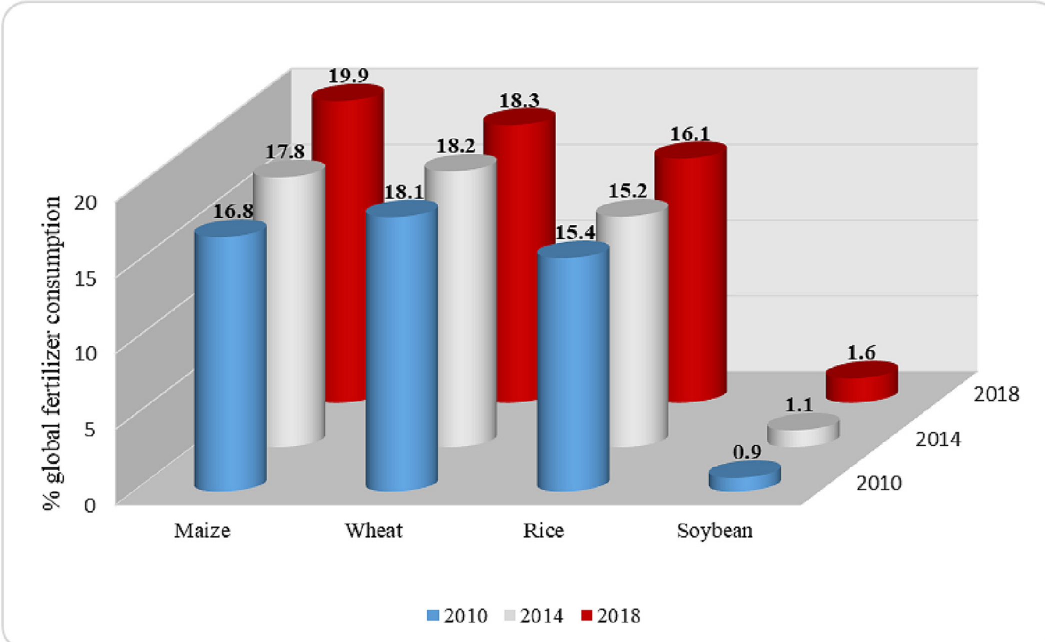


Fig. 3. Changes in the relative shares (%) of global N fertilizer consumption for the top four fertilizer consuming crops during 2010 to 2018 (IFA, 2022).

et al., 2001). Furthermore, nutrients in organic residue elemental composition have different solubility index (Oliver and Gregory, 2015; Cavalli et al., 2018; Jamroz et al., 2020), which hinders predicting the amount and time they will be available (Foereid, 2019). Therefore, it is key to ensure that nutrient release during organic residue decomposition is synchronized with crop nutrient requirements (Parr and Colacicco, 1987; De Vries et al., 2022).

1.3. Organic farming

In the EU alone, in 2014 only 38 % of N fertilizer input was provided by manure waste, and 45 % by mineral fertilizers (EU Eurostat, 2020). N contribution from sewage sludge, compost and industrial waste is insignificant and there is no data from other organic residue provisions (EU Eurostat, 2017). The cycling and supply of nutrients to support crop growth is essential and often a main focus of farm management practices (Gliessman, 2007). Mineralization of added biomass regulates the nutrient release and supply to crops as well as carbon dioxide (CO_2) emissions into the atmosphere (Guntiñas et al., 2012). Sustainable and organic farming requires the return of nutrients, organic matter and other resources removed from the soil through harvesting by the recycling, regeneration and addition of organic materials and nutrients (IFOAM, 2014).

In 2019, there were 72.3 million hectares of organic agricultural land worldwide, and 1.5 % of agricultural land is organic. Global organic food sales heading towards the 110 billion euros in 2019. The top market was the United States (44.7 billion euros), the European Union (41.4 billion euros) and China (8.5 billion euros). Per capita global consumption is 14.0 euros, getting the highest data in Denmark (344 euros) (Willer et al., 2021). In 2018, there were 13 million hectares of organic farming for EU-27. Although it only represents 8 % of the total EU agricultural surface, between 2012 and 2018, sustainable farming has increased significantly by 3.5 million hectares (EU Eurostat, 2020). Curiously, in 2020, the use of mineral nitrogenous fertilizers for European crops remains on a high level too (6.9 % more than in 2010), as 10 million tonnes were needed to cover the demand of the market. However, the geopolitical context has increased nitrogenous fertilizer prices, associated with high costs of energy production (EU Eurostat, 2022). Brunelle et al. (2015) estimated a fertilizer price increase of 0.8 % to 3.6 % per year from 2005 to 2050. Although a reduction in crop farming fertilizer consumption is expected, currently, 6.5 % of raw materials costs are related with fertilizers and soil improvers (EU Eurostat, 2020). This trend could be enhanced by replacing synthetic fertilizers with organic ones. Organic fertilizers are carbon-based mixtures that raise the growth and productivity of crops (Organic Facts, 2017). Organic nutrients are steadily and slowly released, avoiding the possibility of a boom-and-bust cycle. Moreover, organic matter is increased, strengthens the structure, and inhibits topsoil erosion while being comparatively less expensive (Martey, 2018). Additionally, the air circulation as well as soil drainage could also be improved (Pramanik et al., 2007; Sisay and Sisay, 2019; Kandpal, 2021). Organic farming, which primarily depends on organic compounds rather than inorganic fertilizers, is becoming more prominent among both the research community and consumers (Chen et al., 2014). Organic fertilizers with high efficiency could significantly raise crop production without depleting soil structure, making their use beneficial to both food supply and environmental preservation (Cen et al., 2020). Organic fertilizers value should be measured on the basis of its yield contribution (Parr and Colacicco, 1987) and of its rate of efficient nutrient input.

1.4. Circular economy and nitrogen management

Therefore, in order to minimize natural resources overconsumption and restore environmental impacts, there is an imperative need to reshape the existing economic model of “take-make-use-dispose” towards a new one that will focus on “prevention-reuse-remake-recycle” (CEAT, 2021). In this context, the circular economy model is a promising approach for keeping natural resources, providing sustainable, restorative, and regenerative agriculture in the existing context of resource insufficiency, climate change, environmental pollution, and rising food demand (Kuisma and Kahiluoto, 2017; Stegmann et al., 2020; Velasco-Muñoz et al., 2021). Referring to the farming sector, circular agriculture is a principle that promotes the long-term use of existing agricultural inputs and products, serving as a driving force in the future agrifood system (Vasa et al., 2017).

Circularizing agriculture is based on three key aspects to be taken into consideration. Firstly, the efficient use of inputs and prevents wastage, secondly, the promotion of environmental, economic and social sustainability and thirdly the regeneration of systems that enable the closure of nutrient loops and minimize outputs (Zabaniotou et al., 2015; Burgo-Bencomo et al., 2019; Morseletto, 2020; Velasco-Muñoz et al., 2022). Circular economy in the farming sector could be seen as an economic growth driver, as a business strategy plan, or a multi-layered sustainability action (Noya et al., 2017; McCarthy et al., 2019; Nattassha et al., 2020).

In order to enhance the circular economy in the agriculture/farming sector, all stages of the food chain, including growing to consuming and disposing, should be designed to take into consideration sustainable development by default (Kristinn et al., 2021). The combination of mixed crop-livestock, as well as the promotion of organic farming and water recycling, is a critical element of a circular agriculture model, aiming at the reduction of CO_2 emissions and the efficient use of natural resources (Huybrechts et al., 2018; Velasco-Muñoz et al., 2022). Furthermore, emphasis should be given to the promotion of a comprehensive set of policies and strategies that will focus on the investigation of technologies and research for circular farming, to strengthen institutions and incentives for the adoption of circular economy, and to enhance international cooperation (Kristinn et al., 2021).

Circular farming is divided in two different cycles, the biological and the technical (Figs. 4a, b). The biological cycle recovers value from waste in order to convert it into new valuable products that aid crop production, food processing, and energy production. The technical cycle applies to farming technologies by promoting the preserve, return, renew and reuse technologies that increase farming efficiency while reducing waste and cost (CEAT, 2021).

The concept of circular farming economy is not a new innovative concept, taking into consideration that it was extensively used from pre-industrial societies. However, it has been side-lined by modern intensive farming practices that prioritize profit over environmental protection. As mentioned above, the circular economy model is already successfully implemented in farming practices such as: (i) the conversion of biological waste including agricultural stalks and leaves, as well as livestock manure, into fertilizers rich in Nitrogen, Phosphorus and Potassium (NPK); (ii) the wastewater reuse, arising from animal production and irrigation runoff, which can be reused for pastures and plant production after their treatment; (iii) the use of the produced biomass from plant and animal in order to produce biofuels; and (iv) waste minimization through the promotion of 3R strategies (reduce, reuse, recycle) (Patricio et al., 2018; Lüdeke-Freund et al., 2019; McCarthy et al., 2019; Nattassha et al., 2020).

Application of organic wastes to soil and the use of technosols can enhance food security, ecosystem services provision, cultivated land availability and human health (Anwar et al., 2015; Rodríguez-Espinosa et al., 2021a; Rodríguez-Espinosa et al., 2021b). The Food and Agriculture Organization (FAO) of the United Nations (UN), defends organic soil nutrition as a replacement of inorganic fertilization (FAO, 2017). Due to its high nutrient content (Parr and Colacicco, 1987; Navarro-Pedreño et al., 1996b; Rokia et al., 2014; Coull et al., 2021; Oueriemmi et al., 2021; Rodríguez-Espinosa et al., 2023b) using organic waste without mineral supplement can ensure crop yield (Hossain et al., 2017; Bendaly Labaied et al., 2020; Pisciotta et al., 2021) and reduce available fractions of metals (Golia et al., 2017). However, organic waste can entail hidden risk, related to heavy metals and emerging contaminants content (FAO, 2022; Rodríguez-Espinosa et al., 2023a).

Such initiatives are in line with the Sustainable Development Goals (SDGs) of the UN and mitigation of Climate Change as the reduction of inorganic fertilizers and the use of organic wastes contribute positively to the circular economy and pollution control.

The positive impacts of organic agriculture on health, incomes, and the environment are facilitated by its own well-defined standards and market-based certification systems, which ensure premium prices for organic producers. This has helped achieve high consumer awareness of its benefits and increased consumer demand both in developed and in developing countries. Most importantly, organic agriculture fosters gender equality as it creates meaningful work, It offers economic opportunities; promotes health; encourages biodiversity; and ensures equitable work This makes organic agriculture a crucial development strategy in the SDGs era, as its benefits are not only sustainable, but most importantly, enhance the well-being of humanity and that of the planet (Kristinn et al., 2021). With an emphasis on SDGS, organic farming contributes directly or/and indirectly to all the 17 goals. Regarding SDG 1, Organic farming is an important anti-poverty approach, particularly in rural areas, as it provides employment, lowers input costs for small-scale farmers, and raises revenues by providing higher prices for produce. Also improves farm biodiversity and resiliency in the face of increasingly several extreme weather conditions. Concerning SDG 2, due to the fact that organic farming provide more diverse crop production, the threat of significant losses caused by seasonal variations and poor harvests, is reduced, enhancing food security. About SDG 3, the chemical-free farming practices of organic farming could improve the well-being of both farmers and consumers. By increasing women's employment opportunities and empowering them through additional income, organic farming contribute to SDG 5. With regard to SDG 6 the minimization of chemical fertilizer application and the proper soil management reduce runoff, as fertilizers that are not recovered by crops causes eutrophication. Furthermore, groundwater pollution and salinization are also limited. Organic farming is progressively practiced in urban areas and endorses sustainable cities by food recycling and organic wastes through composting that could be used in urban agriculture sector,

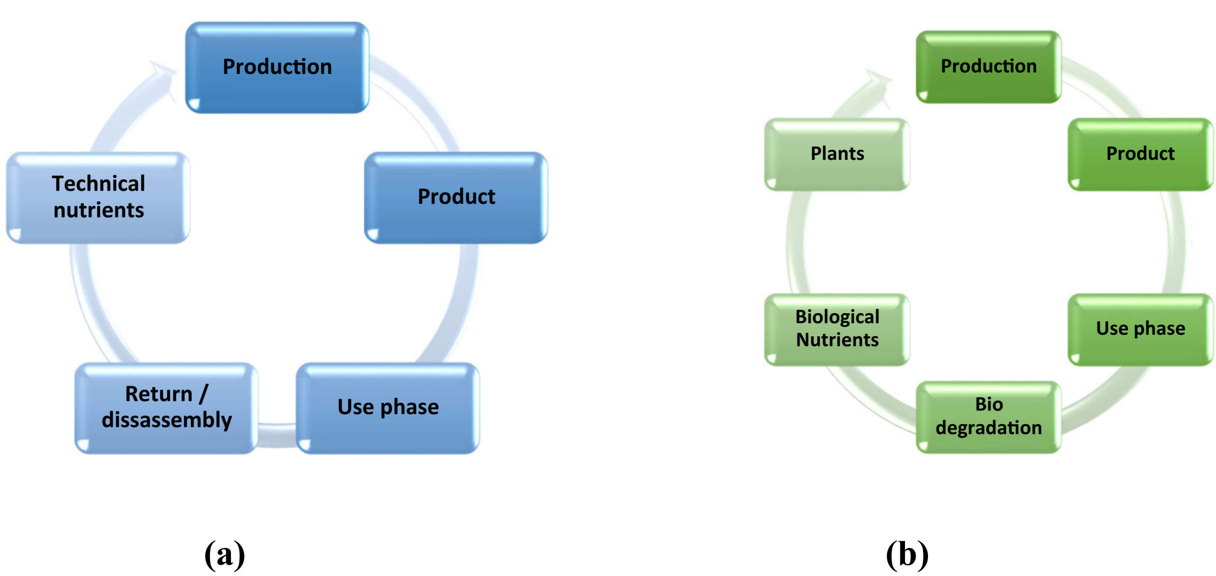


Fig. 4. Technical and Biological Cycles in the Circular AgroFarming Economy: (a) Circular technical cycle for products for services and (b) Circular Biological cycle for products for consumption (Wautelet, 2018).

contributing both in SDG 11 and 12. Concerning SDG 13, and given that agriculture is becoming increasingly vulnerable to changes in environmental conditions as a result of climate change, organic farming could provide solutions by creating resilient productive bases while also offsetting the consequences of climate change (UN, 2015).

Although there are differences between crops, plants uptake nitrogen in soil mineral forms (except leguminous) and the availability of nitrogen from wastes is subjected to the presence of inorganic forms (ammonium and nitrate preferable) presented in the wastes or provide after a mineralization process of the organic matter which is associated to the C/N ratio (Jat et al., 2018). Mineralization process is subjected to several factors, among others: environmental conditions and soil microbial biomass (Spohn et al., 2016). At the same time, depending on the type of waste, lignin and polyphenol content, temperature and soil moisture play a key role, and the type of soil is another limiting factor that affects the mineralization rates (Mafongoya et al., 1998; Deenik, 2006; Carranca et al., 2018; Taguas et al., 2021). Moreover, the type of ecosystem management and land cover significantly affected the mineralization of soil N (Gundersen et al., 2009). For instance, using a leguminous cover cropping for crops that are fertilized with pruning residue can ensure N availability (Pisciotta et al., 2021).

Under these conditions, it is necessary to understand local environment and organic waste characteristics to reach good conditions that could favor the release of inorganic nitrogen for crops. This process usually takes some weeks and affects the easily decomposed organic matter coming from the addition of wastes. However, we should note that lower N content crop residue would be incorporated into the soil, and higher N content and low C/N ratio crop residues can be placed on the soil surface to lower down the risk of N losses and CO_2 emissions as Jat et al. (2018) indicated for Vertisols. Soil taxonomy orders influence chemical changes of elements due to its physicochemical properties (Golia et al., 2018; Li et al., 2020).

The relation between nitrogen mineralization and immobilization is the key to nitrogen cycle in the soil (Cabrera et al., 2005). The organic residues applied to the soil undergo decomposition by microbial biomass and there will be net N mineralization with release of inorganic N. However, we should consider that if the amount of N from the organic waste is equal to the amount required by soil biomass there will be no net mineralization. On the other hand, if the amount of N present in the residue is smaller than that required by the microbial biomass, additional inorganic N will need to be immobilized from soil to complete the decomposition process of organic matter (Corbeels et al., 1999a, 1999b).

For N mineralization, linear and nonlinear models have been used in order to obtain data related to measure the increment of mineralization or cumulative data. Initially, most of the experiments done to determine the N mineralization have been typically performed under temperature and water content conditions optimal or close to optimal for the mineralization processes (Gordillo and Cabrera, 1997; Agomoh et al., 2018) and later considering other environmental factors like pH, soil type, soil management and others (Deenik, 2006; Sierra and Desfontaines, 2018; Braos et al., 2020).

Although there are a lot of factors that can affect the mineralization process of the nitrogen from the use of organic wastes in soils, the application of farming and organic wastes is part of the strategic zero waste action and the circular economy. Moreover, the comparison between residues under the same conditions to have in mind the possibility of providing inorganic nitrogen for crops, should be analysed to help farmers make informed decisions and sustain adequate yields. The main objective of the current study is to understand the nitrogen nutrition provided from organic wastes to cropping systems, reviewing the state of the art and giving an example of the possibilities of nitrogen fertilization available from common organic wastes to promote sustainable farming management.

2. Materials and methods

2.1. State of the art

To analyze the state of the art related to nitrogen fertilization by using organic wastes, the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analysis; www.prisma-statement.org) was used (Fig. 5). The proposed literature was carried out in accordance with the PRISMA process, which includes 27 routes and encompasses the well-defined stages of a systematic review, such as eligibility criteria and related information sources, strategy exploration, selection process, results and data synthesis (Ortiz-Martínez et al., 2019; Voukkali and Zorpas, 2022). The PRISMA 2020 checklist includes seven sections and topics (Title, Abstract, Introduction, Methods, Results, Discussion, and Other Information) and 27 sub criteria to be met.

Specifically the characteristics (inclusion criteria) that the article must have in order for it to be eligible for enclosure in the literature review cover: (i) research/papers/studies related with farming and circular economy, organic and inorganic fertilizers; (ii) articles published from 1990 since today, enabling for a space - time comparison of the numerous studies, and also providing the opportunity for the latest data that reflects the current existing situation; (iii) research mentioning comprehensive outcomes and/or information/data (review papers) for an integrated approach of the topic under study; (iv) methodical demonstration and synthesis of findings; (v) records identified using the keywords chosen by the authors. One the other hand, the characteristic (exclusion criteria) that disqualify the articles from enclosure in the literature review include: (i) narrative reviews, since those studies lack a sufficient scientific foundation; (ii) studies that are not useful to the proposed research, articles that merge information that is not exclusively related to the specific research; and (iii) available papers in languages other than English (iv) everything not included in the inclusion criteria.

For the literature review, the database of Scopus was preferred. As Scopus database option search were "title, abstract, keywords" the following keywords were used: *circular economy* AND *model* OR *farming* AND *circular economy* OR *Inorganic fertilizer in farming*, OR *organic fertilizer in farming*, OR *waste from farming*, OR *organic waste and characterization* OR *nitrogen fertilizers*, OR, *N liberation*, OR *Mineralization process*. All authors participated in the literature review, in order to implement measures to reduce random errors and bias during the research process.

The process started with screening of the titles and the abstract for potential inclusion, taking into account the mentioned criteria. In case of inconsistencies as to whether a specific study/report/manuscript should be included or excluded, these were resolved through extensive discussion among the authors. The 162 references obtained by the Scopus were cross checked with Mendeley software in order to identify any duplicated studies. Full papers were downloaded for further evaluation, when the review team was unsure if a particular paper met or not the inclusion criteria. The Authors collected and evaluated data from 10,388 papers linked to the studied topic.

2.2. Selected residues

Following the strategy to promote sustainability in agriculture, several organic residues were selected on the criteria of circular economy and zero waste strategy. Their potential use to improve soil fertility, centred in N supply, and also the possibility of forming part of formulated technosols. These wastes were the following:

- Almond tree pruning (AP)
- Commercial brown peat (CP)
- Hay straw (HS)
- Olive tree (*Olea europaea* L.) pruning (OP)
- Pomegranate (*Punica granatum* L.) peel (PG)
- Pine (*Pinus halepensis*) needle fall (PN)
- Date palm (*Phoenix dactylifera* L.) leaf pruning (PP)
- Sewage sludge compost (SC)
- Vine (*Vitis vinifera*) pruning (VP)

The origin of these farming (pruning and harvesting) residues (AP, HS, OP, PG, PN, PP and VP) was from Mediterranean agricultural areas close to

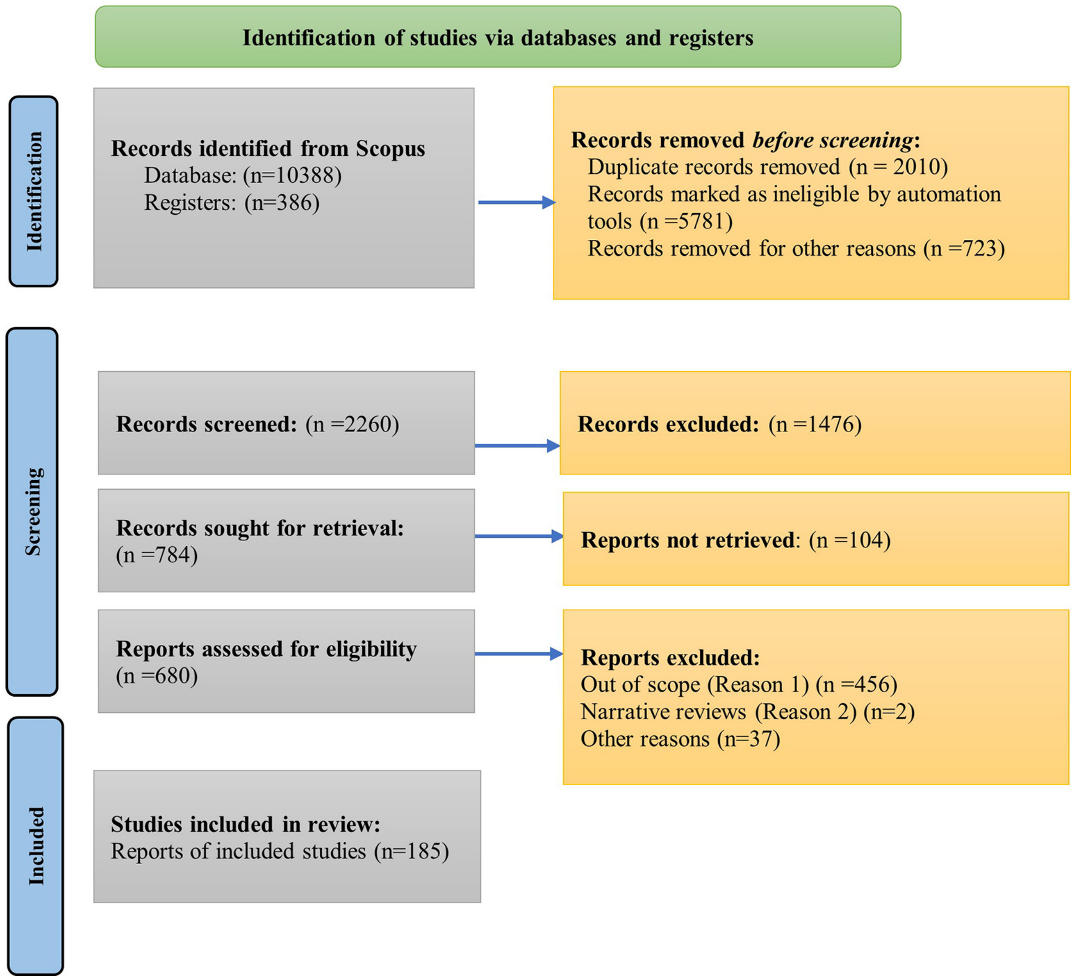


Fig. 5. PRISMA 2020 flowchart for systematic reviews that involves searches of databases and registers exclusively.

Elche (Alicante, Spain) and produced in their farming systems. The quantities of such waste produced in Spain and in other countries were studied by Rodríguez-Espinosa et al. (2023b). The sewage sludge compost (SC) was obtained from Aspe Wastewater Treatment Plant (Alicante, Spain). Domestic wastewater undergoes preliminary treatment, primary treatment, secondary treatment and disinfection. Sludge is thickened, digested in an aerobic environment and dewatered, removing water from the solids using centrifuges. Finally, the remaining solids are composted (EPSAR, 2019). From gardening and forest areas, PP were obtained from Palm Tree orchards of Elche and PN were collected directly from the ground surface in a nearby *Pinus halepensis* forest area.

2.3. Residue characterization

Water content (WC), organic matter (OM), total organic carbon (OC), Kjeldahl nitrogen (N) and ammonium were determined according to the standard procedures. All residues were subjected to a previous conditioning process consisting of air drying at room temperature inside a greenhouse (reaching temperatures over 40 °C) for a month, shredded and sieved previously to the elemental analysis (2 mm).

After that, WC in the samples (five repetitions per each one) was determined by drying at 105 °C (AENOR, UNE-EN 13040, 2008), using a LED digital drying and sterilization oven (J.P. SELECTA®, Conterm 2000253). OC was determined by oxidation (Iglesias and Pérez, 1992; Puyuelo et al., 2011) and OM was determined by loss on ignition at a temperature of 450 °C in a muffle furnace (Nabertherm, controller P320), expressed as percentage by weight of dry matter (AENOR, UNE-EN 13039, 2001).

Mafongoya et al. (1998) recommended Kjeldahl method for analysis of total N (except oxidized N) of organic materials. Samples (five repetitions per each one) were digested in a bloc-digest 20 sample sites (P-Selecta 4000631) equipped with a temperature and time regulator (P-Selecta 4000051) and distilled by a Foss Kjeltec 2100 distilling unit (EN 13342: 2000; Jones, 2001; FAO, 2021; Doyeni et al., 2022). The ratio C/N was determined by using the values obtained for OC and N.

2.4. Sceneries of mineralization of the organic residues

There are several methodologies and models employed to know the mineralization of nitrogen in soils. Recently, Agomoh et al. (2018) proposed a model to calculate net N mineralization from the cumulative amounts of leached N for amended soil, measured as soil inorganic N concentration at time t and corrected for mineralization in the unamended soil and for initial soil inorganic N concentration, and the cumulative net N mineralized ($\%N_{min}$), or the percentage of manure organic N (N_{org}) mineralized between the start of the experiment and time t, was calculated as depicted in Eq. (1):

$$\%N_{min} = \left[\frac{N_{\min(t)}}{N_{org}}\right] \times 100 \qquad (1)$$

Other methods were proposed by Thuriès et al. (2001), Geisseler et al. (2019), Armando Tamele et al. (2020) and Rakesh et al. (2021), among others. However, in this work related to the N supply by organic wastes during a cultivation period, it is used the approach given by Jat et al. (2018)

who indicated that the net C mineralized from the added organic source varied between 11.1 and 14.0 % among the crop residues used in their work.

Although there are a lot of methods and the results are affected by the experimental design and the environmental factors, including soil type as a key factor, we assumed, based on the previous works, an expected mineralization of organic wastes under two sceneries for a cycle of cultivation (approximately six months): 10 % and 15 % of organic matter mineralized. This assumption was based on literature consultation and helps with the comparison of the ability of those organic wastes to supply nitrogen for plant nutrition. Similar percentages for the N mineralization presented in organic matter (sceneries 1 and 2: 10 % and 15 %) are expected. However, this should be considered as an approach to facilitate the comparison because local conditions and characteristics of the different wastes can vary.

Additionally, the influence of the ratio C/N in the organic wastes was investigated as it has an important role for mineralization. The potential ratio C/N that favor the mineralization is around 20–30 as optimal to achieve aerobic and anaerobic microbial metabolism and, below that, N release for plan nutrition starts while a rapid mineralization will pass when this ratio is around 10 (Thuriès et al., 2001; Puyuelo et al., 2011; Repullo et al., 2012; Gomez-Muñoz et al., 2016). A limit for the comparison of the availability of N for plants from organic wastes when the ratio C/N is below 30 is assumed. Over this ratio, the mineralization of the waste would need an additional source of N to mineralize effectively. This source of N in cropping systems comes from the soil organic matter and the nitrogen fertilization.

Several nitrogen fertilizers are used for crops. Three of them were considered to compare the amount needed to add for some crops with the supposed amount of the organic fertilization needed in order to achieve the required nitrogen to supply to selected crops. These commercial fertilizers were: ammonium sulfate (21 % of N) which is a soluble fertilizer used as a source of S (24 % of S) and N (Powlson and Dawson, 2021); ammonium nitrate (60 % of N) used as fertilizer as well as and urea fertilizer (46 % of N), both important sources of N for crops (Furtado da Silva et al., 2020).

3. Results and discussion

3.1. Organic waste characterization

The characterization related to carbon and nitrogen in the organic residues analysed is presented in Table 1. Results are shown in fresh weight -f. w.- (after drying at room temperature) and dry weight -d.w.- (after drying at 105 °C). The processed materials (CP and SC) get the highest rates of WC (527 and 260 g kg^{-1}, respectively) even after a month of drying them at room temperature. As soil moisture is a crucial factor for decomposition of organic matter, particularly in dry climates (Rovira and Vallejo, 1997), the water content of the wastes is important for the mineralization. The pruning and harvesting residues have WC (f.w.) content between 63 and 98 g kg^{-1} (OP and HS). Hence, with low water content, its addition to the soil can even prevent nutrient leaching (Golabi et al., 2017). Organic residues are a good source of organic matter due to the high presence in their composition, between 875 and 950 g kg^{-1} d.w., and SC has a low rate of OM (590 g kg^{-1} d.w.). The last waste comes from the wastewater treatment and the presence of organic matter is lower than the one of farming wastes. All of them can improve soil properties, carbon sequestration and nutrient availability for crops (Papafilippaki et al., 2015; Gomez-Muñoz et al., 2016; Golabi et al., 2017; Almendro-Candel et al., 2018; Oueriemmi et al., 2021; Taguas et al., 2021). OC varied between 266 (SC) to 427 g kg^{-1}d.w. (HS), and this has influenced in the ratio C/N. All pruning and harvesting residues showed low total N content (4.3–9.3 g kg^{-1} d.w.). However, SC achieves 22.6 g kg^{-1} d.w., but its N content does not exceed the percentage of 2.5 % needed to promote nutrient mineralization as Anguria et al. (2017) indicated. PP is the pruning residue that has the highest total N content (9.3 g kg^{-1} d.w.) being the most beneficial rate for decomposition.

Table 1
Water content (WC) Organic matter (OM), organic carbon (OC), total nitrogen content and C/N ratio of the studied residues.

Residue	WC (g kg^{-1} f.w)	OM (g kg^{-1} d.w.)	OC (g kg^{-1} d.w.)	N (g kg^{-1} d.w.)	C/N
AP	80	932	392	4.4	89
CP	527	910	409	8.0	51
HS	98	950	427	4.3	99
OP	63	941	395	7.2	55
PG	82	875	376	5.4	70
PN	90	919	414	5.4	77
PP	86	909	409	9.3	44
SC	260	590	266	22.6	12
VP	93	940	395	4.6	86

The C/N ratio indicated that SC would have a trend to easily mineralize whereas HS has the highest value. This can be reflected in the slow or null N release and its availability for crops. Notwithstanding, it is important to remember that farming managing systems is the key for the adequate use of all of these organic wastes.

3.2. Major crops and N demand

The selected crops and their nitrogen demand are presented in Table 2. This provides previous research findings into foreseeable N demand (kg ha^{-1}) of the listed crops. It can be seen that sugarcane and cereals require a large proportion of N to ensure crop yield (200–300 and 100–300 kg ha^{-1}, respectively) followed by vegetables and fruit trees. Curiously, Wang et al. (2022) considered that N application of more than 300 (kg ha^{-1}) can be excessive and trigger a reduction on soil N availability and microbial activity. Moreover, Navarro-Pedreño et al. (1996a) demonstrated that this excess of nitrogen added to farming systems in Mediterranean environments, can be a source of nitrogen pollution and increase the cost of the farming systems without increment of the yield.

3.3. N mineralization from residues and amount of residue needed for meeting N demand

This work provides the N mineralization (N_{min}) from organic residues within the framework of two expected sceneries: 10 % and 15 % of organic matter mineralized, as stated in Section 2. Data from Table 3 were calculated relying on 10 % of mineralization and Table 4 on 15 %. The amounts were expressed in kilograms of residues needed per hectare to supply N_{min} requirements of crops (Table 2) considering their moisture (after drying at room temperature, f.w.). The minor value of N demand of each type of crop presented in Table 2 for each crop was used in order to prevent excessive N input, as stated before (Wang et al., 2022).

From both tables (Tables 3 and 4), a large quantity of residues per hectare is needed for most of the crops and wastes. As expected, the number of residues in Table 4 is higher than those obtained in Table 3. SC and PP are the residues that can be applied to a lesser extent to meet N demand of crops. It is worth mentioning that these amounts of residues are calculated for N supply (assuming the rate of mineralization and that all nitrogen should be supplied by organic wastes), one of the most present nutrients in organic residues.

Table 2
Selected crops and nitrogen demand expected based on the literature review.

Crop type	N demand (kg ha^{-1})	Reference
Cereals	100–300	Lloyd et al., 1997
Fruits/tree nuts	110	IFA, 2022
Mature fruit trees	108	Carranca et al., 2018
Roots/tubers	65	IFA, 2022
Sugarcane	200–300	Furtado da Silva et al., 2020
Tomato and bean	60–100	Ganeshamurthy et al., 2022
Vegetables	190	IFA, 2022

Table 3
Scenery 1: 10 % of N mineralization (N_{min}) and amount of each residue needed for meeting the N demand of crops.

	N_{min} (g kg^{-1} d.w[a])	Cereals (tons ha^{-1} f.w[b])	Fruits/tree nuts (tons ha^{-1} f.w)	Mature fruit trees (tons ha^{-1} f.w)	Roots/tubers (tons ha^{-1} f.w)	Sugarcane (tons ha^{-1} f.w)	Tomato, bean (tons ha^{-1} f.w)	Vegetables (tons ha^{-1} f.w)
AP	0.44	247.04	271.74	266.80	160.57	494.07	148.22	469.37
CP	0.80	264.27	290.70	285.41	171.78	528.54	158.56	502.11
HS	0.43	257.83	283.61	278.45	167.59	515.65	154.70	489.87
OP	0.72	148.23	163.05	160.09	96.35	296.45	88.94	281.63
PG	0.54	201.73	221.90	217.87	131.12	403.45	121.04	383.28
PN	0.54	203.50	223.85	219.78	132.28	407.00	122.10	386.65
PP	0.93	117.64	129.41	127.06	76.47	235.29	70.59	223.52
SC	2.26	59.79	65.77	64.58	38.87	119.59	35.88	113.61
VP	00.46	239.68	263.65	258.856	155.79	479.36	143.81	455.40

[a] d.w: dry weight.
[b] f.w: fresh weight.

Being aware of the logistical and environmental challenge handling huge amounts of organic residues, a more realistic and practical approach is advisable. To ensure quality and crop yield authors suggest combining organic with synthetic fertilization (Parr and Colacicco, 1987; Chatzistathis et al., 2021; Wang et al., 2022). Wang et al. (2022) concluded that organic and inorganic based fertilization plans can increase soil N availability by accelerating soil organic N mineralization and a N input of 150 kg ha^{-1} can be favorable for most of the crops. In addition, farms that only use inorganic fertilizers and in short supply of organic waste undergo soil organic carbon and N reduction and soil degradation (Hasnat et al., 2022). In this sense, a combined fertilization considering the positive effects of organic residues joined to a controlled inorganic fertilization would achieve good yields and avoid the negative impact of the only use of inorganic fertilizers.

Moreover, both fertilization materials have advantages and disadvantages. Inorganic fertilizers are fuel-based sources and can lead to environmental pollution, soil degradation and reduction of soil microorganisms' activity, including an important carbon footprint for their production and transport. Despite this, the main benefit of using inorganic fertilizers is the immediate provision of nutrients of high mineralization rate that enhance crop yield. Whereas organic residues application enhances ecosystem sustainability, circular economy strategy, soil properties and fertility, and microorganism's biomass. However, organic residues have contamination drawbacks, but the main inconvenience is short-term nutrient availability (Chatzistathis et al., 2021; Rodríguez-Espinosa et al., 2023a). One of the major challenges of using combined organic and inorganic fertilization is the synchronization of nutrients demand of each crop along its life cycle with input application. This is even more difficult when only organic fertilization is used. However, an adequate study of the soils and the environmental conditions can help to understand the mineralization rate and promote the use of a sustainable soil management in farming systems.

Considering the requirements of nitrogen nutrition as stated in Table 2, Table 5 provides the amount of each inorganic fertilizer (mentioned before) needed for crops. In this case, the amount that would be applied is lower than the amount of organic fertilizers needed.

Considering 150 kg ha^{-1} of N input as the optimum demand, it was found a contrast between the amounts of urea fertilizer needed with the kilograms of organic residue that should be applied. The amount of pruning and harvesting residue (farming wastes) must be applied, approximately, between 400 and 1000 times more than urea fertilizer. SC and CP have to be applied 200 and 600 times more, respectively.

3.4. Ratio C/N

As stated before, the C/N ratio is a crucial factor in the success of N mineralization from organic residue and can be considered as a quality indicator of organic inputs (Parr and Colacicco, 1987; Mafongoya et al., 1998). Hence proper quantity and quality of organic residue is needed for ensuring N supply (Wingeyer, 2007). In Table 1, the C/N ratio of those organic residues studied is shown. SC is the one with the lowest C/N ratio (12) since it has proportionally the highest total N content (22.6 g kg^{-1} d.w), so it is the most favorable residue for enhancing mineralization. The pruning and harvesting residues obtain a C/N ratio between 44 and 99 (PP and HS, respectively), that is above the optimum C/N ratio. CP gets a C/N ratio of 51, similar to the one obtained by PP or OP. Our findings (Table 1) are consistent with those obtained by previous studies (Table 6).

Non-manure animal wastes, animal manures, compost, sewage sludge and municipal solid wastes are low C/N ratio wastes (1–17 or 29) and have high total nitrogen content, reaching 156 g kg^{-1} in non-manure animal wastes (Table 6). These are considered high quality organic inputs because they can release nutrients rapidly. However, they can become an environmental pollution source due to heavy metal and N content and leaching (Mafongoya et al., 1998; Wingeyer, 2007; Anwar et al., 2015; Chojnacka et al., 2022; Rodríguez-Espinosa et al., 2023a). On the other hand, pruning residues achieve a higher C/N ratio (43.9–139) and low total N content (Table 6).

Consequences of applying pruning residue to soil, with high C/N ratio (Tables 1 and 6), are N immobilization and a depletion of N available in soil (Gomez-Muñoz et al., 2016; Carranca et al., 2018). Residue C/N initial ratio can increase during the decomposition process as concluded by Cavalli et al. (2018) which maize straw C/N ratio changed from 51 to 68. However, Yilmaz et al. (2017) did not obtain a N depletion after vine pruning addition. Authors agree pruning residue decomposition process is slow

Table 4
Scenery 2: 15 % of N mineralization (N_{min}) and amount of each residue needed for meeting the N demand of crops.

	N_{min} (g kg^{-1} d.w[a])	Cereals (tons ha^{-1} f.w[b])	Fruits/tree nuts (tons ha^{-1} f.w)	Mature fruit trees (tons ha^{-1} f.w)	Roots/tubers (tons ha^{-1} f.w)	Sugarcane (tons ha^{-1} f.w)	Tomato, bean (tons ha^{-1} f.w)	Vegetables (tons ha^{-1} f.w)
AP	0.29	370.55	407.61	400.20	240.86	741.11	222.33	704.05
CP	0.53	396.41	436.05	428.12	257.66	792.81	237.84	753.17
HS	0.29	386.74	425.41	417.68	251.38	773.48	232.04	734.80
OP	0.48	222.34	244.58	240.13	144.52	444.68	133.40	422.45
PG	0.36	302.59	332.85	326.80	196.68	605.18	181.55	574.92
PN	0.36	305.25	335.78	329.67	198.41	610.50	183.15	579.98
PP	0.62	176.47	194.11	190.58	114.70	352.93	105.88	335.29
SC	1.51	89.69	98.66	96.87	58.30	179.38	53.82	170.41
VP	0.31	359.52	395.48	388.28	233.69	719.05	215.71	683.09

[a] d.w: dry weight.
[b] f.w: fresh weight.

Table 5
Amount of each commercial fertilizer (expressed as kg ha^{-1}) needed for supplying the N demand of the selected crops.

	Cereals	Fruits/tree nuts	Mature fruit trees	Roots/tubers	Sugarcane	Tomato and bean	Vegetables
Ammonium sulphate	476	524	514	310	952	286	905
Ammonium nitrate	167	183	180	108	333	100	317
Urea fertilizer	217	239	235	141	435	130	413

and can have a long-term nutrient contribution for crops (Repullo et al., 2012; Gomez-Muñoz et al., 2016; Carranca et al., 2018; Cavalli et al., 2018; Pisciotta et al., 2021).

Recommendations based on N content and C/N ratio of pruning residues are that its application needs to complement with other sources of nitrogen that can be inorganic fertilizers or organic fertilizers with a low C/N ratio. The last combination could be the most useful as a sustainable strategy based on a circular economy.

3.5. Cost saving and organic fertilizer

Fig. 6 shows the price variance for the main inorganic fertilizers for 2015–2021 and a forecast to 2035. Urea cost 229 U.S. dollars per metric ton in 2020, 275 in 2024, and 330 in 2035. In 2020, phosphate rock cost 76 $/metric ton. By 2035, it is expected to cost 130 $/ton. Triple superphosphate (TSP) was 265 $/metric ton in 2020 and expected to reach 400 $/metric ton by 2035. In 2020, diammonium phosphate (DAP) cost 312 U$/metric ton, with a 2035 prediction of 450 U$. In 2020, potassium chloride cost 218 dollars per metric ton. By 2035, it will cost 300 dollars.

As mentioned, crop productivity-boosting inorganic fertilizers are now a major environmental issue (Serpil, 2012; Kumar et al., 2019). Fertilizer use is becoming counterproductive as long-term inorganic fertilizer use may harm crops and plants since chemical-based water-soluble fertilizer leaches, starving the soil (Manivannan et al., 2009; Schulz and Glaser, 2012; Lim et al., 2015; Kandpal, 2021). While farming relies more on organic fertilizers due to rising fertilizer prices, organic fertilizer's economic benefits are still unclear.

Over time, organic fertilizers may be worth the extra cost as they can improve soil after crops absorb nutrients while longer feeding improves soil texture and composition. Inorganic fertilizers are cheaper but add fewer nutrients over time (Gopinath and Mina, 2011; Loncaric et al., 2013; Cen et al., 2020). Martey (2018) illustrated that organic fertilizer users produce and earn more than inorganic fertilizer producers as productivity boosts crop income. Organic matter from green and animal manure increases crop yield over time since organic fertilizer reduces soil degradation and evapotranspiration. Lal (2006) found that root zone soil organic matter greatly increases crop yield. Profitability analysis shows organic fertilizer increases productivity, harvest income, and average annual net returns. Loncaric et al. (2013) found that soil fertility strongly impacts organic fertilization. Added to the fact that organic fertilization could solve agricultural issues like manure, crop yield, soil fertility, manure is 46 % cheaper than inorganic fertilizers which directly affect farmers' costs and savings. Massive, automated plants produce millions of tons of inorganic fertilizers while on the contrary, organic fertilizers are made locally. Thus, organic fertilizer production creates jobs, especially in rural areas with few options. Still, some cost implications still need to be tackled like the fact that machinery and equipment costs make organic-inorganic fertilization 13–39 % more expensive than mineral fertilization.

Table 6
Organic carbon (OC), total nitrogen content (N) and C/N ratio of waste (g kg^{-1}).

Waste	OC (g kg^{-1})	N (g kg^{-1})	C/N	References
Animal manures	–	11.4–117.6	13–29	Parr and Colacicco, 1987
	379	22	17	Thuriès et al., 2001
	376	61	6	
Compost	122.3	13.3	9.2	Pascual et al., 1997
Fruit waste	–	7–19	35	Parr and Colacicco, 1987
Maize straw	–	–	51–68	Cavalli et al., 2018
Municipal solid waste	225.8	16.4	13.8	Pascual et al., 1997
Non-manure animal wastes	–	10–140	3–5	Parr and Colacicco, 1987
	545	146	4	Thuriès et al., 2001
	471	152	3	
	175	156	1	
Pruning residue (olive)	462	10.6	43.9	Gomez-Muñoz et al., 2016
Sewage sludge	393.5	53.1	7.4	Pascual et al., 1997
	396	47.3	–	Nicolás et al., 2012
Tress (leaves)	–	5–15.1	40–80	Parr and Colacicco, 1987
Tress (leaf and litter)	–	–	10–32	Mafongoya et al., 1998
Vegetable residues	–	16–37	11–27	Parr and Colacicco, 1987
Vine pruning residue	543	3.9	139	Yilmaz et al., 2017
	503	11	–	Nicolás et al., 2012
Wheat straw	–	2.1–9.4	80–130	Parr and Colacicco, 1987

3.6. Circular Economy transition of the farming sector

Considering the need to transition to a new economic model that extends product life cycles, several researchers have examined the potential of integrating the circular economy into the agriculture sector (Sartore et al., 2018; Maestre-Valero et al., 2019; Aznar-Sánchez et al., 2020; Maquet, 2020; Suresh and Samuel, 2020; Timonen et al., 2021; Velasco-Muñoz et al., 2022). To improve circular economy in the farm sector, three fundamental principles must be followed: (i) efficient resource use and process optimization that minimizes resource use and prevents waste; (ii) long-term economic and environmental sustainability; (iii) and regenerative systems that close nutrient cycles and reduce leaking (Morseletto, 2020; Velasco-Muñoz et al., 2022). Eliminating waste and pollution improves system efficiency (Ellen MacArthur Foundation, 2015). The second principle of “keeping products and materials in use” suggests maximizing product and by-product quality throughout the supply chain. Finally, replacing scarce inputs with renewable resources in “regenerating natural systems” improves ecosystems (Ellen MacArthur Foundation, 2019a).

With the same philosophy, the “organic farming action plan”, proposed by the EC under the EU Green Deal for the expansion of organic production, is an ambitious strategy with the aim to transform organic farming to a more sustainable farming practice that respects the three pillars of sustainable development and therefore enable meeting the SDGs (El Chami, 2020). The plan's main target is to have at least 25 % of EU agricultural land under organic farming and a significant increase in organic aquaculture by 2030. To meet this goal and support the organics sector the strategy includes financial support for organics through rural development commitments. The EU intends to invest at least 30 % of its budget to research and innovation acts in agribusiness that is specific to or relevant to the organic sector. Elevated crop yields, genetic diversity are examples of such challenges. Furthermore, technical support and the exchange of evidence - based practices and advancements will provided (EU Green Deal, 2019).

Resource scarcity, environmental damage, and uncontrolled waste production are changing the circular economy model while processes and consumption patterns must be altered for a smooth integration of the model into the farming sector (Ghisellini et al., 2016; Ghisellini and Ulgiati, 2020; IPCC, 2021; van Langen et al., 2021; Rótolo et al., 2022a, 2022b). Only 2 % of usable resources are returned to farming for reuse, and 98 % become environmental pollutants and waste, deeming the use of a circular economy model of outmost importance (Ellen MacArthur Foundation, 2019a, 2019b). Circular economy principles in agriculture could boost GDP by 0.1 % by 2030 and create over 100,000 jobs, according to the EU alone (European Commission, 2018). Farmers may profit 3000€/hectare from circularity while simultaneously reducing pollution and adverse

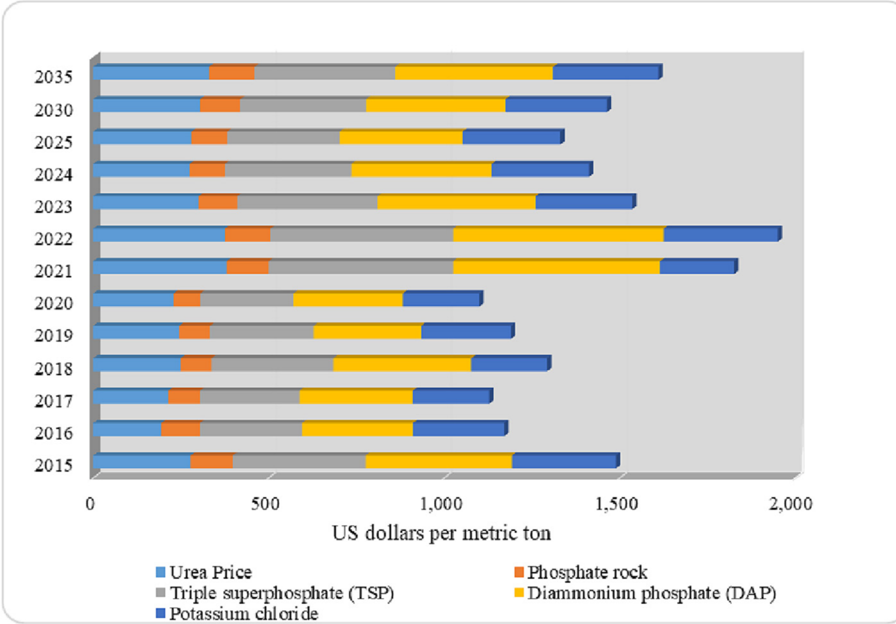


Fig. 6. Price inorganic fertilizers from 2015 to 2021 to 2035 (in U.S. dollars per metric ton) (Statista, 2022).

effects of linear production processes (i.e. soil toxicity, GHGs emissions, human health implications etc.) (Ellen MacArthur Foundation, 2021; Velasco-Muñoz et al., 2022).

Reusing and recycling farming waste can boost local economies and reduce environmental damage. Since these wastes are unavoidable, farms would benefit economically and environmentally. Additionally, animal digestion produces biomass, biofuel, and manure-based organic fertilizer while reducing greenhouse gases and improves soil fertility. Barros et al. (2020) found that recycling and reusing agricultural waste could improve industrial symbiosis. Farm or cooperative components that circulate can boost profits and reduce environmental impact. Simultaneously, farming waste makes biofertilizer biochar which has the ability to boost fertility, climate resilience, and profitability (Yrjälä et al., 2022). Khan and Ali (2022) found that Circular bio-based Europe (CBE), which combines circular economy and bio economy, is becoming more and more popular concerning aspects of food security and sustainable development. Sustainable biomass, increased product life cycle, waste reuse, biofuels and bioenergy, composting, and recycling are CBE's goals (Armanda et al., 2019; Stegmann et al., 2020). At the same time, composting had the greatest market potential while bio-fertilizers are cost-effective and should be used more. Lastly, concerning anaerobic digestion has additional benefits to environmental impact mitigation but uses less farming waste as a feed.

Sekabira et al. (2021) noted the CBE model in an African Farming System study. In their study, the authors mention that after urban consumption, organic waste could collect, recycle, and return to rural areas for reuse on farms. Urban organic waste can be recycled and used on farms since reusing organic waste closes nutrient loops, recharges soil nutrients, and adds organic matter for sustainable productivity (van der Wiel et al., 2019). However, the benefits from CBE approach will only be apparent when there is effective coordination between producers and consumers. Therefore, it would definitely be useful to emphasize on families that are strongly dependent on agriculture as a market for compost and livestock supplies as well as customers as a marketplace for CBE foods.

Precision farm monitoring technologies, which have become more common in the past 30 years, can precisely change input rates regionally, according to Basso et al. (2021). Research has shown that integrating a package of digital agriculture techniques to settle spatial and temporal variation in environmental factors like soil, weather, and topography using hindcasting, nowcasting, and forecasting datasets can significantly improve nutrient-use efficiency and climate mitigating risk (Basso et al., 2019; Martinez-Feria and Basso, 2020).

In applying the circular economy strategy, many researchers study the obstacles to a smooth transition from linear to circular (Ritzén and Sandström, 2017; Aznar-Sánchez et al., 2020; Dieckmann et al., 2020; Grafström and Aasma, 2021; Velasco-Muñoz et al., 2021). Cavicchi et al. (2022) research which focuses on obstacles faced by Australian farming enterprises indicated that initial innovation costs, lack of energy knowledge, insufficient time, inability to assess energy-efficiency initiatives' success, tax complexity, and inflexibility of practices must be addressed to promote circular economy strategy. According to Dieckmann et al. (2020), there are six barriers related with the implementation of CE including financial, structural, regulatory operational, attitudinal and technological issues. In the same sense, Galvão et al. (2018), highlight that the main obstacles for the transition to CE related with policy and legislation, technological innovation, financial and economic aspects, customer behaviour and habits.

Business success requires circular product and bioeconomy production financial incentives. Regarding Circular products, the business should focus to design products that could be repaired, reused, resold, recycled, producing less waste as possible and enabling a systemic shift towards a CE (Rótolo et al., 2022a, 2022b) SMEs may lack financial or technical resources for cleaner production technology. Incentives are intended to address market failures that obstruct or delay the transition to circular products and services. Those incentives should have the potential to add value, minimized risk investments, and boost the competitiveness of value chains, resulting in gross environmental benefits when contrasted to linear economies. Furthermore, targeted financial support could play an important role in promoting innovation and encouraging CE practices. Lowering tax rates on reuse, repair, and remanufacturing actions, such as value added taxes, could encourage circular designs and business models while also promoting the circulation of valuable products. Other financial intensives could also motivate the use of recycled materials and the adaptation of restorative production of food (EC, 2021).

Proper regulation should foster business-government-investor cooperation (Fanelli, 2021; Jalo et al., 2021; Arora et al., 2022). According to Borrello et al. (2016), regulatory restrictions, a lack of reverse logistics, geographic dispersion of industries, customer awareness, demand for technology innovation, and uncertain investment opportunities and incentives are the main barriers to adopting the circular economy model. Rótolo et al. (2022a, 2022b) found that citizens, entrepreneurs, educators, administrators, and politicians must collaborate to overcome circular economy adoption barriers while incentives, financial support, education, awareness, research, innovation, and circular strategies are deemed necessary for a holistic approach towards agri-circular transition (Sgroi, 2022).

Xia and Ruan (2020) examined farm stakeholders (government, farmers, enterprises) and their key considerations for circularity. Regarding government weaknesses they concluded that policies, legislation, and administrative mechanisms are inadequate as there are no scientific priority policies or financial incentives. Tax policy is given less weight by the government and lastly the existing infrastructure is insufficient. Farmers have a limited environmental awareness level, as well as inadequate knowledge and skills. Finally, for enterprises the production costs remain high, there is a clear lack of technological innovation, and there is a significant imbalance between market demand and supply.

4. Conclusion

To reduce natural resource overconsumption and restore environmental impacts, the existing economic model must be reshaped to allow for a smooth transition from linear to circular supply chains. In this context, the circular economy model is a promising approach for conserving natural resources and providing sustainable, restorative, and regenerative agriculture in the face of resource scarcity, climate change, pollution, and rising food demand. Reusing and recycling farm waste can help local economies while also reducing environmental impact. Recycling and reusing agricultural waste may improve industrial symbiosis, while farm or cooperative components that circulate may increase profits while decreasing environmental impact. According to EU legislation, strategies, and incentives, combining the circular economy and bioeconomy can maintain and strive for food security and sustainable development. The implementation of a circular economy in farming practices could significantly contribute to the UN SDGs for the creation of an innovative and sustainable society (SDG 11), characterized by responsible consumption and production (SDG 12). At the same time, aside from recycling, other market opportunities include sustainable biomass, increased product life cycle, waste reuse, biofuels and bioenergy, composting, and recycling, while the use of bio-fertilizers in combination with inorganic fertilizers is suggested as a more environmentally friendly and cost-effective option. According to the study's findings, SC and PP are the organic and pruning residues with the highest total N content and the lowest C/N ratio among the wastes examined. As a result, both residues may provide the best conditions for N mineralization. Considering 150 kg ha^{-1} of N input as the optimum demand, the amount of pruning and harvesting residue (farming wastes) must be applied, approximately, between 400 and 1000 times more than urea fertilizer. Organic and inorganic fertilizers have advantages and disadvantages; therefore, a balanced combination can be critical for sustainable farming, taking advantage of both positive and negative effects. However, other minerals besides nitrogen nutrients should be considered in order to have a holistic approach to organic waste utilization in the farming sector.

Funding

No funding was received for conducting this study.

CRediT authorship contribution statement

Teresa Rodríguez-Espinosa: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Iliana Papamichael:** Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Irene Voukkali:** Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Ana Pérez Gimeno:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **María Belén Almendro Candel:** Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Jose Navarro-Pedreño:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Antonis A. Zorpas:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Ignacio Gómez Lucas:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Data availability

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

Declaration of competing interest

None.

Acknowledgements

The authors would like to acknowledge the Laboratory of Chemical Engineering & Engineering Sustainability of the Open University of Cyprus and the Department of Agrochemistry and Environment of the University Miguel Hernández of Elche for supporting this research.

References

AENOR. UNE-EN 13039, 2001. Mejoradores de suelo y sustratos de cultivo. Determinación del contenido en materia orgánica y de las cenizas.

AENOR. UNE-EN 13040, 2008. Mejoradores de suelo y sustratos de cultivo. Preparación de la muestra para ensayos físicos y químicos. Determinación del contenido de materia seca, del contenido de humedad y de la densidad aparente compactada en laboratorio.Available online (Accessed on 17/12/2022).

Agomoh, I., Zvomuya, F., Hao, X., Akinremi, O.O., McAllister, T.A., 2018. Nitrogen mineralization in Chernozemic soils amended with manure from cattle fed dried destillers grains with solubles. Soil Sci. Soc. Am. J. 82, 167–175. https://doi.org/10.2136/sssaj2017.08.0282.

Almendro-Candel, M.B., Lucas, I.G., Navarro-Pedreño, J., Zorpas, A.A., 2018. Physical Properties of Soils Affected by the Use of Agricultural Waste, in Agricultural Waste and Residues. IntechOpen, London, United Kingdom https://doi.org/10.5772/intechopen.77993. https://www.intechopen.com/chapters/61756.

Anas, M., Liao, F., Verma, K.K., et al., 2020. Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. Biol. Res. 53, 47. https://doi.org/10.1186/s40659-020-00312-4.

Anguria, P., Chemining'wa, G.N., Onwonga, R.N., Ugen, M.A., 2017. Decomposition and nutrient release of selected cereal and legume crop residues. J. Agric. Sci. 9, 6. https://doi.org/10.5539/jas.v9n6p108.

Anwar, Z., Irshad, M., Fareed, I., Saleem, A., 2015. Characterization and recycling of organic waste after co-composting a review. J. Agric. Sci. 7, 4. https://doi.org/10.5539/jas.v7n4p68.

Armanda, D.T., Guin´ee, J.B., Tukker, A., 2019. The second green revolution: innovative urban agriculture's contribution to food security and sustainability – a review. Glob. Food Secur. 22, 13–24. https://doi.org/10.1016/j.gfs.2019.08.002.

Armando Tamele, R., Ueno, H., Toma, Y., Morita, N., 2020. Nitrogen recoveries and nitrogen use efficiencies of organic fertilizers with different C/N ratios in maize cultivation with low-fertile soil by 15N method. Agriculture 10, 272. https://doi.org/10.3390/agriculture10070272.

Arora, C., Kamat, A., Shanker, S., Barve, A., 2022. Integrating agriculture and industry 4.0 under "agri-food 4.0" to analyze suitable technologies to overcome agronomical barriers. Br. Food J. 124 (7), 2061–2095. https://doi.org/10.1108/BFJ-08-2021-0934.

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 10, 1499. https://doi.org/10.3390/agronomy10101499.

Baffes, J., Koh, W.C., 2021. Fertilizer prices expected to stay high over the remainder of 2021. June 8. Accessed 14/12/2022 at:World Bank Data Blog. https://blogs.worldbank.org/opendata/fertilizer-pricesexpected-stay-high-over-remainder-2021.

Barros, M.V., Salvador, R., Carlos de Francisco, A., 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.

Basso, B., Shuai, G., Zhang, J., Robertson, G.P., 2019. Yield stability analysis reveals sources of large-scale nitrogen loss from the US Midwest. Sci. Rep. 9, 5774. https://doi.org/10.1038/s41598-19-42271-1.

Basso, B., Jones, J., Antle, J., Martinez-Feria, R., Verma, B., 2021. Enabling circularity in grain production systems with novel technologies and policy. Agric. Syst. 193, 103244. https://doi.org/10.1016/j.agsy.2021.103244.

Bendaly Labaied, M., Khiari, L., Gallichand, J., Kebede, F., Kadri, N., Ben Ammar, N., Ben Hmida, F., Ben Mimoun, M., 2020. Nutrient diagnosis norms for date palm (Phoenix dactylifera L.) in Tunisian oases. Agronomy 10, 886. https://doi.org/10.3390/agronomy10060886.

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/10.2174/221279840801160304143939.

Braos, L., Lopes Ruiz, J.G.C., Lopes, I.G., Ferreira, M.E., 2020. Mineralization of nitrogen in soils with application of acid whey at different pH. J. Soil Sci. Plant Nutr. 20 (3), 1102–1109. https://doi.org/10.1007/s42729-020-00196-z.

Brunelle, T., Dumasa, P., Souty, F., Dorina, B., Nadaud, F., 2015. Evaluating the impact of rising fertilizer prices on crop yields. Agric. Econ. 46, 653–666.

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. Available online: http://www.revistaespacios.com/a19v40n13/a19v40n13p02.pdf (Accessed 11/3/23).

Cabrera, M.L., Kissel, D.E., Vigil, M.F., 2005. Nitrogen mineralization from organic residues: research opportunities. J. Environ. Qual. 34, 75–79.

Carranca, C., Brunetto, G., Tagliavini, M., 2018. Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. Plants 7, 4. https://doi.org/10.3390/plants7010004.

Cavalli, E., Lange, A., Cavalli, C., Behling, M., 2018. Decomposition and release of nutrients from crop residues on soybean-maize cropping systems. Rev. Bras. Cienc. Agrar. Recife 13 (2), e5527.

Cavicchi, C., Oppi, C., Vagnoni, E., 2022. Energy management to foster circular economy business model for sustainable development in an agricultural SME. J. Clean. Prod. 368, 133188. https://doi.org/10.1016/j.jclepro.2022.133188.

CEAT, 2021. Agriculture and the Circular Economy. Available online: https://ceat.org.au/agriculture-and-the-circular-economy/ (accessed 11/3/23).

Cedrez, C.B., Chamberlin, J., Hijmans, R.J., 2020. Seasonal, annual, and spatial variation in cereal prices in sub-Saharan Africa. Glob. Food Sec. 26, 100438. https://doi.org/10.1016/j.gfs.2020.100438.

Cen, Y., Guo, L., Liu, M., Gu, X., Li, C., Jiang, G., 2020. Using organic fertilizers to increase crop yield, economic growth, and soil quality in a temperate farmland. Peer J. 8, 9668. http://doi.org/10.7717/peerj.9668.

Chatzistathis, T., Kavvadias, V., Sotiropoulos, T., Papadakis, I.E., 2021. Organic fertilization and tree orchards. Agriculture 11, 692. https://doi.org/10.3390/agriculture11080692.

Chen, X.P., Cui, Z.L., Fan, M.S., Vitousek, P., Zhao, M., Ma, W.Q., Wang, Z.L., Zhang, W.J., Yan, X.Y., Yang, J.C., Deng, X.P., Gao, Q., Zhang, Q., Guo, S.W., Ren, J., Li, S.Q., Ye, Y.L., Wang, Z.H., Huang, J.L., Tang, Q.Y., Sun, Y.X., Peng, X.L., Zhang, J.W., He, M.R., Zhu, Y.J., Xue, J.Q., Wang, G.L., Wu, L., An, N., Wu, L.Q., Ma, L., Zhang, W.F., Zhang, F.S., 2014. Producing more grain with lower environmental costs. Nature 514 (7523), 486–489. https://doi.org/10.1038/nature13609.

Chojnacka, K., Moustakas, K., Mikulewicz, M., 2022. Valorisation of agri-food waste to fertilisers is a challenge in implementing the circular economy concept in practice. Environ. Pollut. 312, 119906. https://doi.org/10.1016/j.envpol.2022.119906.

Circle Economy, 2019. The Circularity Gap Report 2019. Available online: https://www.legacy.circularity-gap.world/2019 (accessed 11/3/23).

Corbeels, M., Hofman, G., Van Cleemput, O., 1999a. Soil mineral nitrogen dynamics under bare fallow and wheat in vertisols of semi-arid Mediterranean Morocco. Biol. Fertil. Soils 28, 321–328.

Corbeels, M., Hofman, G., Van Cleemput, O., 1999b. Simulation of net N immobilization and mineralisation in substrate-amended soils by the NCSOIL computer model. Biol. Fertil. Soils 28, 422–430.

Coull, M., Butler, B., Hough, R., Beesley, L., 2021. A geochemical and agronomic evaluation of technosols made from construction and demolition fines mixed with green waste compost. Agronomy 11, 649. https://doi.org/10.3390/agronomy1104064.

De Vries, W., Römkens, P.F.A.M., Kros, J., Voogd, J.C., Schulte-Uebbing, L.F., 2022. Impacts of nutrients and heavy metals in European agriculture. Current and critical inputs in relation to air, soil and water quality. ETC-DI 72 pages.

Deenik, J., 2006. Nitrogen mineralization potential in important agricultural soils of Hawai'i. Soil and Crop Management, July 2006, SCM-15. College of Tropical Agriculture and Human Resources. University of Hawaii.

Dieckmann, E., Sheldrick, L., Tennant, M., Myers, R., Cheeseman, C., 2020. Analysis of barriers to transitioning from a linear to a circular economy for end of life materials: a case study for waste feathers. Sustainability 12 (5), 1725. https://doi.org/10.3390/su12051725.

Doyeni, M.O., Barcauskaite, K., Buneviciene, K., Venslauskas, K., Navickas, K., Rubezius, M., Baksinskaite, A., Suproniene, S., Tilvikiene, V., 2022. Nitrogen flow in livestock waste system towards an efficient circular economy in agriculture. Waste Manag. Res., 1–12 https://doi.org/10.1177/0734242X221123484.

EC, 2020. Communication from the Commission to the European Parliament to the Council, the European Economic and Social Committee and the Committee of the Regions A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. Brussels, COM 381 final, 20/05/2020.

EC, 2021. European Commission, Directorate-General for Research and Innovation, Katrakis, E., Nacci, G., Couder, N., Incentives to boost the circular economy: a guide for public authorities, Katrakis, E. (editor), Nacci, G. (editor), Couder, N. (editor), Publications Office, 2021. https://data.europa.eu/doi/10.2777/794570.

El Chami, D., 2020. Towards sustainable organic farming systems. Sustainability 12, 9832. https://doi.org/10.3390/su12239832.

Ellen MacArthur Foundation, 2015. Schools of Thought – Performance Economy. Available online (Accessed on 17/12/2022). https://www.circular.academy/circular-schools-of-thought-performance-economy/.

Ellen MacArthur Foundation, 2019a. Cities and Circular Economy for Food. Available online (Accessed 26/12/22). https://emf.thirdlight.com/file/24/K6LOnIrKMZq-8vK6HoTK6iyBra/Cities%20and%20circular%20economy%20for%20food.pdf.

Ellen MacArthur Foundation, 2019b. Completing the Picture: How the Circular Economy Tackles Climate Change. Available online: (Accessed: 17/12/2022). www.ellenmacarthurfoundation.org/publications.

Ellen MacArthur Foundation, 2021. The big food redesign: Regenerating nature with the circular economy Available online: https://emf.thirdlight.com/link/TheBigFoodRedsignReport/@/preview/ (accessed 11/3/23).

EN 13342, 2000. Characterization of Sludges - Determination of Kjeldahl Nitrogen.

EPSAR, Entidad pública de saneamiento de aguas residuales de la Comunidad Valencianacollab, 2019. Aspe. Conselleria de Agricultura, Desarrollo Rural, Emergencia Climática y Transición Ecológica. Generalitat Valenciana. https://www.epsar.gva.es/aspe-0.

EU Eurostat, 2020. Agriculture, Forestry and Fishery Statistics. Statistical Books, Luxembourg https://doi.org/10.2785/143455.

EU Green Deal, 2019. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

EU. Eurostat, 2017. Available online: Agri-environmental indicator - gross nitrogen balance. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_gross_nitrogen_balance&oldid=328298 (Accessed 16/01/2023).

EU. Eurostat, 2022. Statistics explained. Agri-environmental indicator - mineral fertiliser consumption - Statistics Explained.Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption (Accessed on 1/12/2022).

EU Regulation 2021/2115EU Regulation 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013.

European Commission, 2018. Directorate-General for Environment, Impacts of circular economy policies on the labour market: final report and annexes. Publications Office. https://data.europa.eu/doi/10.2779/574719.

Fanelli, R.M., 2021. Barriers to adopting new technologies within rural small and medium enterprises (SMEs). Soc. Sci. 10 (11), 430. https://doi.org/10.3390/socsci10110430.

FAO, 2017. Voluntary Guidelines for Sustainable Soil Management Food and Agriculture Organization of the United Nations. FAO, Roma.

FAO, 2019. World fertilizer trends and outlook to 2022. Available online: https://www.fao.org/3/ca6746en/ca6746en.pdf (accessed 11/3/23).

FAO, 2021. Standard Operating Procedure for Soil Nitrogen- Kjeldahl Method Rome.

FAO, 2022. Soils for Nutrition: State of the Art. https://doi.org/10.4060/cc0900en Rome.

FAOSTAT, 2021. Crops and livestock products. https://www.fao.org/faostat/en/#data/QCL (Accessed 16/01/2023).

FAOSTAT, 2023. Available online: https://www.fao.org/faostat/en/#data (accessed 11/3/23).

Ferrari Machado, P.V., Farrell, R.E., Deen, W., Voroney, R.P., Congreves, K.A., Wagner-Riddle, C., 2021. Contribution of crop residue, soil, and fertilizer nitrogen to nitrous oxide emissions varies with long-term crop rotation and tillage. Sci. TotalEnviron. 767, 145107. https://doi.org/10.1016/j.scitotenv.2021.145107.

Foereid, B., 2019. Nutrients recovered from organic residues as fertilizers: challenges to management and research methods. World J. Agric.Soil Sci. 1, 4. https://doi.org/10.33552/WJASS.2019.01.000516.

Furtado da Silva, N., Cabral da Silva, E., Muraoka, T., Teixeira, M.B., Loureiro Soares, F.A., Nobre Cunha, F., Adu-Gyamfi, J., da Silva, Soares, Cavalcante, W., 2020. Nitrogen utilization from ammonium nitrate and use fertilizer by irrigated sugarcane in Brazilian Cerrado Oxisol. Agriculture 10, 323.

Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A., 2008. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320, 889–892. https://doi.org/10.1126/science.1136674.

Galvão, G., Nadae, J., Clemente, D., Chinen, G., Carvalho, 2018. Circular economy: overview of barriers. CIRP J. Manuf. Sci. Technol., 73 https://doi.org/10.1016/j.procir.2018.04.011.

Ganeshamurthy, A.N., Rupa, T.R., Kalaivanan, D., Radha, T.K., Manjunath, B.L., 2022. Management of reactive nitrogen in horticulture systems in India: different approaches. Indian J. Fertil. 18 (8), 720–738.

Geisseler, D., Miller, K.S., Aegerter, B.J., Clark, N.E., Miyao, E.M., 2019. Estimation of annual soil nitrogen mineralization rates using a organic-nitrogen budget approach. Soil Sci. Soc. Am. 83, 1227–1235. https://doi.org/10.2136/sssaj2018.12.0473.

Ghisellini, P., Ulgiati, S., 2020. Circular economy transition in Italy. Achievements, perspectives and constraints. J. Clean. Prod. 243, 183–360. https://doi.org/10.1016/j.jclepro.2019.118360.

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.

Gliessman, S., 2007. Agroecology: The Ecology of Food Systems. 2nd edn. CRC Press Taylor & Francis Group, Boca Raton.

Golabi, M.H., Galsim, F.P., Iyekar, C., Desamito, C., 2017. Agronomic Value of Land Application of Composted Organic Wastes to Porous Soil of Northern Guam. Technical Report 2.

Golia, E.E., Dimirkou, A., Floras, S.A., 2009. Monitoring the variability of nitrogen and cadmium concentrations in soils and irrigation water in the almyros area of Central Greece. Commun. Soil Sci. Plant Anal. 40 (1–6), 376–390. https://doi.org/10.1080/00103620802646902.

Golia, E.E., Füleky, G., Dimirkou, A., Antoniadis, V., Tsiropoulos, N.G., Gizas, G., 2017. Influence of Zeolite and Posidonia oceanica (L.) in the Reduction of Heavy Metal Uptake by

Tobacco (Nicotiana tabacum) Plants of Central Greece. 228, p. 324. https://doi.org/10.1007/s11270-017-3522-2.
Golia, E.E., Tsiropoulos, G.N., Füleky, G., Floras, St, Vleioras, Sp, 2018. Pollution Assessment of Potentially Toxic Elements in Soils of Different Taxonomy Orders in Central Greece. 191, p. 106. https://doi.org/10.1007/s10661-019-7201-1.
Gomez-Muñoz, G., Valero-Valenzuela, J.D., Hinojosa, M.B., García-Ruiz, R., 2016. Management of tree pruning residues to improve soil organic carbon in olive groves. Eur. J. Soil Biol. 74, 104–113. https://doi.org/10.1016/j.ejsobi.2016.03.010.
Gopinath, K.A., Mina, B.L., 2011. Effect of organic manures on agronomic and economic performance of garden pea (Pisum sativum) and on soil properties. Indian J. Agric. Sci. 81 (3), 236.
Gordillo, R.M., Cabrera, M.L., 1997. Mineralizable nitrogen in broiler litter: I. Effect of selected litter chemical characteristics. J. Environ. Qual. 26, 1672–1679.
Grafström, J., Aasma, S., 2021. Breaking circular economy barriers. J. Clean. Prod. 292. https://doi.org/10.1016/j.jclepro.2021.126002.
Gundersen, P., Christiansen, L.S.J., Vesterdal, L., Hansen, K., Bastrup-Birk, A., 2009. Do indicators of nitrogen retention and leaching differ between coniferous and broadleaved forests in Denmark? For. Ecol. Manag. 258, 1137–1146.
Guntiñas, M.E., Leirós, M.C., Trasar-Cepeda, C., Gil-Sotres, F., 2012. Effects of moisture and temperature on net soil nitrogen mineralization: a laboratory study. Eur. J. Soil Biol. 48, 73–80. https://doi.org/10.1016/j.ejsobi.2011.07.015.
Hasnat, M., Alam, M.A., Khanam, M., Binte, B.I., Kabir, M.H., Alam, M.S., Kamal, M.Z.U., Rahman, G.K.M.M., Haque, M.M., Rahman, M.M., 2022. Effect of nitrogen fertilizer and biochar on organic matter mineralization and carbon accretion in soil. Sustainability 14, 3684. https://doi.org/10.3390/su14063684.
Herrero, M., Thorton, P.K., Notenbaert, A.M., Wood, S., Masangi, S., Freeman, H.A., et al., 2010. Smart investments in sustainable food productions: revisiting mixed crop-livestock systems. Science 327, 822–825. https://doi.org/10.1126/science.118372.
Hossain, M.Z., von Fragstein und Niemsdorff, P., Heß, J., 2017. Effect of different organic wastes on soil properties and plant growth and yield: a review. Sci. Agric. Bohem. 48 (4), 224–237.
Huybrechts, D., Derden, A., Van den Abeele, L., Vander Aa, S., Smets, T., 2018. Best available techniques and the value chain perspective. J. Clean. Prod. 174, 847–856. https://doi.org/10.1016/j.jclepro.2017.10.346.
IFA, 2022. Fertilizer use by crop and country for the 2017-2018 period.Available online:International Fertilizer Association (IFA), Paris, France (Accessed 26/12/22) https://www.ifastat.org/consumption/fertilizeruse-by-crop.
IFOAM, 2014. The IFOAM norms for organic production and processing.Available online: https://letis.org/docs/espanol/organicos/ifoam/ifoam_norms_version_july_2014%20(1).pdf (accessed 26/12/22).
Iglesias, E., Pérez, V., 1992. Relationships between organic carbon and total organic matter in municipal solid wastes and city refuse composts. Biores. Technol. 41, 265–272.
IPCC, 2021. Sixth assessment report. Climate change 2021: the physical sciences basis. Technical report.Available online: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/ (Accessed 17/12/2022).
Jalo, N., Johansson, I., Kanchiralla, F.M., Thollander, P., 2021b. Do energy efficiency networks help reduce barriers to energy efficiency?- a case study of a regional Swedish policy program for industrial SMEs. Renew. Sust. Energ. Rev. 151, 111579. https://doi.org/10.1016/j.rser.2021.111579.
Jamroz, E., Bekier, J., Medynska-Juraszek, A., Kaluza-Haladyn, A., Cwielag-Piasecka, I., Bednik, M., 2020. The contribution of water extractable forms of plant nutrients to evaluate MSW compost maturity: a case study. Nat. Sci. Rep. 10, 12842. https://doi.org/10.1038/s41598-020-69860-9.
Jat, R.L., Jha, P., Dotaniya, M.L., Lakaria, B.L., Rashmi, I., Meena, B.P., Shirale, A.O., Meena, A.L., 2018. Carbon and nitrogen mineralization in vertisol as mediated by type and placement method residue. Environ. Monit. Assess. 190, 439. https://doi.org/10.1007/s10661-018-6785-1.
Jones Jr., J.B., 2001. Laboratory Guide for Conducting Soil Tests and Plant Analysis, pp. 191–239 Ch 3.
Kandpal, G., 2021. Review on impact of chemical fertilizers on environment. Int. J. Mod. Agric. 10 (1), 758–763 Ch 3 http://www.modern-journals.com/index.php/ijma/article/view/666.
Khan, F., Ali, Y., 2022. Moving towards a sustainable circular bio-economy in the agriculture sector of a developing country. Ecol. Econ. 196 (107402). https://doi.org/10.1016/j.ecolecon.2022.107402.
Kristinn S.H, Iversen K., Julca, A., 2021. Circular agriculture for sustainable rural development. United Nations. Department of Economic and Social Affairs. Economic Analysis and Policy Division. Development Research Branch. Available online: https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/PB_105.pdf (accessed 11/3/23).
Kuisma, M., Kahiluoto, H., 2017. Biotic resource loss beyond food waste: agriculture leaks worst. Resour. Conserv. Recycl. 124, 129–140. https://doi.org/10.1016/j.resconrec.2017.04.008.
Kumar, R., Kumar, R., Prakash, O., 2019. Chapter-5The Impact of Chemical Fertilizers on Our Environment and Ecosystem. 35, p. 69 Chief Ed.
Lal, R., 2006. Enhancing Crop Yields in the Developing Countries through Restoration of the Soil Organic Carbon Pool in Agricultural Lands. Land Degrad. Dev. 17, 197–209. https://doi.org/10.1002/ldr.696.
Li, J., Nie, M., Pendall, E., 2020. Soil physico-chemical properties are more important than microbial diversity and enzyme activity in controlling carbon and nitrogen stocks near Sydney, Australia. Geoderma 366. https://doi.org/10.1016/j.geoderma.2020.114201.
Lim, S.L., Wu, T.Y., Lim, P.N., Shak, K.P.Y., 2015. The use of vermicompost in organic farming: overview, effects on soil and economics. J. Sci. Food Agric. 95, 1143–1156. https://doi.org/10.1002/jsfa.6849.
Lloyd, A., Webb, J., Archer, J.R., Sylvester-Bradley, R., 1997. Urea as a nitrogen fertilizer for cereals. J. Agric. Sci. 128, 263–271. https://doi.org/10.3390/agriculture10080323.
Loncaric, R., Kanisek, J., Loncaric, Z., 2013. Mineral or Organic Fertilization: Financial Aspects. European Scientific Institute, ESI (publishing), p. 133.
Lüdeke-Freund, F., Gold, S., Bocken, N.M., 2019. A review and typology of circular economy business model patterns. J. Ind. Ecol. 23 (1), 36–61. https://doi.org/10.1111/jiec.12763.
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.
Mafongoya, P.L., Giller, K.E., Palm, C.A., 1998. Decomposition and nitrogen release patterns of tree prunings and litter. Agrofor. Syst. 38, 77–97.
Mangisoni, J.H., 2021. Structure-Conduct Performance of the Fertilizer Market in Malawi. Report prepared for MwAPATA Institute & LUANAR Department of Agricultural and Applied Economics.
Manivannan, S., Balamurugan, M., Parthasarathi, K., Gunasekaran, G., Ranganathan, L.S., 2009. Effect of vermicompost on soil fertility and crop productivity – beans (Phaseolus vulgaris). J. Environ. Biol. 30, 275–281.
Maquet, C., 2020. Wastewater reuse: a solution with a future. Field Actions Sci. Rep. 22, 64–69. https://bit.ly/2V8XPAq.
Martey, E., 2018. Welfare effect of organic fertilizer use in Ghana. Heliyon 4, e00844. https://doi.org/10.1016/j.heliyon.2018. e00844.
Martinez-Feria, R.A., Basso, B., 2020. Unstable crop yields reveal opportunities for sitespecific adaptations to climate variability. Sci. Rep. 10, 1–10. https://doi.org/10.1038/s41598-020-59494-2.
McCarthy, B., Kapetanaki, A.B., Wang, P., 2019. Circular agri-food approaches: will consumers buy novel products made from vegetable waste? Rural. Soc. 28 (2), 91–107. https://doi.org/10.1080/10371656.2019.1656394.
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.
Mosier, A.R., Azzaroli Bleken, M., Chaiwanakupt, P., Ellis, E.C., Freney, J.R., Howarth, R.B., Matson, P.A., Minami, K., Naylor, R., Weeks, K.N., Zhu, Z.-L., 2001. Policy implications of human-accelerated nitrogen cycling. Biogeochemistry 52, 281–320.
Nattassha, R., Handayati, Y., Simatupang, T.M., et al., 2020. Understanding circular economy implementation in the agri-food supply chain: the case of an Indonesian organic fertilizer producer. Agric. Food Secure 9, 10. https://doi.org/10.1186/s40066-020-0026.
Navarro-Pedreño, J., Moral, R., Gómez, I., Mataix, J., 1996a. Reducing nitrogen losses by decreasing mineral fertilisation in horticultural crops of eastern Spain. Agric. Ecosyst. Environ. 59, 217–221.
Navarro-Pedreño, J., Gómez, I., Moral, R., Mataix, J., 1996b. Improving the agricultural value of a semi-arid soil by addition of sewage sludge and almond residue. Agric. Ecosyst. Environ. 58, 115–119.
Naz, S., Fazio, F., Habib, S.S., Nawaz, G., Attaullah, S., Ullah, M., Hayat, A., Ahmed, I., 2022. Incidence of heavy metals in the application of fertilizers to crops (wheat and rice), a fish (common carp) pond and a human health risk assessment. Sustainability 14, 13441. https://doi.org/10.3390/su142013441.
Nicolás, C., Masciandaro, G., Hernandez, T., Garcia, C., 2012. Chemical-structural changes of organic matter in a semi-arid soil after organic amendment. Pedosphere 22, 283–293.
Noya, I., Aldea, X., González-García, S., Gasol, C.M., Moreira, M.T., Amores, M.J., Marín, D., Boschmonart-Rives, J., 2017. Environmental assessment of the entire pork value chain in Catalonia–a strategy to work towards circular economy. Sci. Total Environ. 589, 122–129. https://doi.org/10.1016/j.scitotenv.2017.02.186.
Nyondo, Christone J., Nyirenda, Zephania, Burke, William, Muyanga, Milu, 2021. The Inorganic Fertilizer Price Surge in 2021 Key Drivers and Policy Options.
Oliver, M.A., Gregory, P.J., 2015. Soil, food security and human health: a review. Eur. J. Soil Sci. 66, 257–276. https://doi.org/10.1111/ejss.12216.
Organic Facts, Organic Information Services Pvt Ltdcollab, 2017. https://www.organicfacts.net/organic-products/organic-cultivation/benefits-of-organic-fertilizers.html.
Ortiz-Martínez, M.V., Andreo-Martínez, P., García-Martínez, N., Pérez de los Ríos, A., Hernández-Fernández, J.F., Quesada-Medina, J., 2019. Approach to biodiesel production from microalgae under supercritical conditions by the PRISMA method. Fuel Process. Technol. 191, 211–222. https://doi.org/10.1016/j.fuproc.2019.03.031.
Oueriemmi, H., Kidd, P.S., Trasar-Cepeda, C., Rodríguez-Garrido, B., Zoghlami, R.I., Ardhaoui, K., Prieto-Fernández, Á., Moussa, M., 2021. Evaluation of composted organic wastes and farmyard manure for improving fertility of poor sandy soils in arid regions. Agriculture 11, 415. https://doi.org/10.3390/agriculture11050415.
Papafilippaki, A., Paranychianakis, N., Nikolaidis, N.P., 2015. Effects of soil type and municipal solid waste compost as soil amendment on Cichorium spinosum (spiny chicory) growth. Sci. Hortic. 195, 195–205. https://doi.org/10.1016/j.scienta.2015.09.030.
Papamichael, I., Chatziparaskeva, G., Pedreno, J.N., Voukkali, I., Almendro Candel, M.B., Zorpas, A.A., 2022. Building a new mind set in tomorrow fashion development through circular strategy models in the framework of waste management. Curr. Opin. Green Sustain. Chem. 100638. https://doi.org/10.1016/j.cogsc.2022.100638.
Parr, J.F., Colacicco, D., 1987. Organic materials as alternative nutrient sources. Chapter-5Energy in Plant Nutrition and Pest Control. 4. Elsevier Science Publishers B.V., Amsterdan, The Netherlands, pp. 81–99 Chief Ed.
Pascual, J.A., García, C., Hernández, T., Ayuso, M., 1997. Changes in the microbial activity of an arid soil amended with urban organic wastes. Biol. Fertil. Soils 24, 429–434.
Patricio, J., Axelsson, L., Blomé, S., Rosado, L., 2018. Enabling industrial symbiosis collaborations between SMEs from a regional perspective. J. Clean. Prod. 202, 1120–1130. https://doi.org/10.1016/j.jclepro.2018.07.230.
Pisciotta, A., Di Lorenzo, R., Novara, A., Laudicina, V.A., Barone, E., Santoro, A., Gristina, L., Barbagallo, M.G., 2021. Cover crop and pruning residue management to reduce nitrogen mineral fertilization in Mediterranean vineyards. Agronomy 11, 164. Available online: https://doi.org/10.3390/agronomy11010164. (Accessed 26/12/22).
Powlson, D.S., Dawson, C.J., 2021. Use of ammonium sulphate as a sulphur fertilizer: immplications for ammonia volatilization. Soil Use Manag. 00, 1–13. https://doi.org/10.1111/sum.12733.

Pramanik, P., Ghosh, G.K., Ghosal, P.K., Banik, P., 2007. Changes in organic-C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. Bioresour. Technol. 98, 2485–2494. https://doi.org/10.1016/j.biortech.2006.09.017.

Puyuelo, B., Ponsá, S., Gea, T., Sánchez, A., 2011. Determining C/N ratios for typical organic wastes using biodegradable fractions. Chemosphere 85, 653–659. https://doi.org/10.1016/j.chemosphere.2011.07.014.

Rakesh, S., Sarkar, D., Sinha, A.K., Shikha, Mukhopadhyay, P., Danish, S., Fahad, S., Datta, R., 2021. Carbon mineralization rates and kinetics of surface-applied and incorporated rice and maize residues in entisol and inceptisol soil types. Sustainability 13, 7212. https://doi.org/10.3390/su13137212.

Repullo, M.A., Carbonell, R., Hidalgo, J., Rodríguez-Lizana, A., Ordóñez, J., 2012. Using olive pruning residues to cover soil and improve fertility. Soil Tillage Res. 124, 36–46.

Research Dive Analysis Report, 2022. Fertilizer Market Report. Fertilizer Market by Type, From, Application, and Regional Analysis: Global Opportunity Analysis and Industry Forecast 2022-2030. Advanced Materials.

Ritchie, H., Roser, M., Rosado, P., 2022. Crop Yields. https://ourworldindata.org/crop-yields.

Ritzén, S., Sandström, G., 2017. Barriers to the circular economy – integration of perspectives and domains. Procedia CIRP 2017 (64), 7–12. https://doi.org/10.1016/j.procir.2017.03.005.

Rodríguez-Espinosa, T., Navarro-Pedreño, J., Gómez Lucas, I., Almendro-Candel, M.B., 2021a. Land recycling, food security and technosols. J. Geophys. Res. 2021 (04), 03. https://doi.org/10.30564/jgr.v4i3.3415.

Rodríguez-Espinosa, T., Navarro-Pedreño, J., Gómez, I., Jordán Vidal, M.M., Bech Borras, J., Zorpas, A.A., 2021b. Urban areas, human health and technosols for the green deal. Environ. Geochem. Health https://doi.org/10.1007/s10653-021-00953-8.

Rodríguez-Espinosa, T., Navarro-Pedreño, J., Gómez, I., Almendro Candel, M.B., Pérez Gimeno, A., Jordán Vidal, M.M., Papamichael, I., Zorpas, A.A., 2023a. Environmental risk from organic residues. Sustainability 15, 192. https://doi.org/10.3390/su15010192.

Rodríguez-Espinosa, T., Navarro-Pedreño, J., Gómez Lucas, I., Almendro Candel, M.B., Pérez Gimeno, A., Zorpas, A.A., 2023b. Soluble elements released from organic wastes to increase available nutrients for soil and crops. Appl. Sci. 13, 1151. https://doi.org/10.3390/app13021151.

Rokia, S., Séré, G., Schwartz, C., Deeb, M., Fournier, F., Nehls, T., Damas, O., Vidal-Beaudet, L., 2014. Modelling agronomic properties of technosols constructed with urban wastes. Waste Manag. 34, 2155–2162.

Rótolo, G.C.m, Vassillo, C.A.m, Rodriguez, A., Magnano, L., Milo Vaccaro, M., Civit, B.M., Covacevich, M.S., Arena, A.P., Ulgiati, S., 2022. Perception and awareness of circular economy options within sectors related to agriculture in Argentina. J. Clean. Prod. 373, 133805. https://doi.org/10.1016/j.jclepro.2022.133805 (Accessed 16/01/2023).

Rótolo, G.C., Vassillo, C., Rodriguez, A.A., Magnano, L., Milo Vaccaro, M., Civit, B.M., Covacevich, M.S., Arena, A.P., Ulgiati, S., 2022. Perception and awareness of circular economy options within sectors related to agriculture in Argentina. J. Clean. Prod. 373, 133805. https://doi.org/10.1016/j.jclepro.2022.133805.

Rovira, P., Vallejo, V.R., 1997. Organic carbon and nitrogen mineralization under Mediterranean climatic conditions: the effects of incubation depth. Soil Biol. Biochem. 29, 1509–1520.

Sainju, U.M., Allen, B.L., Lenssen, A.W., Ghimire, R.P., 2017. Root biomass, root/shoot ratio, and soil water content under perennial grasses with different nitrogen rates. Field Crop Res. 210, 183–191. https://doi.org/10.1016/j.fcr.2017.05.029.

Sainju, U.M., Ghimire, R., Pradhan, G.P., 2019. Nitrogen fertilization I: impact on crop, soil, and environment. In: Rigobelo, E.C., Serra, A.P. (Eds.), Nitrogen Fixation. IntechOpen, London https://doi.org/10.5772/intechopen.86028.

Sartore, L., Schettini, E., de Palma, L., Brunetti, G., Cocozza, C., Vox, G., 2018. Effect of hdrolyzed 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.

Schulz, H., Glaser, B., 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. J. Plant Nutr. Soil Sci. 175, 410–422. https://doi.org/10.1002/jpln.201100143.

Sekabira, H., Nijman, E., Späth, L., Krütli, P., Schut, M., Vanlauwe, B., Wilde, B., Kintché, K., Speciose, K., Feyso, A., Kigangu, B., Six, J., 2021. Circular Bioeconomy in African Farming Systems: What Is the Status Quo? Insights From Rwanda, DRC, and Ethiopia. https://doi.org/10.1371/journal.pone.0276319.

Serpil, S., 2012. An Agricultural Pollutant: Chemical Fertilizer. Int. J. Environ. Sci. Dev. 3, 287–292. https://doi.org/10.1016/j.apcbee.2012.03.047.

Sgroi, F., 2022. The circular economy for resilience of the agricultural landscape and promotion of the sustainable agriculture and food systems. J. Agric. Food Res. 8, 100307. https://doi.org/10.1016/j.jafr.2022.100307.

Shiferaw, B., Prasanna, B.M., Hellin, J., et al., 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Sec. 3, 307. https://doi.org/10.1007/s12571-011-0140-5.

Sierra, J., Desfontaines, L., 2018. Predicting the in situ rate constant of soil carbon mineralisation from laboratory-based measurements in tropical soils under contrasting tillage management systems. Soil Till. Res. 180, 175–181. https://doi.org/10.1016/j.still.2018.03.008.

Sisay, A., Sisay, T., 2019. The principal role of organic fertilizer on soil properties and agricultural productivity - a review. Agri Res Tech: Open Access J 22 (2) DOI: ARTOAJ.MS.ID.556192.

Spohn, M., Pötsch, E.M., Eichorst, S.A., Woebken, D., Wanek, W., Richter, A., 2016. Soil microbial carbon use efficiency and biomass turnover in a long-term fertilization experiment in a temperate grassland. Soil Biol. Biochem. 97, 168–175. https://doi.org/10.1016/j.soilbio.2016.03.008.

Springmann, M., Clark, M., Mason-D'Croz, D., et al., 2018. Options for keeping the food system within environmental limits. Nature 562, 519–525. https://doi.org/10.1038/s41586-018-0594-0.

Statista, 2022. https://www.statista.com/search/?newSearch=true&q=fertilizer&qKat=search.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E, Fetzer, I., Bennett, E.M., Biggs, R. Carpenter, 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347, 1259855. https://doi.org/10.1126/science.1259855.

Stegmann, P., Londo, M., Junginger, M., 2020. The circular bioeconomy: Its elements and role in European bioeconomy clusters Resources. Conserv. Recycl. 6, 100029. https://doi.org/10.1016/j.rcrx.2019.100029.

Suresh, A., Samuel, M.P., 2020. Micro-irrigation development in India: challenges and strategies. Curr. Sci. 118 (8), 1163. https://doi.org/10.18520/cs/v118/i8/1163-1168.

Taguas, E.V., Marín-Moreno, V., Díez, C.M., Mateos, L., Barranco, D., Mesas-Carrascosa, F.J., Pérez, R., García-Ferrer, A., Quero, J.L., 2021. Opportunities of super high-density olive orchard to improve soil quality: management guidelines for application of pruning residues. J. Environ. Manag. 293, 112785. https://doi.org/10.1016/j.jenvman.2021.112785.

The World Bank, 2020. Fertilizer consumption (% of fertilizer production). Available online: https://data.worldbank.org/indicator/AG.CON.FERT.PT.ZS (Accessed 11/3/23).

Thuriès, L., Pansi, M., Feller, C., Herrmann, P., Rémy, J.-C., 2001. Kinetics of added organic matter decomposition in a Mediterranean sandy soil. Soil Biol. Biochem. 33, 997–1010.

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.

United Nations, 2015. Transforming Our World: The 2030 Agenda for Sustainable Development. https://sdgs.un.org/2030agenda.

USDA, 2022. Impacts and Repercussions of Price Increases on the Global Fertilizer Market. Available online: https://www.fas.usda.gov/data/impacts-and-repercussions-price-increases-global-fertilizer-market (accessed 11/3/23).

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.

Van Langen, S., Vassillo, C., Ghisellini, P., Restaino, D., Passaro, R., Ulgiati, S., 2021. Promoting circular economy transition: a study about perception and awareness by different stakeholders'groups. J. Clean. Prod. 316, 128–166. https://doi.org/10.1016/j.jclepro.2021.128166.

Vasa, L., Angeloska, A., Trendov, N.M., 2017. Comparative analysis of circular agriculture development in selected Western Balkan countries based on sustainable performance indicators. Econ. Annals-XXI 168, 44–47. https://doi.org/10.21003/ea.V168-09.

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. (ISSN: 0921-3449) 170, 105618. https://doi.org/10.1016/j.resconrec.2021.105618.

Velasco-Muñoz, J., Aznar-Sánchez, J.A., López-Felices, B., Román-Sánchez, I.M., 2022. Circular economy in agriculture. An analysis of the state of research based on the life cycle. Sustain. Prod. Consum. 34, 257–270. https://doi.org/10.1016/j.spc.2022.09.017.

Voukkali, I., Zorpas, A.A., 2022. Evaluation of urban metabolism assessment methods through SWOT analysis and analytical hierocracy process. Sci. Total Environ. (ISSN: 0048-9697) 807 (Part 1), 150700. https://doi.org/10.1016/j.scitotenv.2021.150700.

Wang, Z., Liu, Z., Hu, W., Bai, H., Ma, L., Lv, X., Zhou, Z., Meng, Y., 2022. Crop residue return improved soil nitrogen availability by increasing amino acid and mineralization under appropriate N fertilization. Land Degrad. Dev. 33, 2197–2207. https://doi.org/10.1002/ldr.4241.

Wautelet, T., 2018. The Concept of Circular Economy: Its Origins and Its Evolution. https://doi.org/10.13140/RG.2.2.17021.87523 72 pages.

Willer, H., Trávnícek, J., Meier, C., Schlatter, B., 2021. The World of Organic Agriculture. Statistics and Emerging Trends 2021. Research Institute of Organic Agriculture FiBL, Frick and IFOAM – Organics International, Bonn.

Willett, W., et al., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393, 10170, 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

Wingeyer, A.B., 2007. The Effect of Residue C:N Ratio on the Turnover of N and C in Various Soil Organic Matter Fractions. Theses, Dissertations, and Student Research in Agronomy and Horticulture. Paper 42. http://digitalcommons.unl.edu/agronhortdiss/42.

Xia, X., Ruan, J., 2020. Analyzing barriers for developing a sustainable circular economy in agriculture in China using Grey-DEMATEL approach. Sustainability 12 (16), 6358. https://doi.org/10.3390/su12166358.

Yilmaz, E., Canakci, M., Topakci, M., Sonmez, S., Agsaran, B., Alagoz, Z., Citak, S., Uras, D.S., 2017. The effects of application of vine pruning residue on soil properties and productivity under mediterranean climate conditions in Turkey. Fresenius Environ. Bull. 26 (8), 5447–5457.

Yrjälä, K., Ramakrishnan, M., Salo, E., 2022. Agricultural waste streams as resource in circular economy for biochar production towards carbon neutrality. Curr. Opin. Environ. Sci. Health 26, 100339. https://doi.org/10.1016/j.coesh.2022.100339.

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.

Zhang, W.F., Dou, Z.X., He, P., Ju, X.T., Powlson, D., Chadwick, D., Norse, D., Lu, Y.L., Zhang, Y., Wu, L., 2013. New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. Proc. Natl. Acad. Sci. U. S. A. 110, 8375–8380. https://doi.org/10.1073/pnas.1210447110.

Zipori, I., Erel, R., Yermiyahu, U., Ben-Gal, A., Dag, A., 2020. Sustainable management of olive orchard nutrition: a review. Agriculture 10, 11. https://doi.org/10.3390/agriculture10010011.